Exploring possibilities for climate adaptation in context of the ongoing energy transition.

A case-study of Rotterdam

Master Thesis
Anke Merkx
October 2020

The cover of this report shows an edited copy of an image created by: James O'Brien

Exploring possibilities for climate adaptation in context of the ongoing energy transition

A case-study of Rotterdam

MSc thesis project

By

A. (Anke) Merkx

in partial fulfilment of the requirements for the degree of

Master of Science

in Watermanagement

at the Delft University of Technology,

to be defended publicly on October 16th, 2020.

Supervisors:	Dr. Ir. J.G. (Jeroen) Langeveld,	TU Delft
	Dr. U. (Udo) Pesch,	TU Delft
	Ir. E.M. (Eva) Nieuwenhuis,	TU Delft
	Ir. C.J. (Corjan) Gebraad	Gemeente Rotterdam

TU Delft

Gemeente Rotterdam

Preface

With the finalizing of this graduation thesis, my Master of Science in Water Management at Delft University of Technology comes to an end. I conducted my research in collaboration with the Urban Management – Water Strategy and Development division of the municipality of Rotterdam, by means of a graduate internship.

The topic of this graduate internship was mainly devised through contact between the chair of my graduation committee, Jeroen Langeveld, and my supervisor from the municipality, Corjan Gebraad, and allowed me to combine my interests in in both water management and the energy transition. In addition, I had the ambition to learn more about working in the public sector and about the citywide topics, not only technical, but also social, a large municipality has to deal with. Therefore, I am very grateful for the opportunity that the municipality of Rotterdam has offered me.

I conducted my research the past months with great pleasure and dedication, and, looking back on the entire process, I went through a personal learning curve as well. Not only have I gained substantive knowledge on the subject of this thesis and learned how to conduct scientific research, but by working alone on such a large project, I have learned to challenge myself and to be critical of my data and findings. The start of my thesis was roughly simultaneous to start of the spreading of COVID-19 in the Netherlands, which resulted for me in writing my entire thesis at home, instead of at the municipality office. This was against all my expectations, but at that time, of course, everything went against expectations. However, due to my friends with whom I lived at the time and with whom I developed a consistent work- and break rhythm, I still managed to carry out my research within the initially scheduled time.

I would like to express my gratitude to all graduation committee members from the Delft University of Technology. Many thanks to chair of my committee, Jeroen Langeveld, who introduced me to this research topic and helped me throughout the entire process by asking me the right questions and encouraging me to always go deeper into the findings. Udo Pesch, my second supervisor from the Faculty Technology, Policy and Management, continuously made sure my work was scientifically relevant and valid, and brought, through a slightly different background, refreshing new perspectives on my findings. Special thanks go to my daily supervisor, Eva Nieuwenhuis, for all the discussions we had, the detailed notes on my writing style, the time you always made for my questions, although you were quite busy yourself, and also the informal and fun conversations, walks and coffees we had.

At the municipality of Rotterdam, I had great support throughout the entire process of my thesis. I have had the opportunity to interview over 15 people of different divisions, to obtain new insights and knowledge on my subject, and to visit a construction site in Rotterdam to see how things actually go in practice. In particular, I would like to thank Corjan Gebraad, my daily supervisor from the municipality. He made sure my graduation research could take place at the municipality of Rotterdam and supported and challenged me throughout the entire process, during the weekly meetings we had. He always helped me move forward, by means of comments, suggestions and introducing me to colleagues of the municipality.

During my two-year master's degree, I was lucky enough to study with four, now very good, friends. I would like to thank them for the support during the years and for always making studying more fun. In particular: thank you Oscar, for reading parts of my thesis and for the helpful feedback. Lastly, many thanks to Jasper, who had time to discuss any doubts I faced during graduation and to check my spelling, and to my family, for all the love and support, even more noticeable during these last months of my thesis, when I moved back home for a short while.

To the readers of this thesis: I hope you enjoy reading it as much as I enjoyed writing it.

Anke Merkx

Amsterdam, October 2020

Summary

Cities worldwide are faced with the challenge of adapting to the effects of climate change as well as acting against climate change, in order to keep the urban area liveable in the future. To facilitate climate adaptation and mitigation on a national level, the Netherlands drew up guidelines to induce the energy transition, as part of the 'Climate Agreement', and to guide urban areas to adapt to the effects of climate change, as part of the 'Deltaplan of Spatial Adaptation'. Both the energy transition and climate adaptation require context-specific solutions and place large spatial claims on cities. To create understanding on what the effects of the energy transition are on the possibilities for climate adaptation, an explorative case-study is conducted, based on multiple and diverse cases in Rotterdam. The main question addressed in this study, is:

What does the energy transition imply for Rotterdam's climate adaptation goals with regard to water resilience?

Rotterdam's main climate adaptation goal with regard to water resilience is to make the water-storing capacity of public space sufficient to prevent damage in the event of heavy rainfall (70 mm of rainfall within one hour). In order to find an answer to the question of what the energy transition entails for this goal, five pilot areas in Rotterdam that switch to a gas-free network in the coming years (Rozenburg, Pendrecht, Groot IJsselmonde, Heindijk/Reyeroord, Bospolder-Tussendijken and Prinsenland-Het Lage land) were taken as study sites and were thoroughly analysed to select cases. Cases have been selected based on their criticality: locations that are prone to urban flooding, in addition to the implementation of energy measures. Eventually, five diverse cases were selected for the within-case analysis, to obtain a broad overview of the entire city. For each of the five selected cases, cross-sectional designs were created for three situations: the existing situation, the situation with energy measures (and sewer replacement, if applicable) and the situation with climate adaptation measures. In addition, a top view design was created for the situation with energy measures, in order to indicate the amount of construction work carried out in the street. These designs formed the basis to empirically gather information on the different types of systems integration (project-based, geographical, physical and informational) between the energy transition and climate adaptation and were discussed with experts to check their validity. The different forms of systems integration identified include both technical- and socio-institutional aspects, which in conclusion have led to technical- and socio-institutional implications for the municipality of Rotterdam.

The findings from the within-case analysis revealed that the energy transition mainly poses problems in achieving the climate adaptation goals in neighbourhoods with a high indicative vulnerability to flooding. Out of the five types of district typologies present in Rotterdam, the 'urban building block' district typology, where buildings are built high and where little to no front yards and greenery exist, the indicative vulnerability to flooding is highest. It is thus expected that in those neighbourhoods, an integrated approach towards the energy transition and climate adaptation is most desirable. However, since the selected cases in this research involved only three out of the five types of district typologies identified in Rotterdam, it is advised to study more and different areas, including the remaining district typologies, to gain more knowledge on the different typologies and to what extent the focus should be on which areas.

From the designs of the final situation with climate adaptation, it is deduced that in principle the energy transition negatively affects the possibilities for climate adaptation in terms of space, since less space remains available in public space. However, the results demonstrated that project-based integration (simultaneous implementation) of climate adaptation measures during the installation of a heating network can bring considerable benefits in terms of nuisance for residents and costs for the companies involved in construction. Since a large part of the street is excavated mainly in case of an integral approach (in combination with sewer replacement), this approach brings the most benefits for simultaneously adding adaptive measures. Moreover, it is found that project-based integration of climate adaptation during the installation of energy measures can also be advantageous when measures are desired on private land (in gardens or at the roof), by means of simultaneous implementation. Nuisance can be reduced, since construction work only has to take place once. However, integration of climate adaptation on private land requires close cooperation between the municipality, residents and the contractor, and additional investments from the municipality for, for example, integral funding. As a result of the various forms of advantageous project-based integration that are derived from the designs, it is recommended to the municipality to standardize a form of green climate adaptation in the construction of a heating network in streets where urban flooding occurs or where the percentage of green is low

(<50 %) . A large part of the street is always excavated and standardization of the implementation of a form of green climate adaptation can be easily integrated (in terms of construction) and ensures that something is done on climate adaptation, even though time is too limited for an integral approach in some cases. Furthermore, the results showed that in a densely built-up city such as Rotterdam, in all cases cables and pipes had to be relocated to provide space for the district heating network and climate adaptation. This means close cooperation is required between the municipality, the heat supplier and other utility owners, to eventually arrive to a joint agreement on the design and to use the momentum to execute everything simultaneously. In addition, it is found that in case climate adaptation is not implemented simultaneously to a district heating network, including climate adaptation measures in the design of a district heating network is still important, to reserve space in the subsurface to ensure that climate adaptation measures will remain possible in the future (geographical integration).

With respect to policy implications for the municipality of Rotterdam, this study showed that achieving the climate adaptation goals regarding urban flooding (prevent damage in case of a rain event of 70 mm in one hour) alongside the implementation of the energy transition is possible in all cases investigated. However, it appears that in almost all cases with a significant storage deficit, realizing sufficient rainwater storage is only possible by taking climate adaptation measures on private land or measures in public space that do not comply with Rotterdam’s regulations for the design of public space, in addition to measures in public space that do comply with the regulations. In many streets where both a district heating network is implemented and significantly too little rainwater storage is present, the municipality is thus faced with a dilemma: choose to settle for less rainwater storage (and accept any potential damages) or encourage or oblige measures on private land and/or implement measures that do not comply with Rotterdam's regulations for the design of public space. This dilemma concerns a damage-costs trade-off for the municipality: how large the damage would become in case not enough storage is realized and what the costs and technical risks involved would be in case 70 mm of rainwater storage is achieved with alternative measures. These trade-offs have to be further investigated and quantified in follow-up research, in order to ultimately arrive to a well-considered decision as a municipality.

This study empirically collected information on the types of systems integration between climate adaptation and the energy transition. By analysing five different cases in Rotterdam, concrete examples have been collected of how the implementation and planning of energy measures affect climate adaptation and of what the energy transition ultimately entails for Rotterdam’s climate adaptation goals. In addition, policy dilemmas have been formulated for the municipality with regard to the rainwater storage to be achieved and the extra costs associated with measures. This research indicates the difficulties associated with implementing both the energy transition and climate adaptation in densely built areas and tries to provide suggestions for exploiting potential opportunities that the energy transition can create for climate adaptation. For future research it is recommended to delve deeper in the dilemmas that arise and trade-offs to be made, by studying the costs of damage due to excessive rainfall and the costs for certain climate adaptation measures. In addition, it is recommended to include climate adaptation, the energy transition and other transitions more broadly in future research, by focusing on other climate topics (i.e. drought and heat), on alternative sources for the heat network (i.e. sewer-, aqua- or geothermal heat) and on the remaining transitions (i.e. mobility, economy and circular transitions and the housing challenge).

Contents

List of figures

List of tables

I.

RESEARCH CONTEXT

Chapter 1 – Introduction

(View from the Euromast, Rotterdam - Picture made by Anke Merkx)

Research Context

The first part of this thesis, the research context, presents the motivation and aim of the research. The research questions that this research sets out to answer are presented and the scope is defined.

1. Introduction

Climate change, resulting in excessive rainfall events and long periods of drought, is one of the main challenges the world is facing (Masson-Delmotte et al., 2018). Especially the impact of climate change on urban areas has increased in the last decades, since both climate change and an increase in paved surfaces, as a result of urbanization, result in higher runoff rates, and thereby more frequent flooding of streets (Arnbjerg-Nielsen & Fleischer, 2009). Due to the concentration of people and great reliance on urban infrastructure systems, the vulnerability of cities to the impacts of climate change is amplified (Grafakos et al., 2020).

Rapid climate change is a result of greenhouse gases released in the atmosphere by human activities worldwide. The largest consumers of energy and contributors to greenhouse gas emissions are cities, where people, buildings and infrastructure are concentrated most (Grafakos et al., 2020). Aiming to reduce the emission of greenhouse gases and to keep global warming below 2 °C, the Climate Agreement of Paris was drawn up in 2015. According to this agreement, signed by 195 countries, greenhouse gas emission should be reduced by 49% in 2030, in comparison to 1990 (Encyclopaedia Brittanica, 2015). This means that cities all around the world have to fundamentally change their way of generating energy: the use of fossil fuels should be minimized and replaced by renewable sources. In order to generate such a transition, not only the city's infrastructure needs to be adapted, but changes in the institutional system are needed as well, to influence consumers' energy behaviour (Stigka et al., 2014). Cities worldwide are thus challenged both to adapt to the effects of climate change and to act against climate change, in order to keep the urban area liveable in the future. Since in the Netherlands the most densely built urban areas are situated in the western part of the country, in low-lying areas in proximity of river deltas or at the coast, the challenges of spatial planning regarding water management are even larger (Ritzema & Van Loon-Steensma, 2018).

To facilitate climate adaptation and climate mitigation on a national level, the Netherlands drew up the 'Deltaplan of Spatial Adaptation' (Deltaplan Ruimtelijke Adaptatie, in Dutch) in 2018 and the 'Climate Agreement' in 2019. The 'Deltaplan of Spatial Adaptation' offers guidelines to address the effects of climate change and urbanization, i.e. to make cities climate-proof and water-robust in the near future (Rijksoverheid, 2018). The 'Climate Agreement' is an extension of the 'Climate Agreement of Paris' drawn up in 2015, with the main goal to reduce greenhouse gas emissions by 49% in 2030, in comparison to 1990 (Ministerie van Economische Zaken en Klimaat, 2019).

This research focuses on Rotterdam, which is the second-largest city in the Netherlands. Rotterdam is a densely built and low-lying city (lowest point at approx. NAP -6 m), located in the Delta area of the Netherlands. Hence, the need for both a climate-proof urban water system, as well as a transition towards a sustainable energy supply is high. The current urban water infrastructure in the city does not suffice for the effects of climate change and, to avoid the damage resulting from excessive rainfall, the city has set itself the goal to find more space for water (Gemeente Rotterdam, 2013). Innovative urban water solutions, that drain, store and infiltrate rainfall, could offer opportunities to prevent flooding as well as negative effects from droughts. Besides aiming for innovative water solutions, Rotterdam is working on the implementation of the energy transition (Gemeente Rotterdam, 2019a). Because it is expected that towards 2050 there will be an excess of heat (generated by the industrial activities in the Port of Rotterdam) and a shortage of clean electricity, Rotterdam focuses on district heating as the main sustainable solution. The implementation of a heating network requires additional underground space, as well as a well-coordinated planning (CE Delft et al., 2018).

Both climate adaptation, as well as the implementation of the energy transition, will pose large spatial claims on the city and involve organizational challenges. In Rotterdam, the space available, both above- and underground, is limited. In addition, the timeframe in which major lay-out changes have to be made is tight. Due to different neighbourhood characteristics and vulnerabilities, each neighbourhood needs context-specific solutions (Gemeente Rotterdam, 2019h). Therefore, Rotterdam is facing a great challenge to become a climate-proof city, regarding climate adaptation and the energy transition.

1.1. Problem statement

Ongoing developments in Rotterdam, regarding climate adaptation and the energy transition, require context-specific solutions and place large spatial claims on the city. Both require comprehensive organization, translated into strategy and planning, with a limited amount of time and space available. The above- and underground conflict between the implementation of district heating on the one hand and climate adaptation measures on the other hand, is a considerable problem, affecting many different parties (König, 2020).

Recent studies have shown that developing climate mitigation and adaptation strategies in isolation, can lead to inefficiencies in urban planning, conflicting policy objectives and lost opportunities for synergistic actions (Grafakos et al., 2019; Landauer et al., 2019). It is expected that by integration of the of climate adaptation and mitigation strategy and planning, resources and space needed for implementation can be minimized. The challenging question remains however, how, as there are many parties involved and there are wide differences in neighbourhood characteristics (physical and social-cultural).

Although many studies are conducted on the theory of integration of climate adaptation and mitigation, the reality of urban planning still shows how difficult it is to integrate urban water management into all kinds of projects (Kongsager et al., 2016). Although research is done on potential synergies and conflicts regarding integrated planning, there exists a significant research gap into quantification and specification of integration between climate adaptation and mitigation in practice – focusing on urban water management and energy transition. Too little information has been mapped regarding the interfaces of the two, in the field of planning and implementation, to achieve mutual advantages. This thesis aims to contribute to previous research by creating a better understanding of the possibilities for climate adaptation, in context of the ongoing energy transition.

1.2. Research aim

The objective of this research is to obtain insights in types of systems integration between climate adaptation and the energy transition and to identify how these two developments can reinforce each other, as well as how negative interactions may be limited. This results in insights on what the energy transition implies for Rotterdam's climate adaptation goals, for public space translated into being able to cope with 70 mm of rainfall in 1 hour without damage occurring, and eventually, in recommendations on how Rotterdam can realize these climate adaptation goals, in context of the ongoing energy transition. In order to achieve this objective, an exploratory case study is carried out, based on multiple and diverse cases within the city.

1.3. Research questions

To meet the research objective, the following main question is formulated:

Main question

What does the energy transition imply for Rotterdam's climate adaptation goals with regard to water resilience?

In order to answer the main question, two sets of research questions are formulated. The first set of research questions is answered according to literature and desk-study and the second set of research questions is answered by means of the case study design and the within-case analysis.

Research question 1: Literature- and desk-study

1. How does urban planning play a role in climate adaptation and mitigation strategies, according to literature?
2. What types of urban water systems integration are distinguished in literature and what types of integration are expected for the urban water and energy system?

3. Who are responsible for urban planning and urban water management within the municipality of Rotterdam and what are their responsibilities?
4. What are possible energy transition measures within the built environment of Rotterdam and what are their spatial impacts?
5. What are possible climate adaptation measures within the built environment in Rotterdam and what are their spatial impacts?

Research question 2: Case study design and analysis

1. At which locations in the pilot areas where district heating will be implemented, does urban flooding occur?
2. What climate adaptation measures can be implemented in the cases, in public and private space, alongside the implementation of the energy transition?
3. What types of systems integration can be identified in the cases, regarding implementation of the energy transition and climate adaptation?

1.4. Scope

This study focuses on what the energy transition implies for the climate adaptation goals regarding water resilience in Rotterdam.

The scope of this research is defined by the following aspects:

1. The geographical scope of this research is set on the built environment within the municipality of Rotterdam, on street scale. The study looks at potential energy- and climate adaptation measures from the roof to the subsoil. Currently, Rotterdam has selected 5 pilot areas to make the switch to a gas-free network and to therefore implement the energy transition (Gemeente Rotterdam, 2019a). In these 5 pilot areas, climate issues play a role as well. Therefore, the research will be conducted within these areas.
2. In this research, the realization of Rotterdam's climate adaptation goals regarding water-resilience is focused on one weather extreme: high water levels and flooding due to excessive precipitation. The short-term goal of the municipality is to make the water-storing capacity of public space sufficient to prevent damage in the event of heavy rainfall (70 mm of rainfall within one hour). Storage and infiltration measures that are implemented to cope with excessive precipitation are often also beneficial in times of drought and heat, but these effects will not be considered nor discussed in this research.
3. In addition to the climate adaptation goals, one of the targets of the current councillor in Rotterdam is to increase the greenery in the city with 20 hectares by 2022 (Verlinde, 2020). As well as improving the living environment, greenery can contribute in reducing flooding and drought, by absorbing, retaining and evaporating water. Therefore, planting trees and other green will be included as a potential climate adaptation measure in this study, in case the percentage of unpaved surface in a certain area is low compared to the national average (61,6%) (De Graaf et al., 2013).
4. The transition to sustainable energy systems could include many different options, but in this study the focus lies on an energy system based on a high temperature district heating network, with the possibility of a combination with large-scale installation of solar panels and grid reinforcement. The spatial impacts of the measures in this research are delimited to the spatial impact underground of district heating pipes and the spatial impact on the roof of solar panels. The spatial claim of grid reinforcement, needed in case of large-scale installation of solar panels or an increase in the electricity demand due to electric cooking, is not taken into account, since thickening of the cable is about a few centimetres (W. Terlouw, personal communication, May 19 2020). The impact on the planning process is taken into account for all measures (district heating, solar panels and grid reinforcement).
5. Besides the energy transition and climate adaptation goals, Rotterdam is also engaged in an 'economy transition', 'mobility transition' and 'circular transition' (Gemeente Rotterdam, 2019d). The economy transition is focused on creating a sustainable and innovative work environment for starting and established entrepreneurs. The mobility transition in Rotterdam is focused on future-proof mobility: the public transport network is improved, shared mobility is encouraged

and bike usage is stimulated, by improving the facilities. The circular transition concerns working towards a circular city, in terms of raw material-use. Moreover, Rotterdam is facing a housing challenge, due to the increasing number of inhabitants (Gemeente Rotterdam, 2019f). These four challenges also affect the available space in the city, but will not be considered in this study.

1.5. Research design

In Chapter 2 and Chapter 3, a literature study and desk-study are carried out, to gain insights into the climate vulnerability of the urban environment, possible types of urban water systems integration identified in literature and the need for an integrated urban planning, energy transition and climate adaptation strategy in Rotterdam.

The research methodology and case study design are discussed in Chapter 4 and Chapter 5. The method chosen in this research is an explorative case-study approach, based on multiple and diverse cases. This approach is subdivided into the case study design and the within-case analysis. The data used in this research is mainly collected through quantitative and qualitative desk-study and qualitative interviews with experts from the municipality of Rotterdam.

After the selection of cases in Chapter 5, the within-case analysis is carried out, to identify the possibilities of climate adaptation alongside the implementation of the energy transition. The applicability of adaptation measures in different cases is investigated by literature and by empirical research: creating and testing different designs. Per case an analysis is carried out and each case is discussed separately, in Chapter 6. Interview data is used to validate the applicability of adaptation measures and to discuss the types of systems integration identified. In Chapter 7, the discussion, the results are interpreted and limitations of the research are discussed.

In Chapter 8, final conclusions are drawn from the results and discussion and the main question, '*What does the energy transition imply for Rotterdam's climate adaptation goals with regard to water resilience?'*, is answered. In Chapter 9, recommendations arising from the results are presented, for the municipality of Rotterdam and for further research.

A visualisation of the research design is presented in Figure 1-1.

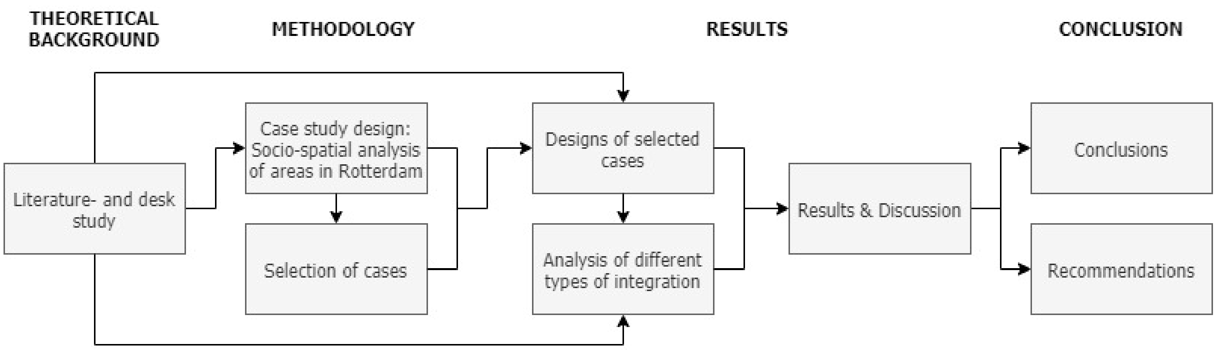

Figure 1-1 Visualisation of the research design

II.

THEORETICAL BACKGROUND

Chapter 2 – Literature study

Chapter 3 – Desk study Rotterdam

Theoretical background

The second part of this thesis, the theoretical background, presents relevant background information for the rest of this research, in two chapters. Chapter 2 delves into literature regarding climate change, urban planning and urban water systems integration. Chapter 3 presents background information of Rotterdam, the research site of this study.

2. Literature study

In this chapter a theoretical framework is outlined for this research and an answer is found on the following research questions:

1.1. How does urban planning play a role in climate adaptation and mitigation strategies, according to literature?

1.2. What types of urban water systems integration are distinguished in literature and what types of integration are expected for the urban water and energy system?

2.1. Climate vulnerability urban environment

The conventional urban water infrastructure and conventional approach for urban water management face major problems with respect to flexibility to deal with changes in the water cycle, as a result of rapid climate change and urbanization, and to develop a long-term sustainable urban water system (Deng et al., 2013). The regular functioning of a conventional urban water infrastructure (a sewer system) in the Netherlands is tested using a design storm with a return period of T = 2 years, several years ago (Stichting RIONED, 2006), which means most urban water systems currently used, are designed according to these guidelines. Looking at the Climate Scenarios of the KNMI, taking climate change and other developments into account, the design storm with a repetition time of T = 2 years does no longer suffice as rain event representative to test the functioning of the water system (KNMI, 2014). Due to heavier storms, flooding of the conventional water system can occur and can cause risks for adjacent areas, which means new urban water solutions are desired. In this section, the effects of climate change and urbanization on climate vulnerability are discussed and the water-related vulnerability of the urban environment is explained.

2.1.1. Climate change and urbanization

According to the Intergovernmental Panel on Climate Change (IPCC), natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change (IPCC, 2015). The increasing emission of CO_2 in the atmosphere, resulting in global warming, is a result of human activities worldwide. Burning of fossil fuels like oil, coal and gas, for generation of electricity, heating and transport, is the largest emitter of carbon dioxide and has increased extremely in the last decades (European Environment Agency, 2017). The largest consumers of energy and thereby the largest contributors to greenhouse gas emissions are cities, where people, buildings and infrastructure are concentrated most (Grafakos et al., 2020). It is said that a large city in an industrialized country produces as many emissions as the entire business sector of a small country: Berlin's emissions for example are compared to those of Croatia (Carbon Disclose Project, 2012).

Moreover, in recent decades countries have been dealing with increasing urbanization, resulting in an intensified influence of climate change (He et al., 2019). In the Netherlands, over 40% of the population lives in urban areas and it is expected that urbanization will further increase in the coming years, due to the natural population growth, the influx of migrants and industrialization (PBL, 2016). As a direct consequence of human activities, the expansion of urbanization has led to major transformations in both land use and land cover (Dadashpoor et al., 2019). As cities develop, buildings, paved roads and other infrastructure replace open land and vegetation (EPA, 2008). The increasing quantity of impervious surfaces have significant implications for the hydrological response of a catchment, in comparison to natural land cover. Impervious surfaces reduce the infiltration capacity, surface storage capacity and evapotranspiration, resulting in more and faster run off. The extent of impervious land cover has increased in urban areas and at the same time the economic activities and amount of people have increased as well (Kaspersen et al., 2017).

2.1.2. Water-related vulnerability urban environment

Global warming has caused in increase in precipitation and long periods of drought over the time period of 1901-2013 (IPCC, 2015). For the Netherlands, this resulted in an increase of the yearly amount of precipitation by 26% over the time period between 1910 and 2013 and an increasing trend in dry periods (KNMI, 2014). According to the Climate Scenarios of the KNMI, especially the effect of increased water vapor in the air on heavy showers was noticeable. Observations show that the amount of precipitation per hour for the most extreme showers increased by approximately 12% per degree of warming of the air (KNMI, 2014).

Due to a combination of climate change and urbanization, it has been widely demonstrated that cities globally are becoming increasingly exposed to the occurrence and impacts of droughts and pluvial flooding (Kaspersen et al., 2017). Pluvial flooding occurs when there is a deficit of surface drainage: as an effect of high rainfall rates when surface runoff cannot be efficiently drained into the underground storm water drainage system (Palla et al., 2018). In addition, the hydraulic performance of the urban drainage system can be affected by the operational conditions of the inlets, through which the stormwater flows in the underground system. This can lead to drainage system failure, resulting in overflow (flooding) (Despotovic et al., 2005).

The economic and human consequences of extreme precipitation and related pluvial flooding of urban areas have increased rapidly in the last decades (Kaspersen et al., 2017). In the Netherlands, the largest economic activity and increasing population occurs in the Delta areas, where climate issues, as land subsidence, sea level rise and increase in precipitation extremes, are even more noticeable. The increasing hazard (climate change) and expanding exposure of assets and people within cities, cause an increasing rainfall-driven flood risk for urban areas.

2.2. Urban planning and climate change

Climate issues in urban areas have increased rapidly due to urbanization and climate change. Urban systems are large contributors to greenhouse gas emissions and their vulnerability to the impact of climate change is increasing. This indicates that corresponding to their impact, responsibility and vulnerability, cities should play a bigger role in the so called ‘global climate governance’ (Hirschl, 2018). Spatial planning in the urban environment is often said to play a major role in responding to the urgent need to address both the causes of climate change and the impacts of unavoidable climate change, as it is holistic, concerned with the link between governance and implementation, and looks ahead to relatively far futures (Wilson & Piper, 2010). Spatial planning is mainly about determining and balancing spatial claims from different government divisions, for housing, water, environment, employment and infrastructure, to eventually create an appropriate and efficient design (Goosen et al., 2013). Due to the large power of spatial planning on land use, private property rights, infrastructures and urban design, it is important to use its role as a strategic tool. Spatial planning can integrate different practices, such as urban infrastructures (energy, water, mobility) and the built environment, and provide a regulatory base for their implementation (De Pascali & Bagaini, 2018).

2.2.1. Energy transition

Climate mitigation can be described as ‘a human intervention to reduce the sources or enhance the sinks of greenhouse gases’ (Grafakos et al., 2020). To reduce the emission of greenhouse gases and to keep global warming below 2 °C, the Climate Agreement of Paris was drawn up in 2015 and signed by 195 countries worldwide. Member States of the EU are required to adopt a national climate strategy for the period of 2021-2030, which is why in 2019 the national government of the Netherlands drew up the ‘Climate Agreement’ regarding climate mitigation, as an extension of the ‘Climate Agreement of Paris’. The ‘Climate Agreement’ has a central goal: reduce greenhouse gas emissions by 49% in 2030, in comparison to 1990 (Ministerie van Economische Zaken en Klimaat, 2019).

Currently, the global energy consumption is still growing, and the growth of renewable energy is too low to offset the growth in fossil energy consumption (FutereEarth & World Climate Research Programme, 2019). This means we have to fundamentally change our way of generating energy: to achieve the goals of the ‘Climate Agreement of Paris’ the transition to a more sustainable energy supply must be set in motion within the next few years.

Urban planning and the energy transition

As the major contributors, cities have a great responsibility to help reduce greenhouse gas emissions, but in densely populated European cities, the land area available for some sort of sustainable energy production is becoming scarce (Hirschl, 2018). The fastest way to reduce greenhouse gas emissions is a substantial reduction of the use of energy carriers, with the highest emission factors, such as coal, oil and gas (Hirschl, 2018).

Cities have the largest share in greenhouse gas emissions and should thus make the largest changes to reduce their emissions. Taking availability of space, energy efficiency and costs into account, solar panels have the largest potential within urban areas, but the supply will not be stable and possibly insufficient (Acatec (National Academy of Science and Engineering) et al., 2016). Sustainable heating, in the form of district heating, creates opportunities for densely built urban areas, but the 'sustainability' aspect depends heavily on the source of heating (Sdringola et al., 2018).

Many governments around the world have made efforts to induce the sustainable energy transition, understanding that it is essential in meeting the climate mitigation objectives. These efforts have resulted in governance strategies and policies designed to change the way of energy generation. The ways in which citizens and corporate actor groups experience a transition is central to possibilities for governance change: all areas of both business, and society must be included and brought on board to plan and establish the goals, strategies and finally the measures desired (Hirschl, 2018).

2.2.2. Climate adaptation

Climate adaptation is described as 'the process of adjustments to actual or expected climate and its effects' (Grafakos et al., 2020). Climate adaptation is required, because even with assertive global action to reduce greenhouse gas emissions, climate mitigation efforts made worldwide will be insufficient to avoid all effects of climate change on society (Mastrandrea et al., 2010). The primary goal of any climate adaptation strategy is to sustain or enhance resilience against climate-related events, such as excessive precipitation or long periods of drought (Davoudi et al., 2013).

Urban planning and climate adaptation

Climate adaptation in densely built areas, like cities in the Netherlands, is strongly intertwined with spatial planning (Goosen et al., 2013). Adaptation measures are most frequently implemented at municipal level, so to compose effective climate adaptation planning, climate effects need to be translated to local scale, so that municipal and district spatial planners can address the specific climate issues within their area (Ford et al., 2011). According to Willows et al. (2003), decision-making on climate adaptation is based on uncertainties: the knowledge of the future climate and its consequences are uncertain (Willows et al., 2003). It is the responsibility of policy-makers, planners and other decision-makers to identify risks associated with climate change and to act against it accordingly. A framework to support decision-making on climate adaptation is designed by Willows et al. (2003) and is shown in Figure 2-1. Step 1 and 2 are about structuring the problem, step 3 to 5 are about analysing the problem and defining possible adaptation measures, step 6 is about the decision-making and step 7 and 8 are post-decision actions. The framework being circular is essential for climate decision-making: this allows for the performance of decisions to be reviewed and to revisit decisions through time, in light of new information regarding climate change and its effects.

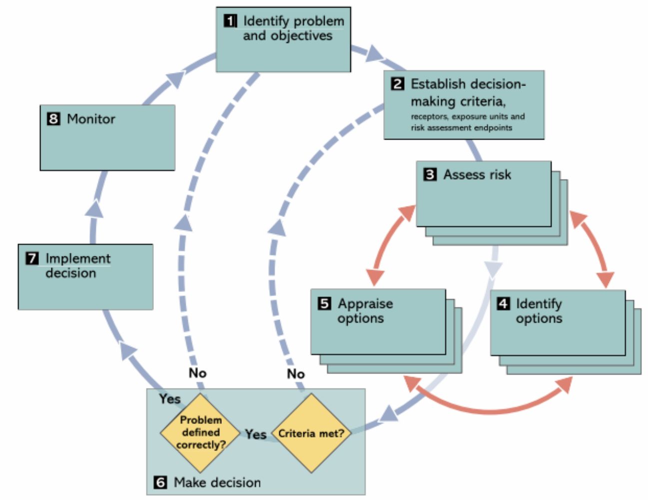

Figure 2-1 Decision-making framework for climate adaptation (Willows et al., 2003)

While traditionally urban drainage was mostly seen as 'problem-solving', conveying water away from urban areas, nowadays, more opportunities that the urban drainage system present are being recognized (Ashley et al., 2013). Possible sustainable adaptation solutions often mentioned to restore natural features within the urban environment are Green Infrastructure (GI) and Sustainable Urban Drainage Systems (SUDS) (Hoang & Fenner, 2015).

Green Infrastructure or Blue-Green Infrastructure, which are the interconnected green pathways and blue spaces formed of surface water bodies, are strongly promoted to improve the thermal comfort within the city, by reducing air temperature and increasing humidity and to increase infiltration and storage of water (Müller et al., 2013). On top of that, (Blue-) Green Infrastructure can be an important component to improve the urban aesthetic.

Sustainable Urban Drainage Systems are stormwater management installations depending on natural hydrological processes, to drain stormwater in a more sustainable way than the traditional stormwater drainage system. SUDS can facilitate a reduction in overloaded sewers and waste water treatment plants in case of heavy rainfall, as they attenuate the rainfall peaks by temporarily storing water and improving infiltration of stormwater into the ground (Hoang & Fenner, 2015). In addition, they improve the water quality (filter the water) and protect aquatic ecosystems in the urban environment (Fletcher et al., 2015).

In conclusion, the urgency in cities to adapt to climate change is increasing. It is more often being recognized that climate adaptation measures can offer a lot of opportunities for the environment: improve the thermal comfort and aesthetics of a city, improve the water quality and protect aquatic ecosystems.

2.3. Urban water systems integration

Industrial ecology scholars argue that systems integration is one of the solutions to tackle environmental problems: existing systems should be integrated in order to create synergies, re-use waste and optimize the environmental performance of industrial regions and cities (Vernay et al., 2013). Vernay et al. (2013) defined systems integration as ‘all attempts that aim at achieving a higher efficiency for two (or more) systems combined, than can be achieved by each system apart’.

Because the expansion of urban areas has resulted in large demands on water and energy resources, a lot of attention in academic research has been given to the interdependence between water and energy based resources into the concept of the ‘water-energy nexus’ (Fang & Chen, 2017). The water-energy nexus can be explained as the interconnection or the cause-effect relationships between water and energy (Kenway et al., 2011) based on resources: electricity generation requires water, and water treatment and transportation require energy (Hamiche et al., 2016). Through empirical research, this study aims to obtain broader insights into the possible system integrations between the energy and the urban water system. Mapping the diverse links between the two critical resources, water and energy, can help to identify where better integrated policy and management strategies are needed and possible (Hussey & Pittock, 2012).

2.3.1. Typology urban water systems integration

Vernay and Boons (2015) characterized a conceptual framework to assess the ‘degree’ of systems integration. This approach focuses on the degree of integration, how integrated certain solutions are, which can help in the understanding of the processes of systems integration, but does not elaborate on the types of systems integration (Vernay & Boons, 2015). The types of integration are related to the relationship between two systems, resulting from the objects of integration. According to Rinaldi et al. (2001), infrastructures are often connected at multiple points through a wide variety of mechanisms, the so-called interdependencies. Infrastructure interdependency is defined as ‘a bi-directional relationship between two infrastructures through which the state of each infrastructure influences, or is correlated to, the state of the other’ (Rinaldi et al., 2001). Four critical types of infrastructure interdependencies are defined: physical interdependency, cyber interdependency, geographic interdependency and logical interdependency.

Based on the principle of interdependencies or Rinaldi et al. (2001) and on the concept of systems integration of Vernay and Boons (2015), a typology for urban water systems integration is defined (Nieuwenhuis et al., 2020). In Table 2-1, the four types of urban water systems integration are explained. It is important to note that systems integration can also come in an overlapping or hybrid form.

Table 2-1 Types of systems integration (Nieuwenhuis et al., 2020)

Types of systems integration	Explanation
Physical	Resource-based integration: a physical linkage between the inputs and outputs of two systems: a commodity produced by one infrastructure can be used by another infrastructure Infrastructure-based integration: one infrastructure uses the other to fulfil or enhance its function Objects of integration are 'resources' or 'infrastructure'
Informational	Combining data of different urban systems, to gain more knowledge about the interactions of the systems Object of integration is 'data'
Geographical	Elements of multiple infrastructures are in close spatial proximity, which means close spatial organization is required: competing spatial interests, both above and below ground, and preventing interference between subsurface and above-ground systems Object of integration is 'space'
Project-based	Project-based integration focuses on possible synergies between urban infrastructure systems in rehabilitation or construction planning Object of integration is 'planning'

The complexity that comes with each of the four types of integration, contains both technical- and socio-institutional aspects. Integration of the water and energy system therefore requires consideration of both aspects (Nieuwenhuis et al., 2020).

2.3.2. Objects of integration of the urban water and energy system

Many different forms of systems integration may exist, and certainly not all these forms are yet discovered in practice. This study focuses on insights into what the integration between the energy system and urban water system could be based on. Examples related to the urban water and energy system integration, currently described in scientific literature and knowledge reports, are displayed in Table 2-2.

Table 2-2 Examples urban water and energy system integration

Type of integration	Object of integration	Example related to urban water and energy system
Physical	Resources	1. Thermal energy from the sewer or effluent - Wastewater as alternative energy source for heating and cooling purposes: water in the sewer is often warm enough to extract energy from it and convert this to heating energy (Hartman & Bloemendal, 2015) 2. Thermal energy from surface water - Surface water as alternative energy source for heating and cooling purposes: heat and cold can be extracted from open water and stored underground, after which users can immediately use the cold or use the heat after upgrading it with a heat pump, or direct cold extraction can be applied in deep pools or canals and rivers with a strong flow (STOWA, 2018)
Physical	Infrastructure	A Multi-Utility Tunnel that can co-locate different underground utilities, such as stormwater drainage and heating network pipes, to facilitate repair and renewal of the pipes and cables while eliminating the need for multiple excavations (Hunt et al., 2014)
Informational	Data	If rainfall within the urban environment and the variations in the cost of energy and variations in sustainable energy supply can be predicted by Real-Time-Control, the pumping stations can pump the water at the most efficient times, to safe costs and to make maximum use of sustainable energy (Pothof et al., 2019)
Geographical	Space	Due to the increasing geographical proximity in the underground in the Netherlands two systems can lie close to each other and potential interference of systems can occur, for example between Aquifer Thermal Energy Storage and the sewer system (Coenen et al., 2010)
Project-based	Planning	Synchronization of rehabilitation and renewal projects planning for specific areas from different right-of-way infrastructure can reduce costs and increase efficiency (Carey & Lueke, 2013)

2.4. Conclusions from the literature study

From the literature study it can be concluded that the urgency for cities to both adapt to and act against climate change is high. Cities need to make the largest changes to reduce their greenhouse gas emissions and in addition, cities are highly vulnerable to the effects of climate change.

The answers to research question 1.1 and 1.2 are presented below.

Research question 1.1: How does urban planning play a role in climate adaptation and mitigation strategies, according to literature?

Spatial planning in the urban environment is often said to play a major role in responding to the urgent need to address both the causes of climate change and the impacts of unavoidable climate change, as it is concerned with the link between governance and implementation, and looks ahead to relatively far futures (Wilson & Piper, 2010). Besides, cities have the largest share in greenhouse gas emissions and should thus make the largest changes to reduce their emissions.

Many governments around the world have made efforts to induce the sustainable energy transition, understanding that it is essential in meeting the climate mitigation objectives. These efforts have resulted in governance strategies and policies designed to change the way of energy generation (Hirschl, 2018). In addition, climate adaptation measures are most frequently implemented at municipal level, so to compose effective climate adaptation planning, climate effects need to be translated to local scale, so that municipal and district spatial planners can address the specific climate issues within their area (Ford et al., 2011).

Research question 1.2: What types of urban water systems integration are distinguished in literature and what types of integration are expected for the urban water and energy system?

Based on the principle of interdependencies of Rinaldi et al. (2001) and on the concept of systems integration of Vernay and Boons (2015), a typology for urban water systems integration is defined (Nieuwenhuis et al., 2020). According to this typology, the four types of urban water systems integration to examine in this research, are: physical, informational, geographical and project-based integration. These types are explained in Table 2-1.

Examples of physical integration based on resources and infrastructure can be widely found in literature, but specific examples of informational, geographical and project-based integration are a lot less studied. An overview of examples is given in Table 2-2. This research will focus on integration between the energy transition, which is translated into district heating and solar panels, and climate adaptation measures to tackle urban flooding. This specific topic is still underexposed in literature, which means that objects of integration will mainly be discovered through this research.

3. Desk study Rotterdam

This chapter entails background information regarding urban planning, energy transition and climate adaptation strategies in Rotterdam. The following research questions are answered:

1.3. Who are responsible for urban planning and urban water management within the municipality of Rotterdam and what are their responsibilities?

1.4. What are possible energy transition measures within the built environment of Rotterdam and what are their spatial and planning process impacts?

1.5. What are possible climate adaptation measures within the built environment in Rotterdam and what are their spatial impacts?

3.1. Responsibilities urban planning and urban water management Rotterdam

In this section, the urban planning and urban water management responsibilities within the municipality of Rotterdam are discussed, to eventually find an answer to research question 1.3: '*Who are responsible for urban planning and urban water management within the municipality of Rotterdam and what are their responsibilities?'*.

Urban planning Rotterdam

The chain from project preparation to implementation of projects and maintenance of public space in Rotterdam is the responsibility of the Public Works-division of the Urban Management Cluster and Urban Development Cluster of the municipality (Gemeente Rotterdam, 2017). Design and layout of the public space of the entire city should be carried out according to the guidelines for spatial planning in Rotterdam (Rotterdamse Stijl, in Dutch) and management should be carried out according to guidelines for technical implication, set by the municipality. The guidelines for design and materialisation within Rotterdam aim to provide handles for the desired coherence and recognisability in the public space of Rotterdam (Gemeente Rotterdam, 2010). In this subsection the main responsibilities of the Public Works-division (Urban Management Cluster) and the Urban Development Cluster are discussed, based on the overview of the planning process of public space projects and responsibilities shown in Appendix A.

Public Works-division (Urban Management Cluster)

The Public Works division of the Urban Management Cluster of the municipality of Rotterdam is responsible for all asset management and maintenance within the city. The division is divided into four departments: Basic Information (basic registration of addresses, buildings and other basic data for the municipality), Subsoil, Water and Infrastructure. To manage all assets efficiently, the municipality is split into six different areas and all areas have their own area managers.

Different managers from the Public Works-division that are active within an area and their responsibilities are:

- Person of contact Water (accountmanager water, in Dutch): creating a point of contact for the area at the Water department with regard to specific knowledge about the water / sewer system (strategic, tactical);
- Asset managers: responsible for the quality and management measures for a specific asset (sewers, infrastructure, green, assets in the subsoil). The object manager determines the long-term maintenance requirement (Meerjaren Onderhoudsbehoefte, in Dutch) of the particular infrastructure system;
- Area manager: responsible for the multi-year maintenance program and the annual plan for management and maintenance in an area. The area manager matches the maintenance needs of different parties in the public space (municipality, gas/electricity supplier, drinking water supplier, heat supplier, telecom companies). In consultation with the project manager, the area

manager ensures that the area management plan of the Public Works-division results in actual projects.

Urban Development Cluster

The Urban Development Cluster of the municipality of Rotterdam is responsible for development of the city in a broad sense: economically and physically. The latter consists of long term spatial policies and planning and short term area developments and public space design. The cluster is divided into four different divisions: Area Development and Quality, Economy and Sustainability, Urban Design and Project Management and Engineering. This cluster has split the city into six different areas as well and all areas have a so-called ‘area account manager’, which can make the match between the efforts and desires in the area. He plays a central role in drawing up the area objectives. In new development projects, the Urban Development Cluster also works on optimal cooperation between the municipality, companies and housing corporations, with the aim of uniting public and private interests. The Urban Management Cluster provides the Urban Development Cluster with boundary conditions for design during the development phase and once new developments in public space have been implemented or the area is redesigned, the assets become the responsibility of the Public Works-division, regarding maintenance.

To finally come to a project planning for an area, the Public Works-division of the Urban Management Cluster and the Urban Development Cluster try to match their maintenance- and development needs, to run projects simultaneously. Currently, sewer maintenance is often taken as a lead in the planning phase, because it is a relatively large maintenance task and various other developments or maintenance can easily take part. A public space project can either turn into a maintenance plan (Onderhouds Plan, in Dutch) or a design plan (Inpassings Plan, in Dutch). A maintenance plan is only carried out by the Public Works-division and includes several maintenance projects in an area, but the design of the public space is basically left as is. A design plan is carried out by the Urban Management and Urban Development-division. It includes maintenance projects, but also plans to redesign the public space and implement new infrastructure.

Urban water management Rotterdam

The Water Law (Waterwet, in Dutch) and Law of Environmental Conservation (Wet Milieubeheer, in Dutch) state that municipalities are responsible for collection, disposal and processing urban waste water and rainwater. In addition, waterboards have a certain responsibility: they purify the urban waste water supplied by the municipality of Rotterdam and they maintain a certain water level and water quality in all city waters and a certain groundwater level in the entire city. All parts of the urban water system are strongly connected, which is why collaboration between the municipality and waterboards is very important (Gemeente Rotterdam, 2016b). Besides the municipality and waterboards, private parcel owners have a responsibility regarding urban water management in Rotterdam, as well. All responsibilities regarding urban water management in Rotterdam and how they influence each other are visualised in Figure 3-1 (Gemeente Rotterdam, 2016b).

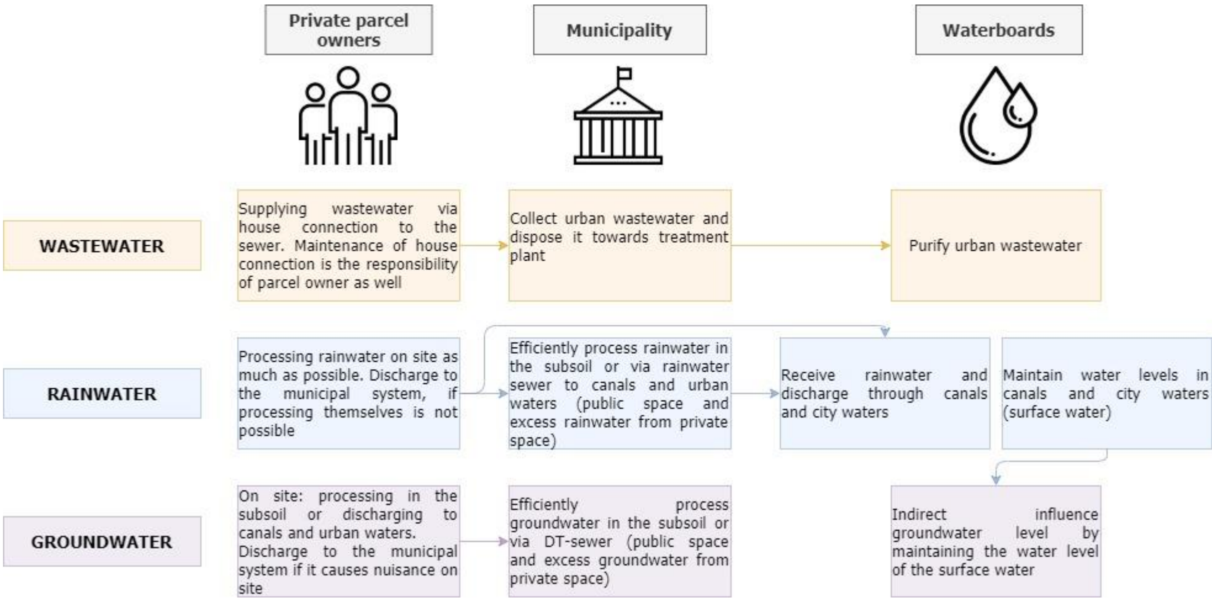

Figure 3-1 Responsibilities urban water management municipality of Rotterdam

3.2. Energy transition strategy built environment Rotterdam

Rotterdam produces more than 20% of the national CO_2-emissions in the Netherlands, which means the city faces a big challenge reducing these emissions (Gemeente Rotterdam, 2019e). Within the 'Council Agreement Energy Transition' (Raadsakkoord Energietransitie, in Dutch) the municipality of Rotterdam has translated the ambitions stated in the Climate Agreement of Paris into local objectives: Rotterdam's annual CO_2-emissions have turned into a downward trend by 2022, a reduction of CO_2-emissions of 49% by 2030 compared to 1990 and a completely climate-neutral municipality by 2050 (Gemeente Rotterdam, 2019e). Not only the need for greenhouse gas reduction is the driver of the 'Council Agreement Energy Transition', but the natural gas extraction in Groningen that needs to quit by 2030, as well. The Sustainability-department of the Urban Development-division of the municipality is responsible for the planning and implementation of the energy transition in Rotterdam.

The 'Plan of Implementation of the Energy Transition' (Uitvoeringsplan Energietransitie, in Dutch) and the 'Climate Agreement of Rotterdam' (Rotterdams Klimaatakkoord, in Dutch) are practically oriented extensions of the 'Council Agreement Energy Transition' and focus on the actual implementation of energy transition measures. For the built environment the translation of the objectives into implementation means nearly 300.000 homes and thousands of buildings need to be better insulated and heated in a sustainable matter by 2050. Various options for sustainable ways of heating have been investigated and for several pilot areas in Rotterdam initial plans are set up. The implementation of sustainable energy solutions will be done district by district, thereby aiming to combine the construction work with work from other projects, like sewer maintenance or other public space projects. Also, there is a lot of cooperation with housing corporations, to carry out a lot of work simultaneously. Because the largest part of houses in Rotterdam is privately owned, private bottom-up initiatives are supported as well, through subsidies or loan funds (Energieswitch010, 2019).

Within the current term of board, Rotterdam has selected 5 pilot areas where the switch to a 'gas-free' energy system is being made. These pilot areas are used to provide input for a standard approach for all districts in Rotterdam. The long-term planning that is followed in Rotterdam to completely switch to a gas-free network is shown in Figure 3-2 and explained below.

Figure 3-2 Phasing of Rotterdam's energy transition (Gemeente Rotterdam, 2018b)

The phasing of the energy transition in Rotterdam is subdivided into four phases:

- *From 2018:* Start with the first pilot areas is being made.

- *2018-2022:* In the current term of board, Rotterdam is making the transition from intentions to actual implementation of district heating within the pilot areas. In total, at least 10,000 buildings need to be made or prepared for gas-free.
- *2022-2030:* In 2030 a reduction of 49% of CO_2 emissions must be achieved, so in this period a trend has to be created, in which a fixed number of buildings is going gas-free each year. The gas-free approach is standardized.
- *2030-2050:* It is expected that in this last phase a standard process for going gas-free has been developed, comparable to processes such as sewer maintenance or maintenance of the gas pipeline network. By 2050 the target has to be achieved that 263.000 buildings are free of natural gas.

Potential energy transition measures in Rotterdam and their spatial impacts

Sustainable energy alternatives for the built environment Rotterdam mentioned so far, are district heating and electrical solutions (all-electric) or a hybrid energy system, combining multiple types of energy generation (Gemeente Rotterdam, 2019a). Because it is expected that towards 2050 there will be an excess of heat (generated by the industrial activities in the Port of Rotterdam) and a shortage of clean electricity, district heating is currently seen as the main sustainable solution for Rotterdam (CE Delft et al., 2018). Residual heat from the port area is mainly extracted from the petrochemical industry: chemical companies, oil refineries, palm oil refineries, biofuel producers, biochemical factories, power plants and a laboratory annex test environment (Port of Rotterdam, 2019). Heat recovery from other sources, such as surface- or wastewater, is now mainly considered for cooling purposes: water from the River Maas is used as cooling water. In the future, however, aqua thermal heat and geothermal heat can also be used for low temperature district heating (Gemeente Rotterdam, 2019i). An all-electric solution in Rotterdam could only work for a few small and remote areas, where a collective solution is not possible (J. Benders, personal communication, March 13 2020). In this research the focus lies on a high temperature district heating network, using residual heat from industrial activities in the Port of Rotterdam.

In addition to the implementation of a district heating network, several housing corporations in Rotterdam, managing 40% of the total housing stock, are aiming to contribute to the reduction of CO_2-emissions and to the plans to become gas-free. The housing corporations aim to insulate houses, make lighting and installations more sustainable and transform houses into a gas-free household. Also solar panels will be widely installed where possible, to generate sustainable electricity in addition to sustainable heating (Energieswitch010, 2019). Because currently the plans completely consist of a high temperature district heating network, limited adjustments are needed in houses. While insulating is always smart to save energy and thus reduce monthly costs, it is not necessary for high temperature district heating. Switching to an electric way of cooking and a connection to the heating network, are two changes that have to be made within buildings that are to be connected to a district heating network (Milieu Centraal, 2019).

To implement district heating in an entire neighbourhood, housing corporations and private owners of real-estate should agree to the adjustments. For both housing corporations and private owners, a subsidy from the municipality should ensure that for the vast majority of residents the monthly costs of any loan they take out for the renovation does not exceed the benefit they book on the energy bill (Gemeente Rotterdam, 2019a).

Spatial impacts: District heating

The district heating network implemented in Rotterdam consists of five elements: a heat source, a pipe network to distribute the heat to various transfer stations in the city, a transfer station that transfers heat from the large network to the connected buildings, a heat unit that transfers the heat to a building's internal heat delivery system and an internal heat delivery system (HVC Groep, 2020). After the heat has been released inside a building, the cooled water flows back to the heat source via the return pipes. In Figure 3-3, the elements of a district heating network are schematized.

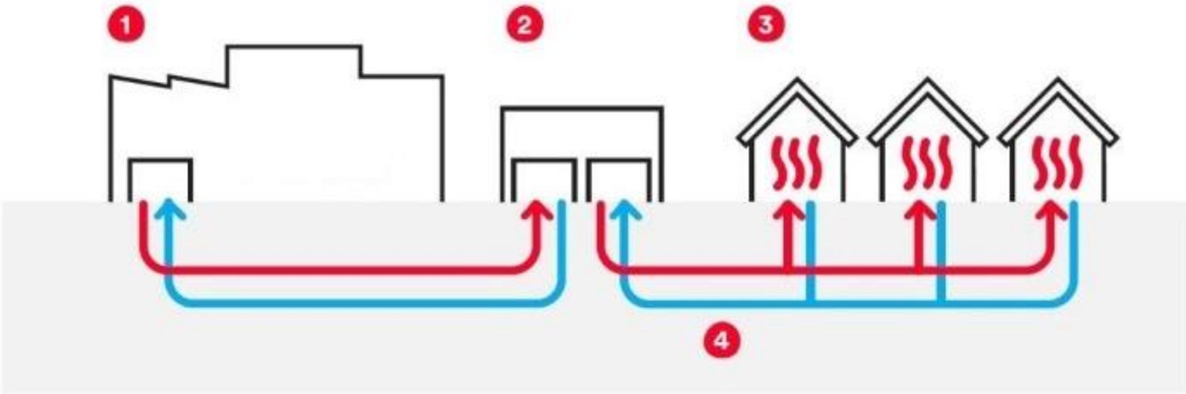

Figure 3-3 Schematized elements of a district heating network (HVC Groep, 2020)

For the pipe network, Rotterdam distinguishes four types of pipes: the transport pipes, the distribution pipes (primary and secondary) and house connection pipes (Gemeente Rotterdam, 2019c).

Transport pipes are suitable for distributing large amounts of heat from its source towards a district and consists of main connection points: points where primary distribution pipes are connected to the transport pipe. The primary distribution pipes transport the heat between the main connection point (of the transport pipe) to the heat transfer stations. The primary distribution pipes are located in a specific part of the city and transport heat on a smaller scale, which means these pipes can also be seen as a transportation network. From the heat transfer stations, the secondary distribution network runs through the streets of a neighbourhood. These pipes are provided with house connections (N.J, Bruin, personal communication, April 18, 2020). When houses on both sides of the street are to be connected to the district heating network, the location of the distribution pipes is desired to be as much in the middle of the street as possible. Currently, sewer pipes are often located in the middle of the street, implying that the desired location of the district heating network and the sewer system conflict. The house connection pipes branch off from the secondary distribution network towards the houses by means of a control station (Gemeente Rotterdam, 2019c). District heating pipes have a lifespan of approximately 60 years (Aedes, 2018).

The transport pipes, distribution pipes and house connection pipes all consist of two pipes: a supply (high temperature) and return (lower temperature) pipe. The supply pipe supplies the heat from its source and distributes it among the houses, after which the return pipe returns the cooled water to the source. In principle all pipes within the municipality of Rotterdam are installed horizontally with respect to each other: only when there is insufficient space to fit all pipes horizontally, pipes are laid above each other (Gemeente Rotterdam, 2019c).

To transport and distribute the heat, the pipes of the district heating network have to cross different pipes (f.e. sewer, telecom, electricity) and have to be placed parallel to different pipes. The municipality of Rotterdam maintains 0,5 metres as minimal horizontal distance (parallel) and 0,2 m as minimal vertical distance (intersection) for cables and pipes (Gemeente Rotterdam, 2019c). Within the 'Underground Management Manual' for the municipality of Rotterdam, a laying scheme for pipes is displayed: indicating how each pipe should cross other pipes vertically (bottom or top) (Gemeente Rotterdam, 2019c). The guidelines regarding district heating with respect to drinking water pipelines are very strict, due to the so-called 'underground urban heat island effect': heat pipes of the district heating network loose heat to the subsurface, which can cause the drinking water to heat up (KWR, 2017). Currently, research is conducted by Deltares and KWR to determine the minimum distance needed and to identify other measures to prevent subsoil heating (Deltares & KWR, 2020). In Table B-1 in Appendix B, an overview is given of information regarding the pipes of a district heating network, used by the municipality of Rotterdam.

To install district heating, excavation in roadways is needed to place the transport, primary- and secondary distribution pipes. When secondary distribution pipes are installed in a street, house connection pipes are linked to the pipes to distribute the heat towards houses. For the house connection pipes, trenches have to be dug towards all houses. In case of a multi-layered apartment complex, only one larger connection pipe will suffice (N.J., Bruin, personal communication, June 9, 2020).

Spatial impacts: Electricity grid and solar panels

In addition to district heating, the energy transition will have an impact on the electricity network in the city. Due to the transition to a gas-free household, more electricity is being used to, for example, cook with. Often, more electricity use requires a reinforced connection within the houses to the electricity grid: this requires an adjustment in the meter cupboard (van Gastel, 2019). In some cases, increased electricity usage also requires reinforcement of the electricity grid. The capacity of the grid can be increased by expanding the cables underground or by installing more transformer substations in the public space above ground, so more electricity can be transported into the area.

Solar panels are mainly installed on roofs in the built environment. When large numbers of solar panels are installed, grid reinforcement is necessary as well. When there is more energy generated than used, for example when it is very sunny, the excess electricity is fed back to the grid and this can cause large peaks, leading to electricity failure. Hence, to limit failures, the grid needs to be adjusted (Liander, 2018).

3.3. Climate adaptation strategy built environment Rotterdam

In 2018, the ‘Deltaplan of Spatial Adaptation’ (*Deltaplan Ruimtelijke Adaptatie)* was drawn up in the Netherlands by municipalities, provinces, waterboards and the state, to offer guidelines for adaptation to the effects of climate change and urbanization. The goal of the Deltaplan is to make the entire country act as climate-resilient and water-robust as possible by 2050, by integrating climate adaptation within policy of all municipalities (Rijksoverheid, 2018). As a result of the Deltaplan and as an extension of previously made plans within the ‘Waterplan 2’ and ‘Rotterdam Adaptation Strategy’ (Gemeente Rotterdam, 2013; Gemeente Rotterdam et al., 2013), the municipality of Rotterdam, three waterboards and Evides signed the ‘Rotterdam Weatherwise Plan’ in February 2019, which includes the municipality’s strategy and goals regarding climate adaptation on local scale for Rotterdam. Due to Rotterdam’s location, a city situated in the Dutch Delta, there is an even larger need for adaptation and therefore, the five parties considered the goals of the Deltaplan not ambitious enough. Rotterdam’s objective, explained in the ‘Weatherwise Urgency Document’, is to scale up and specify the climate adaptation approach for the entire city and therby transform into a climate-resilient city, by taking adaptation into account in all projects (newly-build and renovation), by 2030. If all projects are carried out in a climate adaptive way by 2030, the intention is that the entire municipality will be climate-resilient by 2060. The Water-department of the Urban Management-division of the municipality is eventually responsible for the implementation of this plan. Creating extra water storage in the built environment can be realized as an extension of programs for greening and redesigning neighbourhoods, but also as an extension of sewer maintenance and regular management and maintenance of the public space (Gemeente Rotterdam et al., 2013).

The ‘Rotterdam Weatherwise Plan’ states Rotterdam has to deal with six different climate issues: excessive precipitation, heat, drought, floods (due to sea level rise), groundwater and subsidence (Gemeente Rotterdam, 2019g). The short-term focus of the municipality of Rotterdam lies on high water levels and flooding due to precipitation (pluvial flooding). Climate resilience regarding precipitation, as stated in the ‘Weatherwise Urgency Document’, implies that all buildings, being built or renovated, should be able to capture 70 mm of rainfall in one hour, after which they gradually dispose it. Also, the water retention capacity of public space needs to be sufficient to prevent damage in case of both heavy rainfall and long periods of drought. Based on the future climate scenarios of KNMI, a storm event of 70 mm in one hour, has been defined as a representative of an extreme event in 2050 (KNMI, 2014). Other objectives stated in the ‘Weatherwise Urgency Document’ are: at least 50% of the precipitation runoff must be visible above ground and vital infrastructure must continue to function in case of heavy rainfall. The strategy for climate adaptation is developed on various bases: adaptations of the existing urban water system with the motto: ‘realize open water where possible and look for alternative solutions where necessary’, contribute to prevention of flooding and damage by adapting outdoor space and buildings and encourage a shared responsibility of both public and private parties (Gemeente Rotterdam et al., 2013).

On short term, the goal of the current councillor, in line with the ‘Rotterdam Weatherwise Plan’, is to improve the ‘blue-label’ of houses in Rotterdam. In 2018 all houses were assigned a ‘blue-label’: a blue-label of a house is categorized from A (very safe) till E (water against the façade) in case of heavy rainfall. Currently 12% of the houses in Rotterdam are a risk case (label C, D or E) and the goal is to reduce this percentage to 10% by the end of 2021. This means the risk of flooding should be reduced for approximately 7000 houses in Rotterdam, by taking climate adaptation measures (Verlinde, 2020). In addition, the goal of the current councillor is to increase the greenery in the city with 20 hectares by

2022. The long term climate adaptation plans, to further reduce the blue labels and in line with the goals stated in the ‘Rotterdam Weatherwise Plan’, are still in development.

Potential climate adaptation measures in Rotterdam and their spatial impacts

Rotterdam distinguishes three general types of measures to contribute to rainproof urban areas: infiltration (retention), storage and conveyance of water (Gemeente Rotterdam et al., 2013). Each of these types of measures is best suited for certain types of soil (permeability) and groundwater level. Infiltration solutions can lead to higher groundwater levels, which could be beneficial in case of long periods of drought, but could cause flooding or high groundwater levels, with adverse effects to roads and underground infrastructure, in case of heavy rainfall. To prevent urban flooding as a result of high groundwater levels, an important factor that should always be maintained is the minimal dewatering depth: the distance between the ground level and the phreatic groundwater level. In Rotterdam the minimum dewatering depth that should be maintained is 0,80 meter in the built environment (streets, squares, etc.) and 0,50 meter in public green areas (parks, public gardens, etc.) (Gemeente Rotterdam, 2018a). In principle, climate adaptation measures are never laid above cables and pipes in Rotterdam (N.J, Bruin, personal communication, June 9, 2020). Reasons for this, are (GPKL et al., 2012):

- When climate adaptation measures are placed above cables and pipes, it will take more money and effort for the owners to reach their assets, in case of replacement or maintenance;
- For gas pipes: leakage of the gas can lead to dangerous situations. The place of leakage must still be possible to locate above ground;
- For drinking water pipes: sensitive to damage caused by incorrectly returned foundation materials.

In Rotterdam, a group including engineers, professionals of different sectors, artists, architects and residents, developed ‘building blocks’ for adaptation to extreme rainfall situations (Water Sensitive Rotterdam, 2020). Different climate adaptation measures have been assessed by various divisions within the municipality of Rotterdam and this resulted in a selection of promising measures (‘building blocks’) that should eventually be given a standardized place within urban planning (M. Fang, personal communication, April 15, 2020; J.W. van der Kwaak, personal communication, April 15, 2020). In Table 3-1, an overview is presented of the types of climate adaptation measures (based on the location and facility) and examples of each type. Most examples are based on the building blocks, developed by the municipality. In addition, a paved ditch, trees placed in lowered green, a bioswale and a DT-sewer are added, based on a System Overview Urban Water (Systeemoverzicht Stedelijk Water, in Dutch) developed by the research institute RIONED (Stichting RIONED, 2020).

All measures in Table 3-1 are coupled to the categorization of the municipality mentioned earlier: infiltration, storage and conveyance. In addition, the functioning of each measure is listed: regular functioning (day-to-day event) or design functioning (design event for technical optimization) (Fratini et al., 2012). The functioning indicates the effectiveness of the measure in the field of water storage potential for different storm events.

Table 3-1 Potential climate adaptation measures in Rotterdam

Climate adaptation measure	Location	Categorization	Functioning	Source
A. Water storage in the subsoil below the street profile				
Hollow space in sandy road and parking foundation	Subsoil, Road or parking lanes	Infiltration Storage	Design event	Rotterdam
Water storing road foundation	Subsoil, Road	Infiltration Storage	Design event	Rotterdam

Water storage in coarse granulate below parking lanes	Subsoil, Parking lanes	Infiltration Storage	Design event	Rotterdam
Water storage in crates below parking lanes	Subsoil, Parking lanes	Infiltration Storage	Design event	Rotterdam
B. Water storage at ground level in the street profile				
Water storage on roadway and/or parking lanes	Ground level, Road or parking lanes	Storage	Design event	Rotterdam
Paved ditch	Ground level and subsoil, Road	Storage Conveyance	Design event	RIONED
C. Water storage in the soil through greening				
Water storage in green parking lanes (permeable pavement)	Ground level (permeable pavement) and subsoil (storage), Parking lanes	Infiltration Storage	Regular event/ Design event	Rotterdam
Green strips along façade of building	Ground level (greenery) and subsoil (storage), Along façade of buildings	Infiltration Storage	Regular event/ Design event	Rotterdam
Green in the street profile (plant boxes around trees, road verge)	Ground level (greenery) and subsoil (storage), Street profile	Infiltration Storage	Regular event/ Design event	Rotterdam
Trees placed in (lowered) green	Ground level (tree) and subsoil (roots and storage), Sidewalk	Infiltration Storage	Design event	RIONED
Bioswale	Ground level (greenery) and subsoil (soil improvement), Sidewalk	Infiltration Storage	Regular event/ Design event	RIONED
D. Water storage in the sewer				
Enlarge sewer pipe	Subsoil, Road	Storage Conveyance	Regular event	Rotterdam
DT-sewer (drainage-transport)	Subsoil, Road	Storage Conveyance	Regular event/ Design event	Rotterdam
E. Water storage in/near buildings (private)				

Water storage at the roof (green roofs)	Private property, Roof	Storage	Regular event	Rotterdam
Green façade of building	Private property, Façade	Storage	Regular event	Rotterdam
Rainwater tanks	Private property, Garden	Storage	Regular event	Rotterdam

In Table C-1 and Table C-2 in Appendix C, the possible climate adaptation measures are discussed more detailed and the amount of storage each measure can realize is examined.

3.4. Conclusions from the desk study

The conclusions from the desk study and the answers on the sub-questions are presented below:

Research question 1.3: Who are responsible for urban planning and urban water management within the municipality of Rotterdam and what are their responsibilities?

Urban planning in public space is the responsibility of the Public Works-division of the Urban Management Cluster and the Urban Development Cluster of the municipality of Rotterdam. An overview of the planning process is displayed in Appendix A. The Public Works-division is responsible for all asset management and maintenance within the city. A long-term maintenance requirement (Meerjaren Onderhoudsbehoefte, in Dutch) is determined for all assets within an area, and based on this requirement, the area manager constructs a multi-year maintenance program for management and maintenance of existing assets within the area. The area manager matches the maintenance needs of different assets in the public space. The Urban Development Cluster of the municipality of Rotterdam focuses on new developments in the city, in the field of urban planning. The cluster works on optimal cooperation between the municipality, companies and housing corporations, with the aim of uniting public and private interests. Area account managers from this division matches the efforts and wishes in the area, to finally draw up area objectives. To finally come to an urban planning, the Public Works-division and Urban Development Cluster try to match their maintenance- and development needs, to run projects simultaneously.

Urban water management in Rotterdam is subdivided in wastewater, rainwater and groundwater and is the responsibility of the municipality, waterboards and private parcel owners. The responsibilities and how they influence each other are visualised in Figure 3-1.

Research question 1.4: What are possible energy transition measures within the built environment of Rotterdam and what are their spatial impacts?

Since Rotterdam is a densely built city and it is expected that towards 2050 there will be an excess of heat (generated by the industrial activities in the Port of Rotterdam) and a shortage of clean electricity, district heating is currently seen as preferable sustainable heating solution instead of an all-electric solution. This means that Rotterdam focuses on a high temperature district heating network as the alternative for natural gas, for heating purposes, and solar panels as an alternative for fossil electricity generation. Switching to an electric way of cooking and a connection to the heating network, are two changes that must be made within buildings that are to be connected to a district heating network.

Spatial impacts of implementation of district heating in Rotterdam are especially relevant for the underground pipe network. Within the municipality of Rotterdam a horizontal distance between pipes of 0,5 m (parallel pipes) and a vertical distance between pipes of 0,2 m (intersecting pipes) must be adhered to. A laying scheme, presented by the municipality of Rotterdam, is followed with regards to the depth of pipes and specific information regarding district heating pipes is shown in Table B-1. District heating pipes have a lifespan of approximately 60 years.

In addition to the district heating network, large-scale installation of solar panels involves a spatial claim as well, since solar panels take up space on the roof in the built environment. Grid reinforcement or -adjustments are needed when the electricity demand increases, as a result of the switch to electric cooking, and when a large amount of electricity is fed back to the grid by solar panels, but this only influences the planning process, not the space needed.

Research question 1.5: What are possible climate adaptation measures within the built environment in Rotterdam and what are their spatial impacts?

In this research, the realization of Rotterdam's climate adaptation goals is mainly focused on one weather extreme: high water levels and flooding due to excessive precipitation. The short-term goal of the municipality is that buildings and public space should be able to cope with 70 mm of rainfall within one hour (capture and gradually dispose after), without any damage occurring. The goal of the current councillor is to improve the 'blue label' of houses in Rotterdam. In 2018 all houses were assigned a 'blue label': a blue label of a house is categorized from A (very safe) till E (water against the façade). The risk of flooding (water against the façade) must be reduced for approximately 7000 houses in Rotterdam (Verlinde, 2020).

Taking the certain types of soil and groundwater levels in Rotterdam into account, the 'Water Sensitive Rotterdam' framework developed *building blocks* for adaptation to extreme rainfall situations. These building blocks are a selection of promising measures that can be given a standardized place within the city of Rotterdam. The measures are categorized based on the way they handle the rainfall: infiltration, storage and/or conveyance. The building blocks for Rotterdam and additional promising measures according to literature are listed in Table 3-1 and explained more detailed in Appendix C.

III.

METHODOLOGY

Chapter 4 – Research methodology
Chapter 5 – Case study design

Methodology

The third part of this thesis, the methodology, presents the research approach and the case study design. In Chapter 4, the methodology used for the case study design, the within-case analysis and the validation of the results is discussed. Chapter 5 presents the case study design and the final selection of cases to continue the research with.

4. Research methodology

This chapter elaborates on the research methodology that is used to find an answer to the main question. The main question asked in this research is a global, explorative question: it explains phenomena of events and their relationships. Because not much is currently known or investigated about the interactions between the energy transition and climate adaptation, an explorative and inductive research strategy is chosen (DeGraaf & Huberts, 2008). According to Yin (1994), 'how'-research questions are likely to favour the use of a (multiple) case study and a degree of uncertainty in rationale and direction should underlie an exploratory case study (Yin, 1994). For that reason, the overall-method that is used in this research is an explorative case study approach, based on multiple and diverse cases. The process that is followed to build a theory from multiple cases, is based on the Process of Building Theory from Case Study Research developed by Eisenhardt (1989) and based on the Multiple Case Study Method developed by Yin (2003), and is visualised in Figure 4-1 (Eisenhardt, 1989; Yin, 2003). Each case consists of a 'whole' study, seeking convergent evidence regarding the facts and conclusions for the case. Per case an individual report is written and from those reports cross-case conclusions can be drawn.

From the steps displayed in Figure 4-1, Step 2, selecting cases, and Step 4, analysing data, are performed according to a specific method. Step 1 contains the set-up of the research and research questions (Chapter 1), Step 3 covers the methodology used for the case selection and analysis (discussed in this chapter) and in Step 5 and 6 the results are discussed and conclusions are drawn from the results (Chapters 6, 8 and 9).

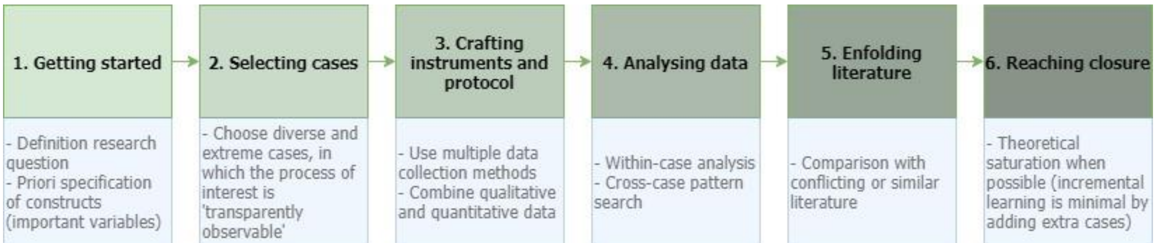

Figure 4-1 Process of building a theory from case study research, based on the study of Eisenhardt (1989) and Yin (2003)

In section 4.1, the methodology followed for the case selection, the case study design, is discussed. The within-case analysis used to present the results of the multiple case study is explained in section 4.2.

4.1. Case study design

The cases studied in this research are based on the 5 pilot areas within Rotterdam, where a start to switching to a gas-free network is currently being made. These areas are: Rozenburg, Pendrecht, Groot IJsselmonde (Heindijk/Reyeroord), Bospolder-Tussendijken and Prinsenland-Het Lage Land (Gemeente Rotterdam, 2018b). The locations of the pilot areas are shown in Figure 4-2.

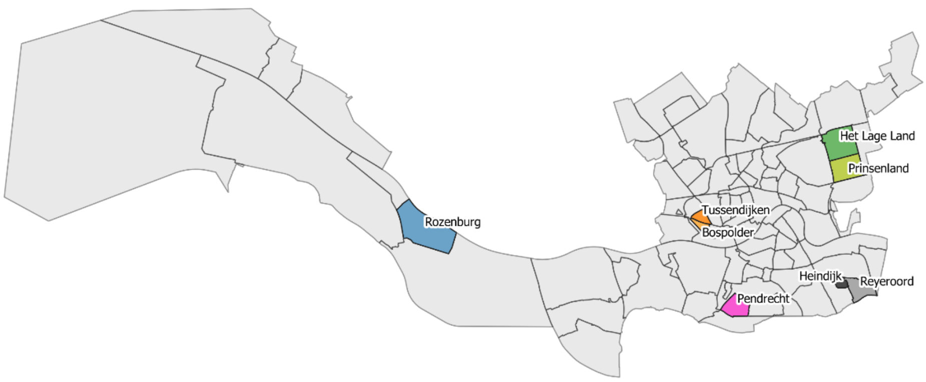

Figure 4-2 An overview of the municipality of Rotterdam and the selected gas-free pilot areas

Rotterdam has selected the five pilot areas as the first districts to go completely gas-free, in consultation with stakeholders, based on the following criteria (Gemeente Rotterdam, 2018b):

- Buildings are promising for the switch to district heating (stacked buildings, built after 1945, with a collective boiler) with relatively high corporation ownership and relatively little private property;
- In addition to implementation of district heating, other construction or maintenance activities in the subsurface or public space are planned (think of sewerage, gas pipes, electricity network, roads or outdoor space);
- Housing corporations are working on their real estate on a large scale and can be a stimulator for the rest of the area;
- A collective alternative is the cheapest social solution for the area.

To learn optimally from experiences gained from the pilot areas, the municipality opted for variation in the selection: a proportional spread across the city is chosen (Gemeente Rotterdam, 2018b). To select cases (streets) from these five pilot areas to continue the research with, differences in characteristics should be taken into account. Since this research is explorative, it should be based on multiple and diverse cases. The diversity of the cases mainly lies in the physical characteristics of the street (space available and climate adaptation measures possible) and the potential construction activities that can be combined (i.e. sewer maintenance). Because of this, it is important to select cases with a variety in:

- Owners of the property;
- Whether or not the sewer will be replaced (based on the age of the sewer);
- Energy measures that will be taken (whether or not solar panels are installed in addition to the district heating network), bringing along consequences for the spatial impact;
- Soil, groundwater and subsoil conditions and space available above- and underground, affecting the type of climate adaptation measures that are possible.

To select cases with that variety, in the subsequent subsections it is explained how the pilot areas are analysed and how critical streets are identified (streets where urban flooding and the implementation of district heating both exist).

4.1.1. Characteristics pilot areas

To create an image of the differences per area, first, relevant characteristics of the pilot areas have been identified and listed, based on municipal data analysed using QGIS. QGIS is an open source geographical information system: geographical data can be displayed, adjusted and analysed (QGIS Development Team, 2020). Relevant characteristics for each area are:

- The building typology of the area: These typologies are based on year of construction of properties, construction height, housing density, share of green areas in the neighbourhood and the function of the buildings;
- The percentage of surface water in the area: This gives an indication of the water storage potential of the area. In general, due to Rotterdam’s low location, less water can be stored in the subsoil, so surface water has a large share in water storage (Esri, 2020);
- Population density: The number of people living in the area per square kilometre, indicating how densely built the area is;
- The percentage of housing corporation: Indicating which part of the property within the area is owned by housing corporations;
- The percentage of unpaved surface in the area: This shows if the percentage unpaved surface is higher or lower than the average in the Netherlands and indicates whether additional green is desired in the area.

Other relevant characteristics of the area, regarding climate adaptation, are the type of subsoil and groundwater level with the corresponding dewatering depth, but these differ a lot over the entire area. Therefore, these characteristics will be determined more specifically on street scale.

4.1.2. Critical sites within the pilot areas

To select cases, critical sites within the pilot areas have been identified. Critical sites are locations where urban flooding coincides with the implementation of district heating. To locate the critical sites within the area and finally select cases, research question 2.1, '*At which locations, in the pilot areas where district heating will be implemented, does urban flooding occur?'*, is answered.

For each pilot area, research is done into the current plans that exist within the area to go gas-free or in case a plan does not exist, assumptions are made. To map urban flooding in all areas, stress tests, carried out by the municipality, have been analysed.

All data used to determine critical sites within the areas was obtained from the gas-free approaches of each area, multiple conversations with area managers (responsible for the gas-free program) of the five pilot areas and climate stress tests that are carried out by the municipality.

For all pilot areas, an analysis of urban flooding locations has been carried out using municipal data in QGIS. The goal of the current councillor is to reduce the overall percentage of risk property (water against the façade in case of heavy rainfall) in Rotterdam from 12% to 10%, before 2022, so the percentage of the property with risk label of the total area indicates the urgency of climate adaptation within that area. However, in most cases urban flooding is solved on local (street) scale. So, to get a view on where overlap between potential energy measures and potential climate adaptation occurs, the stress test map is zoomed in on street level. For all streets where the percentage of risk property is significant, relevant physical characteristics for climate adaptation have been listed. To study information regarding subsurface and street characteristics and characteristics of the built environment, statistics from Statistics Netherlands (CBS) and data from the Register of Addresses and Buildings (BAG) were studied using QGIS. Relevant characteristics listed are:

- Type and age of property;
- Type and age of sewer system;
- Street type: use, lay-out;
- Street structure: material pavement;
- Type of subsoil;
- Ground level, groundwater level and corresponding dewatering depth.

4.1.3. Case selection

To finally make a selection of cases to study types of systems integration, all information regarding the energy plans and urban flooding has been listed and relevant characteristics have been determined for streets where overlap occurs. Eventually, taking the differences in owners of the property, whether or not the sewer is replaced, energy measures that are taken (whether or not solar panels are installed in addition to the district heating network) and what climate adaptation measures are possible (based on the subsoil, groundwater level and space available above- and below ground), into account, a selection of cases has been made.

4.2. Within-case analysis

The within-case analysis consists of designing multiple designs of the cases, to study the spatial claims of energy measures and the applicability of different climate adaptation measures in case of implementation of the energy transition. Finally, the different types of integration in each case are studied. All cases are analysed separately: the designs and types of systems integration are discussed and presented individually for each case in Chapter 6.

Per case, cross-sectional designs have been made for three situations using Adobe Illustrator software. The different cross-sectional designs are discussed in subsection 4.2.1. In addition to the cross-sectional designs, a top view has been created for each case, indicating the parts of the street that are excavated, in both public and private space, in case of the installation of district heating (and sewer replacement). This is discussed in subsection 4.2.2. In Figure 4-3, a visualisation of types of designs created in the within-case analysis is presented.

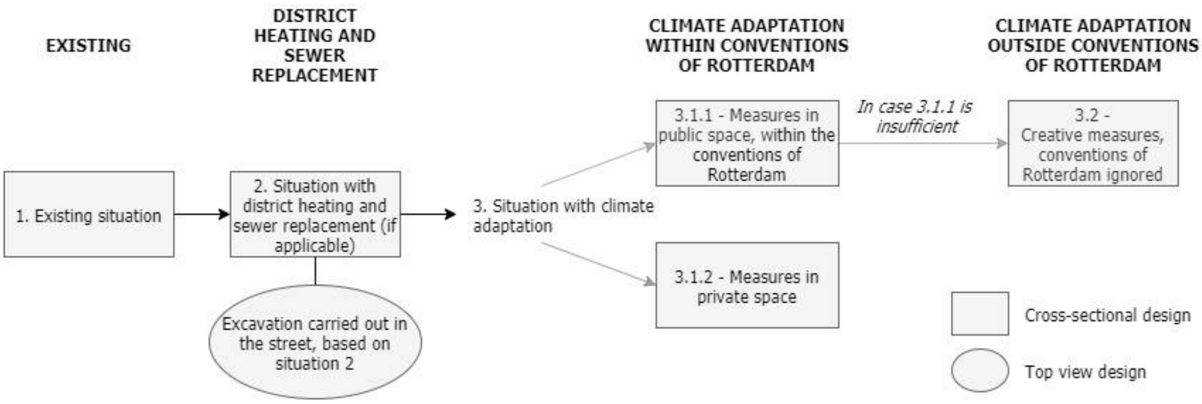

Figure 4-3 Visualisation of the types of designs created in the within-case analysis

Based on the cross-sectional designs and the top view design of all cases, the different types of systems integration (geographical, project-based, physical and informational) identified are eventually examined. This method is discussed in subsection 4.2.3.

4.2.1. Cross-sectional designs

Three different cross-sectional designs of each case have been constructed: the existing situation, the situation with energy measures and potential sewer replacement and the desired situation with the latter and potential climate adaptation. These designs give an impression of space claims of above- and below ground infrastructure in Rotterdam and the applicability of different climate adaptation measures in all cases.

Situation 1: Existing situation

For the cross-sectional design of the existing situation, the current layouts of the street and subsoil have been studied, by analysing the 'underground cable and pipe-collection map' (Gemeente Rotterdam, 2020b). Within Rotterdam, no specific diameters are mentioned for the common cables (electricity and telecom), because they are very thin compared to the other underground infrastructure. The common pipes (sewer, gas and drinking water) do have a corresponding material and diameter, stated in the 'underground cable and pipe-collection map'. Although gas- and drinking water pipes are always constructed of plastic material (PVC, polypropylene and polyethylene), sewers can be constructed of plastic material or concrete. This depends on the function and dimensions of the pipe.

In this research, the groundwater level is assumed to be equal over the entire cross section (street) and is obtained from monitoring well measurements carried out by the municipality. To obtain information regarding the type of subsoil and the road foundations of the street, soil investigation reports and functional water advices from the municipality have been consulted. If no specific information regarding the road foundation was available, the Standard Road Construction Details (Standaard Wegenbouw Details, in Dutch) of the municipality of Rotterdam were considered. 1,0 m of road foundation consisting of sand below roadways and parking lanes is assumed and 60-70 cm of foundation consisting of sand below sidewalks is assumed in this research, based on an interview with Pieter Vreeling (Executive Director Public Space), presented in Appendix D.

Situation 2: Energy measures and sewer replacement

Secondly, knowing the energy- and sewer adjustments (if applicable) in the street, the first cross section is converted into the second cross-sectional view of the street. The rules and guidelines regarding space between cables and pipes used in this research are obtained from the 'Underground Management Manual' of Rotterdam (Gemeente Rotterdam, 2019c).

Energy measures

Energy measures mentioned in the pilot area approaches, that are found in the cases are: district heating, large-scale installation of solar panels including grid reinforcement and grid reinforcement due to the increase in the electricity demand. The spatial impacts, assumed in this research, that the measures will have on the lay-out, are:

- District heating: To implement district heating, two pipes are installed: one for heating and one for cooling. The pipes are placed in a carrying cunette, which provides stability and indicates which part has to be excavated in case of maintenance or replacement. A natural slope (1:3) is used for the cunette (N. Nederpel, personal communication, May 25 2020). Guidelines regarding the location of the pipes, space between the pipes and dimensions of the pipes and the cunette, used in this research, are derived from Eneco. These are discussed in Appendix B.

- Solar panels: In this research, it is assumed large-scale installation of solar panels in the built environment will only have a spatial impact on the roofs.
- Grid reinforcement: The grid itself can be reinforced, transformers can be enlarged and sometimes reinforced house connections are necessary (W. Terlouw, personal communication, May 19 2020). The space claim of a reinforced electricity grid in the subsoil will not change a lot from the initial space claim, as the cables will only thicken with several centimetres (W. Terlouw, personal communication, May 19 2020).

To draw the energy measures in the street lay-out, it is decided only additional spatial claims of the district heating pipes and solar panels are included. The spatial claims of grid reinforcement are not added, since this is about a few centimetres and will have minor impact on the lay-out. Also, enlarged transformers above ground will not be included in the design, since this is very street-specific and it is not decided whether and where this will happen. For the planning process, it is assumed that only in case solar panels are installed on large scale, grid reinforcement is taken into account. Enlarging transformers and grid reinforcement due to the increase in electricity demand will be left out, since these are very location-specific and uncertain.

When the district heating network is installed next to the sewer system, it is important that the cunettes of the heating network and the sewer system do not conflict. The pipes need a certain pressure: the pressure can decrease when excavation in the cunette takes place, which can cause the pipes to shift (N.J. Bruin, personal communication, June 9, 2020). Initially, during the implementation phase of the district heating network, the gas pipes need to remain in place, because the houses will be connected to the heating network in phases. Eventually, when all houses are connected to the heating network, the gas pipes can be removed, but this is not yet shown in the designs in this research, since all pipes need to fit next to each other initially.

Sewer replacement

In recent years, Rotterdam has been trying to disconnect the ‘clean water’ (rainwater) from the ‘polluted water’ (waste water), to reuse it or to discharge it to the surface water at a delay in preparation for more extreme rainfall events. This means that in case the sewer system is replaced, instead of a combined system, a separate sewer system is constructed in many cases with a waste water and rainwater pipe. A rainwater sewer can consist of a closed pipe, but in cases where drainage has to be installed in addition (when infiltration facilities are implemented), a DT (Drainage Transport)-sewer is installed.

In case the sewer is replaced simultaneously to the implementation of district heating, the new spatial claims of the sewer have been based on the functional water advice that is developed by the engineering division of the municipality of Rotterdam. A functional water advice is established for all neighbourhoods where the sewer is aged, between 40-60 years, and where the sewer will in all probability be replaced in the coming 2 to 10 years. It gives an advice on the dimensions, route and design of the new sewer system. Similar to district heating pipes, sewer pipes are placed in a cunette, indicating which part has to be excavated in case of maintenance or replacement. For this cunette, a natural slope (1:3) is used, as well, and a minimum distance of 30 centimetres between the pipe and the edge of the cunette is maintained.

In this research, it is assumed that in case the sewer is replaced simultaneously to district heating, it results in an integrated approach: the street will be opened up from boundary to boundary (façade to façade) to bring the ground level in public space back to the officially determined height (Gemeente Rotterdam, 2016b). Private space in the street is not included in the ground raising, since this is not mandatory and private responsibility. In addition, it is assumed that when cables and pipes lie in the cunettes of the district heating pipes or sewer system, they are relocated or, in all probability, replaced. In principle, pipes that lie the deepest are replaced first, and so on. However, in case cables and pipes need to be relocated to install the sewer system or district heating system, this needs to be carried out first (W. Noordhof, personal communication, September 15, 2020).

Situation 3: Desired situation with possible climate adaptation measures

Lastly, possible climate adaptation measures have been determined in all cases, based on the measures listed in Appendix C and on the characteristics of the street. The flowchart, displayed in Figure 4-4, has been followed, to determine what adaptation measures are possible in each street. The design aspects for permeable pavement, developed by the municipality of Rotterdam, form the base for the flowchart, but the figure is specifically designed for this research (Koudstaal & Trouwborst, 2014).

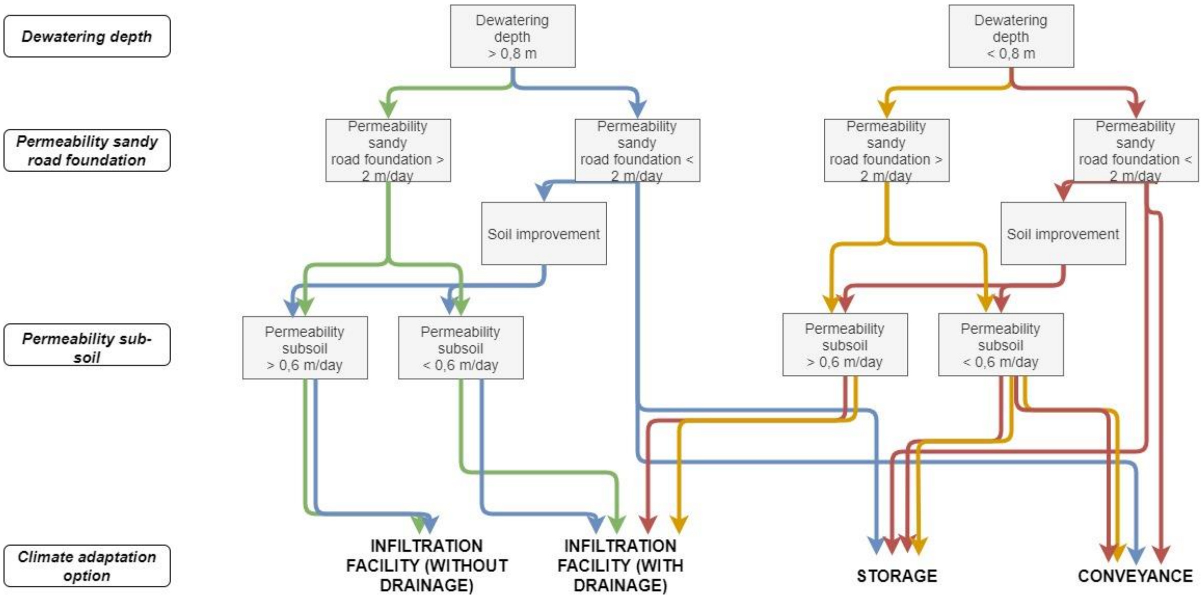

Figure 4-4 Flowchart on decision-making for type of climate adaptation measures

According to the 'Rotterdam Weatherwise' goals, the water retention capacity of public space needs to be sufficient to prevent damage in case of heavy rainfall, i.e. 70 mm in 1 hour. Since no private measures are yet taken in all cases (disconnect rainwater, green roofs), in this research, it is assumed that the 70 mm of rainfall is spread over all public and private space in the street, to calculate the total volume of rainfall that needs to be stored. The total volume of rainfall that needs to be stored to prevent damage is then calculated with a so-called 'linear reservoir model' (lineair oppervlakte-afvoer model, in Dutch) on street level (Stichting RIONED, 2018). The incoming and outgoing water is determined for a street, on street level: the study does not look at how the street is attached to the area, but assumes that all rainwater that falls in a certain street is also processed in that same street.

In Rotterdam, the sewer system (both a combined and a separate rainwater system) is designed according to the traditional design storm with a return period of 2 years (Bui08). This means the overflows in Rotterdam are designed to process 60 litres of rainfall per second per hectare (21,6 mm/hour) (Stichting RIONED, 2019a). The calculation of the system has been made without pre-filling. In this research, a discharge capacity of 20 mm of rainfall per hour is assumed for the sewer system in Rotterdam, based on 100% road surface and 100% roof surface connected to the sewer (Gemeente Rotterdam, 2016a). To account for the effect of possible pre-filling of the system, stationary system storage is not taken into account, resulting in 20 mm per hour as a given equivalent storage volume for the sewer system in all pilot areas. Streets with kerbs on both side of the street can store additional water in the street. Almost all streets in Rotterdam are convex: water flows to the sides and less water than the height of the kerbs can be stored on the streets. The height of the kerbs is assumed to be 120 mm (Haug & Schuurman, 2015). In this research, it is assumed that rainwater from the street will not have a risk of running into buildings (material damage) in case the water level in a street (with kerbs) remains 20 mm lower than the top, to ensure a safe margin. Therefore, 100 mm of rainfall can be stored on the street. The existing green in all cases has also been taken into account, when determining the existing storage potential of the street, according to the equations presented in Appendix C.

For situation 3, multiple scenarios have been created per case. For each scenario it is eventually stated how much storage it can provide.

- In scenario 3.1, the guidelines set by the municipality regarding implementation of climate adaptation and the rules regarding space between cables and pipes have been adhered to, i.e.

the design is made within the conventions of the municipality. The conventions of the municipality mean:

- Climate adaptation measures are not placed above cables and pipes that are not municipality owned (N.J, Bruin, personal communication, June 9, 2020);
- Minimum distances between pipes, stated in the 'Underground Management Manual' of the municipality, are maintained (Gemeente Rotterdam, 2019c);
- The distance from trees to the centre of the nearest cable or pipe is 2 – 3,5 meters and the distance from trees to facades is: 0,5 * crown width * 0,7 + 2 meters (Gemeente Rotterdam, 2010). In case of a root screen: minimum distance from outer side of pipe to outer side of tree is 1,0 meter and minimum distance from root screen to outer side of the pipe is 0,5 meter.

For this scenario, two designs are made: measures that can be taken by the municipality in public space (scenario 3.1.1) and measures that can possibly be taken in private space (scenario 3.1.2). Measures in private space indicate the amount of storage that could be realized on private space, but in practice it is difficult to realize this, due to private ownership of the land. In case that the measures in public space (scenario 3.1.1) provide sufficient storage (70 mm in 1 hour) solely, scenario 1 has been taken as the final design.

- In case the possible measures in public space (scenario 3.1.1) did not provide sufficient storage, scenario 3.2 is created. Scenario 3.2 does not necessarily comply with the conventions of the municipality and creative solutions to provide sufficient storage in public space are created.

As stated before, in addition to the water-resilience goals, one of the targets of the current councillor in Rotterdam is to increase the greenery in public space, close to homes, in the city with 20 hectares by 2022 (Verlinde, 2020). Therefore, in case the percentage of green in a pilot area is low (less than 50%) and the street-view does not show trees or green in the street, planting trees has been included as a potential climate adaptation measure.

4.2.2. Top view design

Apart from the cross-sectional designs, a top view design has been created for each case, indicating the part of the street that is excavated, in both public and private space. The part of the street that is excavated is based on situation 2: the implementation of district heating and sewer replacement (if applicable). The top view design gives an indication of the amount of construction activities carried out in the street and thus of the ease of implementation of climate adaptation simultaneously to district heating (and sewer replacement). The house connection pipes that need to be dug in case of installation of district heating and in case of replacement of the sewer are indicated in the top view design as well. For house connection pipes of the district heating network towards a single house, dimensions of DN32 (110 mm) are assumed and for house connection pipes of the district heating network towards an apartment complex, dimensions of DN150 (280 mm) are assumed. This results in trenches of approx. 1,60 m that are dug towards single houses and trenches of 2,0 m that are dug towards apartment complexes (N.J. Bruin, personal communication, September 15, 2020). For the house connection pipes of the sewer system towards a single house usually a diameter of approx. 125 mm is used, resulting in a trench that needs to be excavated of a width of approx. 0,6 m. For pipes towards an apartment complex usually a diameter of approx. 200 mm is used, resulting in a trench that needs to be excavated of a width of approx. 0,7 m (N.J. Bruin, personal communication, September 15, 2020).

4.2.3. Systems integration

Based on the cross-sectional and top view designs, the different types of systems integration are studied empirically (Nieuwenhuis et al., 2020). From the designs, it is derived how the two systems will interact and what types of integration occur when guidelines and rules from the municipality are adhered to and when they are not. The types of integration contain both a technical and socio-institutional aspect, which are both discussed for each case. Eventually, the designs and the types of systems integration that have been identified are used to draw conclusions on when integration of the two systems is beneficial and on what the energy transition implies for Rotterdam's climate adaptation goals. The types and objects of integration identified in subsection 2.3.1 are taken as leading base.

Per case it is discussed how the energy transition, climate adaptation measures and other underground infrastructure meet, should take account of one another, can benefit from each other and whether and on what grounds an integrated approach towards the energy transition and climate adaptation is desired or not, based on the spatial claims and planning processes. For the planning processes, and therefore project-based integration, the data accessed from a construction site visit and an interview with Pieter Vreeling (Executive Director Public Space) is used. This is presented in Appendix D.

4.2.4. Validation of the results

In order to guarantee the quality of the empirically studied types of systems integration, the 'member checking'-method has been used: the results and interpretations are discussed with the experts, so that they can confirm or contradict (Creswell & Miller, 2000). Two types of validation actions have been taken:

- The assumptions used for the cross-sectional- and top view designs of all cases have been discussed with an expert in the field of climate adaptation and an expert in the field of installation of district heating of the municipality of Rotterdam, and adjusted afterwards when needed;
- The final cross-sectional- and top view designs have been discussed with an expert in the field of urban water and geotechnics, to discuss the types of systems integration identified (and its (dis-)advantages).

5. Case study design

In this chapter, the case study design and the final selection of cases to continue the research with is presented.

5.1. Characteristics pilot areas

Kleerekoper et al. (2017) defined 14 different district typologies that are present in the Netherlands. These typologies are based on year of construction of properties, construction height, housing density, share of green areas in the neighbourhood and the function of the buildings (Kleerekoper et al., 2017). According to the 'Rotterdam Style Manual' (Handboek Rotterdamse Stijl, in Dutch), five types out of the 14 typologies are found in Rotterdam. These typologies are shown in Table 5-1. A map of the different typologies identified in Rotterdam is displayed in Appendix E. Table 5-1 shows the indicative vulnerability to flooding. This number is based on a study conducted by Kleerekoper et al. on the flooding sensitivity of the different types of neighbourhoods, based on the buildings and green structure.

Table 5-1 District typologies in Rotterdam and its characteristics (Kleerekoper et al., 2017)

District typology	Building period	Characteristics	Indicative vulnerability to flooding [scale from 1-3]
High-rise city centre area	1960-now	More than 10 layers	2
Urban building block	Pre 1930	No front yard or green around, 4-8 layers	3
Garden village-area	1910-1930	Spacious front and back gardens, 2-3 layers, a lot of parallel parking, limited municipal greenery	2
Garden city-area	1945-1970	Open building blocks with a lot of green, 2-3 layers, single-family houses	2
'Cauliflower' district	1970-1990	Single-family houses with front and backyard, winding streets and lots of green	1

In Table 5-2, an overview is given of the 5 pilot areas (and its sub-areas) and its relevant characteristics. The district typologies, as described in Table 5-1, present information about the built environment in the area (Kleerekoper et al., 2017). This is determined as most common per area, but does not mean that the entire area is built according to that typology.

Table 5-2 Characteristics of the gas-free pilot areas in Rotterdam

Pilot area	Population density [nr. of people/km²]	District typology	% of surface water	% housing corporation
Groot IJsselmonde ○ **Heindijk**	4.930,6	Garden city-area	2,5-5%	49,45%
Groot IJsselmonde ○ **Reyeroord**	4.930,6	Garden city-area; 'Cauliflower'-district	2,5-5%	13,28%
Pendrecht	10.202,4	Garden city-area	1-2,5%	56,31%
Rozenburg	3.032,4	'Cauliflower' district	1-2,5%	39,75%
Bospolder-Tussendijken ○ **Bospolder**	20.762,7	Urban building block	<1%	63,07%
Bospolder-Tussendijken ○ **Tussendijken**	18.063,3	Urban building block	5-10%	61,94%
Prinsenland – Het Lage Land ○ **Prinsenland**	5.500,6	Garden city-area; 'Cauliflower'-district	5-10%	55,18%
Prinsenland – Het Lage Land ○ **Het Lage Land**	5.009,2	Garden city-area; 'Cauliflower'-district	2,5-5%	41,48%

The percentage unpaved area is calculated for each area in QGIS, using the subsurface and building data from the municipality, and displayed in Table 5-3. This percentage indicates the amount of green areas in an area. The percentage is a little higher than the actual percentage of green area, because unpaved, non-green parts are also taken along, but it gives a good indication. The average percentage of unpaved area in a Dutch city is 61,6% (De Graaf et al., 2013), which means all pilot areas are below average when it comes to unpaved surface.

Table 5-3 Percentages of unpaved area in the gas-free pilot areas in Rotterdam

Groot IJsselmonde (Heindijk, Reyeroord)	51,96%
Pendrecht	43,80%
Rozenburg	46,63%
Bospolder	22,5%
Tussendijken	21,95%
Prinsenland	43,80%
Het Lage Land	40,48%

5.2. Critical sites within the pilot areas

In this section, research question 2, '*At which locations, in the pilot areas where district heating will be implemented, does urban flooding occur?',* is answered. To answer this question, critical sites within the pilot areas are analysed: locations where planned energy transition measures overlap with urban flooding.

5.2.1. Energy transition measures and planning

As discussed before, in section 3.2, Rotterdam defined district heating as the best suited sustainable heating solution and solar panels as the best suited sustainable energy supply.

For each of the pilot areas, the area manager creates its own business case and planning, to decide which parts will be connected to the heating network and when, and to combine planning of different stakeholders in the area. Most schedules currently developed by the area managers are concept versions and some do not have a planning worked out yet, which means assumptions and predictions have been made in some cases. In Rozenburg, Pendrecht, Heindijk and Tussendijken the concept route and dimensions of the network are mostly worked out, while in Reyeroord, Bospolder and Prinsenland-Het Lage Land these decisions are not yet made. For all areas, the existing approach is examined and assumptions are made where necessary.

In all pilot areas, it is assumed that the sewer will be replaced simultaneously to implementation of district heating, in case it is indicated by the long-term maintenance requirement (Meerjaren Onderhoudsbehoefte, in Dutch). The long-term maintenance requirement is based on the age of the sewer: when the sewer is between 40 to 60 years old, it requires maintenance in the near future (Gemeente Rotterdam, 2016b). In addition, is it assumed that in case housing corporations are planning to install solar panels on large scale, all property in the pilot area owned by that corporation will be supplied with solar panels.

<u>Rozenburg</u>

For Rozenburg it is decided that before 2030 the entire area will be completely gas-free, by installing district heating in the entire area. A large part of the property in Rozenburg, spread over the entire area, is owned by the housing corporation Ressort Wonen. Ressort Wonen has promised to insulate houses, transform houses into a gas-free household and to carry out large-scale installation of solar panels.

In Rozenburg the planning for installing district heating is subdivided into three phases:

- 2018 – 2025: Rozenburg southeast
- 2020 – 2027: Rozenburg northeast
- From 2026: Rozenburg west

The implementation of district heating will not happen all at once, but eventually the entire area will be connected to the network. The concept route and dimensions of the primary distribution pipes are already developed and taken into consideration in this research.

Assumptions

Although the current approach of Rozenburg does not say anything about grid reinforcement, in this research it is assumed grid reinforcement is necessary in case of large-scale installation of solar panels. The route and dimensions of the secondary distribution pipes (DN50-DN100) are not yet determined street-specific in Rozenburg, but it is assumed that the pipes will be installed in the majority of the streets within the area, where the primary distribution pipes are not installed. The secondary distribution pipes will be provided with house connection pipes. For the dimensions an average is assumed.

<u>Pendrecht</u>

The entire area of Pendrecht will be connected to a district heating network before 2030. The phasing of the implementation of district heating is divided based on three different parts in the area:

- Pendrecht north: 2021 – 2023
- Slinge and surroundings: Start 2021
- Pendrecht south: Start 2020 (ongoing)

Alongside Pendrecht, main transport pipes are installed and in a part of the south of Pendrecht there already is an existing distribution network (primary and secondary). This distribution network is currently being expanded. For the north and south of Pendrecht, the route and dimensions of the heating pipes are already determined. The route and dimensions are all taken into account in this research. A large part of the property in Pendrecht north is owned by the housing corporation Woonstad (77%). In the south of Pendrecht, housing corporation Woonstad owns approximately 50% of the property. Next to renovating the property to become gas-free, Woonstad is also planning on installing solar panels. In this research it is assumed grid reinforcement is needed

<u>Groot IJsselmonde – Heindijk</u>

For Heindijk, the expected planning to start with installing the heating network is in 2021. The entire area of Heindijk will be connected to the district heating network. The locations of the planned network in Heindijk have already been determined, but the dimensions are not decided yet. A large part of the property within the area is owned by the housing corporation Woonbron.

Assumptions

The dimensions of the secondary distribution pipes (DN50-DN100) are not yet determined street-specific in Heindijk, so an average (DN80) is assumed.

<u>Groot IJsselmonde – Reyeroord</u>

The entire area of Reyeroord will be connected to a district heating network before 2030. It is decided a separate sewer system will be installed in large parts of the area in 2023, so the plan is to implement the heating network simultaneously. The planning of sewer maintenance is the leading base for the phasing of district heating in Reyeroord. Property in Reyeroord is almost all privately owned (90%), which means cooperation with many different private house owners is necessary. In Reyeroord, the route of the primary and secondary distribution pipes is already determined.

Assumptions

The dimensions of the secondary distribution pipes (DN50-DN100) are not yet determined street-specific in Reyeroord, so an average (DN80) is assumed.

<u>Bospolder-Tussendijken</u>

The pilot area Bospolder-Tussendijken is split into Bospolder and Tussendijken, with respect to the energy transition planning. Both Bospolder and Tussendijken will be connected to a district heating network and in both areas there are no existing heating pipes. In Tussendijken the planning to install district heating is already fully detailed and construction will most likely begin at the end of 2020. Due to the densely built environment in Tussendijken and the little space left for public space projects, an integrated approach has been used within the planning. Sewer maintenance and implementing a tree structure in streets where possible, are already included in the energy transition plans. According to the area manager, Anne-Marie Verheijen, these are the only possible climate adaptation measures within the area. Because the district heating plans in Tussendijken are already fully worked out and it is said an integrated approach has already been used, Tussendijken will further be excluded from this research.

In Bospolder, the start to a gas-free network will probably be made in 2024, when Tussendijken is (almost) finished. Before 2030 not the entire area will be connected to the network, but the first focus will be on property of housing corporation Havensteder. The phasing, route of the network and dimensions of the pipes are not determined yet. The business case that will be developed in Bospolder to realize a district heating network will, comparable to Tussendijken, mainly be a cooperation between the municipality, Eneco and Havensteder.

Assumptions

The route and dimensions of the primary (DN50-DN200) and secondary distribution pipes (DN50-DN100 are not yet determined street-specific in Bospolder. In this research, it is assumed that the primary distribution pipes will be laid in the larger roadways and the secondary distribution pipes will be laid in almost all other roadways, where Havensteder owns the property. Tussendijken will be taken as an example. For the dimensions an average is assumed.

<u>Prinsenland – Het Lage Land</u>

The entire area Prinsenland – Het Lage Land will go gas-free before 2030. The phasing of the implementation of district heating in the area is divided based on two different parts in the area:

- Prinsenland east and Het Lage Land east: 2023-2026
- The remaining part of Prinsenland – Het Lage Land: towards 2030

On the border between Prinsenland and Het Lage Land (Prinsenlaan), continuing through three streets in Het Lage Land, there is already an existing distribution network of district heating. In Prinsenland – Het Lage Land the installation of district heating can most likely not be combined with sewer maintenance: in the western part of the area the sewer has just been replaced (5-10 years ago) and in the eastern part of the area the sewer is currently being replaced, which means the installation of district heating is too late. Prinsenland – Het Lage Land is also a pilot area for large-scale installation of solar panels on apartment complexes. The housing corporations Woonstad Rotterdam and Havensteder own a large part of the property (around 50%) in Prinsenland – Het Lage Land.

Assumptions

Although the current approach of Prinsenland – Het Lage Land does not say anything about grid reinforcement in case of large-scale installation of solar panels, in this research it is assumed grid reinforcement is needed. The exact route and dimensions of the primary (DN50-DN200) and secondary distribution pipes (DN50-DN100) of the heating network are not yet determined street-specific, so it is assumed the primary distribution pipes will be laid in the larger roadways and the secondary distribution pipes will be laid in almost all other roadways. For the dimensions an average is assumed.

5.2.2. Climate issues: issues related to excessive rainfall

The main focus of climate issues in this research is on issues related to excessive rainfall. Every municipality is required to carry out a stress test once every 6 years, to identify (potential) vulnerabilities to climate issues within an area. The test collects and creates information that describes the future effect of climate change (the 'stress' placed on a system) and by combining this information with data on the sensitivity of objects, bottlenecks within a municipality can arise (Kennisportaal Ruimtelijke Adaptatie, 2020).

The municipality of Rotterdam carried out a stress test, to map urban flooding in the city, as well. As described in subsection 2.2.2, in 2018 all property within Rotterdam was assigned a blue-label: a categorization of safety in case of heavy rainfall. These blue-labels are assigned, based on an algorithm developed by a national consortium. A rain event of 100 mm in 2 hours has been chosen as a design storm (T = approx. 100 years). Labels A (no water against the façade) and B (water more than 5 cm below threshold) are defined as no-risk property and labels C (water between 5 cm and 0 cm below threshold), D (water between 0 and 10 cm above threshold) and E (water more than 10 cm above threshold) are defined as risk property. The blue-label maps are interpreted from stress test maps: where water, remaining in the streets and public space after a rain event, actually causes damage to property. An assigned blue-label is coupled to one address, so to one household, instead of to an entire building. This is important, since this gives a good indication of the amount of households experiencing nuisance from excessive rainfall.

A map of Rotterdam with the indicated blue-labels, as a result of the model calculations and blue-label interpretations of the entire municipality is shown in Figure 5-1. This map is created by the Water Department of the Public Works-division of the municipality and gives an overview of risk areas within the municipality, based on the percentage of risk property in an area. In the green areas the percentage of property with a risk label in a certain neighbourhood is lower than 10% and orange and red areas indicate neighbourhoods with a percentage of property with a risk label between 10-40 %. This figure is on neighbourhood-scale, which means the percentage is based on the number of buildings with a risk label relative to the total amount of buildings in that area. The dark spots on the map indicate the risk buildings, so buildings with a C, D or E label.

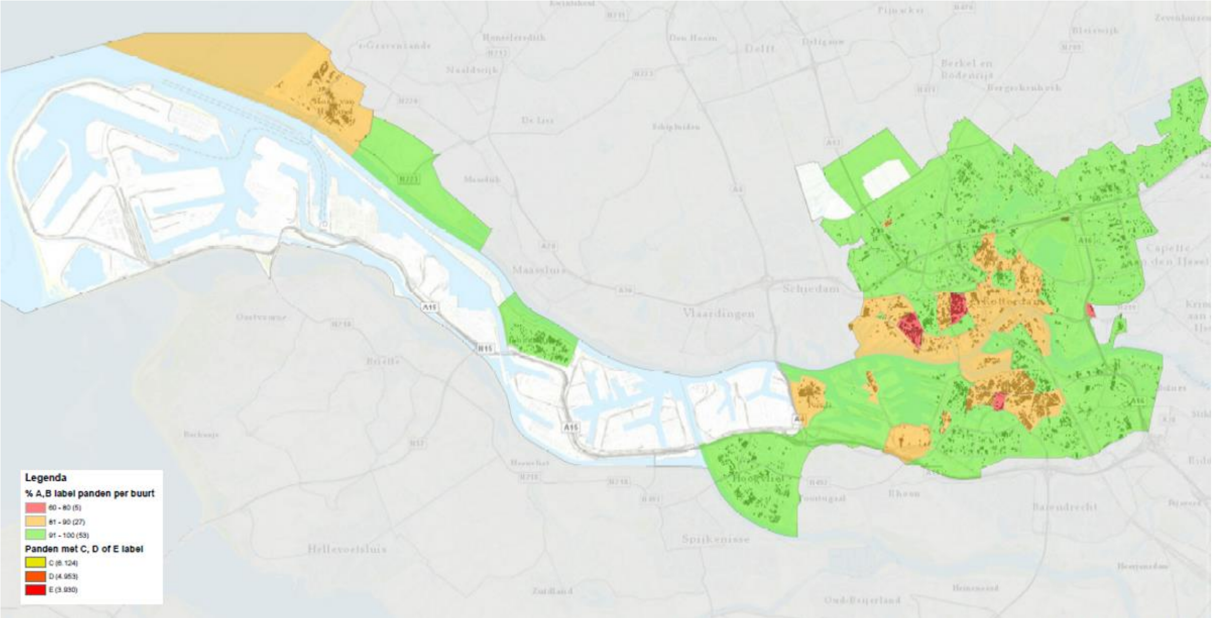

Figure 5-1 Map of blue-labels indicated per neighbourhood in Rotterdam, in case of a rain event of 100 mm in 2 hours (Gemeente Rotterdam, 2019g)

Table 5-4 shows the percentage of property with risk label per area.

Table 5-4 Percentage of risk property (blue label C, D and E) per pilot area

Pilot area	Percentage of property with risk label in entire area (C,D,E)
Heindijk	0,10 %
Reyeroord	12,85%
Pendrecht	6,55%
Rozenburg	16,35%
Bospolder	29,83%
Prinsenland	5,57%
Het Lage Land	7,65%

Initially, an overview was made, per area, of (parts of) streets where the property with a risk label was noticeable, resulting in 51 critical streets. To narrow this amount, a minimum percentage of property in the street with a risk label of 30% was appointed, to obtain a selection of streets where the risk of flooding is significant.

5.2.3. Conclusion on critical sites within the pilot areas

In the latter subsections, research question 2.1, '*At which locations, in the pilot areas where district heating will be implemented, does urban flooding occur?*', is answered. According to the gas-free approaches, the construction of the heating network is in all pilot areas desired to be combined with sewer maintenance, to reduce nuisance and costs, but whether combining is possible depends on the planning of sewer maintenance. In all pilot areas, it is assumed that the sewer will be replaced simultaneously to implementation of district heating, in case the sewer is between 40 to 60 years old (Gemeente Rotterdam, 2016b). Since in approximately all streets of the pilot areas the district heating network will be installed, it can be concluded that whether urban flooding occurs (section 5.2.2) is the critical factor in determining critical locations. For all critical locations, based on urban flooding, the existing information regarding the energy measures within that street has been listed. Eventually, there are 30 remaining streets in total (in Reyeroord, Pendrecht, Rozenburg, Bospolder, Prinsenland and Het Lage Land) where urban flooding occurs significantly (more than 30% property with a risk label) and where district heating will (in all probability) be implemented. This means that in 30 out of the 463 streets (6,5%) where district heating will be implemented, urban flooding occurs significantly. The number and percentage of streets per pilot area where a district heating network will be installed and where urban flooding occurs in addition, are stated in **Fout! Verwijzingsbron niet gevonden.**.

Table 5-5 Information on the number and percentage of streets in the pilot areas where urban flooding occurs, in addition to the implementation of district heating

Pilot area	**Total number of streets heating network**	**Total number of streets urban flooding (in addition to heating network)**	**Percentage of streets where urban flooding occurs, in addition to the implementation of a heating network [%]**
Heindijk	14	0	0
Reyeroord	42	2	4,8
Pendrecht	52	3	5,8
Rozenburg	179	13	7,3
Bospolder	26	8	30,8
Prinsenland	70	2	2,9
Het Lage Land	80	2	2,5
Total:	*463*	*30*	-

For all pilot areas, the percentage of streets where urban flooding occurs, in addition to the implementation of district heating, is lower than 10%, except for Bospolder (30,8%). This finding may be explained by the fact that Bospolder is the only area with an ‘urban building block’ district typology. The ‘urban building block’ typology is characterized by no front gardens or green areas and often high-rise buildings, which means that the indicative vulnerability to flooding is high (Kleerekoper et al., 2017). In the ‘garden city-area’ and ‘cauliflower district’ typologies, which include the other areas, there is little overlap between the implementation of district heating and urban flooding.

5.3. Case selection

Taking the differences in owners of the property, whether or not the sewer is replaced, energy measures that are taken (whether or not solar panels are installed in addition to the district heating network) and what climate adaptation measures are possible, into account, eventually, out of the 30 streets, a number 5 streets is selected to continue the research with: the cases. A table of the 30 critical streets with their characteristics and the final case selection is presented in Appendix F.

IV.

RESULTS

Results

The fourth part of this thesis, the results, presents and discusses the results of the within-case analysis, in two chapters. In Chapter 6, the results are presented for each case separately and the types of systems integration are deduced from the designs. Afterwards, the results are discussed (Chapter 7) and assumptions and limitations are reviewed.

6. Results

In this chapter the results of the research are presented and research question 2.2, '*What climate adaptation measures can be implemented in the cases, in public and private space, alongside the implementation of the energy transition?*' and research question 2.3, '*What types of systems integration can be identified in the cases, regarding implementation of the energy transition and climate adaptation?*', are answered.

In sections 6.1 to 6.5, cross-sectional- and top view designs according to Figure 4-3 are presented and discussed for the five cases selected. In the final cross-sectional designs (situation 3), multiple climate adaptation scenarios are created, according to Figure 4-4. The climate adaptation measures chosen in the designs have been varied over the different cases, to eventually present a wide overview of the implications and effectiveness of different measures. The situation with climate adaptation measures in private space shows what storage could be realized in private space, in case the homeowners would agree to implementation of the measures. In reality, these measures are difficult to achieve, compared to measures in public space, since the municipality cannot simply determine on this measures. The municipality can encourage or oblige the residents or housing corporations, but should then financially contribute. The types of systems integration are derived empirically from the designs and both the technical and socio-institutional aspects of integration are discussed for each case separately. Section 6.6 summarizes the results obtained from the final designs with climate adaptation.

The equations used to calculate the storage capacity of each street and the possible climate adaptation measures, based on the assumptions and equations discussed in subsection 4.2.1 and Appendix C, are listed in Table 6-1.

Table 6-1 Equations to calculate the storage effect of different climate adaptation options

Types of storage	Equation	Explanation
Sewer storage, i.e. the equivalent storage volume	$v_{eff,sewer} = 20\ mm * A_{runoff}$	Where $v_{eff,sewer}$ indicates the equivalent storage volume of the sewer (m^3) and A_{runoff} indicates the total runoff area
Storage on the road between the kerbs, with an assumed kerb height of 120 mm	$v_{eff,road} = 100\ mm * A_{road}$	Where $v_{eff,road}$ indicates the effective storage volume on the street (m^3) and A_{road} indicates the surface area of the road (between the kerbs)
Storage unpaved surface with limited permeability of the subsoil	$v_{eff,unp} = 10 \frac{mm}{h} * 1h * A_{unp} + 10\ mm * A_{unp}$	Storage in and on unpaved surface: 10 mm of surface storage and 10 mm per hour infiltration loss. Where $v_{eff,unp}$ indicates the effective storage volume of the unpaved surface (m^3) and A_{unp} indicates the surface area of the unpaved surface
Storage infiltration facility, with soil improvement	$v_{eff,inf} = V_{inf} * P_{inf} + (V_{gvb} - V_{inf}) * P_{gvb}$	Where $v_{eff,inf}$ indicates the effective storage volume of the infiltration measure (m^3), V_{inf} indicates the volume of the infiltration element (m^3), P_{inf} indicates the porosity of the infiltration element, V_{gvb} indicates the volume of the soil improvement (m^3) and P_{gvb} indicates the porosity of the soil improvement. In this research a porosity of the soil improvement (drainage sand) of 30% is assumed (Gemeente Rotterdam, confidential file).
Storage (absorption) green roofs	$v_{eff,roof} = 0{,}025 \frac{m^3}{m^2} * A_{roof}$	Where $v_{eff,roof}$ indicates the effective storage volume of the green roof (m^3) and A_{roof} indicates the surface area of the green roof

6.1. Case 1: Brittenoord (Reyeroord)

Brittenoord is a residential street, located in the pilot area Reyeroord. Reyeroord is the greenest area of the five pilot areas (the percentage of unpaved surface is 51,96%), which means the urgency for extra green and trees is limited. All property in Brittenoord is privately owned and built around 1965. In Figure 6-1, a street view of Brittenoord is displayed.

Figure 6-1 Street view of Brittenoord (Googlemaps)

In Brittenoord, the implementation of district heating is planned in 2023, according to an integrated approach: in combination with sewer replacement. According to the functional water advice created for Reyeroord, the top layer of the subsoil below roads consists of 1,0 – 2,0 meters of medium permeable sand, with clay and peat layers underneath it. Clay(like) soil is mainly found outside the road pavements, with a top layer of sand of 60 cm. The total length of the street is 111 meters.

6.1.1. Cross sectional- and top view designs

Situation 1: Existing situation

In Table 6-2, the distances from the border of the private gardens (on the left) to the centre of the cables and pipes are stated. The total street width, from the border of the private gardens on the left to the façade of apartment complex on the right, is 15,0 m.

Table 6-2 Distance from the border of the private gardens to the centre of the cables and pipes in Brittenoord and their corresponding dimensions (Situation 1)

Distance from the border of the private gardens (left) to centre of cable/pipe [m]	Pipe/cable	Inside diameter [mm]	Outside diameter [mm]
1,4	Telecom 1	-	-
3,3	Gas	110 (PE)	110
5,1	Combined sewer	500 (BT)	640
8,9	Electricity	-	-
10,0	Drinking water	110 (PVC)	110
10,6	Telecom 2	-	-
11,0	Telecom 3	-	-

In Figure 6-2, the existing cross-sectional situation of Brittenoord is displayed. As can be seen, the dewatering depth in Brittenoord is 1,18 m.

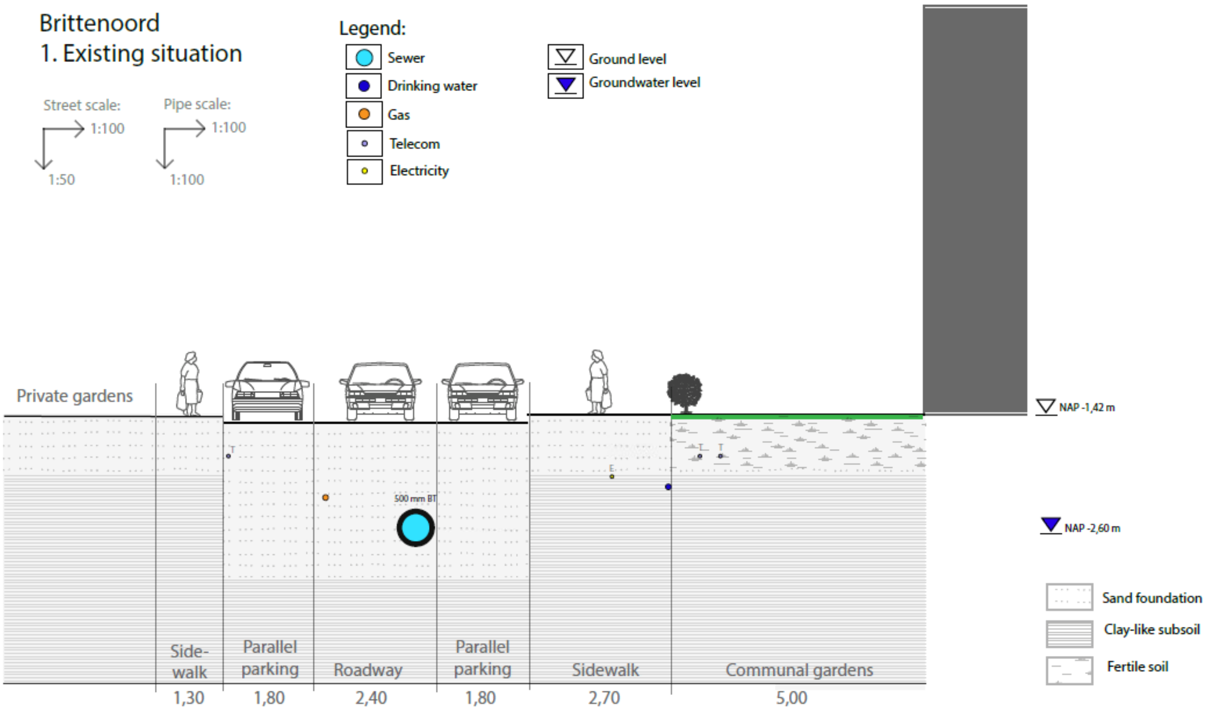

Figure 6-2 Cross-sectional view of Brittenoord – Situation 1: existing situation

Situation 2: Situation with energy measures and sewer replacement

In Brittenoord, secondary distribution pipes of the district heating network are installed, with assumed dimensions of DN80. Simultaneously, sewer replacement is carried out according to the functional water advice of Reyeroord. In order to install a separate sewer system and the district heating network, the telecom cable and the gas pipe at the left have to be relocated, as can be seen in Figure 6-3, so that they do not lie in the excavation cunettes of the sewer system and the heating network.

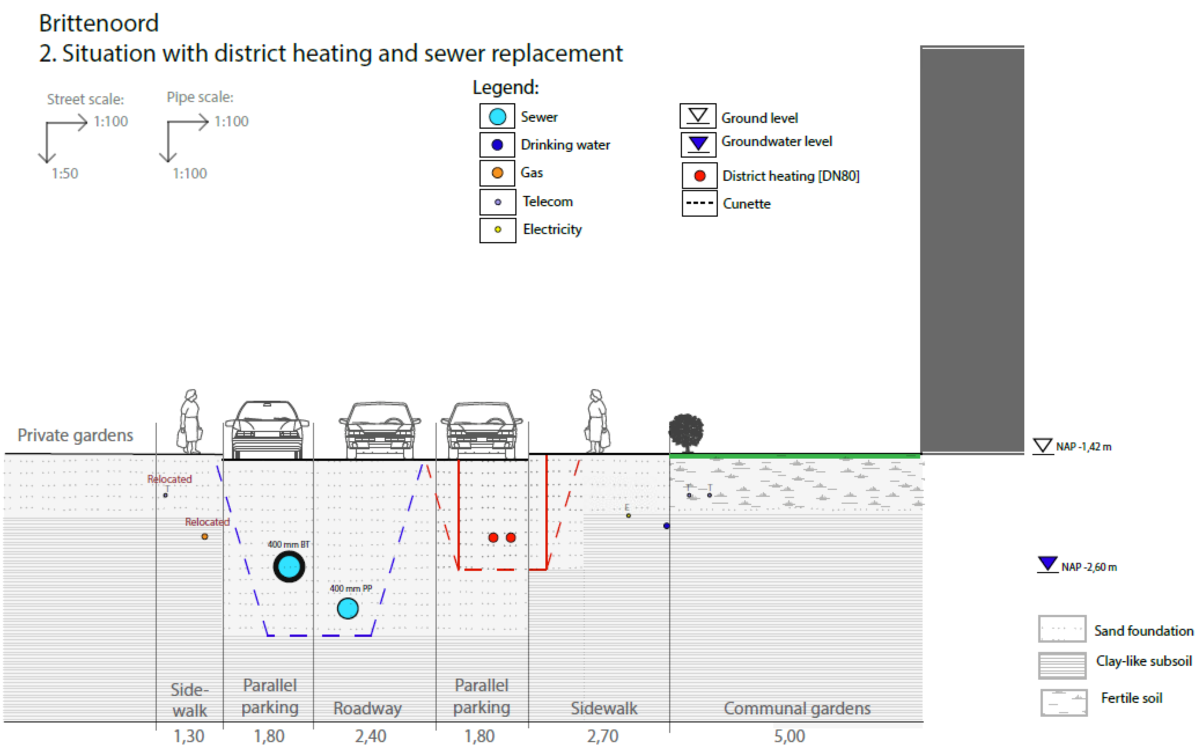

Figure 6-3 Cross-sectional view of Brittenoord – Situation 2: situation with district heating and sewer replacement

In Table 6-3, the new distances from the border of the private gardens to the centre of the cables and pipes are stated.

Table 6-3 Distance from the border of the private gardens to the centre of the cables and pipes in Brittenoord and their corresponding dimensions (Situation 2)

Distance from the border of the private gardens (left) to centre of cable/pipe [m]	Pipe/cable	Inside diameter [mm]	Outside diameter [mm]
0,2	Telecom 1	-	-
0,95	Gas	110 (PE)	110
2,6	Wastewater sewer	400 (BT)	524
3,75	DT sewer	400 (PP)	400
6,6	District heating 1	DN80	180
6,95	District heating 2	DN80	180
8,9	Electricity	-	-
10,0	Drinking water	110 (PVC)	110
10,6	Telecom 2	-	-
11,0	Telecom 3	-	-

The construction activities taking place in Brittenoord in situation 2, with the corresponding execution times, are stated in Table 6-4. The last column shows the time frame in which the activity is carried out in Brittenoord, from the moment the trench or entire street is dug open. This is calculated by dividing the length of the street by the execution time.

Table 6-4 Construction activities in Brittenoord in situation 2, with the corresponding execution times

Activity	Pipe/cable	Execution time [m/day]	Responsibility	Time frame in Brittenoord [days]
Relocate	Telecom	150 – 200	Telecom companies	1
Relocate	Gas	100	Stedin	2
Install	Separate sewer system	5 – 10	Municipality	15
Install	District heating pipes	5 – 10	Heat supplier	15

The excavation that is carried out to install and relocate the cables and pipes stated in Table 6-4, is shown in the top view of Brittenoord in Figure 6-4. In addition to the excavation carried out in the streets and parking lanes, excavation for district heating and sewer replacement is carried out to install the house connection pipes. The officially determined height in Brittenoord is NAP -1,42 meters, which means the current ground level is sufficient and no ground raising is needed in this case. Therefore, it is assumed not the entire street is dug open from façade to façade, but only the necessary parts.

Figure 6-4 Top view of Brittenoord: excavation in situation 2

Situation 3: Situation with climate adaptation

The relevant decision-making information for Brittenoord, regarding climate adaptation (Figure 4-4) is stated in Table 6-5. An infiltration facility with drainage is found to be the optimal climate adaptation solution in this case.

Table 6-5 Information for decision-making on climate adaptation measures in Brittenoord

Dewatering depth	1,18 m (> 0,8 m)
Permeability sandy road foundation	< 2,0 m/day
Permeability subsoil	< 0,6 m/day
Outcome of climate adaptation option	Infiltration facility with drainage (and soil improvement)

The runoff areas in the existing situation are indicated in Table 6-6. With these numbers, the required storage is calculated, in case the water retention capacity needs to be sufficient in case of a rainfall event of 70 mm in 1 hour.

Table 6-6 Rainwater run off areas in Brittenoord

Runoff area	**Surface area [m^2]**	**Percentage of total surface area [%]**
Road (public space)	908	23,3
Sidewalks (public space)	482	12,4
Private property (roofs, private and communal gardens)	2501	64,3
Total runoff area:	3892	100
Total storage required:	$70 \frac{mm}{hour} * 3892\ m^2 = \mathbf{272,5\ m^3}$	

The water storage capacity of Brittenoord, in the existing situation, is calculated in Table 6-7.

Table 6-7 Water storage capacity of Brittenoord in situation 1

Equation 1: Sewer storage	$v_{eff,sewer} = 20\ mm * 3898\ m^2 = 77{,}9m^3$
Equation 2: Storage on the road	$v_{eff,road} = 100\ mm * 908\ m^2 = 90{,}8m^3$
Equation 3: Storage communal gardens (limited permeability)	$v_{eff,unp} = 10\frac{mm}{h} * 1h * 415m^2 + 10\ mm * 415m^2 = 8{,}3\ m^3$
Equation 3: Storage private gardens (limited permeability), 20% of unpaved surface assumed	$v_{eff,unp} = 10\frac{mm}{h} * 1h * 0{,}2 * 630{,}7\ m^2 + 10\ mm * 0{,}2 * 630{,}7\ m^2 = 2{,}0\ m^3$
Total water storage in existing situation:	$v_{eff} = 77{,}9\ m^3 + 90{,}8\ m^3 + 8{,}3\ m^3 + 2{,}0\ m^3 = 179{,}0\ m^3 = 46\ mm$
Storage deficit:	$272{,}5\ m^3 - 179{,}0\ m^3 = 93{,}5\ m^3 = 24\ mm$

Situation 3.1.1: Climate adaptation in public space, within the conventions of Rotterdam

Figure 6-5 shows climate adaptation measures, within the conventions of the municipality of Rotterdam, in public space in Brittenoord, based on Table 6-5. In the figure, permeable pavement is implemented in the roadway, with soil improvement (effective porosity of 25%), resulting in a water-storing road foundation.

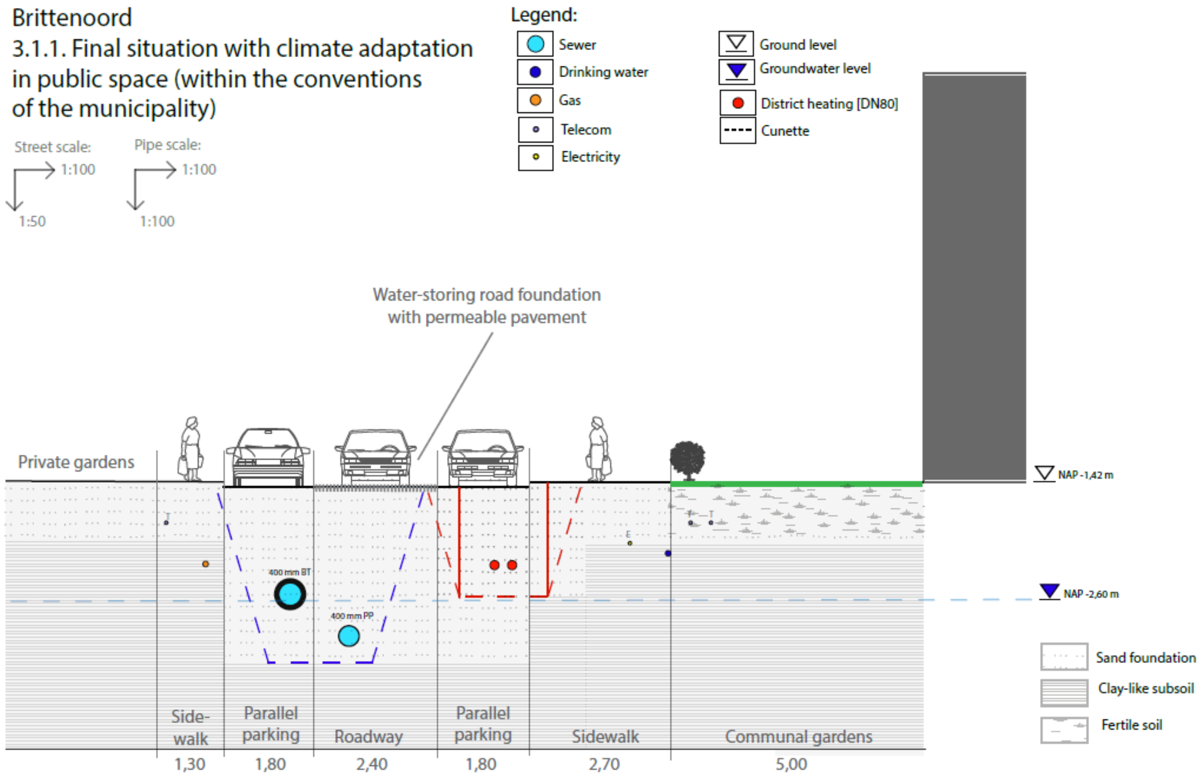

Figure 6-5 Cross-sectional view of Brittenoord – Situation 3: final situation with possible climate adaptation measures in public space, within the conventions of Rotterdam

According to the figure, the rainwater falling on the road is partly disconnected from the sewer system, due to infiltration through the permeable pavement, and temporarily stored in the sandy road foundation. Eventually, the rainwater can be discharged through the constructed DT-sewer. The effects that the climate adaptation measures in Figure 6-5 will have on the water storage capacity of Brittenoord and the final storage deficit are presented in Table 6-8.

Table 6-8 Storage effect of climate adaptation measures in Brittenoord in situation 3.1.1.

Equation 4: Storage infiltration facility, with soil improvement	$v_{eff,inf} = 111\,m * 2{,}4\,m * 1{,}18\,m * 0{,}25 = 78{,}6\,m^3$
Total water storage in situation 3.1.1:	$v_{eff} = 179{,}0\,m^3 + 78{,}6\,m^3 = 257{,}6\,m^3 = 66{,}2\,mm$
Storage deficit:	$272{,}5\,m^3 - 255{,}6\,m^3 = 14{,}9\,m^3 = 3{,}8\,mm$

Situation 3.1.2: Climate adaptation in private space

Brittenoord has 630,7 m² of private front yards (mainly paved) and 415 m² of green communal gardens of the apartment blocks in front. Currently, most of the rainwater falling on private space flows to public space in case of a heavy rain event, but the large areas of private and communal gardens make it possible to (partly) process rainwater on own private ground. Figure 6-6 shows possible climate adaptation measures in private space in Brittenoord.

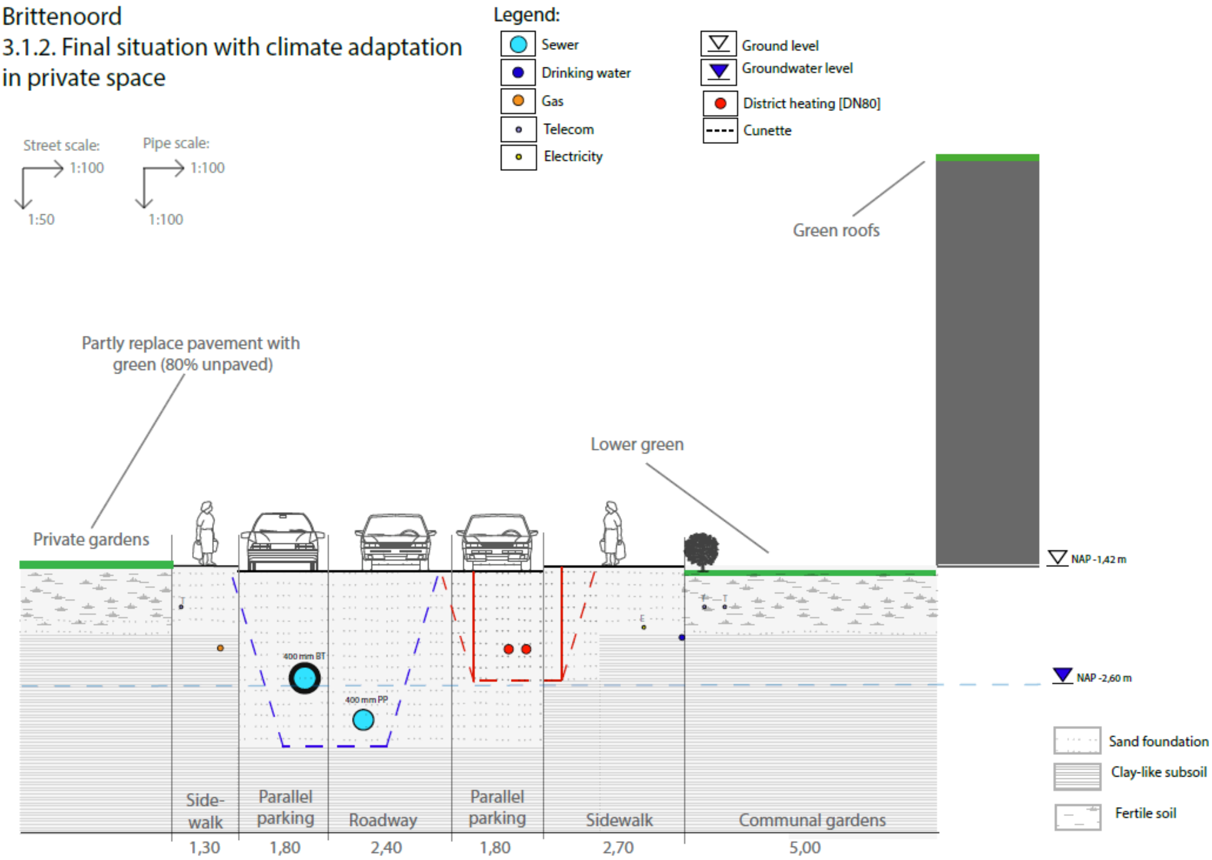

Figure 6-6 Cross-sectional view of Brittenoord – Situation 3: final situation with possible climate adaptation measures in private space

According to the figure, the rainwater falling on private space is partly disconnected from the sewer system and processed in private space, due to replacement of the pavement in gardens with green, lowering the green in the communal gardens and green roofs. The effect that the climate adaptation measures in Figure 6-6 will have on the water storage capacity of Brittenoord is presented in Table 6-9.

Table 6-9 Storage effect of climate adaptation measures in Brittenoord in situation 3.1.2.

Equation 3: Storage private gardens (limited permeability)	$v_{eff,unp} = 10\frac{mm}{h} * 1h * 0{,}8 * 630{,}7\ m^2 + 10\ mm * 0{,}8 * 630{,}7\ m^2 = 10{,}1\ m^3$
Equation 3: Storage lowered communal gardens (limited permeability)	$v_{eff,unp} = 10\frac{mm}{h} * 1h * 415m^2 + 150\ mm * 415m^2 = 66{,}4\ m^3$
Equation 5: Storage green roofs	$v_{eff,roof} = 0{,}025\frac{m^3}{m^2} * 690{,}1\ m^2 = 17{,}3\ m^3$
Total water storage in situation 3.1.2:	$v_{eff} = 77{,}9\ m^3 + 90{,}8\ m^3 + 10{,}1\ m^3 + 66{,}4\ m^3 + 17{,}3\ m^3 = 262{,}5\ m^3 = 67{,}5\ mm$
Storage deficit:	$272{,}5\ m^3 - 262{,}5\ m^3 = 10\ m^3 = 2{,}5\ mm$

Situation 3.2: Climate adaptation in public space, conventions of Rotterdam ignored

Because adaptation measures in public space, shown in Figure 6-5, did not provide sufficient storage, in Figure 6-7, a climate adaptation design is made that does not comply with the conventions of the municipality. In this figure, permeable pavement with soil improvement (effective porosity of 25%) is placed in the roadway and parking lanes, above the separate sewer system and the district heating pipes.

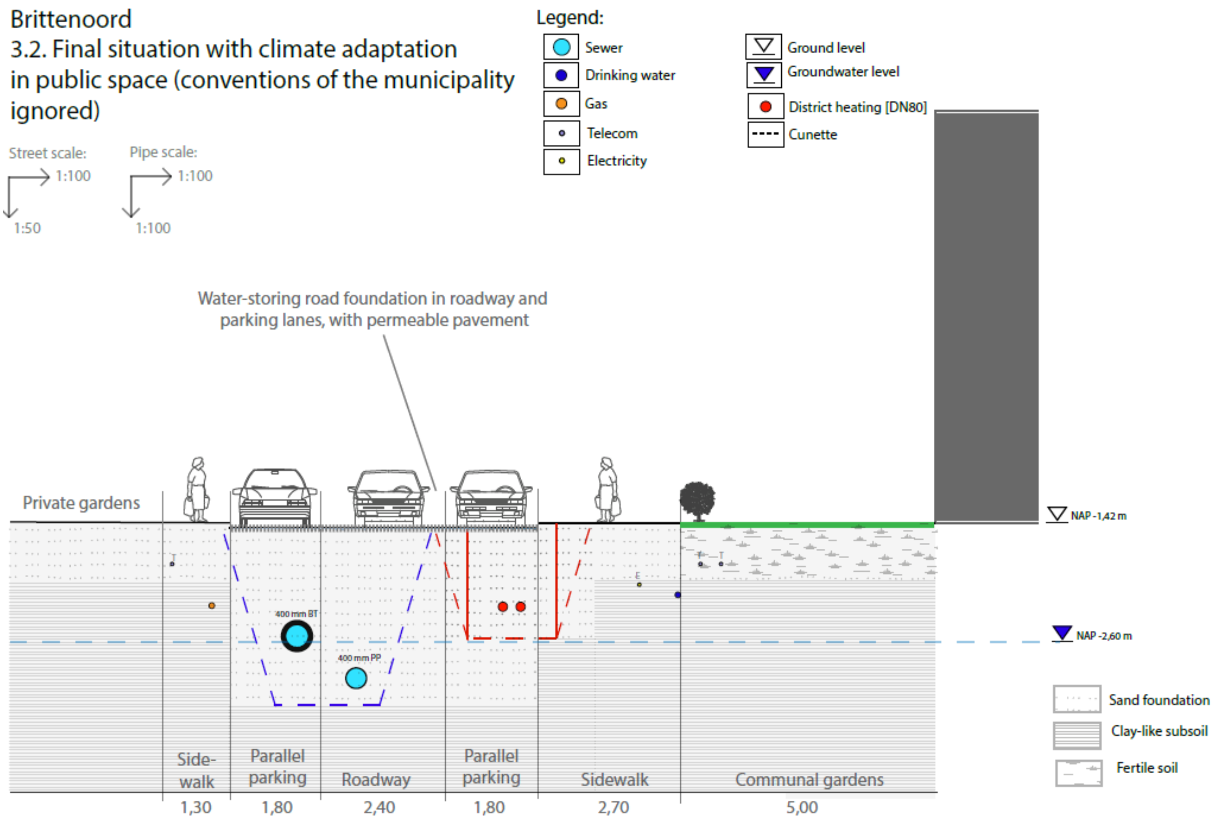

Figure 6-7 Cross-sectional view of Brittenoord – Situation 3: final situation with possible climate adaptation measures in public space, conventions of Rotterdam ignored

According to the figure, the rainwater falling on the road and parking lanes is partly disconnected from the sewer system, due to infiltration through the permeable pavement, and temporarily stored in the sandy road foundation. Eventually, the rainwater can be discharged through the constructed DT-sewer.

The effects that the climate adaptation measures in Figure 6-7 will have on the water storage capacity of Brittenoord, and the final storage surplus are presented in Table 6-10.

Table 6-10 Storage effect of climate adaptation measures in Brittenoord in situation 3.2.

Equation 4: Storage infiltration facility, with soil improvement	$v_{eff,inf} = 111\ m * (2{,}4\ m + 1{,}8\ m + 1{,}8\ m) * 1{,}18\ m * 0{,}25 = 196{,}5\ m^3$
Total water storage in situation 3.2:	$v_{eff} = 179{,}0\ m^3 + 196{,}5\ m^3 = 375{,}5\ m^3 = 96{,}5\ mm$
Storage surplus:	$375{,}5\ m^3 - 272{,}5 m^3 = 103\ m^3 = 26{,}5\ mm$

6.1.2. *Types of systems integration identified*

Measures in public space within the conventions of Rotterdam solely (66,2 mm) come close to the storage needed in case of a heavy rainfall event (70 mm in 1 hour) in Brittenoord. However, due to the small deficit, a design with measures in public space outside the conventions of Rotterdam has been created in addition. To eventually realize the amount of water storage in case of a rain event of 70 mm in 1 hour, a combination of measures in public space within the conventions of Rotterdam (Figure 6-5) and measures in private space (Figure 6-6) and measures in public space that do not comply with the conventions of Rotterdam (Figure 6-7) would suffice. Based on the designs, multiple types of systems integration are identified, with both technical- and socio-institutional aspects.

Geographical integration

- *Technical aspects:*

In Brittenoord, the elements of multiple underground infrastructures (the sewer system, district heating, utilities and climate adaptation measures) are in close spatial proximity, which requires close spatial organization. In principle, the municipality wants both the sewer system and the district heating network as much in the middle of the street as possible (section 3.2). The separate sewer system (Figure 6-3) is located more to the left side compared to the combined system (Figure 6-2), because in that way the district heating network can be placed directly next to the sewer cunette and also lies as much in the middle of the street as possible (Figure 6-3). In order to install the separate sewer system and the district heating network as much in the middle of the street as possible, the telecom cable and the gas pipe at the left need to be relocated (Figure 6-3), so that they do not lie in the excavation cunettes of the sewer system and the heating network.

- *Socio-institutional aspects:*

To organize the underground infrastructure in close spatial proximity, the implementation requirements (location in the street) and spatial impacts of all assets should be known and maintained by the different parties involved. In Brittenoord this means: the Water department of the Public Works-division (responsible for sewer maintenance) has to align its replacement plans with the heat supplier (responsible for the district heating network) in Brittenoord, to create a combined design. In addition, because the telecom cable and gas pipe have to be relocated (Figure 6-3), the designs should be communicated to the telecom operator and gas supplier (Stedin) in order to reach a joint agreement on the design, to give them the opportunity to not only relocate, but also replace it and to use the momentum to execute everything simultaneously.

Project-based integration

- *Technical aspects:*

In Brittenoord, the implementation of district heating and sewer replacement are planned simultaneously and, as stated above, in order to install both, the telecom cable and gas pipe have to be relocated (Figure 6-3). This results in a lot of excavation carried out in the street (Figure 6-4). The construction activities in Brittenoord, their corresponding executing times and the time frame needed in the street are stated in Table 6-4. The gas pipe is relocated first, according to subsection 4.2.1. Secondly, the telecom cable is relocated. Subsequently, according to subsection 4.2.1, the sewer system will be replaced and eventually the district heating network will be installed. It is most advantageous in terms of nuisance for the residents to relocate the cables and install the sewer system and district heating network one after the other as quickly as possible, so that the street only has to be dug open and closed off once.

Measures in public space can be taken in the roadway and parking lanes in Brittenoord (Figure 6-5 and Figure 6-7). Since the entire roadway and parking lanes are dug open due to replacement of the sewer and installation of the district heating pipes (derived from the cunettes in the cross-sectional design in Figure 6-3 and the top view design in Figure 6-4), permeable pavement and soil improvement in the roadway and parking lanes can be implemented simultaneously, when the street is filled up with sand again.

Climate adaptation measures in private space can be taken in the private gardens, communal gardens and at the roof (Figure 6-6). The measures indicate that 20% of the total paved surface area of the private gardens is replaced with green (126,1 m^2) and the entire area of the communal gardens is lowered (415 m^2). To place the house connection pipes in the private gardens (Figure 6-4), 14 trenches with a total surface area of 134,4 m^2 (subsection 4.2.2) are dug to place the house connection pipes of the district heating network and 14 trenches with a total surface area of 50,4 m^2 are dug to place the house connection pipes of the sewer system. To place the house connection pipes in the communal gardens (Figure 6-4), 4 trenches with a total surface area of 45,6 m^2 (subsection 4.2.2) are dug to place the house connection pipes of the district heating network and 4 trenches with a total surface area of 16,0 m^2 are dug to place the house connection pipes of the sewer system. The eventual overlap between the excavation carried out for the sewer and district heating network and the climate adaptation in private space, is presented in Table 6-11.

Table 6-11 Overlap between excavation and climate adaptation measures in private space in Brittenoord

Overlap excavation and climate adaptation measures private gardens Brittenoord	$\frac{134,4\ m^2 + 50,4\ m^2}{126,1\ m^2} * 100\% = 146,5\%$
Overlap excavation and climate adaptation measures communal gardens Brittenoord	$\frac{45,6\ m^2 + 16,0\ m^2}{415\ m^2} * 100\% = 14,8\%$

This means that especially the residents of the single houses (private gardens) can seize the opportunity to simultaneously implement climate adaptation measures (in this case greenery) in their garden with the installation of the heating network and separate sewer system. For residents in the apartment complexed (communal gardens), there is little overlap. Simultaneous implementation of climate adaptation can provide a small advantage regarding excavation. However, simultaneous implementation still results in less inconvenience, due to one moment of construction work. The roofs where green roofs are implemented (Figure 6-6) are flat and made of bitumen, which means the green roofs could be placed without extra measures (although still expensive). Since no other construction activities take place on the roof, integration of implementation of green roofs does not bring benefits during construction of the heating network and therefore does not need to be carried out simultaneously.

- *Socio-institutional aspects:*

In Brittenoord, simultaneous implementation of climate adaptation measures in public space is beneficial in terms of costs and nuisance. To implement climate adaptation measures in public space simultaneously to the implementation of district heating and replacement of the sewer, knowing that urban flooding occurs at that location is crucial information for the sewer and district heating planners and designers, because then they know whether to add climate adaptation in their design.

Besides, connecting to the district heating network instead of the gas network, means households have to switch to an electric way of cooking and instead of a central boiler, houses get a connection to the heating network. Because houses in Brittenoord are privately owned, the residents are responsible for the required adjustments and should all individually agree to the plans to implement district heating. In case climate adaptation measures on private land are desired from the municipality (Figure 6-6), both climate adaptation measures and in-house district heating adjustments are in hands of private owners (residents). In that case, an integrated communication approach from the municipality towards the community is desired, so that they know the advantages of simultaneous implementation and can implement the measures accordingly.

6.2. Case 2: Melissantstraat-north (Pendrecht)

The Melissantstraat is a residential street, located in the pilot area Pendrecht. In Figure 6-8, a street view of the north part of the Melissantstraat is displayed. The percentage of unpaved surface in Pendrecht is 43,80% (below the national average) and as can be seen in Figure 6-8, the street looks mainly paved. Therefore, the urgency for extra green in the Melissantstraat is high. All property in the street is built in 1956 and owned by the housing corporation Woonstad.

Figure 6-8 Street view of the Melissantstraat-north (Googlemaps)

The implementation of district heating in the Melissantstraat is planned to be carried out singularly (without sewer maintenance) between 2021 and 2023. In addition to district heating, solar panels are installed on the roofs of the property in the Melissantstraat.

The permeability of the sandy road foundation in the Melissantstraat is less than 2 m/day, according to an old functional water advice of the Tiengemetensingel (street close to the Melissantstraat). The subsoil consists mainly of clay, alternated locally with thin layers of sand. The total length of the street (the northern part of the Melissantstraat) is 137 meters.

6.2.1. Cross-sectional and top view designs

Situation 1: Existing situation

In Table 6-12, the distances from the façade of the apartments on the left to the centre of the cables and pipes are stated. The total street width, from façade to facade, is 21,8 m.

Table 6-12 Distance from the façade of the apartments to the centre of the cables and pipes in the Melissantstraat and their corresponding dimensions (Situation 1)

Distance from façade of apartment on the left to centre of cable/pipe [m]	Pipe/cable	Inside diameter [mm]	Outside diameter [mm]
1,0	Telecom 1	-	-
5,2	Telecom 2	-	-
7,2	Drinking water	170 PVC	170
9,7	Wastewater sewer	315 PVC	315
10,9	DT sewer	315 PVC	315
12,5	Electricity	-	-
20,75	Telecom 3	-	-

In Figure 6-9, the existing situation of the Melissantstraat is displayed. As can be seen, the dewatering depth is 0,66 m.

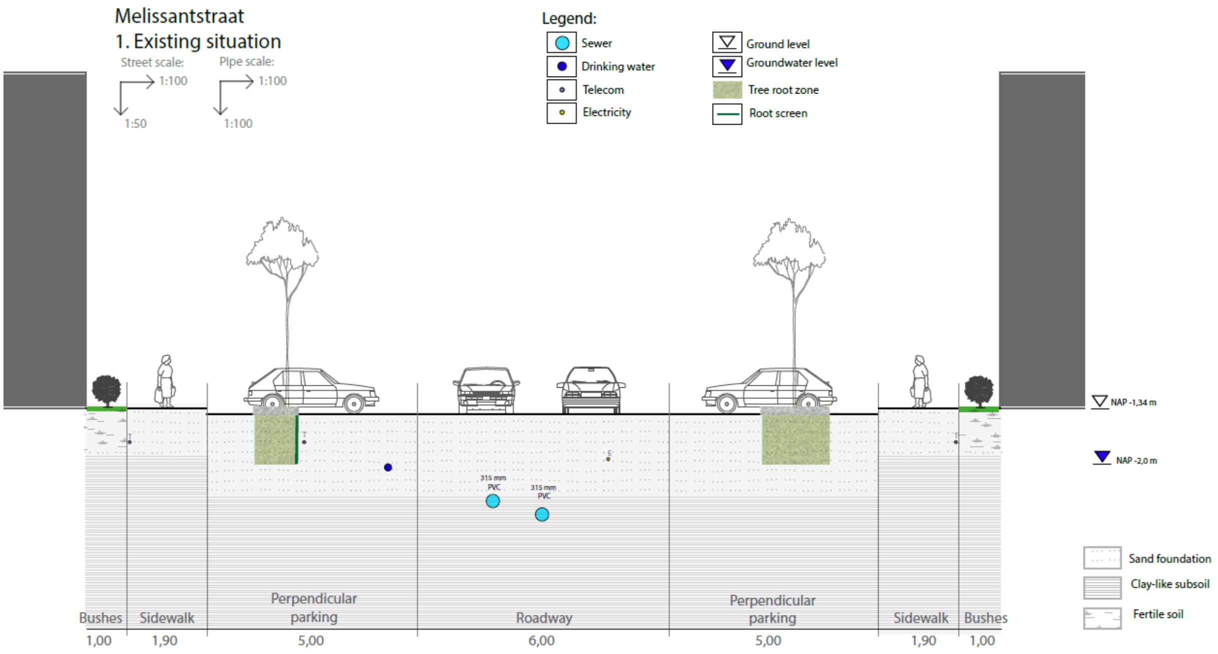

Figure 6-9 Cross-sectional view of the Melissantstraat – Situation 1: existing situation

Situation 2: Situation with energy measures

In the Melissantstraat, secondary distribution pipes of the district heating network are installed, with dimensions of DN80. In addition, it is assumed solar panels are installed on all roofs of the houses in the street (all houses are owned by the housing corporation Woonstad). In case of large-scale installation of solar panels, the electricity cable needs to be reinforced as well (Section 3.2). To install the district heating network and solar panels, the electricity cable has to be replaced and relocated, as can be seen in Figure 6-10, so that it is reinforced and does not lie in the excavation cunette of the heating network. In addition, a root screen needs to be placed in the tree root zone of the tree at the right, so that the roots cannot grow in the district heating cunette.

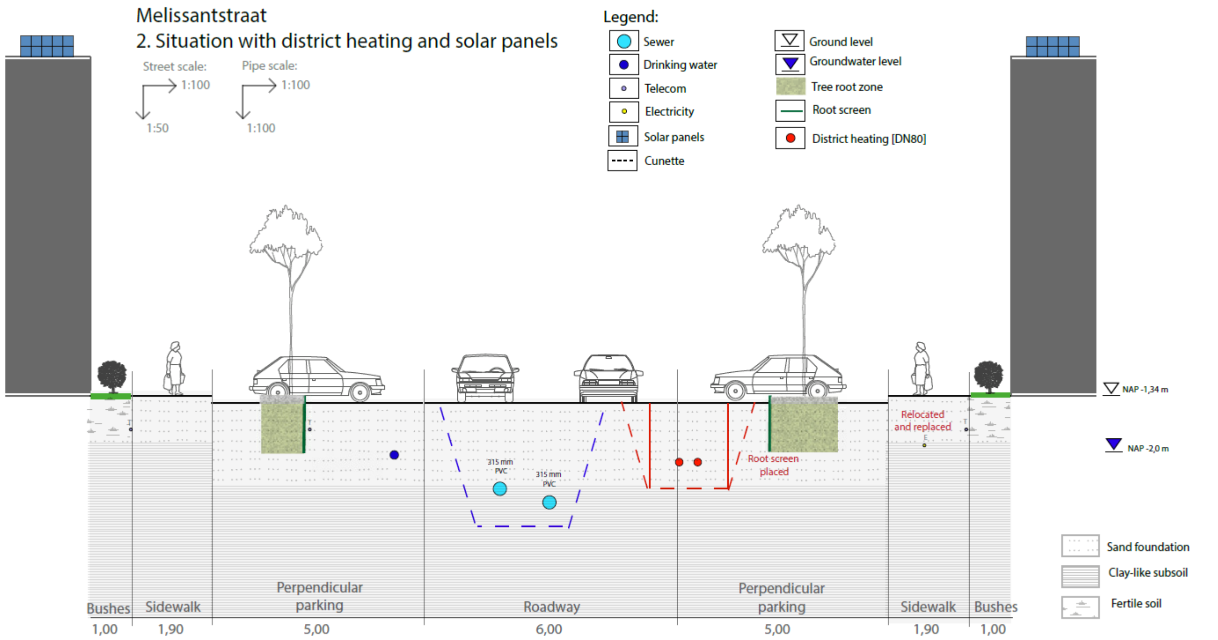

Figure 6-10 Cross-sectional view of the Melissantstraat – Situation 2: situation with district heating and solar panels

In Table 6-13, the new distances from the façade of the apartments on the left to the centre of the cables and pipes are stated.

Table 6-13 Distance from the façade of the apartments to the centre of the cables and pipes in the Melissantstraat and their corresponding dimensions (Situation 2)

Distance from façade of apartment on the left to centre of cable/pipe [m]	Pipe/cable	Inside diameter [mm]	Outside diameter [mm]
1,0	Telecom 1	-	-
5,2	Telecom 2	-	-
7,2	Drinking water	170 PVC	170
9,7	Wastewater sewer	315 PVC	315
10,9	DT sewer	315 PVC	315
14,0	District heating 1	DN80	180
14,5	District heating 2	DN80	180
19,7	Electricity	-	-
20,75	Telecom 3	-	-

The construction activities taking place in the Melissantstraat in situation 2, with the corresponding execution times, are stated in Table 6-14. The last column shows the time frame in which the activity is carried out in the Melissantstraat, from the moment the trench or entire street is dug open. This is calculated by dividing the length of the street by the execution time.

Table 6-14 Construction activities in the Melissantstraat in situation 2, with the corresponding execution times

Activity	Pipe/cable	Execution time [m/day]	Responsibility	Time frame in the Melissantstraat [days]
Replace	Electricity	150 – 200	Stedin	1
Install	District heating pipes	5 – 10	Heat supplier	19

The excavation that is carried out to install and relocate the cables and pipes stated in Table 6-14, is shown in the top view of the Melissantstraat in Figure 6-11. In addition to the excavation carried out in the streets and parking lanes, excavation for district heating is carried out to install the house connection pipes.

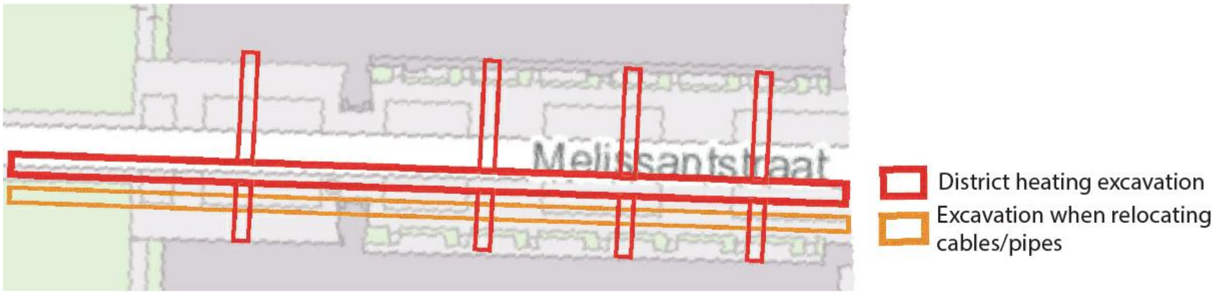

Figure 6-11 Top view of the Melissantstraat: excavation in situation 2

Situation 3: Situation with climate adaptation

The relevant decision-making information for the Melissantstraat, regarding climate adaptation (Figure 4-4) is stated in Table 6-15. Storage or conveyance solutions are found to be the optimal climate adaptation solution in this case.

Table 6-15 Information for decision-making on climate adaptation measures in the Melissantstraat

Dewatering depth	0,66 m (< 0,8 m)
Permeability sandy road foundation	< 2,0 m/day
Permeability subsoil	< 0,6 m/day
Outcome of climate adaptation option	- Storage - Conveyance

The runoff areas in the existing situation in the Melissantstraat are indicated in Table 6-16. With these numbers, the required storage is calculated, in case the water retention capacity needs to be sufficient in case of a rainfall event of 70 mm in 1 hour.

Table 6-16 Rainwater runoff areas in the Melissantstraat

Runoff area	Surface area [m^2]	Percentage of total surface area [%]
Road (public space)	1404	41,5
Sidewalks and bushes (public space)	960	28,3
Private property (roofs)	1022	30,2
Total runoff area:	3386	100
Total storage required:	$70\frac{mm}{hour} * 3386\ m^2 = \mathbf{237,0\ m^3}$	

The water storage capacity of the Melissantstraat, in the existing situation, is calculated in Table 6-17.

Table 6-17 Water storage capacity of the Melissantstraat in situation 1

Equation 1: Sewer storage	$v_{eff,sewer} = 20\ mm * 3386\ m^2 = 67,7\ m^3$
Equation 2: Storage on the road	$v_{eff,road} = 100\ mm * 1404\ m^2 = 140,4\ m^3$
Equation 3: Storage unpaved surface (bushes along the apartments, 7 trees in planters)	$v_{eff,unp} = 10\frac{mm}{h} * 1h * (85 * 2 + 7 * 1,5)\ m^2 + 10\ mm * (85 * 2 + 7 * 1,5)\ m^2 = 3,6\ m^3$
Total water storage in existing situation:	$v_{eff} = 67,7\ m^3 + 140,4\ m^3 + 3,6\ m^3 = 211,7\ m^3 = 62,5\ mm$
Storage deficit:	$237\ m^3 - 211,7\ m^3 = 25,3\ m^3 = 7,5\ mm$

Situation 3.1.1: Climate adaptation in public space, within the conventions of Rotterdam

Figure 6-12 shows possible climate adaptation measures in public space in the Melissantstraat, within the conventions of the municipality, based on Table 6-15. To improve the greenery in the street, the perpendicular parking spots are transformed into parallel parking spots and green roadsides are placed in the extra space that is created. Because extra infiltration is not desired in the Melissantstraat, the green roadsides are not deepened and no soil improvement is applied, so that only a small amount of the rainfall falling on the roadside is infiltrated (10 mm). To create extra water storage in the street, the road is redesigned into a cloudburst street: a v-shaped profile to ensure water flows in the middle of the road, away from the buildings, towards a 'safe' place (Ping, 2017). The Melissantstraat is sloped towards the south (Algemeen Hoogtebestand Nederland), running towards an open parking space with open grass fields, which is where the water from the v-shaped profile is directed to.

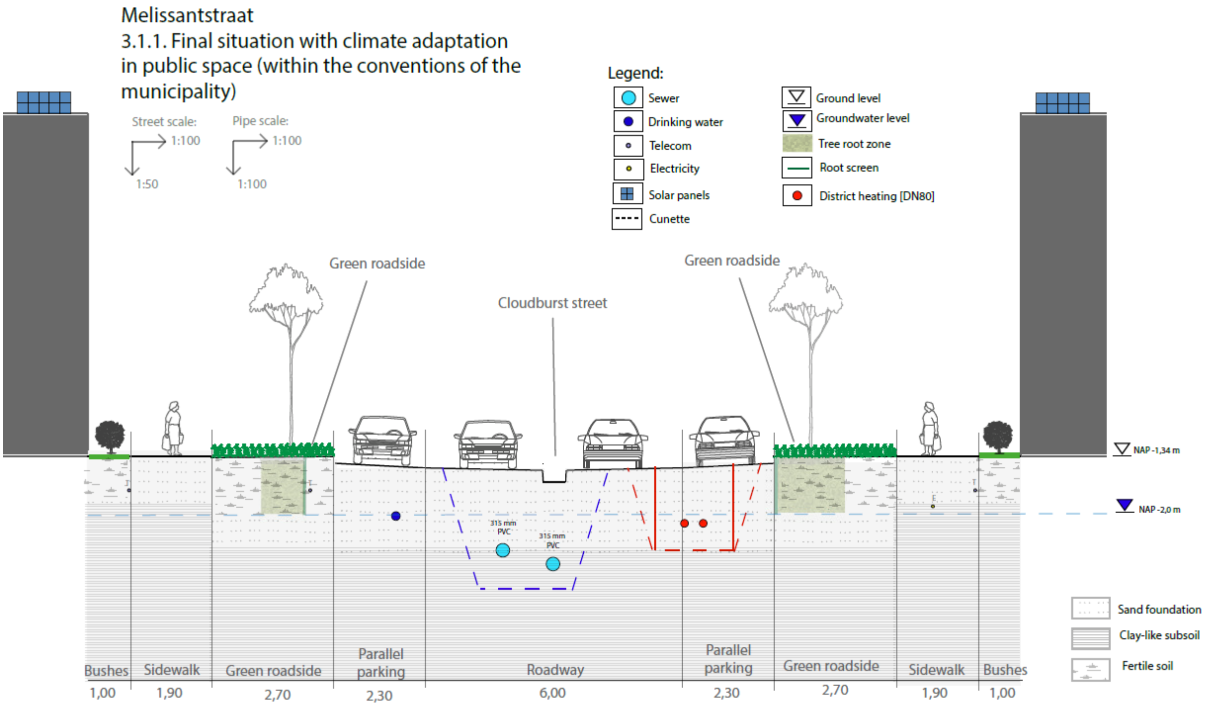

Figure 6-12 Cross-sectional view of the Melissantstraat – Situation 3: final situation with possible climate adaptation measures in public space, within the conventions of Rotterdam

In the existing situation, there are 58 perpendicular parking spots in the Melissantstraat-north, with a width of approx. 2,3 meters. Transforming these spots into parallel parking spots, with a length of approx.5 meters, means the amount of parking spots is reduced to 27. The surface area of the road (road and parking lanes) is reduced to 1034,1 m^2 and the surface area of the green roadsides has become 369,9 m^2.

The effect that the climate adaptation measures in Figure 6-12 will have on the water storage capacity of the Melissantstraat is presented in Table 6-18.

Table 6-18 Storage effect of climate adaptation measures in the Melissantstraat in situation 3.1.1.

Equation 2: Storage on the road	$v_{eff,road,kerbs} = 100\ mm * (1404 - 685 + 315{,}1)m^2 = 103{,}4\ m^3$ $v_{eff,road,vshape} = \left(\frac{1}{2} * 4{,}9\ m * 137m\right) ** 75\ mm * 2 + 0{,}8m * 137m * 125\ mm = 64{,}0\ m^3$
Equation 3: Storage green roadsides	$v_{eff,unp} = 10\frac{mm}{h} * 1h * 369{,}9m^2 + 10\ mm * 369{,}9m^2 = 7{,}4\ m^3$
Total water storage in situation 3.1.1:	$v_{eff} = 67{,}7\ m^3 + 3{,}6\ m^3 + 103{,}4\ m^3 + 64{,}0\ m^3 + 7{,}4\ m^3 = 246{,}1\ m^3 = 72{,}7\ mm$
Storage surplus:	$246{,}1\ m^3 - 237{,}0\ m^3 = 9{,}1\ m^3 = 2{,}7\ mm$

Situation 3.1.2: Climate adaptation in private space

Figure 6-9 shows the apartment blocks in the Melissantstraat do not have private front yards with space available for water storage. As can be seen in Figure 6-13, the possible climate adaptation measures in private space are placed on the roofs and facades: green roofs and green balconies (facades). All roofs in the street are flat and made of bitumen, which means green roofs can be placed without any extra measures. The green balconies (facades) do not improve the water storage capacity of the street, but increase the greenery in the street and thereby improve the street view and reduce the heat.

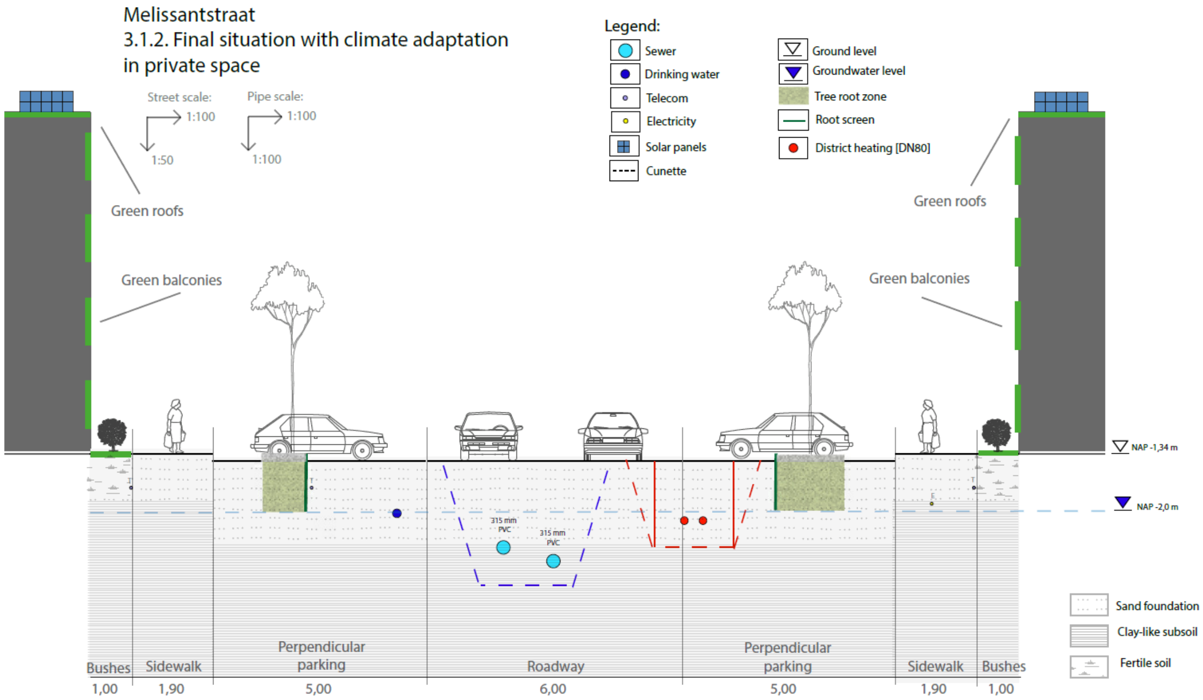

Figure 6-13 Cross-sectional view of the Melissantstraat – Situation 3: final situation with possible climate adaptation measures in private space

The effect that the climate adaptation measures in Figure 6-13 will have on the storage capacity of the Melissantstraat is presented in Table 6-19.

Table 6-19 Storage effect of climate adaptation measures in the Melissantstraat in situation 3.1.2.

Equation 5: Storage green roofs	$v_{eff,roof} = 0{,}025 \frac{m^3}{m^2} * 1022\ m^2 = 25{,}6\ m^3$
Total water storage in situation 3.1.2:	$v_{eff} = 211{,}7\ m^3 + 25{,}6\ m^3 = 237{,}3\ m^3 = 70{,}1\ mm$
Storage surplus:	$237{,}3\ m^3 - 237{,}0\ m^3 = 0{,}3\ m^3 = 0{,}1\ mm$

6.2.2. Types of systems integration identified

Both measures in public space within the conventions of Rotterdam (72,7 mm) solely and measures in private space (70,1 mm) solely can create sufficient storage in case of a heavy rainfall event (70 mm in 1 hour) in the Melissantstraat. Based on the designs, multiple types of systems integration are identified, with both technical- and socio-institutional aspects.

Geographical integration

- *Technical aspects:*

In the northern part of the Melissantstraat (discussed in this research), the elements of multiple infrastructures (the sewer system, district heating and climate adaptation measures) are in close spatial proximity, which requires close spatial organization. According to section 3.2, a district heating network that is connected to both sides of the streets should be placed as much in the middle of the street as possible. Because of the separate sewer system in the Melissantstraat, located in the middle of the street, the heating network is partly placed below the parking lanes at the right. In order to install the district heating network directly next to the sewer cunette, the electricity cable needs to be relocated (and replaced in addition, due to the implementation of solar panels), so that it does not lie in the excavation cunette of the heating network. In addition, a root screen needs to be placed alongside the trees at the right, so that the tree roots cannot grow in the excavation cunette of the heating network.

In the Melissantstraat storage or conveyance climate adaptation measures have to be implemented (no infiltration). Measures in public space can be taken in the roadway and parking lanes in the Melissantstraat (Figure 6-12). To implement these measures, the above-ground layout of the street has changed in its entirely, to improve the green structure and realize sufficient water storage. Changes in the layout that have been made, include:

- 31 parking spots have been lost;
- Green is planted over the entire length of the street, in place of parking spots;
- The roadway is constructed with a slope and deepened further, to create more water storage on the road.
  - *Socio-institutional aspects:*

To organize the underground infrastructure in close spatial proximity, the implementation requirements (location in the street) and spatial impacts of all assets should be known and maintained by the different parties involved. In the Melissantstraat this means: the heat supplier (responsible for the district heating network) in the Melissantstraat has to communicate its plans to the electricity operator (Stedin), in order to reach a joint agreement on the design, to give them the opportunity to both relocate and replace the cable and to use the momentum to execute everything simultaneously.

To implement measures in public space to create sufficient water storage, 31 parking spots in the street have been lost. In order to prevent this from creating problems for local residents, a solution has to be proposed from the municipality, either to create more parking space elsewhere or to stimulate a future scenario where fewer parking spaces are required (mobility transition).

Project-based integration

- *Technical aspects:*

Since the implementation of district heating in the Melissantstraat is planned singularly and only the electricity cable needs to be relocated and replaced, the excavation that is carried out in the street is limited (Figure 6-11). The construction activities in the Melissantstraat, their corresponding executing times and the time frame needed in the street are stated in Table 6-14. To install the heating network, first the electricity cable has to be relocated. It is most advantageous in terms of nuisance for the residents to relocate the cables and install the district heating network one after the other as quickly as possible, so that the street only has to be dug open and closed off once.

As can be derived from Figure 6-11, except for a small part in the parking lane at the bottom, no excavation takes place in the roadway. Therefore, integration of the implementation of the climate adaptation measures in public space (Figure 6-12) during construction of the district heating network does not bring considerable benefits and does not have to be carried out simultaneously.

Climate adaptation measures in private space can be taken at the roof and the façade (Figure 6-13). The roofs are flat and made of bitumen, which means the green roofs can be placed without extra measures. Since solar panels are also placed on the roof by housing corporation Woonstad, placing the green roofs simultaneous to the solar panels can be beneficial with regards to construction. Both include construction work on the roof carried out by housing corporation Woonstad, which allows for an integrated approach to save costs and inconvenience for the residents.

- *Socio-institutional aspects:*

Connecting to the district heating network instead of the gas network, means households have to switch to an electric way of cooking and instead of a central boiler, houses get a connection to the heating network. Because houses in the Melissantstraat are owned by Woonstad, Woonstad is responsible for the required adjustments, installation of solar panels and climate adaptation measures in private space. In case climate adaptation measures are desired in private space in the Melissantstraat, an integrated communication approach from the municipality towards Woonstad is desired, so that one does not preclude the other in the future and so they know the advantages of simultaneous implementation of both.

Physical integration (based on infrastructure)

- *Technical aspects:*

The green roofs that are implemented in case of climate adaptation measures in private space are placed alongside the solar panels on the roofs (Figure 6-13). The cooling effect of a green roof has a positive effect on the power generation and lifespan of solar panels. After a long period of heat, the panels darken and produce less energy. The green roofs reduce that heat (Stichting RIONED, 2015). Therefore, integration of the two can be beneficial to the performance of the solar panels.

- *Socio-institutional aspects:*

Woonstad is responsible for implementation of both solar panels and green roofs. Since integration of the two is beneficial in terms of performance, an integrated communication approach from the municipality towards Woonstad is desired, so that Woonstad knows the advantages and can implement the measures accordingly.

6.3. Case 3: Goudenregenstraat (Rozenburg)

The Goudenregenstraat is a residential street, located in the pilot area Rozenburg. The property in the street is owned by the housing corporations Ressort Wonen, Woonstad and a small part is privately owned. All property is built in 1962 to 1963, according to a 'cauliflower-district typology'. In Figure 6-14 a street view of the Goudenregenstraat is displayed. Rozenburg has a percentage of unpaved surface of 46,63%, which is the second highest of the five pilot areas, but low compared to the national average in cities (61,6%). As can be seen in Figure 6-14, the Goudenregenstraat has a fairly green street view, which means the urgency for extra green or trees is low.

Figure 6-14 Street view of the Goudenregenstraat (Googlemaps)

In the Goudenregenstraat, the implementation of district heating is planned between 2020 and 2027, according to an integrated approach: in combination with sewer maintenance. The housing corporation Ressort Wonen, owning a large part of the property in the Goudenregenstraat, is aiming to install solar panels on large scale. According to the functional water advice in Reyeroord, the top layer of the subsoil below roads consists of 1,0 meters of very permeable sand (k-value = 3-3,5 m / day), with sandy-clay layers below it. The rest of the subsoil (outside the road pavement) is assumed to have a top layer of sand of 60 cm, with sandy-clay layers below it. The total length of the street is 109 meters.

6.3.1. Cross sectional- and top view designs

Situation 1: Existing situation

In Table 6-20, the distances from the border of the sidewalk (on the left) to the centre of the cables and pipes are stated. The total street width, from the border of the sidewalk on the left to the border of the sidewalk on the right, is 9,5 m.

Table 6-20 Distance from the border of the sidewalk to the centre of the cables and pipes in the Goudenregenstraat and their corresponding dimensions (Situation 1)

Distance from the border of the sidewalk (left) to centre of cable/pipe [m]	Pipe/cable	Inside diameter [mm]	Outside diameter [mm]
0,5	Electricity	-	-
1,2	Drinking water	124 (PVC)	124
1,4	Telecom 1	-	-
4,7	Combined sewer	300 (BT)	424
8,1	Telecom 2	-	-
8,7	Gas	118 (PE)	118

In Figure 6-15, the existing situation of the Goudenregenstraat is displayed. As can be seen, the dewatering depth in the Goudenregenstraat is 0,84 m.

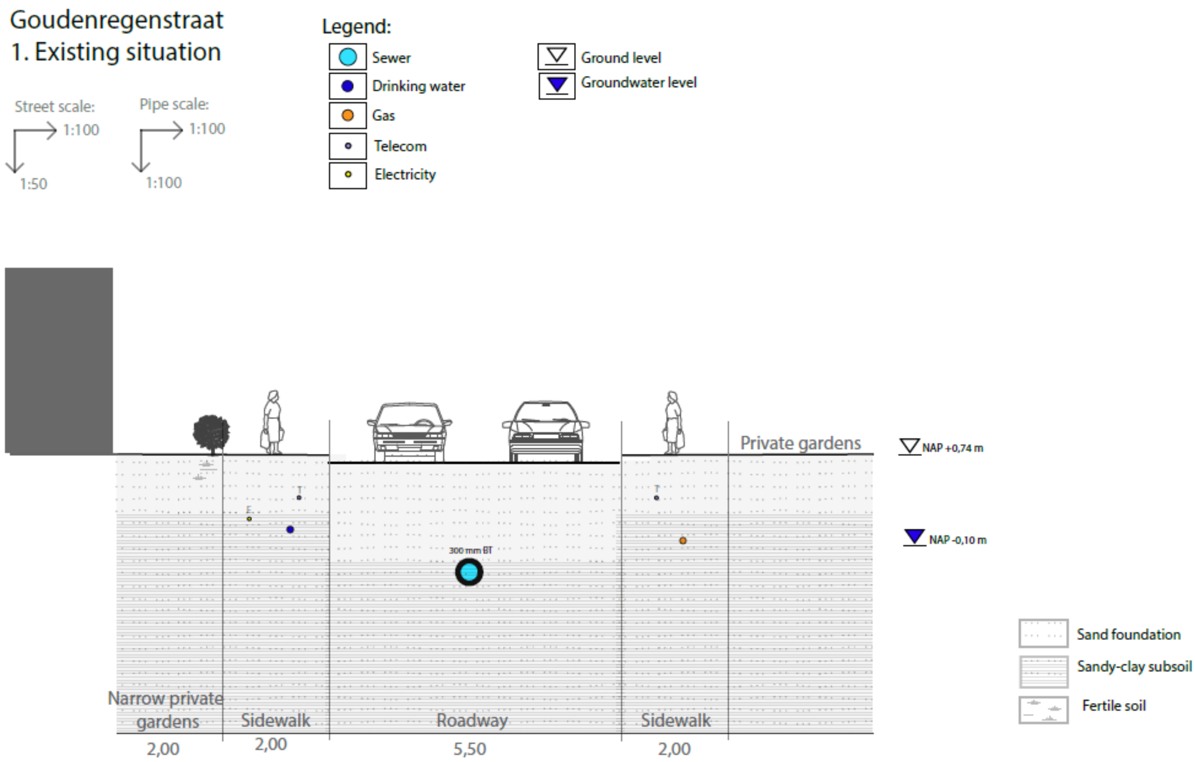

Figure 6-15 Cross-sectional view of the Goudenregenstraat – Situation 1: existing situation

Situation 2: Situation with energy measures and sewer replacement

In the Goudenregenstraat, secondary distribution pipes of the district heating network are installed, with assumed dimensions of DN80. Simultaneously, sewer replacement is carried out according to the functional water advice of Rozenburg (Abelenlaan). In case the sewer is replaced, the ground level will be brought back to the officially determined height, which is +1,00 m in the Goudenregenstraat. In addition, it is assumed solar panels are installed on all roofs of the houses in the street, owned by Ressort Wonen (approx. all houses on the left side of the street). In case of large-scale installation of solar panels, the electricity cable needs to be reinforced as well (Section 3.2). In Figure 6-16 the situation with energy measures and sewer replacement is shown.

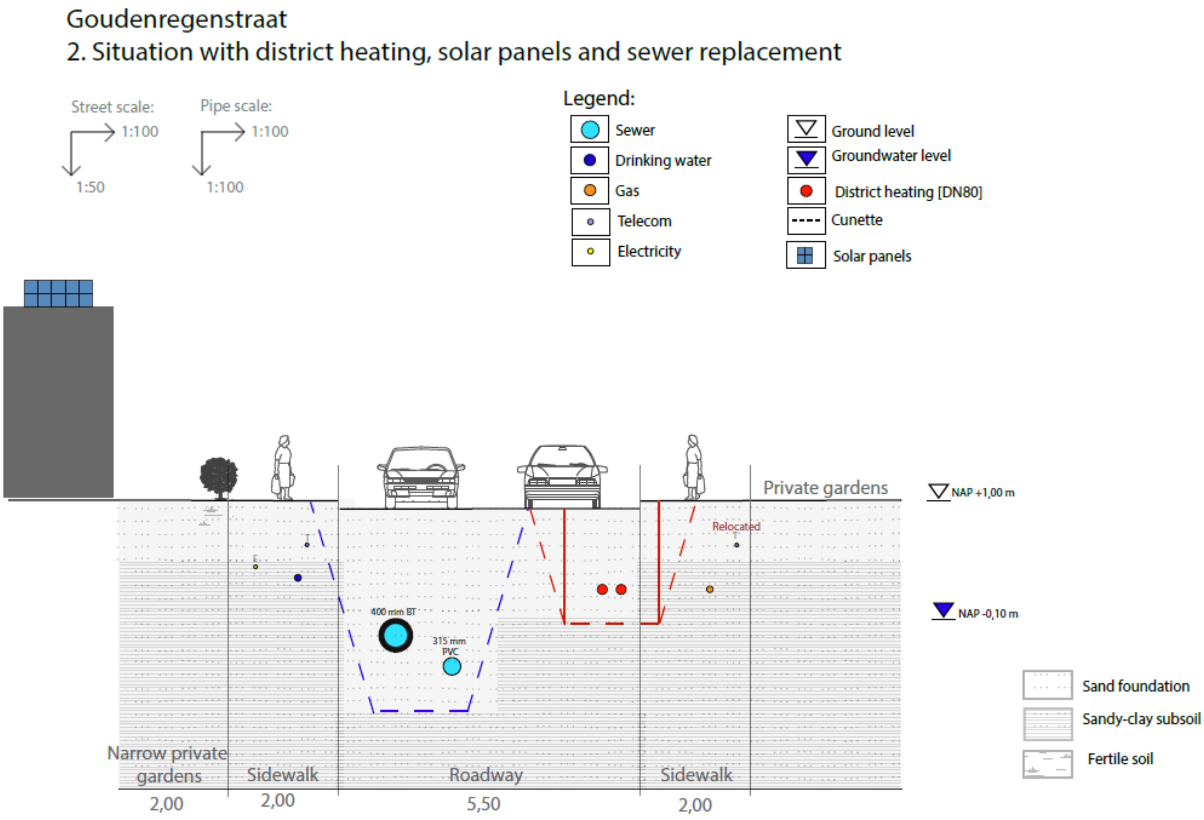

Figure 6-16 Cross-sectional view of the Goudenregenstraat – Situation 2: situation with district heating, solar panels and sewer replacement

To install a separate sewer system and the district heating network, the telecom cable at the right has to be relocated, so that it does not lie in the cunette of the district heating network. In Table 6-21, the new distances from the border of the private gardens to the centre of the cables and pipes are stated.

Table 6-21 Distance from the border of the sidewalk to the centre of the cables and pipes in the Goudenregenstraat and their corresponding dimensions (Situation 2)

Distance from the border of the sidewalk (left) to centre of cable/pipe [m]	Pipe/cable	Inside diameter [mm]	Outside diameter [mm]
0,5	Electricity	-	-
1,2	Drinking water	124 (PVC)	124
1,4	Telecom 1	-	-
3,0	Wastewater sewer	400 (BT)	524
4,0	DT-sewer	315 (PVC)	315
6,8	District heating 1	DN80	180
7,1	District heating 2	DN80	180
8,7	Gas	118 (PE)	118
9,3	Telecom 2	-	-

The construction activities taking place in the Goudenregenstraat in situation 2, with the corresponding execution times, are stated in Table 6-22. The last column shows the time frame in which the activity is carried out in the Goudenregenstraat, from the moment the trench or entire street is dug open. This is calculated by dividing the length of the street by the execution time.

Table 6-22 Construction activities in the Goudenregenstraat in situation 2, with the corresponding execution times

Activity	Pipe/cable	Execution time [m/day]	Responsibility	Time frame in the Goudenregenstraat [days]
Relocate	Telecom	150 – 200	Telecom companies	1
Replace	Electricity	150 – 200	Stedin	1
Install	Separate sewer system	5 – 10	Municipality	15
Install	District heating pipes	5 – 10	Heat supplier	15

The excavation that is carried out to install and relocate the cables and pipes stated in Table 6-22 and to raise the ground level, is shown in the top view of the Goudenregenstraat in Figure 6-17.

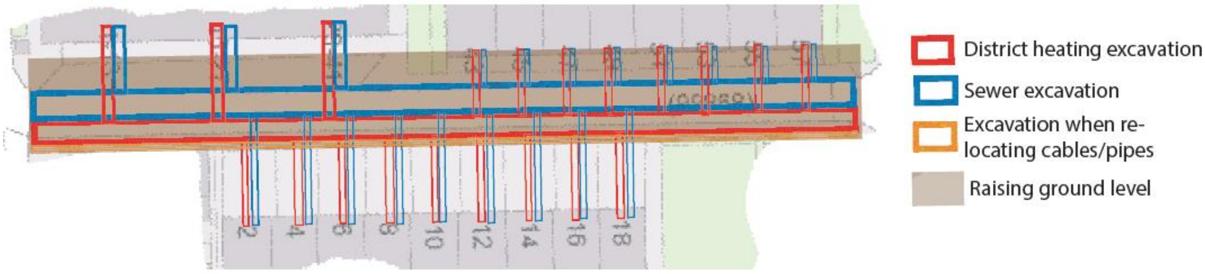

Figure 6-17 Top view of the Goudenregenstraat: excavation in situation 2

Situation 3: Situation with climate adaptation

The relevant decision-making information for the Goudenregenstraat, regarding climate adaptation (Figure 4-4) is stated in Table 6-23. An infiltration facility with drainage is found to be the optimal climate adaptation solution in this case.

Table 6-23 Information for decision-making on climate adaptation measures in the Goudenregenstraat

Dewatering depth	0,90 m (> 0,8 m)
Permeability sandy road foundation	> 2,0 m/day
Permeability subsoil	< 0,6 m/day
Outcome of climate adaptation option	Infiltration facility with drainage

The runoff areas in the existing situation in the Goudenregenstraat are indicated in Table 6-24. With these numbers, the required storage is calculated, in case the water retention capacity needs to be sufficient in case of a rainfall event of 70 mm in 1 hour.

Table 6-24 Rainwater run off areas the Goudenregenstraat

Runoff area	Surface area [m²]	Percentage of total surface area [%]
Road (public space)	575	17,8
Sidewalks (public space)	191	5,9
Private property (roofs, private and communal gardens)	2469	76,3
Total runoff area:	3235	100
Total storage required:	$70 \frac{mm}{hour} * 3235\ m^2 = \mathbf{226,5\ m^3}$	

The water storage capacity of the Goudenregenstraat in the existing situation is calculated in Table 6-25.

Table 6-25 Water storage capacity of the Goudenregenstraat in situation 1

Equation 1: Sewer storage	$v_{eff,sewer} = 20\ mm * 3235\ m^2 = 64,7\ m^3$
Equation 2: Storage on the road	$v_{eff,road} = 100\ mm * 575\ m^2 = 57,5\ m^3$
Equation 3: Storage private gardens (limited permeability), 20% of unpaved surface assumed	$v_{eff,unp} = 10 \frac{mm}{h} * 1h * 0,2 * 692\ m^2 + 10\ mm * 0,2 * 692\ m^2 = 2,8\ m^3$
Total water storage in existing situation:	$v_{eff} = 64,7\ m^3 + 57,5\ m^3 + 2,8\ m^3 = 125\ m^3 = 38,6\ mm$
Storage deficit:	$226,5\ m^3 - 125,0\ m^3 = 101,5\ m^3 = 31,4\ mm$

Situation 3.1.1: Climate adaptation in public space, within the conventions of Rotterdam

As can be seen in Figure 6-18, no space remains in the street itself for climate adaptation measures in public space, within the conventions of Rotterdam, after implementing the heating network (and separate sewer system).

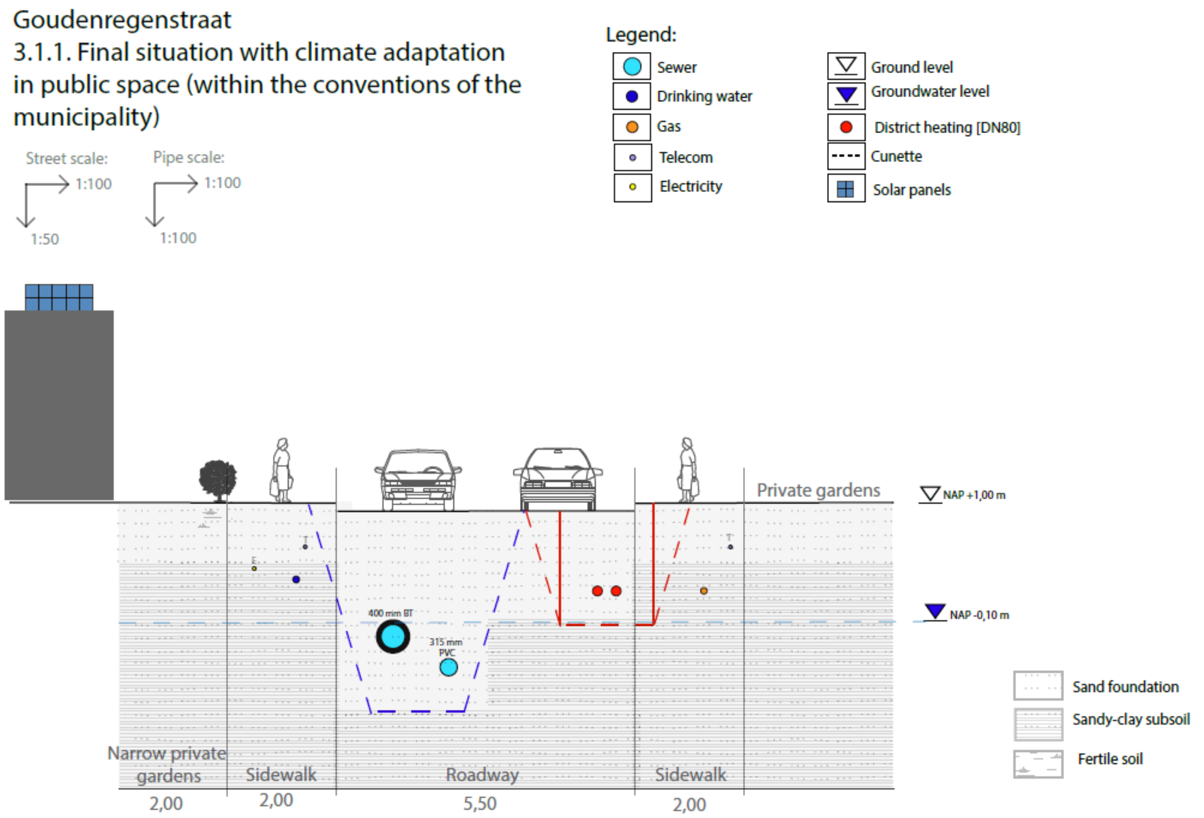

Figure 6-18 Cross-sectional view of the Goudenregenstraat – Situation 3: final situation with possible climate adaptation measures in public space, within the conventions of Rotterdam

Although no space remains in the street, there is an open grass space net to the Goudenregenstraat, as can be seen in Figure 6-17 at the right bottom. This open space has a width of 11 meters and length of 25 meters, so a surface area of 275 m^2, where a bioswale can be realized. The bioswale is connected to the aboveground gutters, draining the water towards the open space. It is assumed the maximum width of the bioswale is 7 meters and the maximum length is 20 meters. The bioswale is displayed in Figure 6-19.

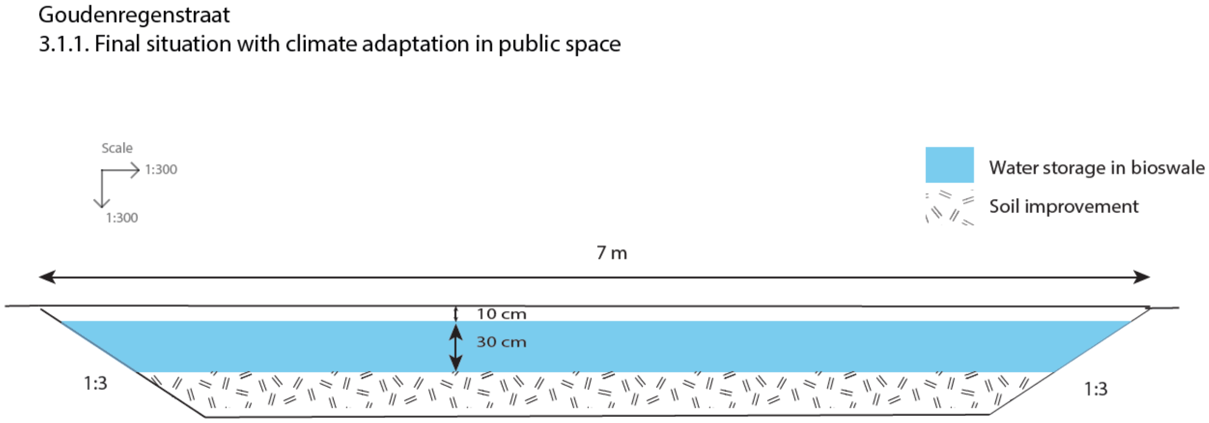

Figure 6-19 Cross-sectional view of a bioswale in the Goudenregenstraat – Situation 3: final situation with possible climate adaptation measures in public space, within the conventions of Rotterdam

The storage volume of the bioswale can be calculated by multiplying the trapezoid surface of the possible water storage times the length of the bioswale (Boogaard et al., 2006):

$$V = \frac{1}{2} * (width\ of\ one\ side + width\ of\ other\ side) * maximum\ water\ height * length$$

The effect that the bioswale will have on the storage capacity of the Goudenregenstraat, assuming sufficient water is transported towards the bioswale, is presented in Table 6-26.

Table 6-26 Storage effect of the bioswale in the Goudenregenstraat in situation 3.1.1.

Storage in bioswale	$v_{eff,swale} = \frac{1}{2} * (6{,}7\ m + 5{,}8\ m) * 0{,}3m * 20m = 37{,}5\ m^3$
Total water storage in situation 3.1.1:	$v_{eff} = 125{,}0\ m^3 + 37{,}5\ m^3 = 162{,}5\ m^3 = 50{,}2\ mm$
Storage deficit:	$226{,}5\ m^3 - 162{,}5\ m^3 = 64\ m^3 = 19.8\ mm$

Situation 3.1.2: Climate adaptation in private space

The Goudenregenstraat contains 692 m^2 of private front yards, which make it possible to (partly) process rainwater on own private ground in greenery or in rainwater tanks. In this case, it is assumed that all in all gardens of the houses on the left side of the street owned by housing corporations (14 houses), the pavement is removed by 80%. The houses on the right side of the street, also almost all owned by housing corporations, are subsidized to install a rainwater tank underground (the remaining 9 houses), to process the rain falling on their ground. The measures are shown in Figure 6-20.

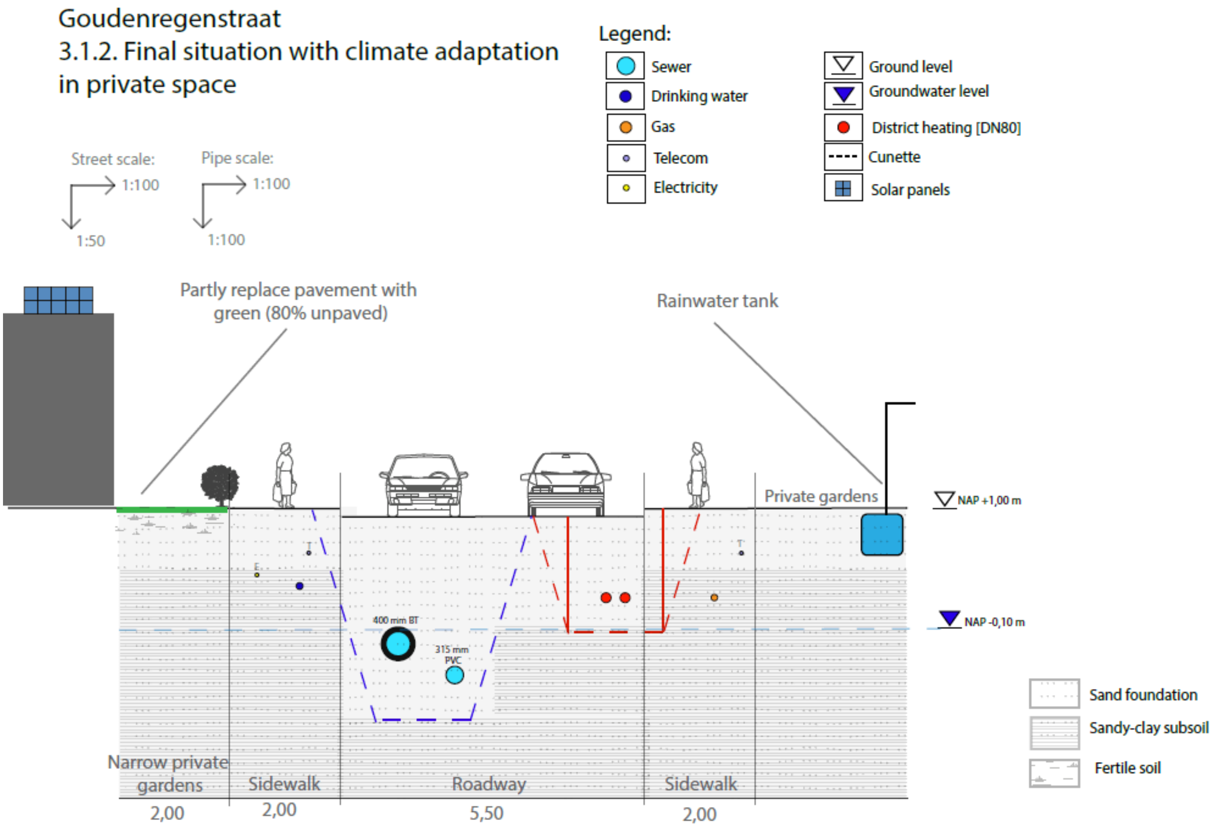

Figure 6-20 Cross-sectional view of the Goudenregenstraat – Situation 3: final situation with possible climate adaptation measures in private space

According to the figure, the rainwater falling on private space is partly disconnected from the sewer system and processed in private space, due to replacement of the pavement in gardens with green and rainwater tanks (with assumed dimensions of: length 1600 mm x width 1600 mm x height 1200 mm). The effect that the climate adaptation measures in Figure 6-20 will have on the water storage capacity of the Goudenregenstraat, is presented in Table 6-27.

Table 6-27 Storage effect of climate adaptation measures in the Goudenregenstraat in situation 3.1.2.

Equation 3: Storage private gardens on the left (limited permeability)	$v_{eff,unp} = 10\frac{mm}{h} * 1h * 0{,}8 * \ 190\ m^2 + 10\ mm * 0{,}8 * 190\ m^2 = \ 3{,}0\ m^3$
Water storage in rainwater tanks	$v_{eff,rainwatertank} = 9 * volume\ tank$ In case volume is 3000 L: $b_{eff,rainwatertank} = 9 * 3000\ l = 27\ m^3$
Total water storage in situation 3.1.2 (rainwater tank 3000 L):	$v_{eff} = 64{,}9\ m^3 + 57{,}5\ m^3 + 3{,}0\ m^3 + 27\ m^3 = 152{,}4\ m^3 = 47{,}1\ mm$
Storage deficit:	$226{,}5\ m^3 - 152{,}4\ m^3 = 74{,}1\ m^3 = 22{,}9\ mm$

According to the table, measures in private space do not provide sufficient storage.

Situation 3.2: Climate adaptation in public space, conventions of Rotterdam ignored

Because adaptation measures in public space within the conventions of the municipality, shown in Figure 6-19, did not provide sufficient storage in the Goudenregenstraat, in Figure 6-21 a climate adaptation design is created which does not comply with the conventions of the municipality. In this figure, electricity, telecom, gas and drinking water cables and pipes are bundled in an underground gutter. This has created space for underground infiltration crates in the sidewalk on the left, connected to the street gutter on the left. As a result, part of the rainwater in the street is disconnected from the sewer and temporarily stored in the infiltration crates (and afterwards drained).

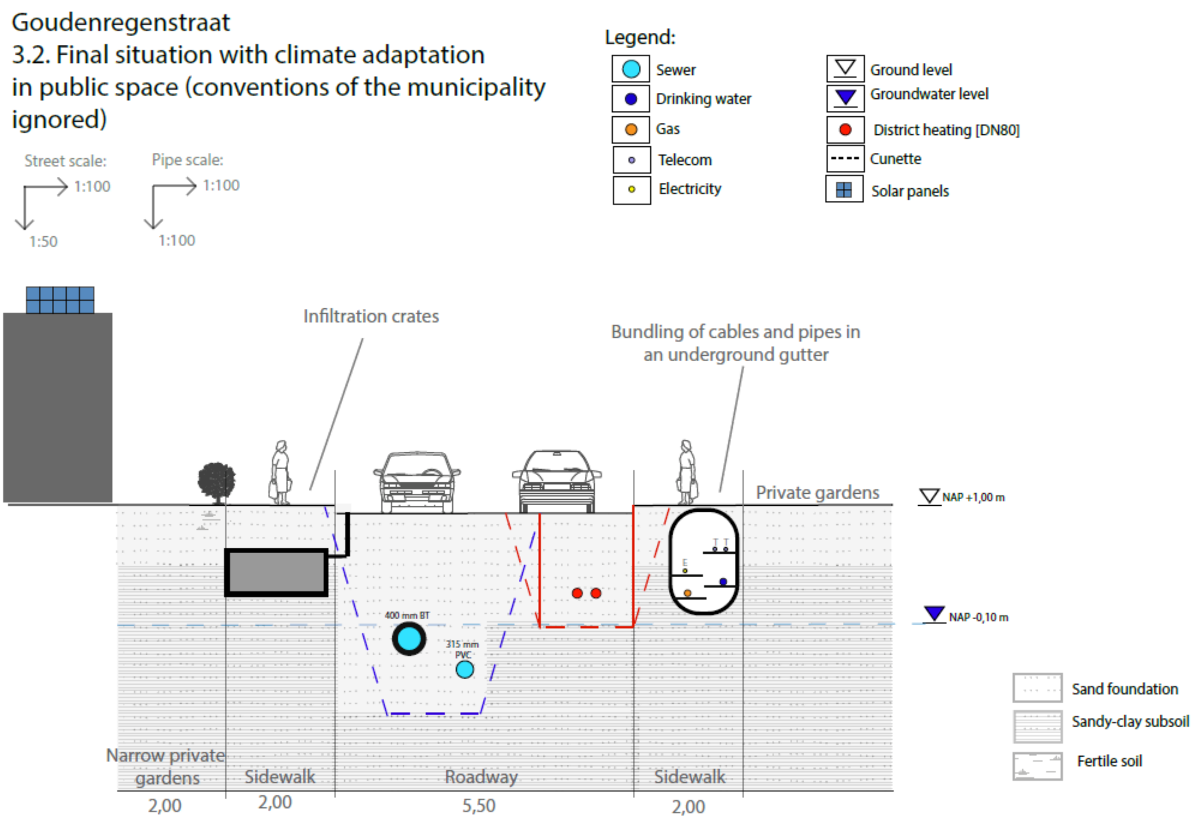

Figure 6-21 Cross-sectional view of the Goudenregenstraat – Situation 3: final situation with possible climate adaptation measures in public space, conventions of Rotterdam ignored

The infiltration crates are installed over the entire street, with a height of 0,4 meters (at least 40 cm below ground level and 30 cm above groundwater level) and a width of 1,9 meters. As stated in Appendix C, the crates have a porosity of 95%. No soil improvement is needed around the facility, due to the sufficient permeability of the natural soil. The effect that the climate adaptation measures in Figure 6-21 will have on the water storage capacity of the Goudenregenstraat is presented in Table 6-28.

Table 6-28 Storage effect of climate adaptation measures in the Goudenregenstraat in situation 3.2.

Equation 4: Storage infiltration facility	$v_{eff,inf} = 109\ m * 0{,}4\ m * 1{,}9\ m * 0{,}95 = 78{,}7\ m^3$
Total water storage in situation 3.2:	$v_{eff} = 125{,}0\ m^3 + 78{,}7\ m^3 = 203{,}7\ m^3 = 63{,}0\ mm$
Storage deficit:	$226{,}5\ m^3 - 203{,}7\ m^3 = 22{,}8\ m^3 = 7{,}0\ mm$

6.3.2. *Types of systems integration identified*

Measures in public space within the conventions of Rotterdam (50,2 mm), measures in private space (47,1 mm) and measures in public space outside the conventions of Rotterdam (63 mm) cannot provide sufficient rainfall storage in case of a heavy rain event (70 mm in 1 hour) solely. To realize sufficient water storage in the Goudenregenstraat, only a combination of measures in public space (Figure 6-19 and Figure 6-21) or of measures in public space and private space (Figure 6-20) would suffice. Based on the designs, multiple types of systems integration are identified, with both technical- and socio-institutional aspects.

Geographical integration

- *Technical aspects:*

In the Goudenregenstraat, the elements of multiple infrastructures (the sewer system, district heating and climate adaptation measures) are in close spatial proximity, which requires close spatial organization. In order to place both the separate sewer system and district heating network as much in the middle of the street as possible, the telecom cable has to be relocated (Figure 6-16), so that it does not lie in the excavation cunette of the heating network.

Measures in public space, outside the conventions of Rotterdam, can be taken below the left sidewalk (Figure 6-21) by means of infiltration crates. The space for these crates is created by bundling the telecom, electricity, drinking water and gas cables and pipes in an underground gutter below the sidewalk at the right. In this scenario, the cunettes of the district heating pipes and sewer system conflict, to provide space for climate adaptation measures. This means that during the planning phase of the sewer replacement and implementation of the district heating network, climate adaptation should already be taken into account and included in the design, so that the cunettes will conflict and this extra space for measures is created.

- *Socio-institutional aspects:*

To organize the underground infrastructure in close spatial proximity, the implementation requirements (location in the street) and spatial impacts of all assets should be known and maintained by the different parties involved. In the Goudenregenstraat this means: the Water department of the Public Works division (responsible for sewer maintenance) has to align its replacement plans with the heat supplier (responsible for the district heating network) in the Goudenregenstraat, to create a combined design. In addition, because the telecom cable has to be relocated (Figure 6-16), the designs should be communicated to the telecom operator in order to reach a joint agreement on the design and to give them the opportunity to not only relocate, but also replace it and to use the momentum to execute everything simultaneously.

Because climate adaptation should already be taken into account in the design phase of the sewer system and district heating network, knowing whether urban flooding occurs at that location, to what extent and what kind of measures are desired, is important information for the sewer and district heating planners and designers.

Project-based integration

- *Technical aspects:*

The implementation of district heating and sewer replacement in the Goudenregenstraat are planned simultaneously. Therefore, it is assumed a total redesign of the street is carried out and the ground level is raised to the officially determined height (from +0,75 m to +1,0 m). This results in a lot of excavation carried out in the street (Figure 6-17). The construction activities in the Goudenregenstraat, their corresponding execution times and the time frame needed in the street are presented in Table 6-22. The telecom cable is relocated first, according to subsection 4.2.1. Subsequently, the sewer system is replaced and eventually the district heating network is installed. Since the entire street is under construction to raise the ground level, the telecom operator, the municipality and the heat supplier can efficiently integrate their construction activities. In that case, they can relocate and install their cables and pipes one after the other as quickly as possible, so that the street only has to be dug open once and nuisance and digging costs are minimized.

To create storage in public space within the conventions of Rotterdam, a bioswale can be realized in the open green space next to the Goudenregenstraat (Figure 6-19). Since the street level is raised and the rainwater on the street has to flow towards the bioswale, this part does not need to be raised. In that case, no excavation takes place in the bioswale area (Figure 6-17), so there are no direct advantages with regard to integral implementation of the bioswale. However, since the entire roadway, parking lanes and sidewalks are dug open, because of the ground raising (Figure 6-17), the infiltration crates and underground gutter for bundling of cables and pipes (Figure 6-21) can be implemented simultaneously, without extra digging, when the street is filled up again.

The effect of replacing the pavement with green in the narrow private gardens at the left is very small (Figure 6-20). However, the rainwater tanks that are installed below the private gardens at the right of the street do have a large effect and can be combined with measures in public space to provide sufficient storage. The rainwater tanks indicate that a surface area of 1,6 m length and 1,6 m width has to be excavated for each tank (9 tanks). To place the house connection pipes in these gardens (Figure 6-17), 9 trenches with a width of 1,6 m (subsection 4.2.2) are dug to place the house connection pipes of the district heating network over the entire length of the garden and 9 trenches with a width of 0,6 m are dug to place the house connection pipes of the sewer system over the entire length of the garden. The total width of both trenches together is 2,2 m (over a length of 8,5 m), which means it covers the entire length and width of the rainwater tanks. Although the rainwater tanks need to be installed 0,3 meters deeper than the house connections (1,2 m deep instead of 0,9 m deep), it is still beneficial for the residents to seize the opportunity to simultaneously implement climate adaptation measures (in this case rainwater tanks) in their garden with the installation of the heating network and separate sewer system. They could also possibly raise their gardens simultaneously, so that the gardens will have the same level as the street again.

- *Socio-institutional aspects:*

Because in the Goudenregenstraat simultaneous implementation of infiltration crates in public space is beneficial in terms of costs and nuisance, knowing that urban flooding occurs at that location is crucial information for the sewer and district heating planners and designers, because then they know whether to add climate adaptation in their design.

Besides, connecting to the district heating network instead of the gas network, means households have to switch to an electric way of cooking and instead of a central boiler, houses get a connection to the heating network. Because houses in the Goudenregenstraat are mainly owned by housing corporations, they are responsible for the required adjustments, installation of solar panels and climate adaptation measures in private space. In case climate adaptation measures are desired in private space in the Goudenregenstraat, an integrated communication approach from the municipality towards the housing corporations is desired, so that they know the advantages of simultaneous implementation and can implement the measures accordingly.

Physical integration (based on infrastructure)

- *Technical aspects:*

Integration of underground utilities in an underground gutter (Figure 6-21) can create additional space for climate adaptation measures in public space. Technical issues of an underground gutter that should be considered, are: enough protection or separation between the gas pipe and other utility infrastructure (gas can otherwise accumulate in a gutter) and the branching of main grids into utility house connections (whether they can be realized in the cased pipes) (Meijberg, 2018).

- *Socio-institutional aspects:*

By co-locating multiple utilities in an underground gutter, challenges regarding responsibility for construction and management arise. Agreements have to be made between the various utility operators (in the Goudenregenstraat telecom, electricity, drinking water and gas) about what companies have to pay for construction, who manages the gutter and how all companies can easily access their cable, and reaching these agreements takes time (W. Noordhof, personal communication, September 17, 2020).

6.4. Case 4: Bospolderplein (Bospolder)

The Bospolderplein-street is a residential street next to to the Bospolderplein-square, located in the pilot area Bospolder. The percentage of unpaved surface in Bospolder is very low (22,5%) compared to the national average (61,6%), which means the urgency for extra green and trees in the area is high. Almost all property in the street is owned by the housing corporation Havensteder and is built before the World War II (1915 – 1925). In Figure 6-22, a street view of Bospolderplein is displayed.

Figure 6-22 Street view of the Bospolderplein-street (Googlemaps)

In Bospolderplein, the implementation of district heating is planned in 2024 singularly, because the sewer system in Bospolderplein has been replaced recently (in 2007). According to an old functional water advice created for Bospolder, the top layer of the subsoil in the area below roads consists of approx. 3 meters of fine sand layers, with clay and peat layers underneath it. The total length of the street is 132 meters.

6.4.1. Cross-sectional- and top view design

Situation 1: Existing situation

In Table 6-29, the distances from the facades of the houses on the right side to the centre of the cables and pipes are stated.

Table 6-29 Distance from the facades of the houses to the centre of the cables and pipes in Bospolderplein and their corresponding dimensions (Situation 1)

Distance from the facades of the houses (right) to centre of cable/pipe [m]	Pipe/cable	Inside diameter [mm]	Outside diameter [mm]
0,5	Telecom 1	-	-
1,4	Drinking water	160 (PVC)	160
2,0	Gas	274 (PE)	274
2,9	Electricity 1	-	-
6,65	Combined sewer	500 (BT)	630
11,0	Electricity 2	-	-
16,9	Electricity 3	-	-

In Figure 6-23, the existing situation of Bospolderplein is displayed. As can be seen, the dewatering depth in the street is 1,34 m.

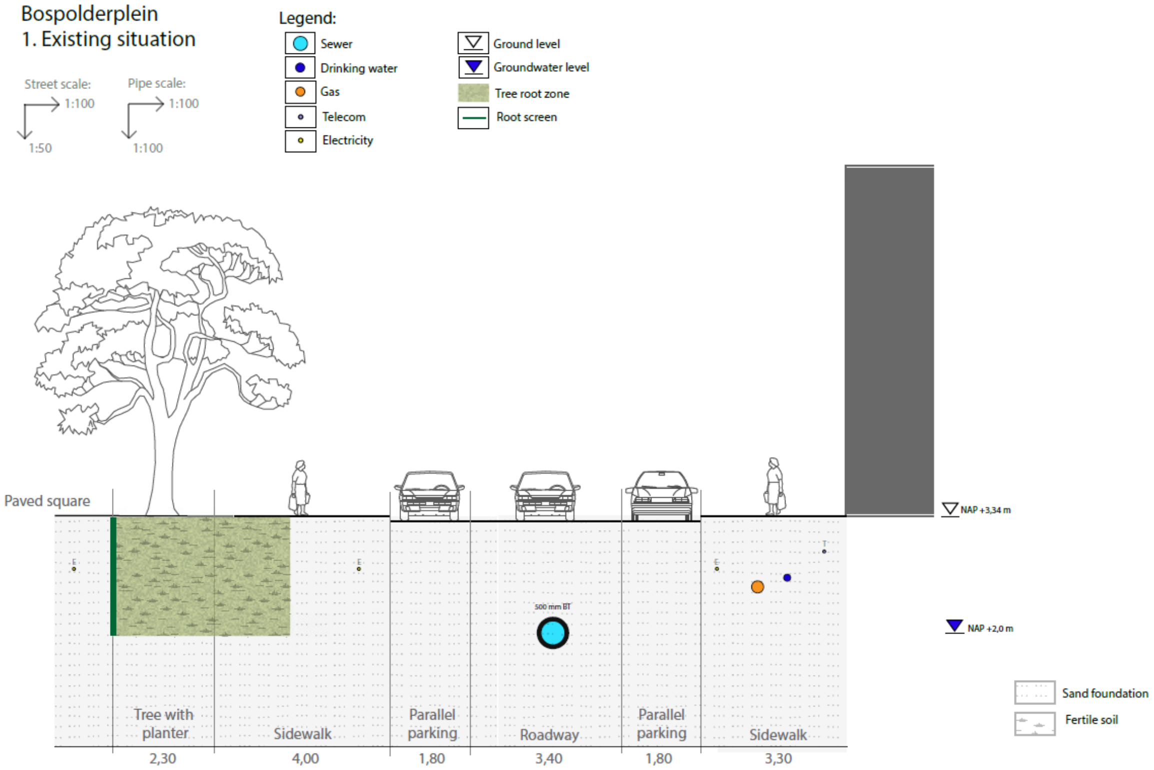

Figure 6-23 Cross-sectional view of the Bospolderplein-street – Situation 1: existing situation

Situation 2: Situation with energy measures

In Bospolderplein, it is assumed that secondary distribution pipes of the district heating network are installed, with dimensions of DN80. To install the district heating network, the electricity cable at the left has to be relocated, as can be seen in Figure 6-24, so that it does not lie in the excavation cunette of the heating network.

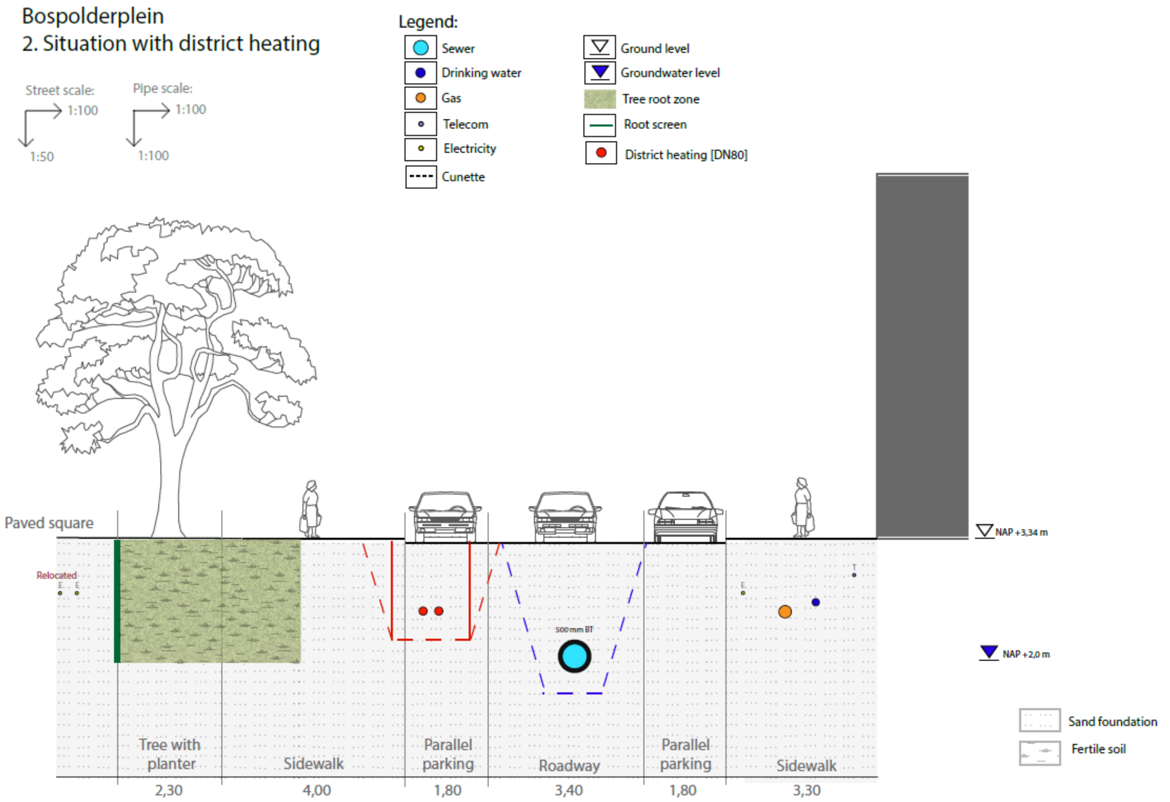

Figure 6-24 Cross-sectional view of the Bospolderplein-street – Situation 2: situation with district heating

In Table 6-30, the new distances from the facades of the houses on the right side to the centre of the cables and pipes are stated.

Table 6-30 Distance from the facades of the houses to the centre of the cables and pipes in Bospolderplein and their corresponding dimensions (Situation 2)

Distance from the facades of the houses (right) to centre of cable/pipe [m]	Pipe/cable	Inside diameter [mm]	Outside diameter [mm]
0,5	Telecom 1	-	-
1,4	Drinking water	160 (PVC)	160
2,0	Gas	274 (PE)	274
2,9	Electricity 1	-	-
6,65	Combined sewer	500 (BT)	630
9,6	District heating 1	DN80	180
10,0	District heating 2	DN80	180
16,9	Electricity 2	-	-
17,3	Electricity 3	-	-

The construction activities taking place in Bospolderplein in situation 2, with the corresponding execution times, are stated in Table 6-31. The last column shows the time frame in which the activity is carried out in Bospolderplein, from the moment the trench or entire street is dug open. This is calculated by dividing the length of the street by the execution time.

Table 6-31 Construction activities in Bospolderplein in situation 2, with the corresponding execution times

Activity	**Pipe/cable**	**Execution time [m/day]**	**Responsibility**	**Time frame in Bospolderplein [days]**
Relocate	Electricity	150 – 200	Stedin	1
Install	District heating pipes	5 – 10	Heat supplier	18

The excavation that is carried out to install and relocate the cables and pipes stated in Table 6-31, is shown in the top view of Bospolderplein in Figure 6-25. In addition to the excavation carried out in the streets and parking lanes, excavation for district heating is carried out to install the house connection pipes.

Figure 6-25 Top view of the Bospolderplein-street: excavation in situation 2

Situation 3: Situation with climate adaptation

The relevant decision-making information for Bospolderplein, regarding climate adaptation (Figure 4-4) is stated in Table 6-32. An infiltration facility with drainage is found to be the optimal climate adaptation solution in this case.

Table 6-32 Information for decision-making on climate adaptation measures in the Bospolderplein-street

Dewatering depth	1,34 m (> 0,8 m)
Permeability sandy road foundation	> 2,0 m/day
Permeability subsoil	< 0,6 m/day
Outcome of climate adaptation option	Infiltration facility with drainage

The runoff areas in the existing situation are indicated in Table 6-33. With these numbers, the required storage is calculated, in case the water retention capacity needs to be sufficient in case of a rainfall event of 70 mm in 1 hour. The Bospolderplein-square, next to the street, contains of a deepened baseball field, so it is assumed no water runs from the square towards the street in case of a heavy rain event.

Table 6-33 Rainwater runoff areas in the Bospolderplein-street

Runoff area	**Surface area [m²]**	**Percentage of total surface area [%]**
Runoff area road (public space)	609	17,5
Runoff area sidewalks (public space)	1415	40,8
Runoff area private property (roofs)	1447	41,7
Total runoff area:	3471	100
Total storage required:	$70\frac{mm}{hour} * 3471\ m^2 = \mathbf{243,0\ m^3}$	

The water storage capacity of Bospolderplein in the existing situation is calculated in Table 6-34.

Table 6-34 Water storage capacity of the Bospolderplein-street in situation 1

Equation 1: Sewer storage	$v_{eff,sewer} = 20\ mm * 3471\ m^2 = 69{,}4\ m^3$
Equation 2: Storage on the road	$v_{eff,road} = 100\ mm * 609\ m^2 = 60{,}9\ m^3$
Equation 3: Storage unpaved surface (11 trees)	$v_{eff,unp} = 10\frac{mm}{h} * 1h * 11 * 5{,}5\ m^2 + 10\ mm * 11 * 5{,}5\ m^2 = 1{,}2\ m^3$
Total water storage in existing situation:	$v_{eff} = 69{,}4\ m^3 + 60{,}9\ m^3 + 1{,}2\ m^3 = 131{,}5\ m^3 = 37{,}9\ mm$
Storage deficit:	$243{,}0\ m^3 - 131{,}5\ m^3 = 111{,}5\ m^3 = 32{,}1\ mm$

Situation 3.1.1: Climate adaptation in public space, within the conventions of Rotterdam

Figure 6-26 shows possible climate adaptation measures in public space in Bospolderplein, within the conventions of the municipality, based on Table 6-32. As shown, infiltration crates are placed below the parking lane on the right in Bospolderplein. In addition, 8 small trees with root screens are planted in green planters, in place of four parking spots on the right, to increase the greenery in the street. To maintain the minimum distance from the root screen of the tree to the cables and pipes (0,5 m), the electricity cable at the right has to be relocated.

Due to the insufficient permeability of the subsoil in Bospolderplein, a drainage pipe should be installed, to drain the water (stored in the infiltration crates) away, in order to keep a sufficiently large dewatering depth. The functional water advice of the area Bospolder states that drainage pipes in Bospolder should be installed above the groundwater level (minimum ground cover of 90 cm). Therefore, a drainage pipe is installed above the combined sewer system in Figure 6-26.

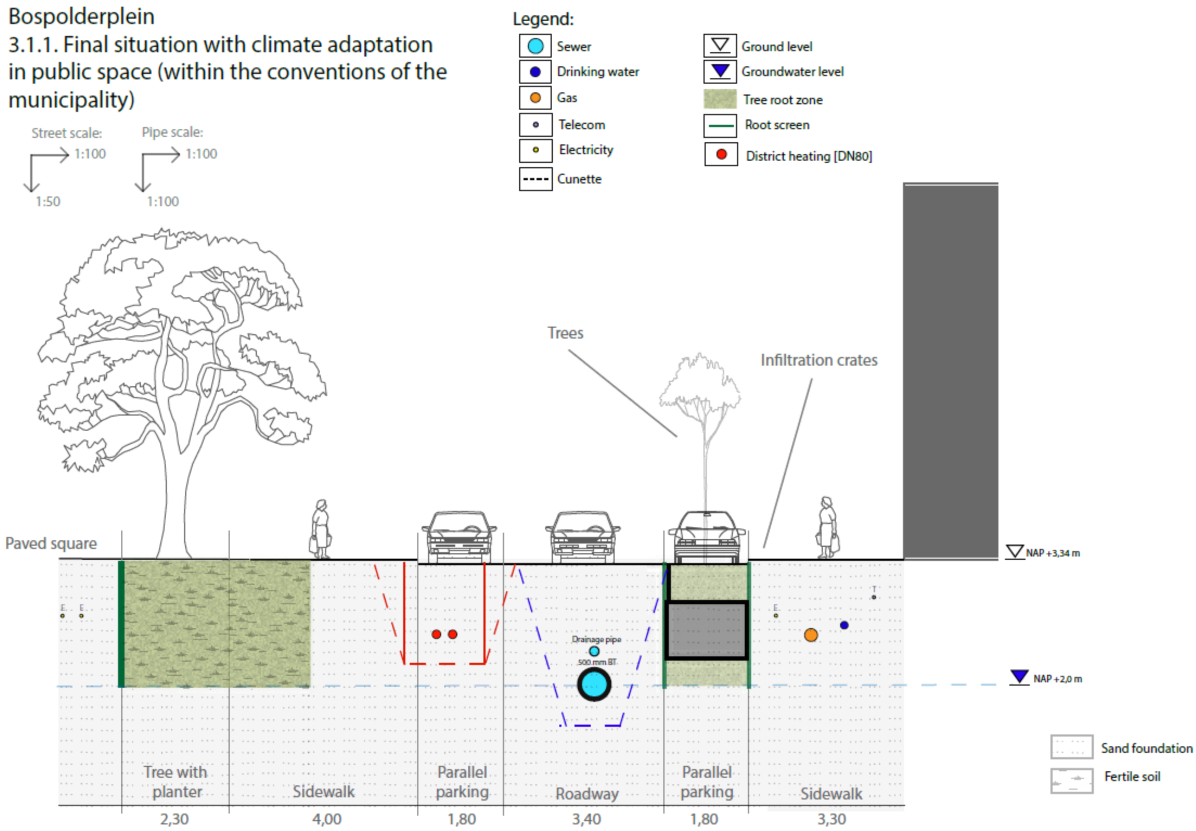

Figure 6-26 Cross-sectional view of the Bospolderplein-street – Situation 3: final situation with possible climate adaptation measures in public space, within the conventions of Rotterdam

Currently, there are 18 parking spots on the right in Bospolderplein, which is reduced to 14 spots by planting 8 trees (one tree with planter has a width of approx. ½ parking spot). The infiltration crates are installed over the entire street, except in the tree root zones of the trees, with a height of 0,6 meters (at least 40 cm below ground level and 30 cm above groundwater level) and a width of 1,8 meters. The crates have a water storing capacity of 95% of their volume (Appendix C).

According to the figure, the rainwater falling on the road is partly disconnected from the sewer system and temporarily stored in the infiltration crates and green planted. The effects that the climate adaptation measures in **Fout! Verwijzingsbron niet gevonden.** will have on the water storage capacity of Bospolderplein and the final storage surplus are presented in Table 6-35.

Table 6-35 Storage effect of climate adaptation measures in the Bospolderplein-street in situation 3.1.1.

Equation 3: Storage unpaved surface (8 trees)	$v_{eff,unp} = 10\frac{mm}{h} * 1h * 8 * 3{,}0\ m^2 + 10\ mm * 11 * 3{,}0\ m^2 = \ 0{,}5\ m^3$
Equation 4: Storage infiltration facility, with soil improvement	$v_{eff,inf} = (132 - 8 * 1{,}8)\ m * 1{,}8\ m * 0{,}6\ m * 0{,}95 = 120{,}7\ m^3$
Total water storage in situation 3.1.1:	$v_{eff} = 131{,}5\ m^3 + 0{,}5\ m^3 + 120{,}7\ m^3 = 252{,}7\ m^3 = 72{,}8\ mm$
Storage surplus:	$252{,}7\ m^3 - 243{,}0\ m^3 = 9{,}7\ m^3 = 2{,}8\ mm$

Because adaptation measures in **Fout! Verwijzingsbron niet gevonden.** provide sufficient storage, no climate adaptation design is made which does not comply with the conventions of the municipality (situation 3.2).

Situation 3.1.2: Climate adaptation in private space

As can be seen in Figure 6-23, houses in the Bospolderplein-street do not have private gardens in front, which makes it difficult to disconnect rainwater falling on the roofs. Figure 6-27 shows possible climate adaptation measures in private space. Most the roofs are flat and made of bitumen, which means green roofs can be placed without extra measures. In addition, green facades are implemented, which do not influence the water storage capacity, but increase the greenery in the street.

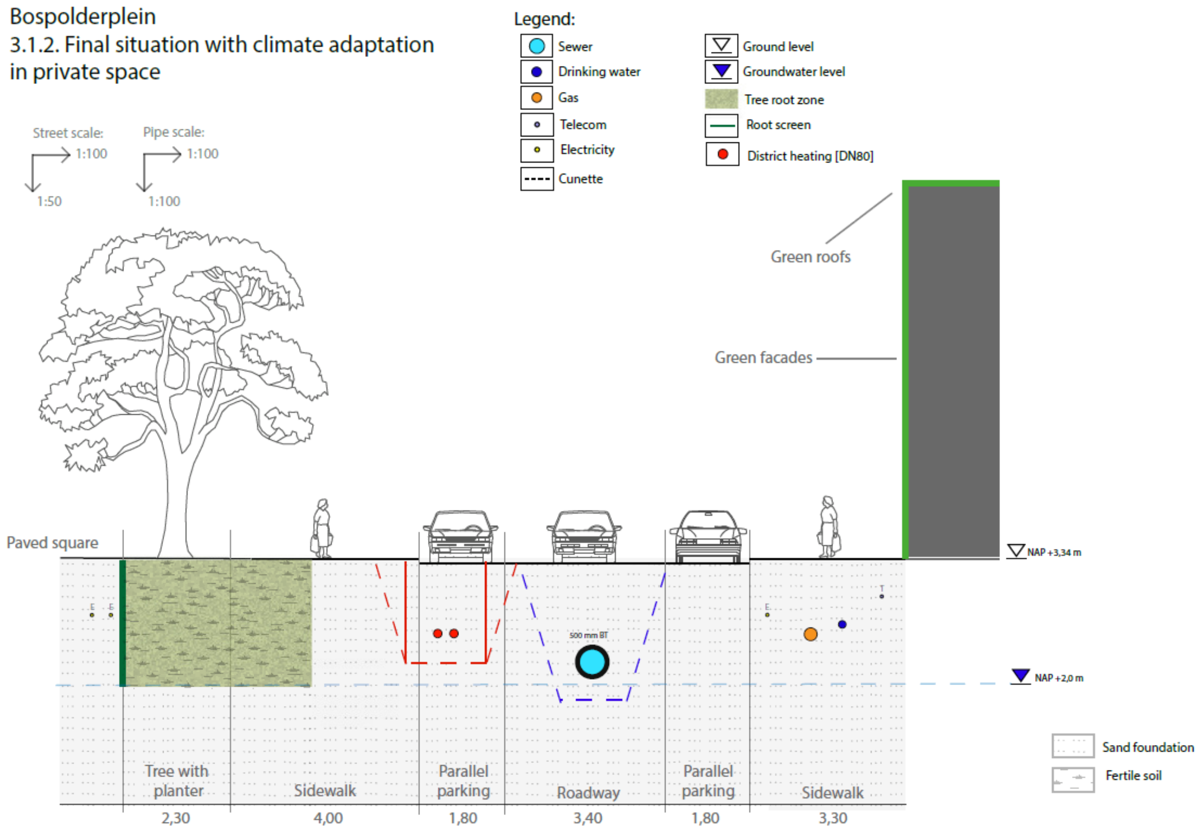

Figure 6-27 Cross-sectional view of the Bospolderplein-street – Situation 3: final situation with possible climate adaptation measures in private space

The effect that the climate adaptation measures in Figure 6-27 will have on the water storage capacity of Bospolderplein is presented in Table 6-36.

Table 6-36 Storage effect of climate adaptation measures in the Bospolderplein-street in situation 3.1.2.

Equation 5: Storage green roofs	$v_{eff,roof} = 0{,}025\frac{m^3}{m^2} * 1287\ m^2 = 32{,}2\ m^3$
Total water storage in situation 3.1.2:	$v_{eff} = 131{,}5\ m^3 + 32{,}2\ m^3 = 163{,}7\ m^3 = 47{,}2\ mm$
Storage deficit:	$243{,}0\ m^3 - 163{,}7\ m^3 = 79{,}3\ m^3 = 22{,}8\ mm$

6.4.2. Types of systems integration identified

Measures in public space within the conventions of Rotterdam (Figure 6-26) solely provide sufficient storage (72,8 mm) to prevent urban flooding in the Bospolderplein-street, in case of a heavy rainfall event (70 mm in 1 hour). There are not many options for climate adaptation in private space in the street, except on the roof and at the facades of the houses (Figure 6-27). Based on the designs, multiple types of systems integration are identified, with both technical- and socio-institutional aspects.

Geographical integration

- *Technical aspects:*

In the Bospolderplein-street, the elements of multiple infrastructures (the sewer system, district heating and climate adaptation measures) are in close spatial proximity, which requires close spatial organization. The sewer in the street has recently been replaced, which means no sewer replacement is assumed simultaneous to the implementation of district heating and a combined sewer system is still present in the street (with a small drainage pipe in Figure 6-26). In principle, the municipality wants the district heating network as much in the middle of the street as possible (section 3.2). Therefore, the district heating cunette is placed directly next to the sewer cunette (Figure 6-24). In order to install the district heating network as much in the middle of the street as possible, the electricity cable at the left has to be relocated (Figure 6-24), so that it does not lie in the excavation cunette of the heating network. In the design with climate adaptation measures in public space (Figure 6-26), no account has been taken of a possible future separate sewer system (only a small drainage pipe), although a separate system could cause even more spatial challenges in the future.

Measures in public space in the Bospolderplein-street can be taken in the parking lanes at the right (Figure 6-26). To implement climate adaptation measures there, 4 parking spots have been lost.

- *Socio-institutional aspects:*

To organize the underground infrastructure in close spatial proximity, the implementation requirements (location in the street) and spatial impacts of all assets should be known and maintained by the different parties involved. In Bospolderplein this means: the heat supplier (responsible for the district heating network) has to communicate its design to the electricity operator (Stedin) to reach a joint agreement on the design and to give them the opportunity to not only relocate, but also replace it and to use the momentum to execute everything simultaneously.

To implement measures in public space to create sufficient water storage, 4 parking spots in the street have been lost. In order to prevent this from creating problems for local residents, a solution has to be proposed from the municipality, either to create more parking space elsewhere or to stimulate a future scenario where fewer parking spaces are required (mobility transition).

Project-based integration

- *Technical aspects:*

In the Bospolderplein-street the implementation of district heating is planned singularly, which means not the entire street is dug open, but only the necessary parts for the implementation of the heating network (secondary distribution pipes and house connection pipes) and for the relocation of the electricity cable (Figure 6-25). The construction activities in Bospolderplein, their corresponding executing times and the time frame needed in the street are stated in Table 6-31. The electricity cable is relocated first, according to subsection 4.2.1, and afterwards the district heating network will be installed. It is most advantageous in terms of nuisance for the residents to relocate the cable and install the district heating network one after the other as quickly as possible, so that the street only has to be dug open and closed off once.

Measures in public space can be taken in the parking lane at the right in Bospolderplein (Figure 6-26). To install the infiltration crates and trees, root screens have to be placed at both sides of the tree, in order to prevent interference between the roots and cables and pipes. To install infiltration crates and at the same time maintain sufficient dewatering depth, a drainage pipe has to be be installed in addition. As can be derived from Figure 6-25, no excavation takes place in the parking lane at the right or within the sewer cunette (for the drainage pipe). Therefore, integration of the implementation of the climate adaptation measures in public space (Figure 6-26) during construction of the district heating network does not bring considerable benefits and does not have to be carried out simultaneously.

Climate adaptation measures in private space can be taken at the roof and the facades (Figure 6-27). The roofs where green roofs are implemented are flat and made of bitumen, which means the green roofs can be placed without extra measures. Since no other construction activities take place on the roof or at the façade, implementation of green roofs or façade gardens does not bring considerable benefits during construction of the heating network and therefore does not need to be applied simultaneously.

- *Socio-institutional aspects:*

Connecting to the district heating network instead of the gas network, means households have to switch to an electric way of cooking and instead of a central boiler, houses get a connection to the heating network. Because houses in the Bospolderplein-street are mainly owned by the housing corporation Havensteder, they are responsible for the required adjustments and in case climate adaptation measures in private space are desired from the municipality (Figure 6-27), both climate adaptation and in-house district heating adjustments are in hands of housing corporation Havensteder. In that case, an integrated communication approach from the municipality towards Havensteder is desired, so that the one does not preclude the other in the future.

6.5. Case 5: Snoekstraat (Bospolder)

The Snoekstraat is a residential street, located in the pilot area Bospolder. The percentage of unpaved surface in Bospolder is very low (22,5%) compared to the national average (61,6%), which means the urgency for extra green in the area is high. The property in the street is owned by the housing corporation Havensteder and privately owned and is built around 1950. In Figure 6-28, a street view of the Snoekstraat is displayed.

Figure 6-28 Street view of the Snoekstraat (Googlemaps)

In the Snoekstraat, the implementation of district heating is planned in 2024, according to an integrated approach: in combination with sewer replacement. According to the functional water advice created for Bospolder, the top layer of the subsoil in the area below roads consists of approx. 3 meters of fine sand layers, with clay and peat layers underneath it. The total length of the street is 119 meters.

6.5.1. Cross-sectional- and top view design

Situation 1: Existing situation

In Table 6-37, the distances from the facades of the houses on the left side to the centre of the cables and pipes are stated. The total street width, from façade to façade, is 14,9 meters.

Table 6-37 Distance from the facades of the houses to the centre of the cables and pipes in the Snoekstraat and their corresponding dimensions (Situation 1)

Distance from the facades of the houses (left) to centre of cable/pipe [m]	Pipe/cable	Inside diameter [mm]	Outside diameter [mm]
0,5	Telecom 1	-	-
2,5	Electricity	-	-
7,8	Combined sewer	400 (BT)	510
12,3	Gas	250 (PE)	250
13,2	Drinking water	110 (PVC)	110
13,7	Telecom 2	-	-
14,4	Telecom 3	-	-

In Figure 6-29, the existing situation of the Snoekstraat is displayed. As can be seen, the dewatering depth in the street is 1,08 m.

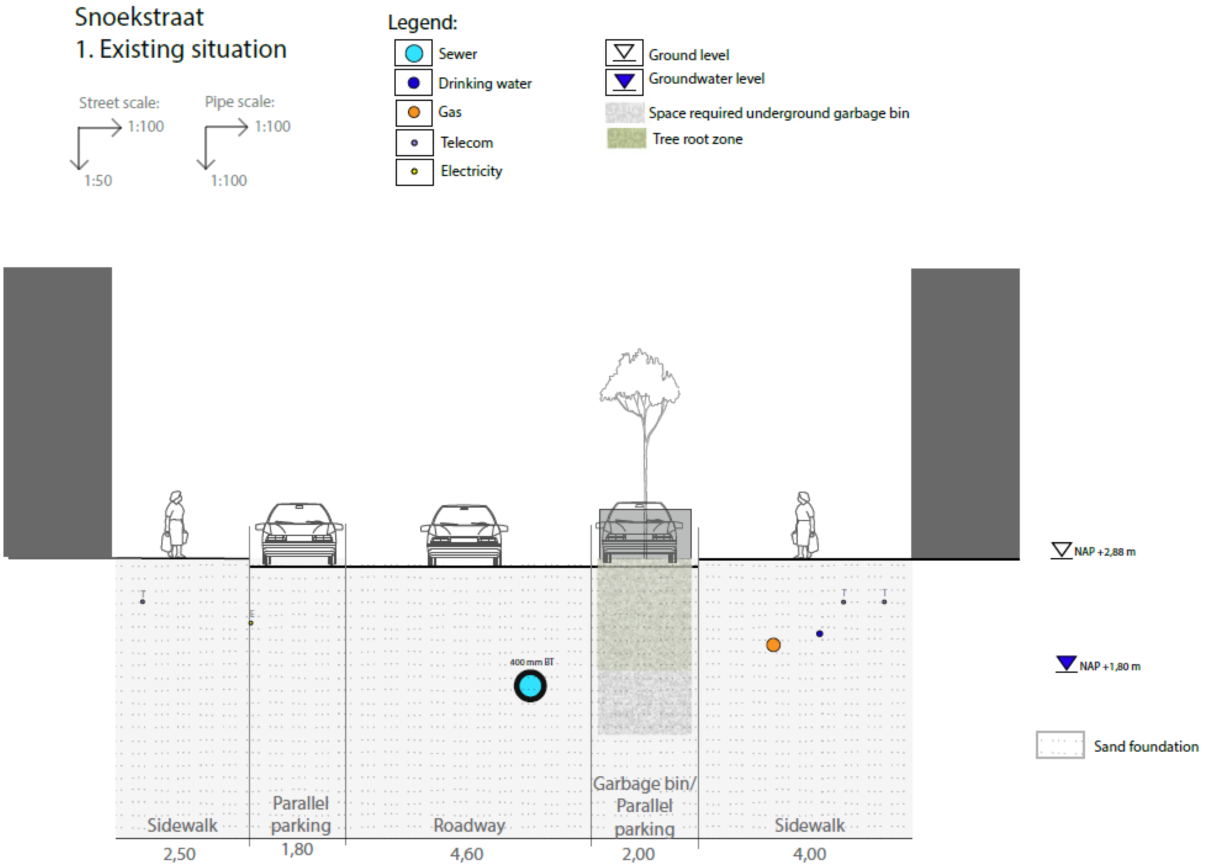

Figure 6-29 Cross-sectional view of the Snoekstraat – Situation 1: existing situation

Situation 2: Situation with energy measures and sewer replacement

Figure 6-30 shows the situation of the Snoekstraat with energy measures and sewer replacement. In the Snoekstraat, it is assumed that secondary distribution pipes of the district heating network are installed, with dimensions of DN80. Simultaneously, sewer replacement is carried out according to the functional water advice of Bospolder. The functional water advice of the area Bospolder states that drainage pipes in Bospolder should be installed above the groundwater level (minimum ground cover of 90 cm).

To install a separate sewer system and the district heating network, the electricity cable at the left has to be relocated, as can be seen in Figure 6-30, so that it does not lie in the excavation cunette of the heating network. The cunette of the sewer system overlaps with the underground garbage bin and tree root zone, but since this is only the case for a small part of the entire length (there are only a 5 trees and one garbage bin), digging can be carried out around .

In case the sewer is replaced, the ground level will be brought back to the officially determined height, which is +3,60 m in the Snoekstraat. As can be seen in Figure 6-30, the dewatering depth in the street in this situation becomes 1,8 m.

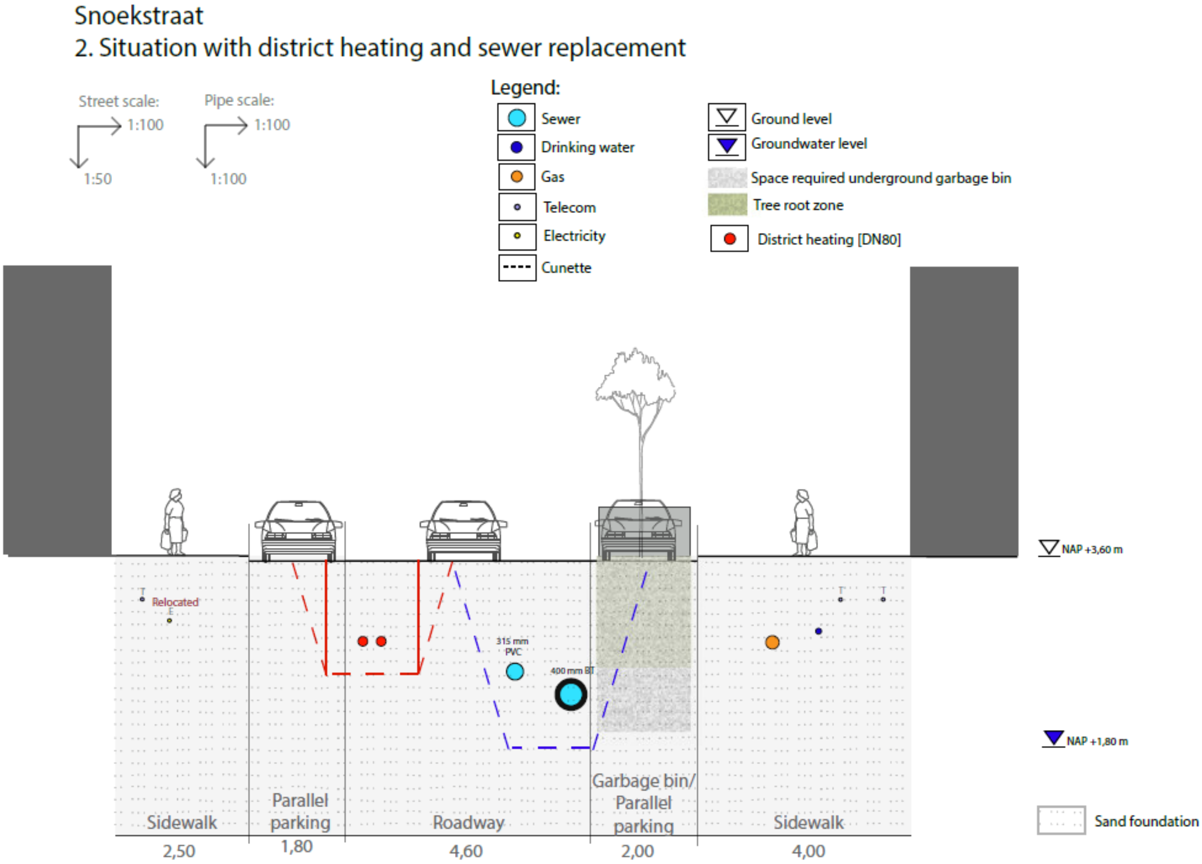

Figure 6-30 Cross-sectional view of the Snoekstraat – Situation 2: situation with district heating and sewer replacement

In Table 6-38, the new distances from the facades of the houses on the left side to the centre of the cables and pipes are stated.

Table 6-38 Distance from the facades of the houses to the centre of the cables and pipes in the Snoekstraat and their corresponding dimensions (Situation 2)

Distance from the facades of the houses (left) to centre of cable/pipe [m]	Pipe/cable	Inside diameter [mm]	Outside diameter [mm]
0,5	Telecom 1	-	-
1,0	Electricity	-	-
4,6	District heating 1	DN80	180
5,0	District heating 2	DN80	180
7,5	DT sewer	315 (PVC)	315
8,6	Wastewater sewer	400 (BT)	510
12,3	Gas	250 (PE)	250
13,2	Drinking water	110 (PVC)	110
13,7	Telecom 2	-	-
14,4	Telecom 3	-	-

The construction activities taking place in the Snoekstraat in situation 2, with the corresponding execution times, are stated in Table 6-39. The last column shows the time frame in which the activity is carried out in the Snoekstraat, from the moment the trench or entire street is dug open. This is calculated by dividing the length of the street by the execution time.

Table 6-39 Construction activities in the Snoekstraat in situation 2, with corresponding execution times

Activity	Pipe/cable	Execution time [m/day]	Responsibility	Time frame in the Snoekstraat [days]
Relocate	Electricity	150 – 200	Stedin	1
Install	Separate sewer system	5 – 10	Municipality	16
Install	District heating pipes	5 – 10	Heat supplier	16

The excavation that is carried out to install and relocate the cables and pipes stated in Table 6-39 and to raise the ground level, is shown in the top view of the Snoekstraat in Figure 6-31.

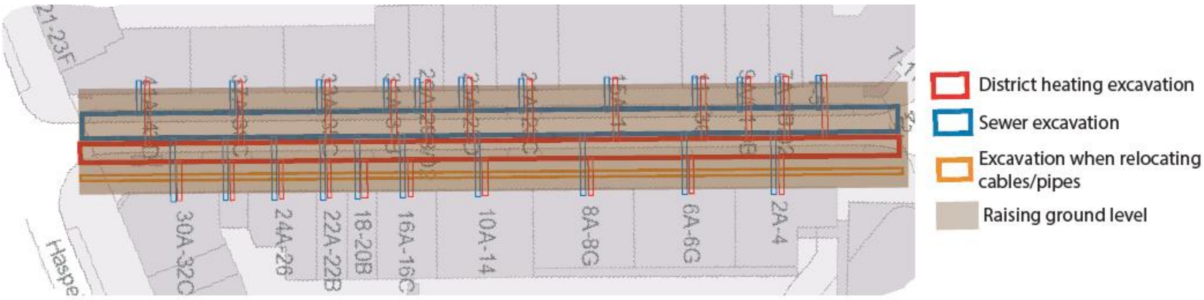

Figure 6-31 Top view of the Snoekstraat: excavation in situation 2

Situation 3: Situation with climate adaptation

The relevant decision-making information for the Snoekstraat, regarding climate adaptation (Figure 4-4) is stated in Table 6-40. An infiltration facility with drainage is found to be the optimal climate adaptation solution in this case.

Table 6-40 Information for decision-making on climate adaptation measures in the Snoekstraat

Dewatering depth	1,8 m (> 0,8 m)
Permeability sandy road foundation	> 2,0 m/day
Permeability subsoil	< 0,6 m/day
Outcome of climate adaptation option	Infiltration facility with drainage

The runoff areas in the existing situation are indicated in Table 6-41. With these numbers, the required storage is calculated, in case the water retention capacity needs to be sufficient in case of a rainfall event of 70 mm in 1 hour.

Table 6-41 Rainwater runoff areas in the Snoekstraat

Runoff area	**Surface area [m²]**	**Percentage of total surface area [%]**
Runoff area road (public space)	851	25,3
Runoff area sidewalks (public space)	773,5	23,0
Runoff area private property (roofs)	1736	51,7
Total runoff area:	3360,5	100
Total storage required:	$70 \frac{mm}{hour} * 3360{,}5\ m^2 = \mathbf{235{,}2\ m^3}$	

The water storage capacity of the Snoekstraat in the existing situation is calculated in Table 6-42.

Table 6-42 Water storage capacity of the Snoekstraat in situation 1

Equation 1: Sewer storage	$v_{eff,sewer} = 20\ mm * 3360{,}5\ m^2 = 67{,}2\ m^3$
Equation 2: Storage on the road	$v_{eff,road} = 100\ mm * 851\ m^2 = 85{,}1\ m^3$
Equation 3: Storage unpaved surface (5 small trees)	$v_{eff,unp} = 10 \frac{mm}{h} * 1h * 5 * 2\ m^2 + 10\ mm * 5 * 2\ m^2 = 0{,}2\ m^3$
Total water storage in existing situation:	$v_{eff} = 67{,}2\ m^3 + 85{,}1\ m^3 + 0{,}2\ m^3 = 152{,}5\ m^3 = 45{,}4\ mm$
Storage deficit:	$235{,}2\ m^3 - 152{,}5\ m^3 = 82{,}7\ m^3 = 24{,}6\ mm$

Situation 3.1.1: Climate adaptation in public space, within the conventions of Rotterdam

Taking the low percentage of unpaved surface and Table 6-40 into account, Figure 6-32 shows possible climate adaptation options in public space in the Snoekstraat, within the conventions of the municipality. Both sidewalks are narrowed, to improve the green structure in the street and implement green roadsides. To create extra surface storage, the roadsides are lowered by 150 mm (Appendix C). The surface area of the green roadsides is 309,4 m².

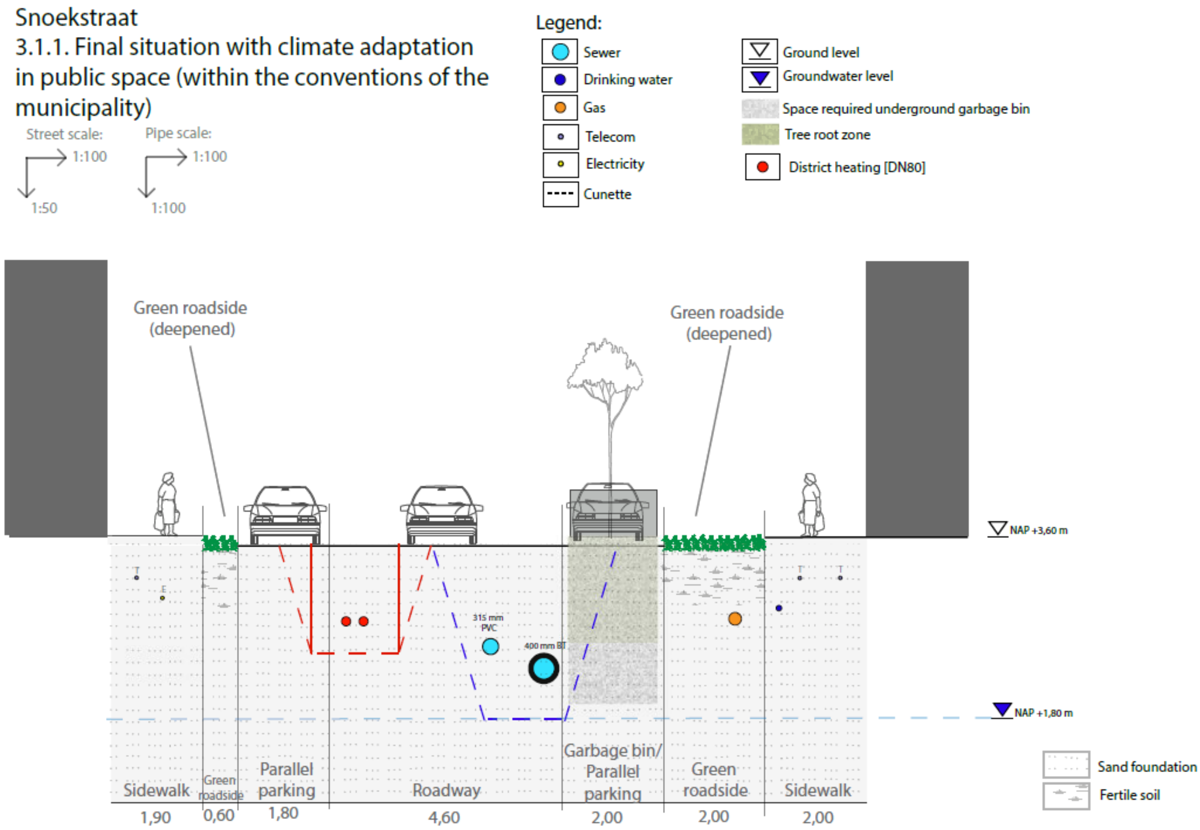

Figure 6-32 Cross-sectional view of the Snoekstraat – Situation 3: final situation with possible climate adaptation measures in public space, within the conventions of Rotterdam

According to the figure, the rainwater falling on the road and roofs is partly disconnected from the sewer system and temporarily stored in the green roadsides. The effects that the climate adaptation measures in Figure 6-32 will have on the water storage capacity of the Snoekstraat and the final storage deficit are presented in Table 6-43.

Table 6-43 Storage effect of climate adaptation measures in the Snoekstraat in situation 3.1.1.

Equation 3: Storage green roadsides	$v_{eff,unp} = 10\frac{mm}{h} * 1h * 309{,}4m^2 + 150\ mm * 309{,}4\ m^2 = 49{,}5\ m^3$
Total water storage in situation 3.1.1:	$v_{eff} = 152{,}5\ m^3 + 49{,}5\ \ m^3\ = 202\ \ m^3 = 60{,}1\ mm$
Storage deficit:	$235{,}2\ m^3 - 202{,}0\ m^3 = 33{,}2\ m^3 = 9{,}9\ mm$

Situation 3.1.2: Climate adaptation in private space

As can be seen in Figure 6-28 and Figure 6-29, houses in the Snoekstraat do not have private front yards, which makes it difficult to disconnect rainwater falling on private space. Figure 6-33 shows possible climate adaptation measures in private space. Most the roofs are flat and made of bitumen, which means green roofs can be placed without extra measures. In addition, green facades are implemented, which do not influence the water storage capacity, but increase the greenery in the street.

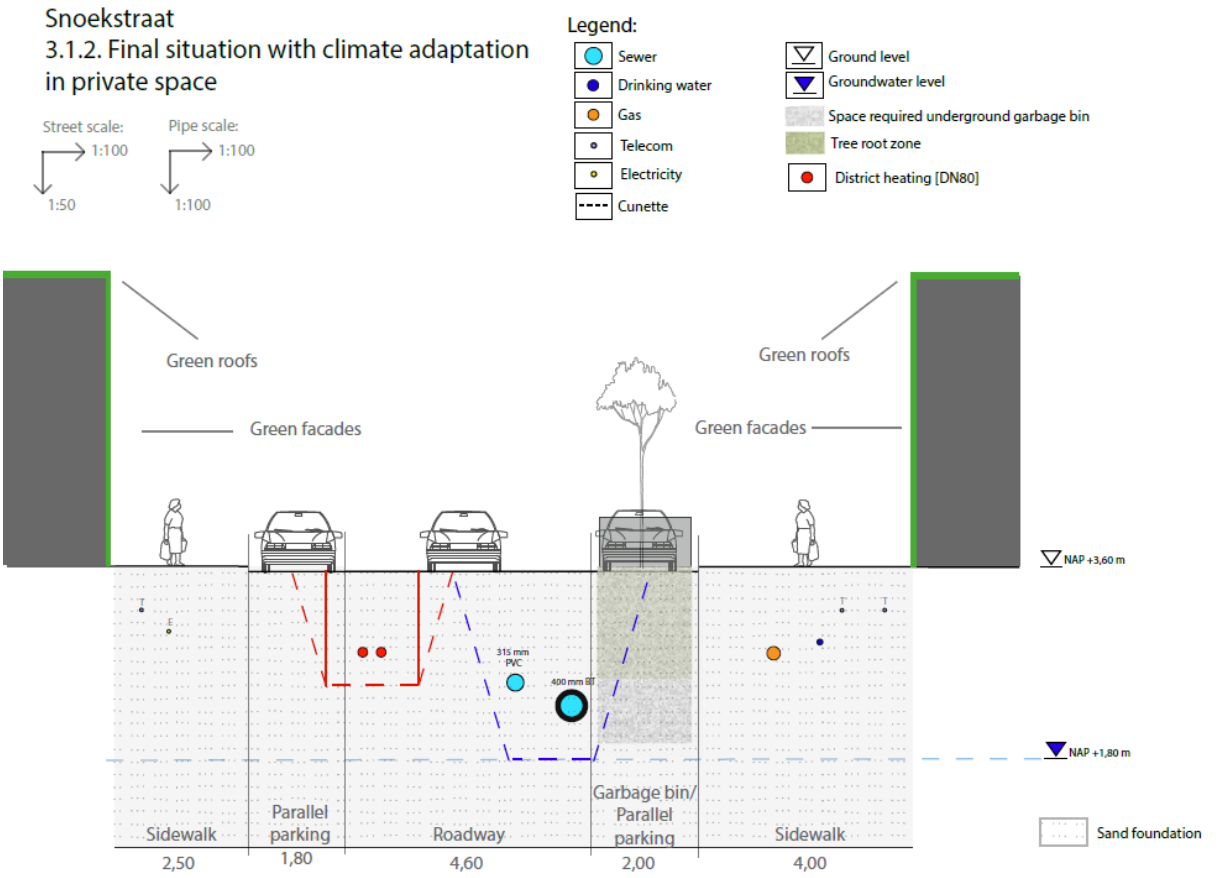

Figure 6-33 Cross-sectional view of the Snoekstraat – Situation 3: final situation with possible climate adaptation measures in private space

The effect that the climate adaptation measures in Figure 6-33 will have on the water storage capacity of the Snoekstraat is presented in Table 6-44.

Table 6-44 Storage effect of climate adaptation measures in the Snoekstraat in situation 3.1.2.

Equation 5: Storage green roofs	$v_{eff,roof} = 0{,}025\,\frac{m^3}{m^2} * 1736\,m^2 = 43{,}4\,m^3$
Total water storage in situation 3.1.2:	$v_{eff} = 152{,}5\,m^3 + 43{,}4\,m^3 = 195{,}9\,m^3 = 58{,}3\,mm$
Storage deficit:	$235{,}2\,m^3 - 195{,}9\,m^3 = 39{,}3\,m^3 = 11{,}7\,mm$

Situation 3.2: Climate adaptation in public space, conventions of Rotterdam ignored

Because adaptation measures in public space, in Figure 6-32, did not provide sufficient storage, in Figure 6-34, a climate adaptation design is made which does not comply with the conventions of the municipality. In this figure, a 0,5 m thick coarse granulate layer is placed below the parking lanes (effective porosity of 40%), behind the underground garbage bins. As can be seen, the granulate layers conflict with the cunettes of the district heating network and sewer system. In addition, 5 trees are planted symmetrically to the right side, on the left side of the road.

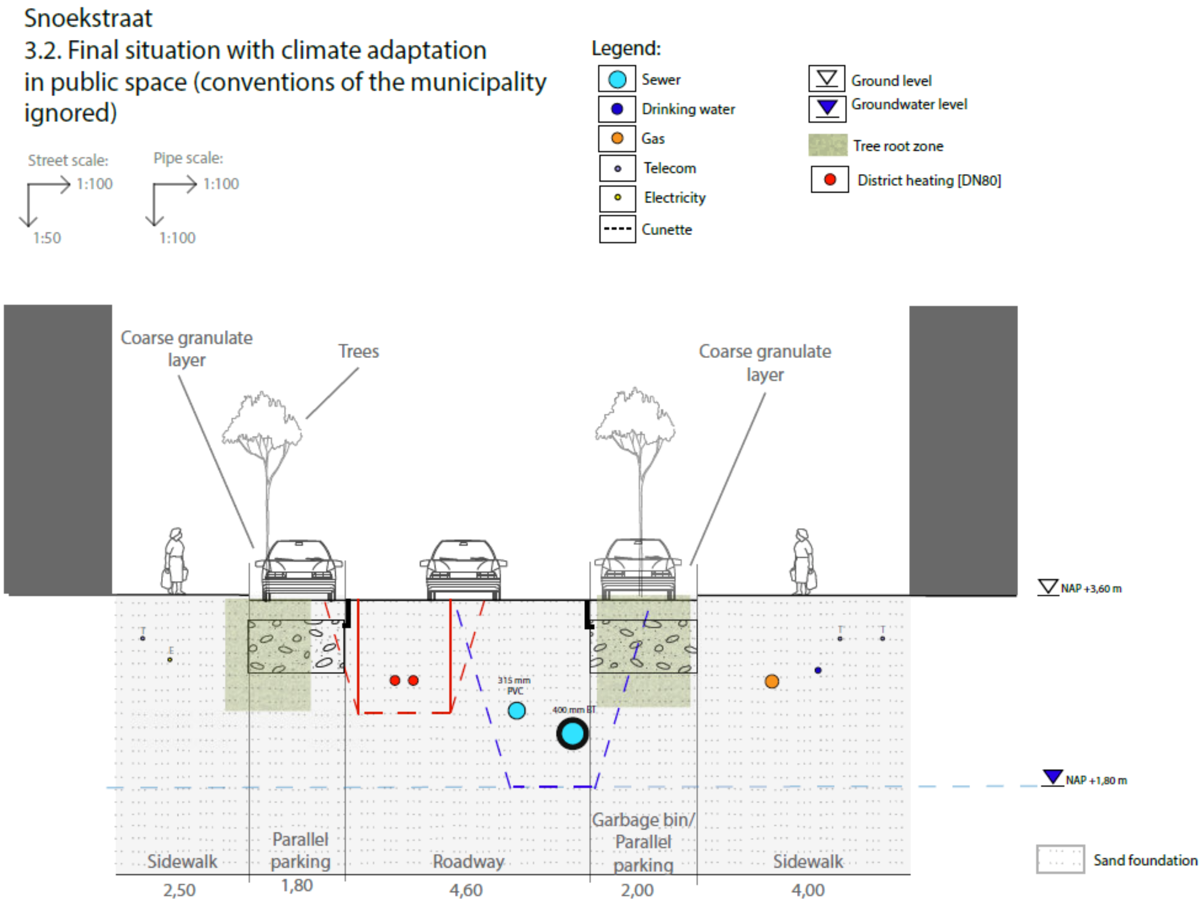

Figure 6-34 Cross-sectional view of the Snoekstraat – Situation 3: final situation with possible climate adaptation measures in public space, conventions of Rotterdam ignored

According to the figure, the rainwater is partly disconnected from the sewer system and temporarily stored in the coarse granulate layer and in the planters of the trees. The effects that the climate adaptation measures in Figure 6-34 will have on the water storage capacity of the Snoekstraat, and the final storage surplus are presented in Table 6-45.

Table 6-45 Storage effect of climate adaptation measures in the Snoekstraat in situation 3.2.

Equation 3: Storage unpaved surface (5 small trees extra)	$v_{eff,unp} = 10\frac{mm}{h} * 1h * 5 * 2\,m^2 + 10\,mm * 5 * 2\,m^2 = 0{,}2\,m^3$
Equation 4: Storage infiltration facility, with soil improvement	$v_{eff,inf} = 119\,m * (1{,}8\,m + 2\,m) * 0{,}5\,m * 0{,}4 = 90{,}4\,m^3$
Total water storage in situation 3.1.1:	$v_{eff} = 152{,}5\,m^3 + 0{,}2\,m^3 + 90{,}4m^3 = 243{,}1\,m^3 = 72{,}3\,mm$
Storage surplus:	$243{,}1\,m^3 - 235{,}2\,m^3 = 7{,}9\,m^3 = 2{,}3\,mm$

6.5.2. Types of systems integration identified

Measures in public space within the conventions of Rotterdam solely (60,1 mm) are not sufficient in case of a heavy rainfall event (70 mm in 1 hour) in the Snoekstraat. Therefore, a design with measures in public space outside the conventions of Rotterdam has been created in addition. To eventually realize the amount of water storage in case of a heavy rain event, a combination of measures in public space within the conventions of Rotterdam (Figure 6-32) and measures in private space (Figure 6-33) and measures in public space outside the conventions of Rotterdam (Figure 6-34) would suffice. Based on the designs, multiple types of systems integration are identified, with both technical- and socio-institutional aspects.

Geographical integration

- *Technical aspects:*

In the Snoekstraat, the elements of multiple infrastructures (the sewer system, district heating and climate adaptation measures) are in close spatial proximity, which requires close spatial organization. In order to place both the separate sewer system and district heating network as much in the middle of the street as possible, the electricity cable has to be relocated (Figure 6-30), so that it does not lie in the excavation cunette of the heating network.

To realize sufficient water storage, measures in public space, outside the conventions of Rotterdam (Figure 6-34) can suffice. As can be seen, an extra row of trees is planted at the left side of the road, to improve the green structure of the street. In addition, two layers of coarse granulate are placed under the parking lanes, to realize additional water storage. The coarse layers of granulate lie within the cunettes of the district heating network and the sewer system, but are placed in a way that vertical excavation is still possible without reaching the granulate layer. To provide space for climate adaptation in this scenario, the cunettes of the district heating pipes and sewer system conflict (Figure 6-34), instead of the situation where they are placed directly next to each other (Figure 6-30). This means that during the design phase of the separate sewer system and district heating network, climate adaptation should already be taken into account and included in the design, so that the cunettes will conflict and this extra space for measures is created.

- *Socio-institutional aspects:*

To organize the underground infrastructure in close spatial proximity, the implementation requirements (location in the street) and spatial impacts of all assets should be known and maintained by the different parties involved. In the Snoekstraat this means: the Water department of the Public Works division (responsible for sewer maintenance) has to align its replacement plans with the heat supplier (responsible for the district heating network) in the Snoekstraat, to create a combined design. In addition, because the electricity cable has to be relocated (Figure 6-30), the designs should be communicated to the electricity operator (Stedin) in order to reach a joint agreement on the design and to give them the opportunity to not only relocate, but also replace it and to use the momentum to execute everything simultaneously.

Because climate adaptation should already be taken into account and included in the design of the sewer system and heating network in the Snoekstraat, knowing whether urban flooding occurs at that location, to what extent and what kind of measures are desired, is important information for the sewer and district heating planners and designers.

Project-based integration

- *Technical aspects:*

The implementation of district heating and sewer replacement in the Snoekstraat are planned simultaneously. Therefore, it is assumed a total redesign of the street is carried out and the ground level is raised to the officially determined height (from +2,88 m to +3,6 m). This results in a lot of excavation carried out in the street (Figure 6-31). The construction activities in the Snoekstraat, their corresponding execution times and the time frame needed in the street are presented in Table 6-39. The electricity cable is relocated first, according to subsection 4.2.1. Subsequently, the sewer system is replaced and eventually the district heating network is installed. Since the entire street is under construction to raise the ground level, the electricity operator (Stedin), the municipality and the heat supplier can efficiently integrate their construction activities. In that case, they can relocate and install their cables and pipes one after the other as quickly as possible, so that the street only has to be dug open once and nuisance and digging costs are minimized.

To create storage in public space within the conventions of Rotterdam, deepened green roadsides can be implemented at both sides of the street, without negatively affecting the under- and above ground infrastructure (Figure 6-32). Since the entire roadway, parking lanes and sidewalks are dug open, because of the ground raising (Figure 6-31), the deepened green roadsides (Figure 6-32) can be implemented simultaneously, without extra digging, when the street is filled up again. Trees and underground granulate layers (measures outside the conventions of Rotterdam (Figure 6-34)) can be implemented simultaneously as well, without extra digging needed. Integration of these climate adaptation measures within the excavation carried out for the sewer system, heating network and thereby ground raising is beneficial in terms of costs and nuisance.

Climate adaptation measures in private space can be taken at the roof and the facades (Figure 6-33). The roofs where green roofs are implemented are flat and made of bitumen, which means the green roofs can be placed without extra measures. Since no other construction activities take place on the roof or at the façade, implementation of green roofs or façade gardens does not bring benefits during construction of the heating network and therefore does not need to be applied simultaneously.

- *Socio-institutional aspects:*

Because in the Snoekstraat simultaneous implementation of climate adaptation measures in public space is beneficial in terms of costs and nuisance, knowing that urban flooding occurs at that location is crucial information for the sewer and district heating planners and designers, because then they know whether to add climate adaptation in their design.

Besides, connecting to the district heating network instead of the gas network, means households have to switch to an electric way of cooking and instead of a central boiler, houses get a connection to the heating network. Because houses in the Snoekstraat are mainly owned by the housing corporation Havensteder, they are responsible for the required adjustments and in case climate adaptation measures in private space are desired from the municipality (Figure 6-33), both climate adaptation and in-house district heating adjustments are in hands of housing corporation Havensteder. In that case, an integrated communication approach from the municipality towards Havensteder is desired, so that the one does not preclude the other in the future.

6.6. Summarized results of the realized storage in different climate adaptation scenarios

The results of the cases, focused on the climate adaptation measures and the storage that could be realized, are summarized in Table 6-46. Out of the five cases outlined, four cases have a significant rainwater storage deficit (> 20 mm) and one a relatively small storage deficit (7,5 mm). Among the four cases with a significant water storage deficit, only in one case (Bospolderplein, section 6.4) the deficit could be solved with climate adaptation measures in public space, within the conventions of Rotterdam only. In the remaining three cases with a significant water storage deficit, measures in public space, within the conventions of Rotterdam, had to either be combined with private measures (which cannot be assumed), or measures that do not comply with the conventions of Rotterdam, in order to achieve 70 mm of rainwater storage capacity of the street.

Table 6-46 Results of the rainwater storage in different scenarios summarized per case

Case	Storage required [mm]	Existing storage situation 1 [mm]	Storage deficit	Storage situation 3.1.1 [mm]	Storage situation 3.1.2 [mm]	Storage realized situation 3.2 [mm]
1. Brittenoord	70	46	24	66,2	67,5	96,5
2. Melissantstraat	70	62,5	7,5	72,7	70,1	x
3. Goudenregenstraat	70	38,6	31,4	50,2	47,1	63
4. Bospolderplein	70	37,9	32,1	72,8	47,2	x
5. Snoekstraat	70	45,4	24,6	60,1	58,3	72,3

As can be derived from Table 6-46, climate adaptation measures in public space within the conventions of Rotterdam can already solve a large part of the storage deficit and can realize more than 50 mm of storage in all cases. However, if the municipality of Rotterdam wants to achieve its goals and realize 70 mm of rainwater storage in all cases, additional costs have to be made and alternative measures have to be taken. This is discussed more in detail in subsection 7.1.2.

7. Discussion

This chapter discusses and interprets the results of the research. The chapter is subdivided into three sections. In section 7.1, the findings from the designs are presented and discussed, resulting in policy dilemmas for the municipality of Rotterdam. Subsequently, section 7.2 describes how the research findings fit into existing literature and municipal files. The last section of this chapter, section 7.3, reflects upon the limitations of the research.

7.1. Findings from the designs

Five different district typologies can be found in Rotterdam (Table 5-1), three of which have been examined in this research. All three typologies examined in this research pose challenges in the field of implementing the energy transition alongside climate adaptation measures (Chapter 6), in streets where urban flooding occurs in addition to implementation of the energy transition. As can be derived from subsection 5.2.3, the neighbourhood Bospolder with the ‘urban building block’ typology benefits most from an integrated approach towards the energy transition and climate adaptation, since the indicative vulnerability to flooding is highest (Table 5-1) and subsequently the percentage of streets where urban flooding occurs, in addition to the implementation of district heating, is highest (Table 5-5). The remaining pilot areas, with the ‘‘cauliflower’ district’ typology and the ‘garden city-area’ typology, both contain of a lot of green and houses with gardens, which means the percentage of streets where urban flooding occurs, in addition to the implementation of district heating, is significantly lower. Although the indicative vulnerability to flooding of the ‘garden city-area’ typology is higher than indicative vulnerability to flooding of the ‘‘cauliflower’ district’ typology according to Table 5-1, the difference in the percentage of streets where urban flooding occurs in addition to the implementation of a heating network is negligible (Table 5-5). In this research, Bospolder is the only neighbourhood analysed with the ‘urban building block’ typology and, as Krusenvik (2016) states, one cannot generalize findings based on one single example (Krusenvik, 2016). This means that the finding that Bospolder benefits most from an integrated approach gives an indication of the sensitivity of the ‘urban building block’ district typology, but multiple areas with this typology would have to be analysed in order to draw a well-founded conclusion on this type of area. However, the fact that an area with little greenery, a lot of high-rise buildings and a lot of paving has a high vulnerability to flooding and therefore more need for an integrated approach seems rather logical. The district typologies not examined in this research, the ‘high-rise city centre area’ and ‘garden-village area’, both have an average indicative vulnerability to flooding (2 out of 3) (Kleerekoper et al., 2017), comparable to the ‘garden-village area’ typology. Therefore, it is expected that the percentage of streets where urban flooding occurs, in addition to the implementation of district heating, is lower in those neighbourhoods than in neighbourhoods comparable to Bospolder (‘urban building block’ typology), but challenges related to the integration of the energy transition and climate adaptation will still arise, comparable to cases 1 to 3 (6.1, 6.2 and 6.3).

The results of the designs of the five cases have been described in detail in Chapter 6. The results, summarized in Table 6-46, strongly imply that in the vast majority of cases with a significant rainwater storage deficit in addition to the implementation of the energy transition, it is difficult to design a street in a climate-adaptive manner, without altering the regulations of Rotterdam or without focusing and investing in water storage on private land. Because the energy transition has a major effects on the possibilities of climate adaptation, the aim of this study, to investigate the different types of systems integration between the energy transition and climate adaptation and to find out what the energy transition implies for Rotterdam’s climate adaptation goals, is of great importance. This can be used to determine what both the positive and negative impacts of the energy transition on climate adaptation are, so that those can either be seized or prevented in the future. It is important to note that this research is limited to measures and rules set by the municipality of Rotterdam, although there are many more different options for storing more rainwater. These options are likely to technically change and improve in the future, as well as the degree of climate change, which is also still uncertain. There are thus more options for a climate-adaptive design of the street and what that climate-adaptive means exactly, which is not discussed in this study.

As can be deduced from the designs, a gas pipe is still present in all situations (also the situation with district heating). During the implementation phase and the first period of use of the district heating network, the gas pipes need to remain in place, because the houses will be connected to the heating network in phases. Eventually, when all houses are connected to the heating network, the gas pipes can be removed and this will create extra space for climate adaptation or other underground infrastructure, but that could take several more years (W. Noordhof, personal communication, September 17, 2020).

In Chapter 6, both the technical- and socio-institutional aspects of the different types of systems integration have been discussed per case. The main findings based on these aspects, are discussed in subsection 7.1.1. The policy dilemmas for the municipality of Rotterdam, following from the cases, are discussed in subsection 7.1.2.

7.1.1. Main findings on types of systems integration

In Chapter 6, research question 2.2, '*What types of systems integration can be identified in the cases, regarding implementation of the energy transition and climate adaptation?*', has been answered. The main findings and interpretations of these findings are presented below.

Geographical integration

As can be deduced from the cases, the ongoing transitions only just fit in a densely built-up city such as Rotterdam. In all cases cables and pipes have to be relocated to provide space for the district heating network (and sewer replacement) and/or climate adaptation measures. This means that in case of an integrated approach, the 'water'-department of the Public Works division of the municipality of Rotterdam (responsible for sewer maintenance) has to align its replacement plans with the heat supplier (responsible for the district heating network) to create a combined design and to get an overview of the cables and pipes that need to be moved. Subsequently, all cable- and pipe owners have to agree to the design. One interpretation of these findings is that, because in Rotterdam the owners of cables and pipes are responsible for relocation and replacement of their own infrastructure (interview Appendix D), forcing them to replace or relocate it can cause friction and resistance from the owners. Therefore, when cables and pipes have to be relocated, the designs have to be communicated to the owners in an early stage in order to reach a joint agreement on the design and to use the momentum to execute everything simultaneously.

In three out of the five cases, the Goudenregenstraat, Bospolderplein and the Snoekstraat, geographical integration of possible climate adaptation measures in the initial design for the district heating network (and possible sewer replacement) is important in particular, because specific space has to be preserved for underground adaptation infrastructure in the future (in these cases: infiltration crates, coarse granulate layer and the tree root zones of trees). It is interesting to note that, although simultaneous implementation of energy- and climate adaptation measures in these cases is not beneficial based on construction (project-based integration), geographical integration, so taking future climate adaptation into account in the district heating design, provides benefits for implementation of climate adaptation measures in the future.

Project-based integration

In three out of the five cases, Brittenoord, the Goudenregenstraat and the Snoekstraat, district heating is implemented simultaneously to sewer replacement, which induces a complete redesign of the street and means that the ground level will be brought back to the officially determined height. The results from those cases, when the entire public space is excavated, imply that the construction locations of climate adaptation measures in public space and potential relocation of cables and pipes have a lot of overlap with the construction activities of the district heating network and sewer replacement. Therefore, an integrated approach seems beneficial. In case of project-based integration of climate adaptation and relocation of cables and pipes in the construction activities for the heating network (and sewer replacement), the street will be open for a longer period of time because work from different parties is carried out one after the other. However, since the street only needs to be dug open and closed off once, project-based integration is still advantageous for all parties involved in terms of digging costs and for local residents in terms of nuisance. To implement climate adaptation measures in public space simultaneously to the implementation of district heating and replacement of the sewer, knowing that urban flooding occurs at that location is crucial information for the sewer and district heating planners and designers, because then they know whether to add climate adaptation in their design.

Project-based integration based on the construction of climate adaptation in private space is found to be beneficial when gardens are dug open to place the house connections pipes of the heating network (and new sewer system) or when solar panels are installed on roofs (and green roofs can be installed simultaneously). Besides, it is found that in case climate adaptation measures are desired from the municipality on private land, an integrated communication approach from the municipality towards the homeowners is desired, so that they know the advantages of simultaneous implementation and can implement the measures accordingly, because in-house adjustments are needed when houses connect to a heating network as well. Climate adaptation of private land entails the risk that the measures may not be properly maintained in the long term, which in turn could reduce storage capacity. When measures in private space are needed, city-citizen commoning of climate adaptation (managing climate adaptation on local scale, by a community) could provide opportunities for sustainable climate adaptation on private land (Wamsler & Raggers, 2018). The complexity of the decision-making that comes with combining the heating network, sewer replacement, relocation of cables and pipes and climate adaptation is related to the different views and perspectives of the actors involved (Fratini et al., 2012). This finding may be explained by the idea that transitions do not only entail new technologies, but changes in the socio-institutional context, as well (Geels, 2010).

Physical integration

In the field of the energy transition and climate adaptation, the findings in this study suggest two forms of physical integration based on infrastructure, both mentioned in literature before (Meijberg, 2018; Stichting RIONED, 2015):

- Integration of green roofs and solar panels on a roof: creating a multi-use roof and a positive effect on the power generation and lifespan of solar panels. An integrated communication approach from the municipality towards the residents or housing corporations is desired, so that one does not preclude the other in the future and so they know the advantages of simultaneous implementation of both.
- Integration of underground utilities in a multi-utility gutter: providing additional space for the heating network and climate adaptation measures underground. By co-locating multiple utilities in an underground gutter, challenges regarding responsibility for construction (both implementation and costs) and management of the gutter arise (W. Noordhof, personal communication, September 17, 2020).

Resource-based physical integration between the energy transition and climate adaptation plays a major role in case the source of the heating network would be sewer- or aqua thermal heat. Since the source of the heating network in Rotterdam is mainly residual heat, resulting in a high temperature heating network, resource-based physical integration is not considered.

Informational integration

Informational integration, based on the combining of data from different urban systems, cannot be directly deduced from the designs presented in Chapter 6 or from the current energy transition approach in Rotterdam. However, according to literature, future district heating systems can play a role in smart energy systems within a city, with next generation heating and cooling technologies based on fluctuating renewable heat and cooling sources (Lund et al., 2018). In case that a heating network is fed by multiple sources, the use of any source can be optimized with real time data, which links the demand of households and the supply of different sources at that time (Lund et al., 2014). In case that waste- or surface water is one of these sources, combining data of the two, so informational integration between the urban water- and energy system, can lead to optimization of the performance of the heating network (Wang et al., 2018). This is currently not yet happening in Rotterdam, but it may offer opportunities in the future when other sources are used instead of residual heat from industry.

7.1.2. Main findings on policy dilemmas for the municipality of Rotterdam

This section discusses the policy dilemmas for the municipality of Rotterdam, in the field of the energy transition and climate adaptation. It focuses on the goals Rotterdam has set itself (implement the energy transition and realize sufficient water storage in a street in case of a heavy rain event (70 mm in 1 hour)) and which trade-offs have to be made when 70 mm of rainwater storage is to be realized at a location where a district heating network is implemented in addition.

As stated above, among the four cases with a significant water storage deficit, in three cases measures in public space, within the conventions of Rotterdam, had to either be combined with private measures (which cannot be assumed), or measures that do not comply with the conventions of Rotterdam, in order to achieve 70 mm of rainwater storage capacity of the street. Trade-offs to be made at that time are the following:

- Fail to comply with conventions of Rotterdam: Conflicting cunettes to provide space for climate adaptation measures (sections 6.3 and 6.5).

  In two cases in this study, the cunettes of the district heating network and sewer system conflict to provide sufficient rainwater storage in a street. Conflicting cunettes of the sewer system and district heating network can cause undesired effects in case one of the two is completely excavated, for maintenance or replacement (subsection 4.2.1). Therefore, an alternative form of excavation has to be used in the future by the municipality and heat supplier, instead of digging out the entire cunette. An alternative form of excavation is, for example, vertical excavation (by means of sheet piles installed), which makes a replacement or maintenance project a lot more expensive than initially, when the entire cunette is excavated (W. Noordhof, personal communication, September 17, 2020). If it is decided to only take measures in the public space within the conventions of Rotterdam, for example 50,2 mm of rainwater can be stored in the Goudenregenstraat (section 6.3) and 60,1 mm of rainwater in the Snoekstraat (section 6.5). In these streets, where conflicting cunettes can provide a solution for more space for climate adaptation, a trade-off has to be made between the future additional excavation costs (and who has to pay them) and the amount of rainwater storage to be realized (and thus the additional costs when damage occurs in the event of a heavy rain event in case insufficient storage has been realized).

- Fail to comply with conventions of Rotterdam: Climate adaptation measures (infiltration facilities) are placed above cables and pipes (section 6.1).

  In one case in this study, permeable pavement is placed above the sewer system and the district heating pipes to provide sufficient rainwater storage in a street, which goes against regulations that state no climate adaptation measures are placed above cables and pipes that are not municipality owned (subsection 4.2.1). This means it will take more money and effort for the municipality and heat supplier to reach their pipes and afterwards close the street properly, in case of replacement and maintenance (GPKL et al., 2012). If it is decided to only take measures in the public space within the conventions of Rotterdam, 66,2 mm of rainwater storage, so a deficit of only 3,8 mm, could be realized Brittenoord (section 6.1). This means that in such cases a trade-off has to be made between the extra effort and costs that measures that do not comply with the conventions of Rotterdam entail in the future (and who has to pay for these extra costs) and the amount of rainwater storage to be realized (and thus the additional costs when damage occurs in the event of a heavy rain event in case insufficient storage has been realized).

- Utilities are bundled in an underground gutter to provide space for climate adaptation measures (section 6.3).

  In one case in this study, cables and pipes are bundled in an underground gutter to provide more underground space for climate adaptation: a multi-utility tunnel. Multi-utility tunnels make utility management more complex, as many public authorities and private companies are involved (Canto-Perello & Curiel-Esparza, 2013). Some single entity should be made responsible not only for initial construction but also for security, access control, and operation and maintenance throughout the life of the project. Besides these organizational challenges, a multi-utility tunnel entails large costs: placing utility lines in a tunnel approximately doubles the initial capital investment (Canto-Perello & Curiel-Esparza, 2013). If it is decided that in the relevant case in this study (section 6.3) only measures in public space within the conventions of Rotterdam are taken, 50,2 mm of rainwater storage could be realized. This means that in such cases a trade-off has to be made between the organizational challenges and additional costs that measures that do not comply with the conventions of Rotterdam entail and the amount of rainwater storage to be realized (and thus the additional costs when damage occurs in the event of a heavy rain event in case insufficient storage has been realized).

- Provide extra space above ground for climate adaptation by removing parking spots (section 6.2 and 6.4).

  In two cases in this study, parking spots are replaced by climate adaptation measures (greenery). The removal of parking spots in a street can cause a lot of commotion from the residents when no alternative parking solution is proposed by the municipality. However, besides the energy transition and climate adaptation, Rotterdam is working on the mobility transition in which the city mainly focuses on cycling and walking, or in other words: active mobility (Gemeente Rotterdam, 2019b). In addition, Rotterdam focuses on improving the public transport with the mobility transition, everything to reduce car transport in the city. For those reasons, it may not be a problem in the future if parking spots disappear, but only if the mobility transition is really set in motion and thus less spots are needed to provide all residents with space for parking. The climate adaptation measures placed instead of the parking spots in this research are mainly green measures, which provide limited additional storage, but above all contribute to the green structure and thus the living environment of the street. This means that in such cases a trade-off has to be made between the challenges that arise for the municipality when parking spots disappear, whether the mobility transition will actually take place in the coming years and the amount of rainwater storage and green to be realized (and thus the additional costs when damage occurs in the event of a heavy rain event in case insufficient storage has been realized).

- More degrees of freedom in public space: other (more undesirable) ways to design the street.

  Rotterdam is in the process of drawing up climate-oriented standards: these standards indicate which forms of nuisance in public space may be acceptable (Gemeente Rotterdam, 2020a). This mainly concerns nuisance for residents, such as water on the street or in the gardens during extreme rain events. When it is decided not to comply with these standards in all streets and, for example, to flood a certain low-lying street more often, additional water storage can be created in an area, without additional climate adaptation measures that are proposed in this research. In areas where extra storage is really needed to prevent damage to property, not complying to climate-oriented standards in certain streets can create cheaper solutions. This means that in such cases a trade-off has to be made between standards that are not adhered to, resulting in extra nuisance for residents, and the costs for alternative climate adaptation measures in a street.

- Climate adaptation in private space (sections 6.1, 6.3 and 6.5).

  In three cases in this study, climate adaptation measures in public space within the conventions of Rotterdam can be combined with measures in private space to obtain sufficient rainwater storage. To realize climate adaptation in private space, measures on private land should be stimulated by, for example, subsidy regulations or by obligations imposed by the municipality. If in the relevant cases in this study (sections 6.1, 6.3 and 6.5) only measures in public space within the conventions of Rotterdam are taken, 66,2 mm of rainwater storage in Brittenoord, 50,2 mm of rainwater storage in the Goudenregenstraat and 60,1 mm of rainwater storage in the Snoekstraat could be realized. In streets where climate adaptation in private space can provide a solution for more rainwater storage, a trade-off has to be made between the extra costs for the municipality through subsidy regulations or imposing obligations on citizens and the amount of rainwater storage to be realized (and thus the additional costs when damage occurs in the event of a heavy rain event in case insufficient storage has been realized).

7.2. Theoretical implications

The findings result in several theoretical implications. In this section, the findings of the research are linked to existing literature and municipal files.

The key findings of this study contribute to the claim that spatial planning in the urban environment plays a major role in responding to the need to both address the causes and impacts of climate change (Wilson & Piper, 2010), since redesign of the public space is required to improve the city's water-resilience along with implementation of the energy transition. According to literature, resources and space needed for implementation of climate mitigation and adaptation strategies can be minimized by integration of the two (Grafakos et al., 2019). However, in literature, there are no explicit examples of how and when system integration of the energy transition and climate adaptation can lead to potential synergies. The results, described in Chapter 6, represent the first direct demonstration of the different types of systems integration between the energy transition and climate adaptation, and the corresponding (dis)advantages. In this study, a distinction has been made between different climate adaptation measures (in public and private space) and different energy measures (district heating and solar panels), to present a broad overview of the possible synergies. As can be derived from sections 6.1, 6.3 and 6.5, indeed resources can be minimized when energy measures and climate adaptation measures are implemented simultaneously in public and private space, since there is only one moment of excavation instead of two.

As can be derived from the findings, corresponding to previous literature, the municipality should play a leading role in the climate change approach, as they are responsible for bringing different parties (utility managers) together and coordinating construction projects (Hirschl, 2018). The findings in Chapter 6 show that bringing the different utility managers together is of major importance, since they have to be included in almost any construction project regarding district heating and sewer replacement to relocate their cables, in order to provide space for new underground assets. For the municipality of Rotterdam this means that playing the leading role by mapping all parties involved in the beginning of a project is important to eventually arrive to a design to which all parties agree and in which both the energy transition and climate adaptation can be realized. The present study also shows that the municipality should not be seen as a whole, but that it consists of different clusters who have to work together and match their maintenance and development needs (section 3.1), to come to an integral approach. In Rotterdam, attempts are currently being made to link the energy transition (Urban Development Cluster) to sewer replacement (Urban Management Cluster), as can be seen in subsection 5.2.1, but this planning does not always take the need and the possibilities for climate adaptation into account. By considering possibilities for climate adaptation in an early stage by all clusters (geographical integration, discussed in subsection 7.1.1), unnecessary costs and effort can be saved in the future, which in turn means minimizing resources, as described above.

The policy dilemmas described in subsection 7.1.2 insinuate that, in order to achieve the climate adaptation goals regarding excessive rainfall alongside the energy transition, current guidelines of the municipality of Rotterdam no longer suffice in some cases. Achieving all climate goals and simultaneously adhering to rules and satisfy all parties involved in the underground is simply impossible and therefore this research shows the importance of revising the guidelines on the one hand or settling for less rainwater storage on the other. This can be seen as a supplement to current municipal files regarding management of the underground, urban water management and spatial planning.

7.3. Limitations of the research

This section discusses the limitations of the research and the limitations of the case study design and the within-case analysis in particular. The method chosen in this research was an explorative case study approach, based on multiple and diverse cases, because not much was known or investigated about the interactions between the energy transition and climate adaptation. However, case study research has limitations as well. The validity or generalization of the results could be reduced due to the small number of cases studied. This makes the ability to generalize the results difficult (Verschuren & Doorewaard, 2010). Besides, it was decided to focus this research only on the energy transition and climate adaptation, although Rotterdam is working on translating the mobility transition, economy transition, circular transition and the housing challenge to the spatial domain in addition (Gemeente Rotterdam, 2019d). This results in a limitation with regards to the complete inclusion of all transitions.

Case study design

One limitation of the case study design, is that the cases have only been selected upon the criteria 'urban flooding', in the field over climate adaptation. In addition to urban flooding, excessive heat and long periods of drought are important issues resulting from climate change, that should be addressed in urban areas in the near future as well (Guerreiro et al., 2018). Because these topics are not included in this research, climate adaptation measures focused on heat and drought are not included as well. This means that a limited type of measures have been considered, only targeting urban flooding.

An additional limitation is that the cases in this research are only selected from the pilot-areas designated in Rotterdam to go gas-free in the near future. This resulted in three different district typologies, out of the five typologies identified in Rotterdam. Because not all typologies are touched upon in the study, it is difficult to generalize the results for the entire city of Rotterdam or any other city.

Lastly, this study does not take any costs into account and therefore the third limitation in the case study design concerns the assumption regarding sewer maintenance. An assumption has been made within this research that the sewer will be replaced, simultaneously to the implementation of district heating, in case it is older than 40 years (Gemeente Rotterdam, 2016a). In reality, this would mean that in many cases the sewer will be replaced, while it could actually remain in place for another 0 – 20 years. As a result, many years of the sewer system could get 'lost' and the extra costs that leads to are not included in this research.

Within-case analysis

There are two potential limitations concerning the results from the within-case analysis. The first limitation concerns the determination of the run-off areas in all cases, and the corresponding rainwater storage required. In this research, it is assumed 70 mm of rainfall is spread over all public and private space, connected to the street, and needs to be processed in the same street. No attention has been paid to how the street is attached to the area and how the course (in terms of height) is in the street itself. This means that no account has been taken of possible points of accumulation of water, and therefore more vulnerable places, but that the spread of water over the whole street is assumed to be equal. In reality this is never the case, so to make a realistic calculation, the question where the water runs to and how high the water will be in the lowest areas should be considered. This can be considered by making a realistic run-off model of an entire area, instead of a street solely (City of Copenhagen, 2011).

The second limitation of the within-case analysis involves the determination of climate adaptation measures in all cases. Firstly, the measures in all cases were chosen empirically and in a way that they would vary over the different designs. Therefore, no unambiguous result has been obtained for a certain measure, tested in different cases, and in some cases the most obvious option may not have been chosen (for example, a water-storing road foundation in Bospolderplein). This choice was made in order to conduct an as explorative research as possible in the given time frame, but therefore may not give the most comprehensive results. Secondly, as indicated earlier, no costs are included in this study and the costs for implementation and maintenance of the various measures have therefore not been taken into account in this research, and thus not been included in the choice of measures (in addition to the costs of the 'lost' years of the sewer system). The focus has been placed on whether the measures could be implemented on a project-based and geographical basis, but as a result, in some cases, very expensive measures may have been chosen that will not quickly be implemented in reality.

Despite these limitations, the present study has enhanced the understanding of the relationship between the energy transition and climate adaptation and hopefully current research will stimulate further investigation of this important area. Possibilities for further research are discussed in section 9.2.

V.

CONCLUSION

Conclusion

The final part of this thesis, the conclusion, presents the conclusions and recommendations, derived from the results and discussion. In Chapter 8, the main question of this research is answered and final conclusions are drawn. Chapter 9 presents recommendations for the municipality of Rotterdam and for further research.

8. Conclusions

In the coming years, Rotterdam wants to simultaneously make the switch to sustainable energy and towards a climate-proof city in terms of extreme rain events, i.e. the water retention capacity of public space needs to be sufficient to prevent damage in case of heavy rainfall (70 mm in 1 hour). However, both the energy transition and climate adaptation require context-specific solutions and place large spatial claims on the already very densely built-up city of Rotterdam. By conducting an explorative case study, based on multiple and diverse cases, this study aimed to gain insights into the different types of systems integration between the energy transition and climate adaptation and thus to gain knowledge on what the energy transition implies for Rotterdam's climate adaptation goals. Eventually, this illustrates how Rotterdam's climate adaptation goals can be achieved, in context of the ongoing energy transition. This chapter concerns the conclusions of this study and answers the main question, formulated in section 1.3:

Main question

What does the energy transition imply for Rotterdam's climate adaptation goals with regard to water resilience?

The answer to the main question, presented in this chapter, is built on the answers to the research questions (section 1.3), studied by means of a literature- and desk study and the case study design and within-case analysis. The answers to the questions studied on the basis of the literature- and desk study involve information on the different responsibilities and role of urban planning in the energy transition and climate adaptation approach (general and in Rotterdam specifically), the different forms of systems integration and the energy transition- and climate adaptation strategies in Rotterdam, and are discussed in detail in section 2.4 and section 3.4. The answers to the research questions studied on the basis of the case study design and within case analysis involve the overlap between locations of the energy transition and required climate adaptation in Rotterdam, the possible climate adaptation measures that can be implemented alongside the energy transition in different cases and the different types of systems integration identified in the cases, and are discussed in section 5.2 and Chapter 6.

The main findings on the types of systems integration, discussed in subsection 7.1.1, broadly indicate that all four forms of systems integration, defined in section 2.3, are identified with regard to climate adaptation and the energy transition: geographical integration, project-based integration, physical integration and informational integration. The types of integration that have been identified in the cases in Chapter 6 involve both the integration of the technical system and the socio-institutional system. What the main research findings and different types of integration entail for Rotterdam's climate adaptation goals, is discussed below.

Firstly, the case study design (Chapter 5) revealed that an area with the building typology 'urban building block' (in this research Bospolder) has the highest percentage of streets where urban flooding occurs, in addition to the implementation of district heating. This is explained by the maximum indicative vulnerability to flooding (Table 5-1) in that type of area. It can be concluded that areas with a high indicative vulnerability to flooding (for example the 'urban building block' typology) need extra attention during the design of the district heating network and climate adaptation measures. In areas with a high indicative vulnerability to flooding, there is a great need for extra greenery in addition to a district heating network and climate adaptation measures, which entails additional problems for the subsoil layout. This allows for the expectation that of the five typologies present in Rotterdam, the energy transition will pose the largest difficulties for the climate adaptation goals in areas with the 'urban building block' typology, where the indicative vulnerability to flooding is highest and in addition less space is available.

Secondly, the results of the within-case analysis confirm that achieving the climate adaptation goals (70 mm of rainwater storage) alongside the implementation of the energy transition is possible in Rotterdam. However, achieving that actual amount of rainwater storage in all cases is only possible if more focus is put on climate adaptation measures on private land or measures that do not comply to the current guidelines of Rotterdam, in addition to the current measures in public space within the conventions of Rotterdam. This aspect of the research suggests that if Rotterdam wants to achieve both its energy and its climate adaptation goals, something will have to change in the current course they follow. The municipality will have to make a trade-off between the water storage to be achieved and the compliance with current guidelines or the area of focus for climate adaptation (public or private space).

The conclusions on the implications of the energy transition for the climate adaptation goals of Rotterdam are presented in section 8.1, by means of a division between technical- and socio-institutional implications. In section 8.2, the policy implications of the energy transition for the municipality of Rotterdam are discussed.

8.1. Technical- and socio-institutional implications of the energy transition for climate adaptation in Rotterdam

The different types of systems integration, identified in the cases in Chapter 6, contain of both technical- and socio-institutional aspects. In this section, main conclusions are drawn from the aforementioned aspects of the types of systems integration identified. These are translated into technical- and socio-institutional implications of the energy transition for climate adaptation in Rotterdam.

On the one hand, the results show that the possibilities for climate adaptation in terms of space are negatively affected by the district heating network, since less space remains available underground in public space. On the other hand, however, the results show that the construction of energy measures is creating a momentum in which other construction work or new adaptations in a street can take part. Taken together the findings, *project-based integration* (synergies between urban infrastructure systems in construction planning) of climate adaptation measures in public space in the implementation of district heating brings significant benefits, in case district heating is installed simultaneously to sewer replacement (an integral approach). In addition, the results reveal that in case the heating network is installed singularly (without sewer replacement), simultaneous implementation of climate adaptation in public space does not bring considerable benefits during construction. However, it is still essential to include climate adaptation in the initial district heating network design of a street, when underground infiltration or storage facilities are desired, to ensure climate adaptation will still be possible in the future. In other words, *geographical integration* of the two systems is necessary in those cases in order to achieve the climate adaptation goals in the future. These two types of systems integration mean that in case of an integrated approach, the municipality of Rotterdam (responsible for sewer maintenance) has to align its replacement plans with the heat supplier (responsible for the district heating network) to create a combined design and to get an overview of the cables and pipes that need to be moved. Subsequently, the designs have to be communicated to the cable and pipe owners that need to move their assets in an early stage in order to reach a joint agreement on the design and to use the momentum to execute everything simultaneously. Next, it is concluded that having an overview of potential urban flooding on street level, over the entire city, is crucial to determine whether additional efforts need to be made to realize an integrated approach, during the planning and design process of any construction project in Rotterdam. In addition, it is found that the different maintenance cycles of above- and underground assets determine whether assets are included in a particular construction or rehabilitation project and whether opportunities arise for integral adding climate adaptive measures in public space. The closer maintenance cycles come to each other, the greater the possibilities for integration become.

All designs of climate adaptation measures in private space in Chapter 6 considered, it can be concluded that climate adaptation measures in private space can contribute significantly to the water storage capacity of the street, in case gardens are present, and to the greenery of the street. Both implementation of a district heating network and installation of solar panels can positively influence climate adaptation on private land, by means of *project-based integration*. In case measures are desired from the municipality on private land, it is found that an integrated communication approach towards the residents or housing corporations is desired, so that the one does not exclude the other in the future and to emphasize the importance of simultaneous implementation. Besides, it is important that the measures are properly maintained to preserve the storage capacity, which also needs extra attention from the municipality.

Finally, it can be concluded that due to the lack of space due to the heating network, in a few streets in Rotterdam alternative climate adaptation solutions had to be found in order to meet the rainwater storage demand. These alternative solutions pose challenges in the technical and socio-institutional field, due to the incompliance with current guidelines. Failure to comply with guidelines can entail technical risks when climate adaptation measures are placed above cables and pipes or if excavation cunettes conflict. In addition, it entails challenges in terms of organization, costs and the division of responsibilities. Whether these challenges are addressed and what the trade-offs are is discussed in the subsequent section: the policy implications of the energy transition for the municipality of Rotterdam.

8.2. Policy implications for the municipality of Rotterdam

From this research it can be concluded that in case 70 mm of rainwater storage is to be achieved in all streets in Rotterdam, climate adaptation measures on private land or measures that do not comply with the regulations of Rotterdam have to be found in addition to measures in public space, within the regulations of Rotterdam. Alternatively, a choice can be made by the municipality to design the street in another, more undesirable, way. When it is decided not to comply with the climate-oriented standards and, for example, to flood a certain low-lying street more often, additional water storage can be created in an area, without additional climate adaptation measures that are proposed in this research. This means that due to the energy transition, the municipality of Rotterdam has to decide the extent to which they want to take risks and incur greater costs to ultimately achieve their climate adaptation goal to store 70 mm of rainwater in a street. A damage-costs trade-off has to be made by the municipality per street: how large the damage would become in case not enough storage is realized, which includes the chance of such an extreme rain event, and what the costs and technical risks involved would be in case 70 mm of rainwater storage is achieved with alternative measures.

Concluding from the findings of the cases, a minimum of 50 mm rainwater storage can be achieved in all cases, without measures on private land or measures that do not comply with the regulations of Rotterdam (Table 6-46). In two out of the five cases, the required 70 mm of storage can also be achieved without additional measures. In the remaining three cases, measures within the conventions of Rotterdam have to be either combined with measures on private land or measures that do not comply with the regulations of Rotterdam to achieve 70 mm of storage. In such cases, a prioritization has to be made by the municipality about what is most important: preventing nuisance and realizing the total amount of storage, on the one hand, or stimulating and/or obligating climate adaptation of private land or non-compliance with regulations on the other. In this prioritization, the additional costs that each choice entails for the municipality play the largest role. The damage costs due to flooding in case of a heavy rain event (if there is not enough storage) and the costs for the alternative climate adaptation (measures in private space or measures that do not comply with the regulations of Rotterdam) will differ per street, and will therefore have to be determined street-specific. In addition, the technical risks involved in the measures that do not comply with Rotterdam’s regulation and the risks of climate adaptation on private land, for example that they are not properly maintained, have to be considered. In this way, a well-considered decision can ultimately be made by the municipality for climate adaptation in a certain street.

In essence, the findings of this study contribute to former research in identifying the different types of systems integration between climate adaptation and the energy transition. These findings can help to ensure that the energy transition will not negatively influence the possibilities for climate adaptation in the future, but rather positively. Moreover, insight is given in the extent to which the climate adaptation goals of Rotterdam can be achieved, alongside the energy transition, and what dilemmas arise and what trade-offs have to be made when sustainable energy measures as well as climate adaptation are desired at a specific location.

9. Recommendations

The findings from this study provide valuable insights for practice, for the municipality of Rotterdam. Furthermore, the study provides guidelines for follow-up research. In this chapter, first the recommendations for the municipality are presented in section 9.1. Then, the recommendations for further research are specified in section 9.2.

9.1. Recommendations for the municipality of Rotterdam

The recommendations for the municipality for practice follow from both the discussion and conclusions and are presented below.

1. *Identify neighbourhoods with a high indicative vulnerability to flooding citywide.*
   The case study design in this research has shown that an integrated approach towards the energy transition and climate adaptation in areas with the 'urban building block' typology creates the most benefits, compared to the other two typologies studied, due to the high indicative vulnerability to flooding. Therefore, it is recommended to map the neighbourhoods in Rotterdam with a high indicative vulnerability to flooding, to know which areas need extra attention in preparation and design of the district heating network, to integrate climate adaptation.

2. *Access to sufficiently detailed information on maintenance cycles of all assets in the city and the risk of urban flooding in relevant areas in Rotterdam.*
   The results showed that climate adaptation measures in public space can efficiently be integrated in the implementation of district heating, in case of an integral approach (in combination with sewer replacement). Therefore, whether an integrated approach towards the energy transition and sewer replacement is possible (depending on the sewer age) and whether urban flooding occurs in an area (and therefore integration of climate adaptation is desired) is important information in the design phase of the district heating network. Accordingly, it is advised to create a detailed map of the risk of urban flooding in the entire city and to map the sewer maintenance needs of the entire system as detailed as possible. It is advised to set guidelines for when the sewerage system is depreciated and when it can therefore be replaced simultaneously to the heating network. In addition, in all cases cables and pipes had to be relocated to implement the district heating network. Relocating cables and pipes is most advantageous when they need to be replaced in addition. Therefore, information on which cables and pipes need to be replaced in the near future is important to determine where the heating network can best be placed. It is advised that the municipality maps the maintenance cycles of all underground assets in the relevant areas. In that way the maintenance cycles can be matched as closely as possible and it can be examined whether opportunities arise for simultaneously adding adaptive measures as well. The information required for an area where a heating network will be implemented and that should be made available to all departments of the municipality dealing with public space maintenance and investments, is:
   - Age and type of all sewer segments in an area;
   - Age and type of other underground assets;
   - Percentage of property with a risk label in an area, due to urban flooding, and results of the 'water on the street' calculation of the municipality of Rotterdam;
   - Analysis per surface water level area (peilgebied, in Dutch) to determine site-specific how much rainwater storage is needed.

   This information is especially important for areas with a high indicative vulnerability to flooding, as described in the first recommendation. Therefore, it is recommended to focus on those areas in the first instance.

3. *Standardize a form of green climate adaptation measures in the construction of a heating network.*
   Because a large part of the road, parking lanes and sidewalks is always excavated during the construction of a heating network (both singularly and integrally (in combination with sewer

replacement)) due to the distribution network and house connections, it is recommended to standardize some form of green climate adaptation measures in the construction of the district heating network in streets where flooding occurs or where the percentage of green is low. This will concern, for example, a few trees on the side of a road, green roadsides or deepened greenery. Because large parts of the street are excavated anyhow, a green adaptation measure can easily be constructed simultaneously. This can in any case ensure that if time is too limited for an integrated climate adaptation and energy transition design, at least something is always done on climate adaptation.

4. *Make a trade-off between the rainwater storage to be realized and the additional costs for the municipality associated with alternative climate adaptation measures (measures that do not comply with Rotterdam's regulations or measures on private land).*
   It is recommended that for every street where the rainwater storage deficit cannot be solved with measures in public space within the regulations of Rotterdam only, a damage-costs trade-off is made by the municipality: how large the damage would become in case not enough storage is realized and what the additional costs and risks involved in achieving 70 mm of rainwater storage would be. In this way, the municipality can make a cost-effective decision on climate adaptation measures in a street. Quantifying the damage and risks would have to be investigated more in detail in further research (section 9.2).

The following recommendations, number 4.1 and 4.2, follow when alternative climate adaptation measures have to be considered. These recommendations follow from the designs and show the most efficient ways in which 70 mm of rainwater storage can be realized alongside the energy transition in a street where measures within Rotterdam's regulations do not suffice. The costs of these measures have yet to be determined by the municipality (recommendation 4), in order to eventually make the trade-off.

4.1. *Extend the current guidelines and rules regarding underground infrastructure in Rotterdam.*
   By extending the current guidelines regarding underground infrastructure, stated in the 'Underground Management Manual' (Handboek Beheer Ondergrond, in Dutch) and following from discussions with experts, additional space is created in public space for the implementation of both the energy transition and climate adaptation measures. The guidelines recommended to extend, are:

   - *The premise that no obstacles may be placed above existing cables and pipes.* By disregarding this rule in case limited space is available underground, much more room is created for climate adaptation. Obstacles placed above existing cables and pipes will cause additional difficulties for owners that need to maintain their cables and pipes prematurely, but it is expected that this will only happen in a few cases. The additional difficulties and costs resulting from an obstacle, in case owners do need to prematurely access their assets, could be covered by the municipality. This has to be weighed up against the costs of damage caused by excessive rainfall (recommendation 4).
   - *The instruction that overlap between the cunettes of underground infrastructures should in all cases be avoided (minimum horizontal distance maintained).* Overlap of cunettes entails risks when one of the two, in case of maintenance of replacement, is completely excavated. If that happens, there is a risk that the pressure on the other pipe drops and that the pipe will pop out of its place. To avoid this risk, vertical excavation should be used in the future instead of excavation of the entire cunette. Vertical excavation can result in considerably higher costs, which again have to be weighed up against the costs of damage caused by excessive rainfall (recommendation 4).

4.2. *Focus on climate adaptation measures in private space (simultaneously to the implementation of the energy transition).*
   Since the implementation of the energy transition can have a positive impact on adaptation measures in private space (i.e. underground measures, green roofs) by means of simultaneous implementation (described in section 8.1), the municipality can also focus on measures on private land in case measures in public space cannot provide sufficient storage. If measures on private land are desired, an integrated communication approach towards the owners of houses

(residents or housing corporations) is recommended, to emphasize the purpose of simultaneous implementation of energy measures and climate adaptation. This argument could be strengthened by offering integral funding and substantial advice for making the house adjustments needed for the heating network and implementing climate adaptation. This also includes organizing meetings in which residents of an entire street come together to make a joint climate adaptation plan and linking the owners of the houses to the contractor of the construction work in public space . The additional costs associated with integral funding, advice and organization have to be weighed up against the costs of damage caused by excessive rainfall (recommendation 4).

9.2. Recommendations for further research

The recommendations for further research follow from both the limitations and the findings of this research and are presented below.

1. *Include implementation and maintenance costs of sewer replacement and climate adaptation within the research.*
   Within the scope of this research, certain assumptions have been made regarding the sewer system and choice of climate adaptation measures, in which the costs of the 'lost' years of the sewer system and costs for implementation and maintenance of the various measures have not been included. By involving these costs in follow-up research, it can be examined whether an integrated approach towards the energy transition, sewer replacement and climate adaptation measures is actually cost-effective. The reduced nuisance for residents due to an integrated approach should also be included in this examination in some way, since an integrated approach can make a big difference to the satisfaction of the residents.

2. *Study the actual costs of damage due to excessive rainfall (if insufficient storage is realized) and the alternative climate adaptation measures (that do not comply to Rotterdam's regulations or in private space).*
   To eventually make a prioritization about what is most important (preventing nuisance and realizing the total amount of storage, on the one hand, or stimulating and/or obligating climate adaptation of private land or non-compliance with regulations on the other), the municipality of Rotterdam has to decide the extent to which they want to take risks and incur greater costs to ultimately achieve their climate adaptation goal to store 70 mm of rainwater in a street. A damage-costs trade-off has to be made and to do so, additional research is needed into the quantification of certain damage and costs.

3. *Translate the energy transition in a broader sense*.
   Because Rotterdam's energy strategy has been followed in this research, only a high temperature district heating network, using residual heat from industrial activities, and solar panels were included as sustainable energy solutions. Therefore, it is recommended other sustainable energy solutions are included in future research as well, such as heat pumps and alternative heating or cooling sources for the district heating network, like sewer-, aqua- or geothermal heat. By including these solutions, the spatial impact of the sustainable energy solutions in public space will become larger and the consequences for climate adaptation will therefore change (and become larger) as well.

4. *Study more and different areas, including the remaining district typologies.*
   The pilot-areas that were studied in this research contained only 3 out of the 5 district typologies, identified in Rotterdam. Accordingly, it is recommended the remaining typologies are studied in further research, to determine to what extent an integrated approach towards the energy transition and climate adaptation is desired in those areas. In addition, due to lack of time, only a limited number of cases has been selected and it would therefore be interesting to study more areas with the same typology in follow-up research.

5. *Focus on the additional climate topics.*
   Due to time limitations, this study only addressed the climate topic 'urban flooding'. However, long periods of drought and excessive heat are additional climate issues that pose major threats on urban areas. These issues require different adaptation solutions than the solutions addressing urban flooding and should therefore also be considered in further research.

6. *Include the remaining transitions.*
   Within the scope of this research, only climate adaptation and the energy transition were addressed, out of the different transition themes Rotterdam is focusing on. However, the mobility, economy and circular transitions and housing challenge pose spatial claims and organizational issues on the city as well. Therefore, it would be interesting to look into the implications of the remaining transitions on climate adaptation possibilities in further research.

Bibliography

Acatec (National Academy of Science and Engineering), ., Leopoldine (National Academy of Sciences), ., & Akademiunion (Union of the German Academics of Sciences and Humanities), . (2016). *Flexibility Concepts for the German power supply in 2050*.

Aedes. (2018). *Aansluiten op warmtenetten - handreiking*. *April*. www.ce.nl

Arnbjerg-Nielsen, K., & Fleischer, H. S. (2009). Feasible adaptation strategies for increased risk of flooding in cities due to climate change. *Water Science and Technology*. https://doi.org/10.2166/wst.2009.298

Ashley, R., Lundy, L., Ward, S., Shaffer, P., Walker, L., Morgan, C., Saul, A., Wong, T., & Moore, S. (2013). Water-sensitive urban design: opportunities for the UK. *Municipal Engineer*, *166*(ME2). https://doi.org/10.1680/muen.12.00046

Atelier GroenBlauw. (2019). *Hoogteverschillen in groen*. https://www.huisjeboompjebeter.nl/acties/relief-in-de-tuin/

Boogaard, F., Bruins, G., & Wentink, R. (2006). *Wadi's: aanbevelingen voor ontwerp, aanleg en beheer*.

Canto-Perello, J., & Curiel-Esparza, J. (2013). Assessing governance issues of urban utility tunnels. *Tunnelling and Underground Space Technology*, *33*, 82–87. https://doi.org/10.1016/j.tust.2012.08.007

Carbon Disclose Project, . (2012). *Measurement for Management: CDP Cities 2012 Global Report: Including Special Report on C40 Cities.*

Carey, B. D., & Lueke, J. S. (2013). Optimized holistic municipal right-of-way capital improvement planning. *Canadian Journal of Civil Engineering*, *40*(12), 1244–1251. https://doi.org/10.1139/cjce-2012-0183

CE Delft, ., APPM, ., & Generation Energy, . (2018). *Basisdocument Regionale Energiestrategie Regio Rotterdam-Den Haag*. https://www.rijswijk.nl/sites/default/files/regionale_energiestrategie_regio_rotterdam-den_haag.pdf

City of Copenhagen. (2011). *Copenhagen Climate Adaptation Plan*.

Coenen, L., Raven, R., & Verbong, G. (2010). Local niche experimentation in energy transitions: A theoretical and empirical exploration of proximity advantages and disadvantages. *Technology in Society*, *32*(4), 295–302. https://doi.org/10.1016/j.techsoc.2010.10.006

Creswell, J. W., & Miller, D. L. (2000). Determining Validity in Qualitative Inquiry. *Theory Into Practice*, *39*(3), 124–130. https://doi.org/10.1207/s15430421tip3903_2

Dadashpoor, H., Azizi, P., & Moghadasi, M. (2019). Land use change, urbanization, and change in landscape pattern in a metropolitan area. *Science of the Total Environment*, *655*, 707–719. https://doi.org/10.1016/j.scitotenv.2018.11.267

Davoudi, S., Brooks, E., & Mehmood, A. (2013). Evolutionary Resilience and Strategies for Climate Adaptation. *Planning Practice and Research*, *28*(3), 307–322. https://doi.org/10.1080/02697459.2013.787695

De Graaf, R., Boeffen, B., den Ouden, T., & Souwer, B. (2013). *Studie naar de huidige en toekomstige waterbehoefte van stedelijke gebieden*.

De Pascali, P., & Bagaini, A. (2018). Energy Transition and Urban Planning for Local Development. A Critical Review of the Evolution of Integrated Spatial and Energy Planning. *Energies*. https://doi.org/10.3390/en12010035

DeGraaf, G., & Huberts, L. W. J. C. (2008). Portraying the nature of corruption using an explorative case study design. *Public Administration Review*, *68*(4), 640–653. https://doi.org/10.1111/j.1540-6210.2008.00904.x

Deltares, & KWR. (2020). *The influence of subsurface heat sources on the drinking water temperature*.

Deng, Y., Cardin, M. A., Babovic, V., Santhanakrishnan, D., Schmitter, P., & Meshgi, A. (2013). Valuing flexibilities in the design of urban water management systems. *Water Research*, *47*(20), 7162–7174. https://doi.org/10.1016/j.watres.2013.09.064

Despotovic, J., Plavsic, J., Stefanovic, N., & Pavlovic, D. (2005). Inefficiency of storm water inlets as a source of urban floods. *Water Science and Technology*. https://doi.org/10.2166/wst.2005.0041

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. In *Source: The Academy of Management Review* (Vol. 14, Issue 4). https://www.jstor.org/stable/258557

Encyclopaedia Brittanica, . (2015). *Paris Agreement | Britannica.com*. https://www.britannica.com/topic/Paris-Agreement-2015

Energieswitch010. (2019). *Rotterdams Klimaatakkoord*. www.energieswitch010.nl

EPA, (US Environmental Protection Agengy). (2008). *Reducing Urban Heat Islands: Compendium of Strategies - Urban Heat Island Basics*. https://www.epa.gov/heat-islands/

Esri. (2020). *Klimaateffectenatlas*. http://www.klimaateffectatlas.nl/nl/

European Environment Agency, . (2017). *Energy and climate change*. https://www.eea.europa.eu/signals/signals-2017/articles/energy-and-climate-change

Fang, D., & Chen, B. (2017). Linkage analysis for the water–energy nexus of city. *Applied Energy*, *189*, 770–779. https://doi.org/10.1016/j.apenergy.2016.04.020

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Steen Mikkelsen, P., Rivard, G., Uhl, M., Dagenais, D., & Viklander, M. (2015). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal*, *12*(7), 525–542. https://doi.org/10.1080/1573062X.2014.916314

Ford, J. D., Berrang-Ford, L., & Paterson, J. (2011). A systematic review of observed climate change adaptation in developed nations. *Climatic Change*, *106*, 327–336. https://doi.org/10.1007/s10584-011-0045-5

Fratini, C. F., Geldof, G. D., Kluck, J., & Mikkelsen, P. S. (2012). *Three Points Approach (3PA) for urban flood risk management: A tool to support climate change adaptation through transdisciplinarity and multifunctionality*. https://doi.org/10.1080/1573062X.2012.668913

FutereEarth, & World Climate Research Programme. (2019). *Global Carbon Budget Presentation*.

Geels, F. W. (2010). Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Research Policy*, *39*, 495–510. https://doi.org/10.1016/j.respol.2010.01.022

Gemeente Rotterdam. (2010). *Handboek Openbare Ruimte Rotterdamse Stijl*.

Gemeente Rotterdam. (2013). *Rotterdamse Adaptatie Strategie*.

Gemeente Rotterdam. (2016a). *Gemeentelijk rioleringsplan*.

Gemeente Rotterdam. (2016b). *Gemeentelijk Rioleringsplan*. https://www.rotterdam.nl/wonen-leven/grp/Gemeentelijk_rioleringsplan.pdf

Gemeente Rotterdam. (2017). *Wijkgestuurd Werken - Werk in Uitvoering - Keten Buitenruimte*.

Gemeente Rotterdam. (2018a). *Plan van Eisen: Stedelijk Water*.

Gemeente Rotterdam. (2018b). *Stappenplan Aardgasvrije Wijken*.

Gemeente Rotterdam. (2019a). *Energietransitie Uitvoeringsplan*. https://www.persberichtenrotterdam.nl/uploads/Uitvoeringsplan Energietransite 2019-2020.pdf

Gemeente Rotterdam. (2019b). *Fietskoers 2025*.

Gemeente Rotterdam. (2019c). *Handboek Beheer Ondergrond Rotterdam*.

Gemeente Rotterdam. (2019d). *Omgevingsvisie “De Veranderstad”* (Vol. 24, Issue 10). https://doi.org/10.1055/s-0039-1700393

Gemeente Rotterdam. (2019e). *Raadsakkoord energietransitie*.

Gemeente Rotterdam. (2019f). *Rotterdam Duurzaamheidskompas* (Issue September).

Gemeente Rotterdam. (2019g). *Rotterdam Weatherwise Urgency Document*. https://www.rotterdam.nl/wonen-leven/rotterdams-weerwoord/

Gemeente Rotterdam. (2019h). *Rotterdams Weerwoord Urgentiedocument*.

Gemeente Rotterdam. (2019i). *Schone Energie Strategie* (Issue September).

Gemeente Rotterdam. (2020a). *Concept Gemeentelijk Rioleringsplan 2021-2025 - Van buis naar buitenruimte*.

Gemeente Rotterdam. (2020b). *Leidingenverzamelkaart*. https://www.gis.rotterdam.nl/gisweb2/default.aspx

Gemeente Rotterdam, Waterschap Hollandse Delta, Hoogheemraadschap van Schieland en de Krimpenerwaard, & Hoogheemraadschap van Delfland. (2013). *Herijking Waterplan 2 Rotterdam*.

Goosen, H., De Groot-Reichwein, M. A. M., Masselink, L., Koekoek, A., Swart, R., Bessembinder, J., Witte, J. M. P., Stuyt, L., Blom-Zandstra, G., & Immerzeel, W. (2013). *Climate Adaptation Services for the Netherlands: an operational approach to support spatial adaptation planning*. https://doi.org/10.1007/s10113-013-0513-8

GPKL, Netbeheer Nederland, & VEWIN. (2012). *Open of gesloten verharding boven kabels en leidingen?* 1–3.

Grafakos, S., Trigg, K., Landauer, M., Chelleri, L., & Dhakal, S. (2019). Analytical framework to evaluate the level of integration of climate adaptation and mitigation in cities. *Climatic Change*, *154*, 87–106. https://doi.org/10.1007/s10584-019-02394-w

Grafakos, S., Viero, G., Reckien, D., Trigg, K., Viguie, V., Sudmant, A., Graves, C., Foley, A., Heidrich, O., Mirailles, J. M., Carter, J., Chang, L. H., Nador, C., Liseri, M., Chelleri, L., Orru, H., Orru, K., Aelenei, R., Bilska, A., … Dawson, R. (2020). Integration of mitigation and adaptation in urban climate change action plans in Europe: A systematic assessment. *Renewable and Sustainable Energy Reviews*, *121*. https://doi.org/10.1016/j.rser.2019.109623

Guerreiro, S. B., Dawson, R. J., Kilsby, C., Lewis, E., & Ford, A. (2018). Future heat-waves, droughts and floods in 571 European cities. *Environmental Research Letters*. https://doi.org/10.1088/1748-9326/aaaad3

Hamiche, A. M., Stambouli, A. B., & Flazi, S. (2016). A review of the water-energy nexus. *Renewable and Sustainable Energy Reviews*, *65*, 319–331. https://doi.org/10.1016/j.rser.2016.07.020

Hartman, E. C., & Bloemendal, J. M. (2015). Warm rioolwater: vergeten energie met potentie. *TVVL Magazine*, *09*, 32–35.

Haug, J. J. M., & Schuurman, F. (2015). *Voetpaden Voor Iedereen*. www.woordendiespreken.nl

He, C., Zhou, L., Ma, W., & Wang, Y. (2019). Spatial assessment of urban climate change vulnerability during different urbanization phases. *Sustainability (Switzerland)*, *11*(8). https://doi.org/10.3390/su11082406

Hirschl, B. (2018). The Urban Energy Transition: Pathways to Climate Neutrality in Our Cities. In *Urban Energy Transition* (pp. 245–254). Elsevier. https://doi.org/10.1016/b978-0-08-102074-6.00027-9

Hoang, L., & Fenner, R. A. (2015). System interactions of stormwater management using sustainable urban drainage systems and green infrastructure. *Urban Water Journal*. https://doi.org/10.1080/1573062X.2015.1036083

Hunt, D. V. L., Nash, D., & Rogers, C. D. F. (2014). Sustainable utility placement via Multi-Utility Tunnels. *Tunnelling and Underground Space Technology*, *39*, 15–26. https://doi.org/10.1016/j.tust.2012.02.001

Hussey, K., & Pittock, J. (2012). The energy-water nexus: Managing the links between energy and water for a sustainable future. *Ecology and Society*, *17*(1). https://doi.org/10.5751/ES-04641-170131

HVC Groep. (2020). *Alles Over Onze Warmtenetten*. https://www.hvcgroep.nl/over-afval-energie/alles-over-onze-warmtenetten#:~:text=Zo werkt een warmtenet&text=Het warme water stroomt via,retourleiding terug naar de warmtebron.

IPCC. (2015). Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Technical report. In *IPCC*. Gian-Kasper Plattner.

Kaspersen, P. S., Ravn, N. H., Arnbjerg-Nielsen, K., Madsen, H., & Drews, M. (2017). Comparison of the impacts of urban development and climate change on exposing European cities to pluvial flooding. *Hydrol. Earth Syst. Sci*, *21*, 4131–4147. https://doi.org/10.5194/hess-21-4131-2017

Kennisportaal Ruimtelijke Adaptatie. (2020). *Bijsluiter gestandaardiseerde stresstest Ruimtelijke Adaptatie*. https://ruimtelijkeadaptatie.nl/stresstest/bijsluiter/

Kenway, S. J., Lant, P. A., Priestley, A., & Daniels, P. (2011). *The connection between water and energy in cities: a review*. https://doi.org/10.2166/wst.2011.070

Kleerekoper, L., Koekoek, A., & Kluck, J. (2017). *Klimaatadaptatie op basis van wijktypen*.

KNMI. (2014). *Klimaatscenario's Voor Nederland 2014*. http://www.klimaatscenarios.nl/images/Brochure_KNMI14_NL.pdf

Kongsager, R., Locatelli, B., & Chazarin, F. (2016). Addressing Climate Change Mitigation and Adaptation Together: A Global Assessment of Agriculture and Forestry Projects. *Environmental Management*. https://doi.org/10.1007/s00267-015-0605-y

König, E. (2020, June 8). Het vergoenen van deze Rotterdamse wijk is een gevecht om de ondergrond. *NRC*. https://www.nrc.nl/nieuws/2020/06/08/ondergronds-puzzelen-met-warmtenet-en-bomen-a4002113

Koudstaal, K., & Trouwborst, E. (2014). *Ontwerpaspecten waterpasserende verharding*. *0279*.

Krusenvik, L. (2016). *Using Case Studies as a Scientific Method: Advantages and Disadvantages*.

KWR. (2017). *Warme drukte in de ondergrond*. https://www.kwrwater.nl/actueel/warme-drukte-in-de-ondergrond/

Landauer, M., Juhola, S., & Klein, J. (2019). The role of scale in integrating climate change adaptation and mitigation in cities. *Journal of Environmental Planning and Management*, *62*(5), 741–765. https://doi.org/10.1080/09640568.2018.1430022

Liander. (2018). *Nieuwe warmteoplossingen: het perspectief vanuit de netbeheerder*.

Lund, H., Duic, N., Østergaard, P. A., & Mathiesen, B. V. (2018). Future district heating systems and technologies: On the role of smart energy systems and 4th generation district heating. *Energy*, *165*, 614–619. https://doi.org/10.1016/j.energy.2018.09.115

Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, J. E., Hvelplund, F., & Mathiesen, B. V. (2014). 4th Generation District Heating (4GDH). Integrating smart thermal grids into future sustainable energy systems. In *Energy* (Vol. 68, pp. 1–11). Elsevier Ltd. https://doi.org/10.1016/j.energy.2014.02.089

Masson-Delmotte, V., Zhai, P., Pörtner, H. O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J. B. R., Chen, Y., Zhou, X., Gomis, M. I., Lonnoy, E., Maycock, T., Tignor, M., & Waterfield, T. (2018). *IPCC 2018: Summary for Policymakers SPM*.

Massop, H. T. L., Kiestra, J. W. J., & van der Gaast, E. (2005). *De doorlatendheid van de bodem voor infiltratiedoeleinden*.

Mastrandrea, M. D., Heller, N. E., Root, T. L., Schneider, S. H., Heller, N. E., & Schneider, S. H. (2010). Bridging the gap: linking climate-impacts research with adaptation planning and management. *Climatic Change*, *100*, 87–101. https://doi.org/10.1007/s10584-010-9827-4

Meijberg, I. E. (2018). *Stop het graven: In 2024 liggen in alle kabels en leidingen in goten*. 1–5.

Milieu Centraal. (2019). *Stappenplan aardgasvrij wonen*. https://www.milieucentraal.nl/energie-besparen/energiezuinig-huis/wonen-zonder-aardgas/stappenplan-aardgasvrij-wonen/

Ministerie van Economische Zaken en Klimaat. (2019). *Klimaatakkoord*. 15–37. https://www.klimaatakkoord.nl/binaries/klimaatakkoord/documenten/publicaties/2019/06/28/klimaatakkoord/klimaatakkoord.pdf

Müller, N., Kuttler, W., & Barlag, A.-B. (2013). *Counteracting urban climate change: adaptation measures and their effect on thermal comfort*. https://doi.org/10.1007/s00704-013-0890-4

Nieuwenhuis, E., Cuppen, E., Langeveld, J., & De Bruijn, H. (2020). *Towards the integrated management of urban water systems*.

Palla, A., Colli, M., Candela, A., Aronica, G. T., & Lanza, L. G. (2018). Pluvial flooding in urban areas: the role of surface drainage efficiency. *Journal of Flood Risk Management*, *11*, S663–S676. https://doi.org/10.1111/jfr3.12246

PBL. (2016). *Cities in Europe - Facts and figures on cities and urban areas*.

Ping, M. C. W. (2017). *Cloudburst Solutions in Copenhagen*. https://acwi.gov/climate_wkg/

Port of Rotterdam. (2019). *Chemische industrie*. https://www.portofrotterdam.com/nl/zakendoen/vestigen/gevestigde-industrie/raffinage-en-chemie/chemische-industrie

Pothof, I., van Heeringen, K.-J., Piovesan, T., Vreeken, T., Loverdou, L., Talsma, J., Kuipers, H., van Esch, B., & et al. (2019). *Slim malen - Energie besparen* (27th ed.). STOWA. www.stowa.nl

QGIS Development Team. (2020). *QGIS 3.4.4 - Geographic Information System, Open Source Geospatial Foundation Project*. http://qgis.osgeo.org

Rijksoverheid. (2018). *Deltaplan Ruimtelijke Adaptatie*. https://ruimtelijkeadaptatie.nl/publish/pages/155078/bestuursakkoord-klimaatadaptatie.pdf

Rinaldi, S. M., Peerenboom, J. P., & Kelly, T. K. (2001). Identifying, understanding, and analyzing critical infrastructure interdependencies. *IEEE Control Systems Magazine*, *21*(6), 11–25. https://doi.org/10.1109/37.969131

Ritzema, H. P., & Van Loon-Steensma, J. M. (2018). Coping with Climate Change in a densely Populated Delta: A Paradigm Shift in Flood and Water Management in The Netherlands. *Irrigation and Drainage*, *67*, 52–65. https://doi.org/10.1002/ird.2128

Sdringola, P., Proietti, S., Astolfi, D., & Castellani, F. (2018). *Combined Heat and Power Plant and District Heating and Cooling Network: A Test-Case in Italy With Integration of Renewable Energy*. https://doi.org/10.1115/1.4040196

Stichting RIONED. (2006). *Stedelijke Wateropgave: Vergelijking normen voor water op straat en inundatie*.

Stichting RIONED. (2007). *Maatregelen*. https://www.riool.net/kennisbank

Stichting RIONED. (2015). *Groene daken nader beschouwd*.

Stichting RIONED. (2018). *Waterstromen In Beeld*. www.stowa.nl

Stichting RIONED. (2019a). *Bui01 - Bui10*. https://www.riool.net/bui01-bui10

Stichting RIONED. (2019b). *Defaultwaarden Inloopparameters Inloopmodellen*. Filterhulp Modelleren Hydraulisch Functioneren. https://www.riool.net/defaultwaarden-inloopparameters-inloopmodellen

Stichting RIONED. (2020). *Systeemoverzicht Stedelijk Water*. 1–74.

Stigka, E. K., Paravantis, J. A., & Mihalakakou, G. K. (2014). *Social acceptance of renewable energy sources: A review of contingent valuation applications*. https://doi.org/10.1016/j.rser.2013.12.026

STOWA. (2018). *Handreiking Aquathermie*.

Van de Ven, F. H. M. (2016). Water Management in Urban Areas. *Tu Delft Faculty of Civil Engineering and Geosciences*, *January*, 357.

van Gastel, E. (2019). *Liander, Enexis en Stedin: huishoudens verzwaren elektriciteisaansluiting vanwege verduurzaming*. Solar Magazine.

Vergroesen, T., Brolsma, R., & Tollenaar, D. (2013). *Verwerking van extreme neerslag in stedelijk gebied*.

Verlinde, J. (2020). *Weerwoord Voorjaarsnota 2020*.

Vernay, A. L., & Boons, F. (2015). Assessing Systems Integration: A Conceptual Framework and a Method. *Systems Research and Behavioral Science*, *32*(1), 106–123. https://doi.org/10.1002/sres.2221

Vernay, A. L., Mulder, K. F., Kamp, L. M., & De Bruijn, H. (2013). Exploring the socio-technical dynamics of systems integration-the case of sewage gas for transport in Stockholm, Sweden. *Journal of Cleaner Production*, *44*, 190–199. https://doi.org/10.1016/j.jclepro.2012.11.040

Verschuren, P., & Doorewaard, H. (2010). *Designing a Research Project* (Issue 1). https://doi.org/10.16309/j.cnki.issn.1007-1776.2003.03.004

Wamsler, C., & Raggers, S. (2018). Principles for supporting city – citizen commoning for climate adaptation : From adaptation governance to sustainable transformation. *Environmental Science and Policy*, *85*(December 2017), 81–89. https://doi.org/10.1016/j.envsci.2018.03.021

Wang, H., Wang, H., Zhou, H., & Zhu, T. (2018). Modeling and optimization for hydraulic performance design in multi-source district heating with fluctuating renewables. *Energy Conversion and Management*, *156*, 113–129. https://doi.org/10.1016/j.enconman.2017.10.078

Water Sensitive Rotterdam. (2020). *No Title*. https://www.watersensitiverotterdam.nl/

Willows, R., Reynard, N., Meadowcroft, I., & Connell, R. (2003). *Climate adaptation: Risk, uncertainty and decision-making*.

Wilson, E., & Piper, J. (2010). *Spatial Planning and Climate Change*. Taylor & Francis Group. https://books.google.nl/books?hl=nl&lr=&id=MfYtCgAAQBAJ&oi=fnd&pg=PP1&dq=spatial+planning+adaptation+mitigation&ots=aflykc_qwr&sig=9nnT_gVCkasK5FhwsSebM5zjcwM#v=onepage&q&f=false

Yin, R. K. (1994). Case Study Research Design and Methods. In *Applied Social Research Methods Series* (2nd ed., Vol. 5).

Yin, R. K. (2003). *Case Study Research: Design and Methods (Applied Social Research Methods)*. Sage Publications.

VI.

APPENDICES

Appendix A – Public space planning process of the municipality of Rotterdam

Appendix B – Spatial impact of the district heating network in Rotterdam

Appendix C – Climate adaptation measures in Rotterdam

Appendix D – Construction site visit and interview

Appendix E – District typologies in Rotterdam

Appendix F – Case study design: case selection

A. Public space planning process of the municipality of Rotterdam

In this Appendix, a concept version of a planning diagram of public space projects within the municipality of Rotterdam is presented. The diagram contains the process from the vision formation up to implementation and all the parties involved.

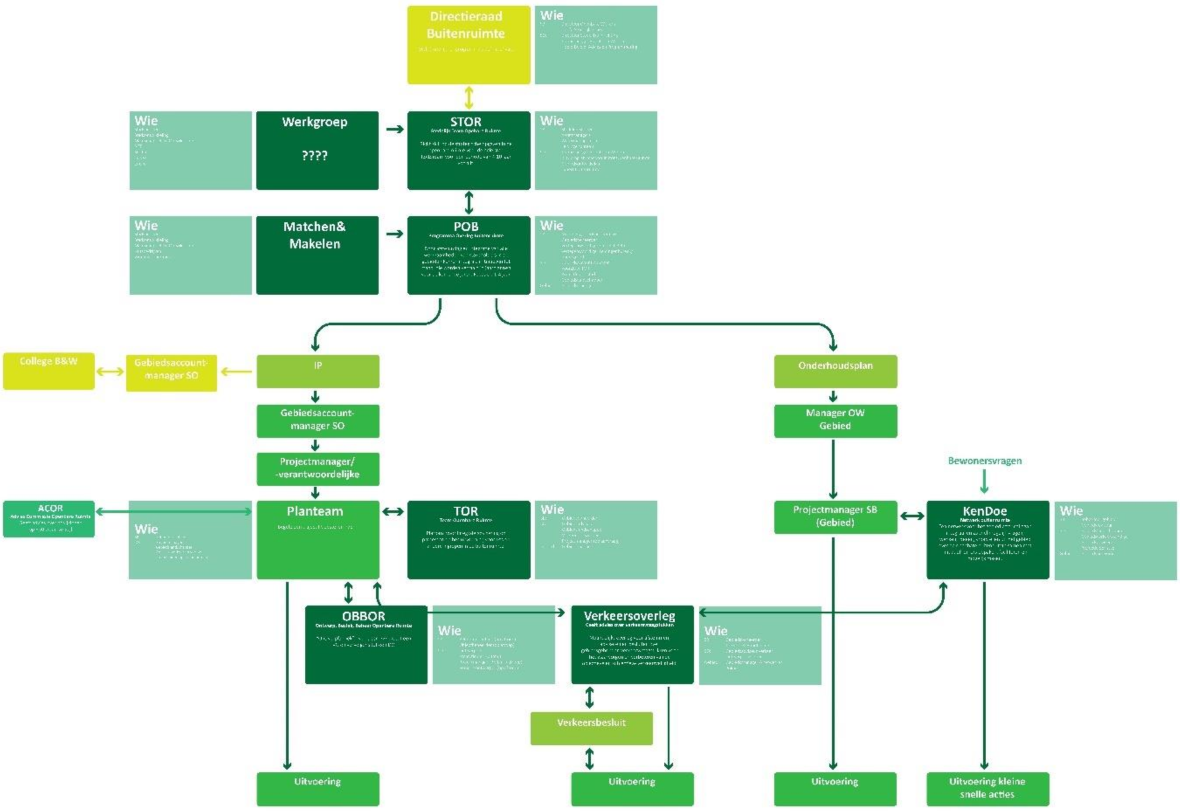

Figure A-1 Concept version of a planning diagram of public space projects within the municipality of Rotterdam: from vision formation up to implementation (Gemeente Rotterdam, 2020)

B. Spatial impact of the district heating network in Rotterdam

In Table B-1, information regarding different pipes of the district heating network, according to the guidelines of Rotterdam, is displayed. The coverage relative to ground level is based on the 'Underground Management Manual' of the municipality of Rotterdam and the diameters of the pipes are based on guidelines offered by Eneco (Eneco, 2020, confidential file).

Table B-1 Information on different pipes of the district heating network

Pipe	Nr. Of pipes	Diameter of pipes, including insulation [mm]	Coverage relative to existing ground level [m]	Location
Transport	2	400 – 710 (DN250-DN500)	1,00	Roadways
Primary distribution	2	140 – 355 (DN50-DN200)	0,70	Roadways
Secondary distribution	2	140 – 225 (DN50-DN100)	0,70	Roadways
House connection	2	110 – 140 (DN32-DN50)	0,90	Roadways and sidewalks

C. Climate adaptation measures in Rotterdam

In this Appendix, possible and promising climate adaptation measures for Rotterdam are discussed. In Table C-1, the ‘building blocks’, composed by the municipality of Rotterdam as promising measures for extreme rainfall, are listed. In Table C-2, additional promising climate adaptation measures, according to the research institute RIONED, are listed. In Figure C-1, a visualisation of all measures is presented.

The guidelines regarding application of all measures and the average lifespan of the measures are based on the study of ‘Deltares’ and ‘Knowledge for Climate’ (Vergroesen et al., 2013) and on adaptation measures research carried out by RIONED (Stichting RIONED, 2007).

The infiltration capacity, and thereby the storage capacity, depends on the permeability of the soil and the moisture content. In this research it is assumed the soil is unsaturated in the beginning of a rainfall event. According to Massop et al. (2005), the following infiltration rates (k-values) for different types of subsoil can be assumed (Massop et al., 2005):

- Clay: k = 0,05 m/day = 2,1 mm/hour
- Sand: k = 2 m/day = 83,33 m/hour
- Peat: k = 0,1 m/day = 4,2 mm/hour

The top layer of the soil in Rotterdam consists of an sand elevation and foundation, but the infiltration capacity has often declined during the years, due to compaction. According to the default values for run-in parameters, for run-in models (Defaultwaarden inloopparameters inloopmodellen, in Dutch), developed by RIONED, the following values, with a safe margin, are used for storage in and on unpaved surface: 10 mm of surface storage and 10 mm per hour infiltration loss (Stichting RIONED, 2019b). These values are used in this research, in case no soil improvement is applied. This means, the total runoff towards the paved surfaces is reduced by:

$$v_{eff,unp} = 10\,\frac{\text{mm}}{\text{hour}} * 1\ hour * A_{unp} + 10\ mm *\ A_{unp}$$ **(Formula C-1)**

Where $v_{eff,unp}$ indicates the effective storage volume of the unpaved surface (m^3) and A_{unp} indicates the surface area of the unpaved surface.

In case the unpaved surface is deepened (i.e. deepened green strips), additional storage is realized. In this research, it is assumed the green is deepened by 150 mm (Atelier GroenBlauw, 2019). In that case the surface storage increases from 10 mm to 150 mm.

In case infiltration facilities are installed, with soil improvement with a sufficiently large k-value (k = 1,5 – 2 m/day), the storage capacity (m^3) can be calculated with:

$$v_{eff,inf} = V_{inf} * P_{inf} + \left(V_{gvb} - V_{inf}\right) * P_{gvb}$$ **(Formula C-2)**

Where v_{eff} indicates the effective storage volume of the infiltration measure (m^3), V_{inf} indicates the volume of the infiltration element (m^3), P_{inf} indicates the porosity of the infiltration element, V_{gvb} indicates the volume of the soil improvement up to the ground water level (m^3) and P_{gvb} indicates the porosity of the soil improvement. In this research, the following effective porosity values are assumed (Van de Ven, 2016):

- Course gravel: 40%
- Fine gravel: 30%
- Sand: 25%

Table C-1 Promising climate adaptation measures for retaining water at street level ('building blocks'), according to the municipality of Rotterdam

Measure	Category	Conditions of application	Life span	Possible water storage capacity	Additional adaptation
A. Hollow space in sandy road and parking foundation	Infiltration and storage	• Sufficient dewatering depth • Soil improvement • Effective porosity of layer = 25%	40 - 60 years (in case of sufficient maintenance)	Formula C-2	Drought
B. Water-storing road foundation	Infiltration and storage	• Sufficient dewatering depth • Soil improvement • Effective porosity of layer = 25%	40 - 60 years (in case of sufficient maintenance)	Formula C-2	Drought
C. Water storage in coarse granulate below the parking lanes	Infiltration and storage	• Sufficient dewatering depth • Soil improvement • Effective porosity of layer = 40% • Max. 0,5 m height	40 - 60 years (in case of sufficient maintenance)	Formula C-2	Drought
D. Water storage in crates below parking lanes	Infiltration and storage	• Well-draining soil improvement is installed around facility (higher permeability than underlying natural soil) • Permeable natural soil, sufficient dewatering depth	30 years (in case of sufficient maintenance)	Formula C-1; Hollow space of crates is 95% of volume	Drought

		• Minimum soil coverage of 40 cm • Bottom at least 30 cm above groundwater level			
E. Water storage on roadway and parking lanes	Storage	• Hollow street profile • Maximum storage of 30 mm	45 years (element pavers)	110 mm * surface area of hollow street	-
F. Water storage in green parking lanes	Infiltration and storage	• Surplus of parking in the street • Sufficient dewatering depth • Soil improvement	Indefinite (in case of sufficient maintenance)	Formula C-2	Heat, drought
G. Green strips along the façade	Infiltration and storage	• Sufficient dewatering depth • Soil improvement	Indefinite (in case of sufficient maintenance)	Formula C-2	Heat, drought
H. Green in street profile (sidewalk, roadway)	Infiltration and storage	• Sufficient dewatering depth • Soil improvement	Indefinite (in case of sufficient maintenance)	Formula C-2	Heat, drought
I. Water storage in the sewer system (enlarge sewer pipe or DT sewer)	Storage, Conveyance	• Well-draining soil improvement is installed around facility (higher permeability than underlying natural soil) • Install horizontally • Top of the pipe 20 cm below canal level	40-60 years	Dependent on pipe dimensions	Drought

J. Water storage at the roof	Storage	• Private measure placed on flat roofs • Suitable roofs: EDPM, bitumen, concrete; not suitable roofs: corrugated iron, sink, roof tiles • Roof slope: 0 – 9%	45-50 years	Water absorption: 25 liters / m^2 = 0,025 m^3/m^2	Heat
K. Green façade	Storage	• Private measure placed on walls	Indefinite (in case of sufficient maintenance)	-	Heat
L. Rainwater tank	Storage	• Private measure placed in gardens • Most common sizes: 3000 L or 5000 L	Indefinite	Volume of the rainwater tank (based on volume of rain that falls on private property)	-

Table C-2 Additional promising climate adaptation measures in urban areas, according to the research institute RIONED (Stichting RIONED, 2020)

Measure	Category	Conditions of application	Lifespan	Possible water storage capacity	Additional adaptation
M. Paved ditch	Storage and conveyance	• In case of conveyance: safe location of water storage needs to be close by • In case of infiltration: sufficient dewatering depth and soil improvement	45 years (element pavement)	Volume of the ditch	-
N. Bioswale (with grass or plants)	Infiltration and storage	• Sufficient dewatering depth • Drainage system included: water can be transported from an area with little infiltration capacity to an area with more infiltration capacity • Permeability drainage sand: >2 m/day	60 years (in case of sufficient maintenanc e)	Volume of the swale below the inlet points for water	Heat, drought
O. Trees	Infiltration and storage	• Sufficient dewatering depth • Soil improvement	40 years	Formula C-2	Heat, drought

In Figure C-1, a visualisation of each measure is presented.

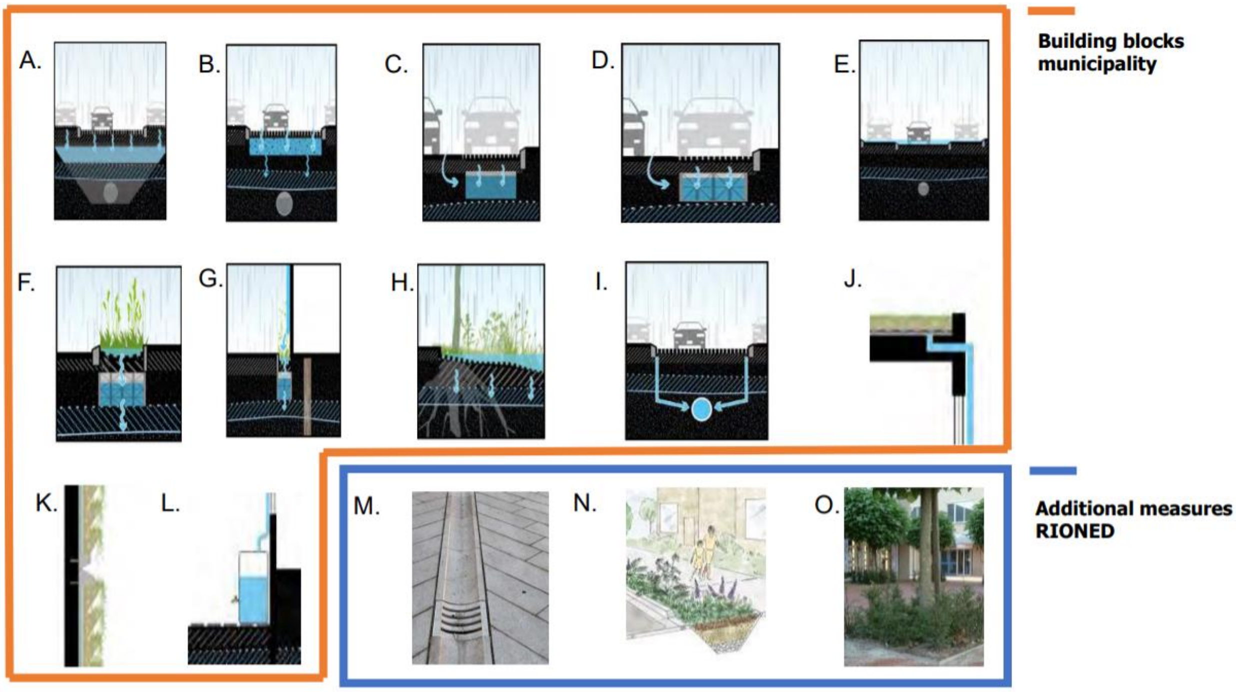

Figure C-1 Visualisation of possible climate adaptation measures presented in Table C-1 and Table C-2

D. Construction site visit and interview

In this Appendix, the site visit on the 10th of July 2020 and the interview with an Executive Director Public Space, Pieter Vreeling, is elaborated. The project that was visited is an integral sewer replacement project in Prinsenland-Het Lage Land, where the street is raised and several other cables and pipes are replaced simultaneously to the sewer. Instead of a combined system, a separate sewer system is implemented in this area, with a DT sewer to transport the rainwater. In addition, information obtained from Alex van Duijvenbode, regarding the execution times of implementation of certain infrastructure, is elaborated.

In Figure D-1, a test trench that is dug to know for sure where cables and pipes are located, is shown. In Figure D-2, a DT-sewer pipe is presented, made of PVC material, with a permeable casing.

Figure D-1 Test trench dug in Prinsenland-Het Lage Land, to know the exact locations of underground infrastructure

Figure D-2 A Drainage Transport-sewer pipe, made of PVC, with a permeable casing

In Figure D-3 and Figure D-4, two overviews of streets where the sewer is replaced are shown. From these pictures it can be derived that in case of an integral project, like this one, a lot of digging is carried out in the streets. Apart from the new separate sewer system, new house connection pipes need to be installed and every 40 – 60 meters a well needs to be installed as well.

Figure D-3 Excavation carried out in a street with an integral sewer replacement project – 1

Figure D-4 Excavation carried out in a street with an integral sewer replacement project – 2

The information obtained from the interview with Pieter Vreeling (and Alex van Duijvenbode) is presented below:

- Planning sewer maintenance:
  - Approx. 3 years in advance it is decided where the sewer will be replaced: A new system is dimensioned and calculated and it is investigated where the new system will conflict with other existing infrastructure.
  - When the design of the new system is ready (approx. 3 years in advance), utility companies that lie in the area of influence are informed about the construction activities that will be carried out. Then they have some time to decide whether they want to replace their cables simultaneously to the sewer replacement or not.
- When the sewer is replaced in a street, the ground level will always be brought back to the officially determined height. It is important that cables and pipes, located in the area of influence of the sewer system, are replaced or relocated first. Afterwards, the new sewer system will be implemented.
- The soil that is excavated during construction will in principal be deposited back at the same location. If soil improvement is desired, it is very important to take the strength of the underlying soil into account. If the improved soil is a lot heavier than the underlying soil, significant subsidence will occur.
- The thicknesses of foundation layers that can be assumed is:
  - Minimum of 80 cm of sand below roads → Assume 1,0 m of sand
  - Minimum of 50 cm of sand below sidewalks → Assume 60 cm of sand
  - 50 cm of fertile soil below greenery → Assume 50 cm of humus and 10 cm of sand below it
  - Below trees: fertile soil (tree root zone) up to the groundwater level
- In total, the street is often open for about 6-8 weeks in case of an integral sewer replacement project. Excavation work, laying and replacing cables and pipes and the new sewer system and finally closing again, are included in these 6-8 weeks.
- The execution times for implementation or relocation of underground infrastructure (measured from the moment the ground is dug open), are stated in Table D-1. This table is based on the interview with Pieter Vreeling and an interview with Alex van Duijvenbode (Projectmanager at the Engineering Company from the municipality of Rotterdam).

Table D-1 Execution time for implementation or shifting of underground infrastructure and their responsible managers

Underground infrastructure	Execution time [m/day]	Responsibility
Sewer pipe	5 – 10	Municipality
District heating pipe	5 – 10	Heat supplier
Gas pipe	Approx. 100	Stedin
Drinking water pipe	Approx. 100	Evides
Electricity cable	150 – 200	Stedin
Telecom cable	150 – 200	Telecom companies

E. District typologies in Rotterdam

In this Appendix, a map is displayed of the distribution of the district typologies in Rotterdam in Figure E-1. Colours on the map that are not marked in the legend at the top left, indicate specific parks and waterways. The district typologies addressed in this research, are the garden-city area, 'cauliflower'-district and urban building block (tuinsteden, wijken na 1970 and stadswijken, in Dutch according to the legend).

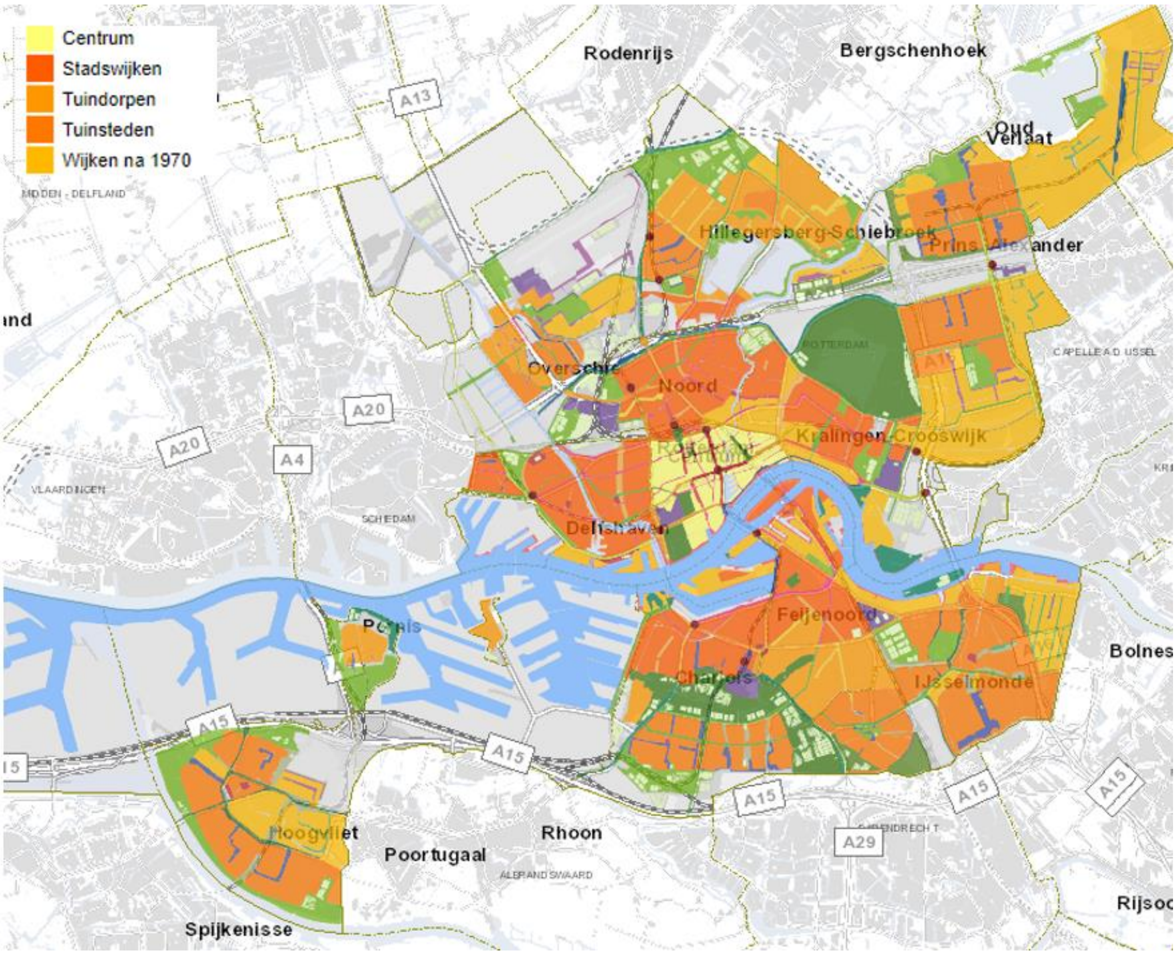

Figure E-1 District typologies in Rotterdam, according to the 'Rotterdan Style Manual' (Handboek Rotterdamse Stijl, in Dutch) (Gisweb 2.2 Gemeente Rotterdam, 2020)

F. Case study design: case selection

In this Appendix, the final case selection is presented. Per pilot area, critical streets are presented with all relevant information in Figure F-1 to Figure F-7. The green marked streets (nr. 2, 4, 12, 20 and 23) are eventually selected to continue the research with. The case selection based on the different characteristics of the streets is shown in Figure F-8.

F1. Reyeroord

Pilot area	District	Concession area	Street	Nr of street	Percentage of property risk label in street	Age of property	Owner of property	Energy transition measures	Age of sewer	Type of sewer	Functional Water Advice [as result of MJOB]	Street type
Reyeroord	Reyeroord	Vattenfall	Quadenoord-Vegelinsoord corner	1	60,42%	1964-1966	Private	1. District heating 2. Grid reinforcements (transformers)	Quadenoord: 2008 Vegelinsoord: 1978	Quadenoord: Combined and drainage Vegelinsoord: Combined	*FA0913 FA Reyeroord 2020:* Quadenoord: No sewer maintenance Vegelinsoord: Sewer replaced + DT sewer installed	Residential street: two roadways, parking along both sides, sidewalks along both sides. Little traffic.
Reyeroord	Reyeroord	Vattenfall	Brittenoord-Nieuwenoord corner	2	33,33%	1964	Private	1. District heating 2. Grid reinforcements (transformers)	1961-1963	Combined	FA0913 FA Reyeroord 2020: Brittenoord: Sewer replacement + DT sewer Nieuwenoord: Sewer replacement + DT sewer	Residential street: two roadways, parking along both sides, sidewalks along both sides. Little traffic.

Street structure	Subsoil	Ground level	Groundwater level	Dewatering depth [m]	Officially determined height that should be maintained	Notes	Possible adaptation measure	Heating network installed before 2030	Planned installation	Elements of heating network	Potential combination sewer - district heating
Element pavement: pavers	The top layer under roads has 1,0 - 2,0 meters of sand layers and peat and clay layers underneath	NAP -1,58 m	NAP - 2,35 m	0,77	NAP -1,45m	Reyeroord Functional Advice Water	Store and drain	Yes	2023	Secondary distribution pipes (125-200 mm)	Quadenoord: No Vegelinsoord: Yes
Element pavement: pavers	The top layer under roads has 1,0 - 2,0 meters of sand layers and peat and clay layers underneath	NAP -1,42 m	NAP -2,60 m	1,18	NAP -1,45m	Reyeroord Functional Advice Water	Store and drain	Yes	2023	1. Corner: heat transfer station 2. Brittenoord: secondary distribution pipe (DN50-DN100) 3. Nieuwenoord: secondary distribution pipe (DN50-DN100)	Yes

Figure F-1 Critical streets Reyeroord (nr. 1-2)

F2. Pendrecht

Pilot area	District	Concession area	Street	Nr of street	Percentage of property risk label in street	Age of property	Owner of property	Energy transition measures	Age of sewer	Type of sewer	Functional Water Advice [as result of MJOB]	Street type
Pendrecht	Pendrecht-North	Vattenfall	Dreischorstraat	3	40,38%	Most 1955 / 1995 / 2000	Woonstad	1. District heating 2. Solar panels (+grid reinforcement)	Top and middle: 1953-1956 Bottom: 2002	Combined	*No functional water advice* No maintenance	Residential street: one roadway, parking along one side, sidewalk along same side, houses direct along other side. Little traffic.
Pendrecht	Pendrecht-North	Vattenfall	Melissantstraat (small part in north)	4	51,59%	1956	Woonstad	1. District heating 2. Solar panels (+grid reinforcement)	2005	Combined and rainwater system	No functional water advice No maintenance	Residential street: one roadway, parking along both sides, sidewalks along both sides with some trees. Little traffic.
Pendrecht	Pendrecht-South	Vattenfall	Kruiningenstraat (part in south)	5	35,96%	1957-1958	Private	1. District heating	2002	North: combined and rainwater system South: combined	*No functional water advice* No maintenance	Residential street: one roadway, parking along one side, sidewalks along both sides. Little traffic.

Street structure	Subsoil	Ground level	Groundwater level	Dewatering depth [m]	Officially determined height that should be maintained	Notes	Possible adaptation measures	Heating network installed before 2030	Planned installation	Elements of heating network	Potential combination sewer - district heating
Element pavement: pavers	Mainly sandy clay, some parts clay-containing sand until 1,5 m below ground level	NAP -0,8 m	NAP -1,7 - -2,0 m	0,9 - 1,2	NAP -1,25m	1. Ground water level increases when sewer is replaced: consider drainage pipes. 2. Water-passing pavement is considered in some parts in Pendrecht, so could be optional. Take 'design aspects of water-passing pavement' into account.	Infiltration (with drainage pipes) Store Drain	Yes	2021-2023	1. Top: secondary distribution pipe (DN65) 2. Middle: secondary distribution pipe (DN100)	Not planned Top and middle (1953-1955) could be combined Bottom: No
Element pavement: pavers	Mainly clay, alternated locally with a layer of sand	NAP -1,34 m	NAP -2,0 m	0,66	NAP -1,25m		Store Drain	Yes	2021-2023	1. Secondary distribution pipe (DN80) 2. Beginning of street: Heat transfer station	No
Element pavement: pavers	0-0,5 m below ground level: sand; 0,5 - 1,5 m below ground level: sand and clay; 1,5 - 2,5 m below ground level: clay	NAP -1,57 m	NAP -2,67 m	1,1	NAP -1,25m		Infiltration (with drainage pipes) Store Drain	Yes	Ongoing	Secondary distribution pipe (DN50)	No

Figure F-2 Critical streets Pendrecht (nr. 3-5)

F3. Rozenburg (1)

Pilot area	District	Concession area	Street	Nr of street	Percentage of property risk label in street	Age of property	Owner of property	Energy transition measures	Age of sewer	Type of sewer	Functional Water Advice [as result of MJOB]	Street type
Rozenburg	Rozenburg-Southeast	None	Bosseplaat	6	33,04%	1965-1967	Ressort Wonen and private	1. District heating 2. Solar panels (+grid reinforcement)	2016	Combined and rainwater system	*No functional water advice* No maintenance	Residential street: two roadways, parking along one side on the street, sidewalks along both sides with green planters next to one sidewalk. Little traffic.
Rozenburg	Rozenburg-Southeast	None	Ruygeplaat	7	59,73%	1965-1967	Ressort Wonen and private	1. District heating 2. Solar panels (+grid reinforcement)	2016-2018	Combined and rainwater system	*No functional water advice* No maintenance	Residential street: two roadways, parking along one side on the street, sidewalks along both sides with green planters next to one sidewalk. Little traffic.
Rozenburg	Rozenburg-Southeast	None	Langeplaat	8	70,48%	1965-1967	Ressort Wonen and private	1. District heating 2. Solar panels (+grid reinforcement)	2016-2018	Combined and rainwater system	*No functional water advice* No maintenance	Residential street: one roadway, parking along one side, large sidewalks along both sides with green planters next one sidewalk. Little traffic.
Rozenburg	Rozenburg-Southeast	None	Amstelstraat	9	90,48%	1968-1972	Ressort Wonen and private	1. District heating 2. Solar panels (+grid reinforcement)	1964	Combined	*No functional water advice* No maintenance	Residential street: two roadways, parking along one side on the street, large parking space next to the street, sidewalks along one side and green planters along other side. Little traffic.
Rozenburg	Rozenburg-Southeast	None	Lekstraat	10	65,52%	1969-1971	Ressort Wonen and private	1. District heating 2. Solar panels (+grid reinforcement)	1964	Combined	*No functional water advice* No maintenance	Residential street: two roadways, parking along one side on the street, sidewalks along both sides with green planters in/next to both sidewalks. Little traffic.
Rozenburg	Rozenburg-Northeast	None	Abelenlaan	11	49,37%	1961-1965	Ressort Wonen and private	1. District heating 2. Solar panels (+grid reinforcement)	1959 / 1986	Combined	*FA0923 FA Abelenlaan e.o. 2018:* Increase diameter wastewater sewer + install DT sewer Implement water-passing pavement	Resendential street: two roadways, parking along one side, sidewalks along both sides, green planters along both sides. Little traffic.
Rozenburg	Rozenburg-Northeast	None	Goudenregenstraat	12	34,21%	1962-1963	Ressort Wonen, Woonstad and private	1. District heating 2. Solar panels (+grid reinforcement)	1959	Combined	FA0923 FA Abelenlaan e.o. 2018: Replace wastewater sewer + install DT sewer Implement water-passing pavement	Resendential street: one roadway, parking along one side, small sidewalks along both sides. Little traffic.

Street structure	Subsoil	Ground level	Groundwater level	Dewatering depth [m]	Officially determined height that should be maintained	Notes	Possible adaptation measures	Heating network installed before 2030	Planned installation	Elements of heating network	Potential combination sewer - district heating
Element pavement: pavers	Until 3,5 m below ground level mainly sand (some local layers of clay)	NAP +0,8 m	NAP -0,1 m	0,9	Officialy determined street levels: NAP +0,8m til NAP +1,5m		Infiltration (with drainage pipes) Store Drain	Yes	2018-2025	Primary distribution pipe (DN200)	No
Element pavement: pavers	Until 3,0 m below ground level mainly sand (one local layer of clay)	NAP +0,8 m	NAP -0,25 m	1,05	Officialy determined street levels: NAP +0,8m til NAP +1,5m		Infiltration Store Drain	Probably	2018-2025	Secondary distribution pipe (DN50-DN100)	No
Element pavement: pavers	Until 3,5 m below ground level mainly sand (some local layers of clay)	NAP +0,75 m	NAP 0,0 m	0,75	Officialy determined street levels: NAP +0,8m til NAP +1,5m		Store Drain	Probably	2018-2025	Secondary distribution pipe (DN50-DN100)	No
Element pavement: pavers	No information: probably comparable to Langeplaat/Lekstraat	NAP +0,74 m	NAP -0,50 m	1,24	Officialy determined street levels: NAP +0,8m til NAP +1,5m		Infiltration Store Drain	Probably	2018-2025	Secondary distribution pipe (DN50-DN100)	Yes
Element pavement: pavers	Until 3,5 m below ground level mainly sand (some local layers of clay)	NAP +0,75 m	NAP 0,0 m	0,75	Officialy determined street levels: NAP +0,8m til NAP +1,5m		Store Drain	Probably	2018-2025	Secondary distribution pipe (DN50-DN100)	Yes
Element pavement: pavers	0,3 - 2 m underneath ground level sand	NAP +0,81 m	NAP -0,1 m	0,91	Officialy determined street levels: NAP +0,8m til NAP +1,5m	Abelenlaan and surroundings Functional Advice Water (Abelenlaan, Goudenregenstraat, Rozenstraat, Leliestraat): 1. Lies on a sandbank: water-passing pavement is considered. Take 'design aspects of water-passing pavement' into account. 2. Permeability = 3,3 m /day	Infiltration (with drainage pipes) Store Drain	Probably	2020-2027	Secondary distribution pipe (DN50-DN100)	1959: Yes 1986: is brought forward 6-26 years
Element pavement: pavers	0,3 - 2 m underneath ground level sand	NAP +0,74 m	NAP -0,1 m	0,84	Officialy determined street levels: NAP +0,8m til NAP +1,5m	Abelenlaan and surroundings Functional Advice Water (Abelenlaan, Goudenregenstraat, Rozenstraat, Leliestraat): Permeability = 3,8 m /day	Infiltration (with drainage pipes) Store Drain	Probably	2020-2027	Secondary distribution pipe (DN50-DN100)	Yes

Figure F-3 Critical streets Rozenburg (nr. 6-12)

F3. Rozenburg (2)

Pilot area	District	Concession area	Street	Nr of street	Percentage of property risk label in street	Age of property	Owner of property	Energy transition measures	Age of sewer	Type of sewer	Functional Water Advice [as result of MJOB]	Street type
Rozenburg	Rozenburg-Northeast	None	Rozenstraat	13	40,00%	1961	Private	1. District heating	1959	Combined	*FA0923 FA Abelenlaan e.o. 2018:* Replace wastewater sewer + install DT sewer Implement water-passing pavement	Resendential street: one roadway, parking along one side, small sidewalks along both sides, planters along one side. Little traffic.
Rozenburg	Rozenburg-Northeast	None	Leliestraat	14	66,67%	1961-1962	Private	1. District heating	1959	Combined	*FA0923 FA Abelenlaan e.o. 2018:* Replace wastewater sewer + install DT sewer Implement water-passing pavement	Residential street: two roadways, parking along one side on the road, small sidewalks along both sides. Little traffic.
Rozenburg	Rozenburg-West	None	Ruysdaelstraat	15	85,86%	1967	Ressort Wonen	1. District heating 2. Solar panels (+grid reinforcement)	1964	Combined	*No functional water advice*	Residential street: one roadway, parking along one side on the road, sidewalks along both sides, green planters along one sidewalk, large parking space next to the planters. Little traffic.
Rozenburg	Rozenburg-West	None	Palet	16	48,57%	1967	Ressort Wonen	1. District heating 2. Solar panels (+grid reinforcement)	1964	Combined	*No functional water advice*	Residential street: two roadways, parking along one side on the road, small sidewalk along one side, large sidewalk/square along other side, with some green planters. Little traffic.
Rozenburg	Rozenburg-West	None	Zuidzijde (de Rozenburcht)	17		2016	Ressort Wonen and private	1. District heating 2. Solar panels (+grid reinforcement)	1972	Combined	*No functional water advice*	Residential street: two roadways, parking along one side, large sidewalks along both sides, one sidewalk with planters. Little traffic.
Rozenburg	Rozenburg-West	None	Wethouder van Heldenstraat	18	30,65%	1959-1960	Ressort Wonen and private	1. District heating 2. Solar panels (+grid reinforcement)	1958	Combined	*No functional water advice*	Residential street: very narrow, one roadway with parking along one side, small sidewalks along both sides. Little traffic.

Street structure	Subsoil	Ground level	Groundwater level	Dewatering depth [m]	Officially determined height that should be maintained	Notes	Possible adaptation measures	Heating network installed before 2030	Planned installation	Elements of heating network	Potential combination sewer - district heating
Element pavement: pavers	0,3 - 2 m underneath ground level sand and a shallow clay layer of 0,5 m is found in the sand layer	NAP +0,80 m	NAP -0,1 m	0,9	Officialy determined street levels: NAP +0,8m til NAP +1,5m	Abelenlaan and surroundings Functional Advice Water (Abelenlaan, Goudenregenstraat, Rozenstraat, Leliestraat): Permeability = 2,1 m /day	Infiltration (with drainage pipes) Store Drain	Probably	2020-2027	Secondary distribution pipe (DN50-DN100)	Yes
Element pavement: pavers	0,3 - 2 m underneath ground level sand	NAP +0,80 m	NAP -0,1 m	0,9	Officialy determined street levels: NAP +0,8m til NAP +1,5m	Abelenlaan and surroundings Functional Advice Water (Abelenlaan, Goudenregenstraat, Rozenstraat, Leliestraat): Permeability = 3,3 m/day	Infiltration (with drainage pipes) Store Drain	Probably	2020-2027	Secondary distribution pipe (DN50-DN100)	Yes
Element pavement: pavers	The soil structure up to a depth of 3.25 m below ground level can be described as alternating slightly sandy to strongly sandy clay with intermediate layers of sand	NAP +1,0 m	NAP -0,8 m	1,8	Officialy determined street levels: NAP +0,8m til NAP +1,5m		Infiltration Store Drain	Probably	From 2026	Secondary distribution pipe (DN50-DN100)	Yes
Element pavement: pavers	The top 1.5 meters consists of clay, below which up to 2.0 m-mv (maximum drilling depth) of sand is present	NAP +0,88 m	NAP +0,19 m	0,69	Officialy determined street levels: NAP +0,8m til NAP +1,5m		Store Drain	Probably	From 2026	Secondary distribution pipe (DN50-DN100)	Yes
Element pavement: pavers	From ground level to a depth of 2.5 m below ground level, the soil consists mainly of sand	NAP +0,96 m	NAP +0,1 m	0,86	Officialy determined street levels: NAP +0,8m til NAP +1,5m		Infiltration (with drainage pipes) Store Drain	Probably	From 2026	Secondary distribution pipe (DN50-DN100)	Yes
Element pavement: pavers	From ground level to approximately 4.2 m below ground level a sand packet is found. A clay layer was found locally in the subsoil.	NAP +1,02 m	NAP -0,4 m	1,42	Officialy determined street levels: NAP +0,8m til NAP +1,5m		Infiltration Store Drain	Probably	From 2026	Secondary distribution pipe (DN50-DN100)	Yes

Figure F-4 Critical streets Rozenburg (nr. 13-18)

F4. Bospolder (1)

Pilot area	District	Concession area	Street	Nr of street	Percentage of property risk label in street	Age of property	Owner of property	Energy transition measures	Age of sewer	Type of sewer	Functional Water Advice [as result of MJOB]	Street type
Bospolder	Bospolder	Eneco	Albregt-Engelmanstraat	19	50,00%	1911-1914 / 1921 / 1997 / 2005	Havensteder and private	1. District heating	1975	Combined	*FA0871 FA Bospolder (2017)* Replace wastewater sewer + install DT sewer diameter 315 mm (connect street gullies); DT sewer installed above groundwater level and min. 90 cm below groundlevel (unique) Implement water-passing pavement	Residential street: one roadway, parking along one side, sidewalk along one side, paved square along other side. Little traffic.
Bospolder	Bospolder	Eneco	Bospolderplein	20	86,96%	1914-1916 / 1921-1922 / 1997	Havensteder and private	1. District heating	2007-2008	Combined	No maintenance	Residential street: one roadway, parking along two sides, sidewalk along one side, paved square with some trees along other side. Little traffic.
Bospolder	Bospolder	Eneco	Bospolderstraat	21	89,02%	1913 / 1922 / 1990 / 2006	Havensteder and private	1. District heating	1988	Combined	No maintenance	Residential street: one roadway, parking along one side, sidewalk along one side, large paved sidewalk/open space along other side. Little traffic.
Bospolder	Bospolder	Eneco	Haspelsstraat	22	68,75%	1914 / 1951 / 2006	Havensteder and private	1. District heating	1973 / 2007 / 2010	Combined	No maintenance	Residential street: spacious, two roadways, parking along both sides, sidewalks with trees along both sides. Little traffic.

Street structure	Subsoil	Ground level	Groundwater level	Dewatering depth [m]	Officially determined height that should be maintained	Notes	Possible adaptation measures	Heating network installed before 2030	Planned installation	Elements of heating network	Potential combination sewer - district heating
Element pavement: pavers	The raised layer is 3 to 5 m thick and consists of fine sand or clay. Below that are clay and thin peat layers.	NAP +3,18 m	NAP +1,70 m	1,48	NAP +3,60m	Bospolder Functional Advice Water (2017): 1. Water-passing pavement is adviced in entire area (subsoil satisfies). 2. Sewer is replaced when older than 35 years or when it is hydraulically desired. 3. Drainage pipes are not necessary due to large dewatering depth, but can offer bit more safety. 4. Permeability of ground is high and dewatering depth is large overall. 5. No surface water in the neighbourhood.	Infiltration (where possible with drainage pipes) Store Drain	Probably	2024	Assumed: secondary distribution pipe (DN50-DN100)	Yes
Element pavement: pavers	The raised layer is 3 to 5 m thick and consists of fine sand or clay. Below that are clay and thin peat layers.	NAP +3,34 m	NAP +2,0 m	1,34	NAP +3,60m	Bospolder Functional Advice Water (2017)	Infiltration (where possible with drainage pipes) Store Drain	Probably	2024	Assumed: secondary distribution pipe (DN50-DN100)	No
Element pavement: pavers	The raised layer is 3 to 5 m thick and consists of fine sand or clay. Below that are clay and thin peat layers.	NAP +3,34 m	NAP +2,0 m	1,34	NAP +3,60m	Bospolder Functional Advice Water (2017)	Infiltration (where possible with drainage pipes) Store Drain	Probably	2024	Assumed: secondary distribution pipe (DN50-DN100)	Yes, but must be brought forward 8-28 years
Element pavement: pavers	The raised layer is 3 to 5 m thick and consists of fine sand or clay. Below that are clay and thin peat layers.	NAP +2,88 m	NAP +1,80 m	1,08	NAP +3,60m	Bospolder Functional Advice Water (2017)	Infiltration (where possible with drainage pipes) Store Drain	Probably	2024	Assumed: secondary distribution pipe (DN50-DN100)	1973: Yes 2007 / 2010: No

Figure F-5 Critical streets Bospolder (nr. 19-22)

F4. Bospolder (2)

Pilot area	District	Concession area	Street	Nr of street	Percentage of property risk label in street	Age of property	Owner of property	Energy transition measures	Age of sewer	Type of sewer	Functional Water Advice [as result of MJOB]	Street type
Bospolder	Bospolder	Eneco	Snoekstraat	23	79,82%	1914 / 1951 / 1954	Havensteder and private	1. District heating	1973	Combined	FA0871 FA Bospolder (2017) Replace wastewater sewer + install DT sewer diameter 315 mm (connect street gullies); DT sewer installed above groundwater level and min. 90 cm below groundlevel (unique) Implement water-passing pavement	Residential street: one roadway, parking along both sides, sidewalk along both sides, with some trees along one side. Little traffic.
Bospolder	Bospolder	Eneco	Schippersstraat	24	43,37%	1913 / 1914 / 1988 / 2008	Havensteder and private	1. District heating	2010	Combined	No maintenance	Residential street: spacious, two roadways, parking along one side, sidewalk along two sides, planters and trees along both sides. Little traffic.
Bospolder	Bospolder	Eneco	Rosenveldtstraat	25	40,00%	1913 / 1952 / 1989 / 1996 / 2007	Havensteder and private	1. District heating	1975 / 2008	Combined	FA0871 FA Bospolder (2017) Replace wastewater sewer + install DT sewer diameter 315 mm (connect street gullies); DT sewer installed above groundwater level and min. 90 cm below groundlevel (unique) Implement water-passing pavement	Residential street: narrow, one roadway, parking along both sides, sidewalk along both sides, some trees in the sidewalk along one side. Little traffic.
Bospolder	Bospolder	Eneco	Watergeusstraat (north)	26	56,76%	1910 -1913	Havensteder and private	1. District heating	1977 / 1985	Combined	FA0871 FA Bospolder (2017) Westside (1977): Replace wastewater sewer + install DT sewer diameter 315 mm (connect street gullies); DT sewer installed above groundwater level and min. 90 cm below groundlevel (unique) Implement water-passing pavement Eastside (1985): no maintenance	Residential street: one roadway, parking along both sides, sidewalk along both sides, some trees in the sidewalk along one side. Little traffic.

Street structure	Subsoil	Ground level	Groundwater level	Dewatering depth [m]	Officially determined height that should be maintained	Notes	Possible adaptation measure	Heating network installed before 2030	Planned installation	Elements of heating network	Potential combination sewer - district heating
Element pavement: pavers	The raised layer is 3 to 5 m thick and consists of fine sand or clay. Below that are clay and thin peat layers.	NAP +2,88 m	NAP +1,80 m	1,08	NAP +3,60m	Bospolder Functional Advice Water (2017)	Infiltration (where possible with drainage pipes) Store Drain	Probably	2024	Assumed: secondary distribution pipe (DN50-DN100)	Yes
Element pavement: pavers	The raised layer is 3 to 5 m thick and consists of fine sand or clay. Below that are clay and thin peat layers.	NAP +3,5 m	NAP +1,85 m	1,65	NAP +3,60m	Bospolder Functional Advice Water (2017)	Infiltration (where possible with drainage pipes) Store Drain	Probably	2024	Assumed: secondary distribution pipe (DN50-DN100)	No
Element pavement: pavers	The raised layer is 3 to 5 m thick and consists of fine sand or clay. Below that are clay and thin peat layers.	NAP +3,27 m	NAP +1,80 m	1,47	NAP +3,60m	Bospolder Functional Advice Water (2017)	Infiltration (where possible with drainage pipes) Store Drain	Probably	2024	Assumed: secondary distribution pipe (DN50-DN100)	1975: Yes 2008: No
Element pavement: pavers	The raised layer is 3 to 5 m thick and consists of fine sand or clay. Below that are clay and thin peat layers.	NAP +3,09 m	NAP +1,60 m	1,49	NAP +3,60m	Bospolder Functional Advice Water (2017)	Infiltration (where possible with drainage pipes) Store Drain	Probably	2024	Assumed: secondary distribution pipe (DN50-DN100)	1977: Yes 1985: must be brought forward 5-25 years

Figure F-6 Critical streets Bospolder (nr. 23-26)

F5. Prinsenland – Het Lage Land

Pilot area	District	Concession area	Street	Nr of street	Percentage of property risk label in street	Age of property	Owner of property	Energy transition measures	Age of sewer	Type of sewer	Functional Water Advice [as result of MJOB]	Street type
Prinsenland	Prinsenland-East	None	Beelstraat	27	68,42%	1989 / 1992	Private	1. District heating	1988 / 1989 / 1991	Combined	No maintenance	Resedential street: spacious, two roadways, parking along one side, paved sidewalk along one side, green wide sidewalk with trees along other side and canal next to it. Little traffic.
Prinsenland	Prinsenland-East	None	Rodaristraat	28	0,89261745	1966	Woonstad and private	1. District heating2. So	2010	Combined and drainage	No maintenance	Residential street: two roadw
Het Lage Land	Het Lage Land-East	None	Blaauwstraat	29	90,79%	1965-1966	Woonstad and private	1. District heating 2. Solar panels (+grid reinforcement)	1974	Combined	*FA Architectenbuurt:* Currently being replaced	Residential street: two roadways, parking along one side on the road, sidewalks along both sides without planters. Little traffic.
Het Lage Land	Het Lage Land-East	None	Henri Eversstraat	30	0,944827586	1965-1966	Havensteder and priva	1. District heating2. So	1962	Combined	FA Architectenbuurt:Currently being replaced	Main road: two-three roadways, parking along both sides, sidewalks along both sides, bike lanes along both sides, green planters with trees along both sides.

Street structure	Subsoil	Ground level	Groundwater level	Dewatering depth [m]	Officially determined height that should be maintained	Notes	Possible adaptation measure	Heating network installed before 2030	Planned installation	Elements of heating netw	Potential combination sewer - district heating
Element pavement: pavers	The top layer (on average about 30 to 40 cm thick) consists of clay and / or sand and / or organic material. Below the soil consists of peat or a clay / peat mixture.	NAP -5,23 m	NAP -6,1 m	0,87	NAP -5,6m til -6,0m		Store Drain Drainage pipes in case of sewer replacements	Probably	2023-2026	Assumed: secondary distribution pipe (DN50-DN100)	No
Element pavement: pavers	The top layer (on average about 30 to	NAP -6,06 m	NAP -6,45 m	0,39	NAP -5,6m til -6,0m		StoreDrainDrainage pipes in ca	Probably	2023-2026	Assumed: secondary distribu	No
Element pavement: pavers	The soil structure is very varied, with peat and clay alternating in the top layers and a single intermediate sand layer.	NAP -6,09 m	NAP -6,80 m	0,71	NAP -6,0 m	Architectenbuurt-Oost Functional Advice Water (2017): 1. Deepest polder in NL 2. Drainage necessary when sewer is replaced (to mitigate effects of increasing groundwater level) 3. Runoff from roof surfaces will remain on combined system 4. DT sewer (drainage transport) will be installed for runoff from roads	Store Drain Drainage pipes in case of sewer replacements	Probably	2023-2026	Assumed: secondary distribution pipe (DN50-DN100)	No; district heating too late
Element pavement: pavers	The soil structure is very varied, with peat and clay alternating in the top layers and a single intermediate sand layer.	NAP -5,93 m	NAP -6,80 m	0,87	NAP -6,0 m	Architectenbuurt Oost Functional Advice Water (2017)	Store Drain Drainage pipes in case of sewer replacements	Probably	2023-2026	Assumed: primary distribution pipe (DN50-DN200)	No; district heating too late

Figure F-7 Critical streets Prinsenland – Het Lage Land (nr. 27-30)

F6. Case selection

Street	Percentage of property risk label	Private owner property	Housing corporation	Sewer combined with district heating (possible	Solar panels + grid reinforcement	Grid reinforcement (trafokastjes)	Street (one-two roa	Climate adaptation
Reyeroord								
1	60,42%	x		x		x	2	S, D
2	33,33%	x		x		x	2	S, D
Pendrecht								
3	40,38%		x		x		1	I, S, D
4	51,59%		x		x		1	S, D
5		x			x		1	I, S, D
Rozenburg								
6		x	x		x		2	I, S, D
7		x	x		x		2	I, S, D
8		x	x		x		1	S, D
9		x	x	x	x		2	I, S, D
10		x	x	x	x		2	S, D
11		x	x	x	x		2	I, S, D
12	34,21%	x	x	x	x		1	I, S, D
13		x		x	x		1	I, S, D
14		x		x	x		2	I, S, D
15			x	x	x		1	I, S, D
16			x	x	x		2	S, D
17		x	x	x	x		2	I, S, D
18	30,65%	x	x	x	x		1	I, S, D
Bospolder								
19	50,00%	x	x	x			1	I, S, D
20	86,96%	x	x				1	I, S, D
21	89,02%	x	x				1	I, S, D
22		x	x				2	I, S, D
23	79,82%	x	x	x			1	I, S, D
24		x	x				2	I, S, D
25	40,00%	x	x	x			1	I, S, D
26	56,76%	x	x	x			1	I, S, D
Prinsenland-Het Lage Land								
27		x			x		2	S, D
28	89,26%	x	x		x		2	S, D
29	90,79%	x	x		x		2	S, D
30	94,48%	x	x		x		2 to 3	S, D

Choice						
Reyeroord: Choose 1 or 2	Private	Sewer	No solar	Trafo kastjes	2	S,D
Pendrecht: Choose 3 or 4	Corporation	No sewer	Solar	No trafo	1	Both
Rozenburg: Choose 12 or 18	Both	Sewer	Solar	No trafo	1	I, S, D
Bospolder: Choose 19, 20, 21, 23, 25 or 26	Both	Both	No solar	No trafo	1	I, S, D
Prins-HetLageLand: Choose 28, 29 or 30	Both	No sewer	Solar	No trafo	2	S, D

Figure F-8 Case selection based on different characteristics of the critical streets

TUDelft