

An aerial photograph of a city, likely Delft, showing a river, a large church (St. Lawrence Church), and various urban buildings and green spaces.

# TO ADAPT OR NOT TO ADAPT

A STUDY INTO ADAPTABILITY OF THE URBAN ENVIRONMENT

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# To adapt or not to adapt: a study into adaptability of the urban environment

by

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## Preface

Before you lies the thesis "To adapt or not to adapt: a study into adaptability of the urban environment", this thesis is written within the educational program of the Master of Civil Engineering at the Technical University of Delft. It is the final product of my master track Water management.

I have come quite a long way before arriving at the topic of adaptability. I started informing at different engineering firms for possible graduation topics, in the end I ended up at Witteveen+Bos, the engineering firm I also did my internship. After some practical (too practical) topics, in cooperation with Frans van de Ven, we came to the topic of adaptability, a quite vague, undiscovered, alpha like topic.

Because of the topic I needed to familiarize myself with more alpha like research techniques, doing a literature research and interviews. Building my thesis upon the thoughts of experts, instead of working on data, models, using rules and boundaries and such.

I would like to thank my supervisors for their guidance, help and support during this process. Furthermore I would also like to thank the experts I interviewed, I had a lot of interesting and inspiring, just fun talks. Lastly I would like to thank the municipality of Dordrecht and Witteveen+Bos for providing me with the tools and data I needed.

I hope you enjoy your reading.

A handwritten signature in black ink, consisting of several overlapping loops and a long horizontal stroke extending to the right.

*Thomas Deurloo  
Breda, March 2016*



## Abstract

The climate and the urban systems are changing, leading to new challenges and opportunities in the urban environment. Adaptation to these challenges is needed, using the vulnerability assessment areas that are vulnerable can be identified. Vulnerability is the likelihood a system experiences harm and is the combination of both risks and adaptability. Finding adaptability can be hard and is not straightforward, therefore this thesis aims to operationalize adaptability for the current urban environment, focussing on climate change and the physical indicators related to adaptability.

Adaptability simply means the ability there is (within a system, society or city) to adapt. A lot of different definitions for adaptability (or adaptive capacity) can be found in literature, which makes talking about, using and comparing adaptability hard. Different fields of interest use different definitions, frameworks and approaches.

Most of the definitions and frameworks found in the literature search of this thesis tend to be meant for assessing social adaptability on regional or country scale. They focus on institutions, economy and (technical) knowledge on larger scales. These assessments come down to, the third world countries have bad adaptability while the first world countries have better adaptability. For decision-making on municipality level assessment on smaller scale is needed.

For this thesis a lot of indicators have been gathered (a grand total of 38) by literature research and interviews with experts. Indicators are one of the ways of assessing adaptability, so by selecting and combining indicators it is able to determine a measure for adaptability.

The used indicators (9 in total) are grouped in so called determinants. There are indicators saying something about space that is available for climate proofing or the type of climate proofing (blue, green or grey solutions) that can be used (space: percentage buildings, percentage water and percentage greening). Furthermore there are indicators that express the underground conditions in an area (underground: soil type and underground infrastructure). There are indicators stressing opportunities regarding climate proofing that may arise (matching: planned works and estimated end of life cycle). There are also indicators that stress the drive for climate proofing (budgets: urgency). Lastly there are indicators related to specific characteristics of an area (function related demands: historical city centre).

The indicators are then combined to construct a rapid assessment tool for the municipality of Dordrecht. This tool can be used to prioritize climate proofing in the Dordrecht area, when used side-by-side with a risk map. Quick wins (high adaptability, high risks) can be identified as well as areas that need further attention, research or innovation (low adaptability, high risks).

The resulting maps from the tool, show expected behaviour. The historical city centre of Dordrecht shows lower adaptabilities, while harbour, park and nature areas show higher adaptabilities.

Assessing and using adaptability adds data and information to your decision-making process. Climate proofing is needed, for it being the least-social-cost strategy, assessing vulnerability helps making good and funded decisions on climate proofing.



# Contents

1. INTRODUCTION.....	3
1.1 Background.....	3
1.2 Problem statement .....	6
1.3 Purpose .....	6
1.4 Objectives and research questions .....	6
1.5 Structure of this thesis .....	7
2. DESK REVIEW: DEFINITIONS AND FRAMEWORK.....	11
2.1 Vulnerability explained .....	11
2.2 Definition resilience .....	12
2.3 Adaptability explained .....	12
2.4 Improving adaptability.....	13
3. INDICATORS: FROM LITERATURE AND INTERVIEWS.....	17
3.1 Indicators from literature .....	17
3.2 Indicators from interviews .....	18
3.3 Selection of indicators .....	20
4. OPERATIONALIZING: A TOOL FOR RAPID ASSESSMENT OF ADAPTABILITY .....	25
4.1 Dordrecht .....	25
4.2 Methodology.....	25
4.3 How to use the tool.....	29
4.4 Showing some results.....	30
5. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS.....	35
5.1 Discussion.....	35
5.2 Conclusions.....	36
5.3 Recommendations.....	37
References.....	38



## Appendices

A. DEFINITIONS FROM LITERATURE .....	45
B. INTERVIEWS: STRUCTURE, REPORTS AND RESULTS.....	52
C. INDICATORS: DATA AND EXPLANATION .....	64
D. CLASSIFICATION: METHODS AND INDICATORS .....	77
E. SENSITIVITY ANALYSIS.....	90
F. THE THREE PS.....	96



# INTRODUCTION



# 1. INTRODUCTION

In the introduction the relevant background of this thesis will be presented, introducing the vulnerability assessment, adaptability and the stresses facing our urban environment. Furthermore the problem statement, purpose and objectives and research questions will be elaborated. And lastly the structure of this thesis will be given.

## 1.1 Background

Our cities will get more prone to risks, climate change and urbanization, both represent great challenges of our time. Climate change on the one hand will further stress our urban infrastructure, productivity, liveability and even our lives, while urbanization concentrates people and economic capital. In order to prevent damage, adaptation measures are needed at the right locations. A way of prioritizing challenges spatially is the vulnerability assessment.

### Vulnerability assessment

In general a vulnerability assessment is the process of identifying, quantifying and prioritizing of the vulnerabilities in a system. A vulnerability assessment in general looks like Figure 2. Vulnerability is the combination of risks and adaptabilities. Nowadays risks are most of the times used to express hazards. Risks can be expressed in monetary units, which makes sense basing decisions on, using least cost method. When using least cost method or another assessment using only risks the component of adaptability is completely ignored; are we able to build adaptations in time and at what efforts? This can have reasonable effects on your decision-making. So use the vulnerability assessment instead!

When vulnerabilities of all areas are known a hotspot map can be created, this map is the spatial representation of vulnerabilities. With a hotspot map decisions can be made regarding climate proofing, areas where for example adaptability is high quick wins might be found, on the other hand areas where adaptability is low, additional investments, research and/or innovation might be needed to solve climate related challenges. Using the information of the maps with risks and adaptabilities, you are able to prioritize and make funded and well-informed decisions.

### Vulnerability concept

Vulnerability is the degree to which a system, human or unit is likely to experience harm. Vulnerability in general consists of exposure, sensitivity and adaptability (or adaptive capacity) ( $V = f(E, S, A)$ ), see Figure 1 (IPCC, 2007).

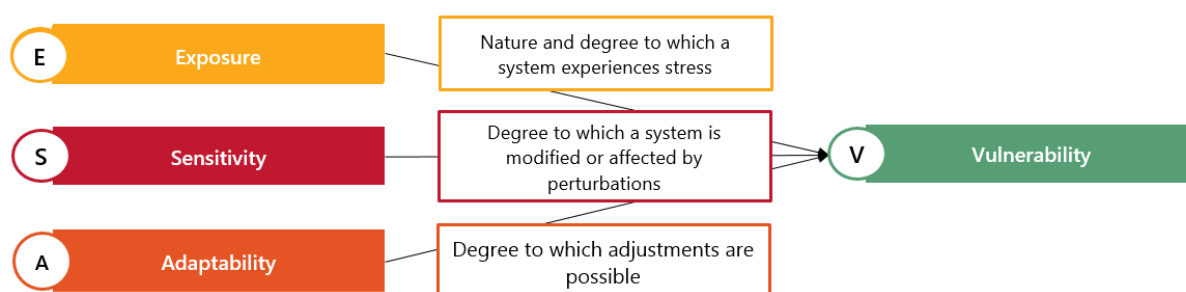


Figure 1 Vulnerability concept, in general  $V = f(E, S, A)$

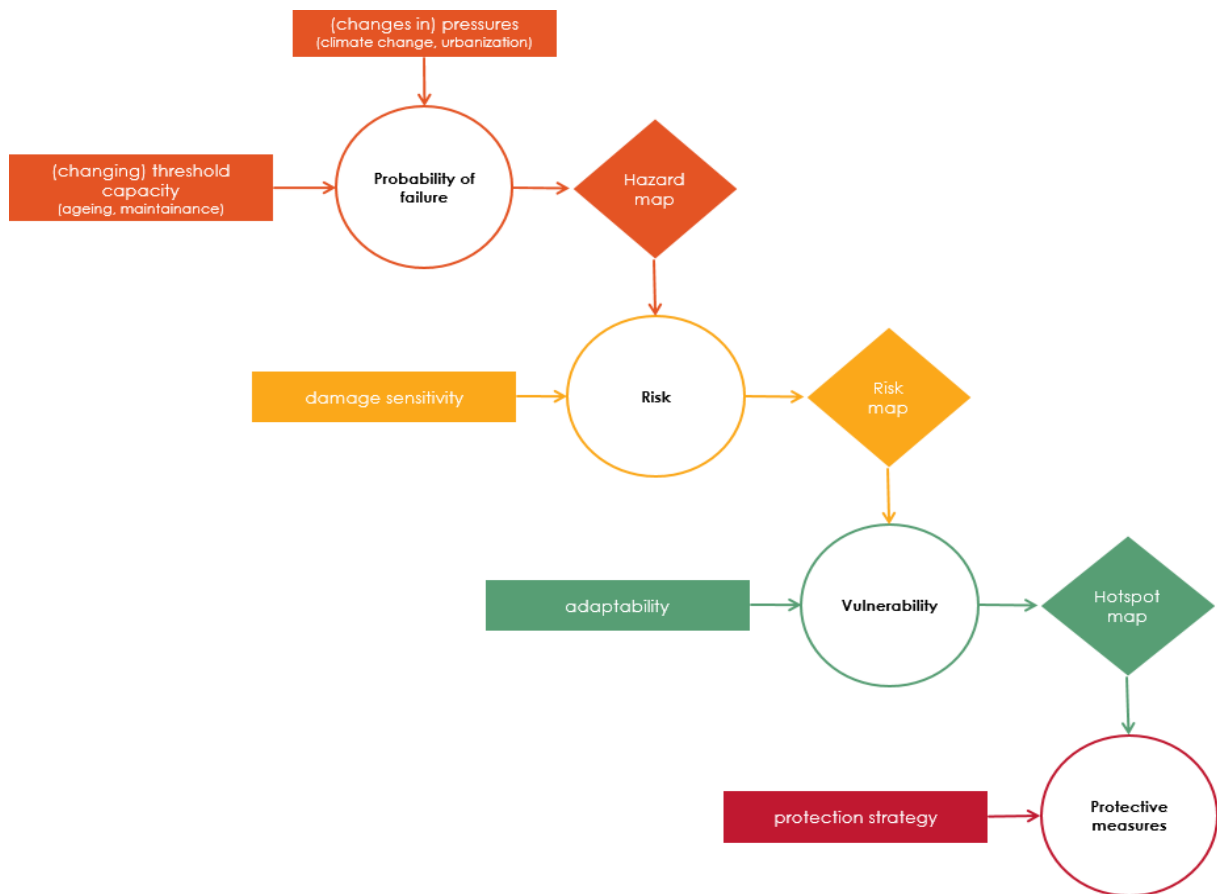


Figure 2 Example of flowchart for a typical vulnerability assessment

## Adaptability

In simple terms adaptability describes the ability there is to adapt. In this thesis adaptability will be defined as follows, “the speeds and efforts in which adjustments are possible in the social practice and processes or physical structures of the current system to projected or actual changes of climate”.



Figure 3 This thesis' view on adaptability

In this thesis, adaptability is seen as a combination of speeds and efforts, resulting in Figure 3. The speeds in which measures can be implemented and efforts needed for this implementation determine adaptability. High speeds and low efforts equal high adaptability, while low speeds and high efforts equal low adaptability.

When the speeds at which measures can be undertaken are slower than the projected climate change risks, areas are increasingly vulnerable to climate change. Efforts express for example the amount of money that is involved in climate proofing, the number of people that have to move or have to be moved, the difficulty of solutions and innovation that might be needed, this are all hindering effects when climate proofing.



The definition stresses the focus of this thesis, it'll look into the adaptability of the current physical system (not involving transformations, but focussing on the adaptation path of the current system), while focusing on the risks of climate change. In the coming paragraphs we'll look a bit further into the stresses, climate change and urbanization.

### Climate change

Climate, defined as the average weather including its statistical distribution, varies spatially and is variable at all timescales. The origin of those variations varies strongly, ranging from changes in solar radiation, the earth-sun geometry, volcanic disturbances of aerosol load and - since fairly recently in the history of the planet – anthropogenic influences on the atmospheric composition and land cover. (IPCC, 2014)

Over the past two decades it has become increasingly clear that climate is changing across the globe. Human influence on the climate system is clear, and recent emissions of greenhouses gases are highest in history. Recent climate change have had and will have widespread influences on humans and natural systems. (IPCC, 2014)

Climate change increases the risk, frequency and intensity of certain extreme events like intense heat waves, flooding from heavy precipitation and coastal storm surges (sea level rise) and disease incidence related to temperature and precipitation changes. Essential urban infrastructure will be increasingly compromised by climate change impacts. (IPCC, 2014)

### Urbanization

Urbanization is a population shift from people in rural to urban areas. This shift is going on for some time now and will continue the coming decades. The United Nations (UN) determined that by the end of 2008 half of the earth's population was living in urban areas. It is predicted that by 2050 about 64% of the developing world and 86% of the developed world will be urbanized. (UNFPA, 2015)

Urbanization increases vulnerability, and has a negative effect on the adaptability. The result of urbanization is a high concentration of people, materials, waste and energy in those urban areas. This leads to higher damage sensitivity to possible hazards of climate change and areas that are not or hard (to) adapt(able). The networks in these urban areas are already highly complex and will only get more complex, think of social networks and infrastructure, making also adaptation to climate change a highly complex task. Another result of urbanization is the lack of space in those areas. Almost every little plot of land in an urban areas has already a destination assigned and/or is already used. Making it harder to implement adaptations.

## 1.2 Problem statement

Climate change and urbanization are problems facing our cities and the urban environment. Direct effects of those challenges are that heat stress, drought and flooding are more likely to occur in the future and room for adaptations will get less and less.

In order to counteract those hazards, measures have to be taken. A method for finding out where vulnerability (the likelihood to harm) is high, is the vulnerability assessment. When doing a vulnerability assessment the risks and adaptability for an area will be found, with this information prioritization of areas and protection strategies can be determined.

It's important to determine the adaptability of an area to find out where measures can be taken with as less effort as possible and in time to counteract climate change related hazards (identifying so called quick wins or opportunities). On the other hand areas where adaptability is low are also important, because larger investments, research and/or innovation and more time are needed to make such an area climate proof. But finding this adaptability is hard and not a straight forward process.

Research done on adaptability focusses on the adaptability of societies on country or region scale. While, for taking measures within the urban environment, the adaptability of both society and the physical system is needed on a local scale (neighbourhood to street level).

The Delta Decision on Spatial Adaptation is the joint ambition of the aggregate government authorities to have the Netherlands as climate-proof and as water-robust as possible by 2050. This Delta Decision stresses the importance of integrating climate proofing and flood-risk management within the existing developments, redevelopments, investments, management and maintenance. The goal is to adapt this working method as from 2020, and have all institutes work on and together on climate proofing and adaptation. (Rijksoverheid, 2015)

If cities, societies, governments don't act, climate change will have an impact on people's health, liveability of neighbourhoods, comfort in homes and buildings, on labour and economy. Climate proofing is not only inevitable but also the least-social-cost strategy.

## 1.3 Purpose

The purpose of this thesis is to investigate the different definitions used in vulnerability studies, to make a definition for adaptability regarding the current urban environment and operationalize it for the Netherlands on neighbourhood level. With this definition in mind a method or tool will be constructed for determining the adaptability of the urban environment that can be used in vulnerability studies and adaptation planning.

## 1.4 Objectives and research questions

Given the problems identified above the main goal of this thesis is developing a way of operationalizing adaptability on local scale, so municipalities can use it in their decision-making and practice; developing a kind of prioritizing tool.

Objective 1: Come up with a own definition of adaptability for the urban water system

Objective 2: Operationalize this definition by means of indicators

Objective 3: Develop a prioritizing tool for municipalities

Subsequently, three research questions are addressed by this research.

Q1: What are important characteristics of adaptability that should be used in the definition of this thesis and the development of the tool?

Q2: What are the most important indicators for determining adaptability?

Q3: What are the potentials of determining adaptability, how can it be used?

## 1.5 Structure of this thesis

Considering the work already done in adaptability (and adaptive capacity) this thesis will first address the already existing frameworks, definitions and indicators. This step will provide an overview of the knowledge on the topic of interest. The definitions found will be used to construct the definition used in this thesis. Furthermore different ways of improving adaptability will be presented.

The following chapter will be on operationalizing adaptability, by using indicators. Questions that will be answered are: what are indicators used in literature and how can they be used in this research? On the other hand there are results of this thesis' fieldwork, the results of the interviews and selection will be presented. In the end of this chapter we will end up with a selection of "the most" important indicators of adaptability.

The last chapter builds further on the indicators from previous chapter, the indicators are used to construct a rapid assessment tool for the municipality of Dordrecht. The methodology for building this tool is given. Furthermore it is explained how the tool should be used and some results of the tool are presented.



**2**

# **DESK REVIEW**





## 2. DESK REVIEW: DEFINITIONS AND FRAMEWORK

This chapter focuses on describing the definitions and relations used in the topic of adaptability. For this purpose, an extensive literature review into the field of vulnerability and resilience studies has been conducted, of course this review focusses on adaptability. First vulnerability and resilience in general will be explained. Subsequently the concept of adaptability and the ways of improving adaptability will be visited.

### 2.1 Vulnerability explained

The vulnerability of a system refers to its physical, social and economic aspects. Vulnerability of systems to climate change is not a straightforward concept. According to (Adger, Brooks, Kelly, Bentham, & Eriksen, 2004) definitions of vulnerability of a system tend to fall in to two categories, viewing vulnerability:

1. In terms of the amount of (potential) damage caused to a system by a particular climate-related event or hazard (hazards and impacts approach), or
2. As a state that exists within a system before it encounters a hazard event.

Some of the more general definitions of vulnerability will be presented here. In the latest assessment report of IPCC<sup>1</sup> (5<sup>th</sup>) vulnerability is referred to as “the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt” (IPCC, 2014). In the previous assessment report (4<sup>th</sup>), vulnerability is “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including variability and extremes. Vulnerability is a function of character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity” (IPCC, 2007). The UNISDR terminology defines vulnerability as “the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard” (UNISDR, 2009) (see Appendix A for more definitions of vulnerability). In general the resulting framework consists of exposure, sensitivity and adaptive capacity (or adaptability), see Figure 4.

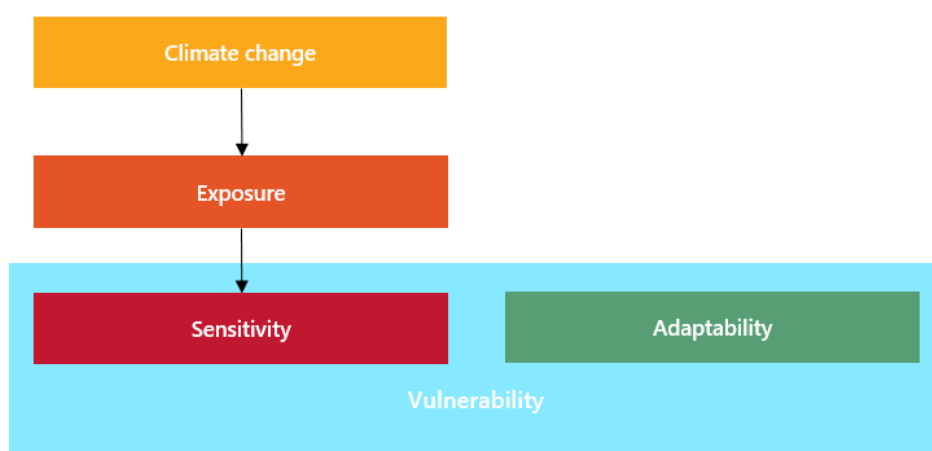


Figure 4 Vulnerability assessment according to IPCC (2014, 2007), which is also applied in most other assessments

<sup>1</sup> IPCC, Intergovernmental Panel on Climate Change is the leading international body for assessment of climate change, <http://www.ipcc.ch/>

In the assessment of vulnerability by IPCC (Figure 4) exposure is the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected. Sensitivity is the degree to which a system or species is affected, either adversely or beneficially, by climate change. The effect may be direct or indirect. (IPCC, 2014)

Vulnerability, its elements of exposure, sensitivity and adaptability, and their determinants are dynamic (they vary over time), they vary by type, they vary from stimulus to stimulus and they are place- and system specific. (Brooks, 2003)

## 2.2 Definition resilience

Resilience is a concept closely related to vulnerability, the IPCC defines resilience as “the capacity of social, economic, and environmental systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity of adaptation, learning and transformation” (IPCC, 2014). In general resilience is the ability to recover from an event.

Resilience can be seen as part of adaptability (mostly global environmental change studies) on the other hand adaptability can be seen as part of resilience (hazard studies), which can be rather confusing. (Cutter, et al., 2008)

## 2.3 Adaptability explained

Adaptability, adaptive capacity and coping capacity are terms used in vulnerability and resilience studies, they can be used as each other's synonyms, but their definitions can also be completely different.

Adaptability is originally defined in biology to mean an ability to become adaptive (i.e. to be able to live and reproduce) to a range of environments. In the human system it goes far beyond “being able to live and reproduce”, it includes viability of economic and social activities and the quality of human life. (Gallopín, 2006)

In simple terms adaptability describes the ability to adapt. IPCC refers to adaptability (which is in their book the same as adaptive capacity) as “the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences”. The context, system and place are important aspects of the definition (for more definitions see Appendix A).

Adaptability can be divided into two parts, the initiate adaptability to adapt and the anticipatory or planned adaptability (Engle, 2011). Adaptability is dynamic (it varies over time), differences between contexts and systems and is not equally distributed (IPCC, 2007).

### Mapping of definitions of adaptability

Because of the enormous amount of definitions, mapping the definitions can help understand and organize the different definitions used. Some definitions are more orientated to social adaptability and while others are orientated to physical adaptability, some definitions mention resources while others mention abilities or characteristics of a system. These differences can be used to make a framework and map the different definitions (see Figure 5). Examples of definitions for each mapped quadrant can be found Table 1.

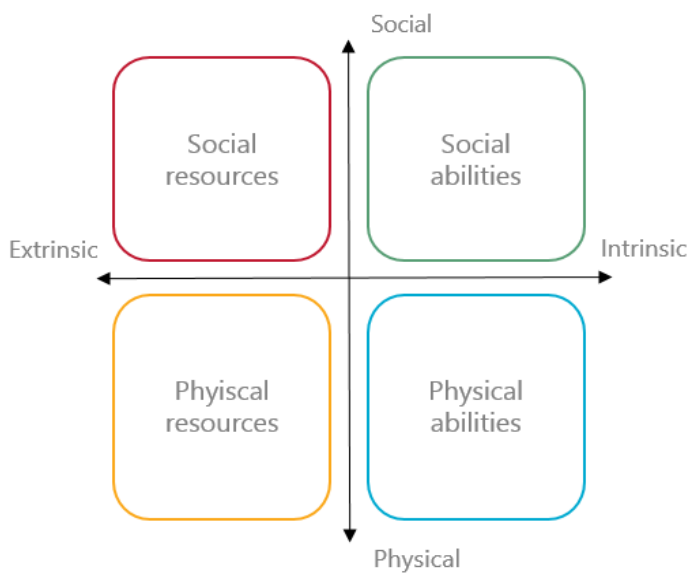


Figure 5 Mapping of definitions, social - physical, intrinsic - extrinsic

### Social - physical

This separation is quite straightforward, there are definitions more orientated to the social part of adaptability, focused on institutions, economy and knowledge. On the other hand there are definitions more orientated to the physical part of adaptability.

### Intrinsic - extrinsic

Another separation can be made when looking at whether adaptability is seen as an ability or characteristic of a system (intrinsic, more planned adaptability), or is seen as the resources that are available, such as; budgets, materials or social resources such as manpower or disaster response (extrinsic, more anticipatory adaptability).

### Examples

Social resources	The availability of social resources for sector-specific adaptation. In some cases, these capacities reflect sustainable adaptation solutions. In other cases, they reflect capacities to put newer, more sustainable adaptations into place. (University of Notre Dame, 2015)
Social abilities	The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. (IPCC, 2014)
Physical abilities	Adaptive potential is the physical ability of a system to modify or change its characteristics to cope better with existing or anticipated external stresses. (van de Ven, et al., 2010)
Physical resources	None found

Table 1 Some examples of definitions that can be mapped

The definition used in this thesis, "the speeds and efforts in which adjustments are possible in the social practice and processes or physical structures of the current system to projected or actual changes of climate", says something about physical (structures) as well as social (practices and processes) adaptability, and doesn't specify whether it only looks at intrinsic or extrinsic adaptability. So it takes all different definitions and views on adaptability into account.

## 2.4 Improving adaptability

There are four common ways of improving adaptability, improving one of the generic determinants of adaptability, anticipating to changing circumstances, match measures with big infrastructural works and introducing flexibility.

## Generic determinants

Improving one of the generic determinants of adaptability is the first way of improving adaptability. There are plenty of suggestions on what those generic determinants are, some determinants can be found in multiple or almost all studies some are unique. (Metzger, 2005) made an assessment of indicators in the European region, determinants found include; equity, knowledge, technology, infrastructure, flexibility and economic power. One of the first studies into determinants of adaptability was done by (Yohe & Tol, 2002), which had a more describing approach of the 8 determinants they found:

1. The range of available technological options for adaptation,
2. The availability of resources and their distribution across the population,
3. The structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed,
4. The stock of human capital including education and personal security,
5. The stock of social capital including the definition of property rights,
6. The system's access to risk spreading processes,
7. The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers, themselves, and
8. The public's perceived attribution of the source of stress and the significance of exposure to its local manifestations.

In general adaptability will increase if the economy is growing, (technological) knowledge is available or authorities are being built, concluding if there are resources available to adapt. If the economic (or material) assets (currently or even shortly) are not available the adaptability will decrease. (Smit, Burton, Klein, & Wandel, 2000)

## Anticipating

A second way of improving adaptability is by anticipating to changing circumstances. The goal of this kind of activities is to facilitate implementation of measures and multiple adaptation paths. Fixed policies can fail for particular scenarios because they fail to exploit opportunities that arise, ignore crucial vulnerabilities, or depend for their performance on critical assumptions that fail to hold, thus policies should be adaptive. Examples are reserving space for measures and innovating. (Walker, Rahman, & Cave, 2001)

## Matching (in Dutch, "meekoppelen")

A third way is to match climate proofing with big infrastructural works already planned in the area. In this way a reduction of costs and nuisance can be attained, which poses two of the biggest obstacles for implementing measures. (Roosjen, van der Brugge, Morselt, & Jeuken, 2012)

## Introducing flexibility

The final and fourth way to improve adaptability is introducing flexibility within the already existing set of agreements and rules. Examples from water control are flexible level management, multi-level safety barriers and building adaptive. (Roosjen, van der Brugge, Morselt, & Jeuken, 2012)



**3**

# INDICATORS



### 3. INDICATORS: FROM LITERATURE AND INTERVIEWS

Indicators are characteristics that make quantifying determinants possible and so finding a measure of the adaptability for an area. Using indicators is one of the ways of assessing adaptability and so vulnerability, as explained in Chapter 2.

Plenty of suggestions on what those indicators might be can be found in literature. Further investigation on and gathering of indicators is done by interviewing experts. Combining those indicators a list can be constructed that can be used for assessing adaptability.

Most important indicators will be selected to make the set of data workable. This selection will be done by the experts by means of an enquiry and focusses on the operationalization, what is the purpose of the tool, what will it be used for?

#### 3.1 Indicators from literature

A lot of suggestions on possible indicators can be found in literature (Yohe & Tol, 2002; Metzger, 2005; O'Brien, Eriksen, Schjolden, & Nygaard, 2004; Adger, Brooks, Bentham, Agnew, & Eriksen, 2004; Smit & Wandel, 2006; IPCC, 2007; Jones, Ludi, & Levine, 2010; Meijerink, et al., 2010; Engle, 2011; ESPON Climate, 2011; Phi, 2011, Adapting to Climate Change in Time, 2011; EEA, 2012 & IPCC, 2014). Problem is most of these indicators are meant for assessing social adaptability, those indicators are based upon economy, (technical) knowledge and institutions.

For his MSc Thesis at Wageningen University Long Hoang Phi investigated determinants and indicators used in nineteen published documents on adaptive capacity and adaptability (see Figure 6). This research confirms the findings of the desk review of this thesis; most of the research into adaptability is done in determinants and indicators related to social processes (e.g. institutes, (technical) knowledge and economy). Actually his research found no indicators or determinants based on physical characteristics or resources of the system.

Another problem that arises when looking at the available literature, is that the indicators are meant (or can only be used) for assessing the adaptability of a country or region. The indicators are spatially stable on larger scales, meaning there is no differentiation of the indicator on smaller scales. They cannot be used for assessment on local scales, which is needed when implementing measures on municipality level.

Few indicators on the physical adaptability on local scale can be found in literature (PBL, 2009, van de Ven, et al., 2010 & Veerbeek, Ashley, Zevenbergen, Rijke, & Gersonius, 2010). (PBL, 2009) mentions the quality and age of the urban environment and the profitability of new investments or adjustments. (Verbeek, Ashley, Zevenbergen, Rijke, & Gersonius, 2010) and (van de Ven, et al., 2010) both state the turnover of existing property and infrastructure; evaluating the age of buildings and infrastructure with respect to the expected end of the life cycle.

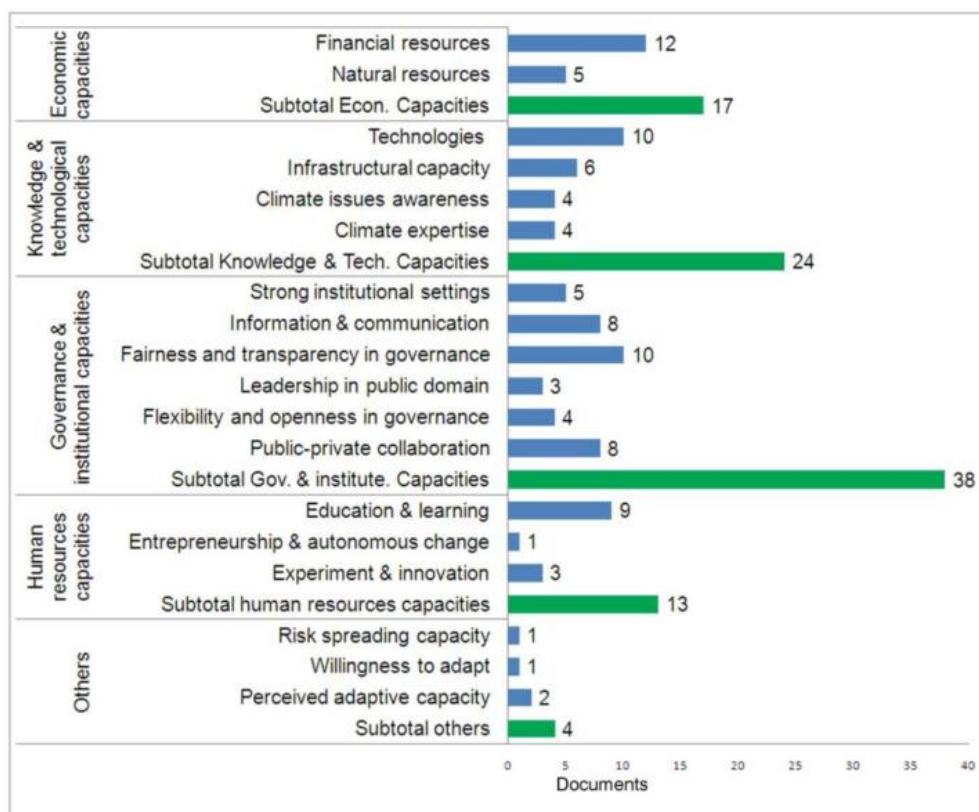


Figure 6 Indicators and determinants of adaptability found in nineteen publications in another thesis (Phi, 2011)

### 3.2 Indicators from interviews

Nine interviews with experts from across the field of urban water management and urban planning were conducted, with the purpose of finding more and other indicators for the adaptability of the urban water system. The interviews were not really structured, they were more like one-on-one brainstorm sessions, with the goal of finding as much indicators as possible. For the structure of interviews, questions and reports of the interviews see Appendix C.

The interviews resulted in a list of indicators (in total 37), those indicators are grouped on topic, resulting in determinants. The following determinants are found:

- space; space is needed for implementing measures, when there is space available this limits the efforts needed,
- underground; the underground puts limits to possible solutions,
- matching; with matching a lot of efforts can be saved by combining works, matching also gives an indication on when opportunities will arise,
- budget; gives an indication about how much and when money is available for measures and the pressures that may exist from the community,
- ownership; is about the stakeholders, the responsibility of different institutions and participation,
- function related demands; are demands related to specific areas, those areas require extra efforts to implement measures,
- water system; the current water system puts boundaries to what is possible.

Trying to represent the found determinants graphically in the given frameworks for adaptability (efforts-speeds and social-physical, intrinsic-extrinsic see 2.3 Adaptability explained) results in the following figures (see Figure 7 and Figure 8).

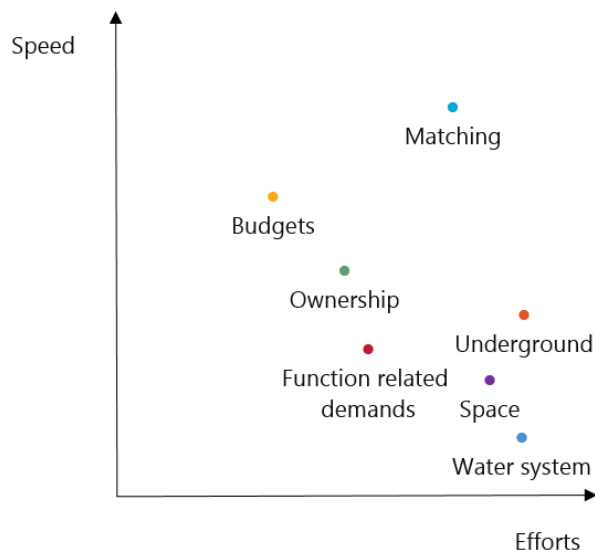


Figure 7 Determinants of adaptability plotted on speed-effort axis

In this figure (Figure 7) the identified determinants from the interviews are plotted on the efforts and speed axis. The placement of the determinants is based upon the indicators in each of those determinants and their relation to speeds and efforts of implementation.

Budgets and matching have the biggest impact on speed, matching gives an indication on when opportunities for climate proofing might arise and budgets give an indication of when money might be available for climate proofing.

Water system, space and underground are important indicators when looking at efforts. When there isn't an existing open water system additional efforts will be needed e.g. measures will be needed to transport the water on the other hand certain solutions need water (blue solutions). If there isn't space available for measures, space has to be created or innovative solutions requiring less space are needed, leading to more effort. The underground is limiting in a lot of situations because of for example a high concentration of underground infrastructure, contaminations or bearing capacity, this limitations can lead to additional efforts.

Ownership and function related demands are kind of in the middle of efforts and speed having an effect on both. Ownership has an effect on the speed and efforts at which measurements can be taken, for example when people have to be moved this takes time and effort, when there is no participation additional time and effort are needed to implement measures. Research when function related demands are at play also requires additional efforts and time.

From this figure can be seen that matching is one of the most important determinants it has huge effects on both speed and efforts. Without any form of matching climate proofing is most of the time impossible in the current Dutch context.

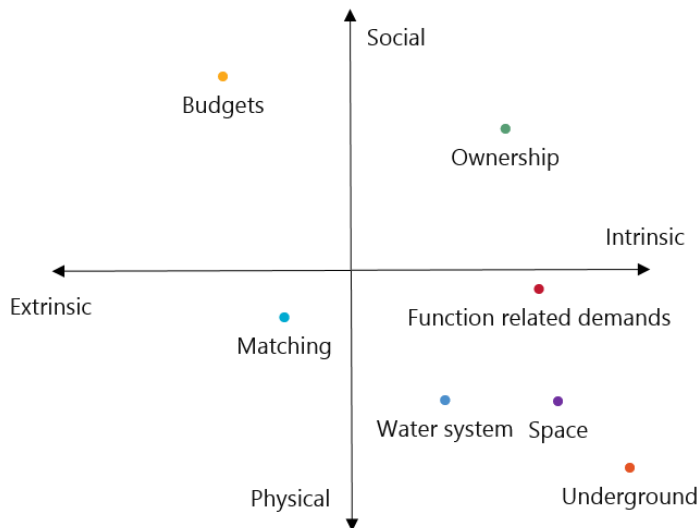


Figure 8 Determinants plotted on social-physical, intrinsic-extrinsic axis

See Figure 8, most of the determinants found are in the physical, intrinsic plane meaning most of the determinants consist of physical characteristics of the system. Matching says something about the resources (opportunities) that will become available in the future.

### 3.3 Selection of indicators

The found indicators during interviews and in literature are further selected by the experts, by means of an inquiry. The experts are asked to point out the most important indicators. The results of this enquiry can be found in Appendix B.

The use of the data that came out of this selection process depends on what you want to do with the indicators, what will the indicators be used for? Three possibilities are identified: using indicators for a rapid assessment, a thorough assessment or individual assessment of each indicator. It goes without saying that for the rapid assessment less indicators will be needed than for the thorough assessment and when using individual assessment all indicators can be used (if you want to).

In consultation with experts from the field the rapid assessment has been chosen as the most useful tool, for now. With this tool decisions can be made on how to approach climate proofing in a certain area, prioritisation can be done, areas with high adaptability (quick wins and opportunities) and areas with low adaptability (innovation and high efforts) can be identified. After this identification further research will be needed to point out the exact problems and opportunities in these areas.

Using a threshold of 5 out of 9 votes, the following indicators are selected.

#### Interviews $\geq 5$ votes

- Percentage buildings
- Percentage water
- Percentage green
- Soil type
- Cables and pipes
- Planned works

- Urgency
- Available budgets
- Types of stakeholders
- Percentage public property
- Historical city centre
- Open water system

The indicator that is found in literature isn't selected by the experts, only 3 experts voted for the expected lifespan of buildings and infrastructure compared to its current age. This indicator gives an indication on when redevelopment or an upgrade will probably take place of the selected buildings or infrastructure, giving an opportunity for climate proofing. What could be a reason for this is the variability in lifespans of the existing building stock, giving a high uncertainty.

#### From literature

- Estimated end of life cycle (EEOLC)

#### Using framework with the selected indicators

The framework presented in 2.3 Adaptability explained is used again to map the selected indicators of adaptability. The social-physical axis and intrinsic-extrinsic axis divide the system in four quadrants each of the quadrants represents another view on adaptability. Using at least one indicator of each quadrant it is possible to incorporate the different views on adaptability in the rapid assessment tool.

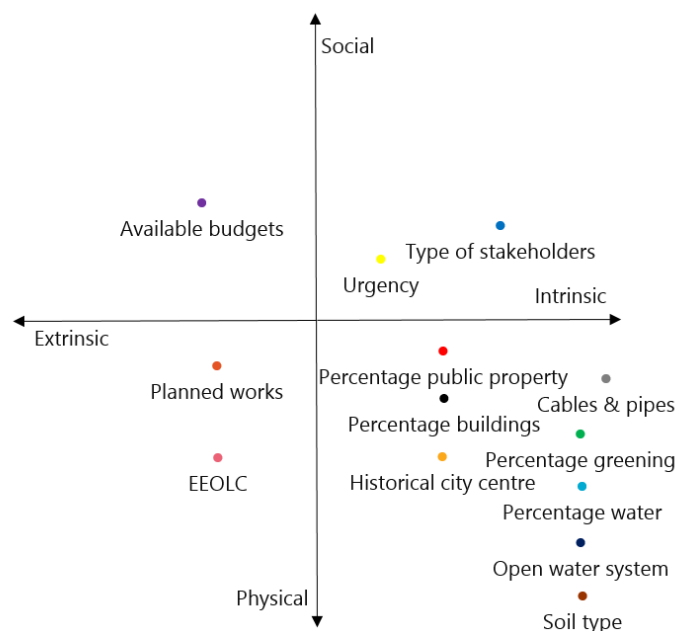


Figure 9 Indicators ( $\geq 5$  votes and from literature) plotted in framework

Plotting the indicators in the framework leads to the following figure, Figure 9. The locations of the indicators within the quadrant are indicative. As can be seen the indicators are not spread evenly over the quadrants. 8 out of 13 indicators are found in the physical intrinsic quadrant, this is due to the focus of this thesis on the physical side of adaptability, and the intrinsic plane seems to be more apparent overall in adaptability.

When looking at relations between indicators, the percentage water and the presence of an open water system seem related, so are the percentage buildings and an area being a historical city centre.

One of the water indicators can be dropped, both indicators represent the same processes that make an area more or less adaptable. The possible solutions (blue solutions) that can be implemented (when there is already open water available there a lot more possible solutions than when there is not) and the distance to open water (meaning less transportation, so less efforts) are underlying processes related to these indicators. The presence of an open water system can be dropped as indicator. The indicator of percentage open water is chosen over the other because it contains more information it contains a percentage instead of only yes/no.

In the other case, the historical city centre says more than only the high percentage of buildings and so the lack of space. It adds to it, narrow streets, old foundations, monuments, high spatial stability, somewhat endless end of life cycle and the old historical character which cannot be presented only by the high percentage buildings in these areas. This is why both indicators are kept, both are important for determining adaptability.

This leads to the following set of possible indicators: percentage buildings, percentage water, percentage greening, soil type, cables and pipes, planned works, estimated end of life cycle, urgency, available budgets, type of stakeholders, percentage public property and historical city centre.



4

**OPERATIONALIZING**



## 4. OPERATIONALIZING: A TOOL FOR RAPID ASSESSMENT OF ADAPTABILITY

In this chapter the tool will be “build” for the municipality of Dordrecht. First I brief introduction into the municipality of Dordrecht will be given. Furthermore the methodology of developing the tool will be presented. Lastly we’ll look into the use of the tool and some results of the tool itself.

### 4.1 Dordrecht

Dordrecht is a city and municipality in the south of the province of South Holland, the Netherlands. It is the fourth biggest city in the province with a population of approximately 120.000. The city of Dordrecht was formed in the midst of peat swamps and is the oldest city in Holland, having a rich history and culture.



Figure 10 Location of municipality of Dordrecht

The city and water are inextricably connected, an island surrounded by water, the harbours, canals and the Biesbosch. The city is part of the Meuse-Scheldt delta complex, and lays at the intersection point of the salt water from the sea and the fresh water from the rivers. Most parts of the outer dike area have been urbanised in the past and still are under influence of the tides, the lowest quays lay at +1,75 m NAP. In the inner dike areas the water is constantly managed.

### 4.2 Methodology

Here the different steps, data, tools and programming languages used in developing the tool are presented.

#### Gathering data

Most of the data used for the tool is open source, and freely available for everyone (see Table 2). Although some specific data from the municipality itself is used, the data for the planned works for the coming years, in this case the maintenance planning and the location of the main cables and pipes has been supplied by the municipality of Dordrecht.

In the end I didn’t get my hands on data for the indicators of percentage public property, type of stakeholders and available budgets. The data needed for percentage public property and type of stakeholders is a map which expresses the owner of each parcel, this map is owned by the cadastre and is very expensive, and unfortunately the municipality also didn’t own this data. The data needed for available budgets is simply not there yet, because no money is spend on climate proofing, maybe it will come available in the future.

Table 2 Data sources for tool

Name	Source	Used for
TOP10Vector	<a href="https://www.pdok.nl/nl/producten/pdok-downloads/basis-registratie-topografie/topnl/topnl-actueel/top10nl">https://www.pdok.nl/nl/producten/pdok-downloads/basis-registratie-topografie/topnl/topnl-actueel/top10nl</a>	Percentage green & percentage water
Inspire Adressen	<a href="https://www.pdok.nl/nl/service/wfs-adressen-inspire-geharmoniseerd">https://www.pdok.nl/nl/service/wfs-adressen-inspire-geharmoniseerd</a>	Percentage buildings, historical city centre & EEOLC
Kerncijfers buurten en wijken	<a href="http://www.cbs.nl/nl-NL/menu/methoden/dataverzameling/kerncijfers-wijkbuurt-kob.htm">http://www.cbs.nl/nl-NL/menu/methoden/dataverzameling/kerncijfers-wijkbuurt-kob.htm</a>	EEOLC
GeoTopDL5	<a href="http://www2.dinoloket.nl/nl/about/modellen/geotopdl5.html">http://www2.dinoloket.nl/nl/about/modellen/geotopdl5.html</a>	Soil type
Cultuurhistorische hoofdstructuur	<a href="https://data.overheid.nl/data/dataset/cultuurhistorische-hoofdstructuur-archeologie-monumenten">https://data.overheid.nl/data/dataset/cultuurhistorische-hoofdstructuur-archeologie-monumenten</a>	Historical city centre

### Editing of data

The data is edited with the help of a graphical information system (GIS), in this case QGIS is used. QGIS is open source GIS software, it can be used to visualize, edit and transform graphical data. Some of the tools that were used:

- \$area, which calculates the area of a polygon,
- join attributes by location, which is able to join features based on their location, for example patches of green (e.g. grasslands, forest or parks) within a neighbourhood,
- clip tool, which clips data to a given extend,
- the vector grid, which makes it possible to cut up large polygons in small squares in order to calculate the area for each neighbourhood,
- sum line lengths, with this tool the length of lines within a polygon can be calculated,
- and a lot different database operations in which the SQL language can be used.

This resulted in different maps in QGIS containing the data of each indicator calculated for each of the neighbourhoods. The explanation and graphical representation of each of the selected indicators can be found in Appendix C.

### Scale

Adaptability and its indicators will be determined on neighbourhood scale. This is a scale at which physical relations, characteristics and patterns are still holding. Buildings and infrastructure are more likely to have the same characteristics and are built within the same period, giving emergent patterns to work with. On the other hand neighbourhood level is still small enough to determine strategies on municipality level.

### Classification of data

Three classification methods are used to classify the data, to make the data comparable to one another and to be able to calculate a measure of adaptability (the classification of all indicators can be found in Appendix D):

- the Jenks classification which is designed to place variable values into naturally occurring data categories,
- the quantile classification which distributes a set of values into groups that contain an equal number of values,

- the geometric interval classification works well on non-normal distributed data, it is designed to work on heavily skewed data with a preponderance of duplicate values.

### Graphical representation of data

Leaflet is used for the graphical representation of the data. Leaflet is an open-source JavaScript library for interactive maps. It uses JavaScript to build interactive maps which can be opened in any browser (HTML and CSS are also used to style the webpage). It is fluidly able to show large datasets, without requiring any new or additional software for everyone using it.

Leaflet uses GEOjson files and tile layers. GEOjsons are text strings containing data and geographical information. QGIS is able to export this file type, so when data is altered in QGIS it is saved as GEOjson and can be used and visualized by the Leaflet library. Leaflet also uses tile layers, which are base layers containing topographical data which can be downloaded from several sources on the web, in this case tiles from Mapbox are used.

### Changing weights

It is also possible to change the weights of the indicators used, the adaptability will then be calculated using the changed weights. This is accomplished by using PHP, which is a server scripting language. The GEOjson file is loaded, decrypted, altered (by using SQL queries) and encrypted and saved again using PHP. The resulting file is then shown using Leaflet.

### Sensitivity analysis

The one-at-a-time (OAT) technique is used to look at the sensitivity of the indicators, for a full report of the sensitivity analysis see Appendix E. One-by-one one of the indicators is left out and the result is then compared to the result using all indicators. Doing this the importance of each indicator on the average adaptability can be determined and the effect on the average adaptability (see Table 3).

Table 3 Results of OAT sensitivity analysis

Indicator that is changed	Contribution of each indicator (%)	Effect on adaptability (positive/neutral/negative)
Percentage buildings	13,8	positive
Percentage water	19,8	neutral
Percentage green	22,3	positive
Soil type	6,7	negative
Main cables and pipes	3,7	negative
Planned works	14,0	negative
EEOLC	12,0	neutral
Urgency	6,8	negative
Historical city centre	0,9	negative

From this sensitivity analysis can be seen that the space related indicators (percentage buildings, percentage water and percentage green) have by far the most impact on the overall adaptability of the Dordrecht area, this doesn't say that those indicators also have most impact on neighbourhood level. For example historical city centre has a minor effect on the overall adaptability, while it has quite a big effect on the adaptability in the city centre itself.

## Validation

To check whether the results from the tool make sense a feedback session with two people working at the municipality of Dordrecht is done. Edwin van Son works as urban developer at the municipality, while Karin Noeverman works on water policy. After introducing them into adaptability they are asked to point out the areas of Dordrecht which they think have high adaptability and low adaptability. The results of this task can be found in Figure 11.

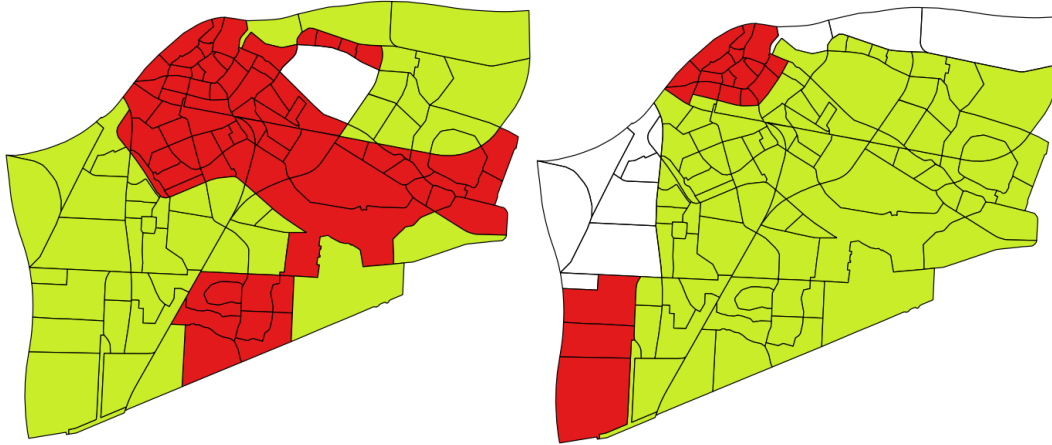


Figure 11 Results of areas with high adaptability (green) and low adaptability (red) on the left Edwin's and on the right Karin's

Edwin focussed on type of buildings, property in an area thinking about whether buildings are privately owned or by a cooperation and projects that will be started in the future. While Karin focussed on percentage green and space available for adaptation.

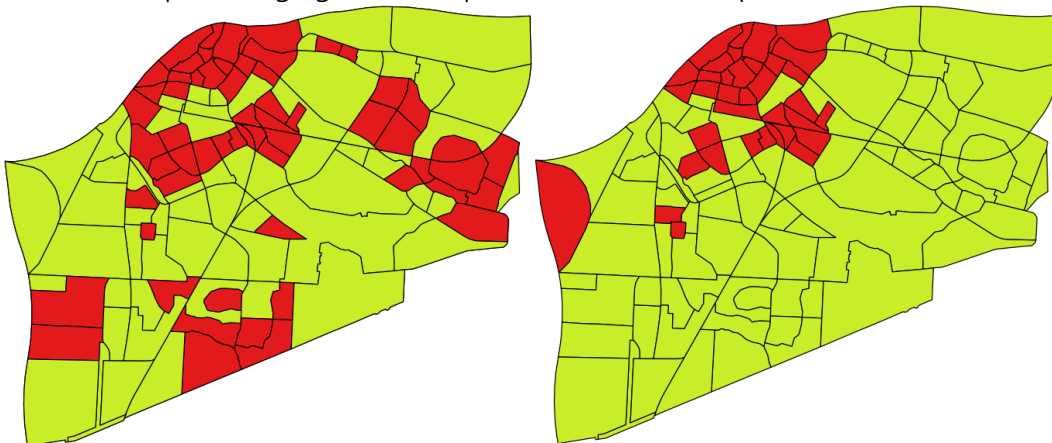


Figure 12 Results on the left combination of percentage buildings and EOLC (trying to recreate Edwin's thinking process) and on the right combination of percentage buildings and percentage green (Karin's)

When comparing Edwin's map (left map of Figure 11) with the left map of Figure 12, it can be seen that the neighbourhoods on the far right and below are selected by the tool as well as the indication of Edwin. This is due to being a recently built neighbourhood consisting of buildings that are privately owned (long life cycle).

When comparing Karin's map (right map of Figure 11) with the right map of Figure 12, it can be seen that the historical city centre is red (so low adaptability on both maps). The area Karin indicated in the lower left corner as having low adaptability, turns out to have quite some green, because of not all plots of this industrial area being given out yet.

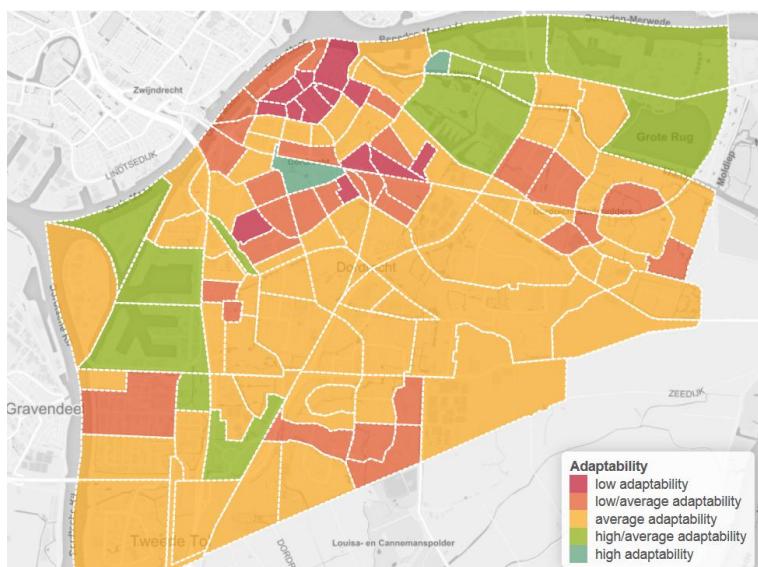


Figure 13 Result from the tool using pre-set configuration of indicators

When comparing the results from the session with an actual map from the tool (in this case my own selection of indicators). Both Edwin and Karin indicated the historical city centre having low adaptability, this area is also the area in the tool that has lowest adaptability. The shape that Edwin sketched can also kind of be found in this produced map from the tool. The left side and upper right side have highest adaptabilities, and kind of in the middle there are the lowest adaptabilities.

What can be concluded from this validation session is that the tool produces outcomes that are in line with the thoughts from two of the municipalities employees. It includes most of the indicators they thought of when making their picture of adaptability. Again the importance of property is stressed, this could unfortunately not be included in this tool because of lack of data.

### 4.3 How to use the tool

Adaptability is determined by our tool to help find vulnerability, vulnerability is the combination of risks and adaptabilities. So combining the generated adaptability maps with risks maps is a logical next step after using the tool.

#### Use risk maps and adaptability maps side-by-side

Comparing risks and adaptability maps, areas with high vulnerability and low vulnerability can be identified. Furthermore quick wins can be identified, those are areas with high adaptability, if risks in those areas are high as well, it makes sense to adapt those first. On the other hand areas with challenges regarding climate proofing can be identified, those are areas with low adaptability. If the risks in those areas are high as well, it makes sense to start working on those challenges, doing research looking into possible innovation and using all opportunities regarding matching that arise. Areas with low adaptability and low risks on the other hand might not be the first areas of your concern.

So using the risk map and adaptability map side-by-side a prioritization of climate proofing can be made. Which areas make sense to climate proof first, because of high risks or quick wins and which areas can be focussed on later, low risks.



#### 4.4 Showing some results

Here some of the results from the tool for the Dordrecht case (<http://thomas.engineering>) will be discussed, the map which includes all indicators with equal weights will be shown, as well as my own “favourite” selection of indicators and weights for those indicators.

##### Using all selected indicators

When all selected indicators are used and weights are the same for each indicator, the resulting map looks like Figure 14. The first thing that can be seen all over the map is that all neighbourhoods have an adaptability around average adaptability, the more indicators you use, the more likely it is that adaptability will be around average.

It can be seen that adaptability is low/average in the historical city centre of Dordrecht, which is as expected, the adaptability is also low/average in highly built up neighbourhoods having low percentages of water and greening. Adaptability is high (high/average) in some of the neighbourhoods near the Merwedehaven, quite some money is invested in maintenance in those areas, water and greening is available and the percentage of buildings is quite low.

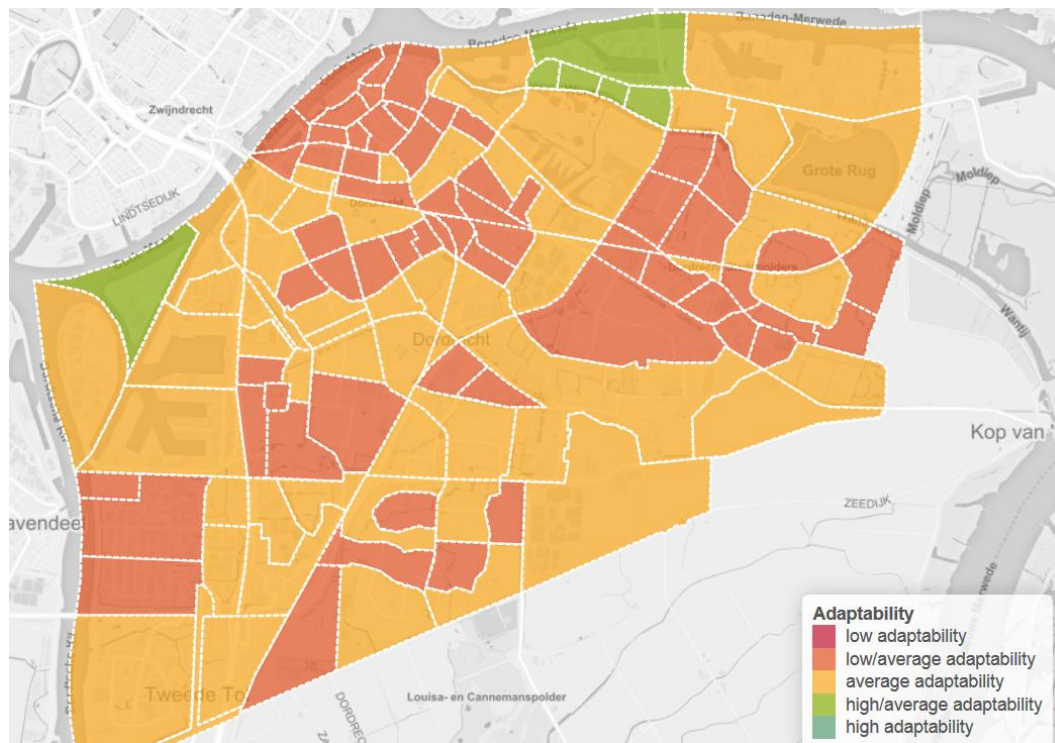


Figure 14 Map of adaptability for the municipality of Dordrecht using all indicators and equal weights



### My own selection of indicators and weights

Using the tool it is possible to create your own map, using the indicators and weights you, yourself think represent adaptability most accurate. My selection consists of the following indicators and weights, percentage buildings (1), percentage water (1), percentage green (0.5), planned works (0.2), estimated end of life cycle (1), urgency (0.5) and historical city centre (1).

I personally think percentage buildings, percentage water, estimated end of life cycle and historical city centre are most important indicators for adaptability. Soil type is not important because it should be kind of the same for the whole Dordrecht area, this indicator only further averages the adaptability over the area. Furthermore I think the main cables and pipes don't have a great impact on adaptability, the area of those main cables and pipes is very small when compared to the total area of the neighbourhoods, and most cables and pipes are situated outside urbanized areas. The planned works, is not that important because it includes only the maintenance for the coming years (so only small part of planned works are taken into account), which can create unwanted distortion. The estimated end of life cycle can have high inaccuracy, but redevelopments and renewal are very important and can give important strategic insights, furthermore it gives an indication of social indicators within a neighbourhood it includes the WOZ value and the dominating property type (rental or bought) of an area.

Using this selection there is more distribution of adaptability over the neighbourhoods, see Figure 15. There are more neighbourhoods with a high or high/average adaptability (most of them are not urbanized areas), which I think is more realistic. Most of these areas consist of a lot of water and/or green, and low percentages of buildings, such as harbour areas and parks.

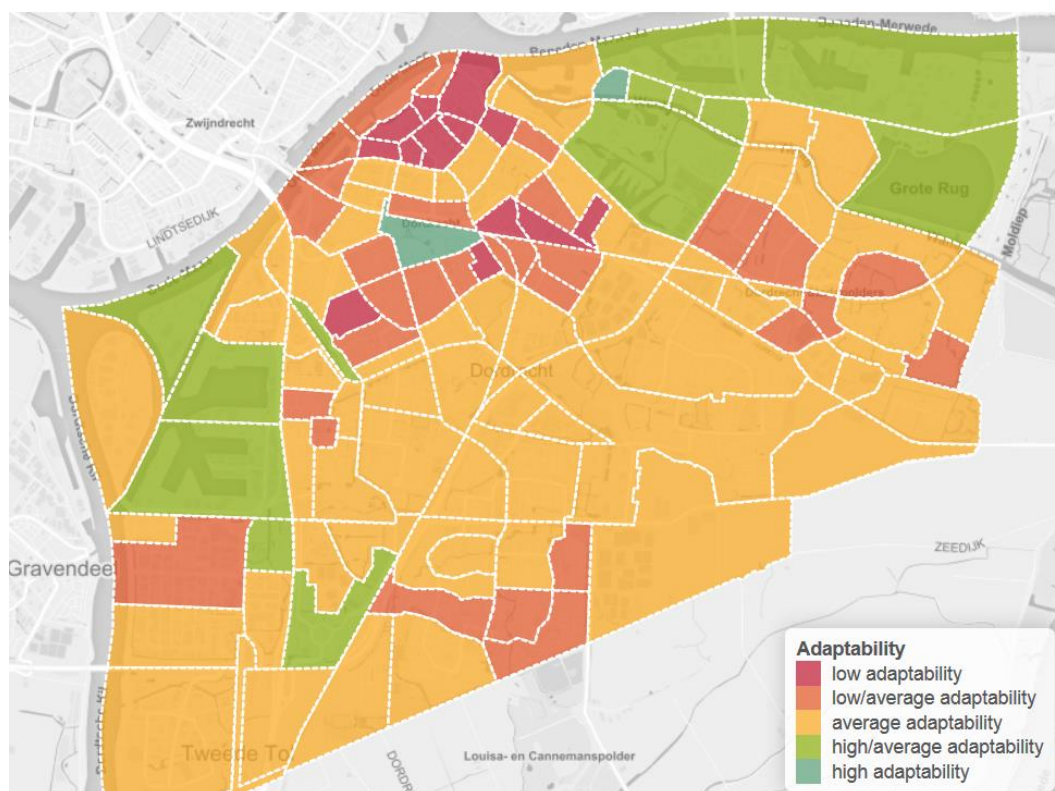


Figure 15 Map of adaptability for municipality of Dordrecht using my own selection of indicators and weights





# **CONCLUSIONS AND DISCUSSION**



## 5. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

This chapter starts off with a discussion on lessons learned, limitations and future perspectives. Furthermore this chapter synthesizes main findings, conclusions and ends with some general recommendations for the municipality of Dordrecht.

### 5.1 Discussion

Most previous research into adaptability has been done into social adaptability, looking at institutions, relations, knowledge and economy. This thesis tried to focus more on the practical, physical adaptability, but also tried to include the social part of adaptability. But maybe it focussed a bit too much on the physical part, most interviews lead to a great number of physical indicators, but only few social, due to this focus. Some important social indicators might have been overlooked.

Some social indicators such as, average income per household, unemployment, crime rates leading to problem areas, may have significant effects on adaptability. For example degradation of neighbourhoods due to vacancy of buildings and shrinking municipalities in the North-Eastern part of the Netherlands, will attract less investments, have lower budgets and less pressure, willingness and drive to adapt. Further research into the subject of adaptability should also include more social indicators that can be expressed on street or neighbourhood level.

I was unable to retrieve data for three indicators. One of those indicators, types of stakeholders, includes mechanisms that are hard to predict or express, so inaccuracy of this indicator would already be high, maybe unusable. The other indicator, percentage public property, uses the same dataset, but the dataset was too expensive and unavailable from the municipality. This indicator can be very useful, and constructing this indicator may lead to increased performance. The last indicator that couldn't be constructed is available budgets, this is due to no money being invested in climate adaptation. In the future this indicator could help indicate municipalities that have problems with adaptation, and so have a low adaptability. But on neighbourhoods scale this indicator isn't important, because it doesn't vary spatially.

I'd like to further stress the importance of property. Almost all (or maybe we could say all) climate proofing done by municipalities will take place on public ground. It is too time consuming and takes too much effort to do climate proofing on municipality scale on private ground. This doesn't mean that a municipality can't activate private and semi-private sector to help in climate proofing, for example citizens unpaving their gardens and housing associations building climate adaptive. In further research on adaptability this indicator must be included.

As stressed before matching is most of the time needed when climate proofing, you need maintenance, redevelopments or developments to include climate proofing. One of the indicators used to "predict" this process is planned works, this indicator looks at works that are already planned, for example sewerage replacements and redevelopments of neighbourhoods or streets. The data used for and from the municipality of Dordrecht only includes one multiple year maintenance planning, leaving a lot of works not included. So the completeness of this indicator can be brought up for discussion, for the time being this was the only available data. The municipality is currently working on making matching general practice, including it in all coming works from the municipality and other institutions. Mapping all the coming works this indicator can probably be improved significantly.

This thesis focussed on the current urban environment, neglecting transformations. In the future it might be interesting to include transformations between different adaptation paths, because there will probably be a time we need to transform our adaptation path. When including transformations do the selected indicators for adaptability still hold? Are additional indicators or different indicators needed when adding transformations? Research can be done on what effect transformations have on adaptability and its indicators.

Nine interviews were conducted to find indicators, statistically speaking this may not be representative. But for the goal of this thesis, discovering the field of physical adaptability, it satisfies. Building further on this first proposal of physical adaptability, discovering more and maybe better indicators, it is can be advised to conduct more interviews with people who are more into the field of urban/spatial planning and less into the field of water management.

Of course when I just finished my tool I thought of maybe a better way of determining adaptability. In my opinion it is at least a more structured way of determining adaptability, because the indicators in the tool might seem a bit random. In this new method the indicators used can be divided in physical characteristics, property and process (the three Ps). Physical characteristics include the type of building block which can be determined using Spacematrix (Berghauser Pont & Haupt, 2009), which uses densities (FSI and GSI) to determine building block type, furthermore we can also take into account water and/or green. Property takes into account whether an area is private or publicly owned. Lastly process looks at when opportunities regarding climate proofing arise, so taking into account estimated end of life cycle and planned works. This method includes less indicators, but includes the most important ones and is able to give a structured view on adaptability. The indicators probably need to be expressed on a smaller scale, like plot or street scale, to use the indicators most effectively. For a more extensive explanation and some experimentation with this idea see Appendix F.

## 5.2 Conclusions

In general adaptability is defined as the ability there is to adapt. I like to see adaptability as a combination of speeds and efforts in which adaptations can be implemented. For our definition of adaptability it is important to include both a reference to the physical and social systems, because we try to incorporate both. Furthermore the focus of this thesis is on the challenges and opportunities that arise from climate change to the current system (so ignoring transformations). With this in mind the following definition of adaptability is constructed, "the speeds and efforts in which adjustments are possible in the social practice and processes or physical structures of the current system to projected or actual changes of climate".

Indicators of adaptability have been collected from literature research and interviews with experts. This inventorization lead to 38 indicators spread over 7 determinants. Selection of this indicators is also done with the help of the experts, by means of an enquiry in which they had to select the most relevant indicators for each determinant. Using a threshold of 5 votes out of 9, this lead to the following selection of indicators for adaptability (in total 12): percentage buildings, percentage water, percentage green, soil type, cables and pipes, planned works, urgency, available budgets, types of stakeholders, percentage public property, historical city centre and open water system. The indicator that showed up in literature for determining the physical adaptability multiple times isn't selected by this threshold, but is included, estimated end of life cycle.

The resulting maps from the tools can be used to prioritize climate proofing within the municipality of Dordrecht. Using the adaptability maps side-by-side with the risk maps this prioritizing can be achieved. Areas having high risks and high adaptability, quick wins might be at play. In areas where risks are high and adaptability is low, challenges regarding climate proofing lay ahead, research, innovation and/or (more) investments may be needed to make such an area climate proof.

As expected the historical city centre of Dordrecht has a low adaptability due to a high concentration of buildings, not much greening, no planned works and it being a historical city centre, so challenges lay ahead in these areas. Most of the harbour, park and nature areas have high to average adaptability, due to high percentages of water and/or green, low percentages of buildings, investments in some of those areas and short life cycles of buildings (especially in the harbour and industrial areas), so opportunities may lay ahead in those areas.

Using a vulnerability assessment instead of a risk assessment you are able to improve your decision-making, by including more data and information than a standard risk assessment. When adaptability is determined an indication of the amount of efforts and time needed for climate adaptation is known before hand, this is an important input for both decision-making and planning (prioritization). In the end using vulnerability assessments and climate proofing is the least-social-cost strategy.

### 5.3 Recommendations

Lastly some general recommendations for the municipality of Dordrecht:

Dordrecht has a lot of water in its surroundings, rivers, ponds and canals are abundant, this leads to risks but also opportunities regarding climate proofing, so called blue solutions, using this opportunities can create additional benefits.

Furthermore a lot of challenges regarding climate proofing within the historical city centre will probably arise in the near future. Starting as soon as possible with research and innovation into making this area climate proof is important. Taking all opportunities that arise regarding climate proofing in this area, maintenance, redevelopments and rebuilding is one of the important first steps. Try to bring some green and blue adaptation solutions the historical city centre.

Matching, using planned works, making use of opportunities that arise, is the (in capitals) way of climate proofing. Building good structures for finding, identifying and using these opportunities is important. When these opportunities can and will be used a lot of efforts can be saved.

Try to involve other institutions, semi-private or public companies and citizens in climate proofing of Dordrecht. Trying to bundle forces and have the same goals across institutions. Look at planned works for for example the water board, province and housing associations have regular meetings and involve one another. Try to involve and motivate your citizens to help in making Dordrecht climate proof.

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# APPENDICES



## A. DEFINITIONS FROM LITERATURE

In this appendix the different definitions of vulnerability, resilience, adaptability and adaptive capacity found during the desk review will be presented. The definitions are sorted in groups to stress the differences in definitions.

### Vulnerability

Vulnerability is sorted in definitions of general vulnerability (meaning no specification of which adaptability is meant) and other vulnerability, e.g. social, socio-economic and engineering.

#### General vulnerability

The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt. (IPCC, 2014)

The characteristics and circumstance of a community, system or asset that make it susceptible to the damaging effects of a hazard. (UNISDR, 2009)

The degree to which a community, population, species, ecosystem, region, agricultural system or some other quantity is susceptible to, or unable to cope with, adverse effects of climate change. (OECD, 2006)

The degree to which the exposure unit is susceptible to harm due to exposure to a perturbation or stress, and the ability (or lack thereof) of the exposure unit to cope, recover, or fundamentally adapt (become a new system or become extinct). It can also be considered as the underlying exposure to damaging shocks, perturbation or stress, rather than the probability or projected incidence of those shocks themselves. (UNDP, 2005)

The degree to which an individual, group or system is susceptible to harm due to exposure to a hazard or stress, and the (in)ability to cope, recover, or fundamentally adapt (become a new system or become extinct). (Tompkins, et al., 2005)

Studies on urban vulnerability tend to portray it in negative terms, as the possibility to be harmed, that is, as the degree to which a system (e.g. city, population, infrastructure, and economic sector) is susceptible to and unable to cope with adverse effects of a single, or several hazards or stresses (e.g. climate change and political instability). (Lankao & Qin, 2011)

Vulnerability is often defined as the sensitivity of a system to exposure to shocks, stresses and disturbances, or the degree to which a system is susceptible to adverse effects, or the degree to which a system or unit is likely to experience harm from perturbations or stress. (De Graaf, 2009)

#### General vulnerability to climate change

The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity. (IPCC, 2001; IPCC, 2007)

The term vulnerability is generally used to describe that a valued characteristic of a system (e.g. the income basis of a community or the carbon stock of a forest ecosystem) is threatened due to exposure to one or more stressors (e.g. extreme weather events or long-term climate change). Vulnerability is defined as a function of 1) the exposure to climate change impacts, 2) the sensitivity and 3) the adaptive capacity of a system or territory. (EEA, 2012)

The extent to which a natural system or human society is unable to cope with the negative impacts of climate change, variability and extremes. It depends on changes in climate as well as the sensitivity and adaptive capacity of the system or society. (Australian Greenhouse Office, 2003)

Refers to the magnitude of harm that would result from a particular hazardous event. The concept recognises, for example, that different sub-types of a receptor may differ in their sensitivity to a particular level of hazard. Therefore climate vulnerability defines the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. It depends not only on a system's sensitivity but also on its adaptive capacity. Hence arctic alpine flora or the elderly may be more vulnerable to climate change than other components of our flora or population. (UK CIP, 2003)

Vulnerability measures a country's, exposure, sensitivity and capacity to adapt to the negative effects of climate change. ND-GAIN measures overall vulnerability by considering six life-supporting sectors: food, water, health, ecosystem service, human habitat, and infrastructure. (University of Notre Dame, 2015)

#### Socio-economic vulnerability

Socio-economic vulnerability is an aggregate measure of human welfare that integrates environmental, social, economic and political exposure to a range of harmful perturbations. (UNDP, 2005)

#### Social vulnerability

Social vulnerability is determined by factors such as poverty and inequality, marginalisation, food entitlements, access to insurance, and housing quality. (Brooks, 2003)

#### Engineering vulnerability

Engineering vulnerability is defined as the shortfall in the ability of public infrastructure to absorb the negative effects, and benefit from the positive effects, of changes in the climate conditions used to design and operate infrastructure.

Vulnerability is a function of:

- Character, magnitude and rate of change in the climatic conditions to which infrastructure is predicted to be exposed;
- Sensitivities of infrastructure to the changes, in terms of positive or negative consequences of changes in applicable climatic conditions; and
- Built-in capacity of infrastructure to absorb any net negative consequences from the predicted changes in climatic conditions.



### Intrinsic vulnerability

Exposure, the extent and intensity where the hazard comes into contact with assets (built environment, people, ecosystems, etc.);

Sensitivity, the level in which exposure to some climate related effect (e.g. flooding) results in an effect (e.g. damages, health problems);

Intrinsic vulnerability is the aggregation of exposure and sensitivity. (van de Ven, et al., 2010)

### Physical/biophysical vulnerability

Biophysical vulnerability is concerned with the ultimate impacts of a hazard event, and is often viewed in terms of the amount of damage experienced by a system as a result of an encounter with a hazard. (Brooks, 2003)

### Resilience

Resilience definitions are sorted in general definitions and specific definitions (e.g. infrastructure resilience and engineering resilience).

#### (General) resilience

The capacity of social, economic, and environmental systems to cope with hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation. (IPCC, 2014)

The ability of social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change. (IPCC, 2007)

Amount of change a system can undergo without changing state. (IPCC, 2001)

The ability of a system, community or society exposed to hazard to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. (UNISDR, 2009)

The ability of a system to recover from the effect of an extreme load that may have caused harm. (UK CIP, 2003)

Resilience refers to three conditions that enable social or ecological system to bounce back after a shock. The conditions are: ability to self-organize, ability to buffer disturbances and capacity for learning and adapting. (Tompkins, et al., 2005)

The capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks – in other words, stay in the same basin of attraction. (Walker, Carpenter, & Kinzig, 2004)

A measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between population or state variables. (Holling, 1973)

The buffer capacity or the ability of a system to absorb perturbations, or the magnitude of disturbance that can be absorbed before a system changes its structure by changing the variables and processes that control behaviour. (Adger, 2000)

### Infrastructure resilience

We define infrastructure resilience as the capacity to manage shifts between attractors for the purpose of preserving an infrastructure service. This definition inherently reflects the notion of infrastructures as complex adaptive systems with multiple attractors, and emphasizes the reality that it may not always be desirable to preserve the operation of an infrastructure within the same basin of attraction. It also takes into account the centrality of concepts like adaptation, learning and graceful degradation to infrastructure resilience, as reflected in existing literature. (Bollinger & Dijkema, 2012)

### Engineering resilience

Engineering resilience focuses upon the vulnerability of people and places to hazardous environments and natural disasters, forecasting the likelihood of catastrophic events and systemic breakdowns and their social and economic implications. (Pike, Dawley, & Tomaney, 2010)

### Adaptability

Adaptability is sorted in adaptability used in vulnerability studies and in resilience studies, furthermore adaptability used in vulnerability studies is separated in general definitions and definitions including climate change. The adaptability definitions used in resilience studies are separated in general ones and ones applied to human systems

#### (General) adaptability (vulnerability)

The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. (IPCC, 2014)

Adaptive capacity, or adaptability; meaning the ability of a system to prepare for stresses and changes in advance or adjust and respond to the effects caused by the stresses. (Engle, 2011)

Whereas adaptability is defined as the dynamic capacity to effect and unfold multiple evolutionary trajectories, through loose and weak couplings between social agents, that enhance the overall responsiveness of the system to unforeseen changes. (Pike, Dawley, & Tomaney, 2010)

Whereas adaptability may be defined as: 'those characteristics of a plan, strategy or scheme that sustain and enhance the function of a system in the face of continuing change or uncertainty. Adaptability is about building flexibility, not closing of future options prematurely but enabling evolution of both the strategy or scheme, and also the function of the system. (Veerbeek, Ashley, & Zevenbergen, 2010)

#### Adaptability to climate change (vulnerability)

The ability, competency or capacity of a system to adapt to (to alter, to better) climatic stimuli. (Olmos, 2001)

Adaptability, refers to the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate change. Adaptation can be spontaneous or planned, and can be carried out in response or in anticipation of change in conditions. (Smit, Burton, Klein, & Wandel, An anatomy of adaptation to climate change and variability, 2000)

#### (General) adaptability (resilience)

We use the term adaptability to describe the capacity to manage shifts between attractors on an evolutionary level, and apply the term resilience exclusively to the operational level. An adaptable infrastructure is thus one that is able to shift between evolutionary attractors in order to meet new demand or adjust to environmental fluctuation. (Bollinger & Dijkema, 2012)

#### Adaptability of human systems (resilience)

Adaptability is 'the collective capacity of the human actors in the system to manage resilience. Adaptability can take many forms, including: (i) making desirable basins of attraction wider and/or deeper, and shrinking undesirable basins; (ii) creating new desirable basins, or eliminating undesirable ones; and (iii) changing the current state of the system as to move either deeper into a desirable basin, or closer to the edge of an undesirable one.

Adaptability is the capacity of its actors in the system to influence resilience (in a SES, essentially to manage it). Adaptability captures the capacity of a SES to learn, combine experience and knowledge, adjust its responses to changing external drivers and internal processes and continue developing within the current stability domain or basin of attraction. (Walker, Carpenter, & Kinzig, 2004)

#### Adaptive capacity

Adaptive capacity is separated in general, applied to climate change and different systems it is meant for (e.g. society, SES).

#### (General) adaptive capacity

The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences. (IPCC, 2014)

The forces that influence the ability of the system to adapt are the drivers or determinants of adaptive capacity. Local adaptive capacity is reflective of broader conditions. At the local level the ability to undertake adaptations can be influenced by such factors as managerial ability, access to financial, technological and information resources, infrastructure, the institutional environment within which adaptations occur, political influence, kinship, network, etc. (Smit & Wandel, Adaptation, adaptive capacity and vulnerability, 2006)

Adaptive capacity is the ability of a system to evolve in order to accommodate environmental hazards or policy change and to expand the range of variability with which it can cope. (Adger, 2005)

Broadly speaking, adaptive capacity denotes the ability of a system to adjust, modify or change its characteristics or action to moderate potential damage, take advantage of opportunities or cope with the consequences of a shock or stress. (Brooks, 2003)

### Adaptive capacity to climate change

The ability of a system to adjust to climate change (including variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. (IPCC, 2001)

Adaptive capacity is the property of a system to adjust its characteristics or behaviour, in order to expand its coping range under existing climate variability, or future climate conditions. The expression of adaptive capacity as actions that lead to adaptation can serve to enhance a system's coping capacity and increase its coping range thereby reducing its vulnerability to climate hazards. The adaptive capacity inherent in a system represents the set of resources available for adaptation. It is possible to differentiate between adaptive potential, a theoretical upper boundary of responses based on global expertise and anticipated developments within the planning horizon of the assessment, and adaptive capacity that is constrained by existing information, technology and resources of the system under consideration. (UNDP, 2005)

The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in climatic conditions. (UK CIP, 2003)

Adaptive capacity can reflect the intrinsic qualities of a system that make it more or less capable of adapting, but can also reflect the abilities to collect and analyse information, communicate, plan and implement adaptation strategies that ultimately reduce vulnerability to climate change impact. (Adapting to Climate Change in Time, 2011)

Adaptive capacity: the potential or capability of a system to adapt to (to alter, to better) climatic stimuli. (Olmos, 2001)

Adaptive capacity: the ability to apply climate related responses. Note that the adaptive capacity does not necessarily relate only to the current response capacity but also includes the capacity for future responses. (van de Ven, et al., 2010)

In general terms, adaptive capacity is defined in the climate change literature as "the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change". (O'Brien, Eriksen, Schjolden, & Nygaard, 2004)

### Adaptive capacity of society

A combination of all the strengths and resources available within a community, society or organization that reduce the level of risk, or the effects or disaster. (Capacity may include physical, institutional, social or economic means as well as skilled personal or collective attributes such as leadership and management.) (UNISDR, 2009)

Adaptive capacity is the capacity of a society to anticipate on uncertain future developments. This includes, catastrophic, not frequently occurring disturbances like extreme floods and severe droughts. The time orientation of adaptive capacity lies in the future. Although a system may be functioning well at present, human and environmental developments, both from inside and outside the considered system, can put a system under strain and threaten its future functioning. Examples are climate change, population growth, and urbanisation. Central to the importance of adaptive capacity is the acknowledgement that these processes may be influenced but cannot be predicted, engineered or controlled. (De Graaf, 2009)

The availability of social resources for sector-specific adaptation. In some cases, these capacities reflect sustainable adaptation solutions. In other cases, they reflect capacities to put newer, more sustainable adaptations into place. Adaptive capacity also varies over time. (University of Notre Dame, 2015)

### Adaptive capacity of SES

Adaptive capacity of social-ecological systems is the capacity to provide materials, qualities and capabilities for adaptation. It is determined by the complex interplay among system's components and their configuration; functions; and interactions that, actually or potentially, provides good conditions, enables and drives the system's adjustments so that it can sustain and improve its performance when exposed to climate change impacts. (Phi, 2011)

### Other capacities

Some other definitions of capacity are presented here, some have the same meaning as adaptive capacity others apply only to a certain system.

#### Coping capacity of society

The ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disasters. (UNISDR, 2009)

Coping capacity is the capacity of society to reduce damage in case of a disturbance that exceeds the damage threshold. For flood management coping capacity of society is determined by the presence of effective emergency and evacuation plans, the availability of damage reducing measures, a communication plan to create risk awareness among inhabitants, and a clear organisational structure and responsibility for disaster management. (De Graaf, 2009)

#### Capacity of response

Given that capacity of response, as an element of vulnerability, is supposed to refer to the response of the system to structural changes, it would appear that resilience should be considered as a subset, or a component, of capacity of response. (Gallopín, 2006)

#### Adaptive potential

Adaptive potential is the physical ability of a system to modify or change its characteristics to cope better with existing or anticipated external stresses. Knowledge about the adaptive potential of the built environment is important for developing adaptive strategies against minimum costs, because it allows for maximum use of opportunities that emerge from ongoing urban dynamics. (van de Ven, et al., 2010)

## B. INTERVIEWS: STRUCTURE, REPORTS AND RESULTS

In this appendix the structure and presented questions during the interviews will be briefly explained. Also a short report of each of the interviews can be found here and the results of the enquiry.

### Structure

The interviews started off with introducing one another. Then a short PowerPoint introducing the concept of vulnerability and adaptability and the goal of the research and interview is showed. I also mentioned the relation between adaptability and implementing measures, most of the time when measures are implemented adaptability is taken into account in one way or another, for example by optimizing costs (by searching a place where there is space available, which is possibly already owned by the contractor etc.).

The following questions guided the conversation about adaptability and extraction of practical knowledge from the experts.

- What do you think of when talking about adaptability?
- Did you ever use the concept adaptability in any your work? If yes, how?
- Have you ever determined the adaptability of a certain area? If yes, how, what did you use?
- Do you have any idea about possible factors that could have impact on the adaptability of an area? (these factors can be translated to indicators most of the time)

If they hadn't had any clue we visited by the different determinants determined during previous interviews (space, underground, matching, budget, ownership, function related demands and water system). I explained what the determinants meant and showed several examples, and asked if they had any idea on other possible factors influencing adaptability.

### Experts

#### Governmental

Ellen Kelder, municipality of Dordrecht

Rob Koeze, Waternet

Hans Gehrels, ministry of infrastructure and environment, Deltares (also company)

#### Research

Rutger de Graaf, Hogeschool Rotterdam, DeltaSync (also company)

Berry Gersonius, UNESCO-IHE, municipality of Dordrecht (also governmental)

Peter van Veelen, PhD faculty of architecture, municipality of Rotterdam (also governmental)

#### Companies

Gerda Roeleveld, Deltares

Leon Valkenburg, Witteveen+Bos

Jaap Klein, Witteveen+Bos

## Reports of interviews (chronological)

The interviews are meant to gather practical knowledge from experts working with measures in urban areas regarding climate change. Finding determinants and indicators for adaptability is the main goal of those interviews. Experts are selected from different fields to try to get a broad view of the concept.

The expert is introduced shortly and any remarks given are presented, the adaptability part shows the findings regarding determinants and indicators for each session.

Jaap Klein, Witteveen+Bos, 30/09/2015 13:00, Amsterdam

Jaap is a water manager by origin and is head of the group urban water and sewerage at Witteveen+Bos. He has worked with risk analyses in the past, the term of vulnerability is normally not used in his projects. Although adaptability is taken into account when implementing measures, but isn't appointed as adaptability.

He stresses the importance of exposure, sensitivity and measures and the relation and impact these have on adaptability. The exposure and measures partly determine the adaptability. For example when a city is built in a lower lying area (compared to its surroundings) this already implies the importance of adaptability regarding flooding (urgency).

### Adaptability,

#### *Space*

- Ground space index
- Percentage greening
- Clearings that can be used

#### *Underground*

- Soil permeability
- Slope of the terrain

#### *Matching*

- Big infrastructural works planned
- Age of buildings/infrastructure compared to end of lifecycle

#### *Budget*

- Economic capacity of the neighbourhood

#### *Function related demands*

- Natura 2000
- Historical city centre
- Monuments

#### *Water system*

- Possibilities regarding flexible water level (agriculture, wooden pile foundation)

Gerda Roeleveldt, Deltares, 05/10/2015 15:30, Utrecht

Gerda studied landscape architecture. She has worked for the ministry of VROM on urban planning and policy. Nowadays she is working at Deltares, she is a so called designing researcher, although she still does some policy work. She is interested in the spatial part of research and tries to incorporate this into the research done at Deltares.

*Adaptability (in addition to Jaap's list),*

#### *Space*

- Percentage of gardens (flooding and ecological value)
- Percentage of flat roofs
- Percentage of open water
- Physical boundaries

#### *Budget*

- Economical value (land is very expensive)
- Price of land, when not public

#### *Ownership*

- Percentage of public property
- Number of stakeholders (one or a lot of parties can be a problem)

#### *Underground*

- Storage capacity in the soil
- Bearing capacity of the soil
- Presence of freshwater

#### *Upgrade*

- Buildings on existing infrastructure (buildings on dike for example)

#### *Energy*

Suggestions that are more towards *sensitivity*,

- Direction of building with respect to sun and wind (important to expand city in favourable positioning)
- Fixed and flexible infrastructure (train tracks are more fixed than roads)
- Ground level of area, sensitivity to flooding



Ellen Kelder, municipality of Dordrecht, 06/10/2015 14:30, Dordrecht

Ellen is by origin a political scientist, she works at the municipality of Dordrecht as program leader of climate adaptation and water safety.

She stresses the importance of the matching part of adaptability, municipalities can barely act on behalf of climate adaptation without matching it to maintenance works or to the renewal or building of a neighbourhood. They are bound to the existing budgets.

She also stresses the importance of ownership, the municipality is not responsible for climate adaptation in some cases. For example when you're living outside the protected dike area, you as owner of a home have to come up with your own flood protection. This doesn't mean that the municipality doesn't try to help, but it's your own responsibility. So is the case for more extreme events the municipality designs their sewers for a BUI08 (a once in a two year rainfall), everything beyond this threshold is a citizens own responsibility.

#### Adaptability (in addition of previous)

##### *Matching*

- Budgets of municipality, for example the sewerage budget

##### *Ownership*

- Buildings outside the protected dike area

##### *Function related demands*

- Natura 2000, can be positive when there are for example paved areas

Leon Valkenburg, Witteveen+Bos, 09/10/2015 10:00, Den Haag

Leon studied water management and nowadays works as part of the group of area development at Witteveen+Bos. He is project leader of civil engineering works, climate adaptation issues, urbanism, spatial planning and resilience. He also works on governance.

He stresses the importance of the underground, it imposes boundaries on the possibilities and implementation. Think of old bombs, breeding birds, contaminants and archaeology.

It is more important to look at the adaptability above the thresholds of the municipalities for example above BUI08 and the houses and areas outside the dikes. Because the vulnerability within these boundaries is normally low in the Netherlands.

#### Adaptability (in addition to previous)

##### *Underground*

- Subsidence
- Pipes and cables
- Contaminations
- Archaeology
- Bombs
- Breeding birds
- Protected flora and fauna

##### *Function related demands*

- Zoning plan
- Permits

##### *Matching*

- Maintenance policy

Peter van Veelen, TU Delft & municipality of Rotterdam, 12/10/2015 15:30, telephone

Peter studied landscape architecture. He works as urban planner and designer at the city of Rotterdam and does a PhD at the TU Delft. He is a specialist in integrated and multi-layered coastal flood risk adaptation and water sensitive urban development. His PhD research at Delft University focusses on the design and planning of multifunctional and adaptive coastal waterfront development.

Peter mentions that most of the indicators have some or multiple linkages to for example economy, humans and society, making them less predictable and useful. Adaptability is more of the speed in which adaptations can be rolled out to practice in his opinion.

He suggests to look at one or some smaller case(s) and make a more qualitative assessment of what is happening and what relations are at play, motivation is key. For example looking at pavement in gardens. What kind of motivation can be used to make people remove pavement? How fast is this going to change and how much of the flooding problem of a city can be solved by this measure?

Rob Koeze, Waternet, 14/10/2015 9:30, Amsterdam

Rob did a study focussing on water management. Nowadays he works as senior policy advisor at Waternet his focus is on water safety and spatial planning. He is also coordinator of the Delta Programme and Amsterdam water resilient for Waternet.

Rob had a lot of interesting projects regarding climate adaptation. Most of the projects were still in their planning phase so they were not yet to planning and selecting locations and so they didn't yet look at adaptability or indicators. (Amsterdam Rainproof)

He stresses the importance of the underground giving limitations to the possible solutions.

Adaptability (in addition to previous)

*Ownership*

- Responsibilities of institutions

*Water system*

- Routing

Berry Gersonius, UNESCO-IHE & municipality of Dordrecht, 19/10/2015 10:30, Delft

Berry studied civil engineering, water management. He is a senior lecturer in urban flood resilience at UNESCO-IHE. At the municipality of Dordrecht he is an expert on flood safety and storm water.

Berry suggest using the layer approach (underground, networks and occupation) to sort out the indicators.

He had a lot of examples from municipality of Dordrecht where they are working on matching and how to organise this in project management.

*Adaptability (in addition to previous)*

*Space*

- Height of road compared to height of doorsteps

*Matching*

- Investment planning
- Works planned

*Ownership*

- Who owns which budgets
- Responsibility

*Function related*

- "Visie Ruimte en Water"

Hans Gehrels, Deltares & ministry of infrastructure and environment, 19/10/2015 12:00, Delft

Hans is by origin a hydrologist. He works at Deltares as manager of the project team Sustainable Cities. At the ministry of infrastructure he works on spatial adaptation, he is also one of the initiators of the knowledge for climate programme.

He stresses the principles of spatial adaptation from the Delta decisions. By 2020 all government institutions have to work by the principles of spatial adaptation. This means when looking at spatial problems they need to analyse water robustness and climate resilience of an area ('weten'), the results of this analyses should result in ambitions and an adaptation strategy with concrete goals ('willen') and a building policy and legal impact for this ambition to secure execution ('werken'). By 2050 the whole of the Netherlands should be as adaptive to climate as possible.

#### Adaptability (in addition to previous)

##### *Matching*

- Administrative composition of who is responsible for what

##### *Budget*

- Urgency (based on sensitivity of the area)

##### *Ownership*

- Kind of stakeholders (public utilities, public, private)

##### *Function related*

- Contaminations
- Water-collection area
- Zoning plans (changing by 2017 due to new "omgevingswet")

##### *Water system*

- Depth of water table
- Possibilities with regards to water system, space available, bringing it back to original state
- Type of sewerage
- Is there an open water system available?

Rutger de Graaf, DeltaSync & Hogeschool Rotterdam, 20/10/2015 15:00, Rotterdam

Rutger studied water management and did a PhD about transitions to more sustainable urban water management. During his PhD he founded DeltaSync, a company specialized in floating urbanisation. He is also part-time lecturer at Hogeschool Rotterdam, giving lectures about water and sustainability.

Rutger stresses the importance and difference of transitions and “normal” adaptations. Transitions are the ability of a system to completely shift to another approach, while adaptation is about adapting the current system and using the current big infrastructure. The adaptability used in this thesis is focused on adapting the current system and building on this.

*Adaptability (in addition to previous)*

*Matching*

- Partnerships (existing relations between different parties, plans, projects)

*Ownership*

- Resident participation

*Budget*

- Dynamic or static neighbourhood

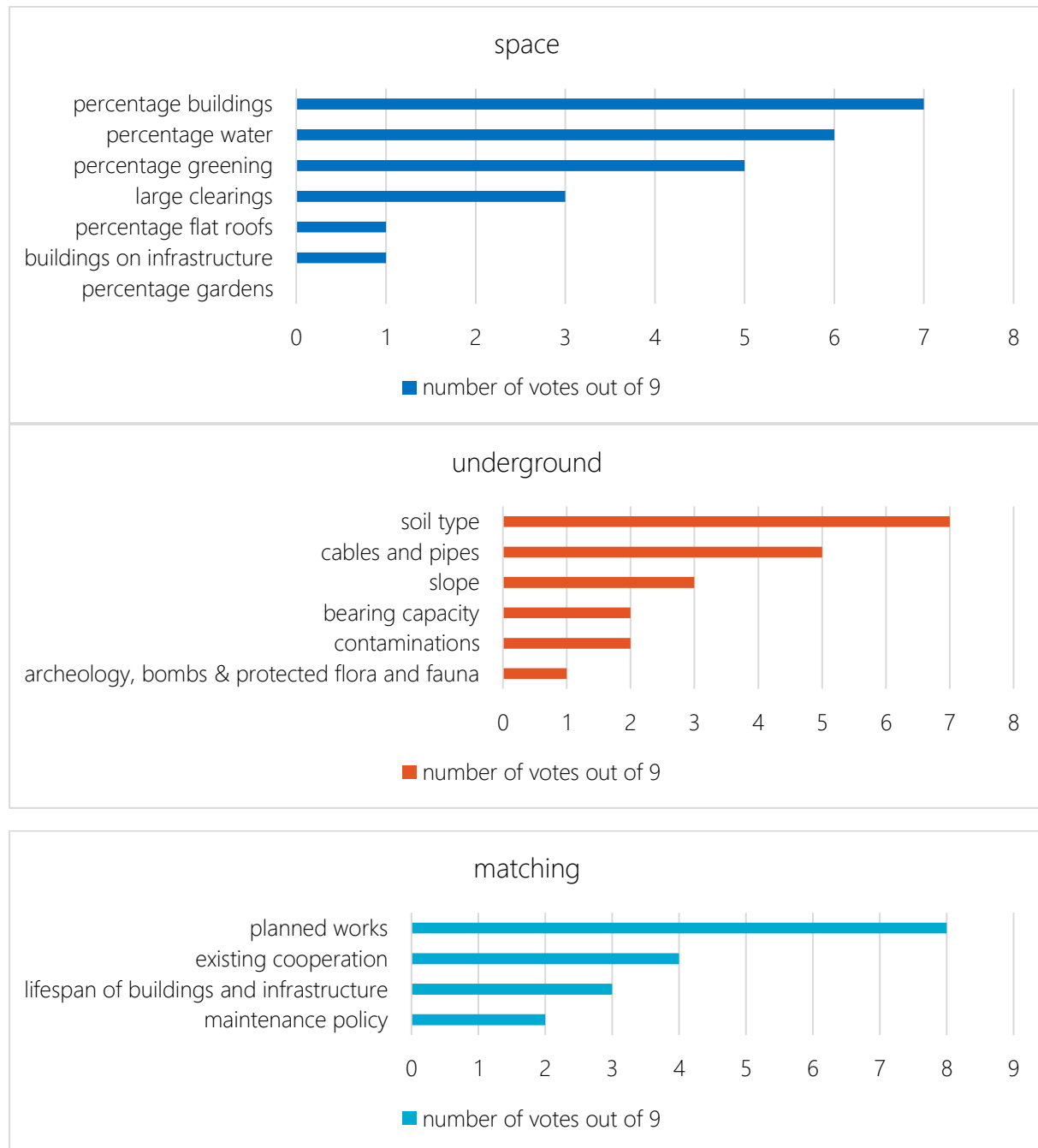
*Water system*

- Seepage
- Experience with water innovations

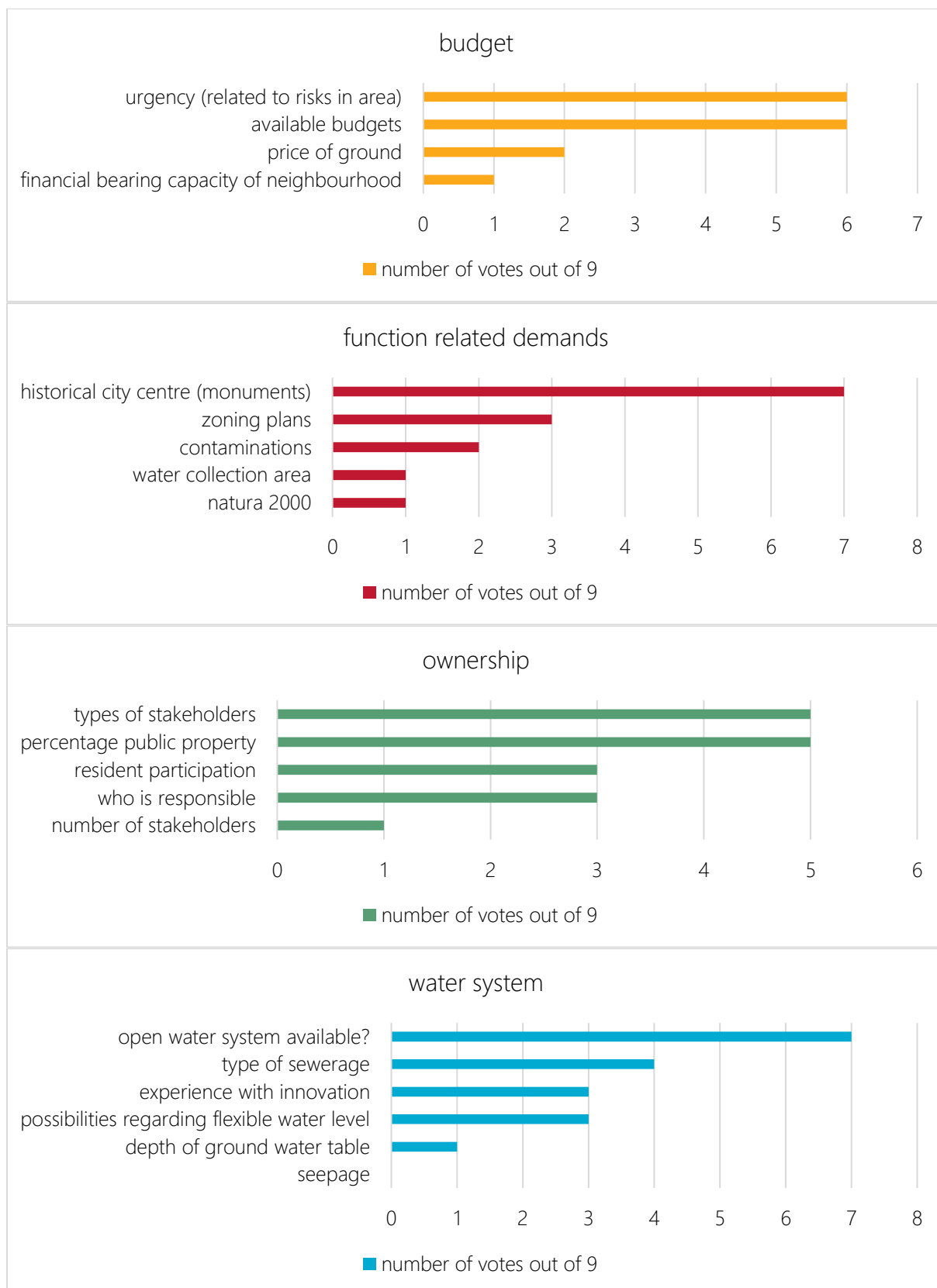
## Selection by experts

After all indicators are gathered from interviews, the experts are asked to fill out an enquiry, this enquiry focusses on finding the most important indicators of adaptability. The experts are asked to select the indicators which they think are most important for adaptability. This resulted in the following selection, see Figure 16.

Figure 16 Bar plots of the results from the selection process, more votes means more likely to be important for adaptability







## C. INDICATORS: DATA AND EXPLANATION

In this appendix the selected indicators and their relation to adaptability will be explained. Furthermore the data of the indicators will be shown and explained.

### Percentage buildings

Percentage buildings in an area is one of the more straightforward indicators, even though the social and physical effect of the indicator on adaptability is different. The social effect of a high concentration of buildings is that it is more likely there are a lot of people living in that area, making it more likely that action against climate related risks will be taken. On the other hand a high concentration of buildings means that there is less space available for adaptations, making it harder, more expensive and time-consuming to adapt.

The percentage of buildings in an area can easily be determined using 'de BAG' (Basisadministratie Adressen en Gebouwen), this is a product from the Netherlands' cadastre, land registry and mapping service. This products consists of all the buildings in the Netherlands, having a unique ID, state and year of construction. The data is filtered based on the state, demolished and planned buildings are also contained in the BAG and have to be removed. When those buildings are removed the cadastre drawings can be used to calculate the total area of buildings in each of the neighbourhoods. Using the neighbourhood outlines from the CBS (but subtracting the area in each neighbourhood that is water), the percentage of buildings can be calculated, the result can be found in Figure 17.

#### Percentage buildings, Dordrecht

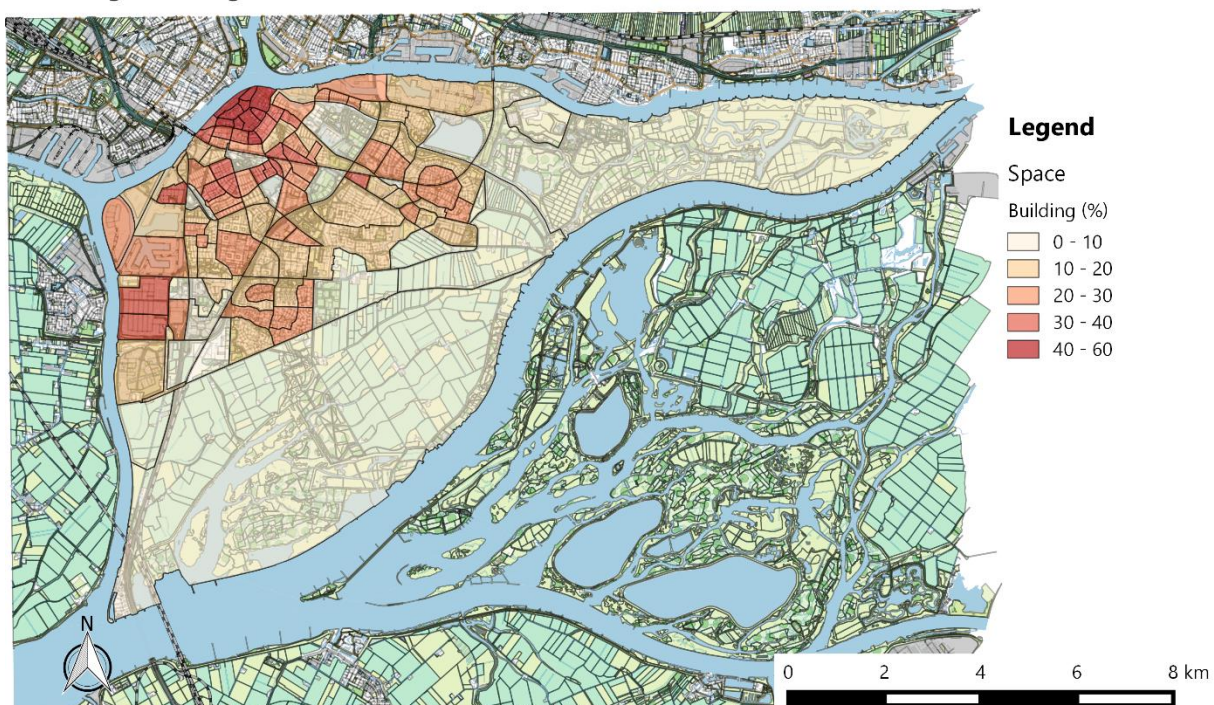


Figure 17 Percentage buildings for each neighbourhood in Dordrecht

## Percentage water

The percentage of open water gives an indication of the amount of water available in each neighbourhood and says something about possible measures and transportation efforts. When there is water available, there are more possibilities regarding measures and climate proofing, so called blue solutions. Also water doesn't have to be transported over long distances, when there isn't any water available in the neighbourhood water has to be transported by means of pipes, or newly built canals. When there is open water available in the area efforts can be saved.

The map with percentages of open water for each neighbourhood (see Figure 18) is constructed with the TOP10Vector map and CBS key figures and outlines of neighbourhoods. The outlines of the neighbourhoods are edited to not include the Merwede, Dordtsche Kil and Oude Maas. Then the open water areas of the TOP10Vector map (the TOP10Vector doesn't include canals smaller than 6m) are determined for each neighbourhood and divided by the total area, giving the fraction of water in each neighbourhood (see Figure 18).

### Percentage water, Dordrecht

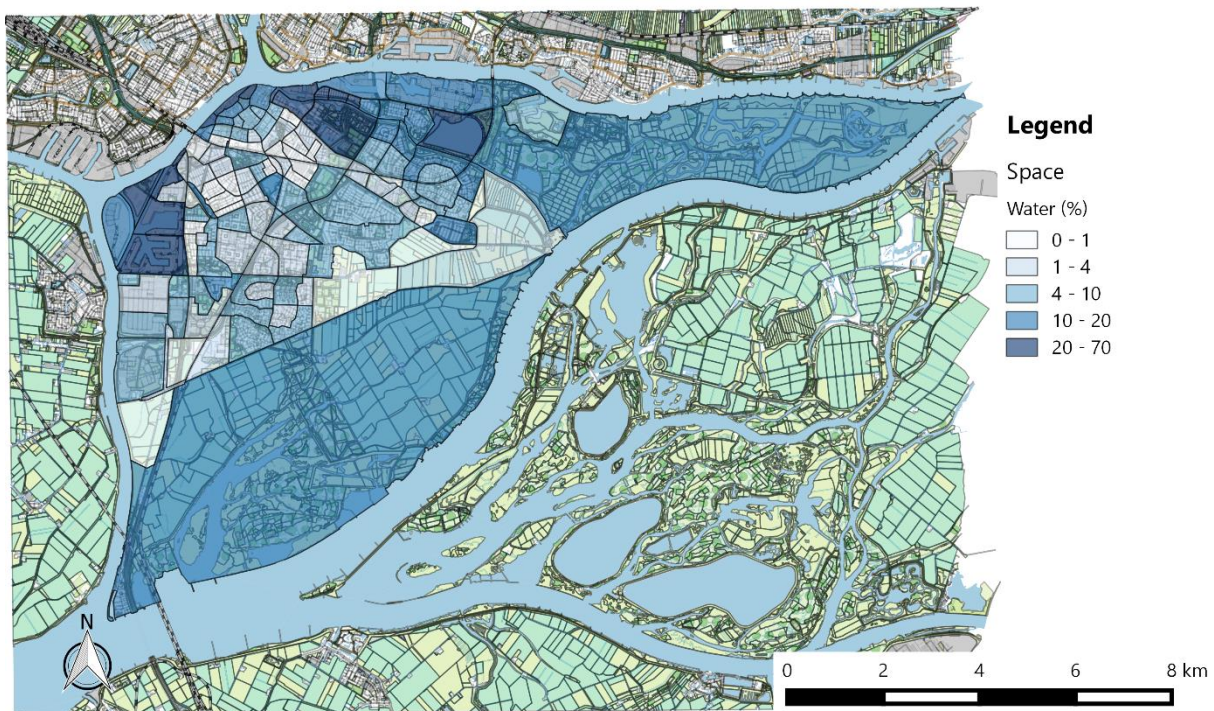


Figure 18 Percentages open water for each neighbourhood in Dordrecht



## Percentage green

Percentage green says something about the space that is available and can lead to additional benefits. When there is a high percentage of green in a neighbourhood, compared to a neighbourhood with a low percentage of green (given all other indicators are the same) the neighbourhood with the higher percentage of green is expected to have a higher adaptability. Of course percentage green is related to percentage buildings and percentage water, when a space is taken either by buildings or water there can't be any greening. Adaptation to climate change is most of the time coupled to either green or blue solutions, meaning using green for adapting, for example creating infiltration, using wadi's or other green solutions. It is about coupling climate adaptation to greening to create additional benefits.

The map showed in Figure 19 is made with the TOP10Vector map. Green terrains (for example meadows, forests and croplands) and functions (for example sports parks, golf courses and allotments) are selected and added for each neighbourhood to get to a certain area of green for each area. This green area is then divided by the land area of each neighbourhood to get to the fraction of green for each neighbourhood.

### Percentage green, Dordrecht

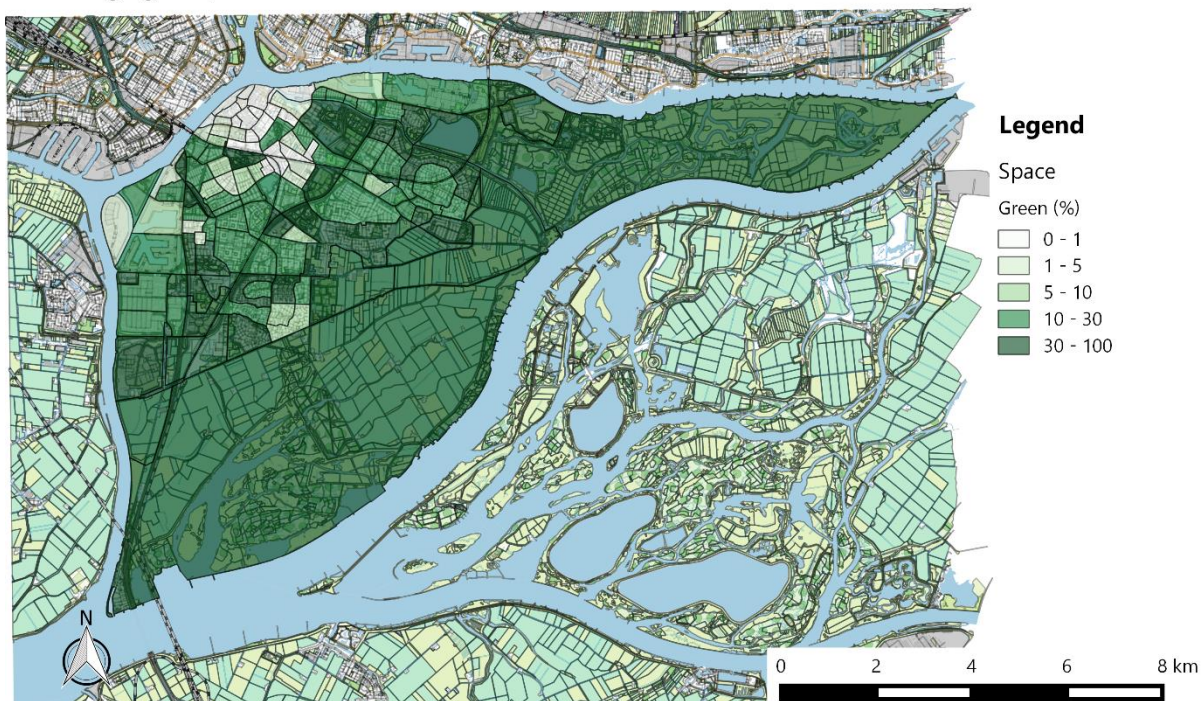


Figure 19 Percentage green for each neighbourhood of Dordrecht

## Soil type

Soil type has impact on the construction costs and can limit possibilities. In areas with poor soil conditions the soil must be altered in order to build on it. This can be done by means of stabilization or modification of the soil or one could replace the poor quality soil with good quality soil. If soil replacements, stabilization or modifications are ineffective, impractical or too expensive, foundations can be used either alone or in combination with soil improvements. (van Tubbergh, 2012). The soil can also limit the possibilities, think of lowering groundwater levels and subsidence, slow infiltration rates and stability.

The map in Figure 20 is constructed with a map from the DINOLoket. This map is based on the GeoTOP, this 3D model gives a detailed image of the upper 30 meters of the soil, in 100x100 grid cells. The product used from this model is the average soil type of the upper 8 meters. Averaging the soil type (taking soil type that is most abundant) for each neighbourhood gives the map presented in Figure 20.

### Soil type, Dordrecht

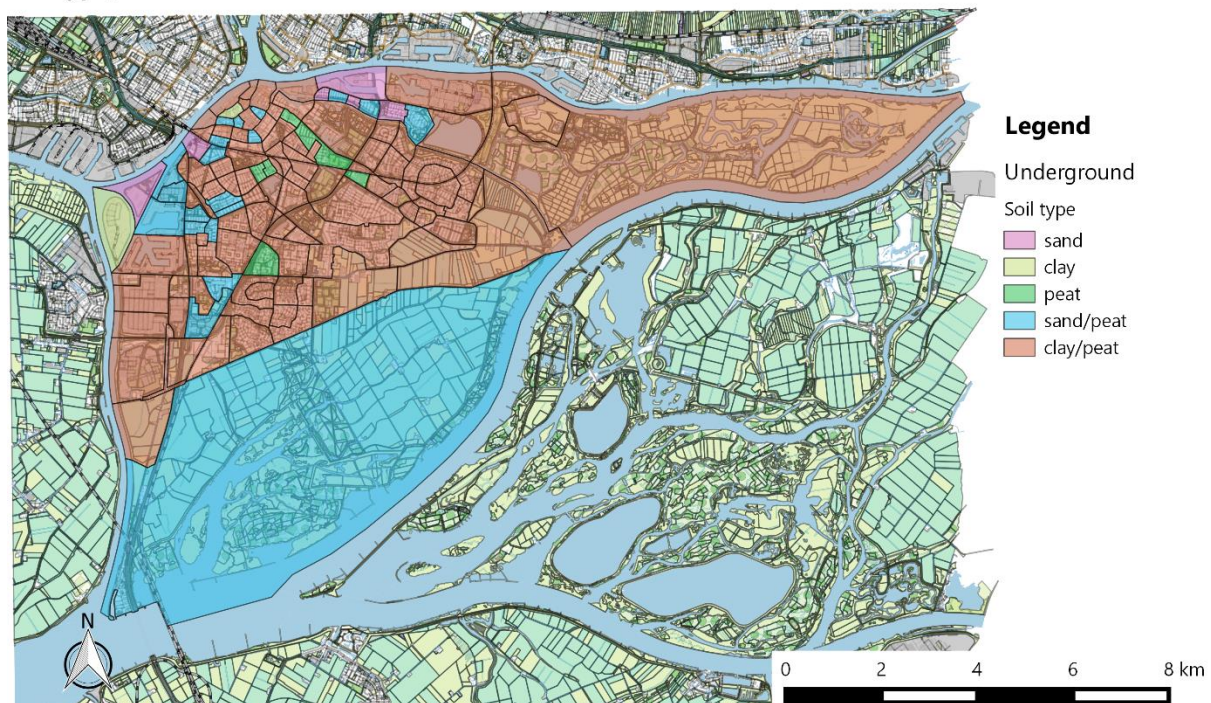


Figure 20 Averaged soil types for neighbourhoods in Dordrecht



## Cables and pipes

The underground nowadays is very crowded, pipes and cables are everywhere, making adaptation hard. Gas mains, water supply system, sewerage system and the power grid are some examples. But it's hard to get some number of how crowded the underground is for each neighbourhood or even getting all these data. That is why this indicator is based on the main cables and pipes, the main gas, water and electricity lines. These infrastructures are large compared to the gas mains and power grid in a neighbourhood. There are also some restrictions around these main cables and pipes, for example buildings and infrastructure may not be closer than 50 meters to the main gas pipes. The presence of these cables and pipes only has a negative effect on adaptability.

The main water, gas and electricity network around Dordrecht is used, the location of those is taken from a map with critical infrastructure around the city of Dordrecht. The length of each water, gas and electricity network in a neighbourhood is calculated (km). The km of main gas pipes are multiplied by 3, this is because of the restrictions around these pipes. Electricity is multiplied by 2, this is because of the large constructions involved. Water is multiplied by 1, the downsides of main water network are smaller when compared to electricity and gas. Adding these number and dividing them by the neighbourhood area ( $\text{km}^2$ ), an indication of nuisance, additional efforts by these main pipes for each neighbourhood can be calculated, see Figure 21.

### Cables and pipes, Dordrecht

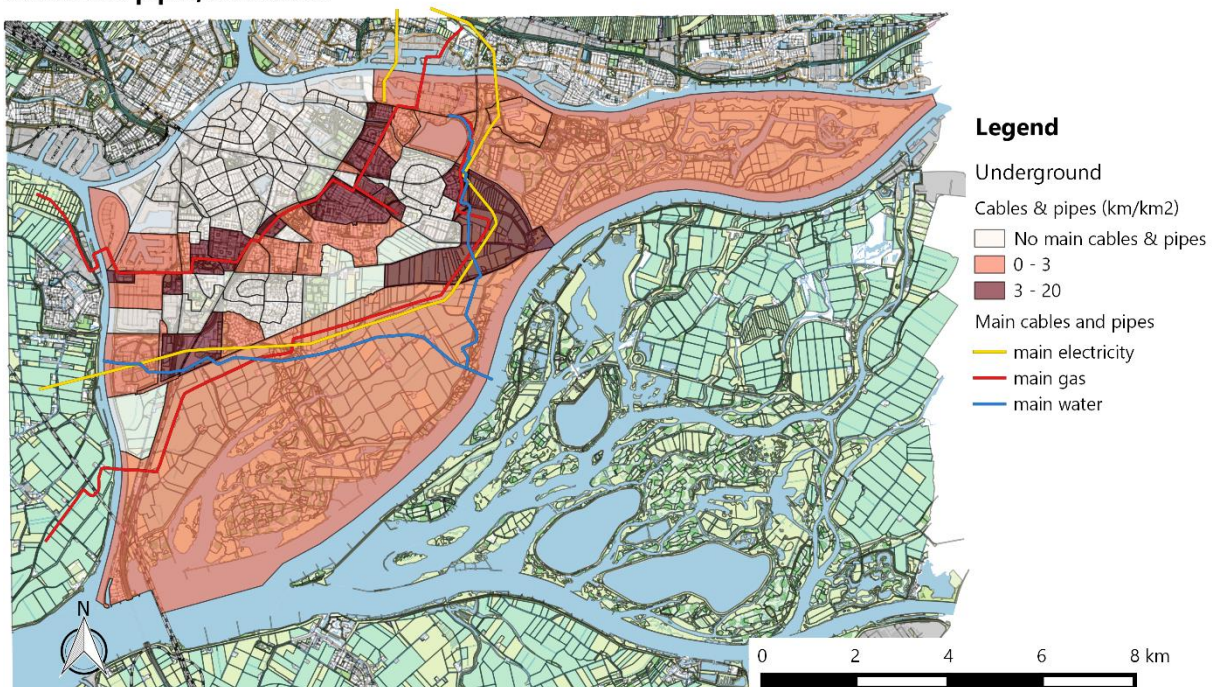


Figure 21 Main cables and pipes (km/km<sup>2</sup>) for each neighbourhood in Dordrecht

## Planned works

Planned works give an indication of when and the size of opportunities that arise regarding matching. The budget of a planned work gives an indication of the size of the project and the possibilities that may arise regarding climate proofing, larger budgets indicate larger opportunities. Also the planning of those works gives an indication on when those opportunities arise, when there isn't any maintenance or redevelopments planned for a neighbourhood in the coming say 50 years, great challenges regarding climate proofing arise. Climate proofing on neighbourhood scale in the current Dutch context has to be coupled to existing budgets or planned works, redevelopments or maintenance.

When for example maintenance on the sewer, replacement of the pavement or neighbourhoods are redeveloped huge opportunities arise regarding climate proofing. Identifying these opportunities and using them is still a big problem for most municipalities. Dordrecht is working on a method to effectively identify and use these opportunities, one of their products is used here; the MOP, this is a maintenance planning for the coming years. This planning is used to create the map in Figure 22. The planning consist of a budget for each of the planned works. Some of the planned works cover multiple neighbourhoods, the area of the work in each neighbourhood is used to divide the budget over these neighbourhoods.

### Budget of maintenance planning, Dordrecht

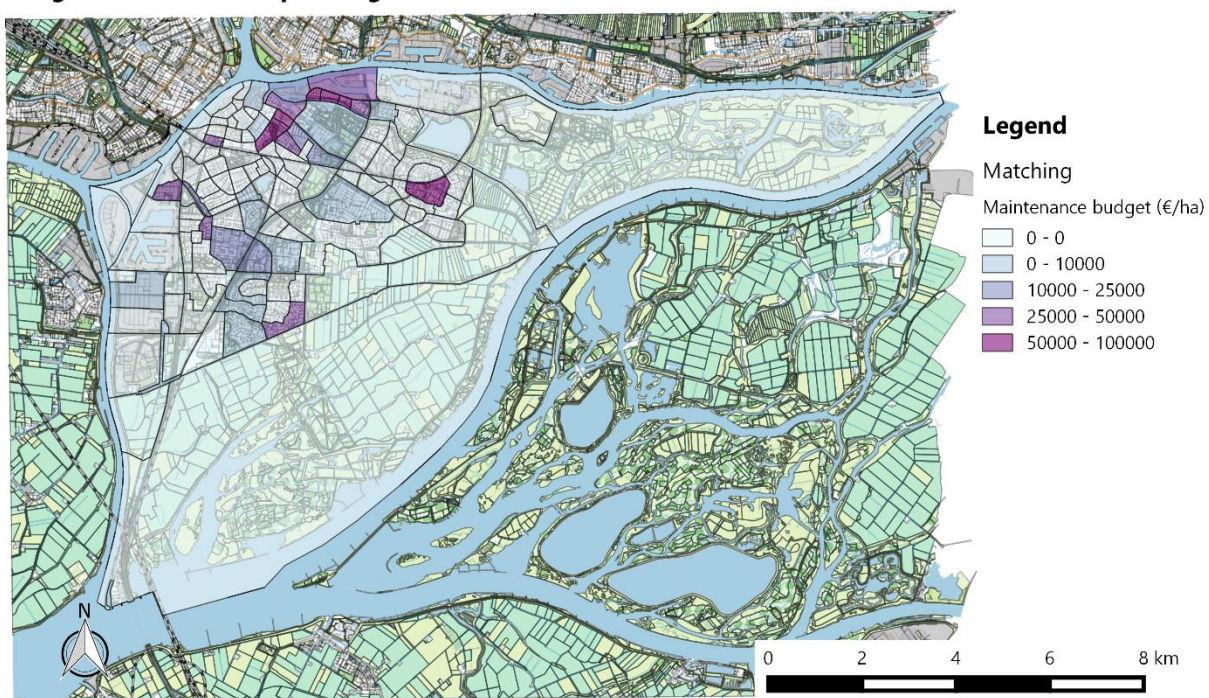


Figure 22 Budget of planned redevelopments/maintenance for each neighbourhood for the coming years



## Estimated end of life cycle

While it is difficult to upgrade existing buildings and other assets (being costly and difficult), the construction of new buildings and assets provides great opportunities regarding climate proofing. This gradual upgrading strategy (based on making all new built buildings and assets climate proof, i.e. opportunistic adaptation) depends on the age of the existing building stock. To assess the adaptability, it is important to determine the expected end of life cycle and replacement rate of assets. Although predications on individual asset level are surrounded by large levels of uncertainty, a strategic insight on the replacement rate on neighbourhood level can be acquired. This insight is an indication of when and where adaptation can be matched to renewal of a neighbourhood.

Using the work of Ir. Evert Hasselaar (TU Delft) in which research is done into the end of life cycle (EOLC) and the relation to characteristics of dwellings. With this an insight into the estimated end of life cycle (EEOLC) of dwellings in the Dordrecht area can be acquired. When looking at the trend from the 16<sup>th</sup> century until present, a regular pattern of filtering takes place, the worst buildings are being demolished and the other part is being adapted and continues to be used for ages. Looking at statistics Evert found out that the chance of a building reaching the age of 50 years is 97%, 77% that it reaches an age of 75 and 57% that the building is being used for 100 years or more.

Looking at the characteristics of those dwellings with respect to their EEOLC the following relations can be spotted, see Figure 23. The filtering process takes mainly place in the period of 75 to 125 years. Single family rental dwellings are an exception to this, the filtering process starts earlier but they have the largest chance of survival, it's even bigger than the chance of survival of single family bought dwellings. When looking at multifamily dwellings the filtering process is way more drastic, especially in the rental sector. In general how bigger the dwelling, how larger its chance of survival.

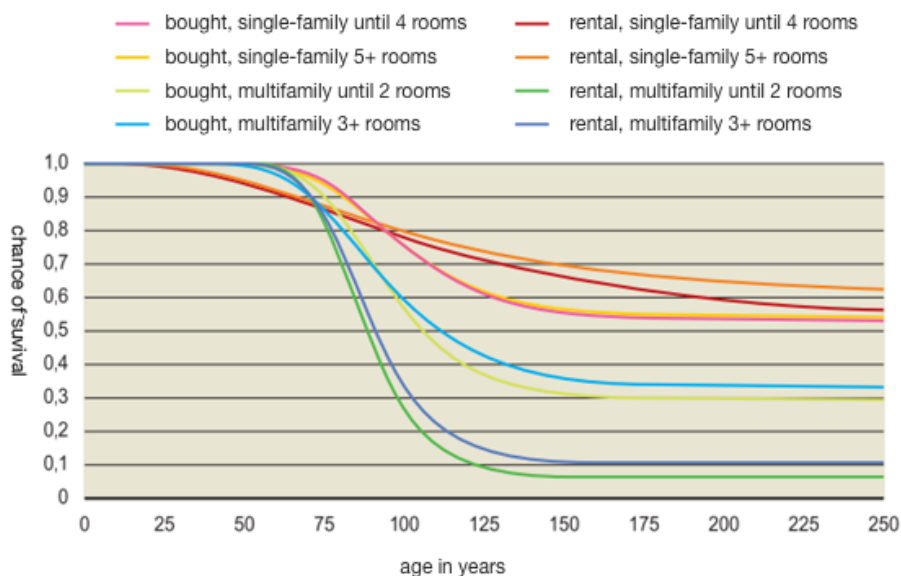


Figure 23 Chance of survival for multiple characteristics of buildings (Elsinga & Lamain, 2003), based upon removal in the period of 1961 to 2000

Combining the findings with available data from CBS for the neighbourhoods of Dordrecht, the following distribution of expected average dwelling removal age for each neighbourhood is made, see Table 4. The percentages of purchased or rented dwellings, the percentage of multifamily or single-family dwellings and the average value of dwellings in each neighbourhood is used to determine the renewal rate (data from CBS neighbourhoods).



The areas with either mixed purchased/rental, or multifamily/single-family are assigned manually, using findings from Figure 23. For some areas no data was available, here an average of 100 years is assigned there. The historical city centre is left out of the assessment because buildings in this area are far beyond their estimated end of life cycle.

Table 4 Distribution of EEOLC based upon, % purchased, % rental, % multifamily, % single-family and value

Renewal rate (years)	Purchased (%)	Rental (%)	Multifamily (%)	Single-family (%)	Value >€200.000	Value <€200.000
75	-	>60	>60	-	-	x
80	-	>60	>60	-	x	-
100	>60	-	>60	-	-	x
110	>60	-	>60	-	x	-
125	>60	-	-	>60	-	-
175	-	>60	-	>60	-	x
200	-	>60	-	>60	x	-

Of course not all buildings in Dordrecht are residential. Some non-residential and industrial areas (i.e. harbours and business areas) can be identified. An removal rate of 50 years is assigned to those areas.

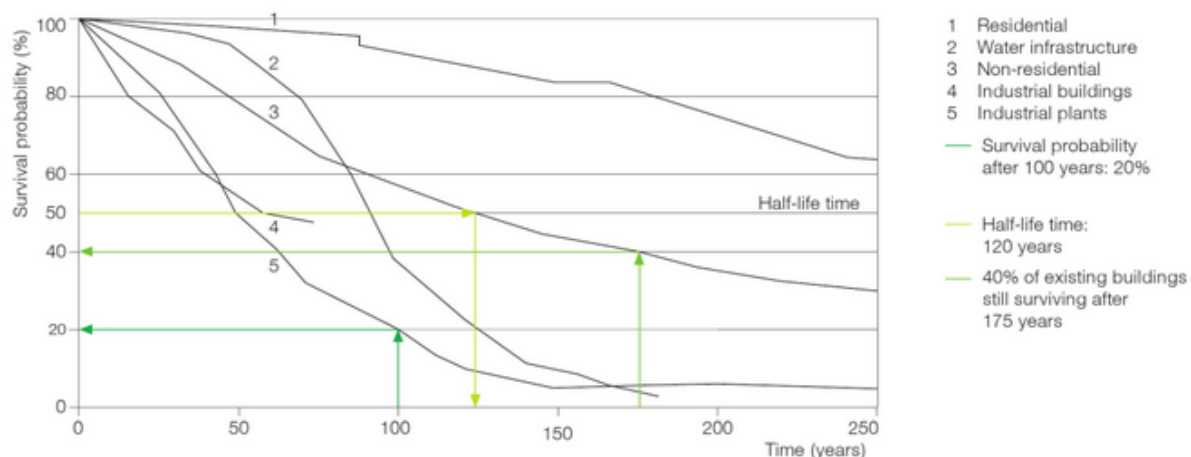


Figure 24 Survival probability for different building types (König, Kohler, Krießig, & Lützkendorf, 2010)

Combining the above estimated removal rate and the average building period of each neighbourhood. The average building period can be determined using the 'BAG' again, looking at the mean and median of the year of construction for each neighbourhood an average building period can be assigned. The estimated average end of life cycle for each neighbourhood can be determined, by adding the estimated removal rate to the average building period for each neighbourhood, see Figure 25.

Estimated expected end of life cylce, Dordrecht

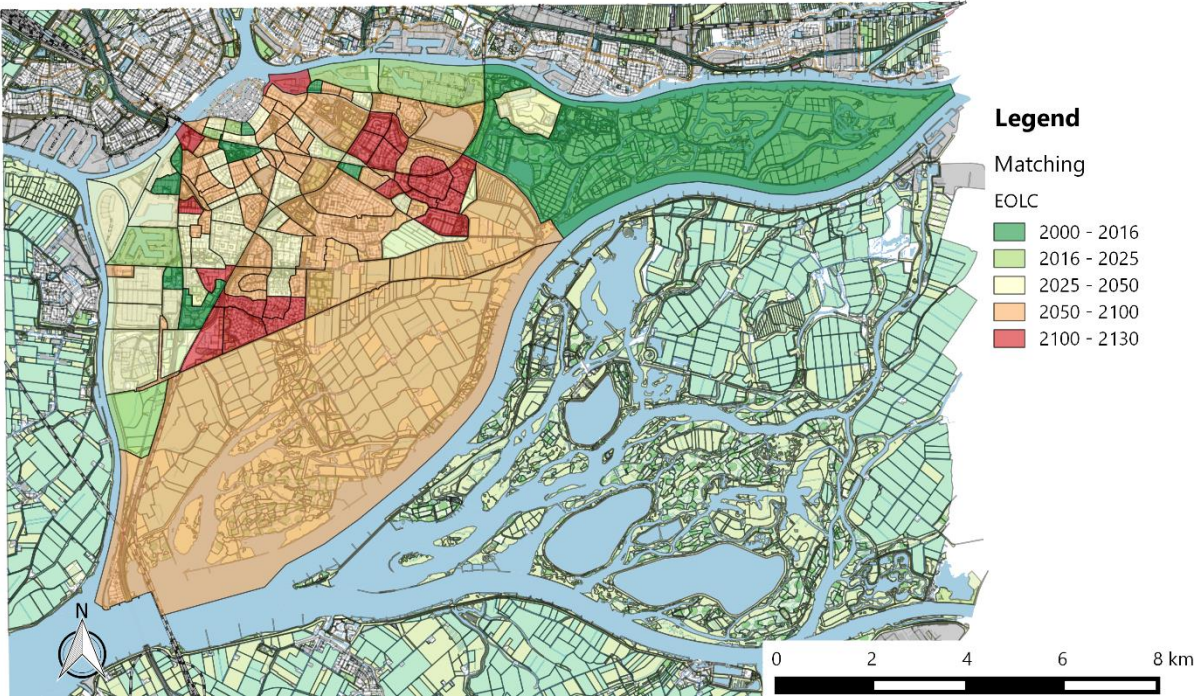


Figure 25 Estimated end of life cycle for each of the neighbourhoods in Dordrecht

## Urgency

Urgency is related to risks facing a city, the severity and number of those risks determines the urgency and has an influence on adaptability. When urgency is high, it is more likely that municipalities or communities are already working on or thinking about adapting. Making it easier to adapt because structures for adapting are already available and used. Furthermore there will probably be more willingness, maybe even pressure from society to invest in climate proofing, making it easier to make money available. Concluding there will be more willingness and budget to adapt, compared to an area where urgency is low.

The urgency is related to the risks. So looking at calculations of flooding, drought and heat, can give an indication of the urgency in an area. Iris Koekkoek, intern at the municipality of Dordrecht, did research into the vulnerability of Dordrecht. She used a model of UNESCO-IHE to calculate the flooding in each neighbourhood (80mm in 2 hours), furthermore data from the climate adaptation atlas is used for drought (rotting of wooden pile foundations for current climate), heat (number of nights above 20 degrees Celsius for W+2050) and land subsidence (for W+2050) (Climate Adaptation Services, 2016). She made a classification for each neighbourhood for each of the climate related challenges: non-relevant, relevant and dominant. This classification is used to determine the urgency for each neighbourhood. It turns out that using this classification only 2 groups are created, see Figure 27. Using the same number of classes (5) that are used in all other classifications, more diversity and a better view on the urgency can be created, see Figure 27.

### Urgency (related to risks), Dordrecht

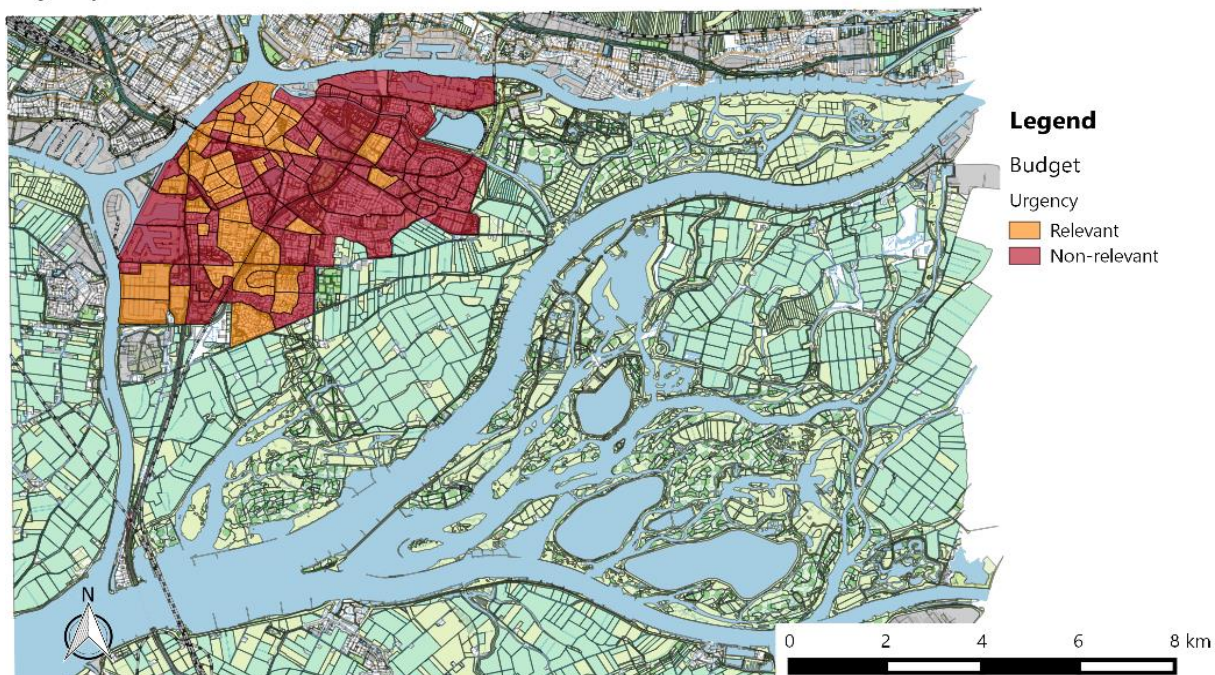


Figure 26 Iris' classification of vulnerability for some of the Dordrecht neighbourhoods



### Urgency (related to risks), Dordrecht

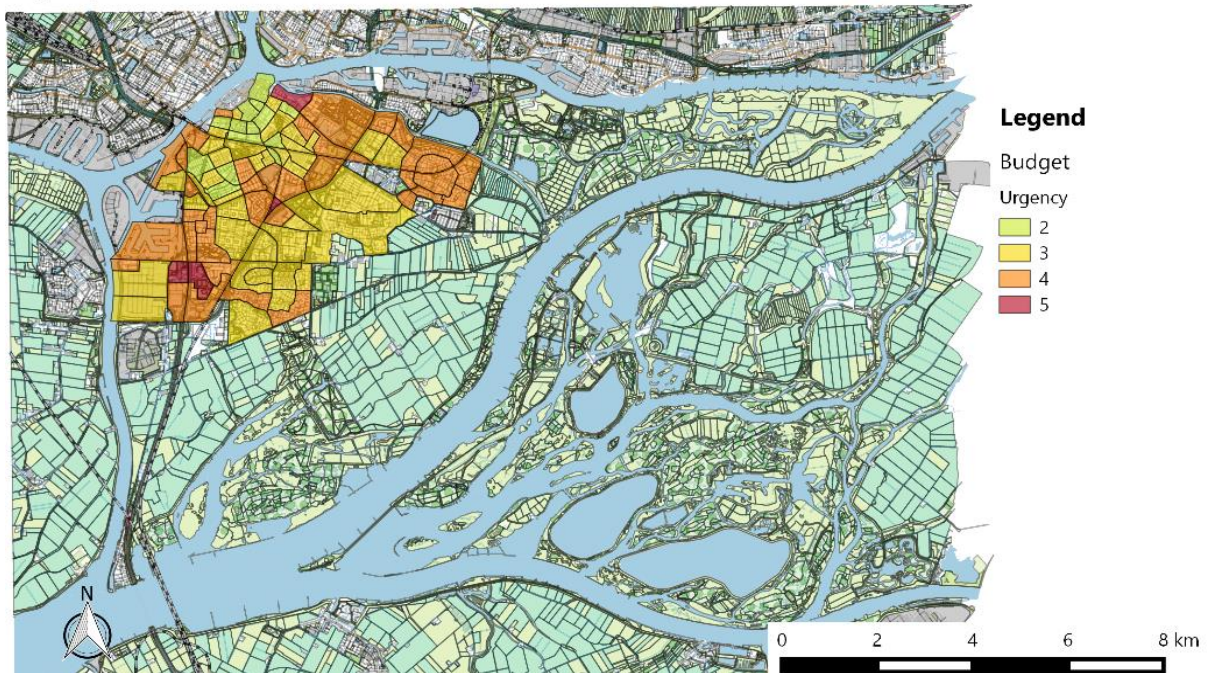


Figure 27 My own classification for some of the Dordrecht neighbourhoods

## Historical city centre

A historical city centre has characteristics that make adapting harder. The pressure regarding space is high and there are many other considerations that must be taken into account. Such as preservation of the city's historical character, multifunctional uses, old foundations and narrow streets. The spatial stability of such an area is high, caused by the high complexity of networks the pressure of space and the ground price in the centre (Mander, Tiezzi, & Brebbia, 2006). Almost every little plot of land and space is used and has a function making adaptation a time-consuming task with high efforts. Another way of dealing with this lack of space is using innovation to climate proof, but this is also time-consuming and costly.

To determine the historical city centre the database of national monuments and the year of construction from 'de BAG' is used. Combining these data an area can be designated as the historical city centre. This area is also the area where the percentage of buildings is highest.

### Historical city centre, Dordrecht

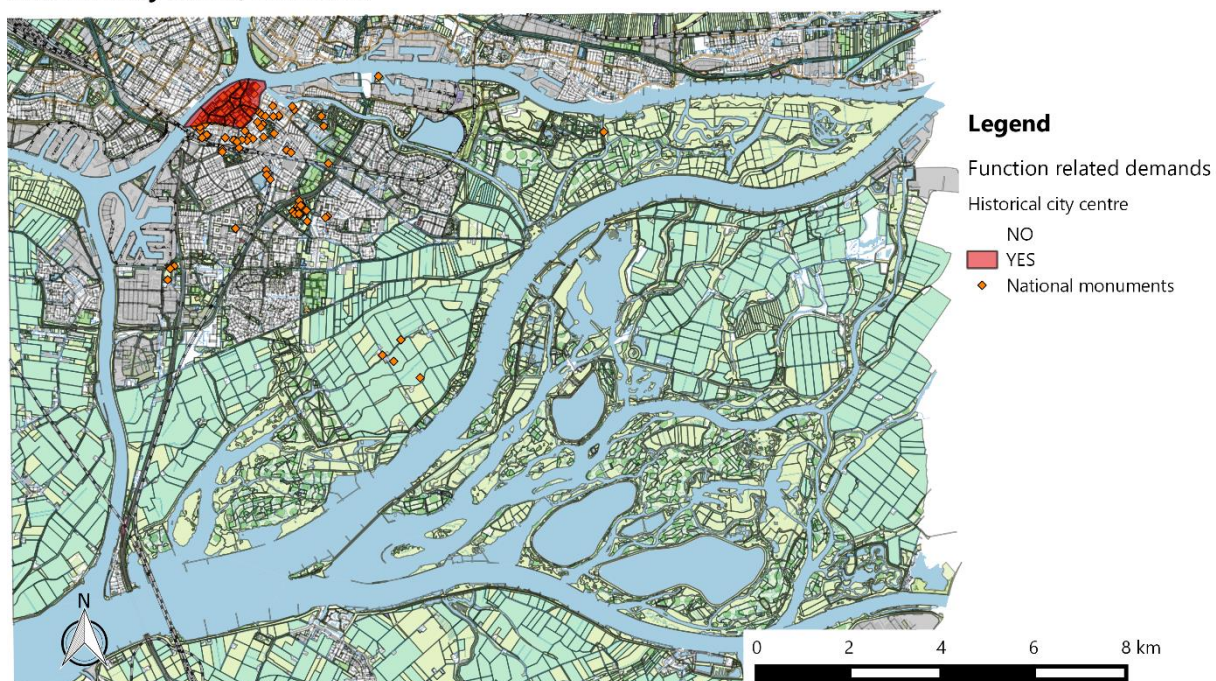


Figure 28 Identification of historical centre of Dordrecht

## Available budgets

In the current Dutch context there is no money available for climate proofing, so funding of climate proofing has to come from existing budgets (private companies, funds or the government). Examples of these budgets are the sewerage budget and the spatial planning budget. An indication of money used for climate proofing gives an idea of what the focus is of a municipality and the money that is available. When there is a lot of money available and used for climate proofing, adaptability is high, when there is almost no money available and used for climate proofing, adaptability is low.

Problem is this data is not available, climate proofing is not on the agendas of municipalities. One could therefore argue that adaptability is low because of no money being spent on climate proofing. Another problem is that the budgets don't spatially vary within a municipality, so when looking at adaptability within a municipality it won't have any effect on the adaptability.

## Types of stakeholders

The type of stakeholders in an area gives an indication of the kind and amount of pressure to expect from the community and the time that goes into the negotiation process. Businesses have for example completely other interests than citizens and farmers have again other interest, leading to other pressures. When there are a lot of different types of stakeholders negotiations tend to get harder and more time consuming.

Data containing data of owners of parcels is available from the cadastre. Unfortunately this data is very expensive (€1,35 for each parcel), and the municipality also didn't have this information available. So this indicator couldn't be used for this tool. The processes explained above are also really hard to predict or to quantify, so even if the data was available using it would be hard.

## Percentage public property

Space that is publicly owned is perfect for climate adaptation, and most of the time will be the space that will be used for climate proofing. Public space is already owned by the municipality, so they don't have to acquire space. They also have to deal with less stakeholders.

The same data as introduced in 'Types of stakeholders' could be used to determine this, but as explained above is too expensive. So this indicator couldn't be used for this tool.

## D. CLASSIFICATION: METHODS AND INDICATORS

First the used classification methods will be explained. Thereafter the classification of the indicators will be explained and given.

### Different classification methods

Three classification methods are used as guidelines to assign values to the indicator data, the Jenks Natural classification, the quantile classification and the geometrical interval classification (sometimes referred to as smart quantiles). The classification methods will be explained briefly.

#### Quantile classification

Each class contains an equal number of features. Quantile assigns the same number of data values to each class. There are no empty classes or classes with too few or too many values. The resulting map of quantile classification can often be misleading. Similar features can be placed in adjacent classes, or features with widely different values can be put in the same class. This distortion can be minimized by increasing the number of classes. It is best used with linearly distributed data. (ESRI, 2016)

#### Jenks classification

The Jenks classification is designed to place variable values into naturally occurring data categories. Natural breaks in the data are identified by finding points that minimize within-class sum of squared differences, and maximizes between group sum of squared differences. Essentially, the Jenks method minimizes within class variances (makes them as similar as possible) and maximizes variance between groups (makes data classes as different as possible). The advantage of the Natural Breaks (Jenks) classification is that it identifies real classes within the data. It is best used on data that has high variances. (Jones, 2010)

#### Geometrical interval classification

The geometrical interval classification scheme creates class breaks based on class intervals that have a geometric series. The geometric coefficient in this classifier can change once (to its inverse) to optimize the class ranges. The algorithm creates geometric intervals by minimizing the sum of squares of the number of elements in each class. This ensures that each class range has approximately the same number of values with each class and that the change between intervals is fairly consistent. This method can be used on data that is heavily skewed with a preponderance of duplicate values, it creates a balance between highlighting changes in middle values and extreme values. (ESRI, 2016)

### Classification of indicators

Here the data and classification of the indicators used in the tool will be explained, histograms will be used to graphically represent the data for each indicator.



## Percentage buildings

Looking at the data (see Figure 29) it can be seen that the data points are quite evenly spread across 0-40% with some outliers in the 40-60.8% ( $\mu = 22\%$ ,  $\sigma = 13\%$ ). Quantile classification or Jenks classification could be used in this case, see classification, Table 5 and Code 1, the resulting code in QGIS.

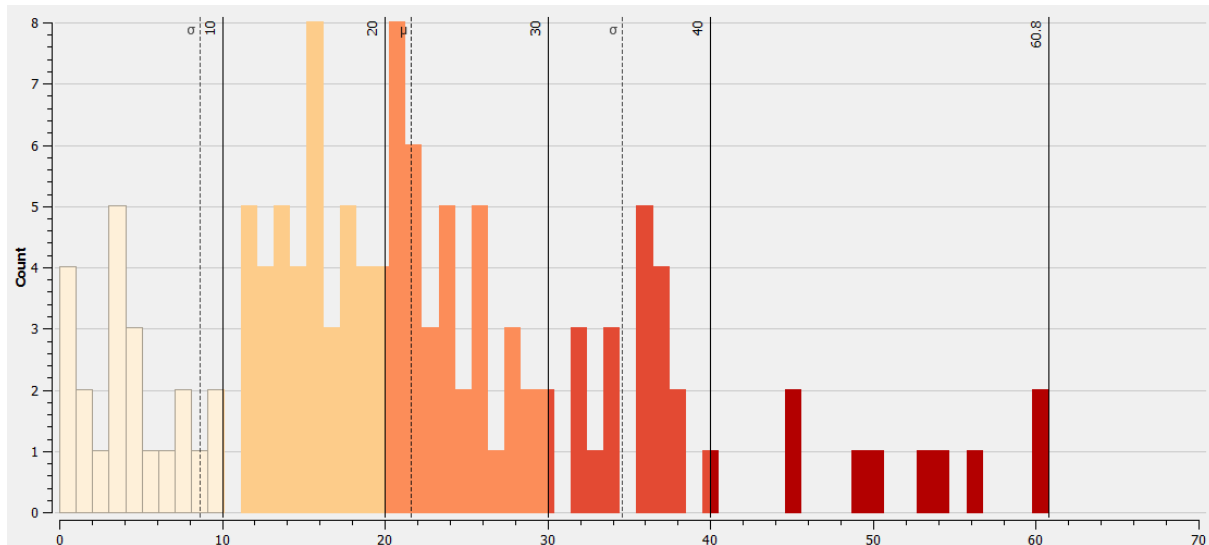


Figure 29 Histogram of dataset percentage buildings for each neighbourhood

Table 5 Classification of percentage buildings for classification method and chosen classification

Label	Quantile	Jenks	Geometrical	Chosen
1	0-12	0-8	0-10	0-10
2	12-17	8-18	10-18	10-20
3	17-22	18-28	18-28	20-30
4	22-32	28-40	28-42	30-40
5	>32	>40	>42	>40

```

CASE WHEN ("buildings" <= 10) THEN 1
WHEN ("buildings" > 10 AND "buildings" <= 20) THEN 2
WHEN ("buildings" > 20 AND "buildings" <= 30) THEN 3
WHEN ("buildings" > 30 AND "buildings" <= 40) THEN 4
WHEN ("buildings" > 40) THEN 5
END

```

Code 1 Resulting code for classification of percentage buildings in QGIS



## Percentage water

The dataset for the percentage water indicator looks somewhat different than the previous one. It looks more like an exponential distribution, with a preponderance of zero values ( $\mu = 8\%$ ,  $\sigma = 11\%$ ). Geometrical classification could be used for such a dataset. There is also regulation on the minimal percentage open water in urban areas, this is based on the Watertoets, and regular values are between 5 and 10% of the total area, this is also taken into account. See classification, Table 6 and Code 2, the resulting code in QGIS.

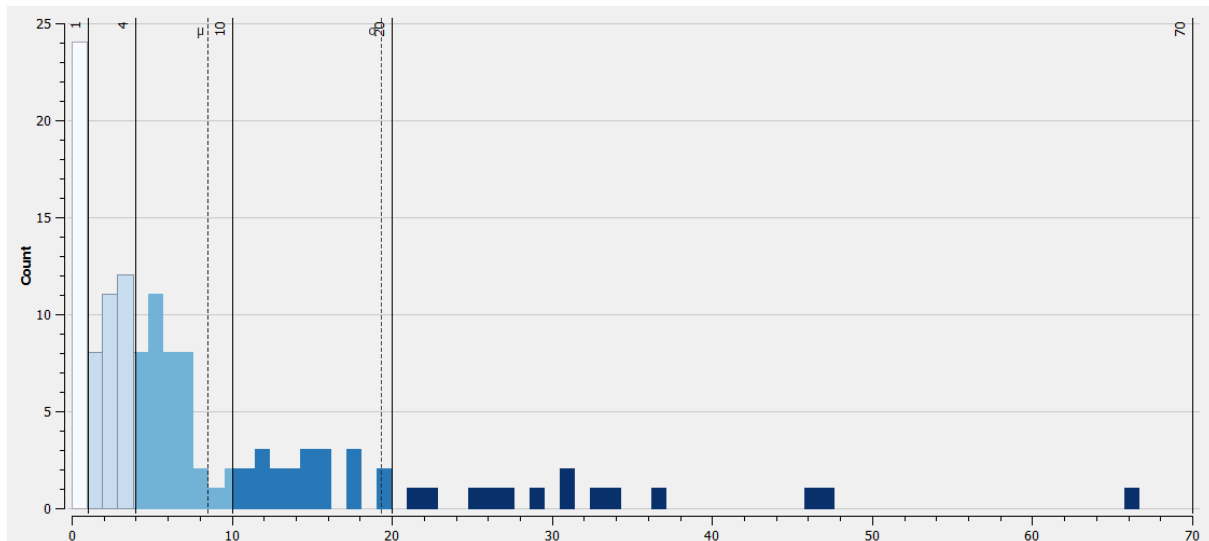


Figure 30 Histogram of dataset percentage water for each neighbourhood

Table 6 Classification of percentage water for classification method and chosen classification

Label	Quantile	Jenks	Geometrical	Chosen
1	>13	>37	>28	>20
2	6-13	21-37	11-28	10-20
3	3-6	10-21	4-11	4-10
4	1-3	3-10	1-4	1-4
5	0-1	0-3	0-1	1

```

CASE WHEN ("water" <= 1) THEN 5
WHEN ("water" > 1 AND "water" <= 4) THEN 4
WHEN ("water" > 4 AND "water" <= 10) THEN 3
WHEN ("water" > 10 AND "water" <= 20) THEN 2
WHEN ("water" > 20) THEN 1
END

```

Code 2 Resulting code for classification of percentage water in QGIS

## Percentage green

For percentage green data is very widely spread and evenly spread between 1-50% with quite some outliers in >50% and a preponderance of zero values (20x) ( $\mu = 25\%$ ,  $\sigma = 23\%$ ). Based on the data geometrical classification should be the best classification method for this kind of dataset. See classification, Table 7 and Code 3, the resulting code in QGIS.

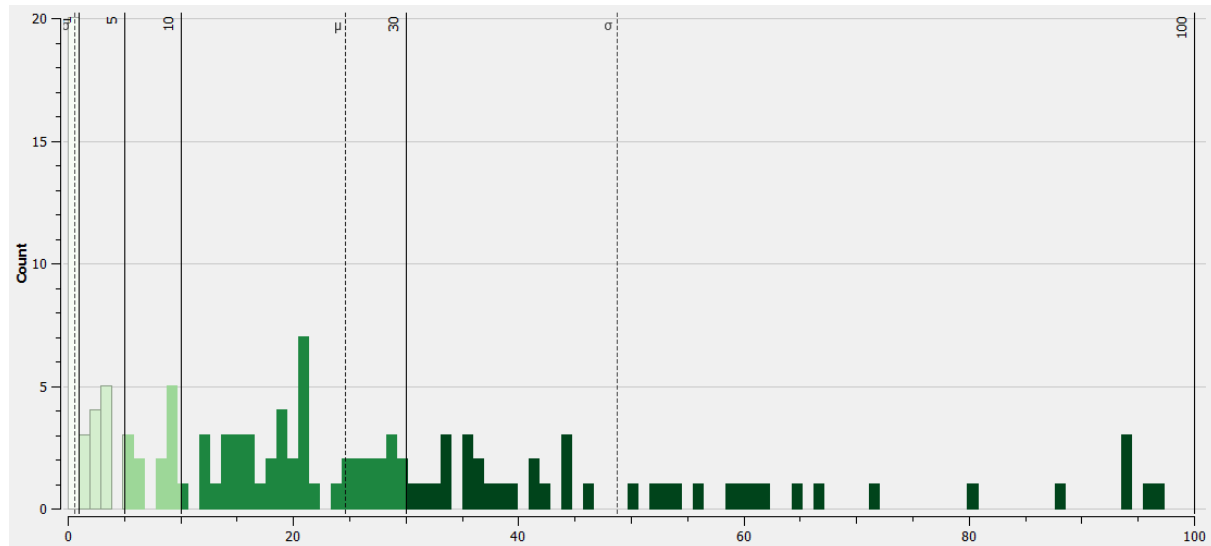


Figure 31 Histogram of dataset percentage green for each neighbourhood

Table 7 Classification of percentage green for classification method and chosen classification

Label	Quantile	Jenks	Geometrical	Chosen
1	>40	>72	>50	>30
2	24-40	45-72	24-50	10-30
3	14-24	25-45	11-24	5-10
4	3-14	10-25	4-11	1-5
5	0-3	0-10	0-4	0-1

```

CASE WHEN ("green" <= 1) THEN 5
WHEN ("green" > 1 AND "green" <= 5) THEN 4
WHEN ("green" > 5 AND "green" <= 10) THEN 3
WHEN ("green" > 10 AND "green" <= 30) THEN 2
WHEN ("green" > 30) THEN 1
END

```

Code 3 Resulting code for classification of percentage green in QGIS

## Soil type

Soil type has already 5 different types (sand, clay, peat, sand/peat and clay/peat) which makes classification easier. Sand has the best underground characteristics and peat the worst, in between are clay, sand/peat and clay/peat (see Table 8). The most abundant soil type in this area is clay/peat (see Figure 32).

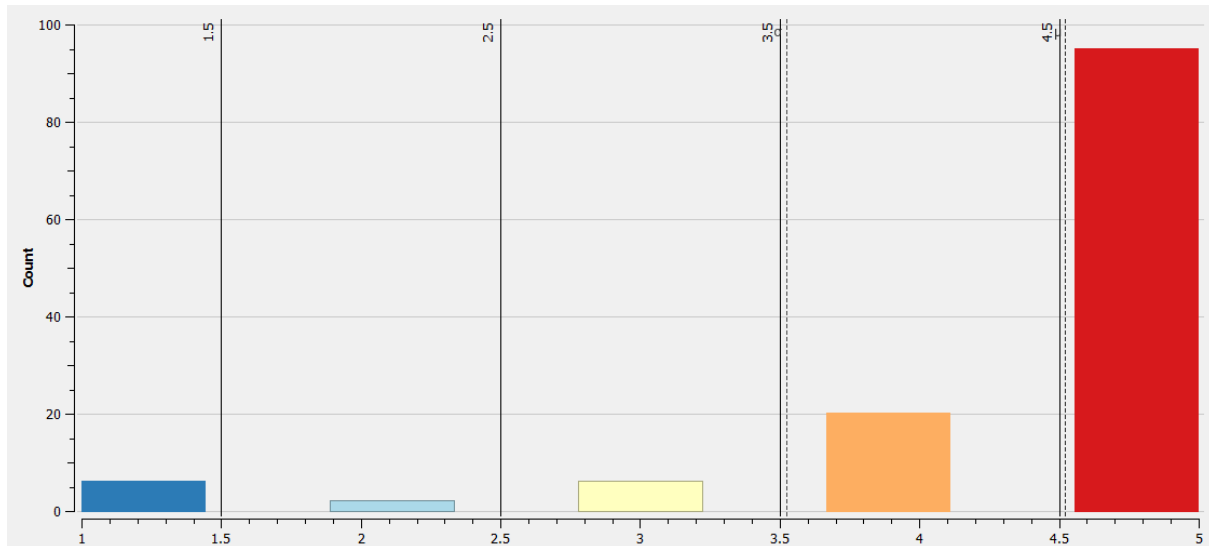


Figure 32 Histogram of dataset soil type for each neighbourhood

Table 8 Classification of soil type

Label	Chosen
1	1 (sand)
2	2 (clay)
3	4 (sand/peat)
4	5 (clay/peat)
5	3 (peat)

```
CASE WHEN ("soil" = 1) THEN 1
WHEN ("soil" = 2) THEN 2
WHEN ("soil" = 4) THEN 3
WHEN ("soil" = 5) THEN 4
WHEN ("soil" = 3) THEN 5
END
```

Code 4 Code for classification of soil type in QGIS

## Cables and pipes

Cables and pipes has again a really skewed distribution ( $\mu = 1 \text{ km/km}^2$ ,  $\sigma = 3 \text{ km/km}^2$ ), with an abundance of zeroes (95/127), see Figure 33. This is due to absence of main cables and pipes in most neighbourhoods. The presence of main cables and pipes is always negative that is why only 4 and 5 values are assigned, see Table 9 (low adaptability and average/low adaptability). If there are no main cables or pipes presence this indicator is not taken into account

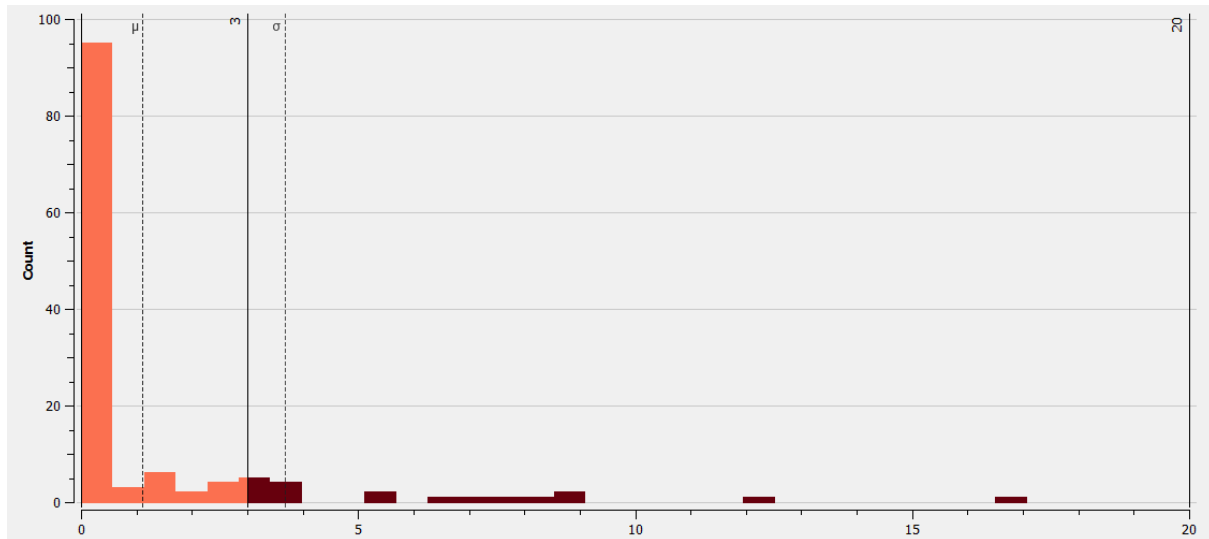


Figure 33 Histogram of dataset cables and pipes (km/km<sup>2</sup>) for each neighbourhood

Table 9 Classification of cables and pipes

Label	Chosen
4	0-3
5	>3

```

CASE WHEN ("cables" > 3) THEN 5
WHEN ("cables" <= 3 AND "cables" > 0) THEN 4
ELSE NULL
END

```

Code 5 Code for classification of cables and pipes in QGIS

## Planned works

Another skewed distribution ( $\mu = 5000$  €/ha,  $\sigma = 16000$  €/ha) is the one of planned works, this is due to maintenance not being executed in all neighbourhoods, but is concentrated in only few neighbourhoods, see Figure 34. When there are no maintenance works in the coming years it can be seen as negative for adaptability, so when there are no investments a 5 is assigned. Investments in a neighbourhood should work positively on adaptability that is why 4 (low/average adaptability) is left out. The geometrical classification can probably be used in this case, see Table 10.

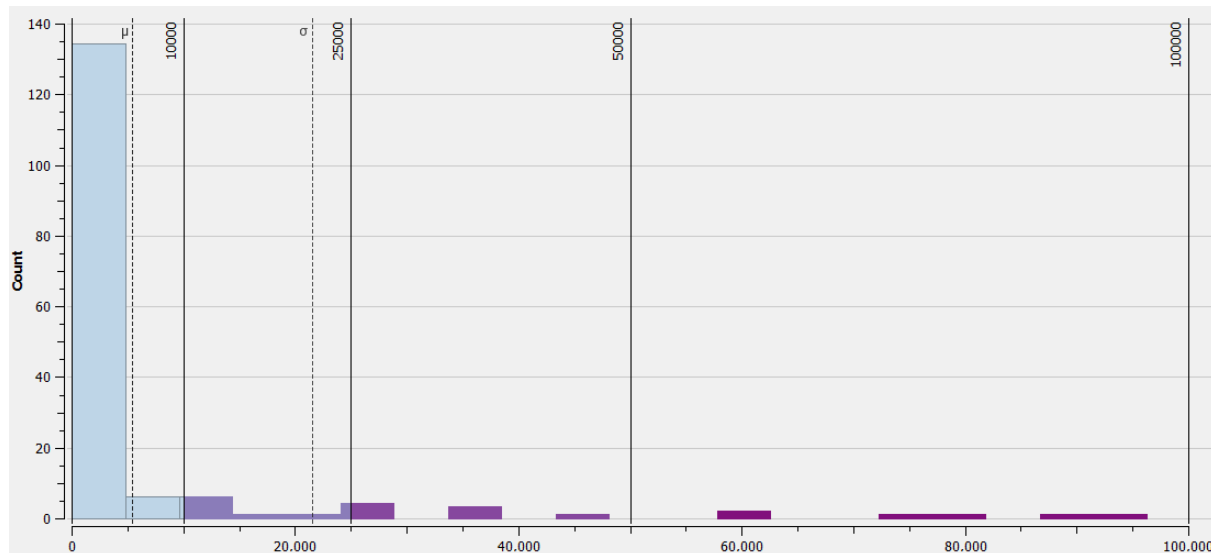


Figure 34 Histogram of dataset planned works for each neighbourhood

Table 10 Classification of planned works for classification method and chosen classification

Label	Quantile	Jenks	Geometrical	Chosen
1	>13813	>45889	>9214	>50000
2	0-13813	14737-45889	811-9214	25000-50000
3	0-0	0-14737	0-811	0-25000
4				
5				0

```

CASE WHEN ("matching" = 0) THEN 5
WHEN ("matching" > 0 AND "matching" <= 25000) THEN 3
WHEN ("matching" > 25000 AND "matching" < 50000) THEN 2
WHEN ("matching" > 50000) THEN 1
END

```

Code 6 Code for classification of planned works in QGIS

## EEOLC

The estimated end of life cycle (EEOLC) looks like a normal distribution ( $\mu = 2061$ ,  $\sigma = 33$  years), see Figure 35. The neighbourhoods that are assigned as historical city centre are left out. The Jenks natural distribution could be used as guideline, see Table 11.

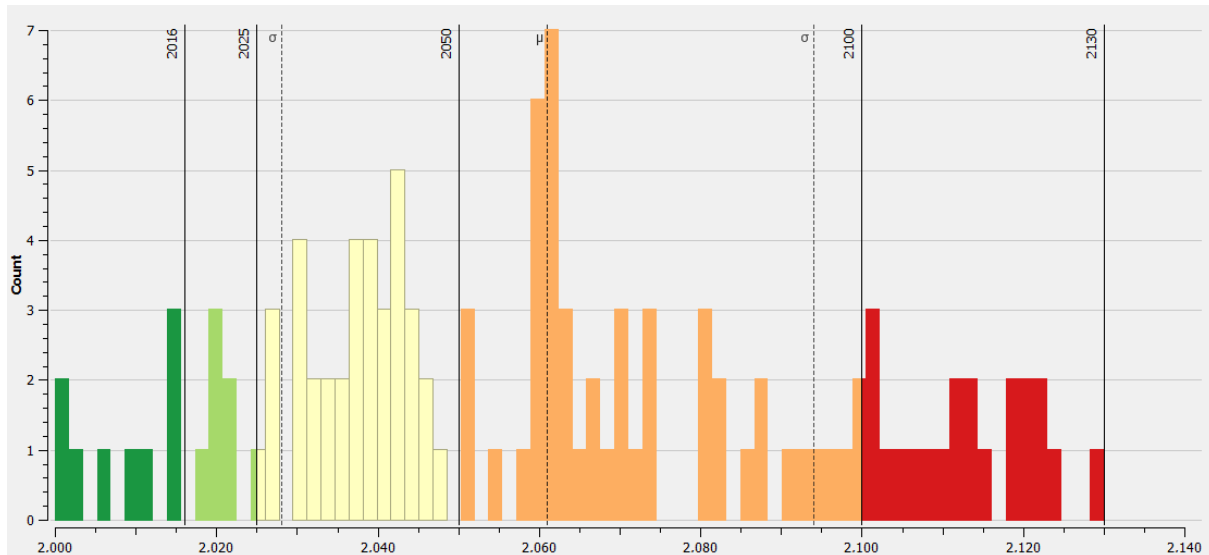


Figure 35 Histogram of dataset EEOLC for each neighbourhood

Table 11 Classification of EEOLC for classification method and chosen classification

Label	Quantile	Jenks	Geometrical	Chosen
1	<2032	<2022	<2023	<2016
2	2032-2045	2022-2047	2023-2042	2016-2025
3	2045-2063	2047-2074	2042-2065	2025-2050
4	2063-2093	2074-2104	2065-2094	2050-2100
5	>2093	>2104	>2094	>2100

```

CASE WHEN ("EOLC" <= 2016) THEN 1
WHEN ("EOLC" > 2016 AND "EOLC" <= 2025) THEN 2
WHEN ("EOLC" > 2025 AND "EOLC" <= 2050) THEN 3
WHEN ("EOLC" > 2050 AND "EOLC" <= 2100) THEN 4
WHEN ("EOLC" > 2100) THEN 5
END

```

Code 7 Code for classification of EEOLC in QGIS

## Urgency

To create the urgency classification multiple datasets are used and combined to come to one value for urgency. These datasets consist of text strings instead of values so histograms can't be made before classification. The climate adaptation atlas already made a kind of classification this classification will be used here as well, but will be transformed to the used classification of 1 – 5.

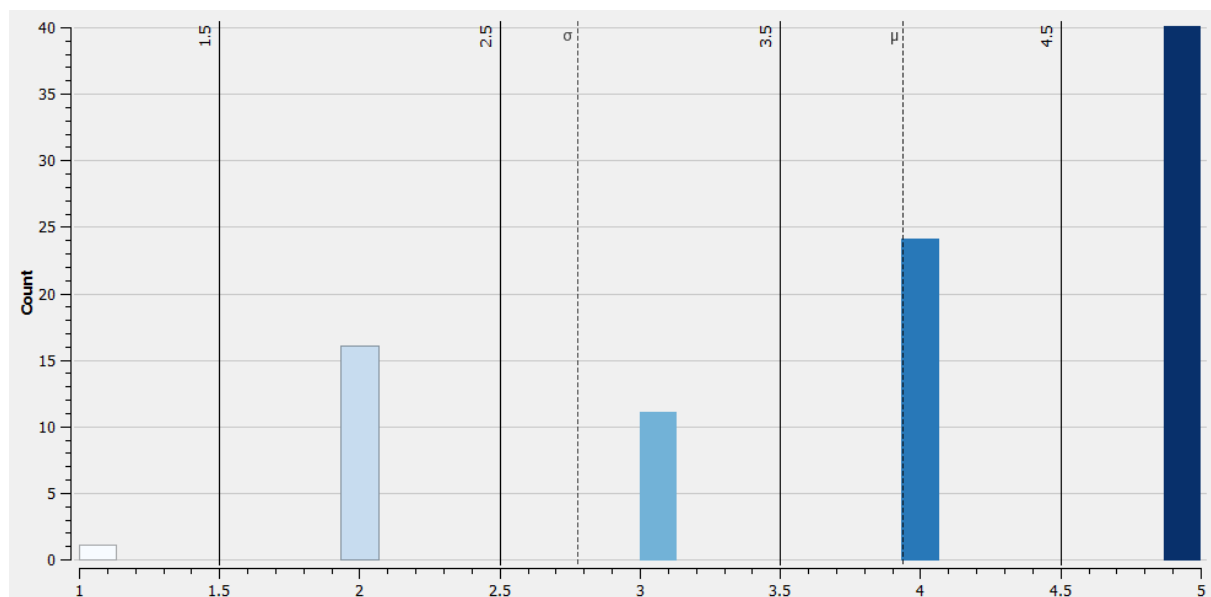
## Subsidence

Shortage of water in result of drought leads to subsidence in clay/peat areas. The used data is modelled by using W+ scenario for 2050. It is assumed that the current water control is maintained.

The subsidence happened to already have a classification consisting of 5 values, so these values are simply sorted from high to low values. So first the code, Code 8, when the classification is changed to values between 1 and 5, the resulting histogram, Figure 36.

```
CASE WHEN ( "subsidence" = '0 - 0,1') THEN 5
WHEN ( "subsidence" = '0,1 - 0,3') THEN 4
WHEN ( "subsidence" = '0,3 - 0,5') THEN 3
WHEN ( "subsidence" = '0,5 - 2') THEN 2
WHEN ( "subsidence" = '1 - 2') THEN 1
END
```

*Code 8 Code for classification of subsidence (urgency) in QGIS*



*Figure 36 Histogram of dataset subsidence (urgency) for each neighbourhood*

## Heat stress

Heat stress is related to urban areas and its characteristics, this effect is called the urban heat island (UHI). Three years of temperature records of the local monitoring network of Rotterdam are related to the urban characteristics. Relations are found between the temperature and amount of paved area, greening and average building height in the surrounding area (Van Hove, et al., 2014). These relations are used to extrapolate UHI to the whole of the Netherlands to get a global picture of the effect of the UHI. The data of the W+ scenario for 2050 is used again.

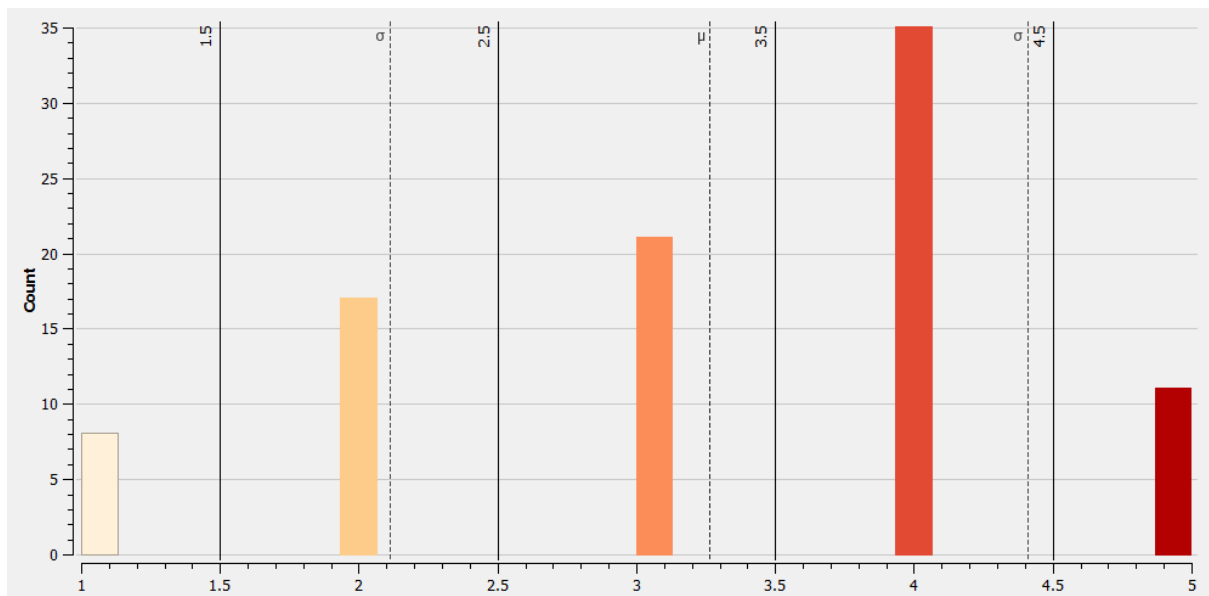
Heat had been divided in 7 classes by climate adaptation atlas, this means that multiple classes have to be assigned to one of the 5 classes. See the classification, Code 9, and the resulting histogram, see Figure 37.

```

CASE WHEN ( "heat" = '3 weken') THEN 1
WHEN ( "heat" = '2,5 - 3 weken') THEN 2
WHEN ( "heat" = '2 - 3 weken') THEN 2
WHEN ( "heat" = '2,5 weken') THEN 3
WHEN ( "heat" = '2 - 2,5 weken') THEN 4
WHEN ( "heat" = '2 weken') THEN 5
WHEN ( "heat" = '1,5 - 2 weken') THEN 5
END

```

*Code 9 Code for classification of heat stress (urgency) in QGIS*



*Figure 37 Histogram of dataset heat stress (urgency) for each neighbourhood*

## Flooding

A calculation of the flooding is done by using a 1D-Sobek model from UNESCO-IHE. This model calculates the volume of water that can't be transported by the sewer network. This volume is then divided by the total area of streets in a neighbourhood (within a radius of 50m from the sewer). To get an indication of the flooding on the streets in each neighbourhood in mm, see histogram in Figure 38.

The data from this model is kind of exponentially divided. The resulting classification can be found in Code 10.



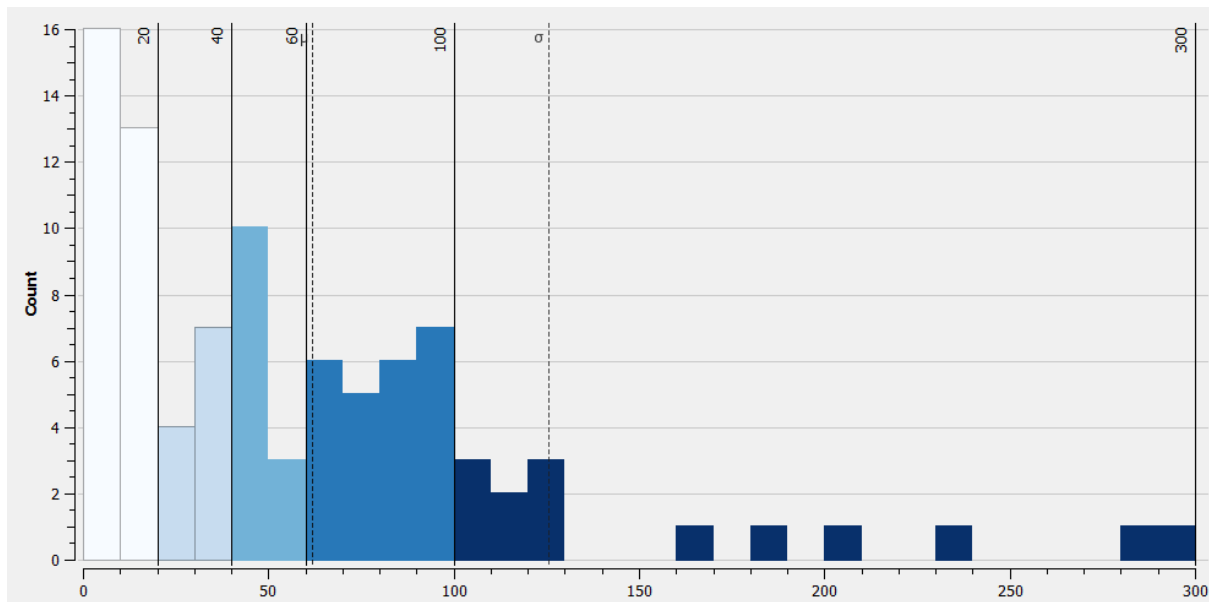


Figure 38 Histogram of dataset flooding (urgency) for each neighbourhood

```

CASE WHEN ( "flooding" > 100) THEN 1
WHEN ( "flooding" > 60 AND "flooding" <= 100) THEN 2
WHEN ( "flooding" > 40 AND "flooding" <= 60) THEN 3
WHEN ( "flooding" > 20 AND "flooding" <= 40) THEN 4
WHEN ( "flooding" <= 20) THEN 5
END

```

Code 10 Code for classification of flooding (urgency) in QGIS

### Rotting of wooden pole foundations

As a result of a dryer climate a lowering of the ground water level can be possible, this lowering can lead to rotting of wooden pole foundations. Deltares did a research into the risk of rotting of these foundations. This risk is calculated for the current climate.

The risks are divided into 7 classes, see Code 11, the resulting histogram can be found in Figure 39.

```

CASE WHEN ( "poles" = 'Geen gegevens') THEN NULL
WHEN ( "poles" = 'Geen') THEN 5
WHEN ( "poles" = 'Geen tot weinig') THEN 5
WHEN ( "poles" = 'Weinig') THEN 4
WHEN ( "poles" = 'Geen tot matig') THEN 4
WHEN ( "poles" = 'Matig') THEN 3
WHEN ( "poles" = 'Geen tot groot') THEN 2
WHEN ( "poles" = 'Groot') THEN 1
END

```

Code 11 Code for classification of rotting of wooden pole foundations (urgency) in QGIS

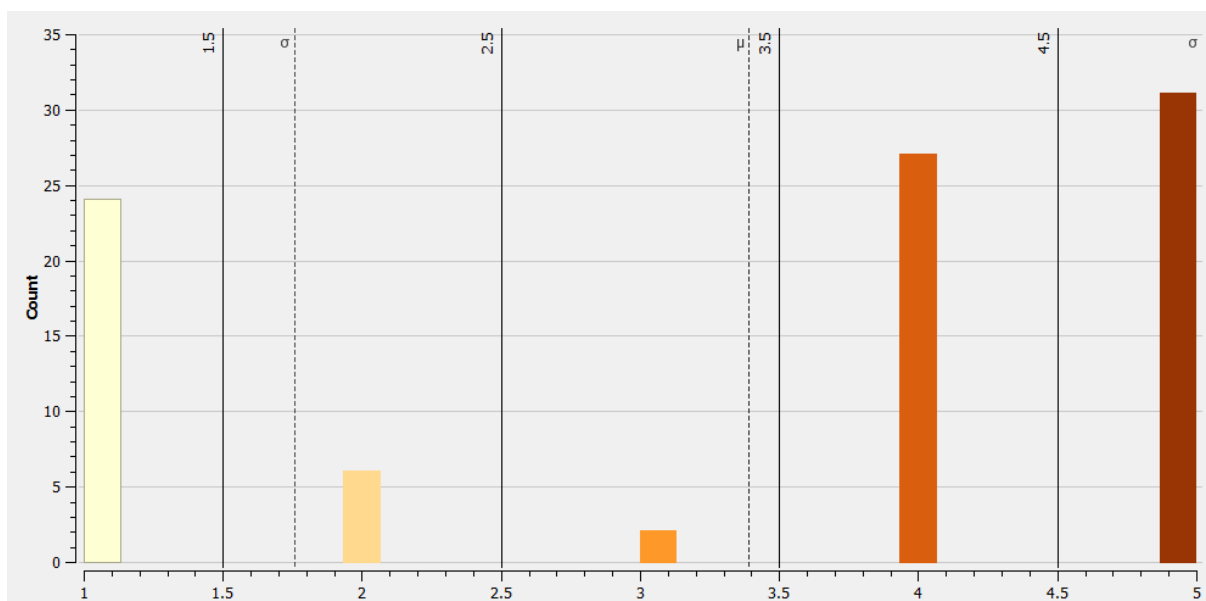


Figure 39 Histogram of dataset rotting of wooden pole foundations (urgency) for each neighbourhood

### Combining the climate related risks

The risks are combined in the same manner as the indicators are combined to find a measure for adaptability. All classified risks are added together and divided by the number of risks (some neighbourhoods have no data for some of the risks or have no data at all). Keep in mind that a 5 in this classification, means almost no risks and a 1 is high risks. See the histogram of the resulting urgency classification, Figure 40.

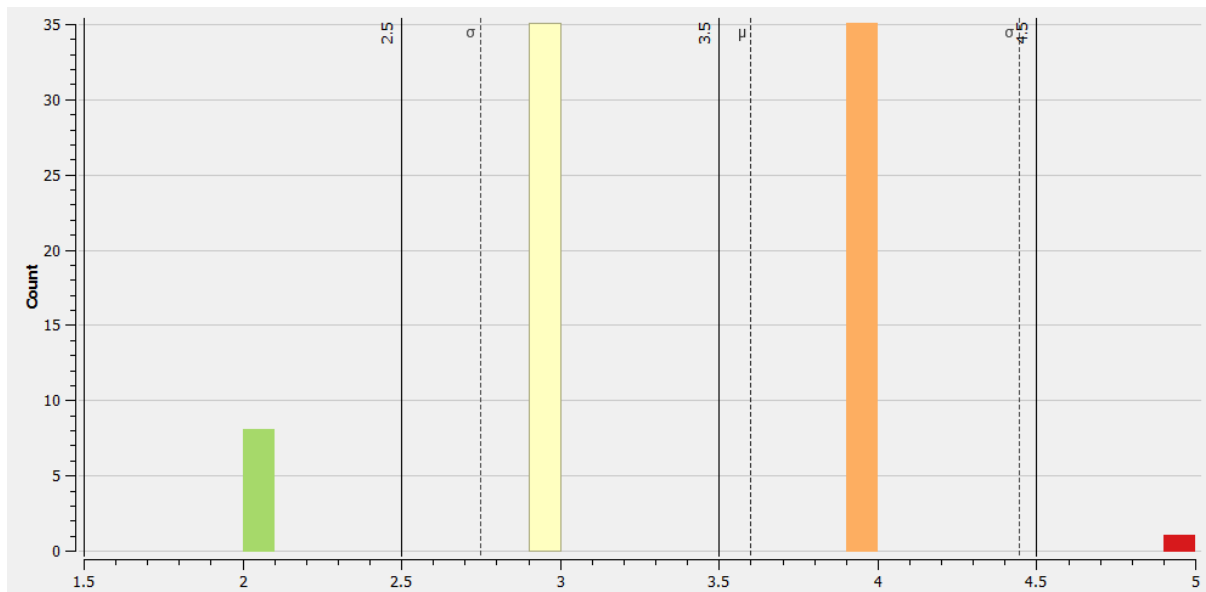


Figure 40 Histogram of dataset urgency for each neighbourhood

## Historical city centre

The historical city centre only works negatively on the adaptability. The possible values it can have are only yes it is a historical city centre or no it isn't. This resulted in the following code for QGIS, see Code 12.

```
CASE WHEN ("histcentre" = 0) THEN NULL
WHEN ("histcentre" = 1) THEN 5
END
```

*Code 12 Code for classification of historical city centre in QGIS*

## Classification of adaptability

The classified indicators are used to come to some measure or indication of the overall adaptability for each neighbourhood. The indicators for each neighbourhood are added and divided by the number of indicators used.

### Coding the classification of adaptability

The classification of adaptability above sounds pretty easy and not that hard, problem is there are lots of indicators that don't have data for all neighbourhoods or have data only for specific neighbourhoods. Taking this into account and adapting the number of indicators required some coding, the code used in QGIS can be found in Code 13. The indicators that have to be checked for each neighbourhood are the historical city centre (which has only data for the historical city centre, and is exactly the opposite of EEOLC, which has no data for historical city centre), the main cables and pipes, which has only data for the neighbourhoods where those cables and pipes are located and the urgency, where data is missing for some neighbourhoods.

```
CASE WHEN ("chis" = 5 AND "ccables" = 0 AND "curgence" = 0) THEN ( "cbuildings" + "cwater" +
"cgreen" + "csoiltype" + "cmatching" + "chis" ) / 6
WHEN ("chis" = 5 AND "ccables" = 0 AND "curgence" IS NOT 0) THEN ( "cbuildings" + "cwater" +
"cgreen" + "csoiltype" + "cmatching" + "curgence" + "chis") / 7
WHEN ("chis" = 5 AND "ccables" IS NOT 0 AND "curgence" = 0 ) THEN ( "cbuildings" + "cwater" +
"cgreen" + "csoiltype" + "cmatching" + "ccables" + "chis") / 7
WHEN ("chis" = 5 AND "ccables" IS NOT 0 AND "curgence" IS NOT 0) THEN ( "cbuildings" +
"cwater" + "cgreen" + "csoiltype" + "cmatching" + "ccables" + "chis" + "curgence") / 8
WHEN ("chis" = 0 AND "curgence" = 0 AND "ccables" = 0 ) THEN ( "cbuildings" + "cwater" +
"cgreen" + "csoiltype" + "cmatching" + "ceolc") / 6
WHEN ("chis" = 0 AND "curgence" = 0 AND "ccables" IS NOT 0 ) THEN ( "cbuildings" + "cwater" +
"cgreen" + "csoiltype" + "cmatching" + "ceolc" + "ccables") / 7
WHEN ("chis" = 0 AND "curgence" IS NOT 0 AND "ccables" = 0 ) THEN ( "cbuildings" + "cwater" +
"cgreen" + "csoiltype" + "cmatching" + "ceolc" + "curgence") / 7
WHEN ("chis" = 0 AND "curgence" IS NOT 0 AND "ccables" IS NOT 0 ) THEN ( "cbuildings" +
"cwater" + "cgreen" + "csoiltype" + "cmatching" + "ceolc" + "curgence" + "ccables") / 8
END
```

*Code 13 Code for classification of adaptability in QGIS*

## E. SENSITIVITY ANALYSIS

Generally, sensitivity analysis is defined as the study of how uncertainty in the output of a model can be attributed to different sources of uncertainty in the model input. A local sensitivity analyses using the one-at-a-time (OAT) technique will be used here. OAT technique analyses the effect of one parameter at a time, keeping the other parameters fixed. Sensitivity can then be measured by looking at differences in output.

Sensitivity can be used for model understanding, development, decision making and communication. By varying inputs deeper understanding of the relationship between input and output can be developed. This way the model can also be developed to become more correct, simpler or more robust if data is missing or of poor quality. Decision making can be improved by identifying important factors. The communication of those decisions can be made more understanding and credible using the result of the sensitivity analysis.

### OAT technique

Using the one-at-a-time technique each of the indicators are left out one-by-one, this are the resulting linear regression plots. From this plots you can acquire some important information about the indicators, the  $R^2$  gives an indication of the total effect the indicator has on the average adaptability, while the function gives an indication of whether the indicator has an overall positive or negative effect on adaptability.

### Percentage buildings

The resulting linear regression plot for percentage buildings can be found in Figure 41, for this case the situation with all indicators (on y-axis) and using other indicators but leaving out percentage buildings (on x-axis) is compared. What can be concluded from this plot is that percentage buildings has quite some effect on the overall adaptability ( $R^2 = 0.8988$ , the further away from 1 (meaning both datasets are the same), the more effect it has on adaptability) and has an overall positive effect on adaptability for the municipality of Dordrecht.

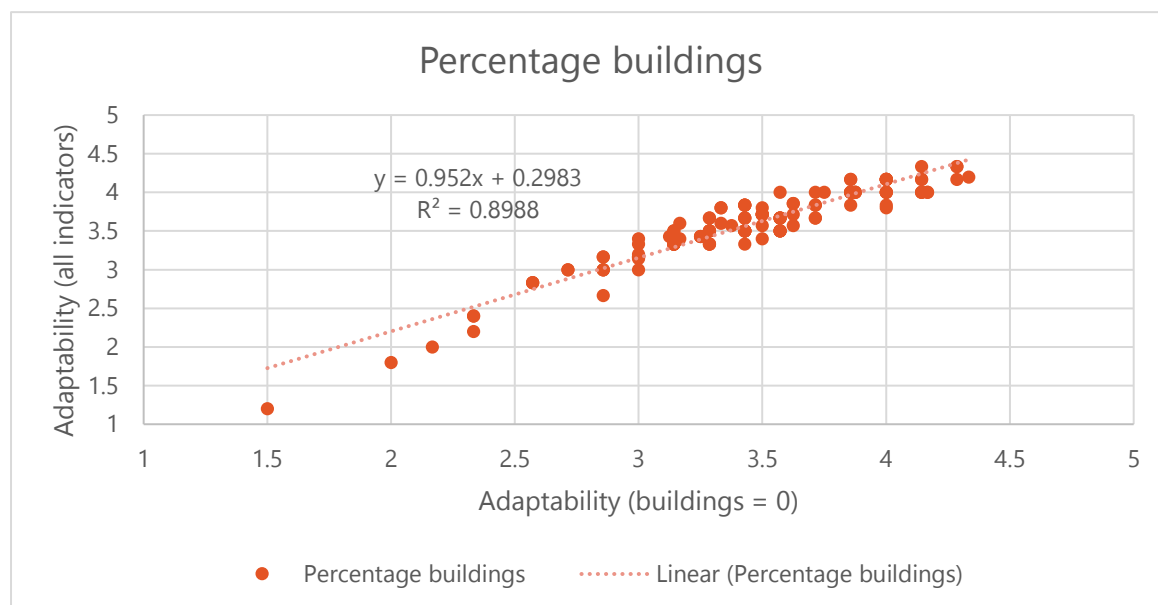


Figure 41 Linear regression plot for percentage buildings, using OAT technique

### Percentage water

The resulting linear regression plot for percentage water can be found in Figure 42. Percentage water also has quite some effect on the overall adaptability ( $R^2 = 0.8554$ ), which is just a bit more than percentage buildings. The overall effect of percentage water on the outcome of adaptability is negative, but really small.

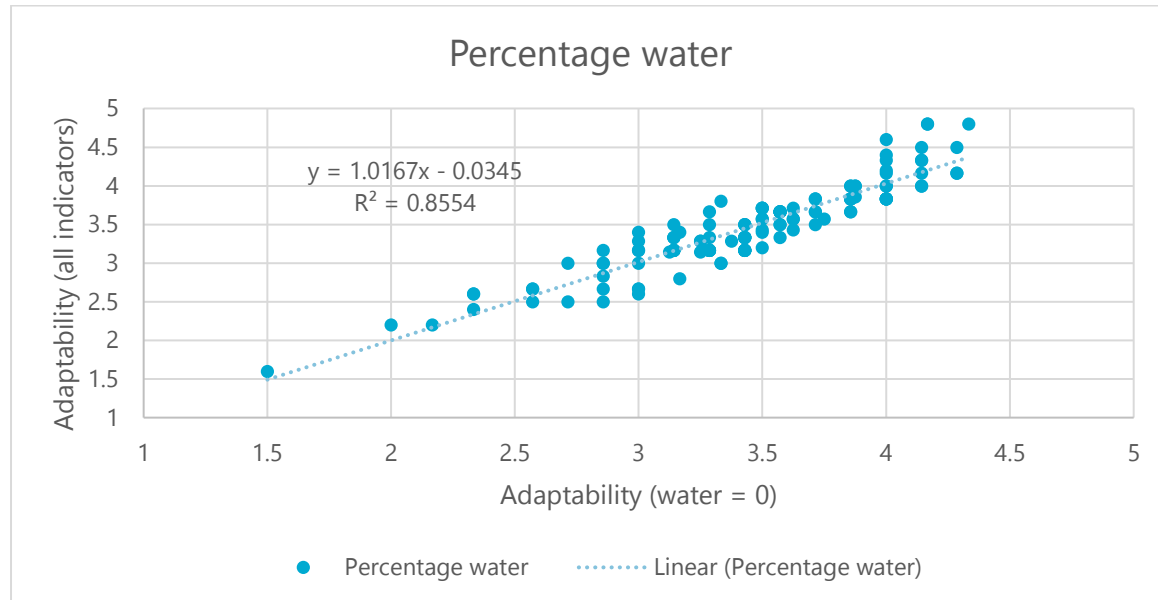


Figure 42 Linear regression plot for percentage water, using OAT technique

### Percentage green

The resulting linear regression plot for percentage green can be found in Figure 43. Percentage green has the largest effect of all indicators on the overall adaptability ( $R^2 = 0.8369$ ), due to all neighbourhoods having values assigned, and a lot of low (5) and high (1) values assigned in percentage green. On average the effect of percentage green is positive.

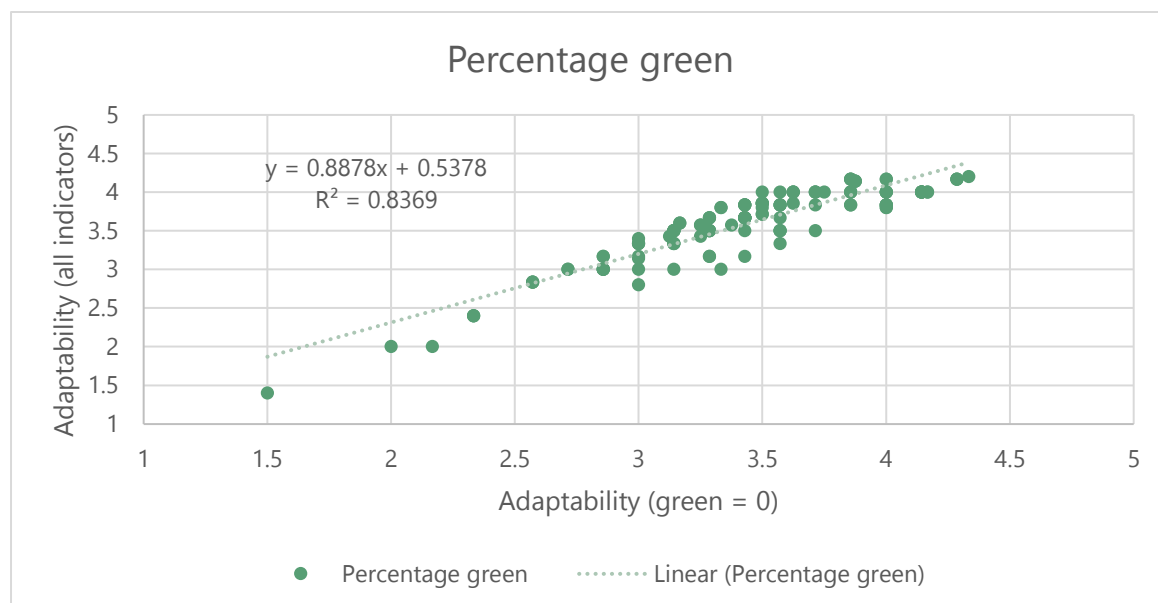


Figure 43 Linear regression plot for percentage green, using OAT technique

## Soil type

The resulting linear regression plot for soil type can be found in Figure 44. Soil type has not a big effect on the overall adaptability ( $R^2 = 0.9513$ ). The overall effect of soil type on the outcome of adaptability is negative, due to poor soil conditions in the Dordrecht area.

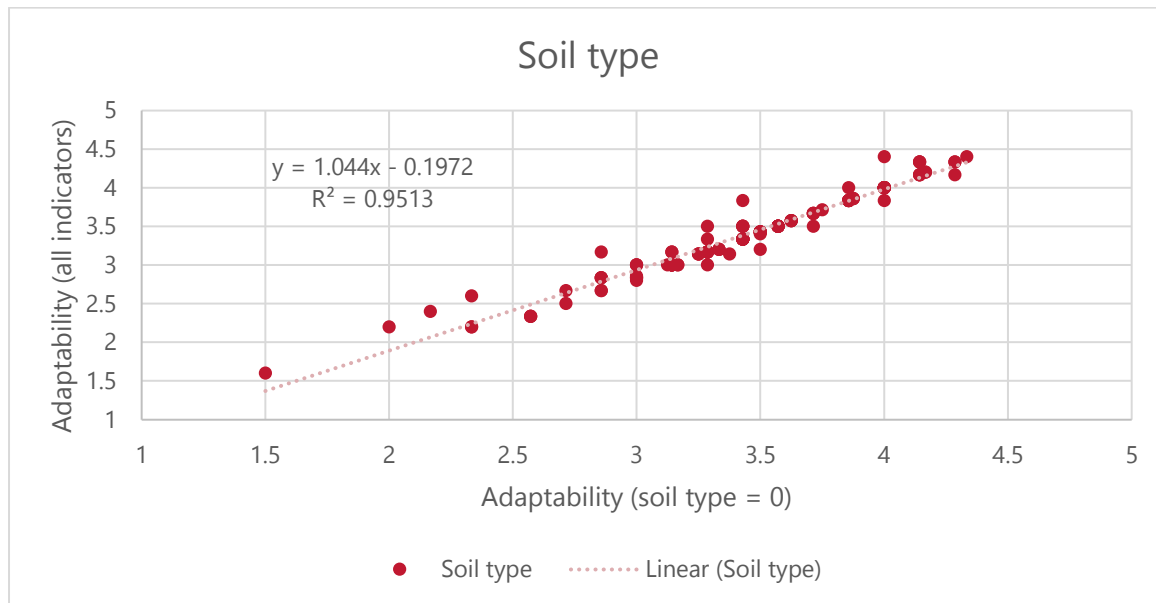


Figure 44 Linear regression for soil type, using OAT technique

## Main cables and pipes

The resulting linear regression plot for main cables and pipes can be found in Figure 45. Main cables and pipes have small effect on the overall adaptability ( $R^2 = 0.9731$ ), due to only few neighbourhoods having a value assigned for main cables and pipes. The overall effect of main cables and pipes on the outcome of adaptability is negative, due to only assigning low adaptability values in neighbourhoods where there are main cables and pipes and assigning no values to all other neighbourhoods.

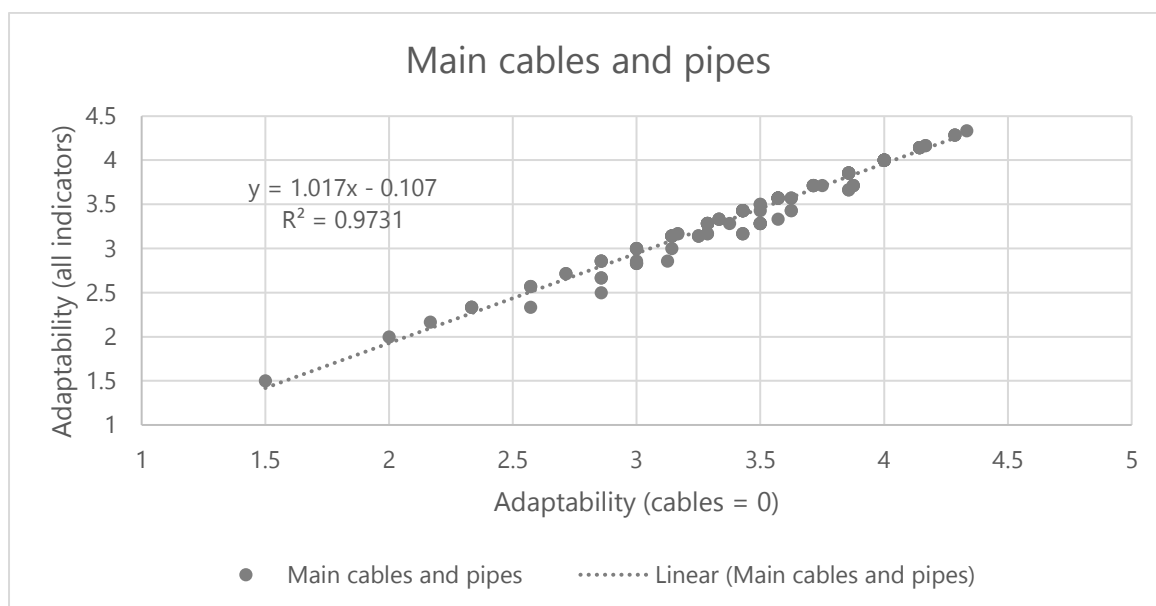


Figure 45 Linear regression for main cables and pipes, using OAT technique

### Planned works

The resulting linear regression plot for planned can be found in Figure 46. Planned works has large effect on the overall adaptability ( $R^2 = 0.8972$ ). The overall effect of planned works on the outcome of adaptability is negative, due to more neighbourhoods having no planned works than neighbourhoods having.

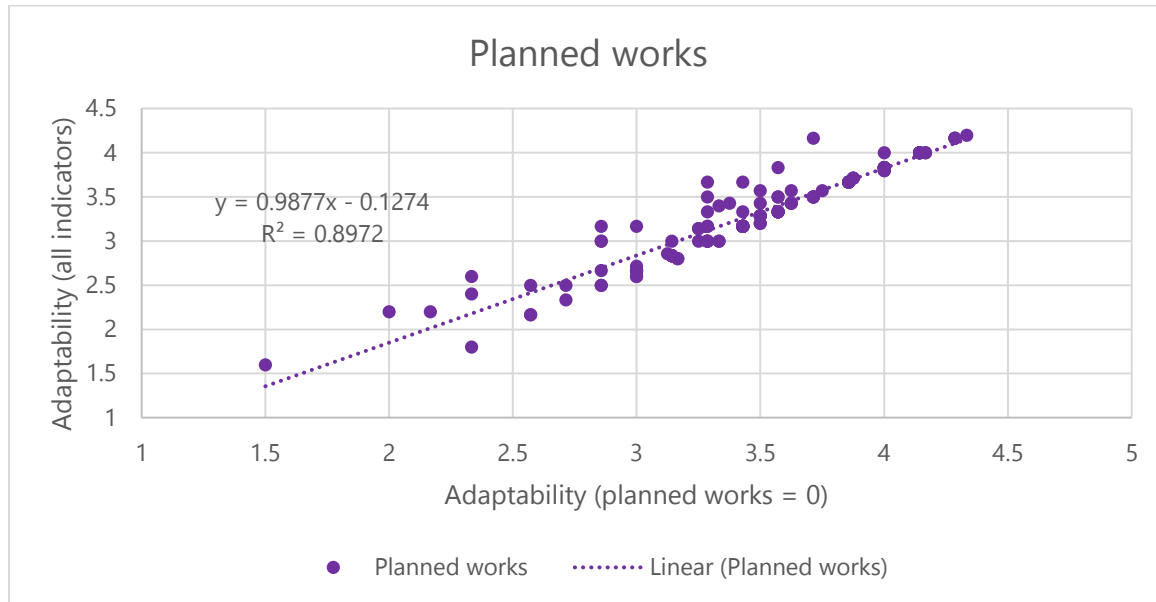


Figure 46 Linear regression for planned works, using OAT technique

### Estimated end of life cycle

The resulting linear regression plot for estimated end of life cycle can be found in Figure 47. EEOLC has a quite large effect on the overall adaptability ( $R^2 = 0.9125$ ). The overall effect of EEOLC on the outcome of the average adaptability is neutral, positive and negative kind of evens out.

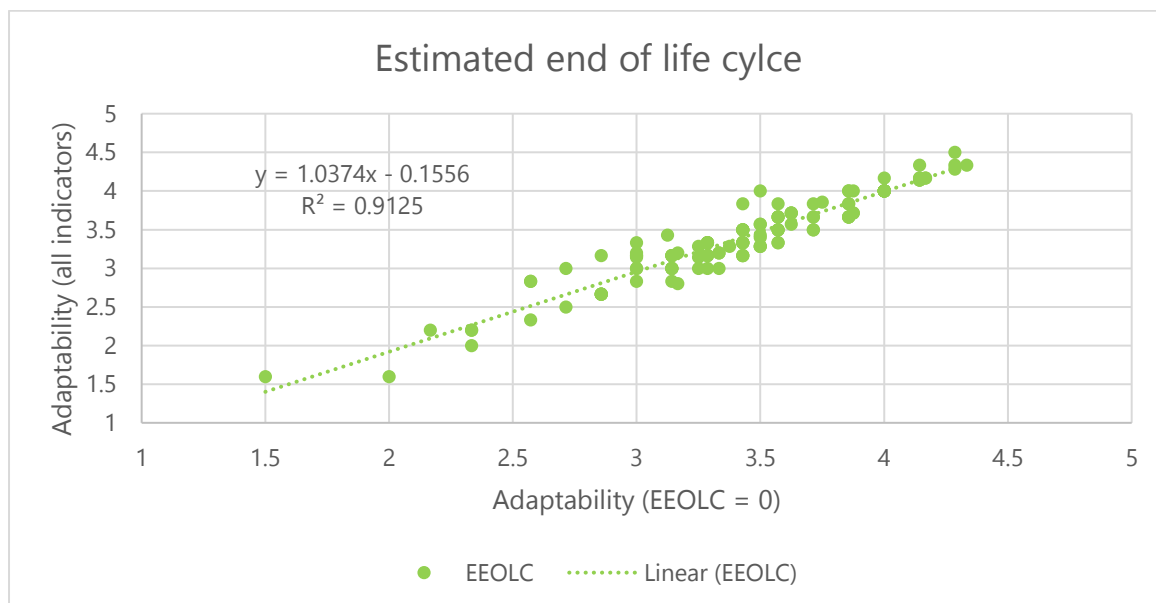


Figure 47 Linear regression for EEOLC, using OAT technique

## Urgency

The resulting linear regression plot for urgency can be found in Figure 48. Urgency has a small effect on the overall adaptability for the city of Dordrecht ( $R^2 = 0.9502$ ), because some neighbourhoods don't have urgency data. The overall effect of urgency on the outcome of adaptability is negative, due to quite some challenges regarding climate change in the Dordrecht area.

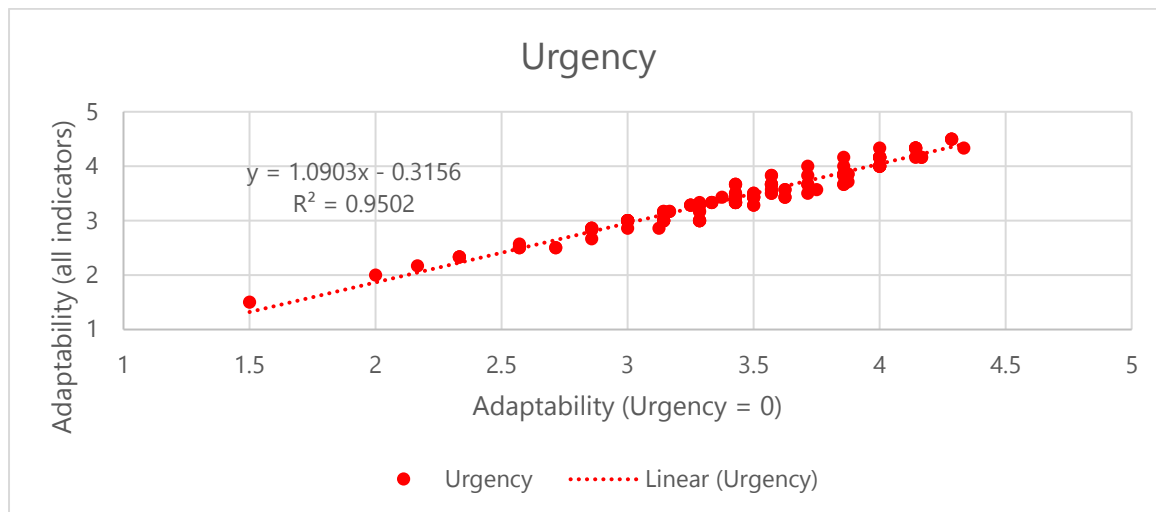


Figure 48 Linear regression plot for urgency, using OAT technique

## Historical city centre

The resulting linear regression plot for historical city centre can be found in Figure 49. Historical city centre has almost no effect on the overall adaptability in this case ( $R^2 = 0.9935$ ), due to only few neighbourhoods being assigned as historical city centre. The overall effect of historical city centre on the outcome of adaptability is negative, due to only assigning low adaptability in neighbourhoods that are in the historical city centre. You can also see that only few values in the high adaptability part of the graph are differing from the line of  $y = x$ , historical city centre has low adaptability.

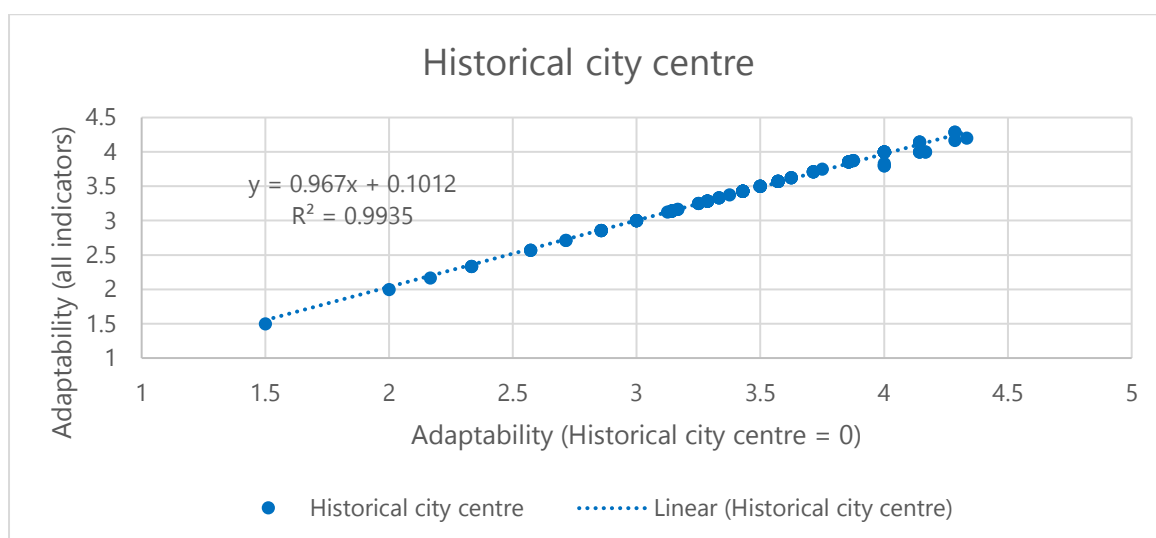


Figure 49 Linear regression plot for historical city centre, using OAT technique



## Results

In Table 12 the results of the sensitivity analysis are presented. The contribution of each indicator to the average adaptability of the whole dataset is calculated (total is 100%), and the effect of each indicator on the adaptability, does it improve the average adaptability of the dataset, is it neutral or negative.

Table 12 Summary of findings from sensitivity analysis

Indicator that is changed	Contribution of each indicator (%)	Effect on adaptability (positive/neutral/negative)
Percentage buildings	13,8	positive
Percentage water	19,8	neutral
Percentage green	22,3	positive
Soil type	6,7	negative
Main cables and pipes	3,7	negative
Planned works	14,0	negative
EEOLC	12,0	neutral
Urgency	6,8	negative
Historical city centre	0,9	negative

From the sensitivity analysis can be concluded that for the municipality of Dordrecht percentage green (22,3%), percentage water (19,8%), planned works (14%), percentage buildings (13,8%) and estimated end of life cycle (12%) are the most important indicators for the average adaptability of the municipality of Dordrecht. This is due to having data for all neighbourhoods for those indicators and these indicators having broad distributions. On the other hand historical city centre (0,9%), main cables and pipes (3,7), soil type (6,7%) and urgency (6,8%) are least important indicators. Some of these indicators don't have data for all neighbourhoods, or only for few, other have a very narrow distribution. From this sensitivity analysis cannot be deduced that indicators are not important on neighbourhood level, for example historical city centre is very important when looking at a neighbourhood in this centre, but has low impact on the average adaptability of Dordrecht.

Another thing that can be concluded from sensitivity analysis for this case is that, percentage buildings and percentage green have positive outcome on the average adaptability of this area, while soil type, main cables and pipes, planned works, urgency and historical city centre have negative outcome.

## F. THE THREE PS

The three Ps is a method in which adaptability can be determined in a more structured way. The Ps consist of physical characteristics, property and process, which will be explained in more detail below. Furthermore some experimentation with available data is done to look at possible methods to determine the indicators.

### Physical characteristics

Physical characteristics, or neighbourhood type, can be used to predict the adaptability of a neighbourhood or building block. When the neighbourhood type is know, you are able to predict the amount of space available, percentage green and buildings types within a neighbourhood, these are indicators that all have an impact on adaptability. So neighbourhood type can be coupled to adaptability.

Neighbourhood types can be determined using Spacematrix, this method uses densities to determine neighbourhood type. The following densities are used floor space index (FSI) and ground space index (GSI). The Spacematrix method and its variables will be explained below (Berghauser Pont & Haupt, 2009).

#### Building Intensity (FSI)

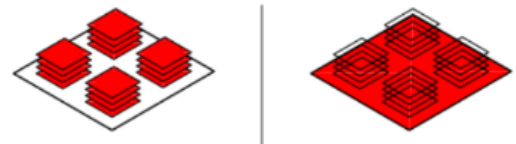
FSI reflects the building intensity independently of the programmatic composition and is calculated as follows for all levels of scale as described earlier:

$FSI_x = F_x / A_x$  where,

$F_x$  = gross floor area ( $m^2$ )

$A_x$  = area of aggregation  $x$  ( $m^2$ )

$x$  = aggregation (lot (l), island (i), fabric (f), or district (d))



#### Coverage (GSI)

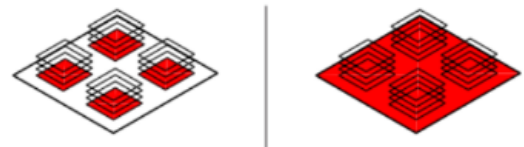
GSI, or coverage, demonstrates the relationship between built and non-built space and is calculated as follows for all levels of scale as described earlier:

$GSI_x = B_x / A_x$  where,

$B_x$  = footprint of ( $m^2$ )

$A_x$  = area of aggregation  $x$  ( $m^2$ )

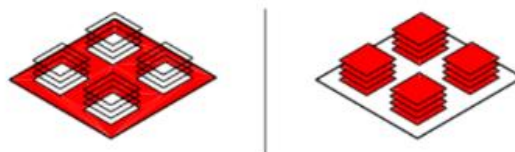
$x$  = aggregation (lot (l), island (i), fabric (f), or district (d))



#### Spaciousness (OSR)

The variable OSR, or spaciousness, is a measure of the amount of non-built space at ground level per square metre of gross floor area. This figure provides an indication of the pressure on non-built space. If more floor area is developed in an area (with the same footprint), the OSR decreases and the number of people who will use the non-built space increases. The unit of OSR is  $m^2/m^2$ .

$OSR = (1 - GSI_x) / FSI_x$

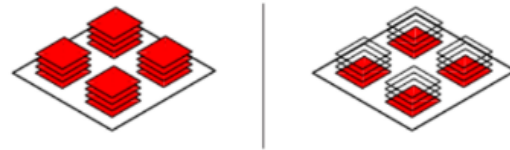


## Building height (L)

The average number of storeys (or layers),  $L$ , can be arrived at by ascertaining the intensity and coverage or, FSI and GSI, for the aggregation  $x$ . If more floor area is developed in a certain area, without changing the footprint,  $L$  will increase.

If the building height should remain constant, FSI and GSI have to increase.

$$L = \text{FSI}_x / \text{GSI}_x$$



If  
then

So when FSI and GSI are known for an aggregation the building type of this aggregation can be determined, using Figure 50, this figure is based upon samples from different types of Dutch building blocks.

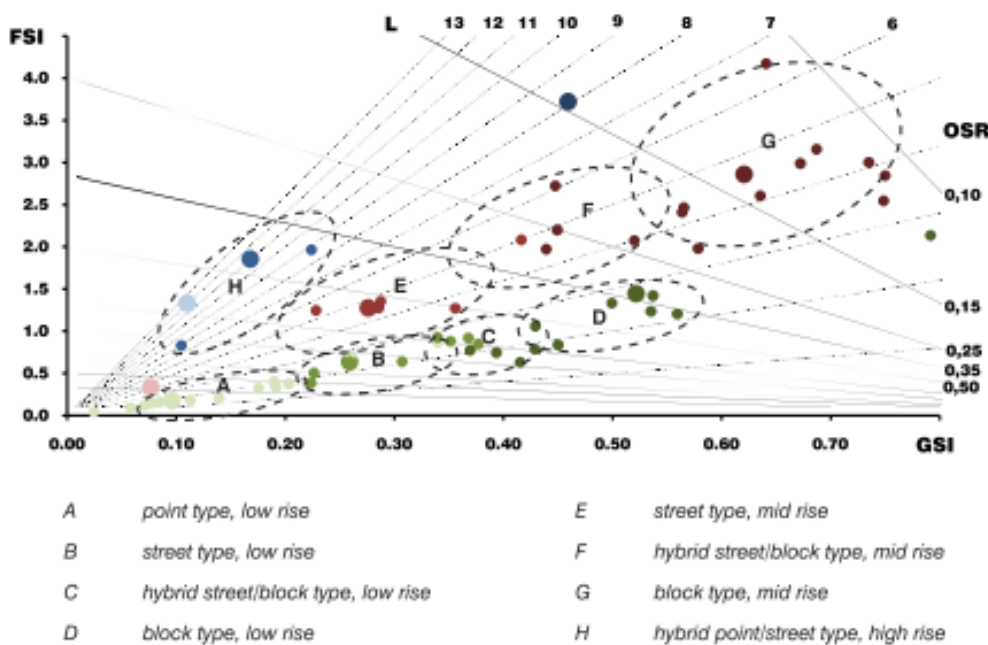


Figure 50 Different buildings types for combinations of densities, this figure is based upon Dutch samples

Using the BAG, the Spacematrix densities can be determined, but it is important to determine these densities on the proper scale. Big enough, so emergent patterns still hold but also small enough to include only one building type in each aggregation. Therefore three methods are compared, using neighbourhood outlines, using a grid and using the streets.

## Neighbourhood outlines

The neighbourhood outlines are provided by the CBS and are based upon socio-economical characteristics. For the municipality of Dordrecht 147 neighbourhoods are identified. These outlines can be used as aggregation for determining FSI and GSI. But aggregations include different buildings types. These outlines are too large, but you might be able to determine the governing buildings type within a neighbourhood and work from there.

### Grid lines

Using a grid of 200m x 200m, you are able to look at smaller scales than neighbourhood outlines. This means it is more likely that a grid cell includes only one building type, problem is the grid breaks up the patterns that exist within the urban environment. While some grid cells might only include one building type others might include multiple, because of the breaking of urban patterns. This can give skewed results.

### Streets

The third and final method uses the streets to determine blocks of buildings, this, I think is the most promising way of breaking up the urban environment. This method is able to break up the urban environment in smaller parts and keeping emergent patterns. The buildings blocks that are created have most of the time the same building type and will probably give the best and most reliable results.

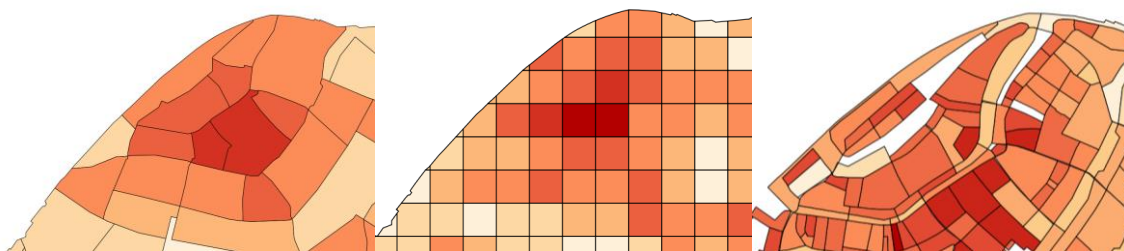


Figure 51 Examples of GSI for neighbourhood outlines (left), grid (middle) and based upon streets (right)

### Property

Property looks whether a particular plot is privately, semi privately, semi publicly or publicly owned. This gives an indication on what is possible, e.g. on public plots big works can be done such as WADI's or creating ways of water storage, on private plots you can't really do anything but you can motivate people to do things such as unpaving their gardens. When talking about housing associations huge opportunities might arise regarding matching on maintenance or redevelopment. Property gives an indication on the possibilities regarding climate change and so adaptability.

### Process

Process tries to incorporate when adaptability is possible, looking for example at matching and estimated end of life cycle, to give an indication on when opportunities might arise.

Using a combination of physical characteristics, property and process the full picture of adaptability can be expressed with limited data, efforts and indicators. So being a good (probably even better) alternative to the proposed indicators in this thesis.