Evaluating the potential of private adaptation in reducing pluvial flooding in urban areas: Case study in the management area of HHNK

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Abstract

As a result of climate change, the intensity and frequency of extreme precipitation events in the Netherlands increases. The impact of these precipitation events can be problematic, especially in urban areas. In these areas storm water can barely infiltrate into the soil and needs to be drained by the sewer systems. Due to the intensity of the precipitation events, the capacity of the sewer systems is insufficient and water accumulates on the surface, known as pluvial flooding. Since increasing the sewer capacity is expensive and time consuming, and a large share of urban areas is private property, it might be efficient to focus on adaptation on a private scale. Therefore, the Dutch water authority Hoogheemraadschap Hollands Noorderkwartier (HHNK) aims to motivate citizens in problem areas to take measures in order to reduce the risk of pluvial flooding. By temporarily storing the water on private properties, the pressure on the sewer system can be reduced, which might reduce the risk of pluvial flooding and possible damages. One potential tool HHNK considers to use is the so-called 'Waterlabel'. This label indicates whether a property buffers the storm water well (A) or that it discharges it directly to the sewer system or surrounding area (G).

The aim of this study was determine to what extent improvement of the rainwater retention capacity on private properties can contribute to the reduction of pluvial flooding in urban areas of the management area of HHNK. Firstly, the calculation method of the Waterlabel was evaluated based on expert judgement and scientific literature, to determine to what extent the label provides a decent indication of the rainwater retention capacity. It became clear that several improvements can be made to increase the representativeness of the label, such as inclusion of soil type and groundwater level. However, a balance should be maintained between a realistic representation of the water retention of a property and the purpose of informing people in order to improve water awareness. Therefore, the calculation of the Waterlabel on the website should be kept as simple as possible, in order for people to understand the principles. Secondly, to test the statement of the Waterlabel (2017) that a better Waterlabel (e.g. A or B) results in less pluvial flooding, a correlation between these two variables was determined. It appeared that there is a very weak negative correlation, meaning that when the Waterlabel increases the risk of pluvial flooding decreases, which is in line with the statement.

By combining the spatial pattern of bad Waterlabels (G) with that of a high pluvial flood risk, the locations where adaptation is most needed were identified. To determine which private adaptation measures are most effective, three neighbourhoods were selected and six adaptation measures were evaluated by executing simulations in the program RainTools. This tool simulates the effect of different measures on a property by using a water balance approach. The results of these simulations showed that lowering the garden, implementing of an infiltration crate and pervious pavement were the most effective measures.

The reliability of the obtained results might be influenced by the methods and data used. For the definition of pluvial flood risk, a map from the 'Klimaatatlas' was used that visualized the water depth after an extreme precipitation event. However, infiltration of water into the soil and drainage by the sewer system was not taken into account in the composition of this map.

Therefore, it is recommended to improve the water depth map, as well as the calculation method of the Waterlabel, before starting communication of HHNK with regard to private adaptation. Additionally, it appears that private adaptation can reduce the risk of pluvial flooding, however further research is needed to determine to what extent. Finally, it is recommended to exchange knowledge and experience between different water authorities and other organisations, to learn from each other and cooperate where possible.

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1. Introduction

1.1 Background

Figure 1 shows the flooding of excess storm water from the sewer system in Copenhagen, a sighting that will become more frequent due to the effects of climate change. The Intergovernmental Panel on Climate Change (IPCC) (2013) states that the frequency of extreme weather events, such as heat waves, storms and heavy precipitation, is increasing. The IPCC defines an extreme event as ''the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable''. The Netherlands experiences heavy precipitation twice as often compared to 1950, according to the Royal Netherlands Meteorological Institute (KNMI) (KNMI, 2017). Furthermore, the warmer the atmosphere, the more water vapour it can contain, which results in an intensification of 12% of the most extreme precipitation events for each degree of warming (KNMI, 2014). Van Oldenborgh & Lenderink (2014) stated that the hourly intensity of precipitation in the Netherlands has already increased by 20% over the last century.

Figure 1. Pluvial flooding as result of a cloudburst on July 2nd 2011 in Copenhagen (The City of Copenhagen, 2012)

Particularly in urban areas, the effects of extreme precipitation events can be problematic. An example of the impact of extreme precipitation is the storm in Copenhagen in July 2011, which resulted in insurance damages of 700 million euros and damages to infrastructure of about 65 million (EEA, 2012; Haghighatafshar, 2014). On this day, the largest single rainfall event since mid-1800 happened, which corresponded with 150 mm rain in just 2 hours (EEA, 2012). For reference, the average monthly precipitation in Denmark for July is 66 mm (Worldbank, 2017). The combined sewer system was far from capable of discharging this amount of water, which resulted in severe pluvial flooding (figure 1). Pluvial flooding is defined as ''flooding that results from rainfall-generated overland flow and ponding before the runoff enters any watercourse, drainage system or sewer, or cannot enter it because the network is full to capacity'' (Falconer et al., 2009). The water caused damages to buildings and infrastructure, and almost led to the evacuation of the two main hospitals (Haghighatafshar, 2014).

There are several factors in the urban environment that intensify the effects of extreme precipitation, resulting in a higher risk of pluvial flooding. Firstly, the large share of paved surface reduces the infiltration of precipitation into the soil (EEA, 2012; Voskamp & Ven, 2015). As can be seen in figure 2, on natural ground cover, approximately 50% of the precipitation infiltrates into the soil and only 10% is discharged as surface runoff, while in urban areas the surface run off increases to 55% (FISRWG, 1998). This runoff needs to be drained by the sewer system, which is the second factor that influences the risk of pluvial flooding. The majority of the sewer systems in urban areas cannot cope with extreme precipitation events (Revi et al., 2014; Voskamp & Ven, 2015). When the sewer systems were constructed, their capacity was based on the design rainfall at that moment, not taking into account an increase in rainfall intensity within the lifespan of these systems, which can be up to 100 years (Waters et al., 2003). Furthermore, the conventional way of handling storm water contributes to overloaded sewer systems, since the purpose of the design is to carry away the water as quickly as possible though concrete underground pipes. This means that no temporal buffering of water is possible in case of extreme precipitation. Additionally, expansion of the capacity is difficult, time consuming and expensive (EEA, 2012).

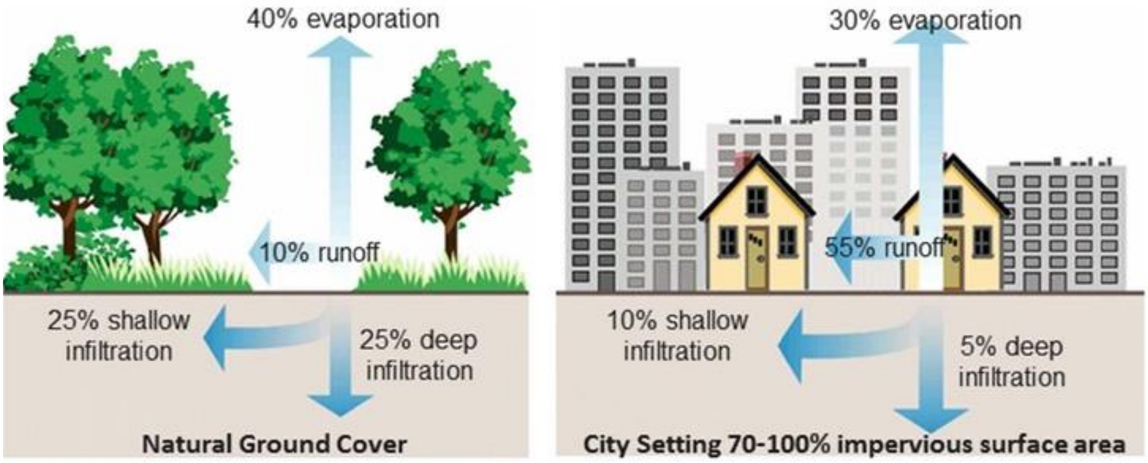

Figure 2. Effect of urbanisation on infiltration and runoff of storm water (FISRWG, 1998)

Another aspect that increases the vulnerability of urban areas to extreme precipitation, is the high density of people, infrastructure, and economic activity. Rovers et al. (2014) state pluvial flooding results in higher damages than several decades ago, due to more intensive and expensive design of the urban environment. In Europe, 75% of the population lives in cities and this will likely increase to 80% by 2020 (Carter, 2011; Voskamp & Ven, 2015). The high density of people and businesses increases the risk of damages and causalities in case of pluvial flooding. According to recent studies, water on the street due to pluvial flooding is a risk to public health due to the high concentration of pathogens (Man & Leenen, 2014; Sales Ortells & Medema, 2014) Summarizing, the characteristics of urban areas increase the chance of flooding, and the high density of people, assets and companies increase the risk of more and higher damages when pluvial flooding occurs (Carter, 2011).

As a response to the effects of climate change, there are two main approaches; adaptation and mitigation. As stated by Laukkonen et al. (2009) ''mitigation aims to avoid the unmanageable and adaptation aims to manage the unavoidable''. This means that mitigation aims to prevent or reduce the pace of climate change, by for example reducing greenhouse gas emissions (Bierbaum et al., 2007). Adaptation on the other hand, focuses on adapting the environment in such a way that the effects of climate change on this environment are reduced, for example by flood proof building or construction of water retention areas (IPCC, 2001). Numerous studies emphasize that a combination of mitigation and adaptation is required to cope with the effects of climate change. They state that a focus on solely mitigation will not be sufficient since part of the effects of climate change will be unavoidable (Bierbaum et al., 2007; IPCC, 2013). An adaptation-only approach would not be optimal either, due to the fact that adaptation measures cannot keep up with the effect of climate change, and will become too costly.

1.2 Problem Description

In the management area of the water authority Hoogheemraadschap Hollands Noorderkwartier (HHNK) the risk of pluvial flooding is growing problem as well. For instance, precipitation events in 1998 and 2012 caused damages up to half a million euros (''Wateroverlast in Noord-Holland na hevige stortbuien'', 1998). The management area of HHNK covers a large part of the province North-Holland, including the Wadden island Texel (figure 3). The responsibilities of the water authorities in the Netherlands are regional water management, flood protection and treatment of urban wastewater (Unie van Waterschappen, 2017; Lazaroms & Poos, 2004). With regard to urban wastewater, the municipalities are responsible to collect the water within the municipal boundaries. HHNK is responsible for transporting this water to the treatment plant or discharge to the surface water (M. Lamers, personal communication, May 9, 2017). In case of extreme precipitation, the capacity of the sewer systems might not be sufficient, resulting in pluvial flooding or overflow of contaminated water into the surface water. If HHNK receives too much water from the municipal system, it has to discharge the excess water to the surface waters which acts as storage. However, this storage capacity is decreasing as well, due to, increased reclamation of land, urbanization and subsidence. An example of this decrease in storage is visualized in figure 4 which shows the canals in and around the city of Hoorn in 1939 and 1989 (Schreijer et al., 2012).

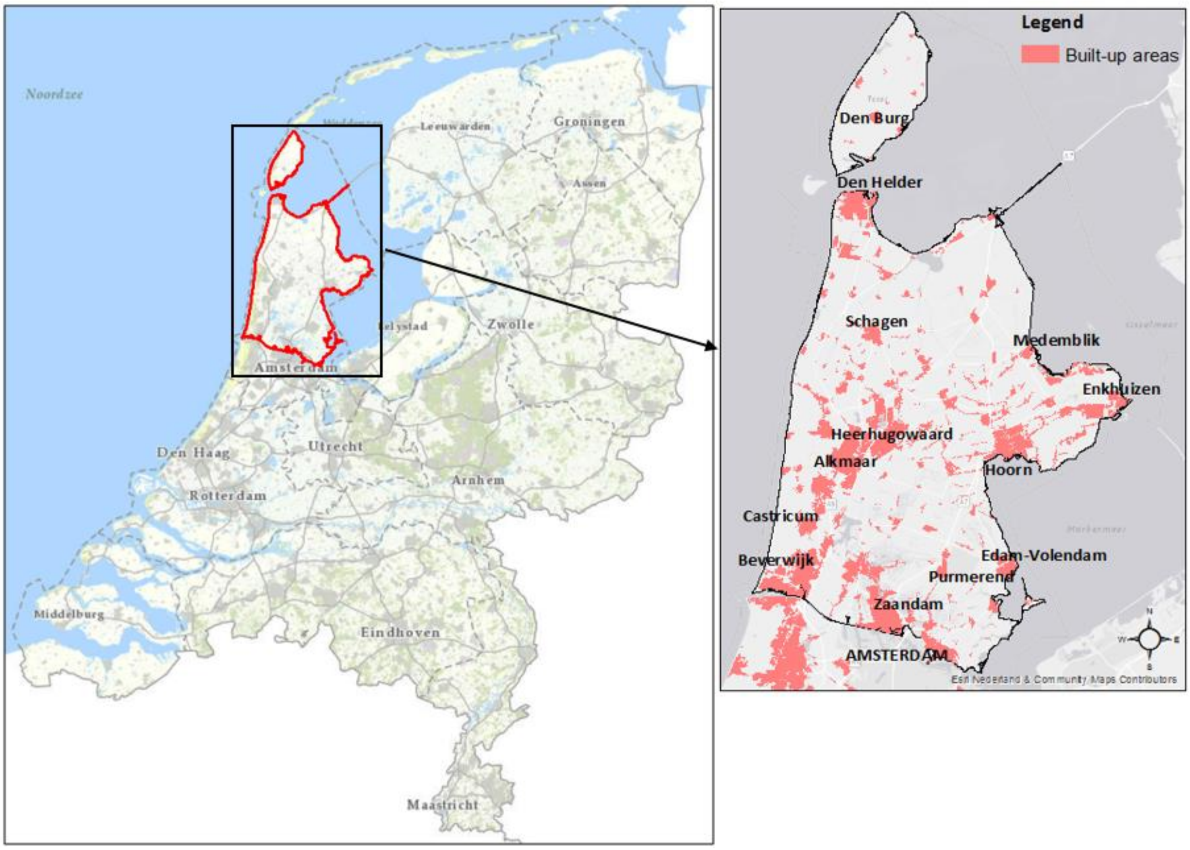

Figure 3. Management area of HHNK (HHNK, 2017a)

Figure 4. Canals in and around the city of Hoorn in 1939 and 1989 (Schreijer et al., 2012)

With regard to reducing the risk of pluvial flooding, the first option that comes to mind is to expand the capacity of the sewer systems in such a way that they can cope with the extreme precipitation events. However, there are several reasons why this is not the most optimal approach. As mentioned above, the majority of the sewer systems consists of underground concrete pipes and basins, which are very rigid. Enlarging these pipes in order to increase the capacity is extremely time consuming and costly, and is therefore considered as an inefficient approach (M. Lamers, personal communication, May 9, 2017; Stichting RIONED, 2007; Zhou, 2014). Moreover, due to the long lifespan of conventional sewer systems, the periods between technical (capacity) upgrades of the system are long, which decreases the flexibility of the system.

Therefore, HHNK aims to evaluate the potential of private adaptation in order to improve the buffer capacity of storm water within urban areas. Examples of private adaptation are: increasing the surface area of green space, or using a rain barrel to temporarily store water. This approach is chosen for several reasons. Firstly, realizing more storage areas or expanding existing storage areas in the proximity of cities is expensive or even impossible (K. Bruin-Baerts, personal communication, February 14, 2017). Secondly, a large share of urban areas is private property (Mees et al., 2015). For example, the city of Rotterdam consists for 80% out of private properties or properties owned by businesses. This reduces the influence of governmental organisations, such as the municipality or the water authority. Thirdly, increasing the buffer capacity within urban areas contributes to the Dutch National Delta Program, which aims to ensure that the flood risk management and spatial planning will be climate-proof and water-resilient by 2050 (Deltacommissaris, 2017). According to Albers et al. (2015) the Delta Program struggles with adaptation to extreme precipitation events, since this requires a local approach instead of a national strategy. This indicates that more insight is needed into policies on a local scale, such a private adaptation. Lastly, the Organisation for Economic Co-operation and Development (OECD) concluded in 2014 that the water awareness in the Netherlands was lacking. They stated that Dutch citizens take water security for granted, which results in an underestimation of the risks of (pluvial) flooding. If HHNK decides to communicate to citizens with regard to private adaptation, this might improve the water awareness, since people will be informed about the risks of pluvial flooding and how they can reduce these risks (K. Bruin-Baerts, personal communication, February 14, 2017).

To stimulate private adaptation, HHNK considers to use 'Waterlabel' as communication tool. The Waterlabel was conceived in 2014 by the Dutch knowledge institute 'De Waag', and ranges from A (high/good) to G (low/bad) (Waterlabel, 2017). When a property has a low Waterlabel, such as F or G, this means that it discharges storm water directly to the sewer system or the surrounding environment (figure 5). When a property has a high Waterlabel, such as A or B, it means that it buffers the storm water on the property, which reduces the pressure on the sewer system (Waterlabel, 2017). The classification of the labels is based on points that are awarded to different characteristics of the property, such as the amount of green space in the garden, the way storm water is discharged and the presence of a rain barrel or façade garden.

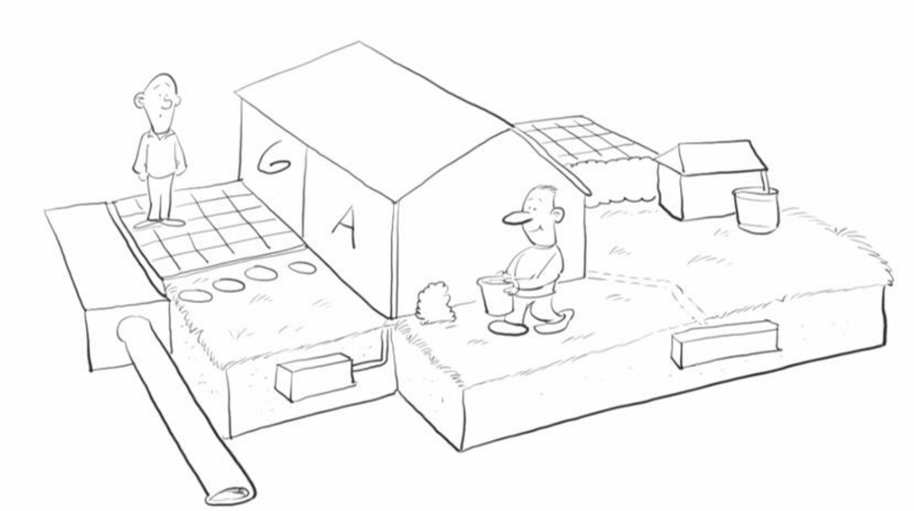

Figure 5. Animation of the difference between a property with a Waterlabel G and a property with a Waterlabel A (Waterlabel, 2017).

Since the effects of climate change are getting more visible, there is a growing demand for information with regard to the effectiveness of adaptation, especially in urban areas (Albers et al., 2015). However, the available scientific literature with regard to this subject is still limited. Due to negative impacts by extreme precipitation or heat waves, an increase in climate adaptation plans composed by municipalities or other governmental organisations can be distinguished (Rovers et al., 2014; City of Rotterdam, 2013). However, knowledge with regard to the most optimal adaptation measures is lacking is deficient, resulting in a lack of or ineffective adaptation. Doria et al. (2009) state that the goal and definition of successful adaptation is often unclear. In addition, uncertainties related to the climate system, the impacts on society, and the effectiveness of adaptation hinder the implementation of effective measures according to Mees et al (2012). On a private scale additional aspects hamper adaptation, such as costs, and a lack of water awareness and information (Douglas et al., 2010). In the Netherlands, adaptation to water is not a new phenomenon, since this has been done for many centuries to keep the low-lying country dry. However, widening the perspective of policies and research to pluvial flooding, and other effects of climate change, seems complicated (Albers et al., 2015). The abovementioned Dutch National Delta Program makes a start by addressing climate adaptation, however this is still very general. Albers et al. (2015) state that the most important policies with regard to the effects of climate change require a local approach. This remains a scientific challenge, to which this study might contribute.

Since the Waterlabel is only recently developed, scientific evaluation of its potential or effect is lacking. One report is available, based on a case study of Nelen & Schuurmans. In this study students of the Utrecht University, Boon et al. (2016), evaluated the calculation method of the Waterlabel, as well as the water awareness of people. They concluded that the calculation method could be improved by using a water balance approach for the different storage capacities present on a private property, and by including the soil type. In addition, Boon et al (2016) stated that people lack the knowledge about which measures are most effective to implement on their property which hampers adaption. Nelen & Schuurmans took these results into consideration, and started to develop an improved calculation method for the Waterlabel. However, this method was not taken into considering in this study, since it was not finished yet.

1.3 Aim & Research Questions

The general aim for HHNK was to determine if the Waterlabel could be a useful tool to reduce the risk of pluvial flooding and to improve the water awareness of citizens. This study will focus technical aspects of the Waterlabel and the potential of private adaptation. Before HHNK uses the Waterlabel as communication tool, it is crucial to know the underlying calculations and assumptions of this tool. Furthermore, it is important to determine in which areas private adaptation is needed and to what extent it can reduce the pluvial flood risk. This study comprises two main sections, the first one focussing on the Waterlabel and the second one on private adaptation. The following main- and sub questions are composed:

''To what extent can improvement of the rainwater retention capacity on private properties, expressed by the Waterlabel, contribute to the reduction of pluvial flood risk in urban areas of the management area of HHNK?''

Waterlabel

1. What kind of method is used to calculate the Waterlabels, and what are the advantages and disadvantages of this method for determining the rainwater retention capacity of properties?
2. Is there a correlation between the spatial pattern of the Waterlabel and that of pluvial flood risk?

Private adaptation

3. In which areas is private adaptation most needed, based on the Waterlabel and pluvial flood risk?
4. Which measures are most effective in reducing the pluvial flood risk at three selected locations within the management area of HHNK?

1.4 Content of Report

In chapter two, the methods and materials used to answer the abovementioned questions will be explained. Thereafter, the results will be presented for each sub question. In chapter four the reliability and relevance of the results will be discussed, as well as the limitations of this study and recommendations for further research. Finally, conclusions will be drawn related to the main question and recommendations will be given with regard to the aim of HHNK.

2. Methodology

2.1 General Approach

Following the sequence of the main and sub-questions stated above, the set-up of this research is visualized in figure 6. In this chapter the methods and data used in this study are discussed. Since the aim was to evaluate the potential of the Waterlabel as communication tool for HHNK, the first part focuses on the details of the Waterlabel. The calculation method is evaluated, as well as the correlation between the spatial pattern of the Waterlabels and that of pluvial flood risk. In order for HHNK to determine on which areas they should concentrate, focus areas are identified and the most effective private adaptation measures were determined.

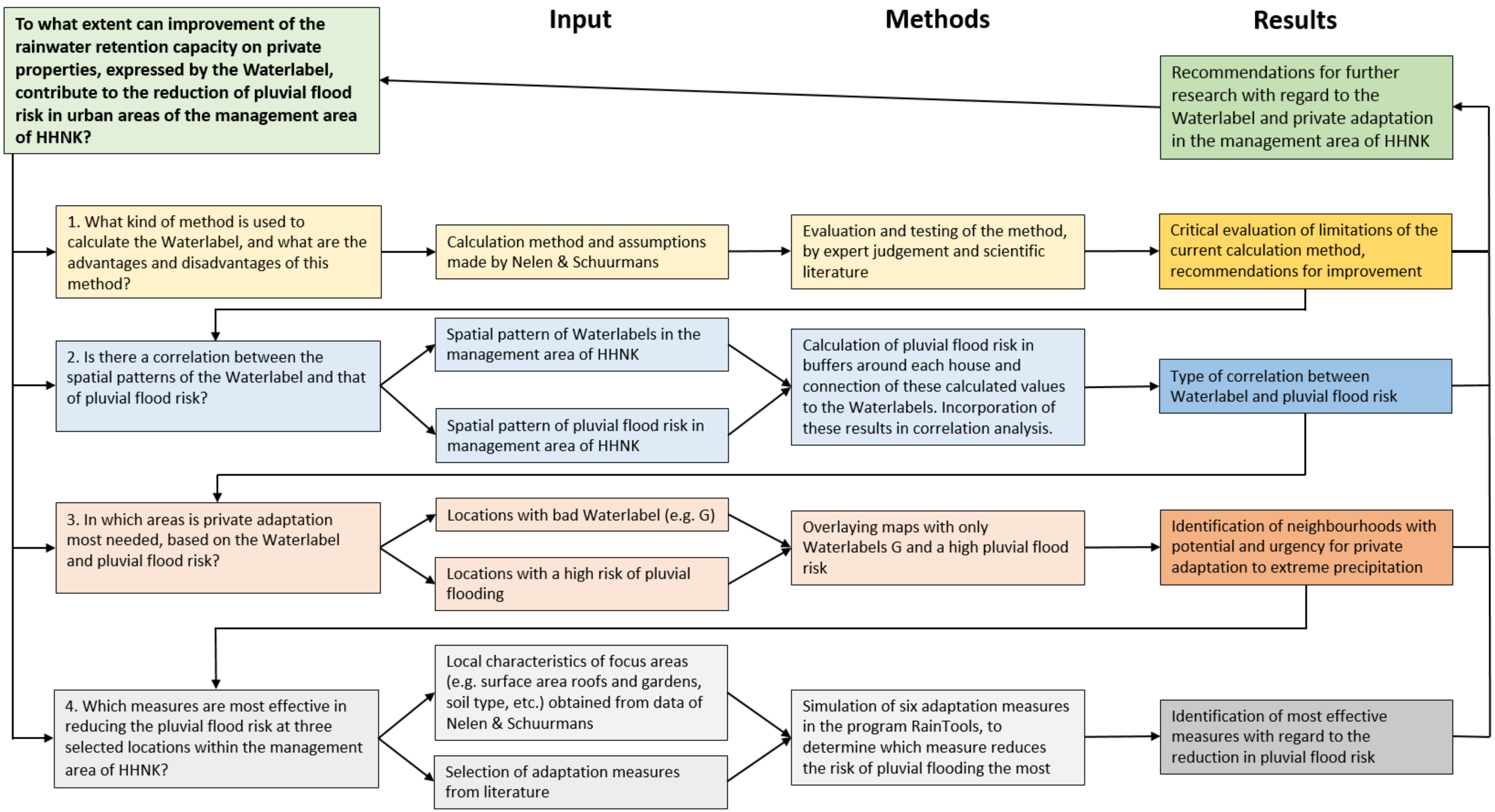

Figure 6. Set up of research

2.2 Waterlabel

2.2.1 Calculation Method

The method to calculate the Waterlabel was developed by Nelen & Schuurmans, in cooperation with De Waag and the municipalities of Amsterdam, Rotterdam and The Hague (Boon et al., 2016). The details of this calculation method were conducted by personal communication with L. Coppens, consultant urban water management, ecology and water quality at Nelen & Schuurmans. In order to gain insight into the method, some Waterlabels were manually calculated by the author, using aerial photographs and information about the sewer system. With these results, the different sections of the method were separately evaluated.

According to L. Coppens, it was necessary for Nelen & Schuurmans to make several assumptions to calculate the Waterlabels for the whole management area of HHNK. In order to get a substantiated evaluation of these assumptions and the general calculation method, the study of Boon et al. (2016) and other scientific literature in combination with the author's own interpretation were used.

2.2.2 Correlation between spatial patterns of Waterlabels and pluvial flood risk

It is stated on the website of the Waterlabel that properties with a low Waterlabel (e.g. F or G) increase the risk of pluvial flooding in their direct environment during extreme precipitation events (Waterlabel, 2017). The explanation given for this statement is that these properties discharge all storm water directly to the sewer system or their environment. To determine whether this is the case, a correlation analysis was executed between the Waterlabels and the pluvial flood risk in the management area of HHNK. After determining the spatial patterns of the Waterlabels and the pluvial flood risk, a correlation between these variables was determined with the statistical program SPSS.

The spatial pattern of the Waterlabels was derived from the shapefile with the attached attribute table delivered by Nelen & Schuurmans. A shapefile is a data format that can be visualized in the Geographic Information System (GIS) programme, ArcMap. The attribute table contains all the underlying information used by Nelen & Schuurmans to calculate the Waterlabels: such as sewer type, surface of green space, and roof surface area. Each label category was visualized in a separate map, which resulted in seven maps, one with the A labels, one with the B labels, etcetera. Based on these visualizations, it became clear at which locations the good Waterlabels were located and which areas had bad Waterlabels.

Before the spatial pattern of the pluvial flood risk could be determined, this risk needed to be quantified. This was done by using a map that shows where water accumulates on the surface at the moment an extreme precipitation event of 100 mm in two hours ends (figure 7). This map is part of the so-called 'Klimaatatlas' (Climate Atlas), a map database provided by HHNK to provide information and stimulate cooperation with municipalities in order to increase climate-proof initiatives (HHNK, 2017b). The water depth map was composed by Nelen & Schuurmans who modelled the flow of water at the ground surface with a detailed hydraulic elevation model (3Di). To model the flow of water, the only input used was the elevation map with a resolution of 0.5 square metres. Drainage by the sewer system or infiltration into the soil was not taken into account (HHNK, 2017b).

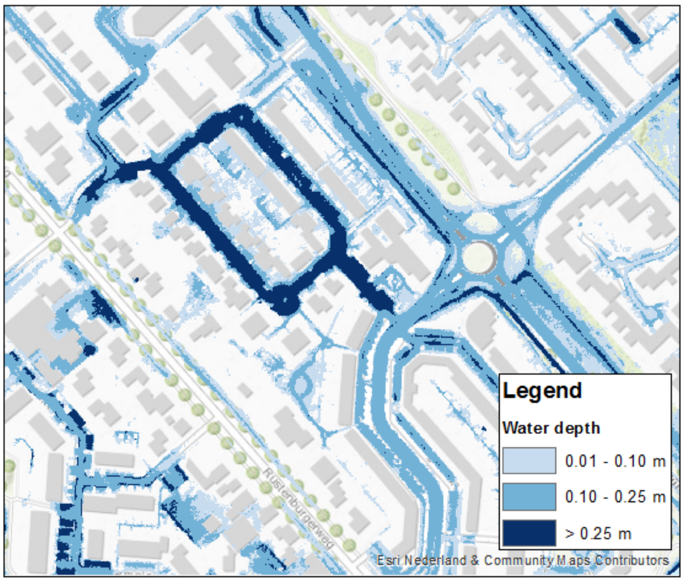

Figure 7. Visualization of the flooding map from the 'Klimaatatlas' in Arcmap, showing the water depth after a 100 mm rainfall event (Klimaatatlas, 2017)

To determine if the water depth correlates with the Waterlabel, buffers were composed around each house (figure 8). As can be seen, to each house the calculated Waterlabel is connected. The buffers are composed in order to calculate the mean water depth within these buffers, such that this value can be coupled to the Waterlabel of the house. With these results a correlation can be determine between these two variables.

Before calculating the mean water depth, two adjustments had to made to the water depth map. Firstly, the locations on the map where no water accumulates, contained no data. This means that these pixels would not have been taken into account when calculating the mean water depth, resulting in unreliable results. In order to incorporate these 'no data pixels' in the calculation, they had to be changed to the value zero by converting the whole map to a raster file. Secondly, the surface areas of the houses were identified as a water depth of zero as well. Since there is no water accumulation on the houses, the surface areas of the houses were subtracted from the buffer areas, to exclude them from the calculations (figure 9).

The initial approach was to calculate the mean water depth for all the buffers in the management are of HHNK, approximately 500.000. However, this was impossible due to the server capacity at HHNK. Another reason to deviate from this approach was the overrepresentation of certain water depths. As can be seen in figure 9, buffers overlap and when a water depth pixel is present in multiple buffers, this pixel will be overrepresented compared to a pixel that is present in only one buffer. This would have led to a bias in the correlation analysis between water depth and Waterlabels (dr. Maria Joao Ferreira Dos Santos, personal communication, July 10, 2017). Therefore, it was decided to focus only on the buffers in the urban areas, and to take a random sample from these buffers. To avoid overlap, this random sample was taken with the condition that the minimum distance between the buffers was 60 metres (figure 9). By using the 'Zonal Statistics as table' tool in Arcmap, the minimum, maximum, range, and mean water depth were calculated within each buffer. Due to large buildings, some overlap was still present. This overlap was eliminated by deleting the overlapping buffers from the sample. The resulting table with the calculated mean water depth for each buffer in the sample, and thus for each for each Waterlabel, was used as input in SPSS.

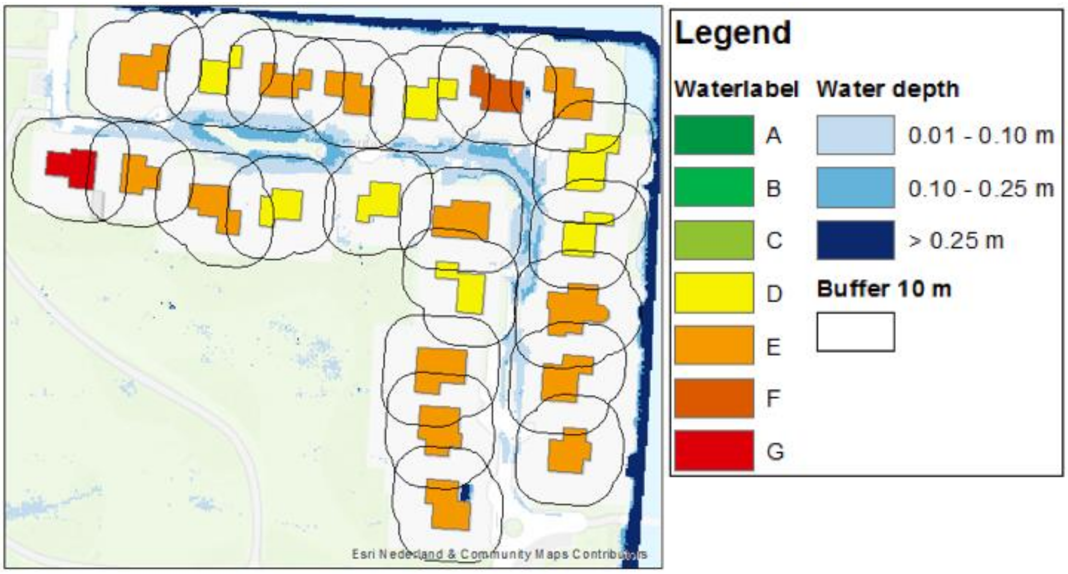

Figure 8. Visualization of the 10 meter buffers around the houses, in order to calculate the details of the water depth within these buffers.

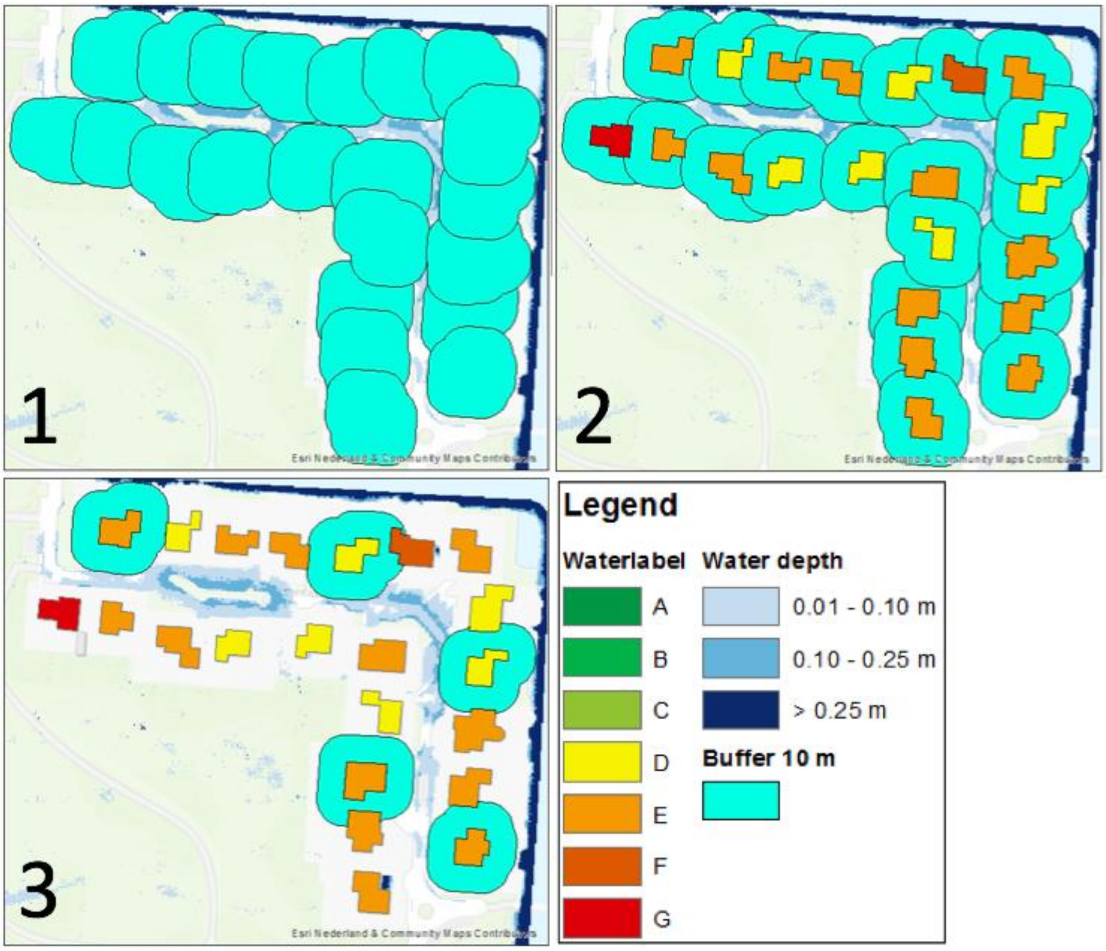

Figure 9. 1. Original buffers of 10 meter around each house, 2. Extraction of the surface area of the houses from the buffers, 3. Buffers from sample with the condition of a minimum distance of 60 meters between the buffers.

After exporting the data from ArcMap to SPSS, a scatter plot of the pluvial flood risk and the Waterlabels was created to determine whether the variables showed a monotonic relationship. In case of a monotonic relationship, either the variables increase/decrease in value together, or as one variable decreases the other increases (Leard Statistics, 2017). A monotonic relationship is one of the criteria for a Spearman's correlation. The other criterion is that the variables should be of ordinal, interval or ratio scale (Leard Statistics, 2017). Since the Waterlabel has an ordinal scale, e.g. the order of the classes is important but the difference between the classes is not exactly known, the Spearman's correlation was chosen to determine the correlation between the pluvial flood risk and the Waterlabels (Stevens, 1946). To incorporate the Waterlabels into the correlation analysis, the labels were converted from letters to numbers, e.g. label G was converted to 1, F to 2, E to 3, etcetera.

2.3 Private Adaptation

If HHNK decides to stimulate private adaptation, it is important to know in which areas adaptation is most needed. By combining the water depth map and the Waterlabels, numerous focus areas were identified. Additionally, the most effective private adaptation measures were determined for three selected neighbourhoods.

2.3.1 Focus Areas

To determine at which urban locations private adaptation is most needed, several criteria were composed. To start with, the scale used for the focus areas is street level, since HHNK aims to operate on this level. Additionally, the focus areas should have a low Waterlabel (G). A low Waterlabel means that a property has a relatively low rainwater retention capacity, which indicates that there is potential for private adaptation measures to improve this retention capacity. However, a low Waterlabel does not automatically mean that a property has a high risk of pluvial flooding and vice versa, for example when a property with a low Waterlabel is situated on a higher elevation it might have no risk of pluvial flooding. Therefore, the focus should be on areas with a high pluvial flood risk and a low Waterlabel, the pluvial flood risk is again defined with the water depth map from the 'Klimaatatlas'. In this study a high risk of pluvial flooding is defined as a water depth of 25 cm or more at the end of the precipitation event of 100 mm in two hours. This threshold is based on the average height of sidewalks, 20 cm, and the statement of Rovers et al. (2014) that severe nuisance takes place at a water depth of 25-30 cm.

To identify the focus areas, a map was created in ArcMap with only the lowest Waterlabels (G), calculated by Nelen & Schuurmans. Thereafter, the water depth map was adjusted in such a way that it only showed the water depth of 25 centimetres or more. These two maps were combined, to identify the locations with low Waterlabels and a high risk of pluvial flooding.

2.3.2 Effective Measures

In order to stimulate private adaptation, it is important to determine which private adaptation measures are most effective in the area of focus. In this way, if communication would take place, specific measures can be recommended. Since pluvial flooding is caused by an exceedance of the capacity of the sewer system, this study defines an effective measure as a measure that improves the rain water retention capacity of a property in order to reduce or delay the discharge towards the sewer system in case of extreme precipitation (Falconer et al., 2009).

To get an indication of the most effective measures, it was decided to select three neighbourhoods where problems with regard to the sewer system capacity already occurred in the past. This selection was made from the already determined focus areas, based on expert judgement of HHNK and additional research on sewer systems (M. Lamers, personal communication, May 9, 2017). Furthermore, the locations were chosen in such a way that they each had a different soil type, to determine if this influences the effectiveness of the adaptation measures. To determine the effect of different adaptation measures, the simulation tool 'RainTools' was used. This tool was developed in 2015 by RIONED, a knowledge institute specialized in urban water management and sewer systems in the Netherlands (Stichting RIONED, 2017c). Since the software was still under development, a test version was used for this study. This tool was used because it can simulate the storage and flow of storm water in and between different components of a property (Stichting RIONED, 2017b). The visualization of a property is given in figure 10, the numbers represent the following components:

1. Substrate layer roof
2. Drainage layer roof
3. Infiltration measure
4. Cunette (layer of ground) around the infiltration facility
5. Upper layer impervious pavement
6. Cunette beneath the impervious pavement
7. Upper layer green surface
8. Cunette beneath the green surface

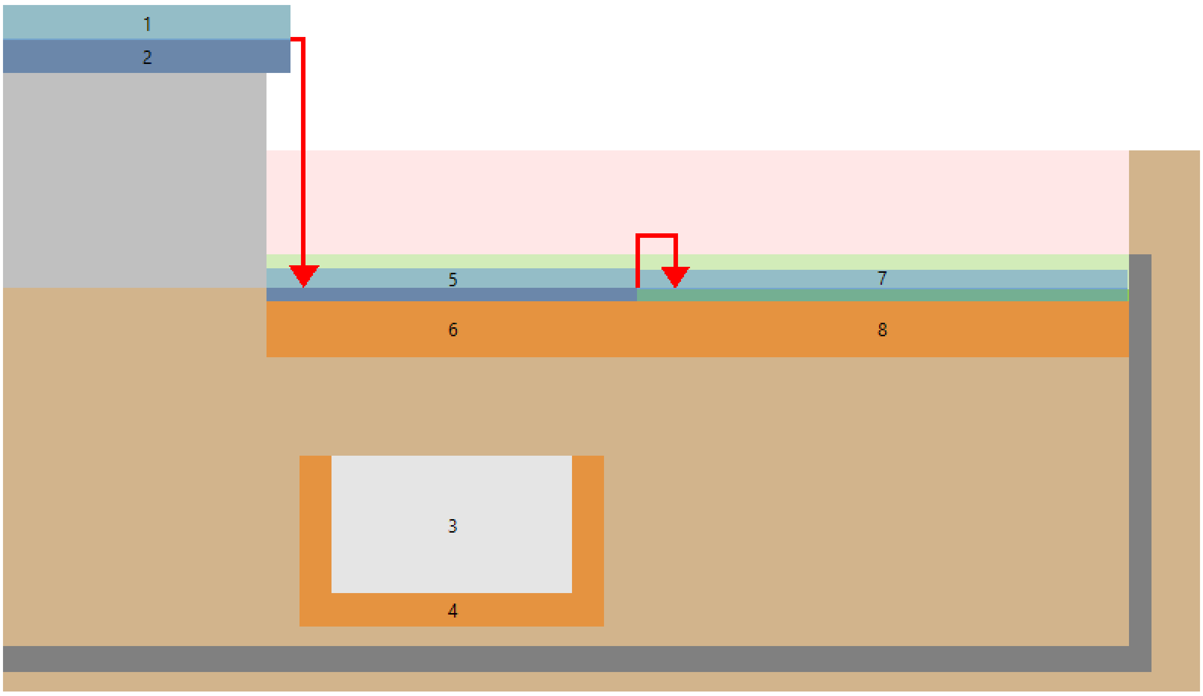

Figure 10. Lay-out of property with a green roof and 50 square metres of impervious surface and 150 square meters of green surface, RainTools

In figure 10 the property has a green roof, which will store water until the capacity is reached, then it will overflow onto the terrace, and the terrace will overflow into the garden. All different parameters can be adjusted, such as surface area of the roof and garden, capacity of the sewer system and the hydraulic conductivity of the soil.

In the results, the volume of storm water (m^3) in each component is calculated, using the following variables (RainTools, 2015):

- Inflow into the component
- Moisture content
- Evaporated volume
- Infiltrated volume: only applicable for components where infiltration is possible, such as grass
- Emptied volume: water that is emptied into another section
- Stored volume
- Overflow volume
- Exchanged volume: volume that is exchanged between different components
- Storage above ground level: for example, the storage on the terrace
- Nuisance: for example, when a threshold of 20 cm water on the terrace is set, this value indicates the amount of water that has exceeded this threshold.
- Emergency overflow: this variable can be turned on and off, and indicates the overflow into the sewer system when the water on the terrace or grass reaches a certain threshold

With regard to the amount of precipitation, one can choose between precipitation series, regular or extreme precipitation events. For the simulations in this study an extreme precipitation event of 79 mm in 3 hours was used, which has a probably of once in 100 years (Stichting RIONED, 2017b).

The input needed for RainTools with regard to the characteristics of the property was derived from the data of Nelen & Schuurmans. They calculated the characteristics of properties in order to determine the Waterlabel. Since RainTools can only simulate on a property level, the 'average property' was calculated for each selected neighbourhood. The following components were used to determine the 'average property' of each neighbourhood:

- Roof surface area
- Garden surface area
- Surface area of green space
- Surface area of impervious surface

In Excel the average values for all these components were calculated, to determine one 'average property' for each of the three neighbourhoods. Some additional information was needed for the simulations, such as sewer system capacity, elevation and soil type. The capacity of the sewer system was determined by expert judgement of HHNK and literature of RIONED (M. Lamers, personal communication, May 9, 2017; Stichting RIONED, 2015). The soil types were derived from the so-called ''DINO-loket'', which is the online open data portal of the Geological Survey of the Netherlands (DINO-loket, 2017).

Based on the simulation options in RainTools and the available data from Nelen & Schuurmans, a selection of private adaptation measures was made from literature and information platforms that stimulate adaptation to climate change, such as 'Amsterdam Rainproof' and 'Huisje, Boompje, Beter' (Rainproof, 2017b; Huisje Boompje Beter, 2017). Criteria for the selection were that the measures could be incorporated into RainTools and that the information needed could be derived from the data of Nelen & Schuurmans. For example, an intensive green roof is only possible on a flat roof, however the surface area of flat roofs cannot be derived from the data of Nelen & Schuurmans. Therefore, it cannot be simulated what will happen if an intensive green roof is implemented on the flat roof of the average property in the selected neighbourhood. Taking this into account, the following measures were selected:

1. Extensive green roof

Green roofs are buffering measures, that slow down and reduce the discharge towards the sewer system by temporally storing water and by evapotranspiration due to the vegetation (figure 11). There are two types of green roofs, extensive and intensive, in general the division between the types is based on the thickness of the substrate layer. However, Berndtsson (2010) stated that this division is rather inconsistent, since different articles use different classifications. On average, it can be stated that extensive green roofs have a substrate layer of up to 150 mm and intensive green roofs have a substrate layer of more than 150 mm (Berndtsson, 2010; Broks & Luijtelaar, 2015; Mentens et al., 2006). In this study only the effect of an extensive green roof will be evaluated, since these can be implemented on sloped roofs, while intensive green roofs are only possible on flat roofs (Mentens et al., 2006). With regard to the water retention capacity of green roofs, the same inconsistency is present among scientific articles. The retention capacity of a green roof depends on numerous variables, such as water content and thickness of the substrate layer, amount of precipitation, type of vegetation, and climate. Based on research of RIONED and the Climate Poof Cities, it is assumed that an extensive green roof as a water storage capacity of 15 mm (Rovers et al., 2014).

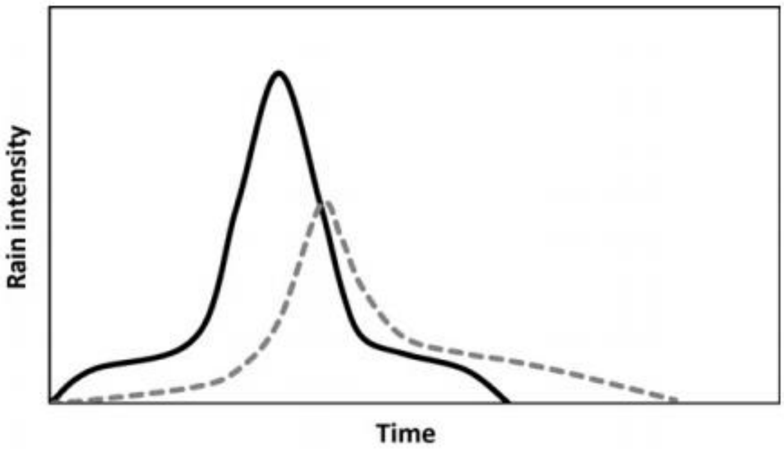

Figure 11. Runoff from a green roof (dashed line) as a result of a certain rainfall event (black line)

2. Rain barrel

The maximum capacity of a rain barrel is approximately 200 litres, which is used in the simulations, when this capacity is reached the excess water will overflow into the garden (Rainproof, 2017a). It was thus assumed that the rain barrel is completely empty at the start of the simulation.

3. Infiltration crate

Infiltration crates can store approximately 4 to 8 cubic metres, in this study an infiltration crate of 4 cubic metres is evaluated. In the simulations the terrace overflows into the infiltration crate instead of discharging the excess water to the sewer system.

4. Lowering the garden

By partly lowering the garden, a temporal water retention pond is created in case of extreme precipitation (figure 12). When the precipitation event ends, the water can infiltrate into the soil (Rianproof, 2017a). In the simulations it is assumed that the grass is lowered by 10 cm compared to the terrace.

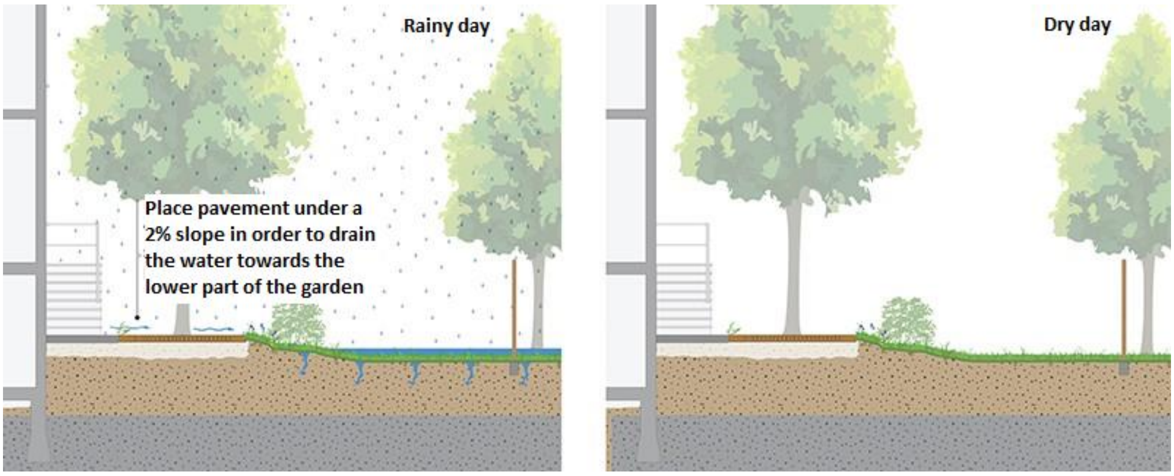

Figure 12. Lowering part of garden in order to temporarily store rainwater(Rainproof, 2017a)

5. Replacement of impervious pavement by pervious pavement

To increase the infiltration of storm water, normal pavement can be replaced by permeable pavement. As can be seen in figure 13, permeable pavement allows the water to infiltrate into the soil (Rainproof, 2017a). The amount of water than can be stored in the underlying soil will depend on the soil type, since this corresponds with a certain hydraulic conductivity. The hydraulic conductivity represents the ability of a soil to transmit fluid through the pore spaces or fractures (Klute & Dirksen, 1986). For the simulations in RainTools it is assumed that the present impervious pavement is replaced by pervious pavement with a permeability of 90 mm/hour (Febestral, 2017).

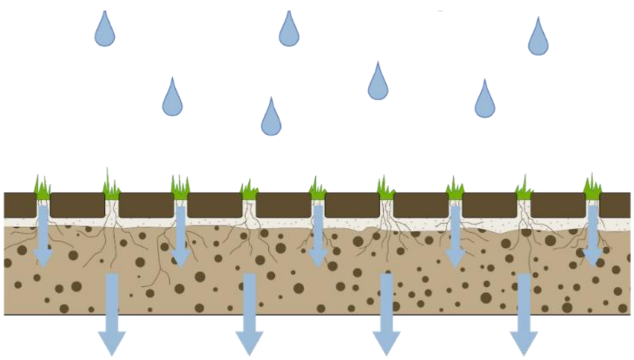
Figure 13. Permeable pavement (Rainproof, 2017a)

6. 40% impervious pavement and 60% grass

HHNK started a campaign to motivate people to increase the amount of green space in their garden. One of the advices was to have a maximum of 40% impervious pavement in the garden and 60% of green space. This measure will be simulated in RainTools as well, by adjusting the surface areas of impervious pavement and grass.

3. Results

3.1 Waterlabel

3.1.1 Calculation Method

The method used to calculate the Waterlabel is visualized in figure 14. As can be seen, the method is divided into a property, roof and garden part. Each part is divided into numbered sections. The more points awarded to a property, the better the Waterlabel will be, as can be seen in section 10. How these points are awarded, is explained in this paragraph. The method will be discussed based on hypothetical values, which are put in the green marked cells (figure 14). The yellow cells visualize the output (figure 14). As mentioned before, Nelen & Schuurmans had to make several assumptions in the calculation of the Waterlabels for HHNK. These assumptions will be discussed at the end of this paragraph.

Input
Result

			Input	unit	Restrictions	Input (%)	Max points	Points per section		Points in proportion	
Property	1	Roof surface house	100	m²	0 < X	67%					
		Roof surface shed	50	m²	0 < X	33%					
		Total roof surface	150	m²		65%					
	2	Backyard	60	m²	0 < X	75%					
		Front yard	20	m²	0 < X	25%					
		Total yard surface	80	m²		35%					
		Property	230	m²							
Roof	3	Storage roof house	10	m²	0<X<roof surface house	10%	50	3.33333			
		Storage roof shed	0	m²	0<X<roof surface shed	0%	50	0			
	4	Discharge roof house	Separate system		list below	40%	90	24			
		Discharge roof shed	Garden		list below	100%	90	30			
					Combined system	0%			57.333	37	5
					Separate system	40%					
					Infiltration sewer	100%					
					Garden	100%					
			Input	unit	Restrictions		Max points	Points per section			
Garden	6	Green surface backyard	20	m²	0 < X < backyard	33%	100	24.99996			
		Green surface front yard	0	m²	0 < X < front yard	0%	120	0			
									25	9	7
	8	Rain barrel	100	L	0 < X		20	5		5	
		Facade garden	yes		yes/no	100%	15	15		15	
					yes	100%					
					no	0%					

Total	Waterlabel	
66.0	C	9

Classification

100.0		A	10
80.0	80 - 99	B	
60.0	60 - 79	C	
40.0	40 - 59	D	
20.0	20 - 39	E	
10.0	10 - 19	F	
	< 10	G	

Table 1. Calculation method Waterlabel (L. Coppens, personal communication March 6, 2017)

Property

The first block focuses on characteristics of the property, section 1 describes the characteristics of the roofs on the property and section 2 addresses the garden areas (table 2).

			Input	unit	Restrictions	Input (%)
Property	1	Roof surface house	100	m²	0 < X	67%
		Roof surface shed	50	m²	0 < X	33%
		Total roof surface	**150**	m²		65%
	2	Backyard	60	m²	0 < X	75%
		Front yard	20	m²	0 < X	25%
		Total yard surface	**80**	m²		35%
		Property	**230**	m²		

Table 2. Property part of the calculation of the Waterlabel

As can be seen in table 1, the hypothetical property has a roof surface area of 100 square metres for the house and 50 square metres for the shed. These values of the roof surfaces are converted to percentages in such a way that the total roof surface area is 100%. This result in 67% roof surface of the house and 33% roof surface of the shed. The same is done for the front and backyard, in section 2 (75% backyard and 25% front yard). The total surface area of the property is calculated by adding up the total surface of the roofs and gardens, in this case 230 square metres. This 230 square metres is 100%, which is divided between the total surface area of the roofs (65%) and the gardens (35%). These percentages are calculated in order to weigh the implemented measures in section 3 and 4.

Roof

In this part, the characteristics of the roofs are addressed. In section 3 (table 3) the storage of the roofs is calculated. Section 4 contains the information with regard to the type of discharge. In section 5 the awarded points for the roof storage and type of discharge are added.

			Input	unit	Restrictions	Input (%)	Max points	Points per section		Points in proportion	
Roof	3	Storage roof house	10	m²	0<X<roof surface house	10%	50	3.33333			
		Storage roof shed	0	m²	0<X<roof surface shed	0%	50	0			
	4	Discharge roof house	Separate system		list below	40%	90	24			
		Discharge roof shed	Garden		list below	100%	90	30			
					Combined system	**0%**			57.333	37	5
					Separate system	**40%**					
					Infiltration sewer	**100%**					
					Garden	**100%**					

Table 3. Characteristics of the roof and type of discharge of the property

For section 3, the surface area of flat or very gently sloped roofs serves as input, since water storage is only possible on these types of roofs. In this example 10 square metres of the roof of the house has the capability of storing water. This 10 square metres is 10% of the total roof surface area of the house (100 m²). The amount of points achieved with roof storage depends on its proportion of the roof surface. To calculate the points awarded, the percentages from section 1 are used (table 2), in this case 67% of the total roof surface belongs to the house. Of this 67%, only 10% is capable of storing water and the maximum amount of points is 50. This results in the following formula to calculate the points achieved with roof storage:

$$\text{Points storage} = \text{percentage roof surface house} \times \text{percentage storage} \times \text{maximum points}$$

Result:
$$\text{Points storage} = 67\% \times 10\% \times 50 = 3.33$$

In section 4 the type of discharge is selected from the four possible options; combined system, separate system, infiltration system and infiltration into the garden. In a combined sewer system wastewater and storm water are transported and treated together, while in a separate system storm water is discharged directly to the surface water and only wastewater is transported to the treatment plant (Koukoui et al., 2015). The disadvantage of a combined system is that when the maximum capacity is reached, overflow of contaminated water into surface water occurs (Semadeni-Davies et al., 2006). Additionally, storm water is relatively clean compared to waste water, by combining these two types of water the polluted wastewater is strongly diluted, which complicates the treatment. The third option in the Waterlabel method is an infiltration sewer system, which is comparable to a separate sewer system. In both systems the storm water is collected and transported separately from wastewater, however, the infiltration sewer system uses pipes that are permeable. This makes it possible for the storm water to infiltrate into the soil. The last option is direct infiltration into the garden, which is accomplished by disconnecting the drainpipes. Since both the infiltration system as the infiltration into the garden are based on the process of infiltration, they are awarded with the maximum amount of points, which is 90. A separate sewer system gets 40% of the points and a combined system 0%. In this example the roof of the house discharges the water through a separate sewer system, and the roof of the shed discharges the water directly into the garden to infiltrate into the soil. The points are calculated as follows for the discharge from the roof of the house, the values of 67% and 33% are again the percentages from section 1 (table 1).:

$$\text{Points discharge} = \text{percentage roof surface house} \times \text{percentage discharge} \times \text{maximum points}$$

Result roof surface of the house:
$$\text{Points discharge} = 67\% \times 40\% \times 90 = 24$$

Result roof surface of the shed:
$$\text{Points discharge} = 33\% \times 100\% \times 90 = 30$$

In section 5 (table 3) all the points with regard to the roof are added up, this makes: $3.33 + 24 + 30 = 57.33$. This is multiplied with the proportion of the roof surface area as compared to the total property area. It can be seen in section 1 that this is 65% percent, which makes the total amount of points for the 'roof-section' in this case $57.33 \times 65\% = 37$.

Garden

The sections 6 till 8 focus on the garden of the property (table 4). In section 6 the green surface areas of the back- and front yard are filled out. In section 7 all the points with regard to the green surface are added up. Section 8 addresses the presence of possible adaptation measures, namely a rain barrel or a façade garden.

			Input	unit	Restrictions		Max points	Points per section			
Garden	6	Green surface backyard	20	m²	0 < X < backyard	33%	100	24.99996			
		Green surface front yard	0	m²	0 < X < front yard	0%	120	0			
									25	9	7
	8	Rain barrel	100	L	0 < X		20	5		5	
		Facade garden	yes		yes/no	100%	15	15		15	
					yes	100%					
					no	0%					

Table 4. Characteristics of the gardens of the property and the presence of adaptation measures

As can be seen in section 6, the backyard has 20 square meters of green surface, and the front yard none. The points awarded are calculated in the same way as for the measures with regard to the roof. The backyard covers 75% of the garden surface, and of that 75%, 33% is green. This results in the following formula to calculate the points achieved with green space:

$$\text{Points green space} = \text{percentage backyard} \times \text{percentage green space} \times \text{maximum points}$$

Result:

$$\text{Points green space} = 75\% \times 33\% \times 100 = 25$$

In section 7 all the points with regard to the green surface are added up, this makes 25 in total since the front yard has no green surface. This number is multiplied by the proportion of garden area in relation to the total property area. As can be seen in section 2 of table 2, this is 35% percent, which makes the total amount of points for this section $25 \times 35\% = 9$

In section 8 two measures can be added to the property, a rain barrel and a façade garden. A façade garden is a small strip of green against the façade of the house (figure 14). For the presence of a façade garden 15 points are awarded. A rain barrel can contribute a maximum of 20 points, which are calculated as follows:

$$\text{Points rain barrel} = \min\left(\frac{\text{capacity rain barrel}}{20}; 20\right)$$

Result:

$$\text{Points rain barrel} = \min\left(\frac{100}{20}; 20\right) = 5$$

By choosing the minimum value, the maximum amount of points is always 20 since this will be the minimum value when the capacity of the rain barrel exceeds 400 litres. In this example 5 points are awarded for the rain barrel, and 15 points for the presence of the façade garden.

Figure 14. Façade garden (Rainproof, 2017a)

Classification

In section 9 (table 5) all the points are added and the result is rounded on integers, which in this case is 66 points in total. This corresponds to a Waterlabel C as can be seen in section 10. By weighing the different components according to their proportion, the eventual label is not dependent on the size of the property. Additionally, when a property has no garden at all, the maximum amount of points that can be achieved is 150. In this way it is possible for all kinds of properties to get an A-label (L. Coppens, personal communication, March 6, 2017).

Classification

100.0		A	
80.0	80 - 99	B	
60.0	60 - 79	C	10
40.0	40 - 59	D	
20.0	20 - 39	E	
10.0	10 - 19	F	
	< 10	G	

Total	Waterlabel	
66.0	C	9

Table 5. Total points and classification of the Waterlabels

Data collection and assumptions Waterlabels HHNK

The abovementioned method is the basis of the website of the Waterlabel (waterlabel.net) and is based on the assumption that the input will be provided by the owner of the property. However, for the calculation of the Waterlabels in the management area of HHNK, Nelen & Schuurmans had to retrieve the details of the properties from public sources. To determine the surface areas of the properties, roofs and gardens the land register database was used. The amount of green space was derived from aerial photographs by using an algorithm that has the ability to identify the colour green. Since the calculations are on such a large scale, several assumptions had to be made (L. Coppens, personal communication, March 6, 2017). For example , it is unknown to Nelen & Schuurmans whether a property has a rain barrel or façade garden, so it is assumed that neither of these measures are present. Secondly, it is assumed that the type of discharge is the one that lies closest to the property and that the house and the shed have the same type of discharge. Making these assumptions was unavoidable, since it is impossible to know these details for each property.

3.1.2 Correlation between spatial patterns of Waterlabels and pluvial flood risk

Nelen & Schuurmans calculated approximately 500,000 Waterlabels for the management area of HHNK. The frequency of each Waterlabel is visualized in figure 15. It can be seen that the 'good' Waterlabels, such as A and B are barely present, and that the Waterlabel E is most frequent.

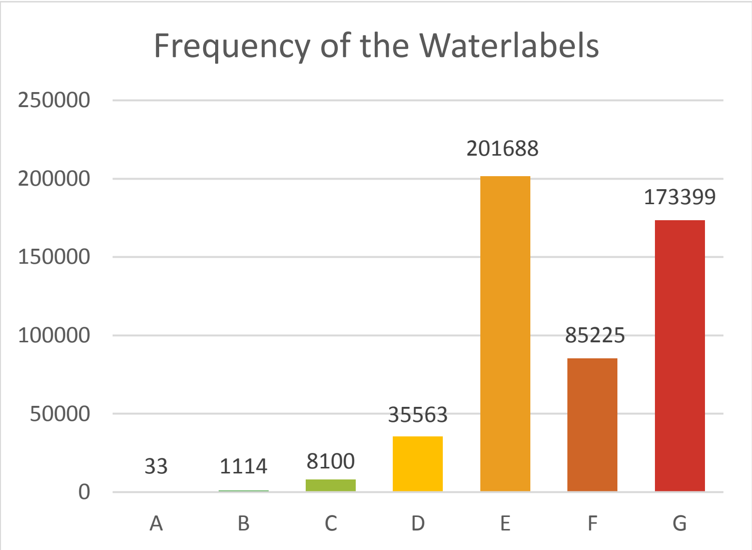

Figure 15. Frequency of the Waterlabel in the management area of HHNK based on the calculated Waterlabels by Nelen & Schuurmans.

To get insight into the spatial pattern of the Waterlabels, the different label categories are visualized one by one in ArcGIS (figure 16)[1]. It can be seen that the good Waterlabels (A and B) are mostly found outside of urban areas, where in general the properties have a relatively high amount of green surface. On the other hand, the bad Waterlabels (E, F and G) are mostly present in the urban areas.

[1] When this report is printed in black and white, the maps in appendix 1 might be better readable.

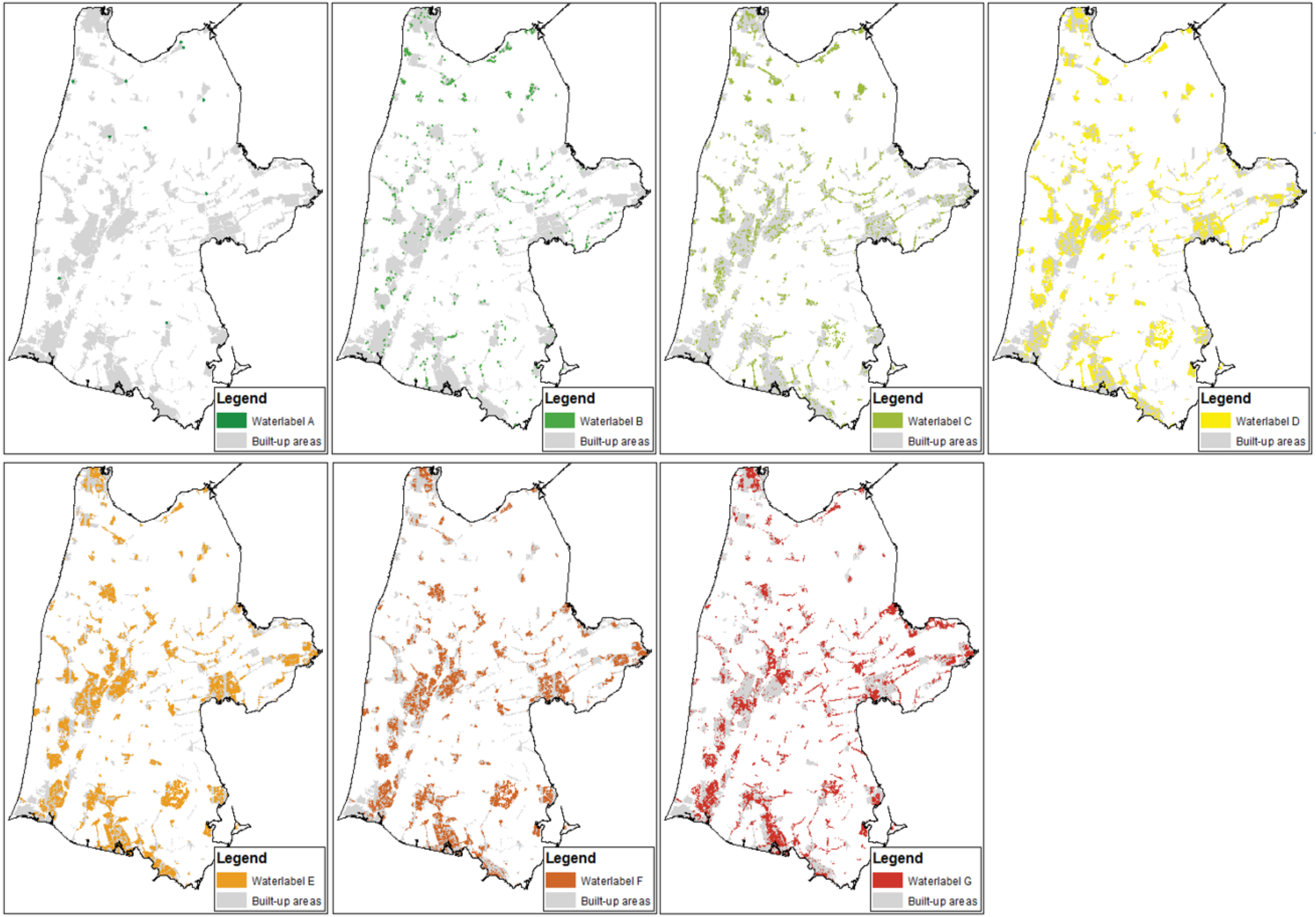

Figure 16. Spatial patterns of the different Waterlabels in the management area of HHNK

To determine whether the spatial pattern of the Waterlabel correlates with that of the pluvial flood risk, a Spearman's correlation is executed in SPSS. For the correlation, buffers of 10 meters were created around each house in order to calculate the mean water depth in each buffer. In this way, the mean water depth could be connected to the Waterlabel of the house. As input for the correlation, a sample of 10,000 buffers was taken from a total of 223,379 buffers in urban areas (figure 17). From the sample the overlapping buffers were extracted, which resulted in a sample size of 9443.

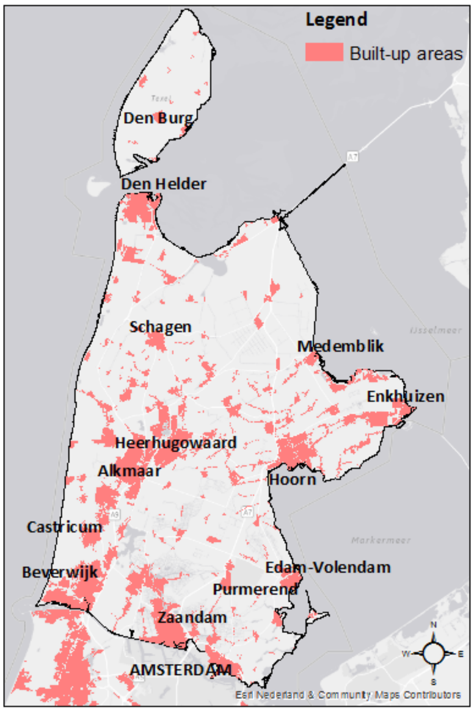

Figure 17. Urban areas of HHNK

Before executing the correlation analysis, a scatter plot was created to determine if the variables had a monotonic relationship. As can be seen in figure 18, the lower the Waterlabel, the higher the mean water depth. This is a case of a monotonic relationship, since one variable decreases (the Waterlabel) and the other increases (water depth) (Leard Statistics, 2017).

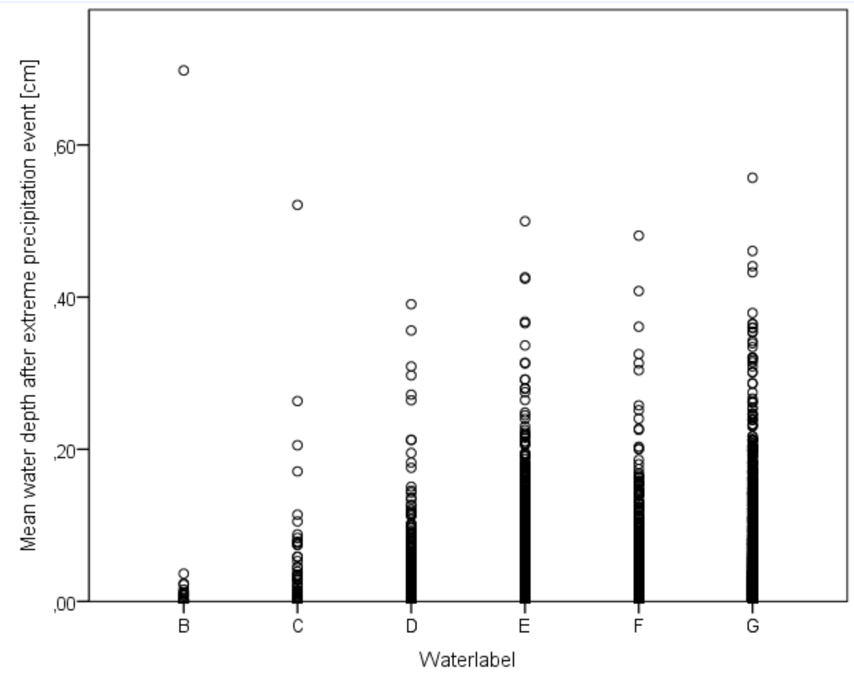

Figure 18. Scatterplot of relationship between the Waterlabel and mean water depth

The result of the Spearman's correlation is given in table 6. It shows that there is a very weak positive correlation between the Waterlabel of a house and the mean water depth in the buffer of 10 meters. This means that when the Waterlabel decreases (G is 1 and A is 7), the mean water depth increases. The correlation is significant, since the p-value (Sig. in the table) is less than 0.05.

Correlation Waterlabel and mean water depth			
			Mean water depth
Spearman's rho	Waterlabel	Correlation Coefficient	-,097**
		Sig. (2-tailed)	0.000
		N	9443
**. Correlation is significant at the 0.01 level (2-tailed).			

Table 6. Result of Spearman's correlation between Waterlabel and mean water depth

3.2 Private Adaptation

3.2.1 Focus Areas

The criteria for the focus areas were that they should be on street level, in an urban area and with a water depth of 25 cm or more combined with Waterlabels G. With this approach 17 streets were identified in the urban areas of HHNK, six of them are showed in figure 19 till 21, and the rest can be found in Annex 2.

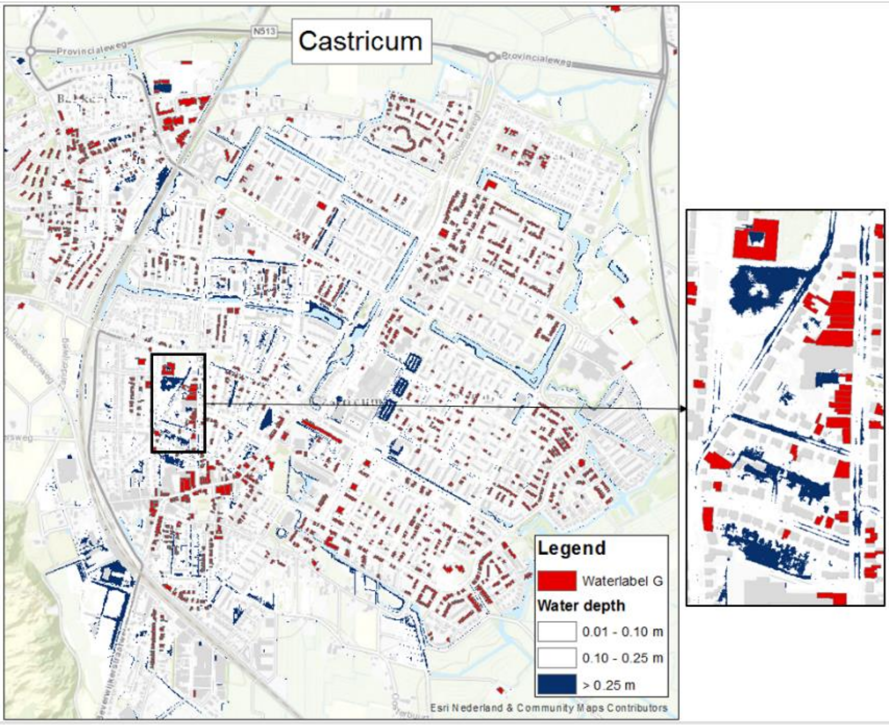

Figure 19. Street in Castricum identified as focus area based on low Waterlabels (G) and high pluvial flood risk

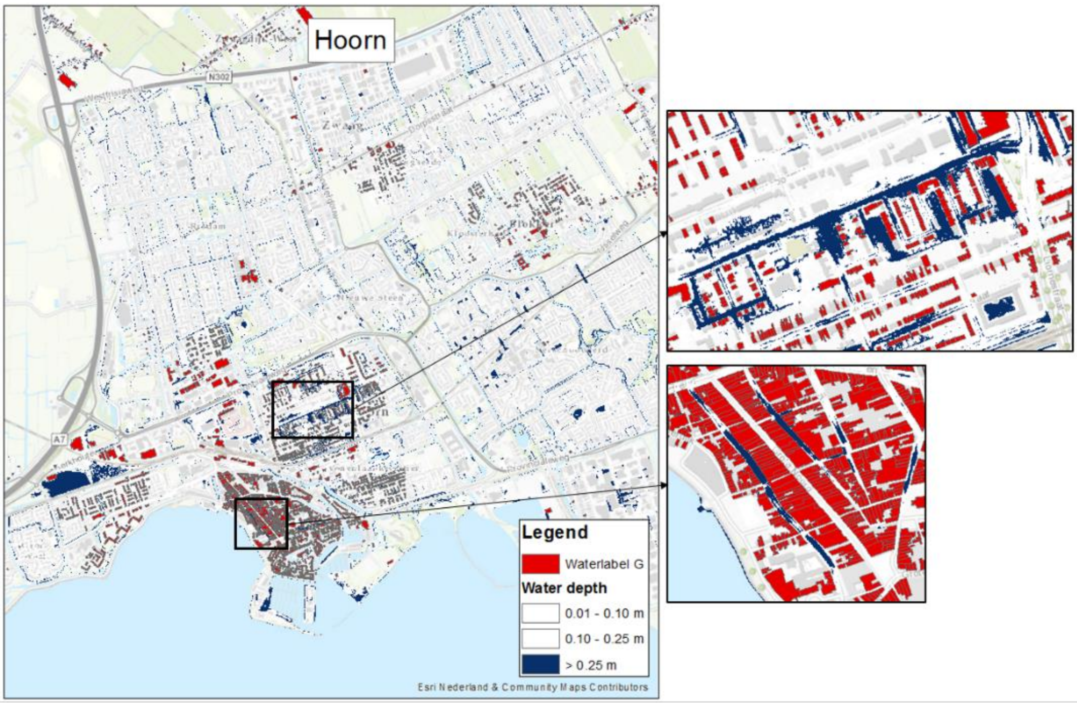

Figure 20. Streets in Hoorn identified as focus areas based on low Waterlabels (G) and high pluvial flood risk

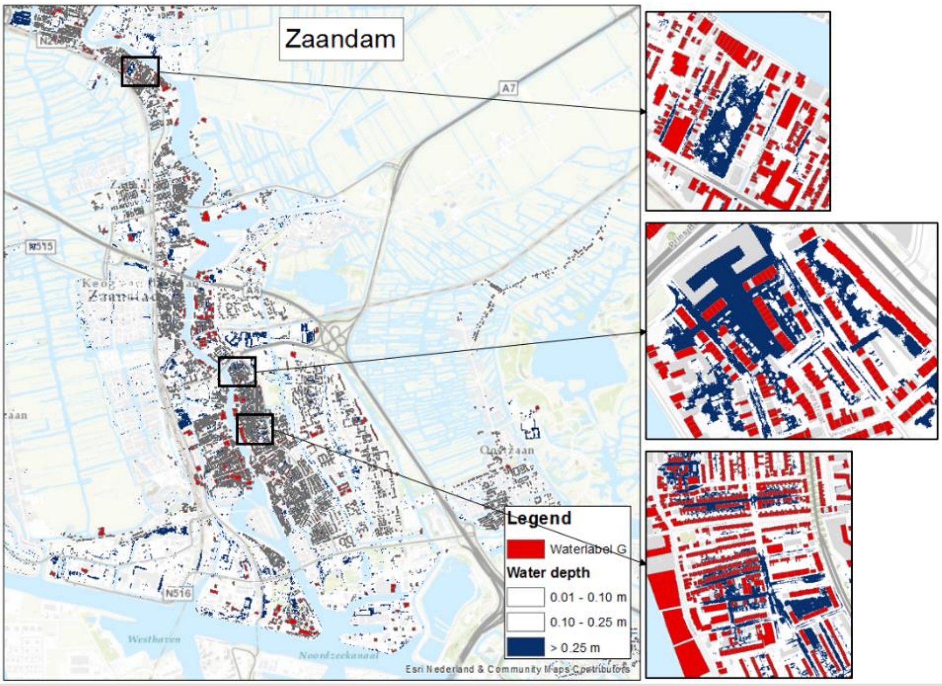

Figure 21. Streets in Zaandam identified as focus areas based on low Waterlabels (G) and high pluvial flood risk

3.2.2 Effective Measures

In order to determine the most effective measures, three streets are selected from the focus areas in the previous section. These streets are chosen based on expert judgement from HHNK with regard to bottlenecks in the sewer system and complementary studies. Firstly, the street in Castricum is selected (figure 22) because Nelen & Schuurmans has executed an extensive sewer system analysis for the municipality of Castricum (Nelen & Schuurmans, 2016). This analysis indicates locations where it is expected that the capacity of the sewer system is insufficient in case of extreme precipitation. In figure 22 the duration of water on the street is visualized for the chosen street in Castricum, in case of a precipitation event of 19.8 mm in one hour (Nelen & Schuurmans, 2016).

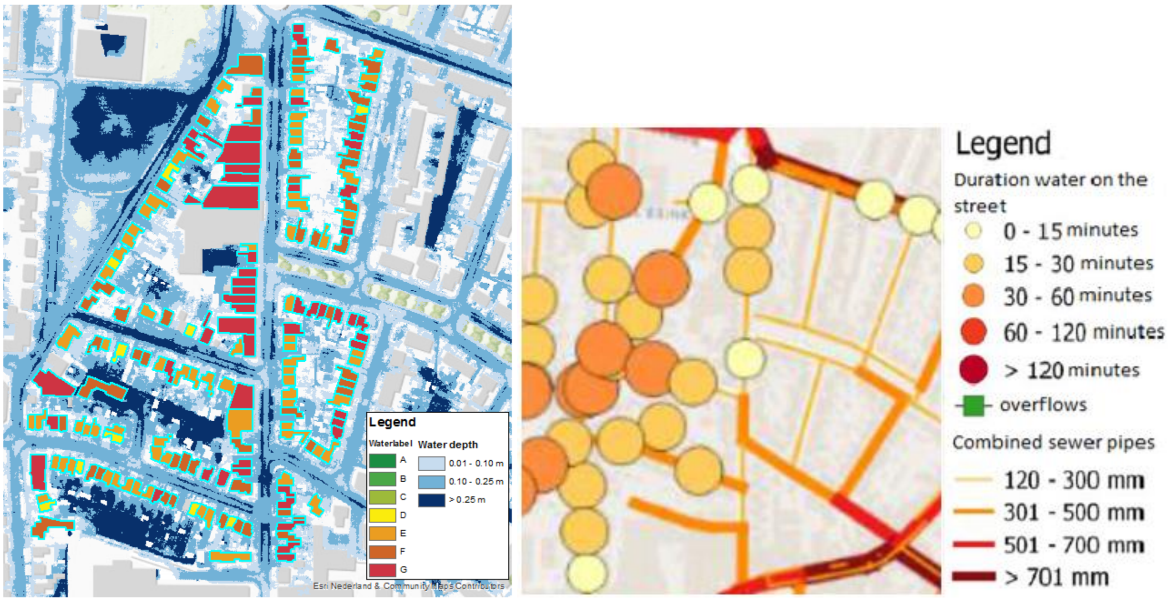

Figure 22. Left: Selected streets in Castricum (blue outline) , Waterlabels calculated by Nelen & Schuurmans and water depth derived from the Klimaatatlas. Right: Duration of water on the selected street in Castricum in case of a 08 rainfall event (19.8 mm), as determined by Nelen & Schuurmans by using a hydrodynamic sewer system model (Nelen & Schuurmans, 2016).

Secondly, a street in Hoorn was chosen due to problems with pluvial flooding in the past (M. Lamers, personal communication, June 26, 2017; ''Wateroverlast in Noord-Holland en Flevoland'', 2012). In figure 23 the selected street is visualized, in combination with the water depths from the 'Klimaatatlas'.

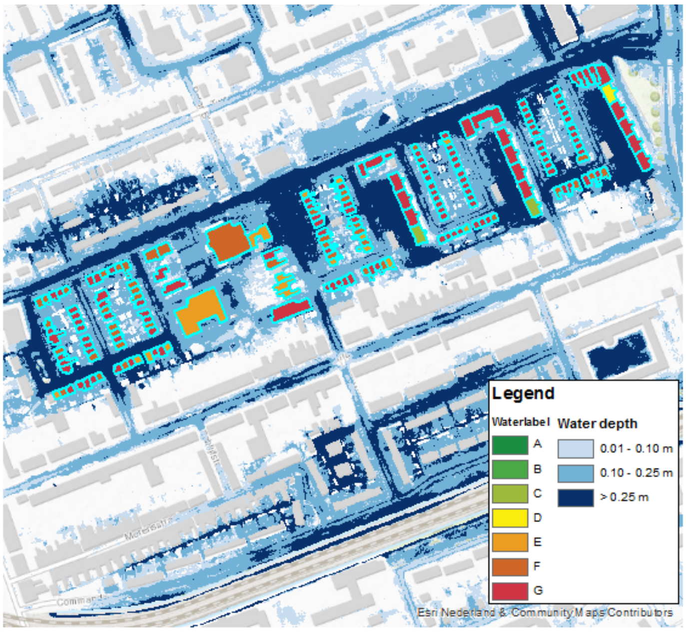

Figure 23. Selected streets in Hoorn, Waterlabels calculated by Nelen & Schuurmans and water depth derived from the Klimaatatlas. The coloured and blue outlined houses represent the selection used to determine the average property of this neighbourhood.

Lastly, a street in Wormerveer (Zaandam) is selected (figure 24), since numerous overflows of combined sewer systems discharge into one small canal. This results in pluvial flooding in case of extreme precipitation (M. Lamers, personal communication, June 26, 2017).

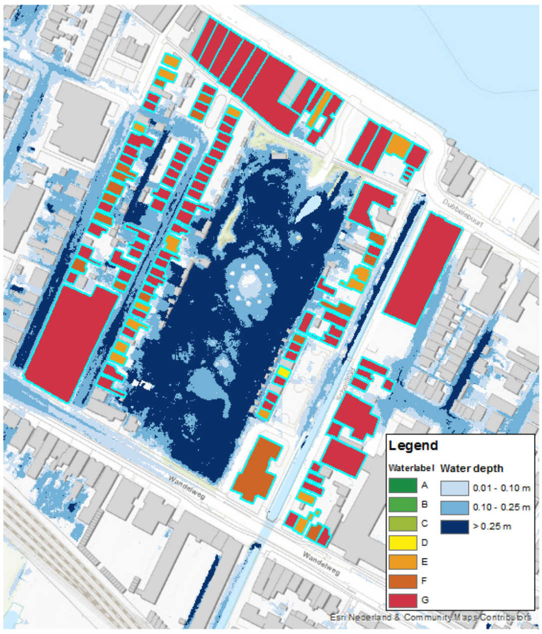

Figure 24. Selected streets in Wormerveer, Waterlabels calculated by Nelen & Schuurmans and water depth derived from the Klimaatatlas. The coloured and blue outlined houses represent the selection used to determine the average property of this neighbourhood.

For each of these neighbourhoods the 'average property' was calculated with the data of Nelen & Schuurmans. The results of these calculations can be found in table 7.

Components of properties	**Unit**	**Castricum**	**Hoorn**	**Wormerveer**
Number of properties selected street	-	209	288	245
Average roof surface area	m^2	110	111	849
Average garden surface area	m^2	179	388	177
Average amount of green space	m^2	48	202	45
Average amount of impervious pavement	m^2	131	186	132
Type of sewer system	-	combined	combined	combined
Storage sewer system	mm	7	7	7
Soil type	-	Sand	Clay	Peat
Permeability of soil	mm/d	1000	5	100

Table 7. Calculated components of properties in selected neighbourhoods, data obtained from Nelen & Schuurmans.

The data from table 7 was used as input for the simulations in RainTools. In total 7 situations were simulated, which are described in table 8.

Simulations	**Adjustments**
1. original situation	Original situation as calculated with the data of Nelen & Schuurmans, without adjustments or adaptation measures
2. extensive green roof	Storage of substrate layer of the roof adjusted from 0 to 15 mm
3. rain barrel	Addition of infiltration measure with a capacity of 0.2 m^3
4. infiltration crate	Addition of infiltration measure with a capacity of 4 m^3
5. lowering garden	Grass surface lowered by 10 cm compared to terrace
6. pervious pavement	Permeability of terrace adjusted from 1 to 90 mm/h
7. 60% grass 40% impervious surface	Adjusting the surface areas of grass and impervious surface in such a way that they relate in the 60/40 ratio

Table 8. Description of simulations executed with RainTools

Each simulation runs for three hours, with a total of 79 mm of precipitation during the total simulation. The results of the simulations are given in figure 25 till 27. For each 'average property' the amount of precipitation received is calculated, by multiplying the amount of precipitation per square metre by the average surface area of the property. The distribution of the storm water is visualized as percentage of the total precipitation received by the property. In the graphs, the left hand side of the y-axis represents the storm water on the property itself and the right hand side represents the water on public area, such as the street. The water storage in the garden is the amount of water stored on top of the grass and the terrace. This can be seen clearly in the fifth simulation, by lowering the garden the water storage in the garden increases. The overflow from the garden is visualized by the grey bars, and represents the overflow from the roof and the overflow by the 'emergency overflow' at the terrace and grass surface. Water on the street represents the amount of water that cannot be stored in the sewer systems and ends up at the street. Lastly, water nuisance represents the amount of water that exceeds the threshold of 'water on the street' and therefore changes into water nuisance (Stichting RIONED, 2015).

The most effective measures are the ones that reduce the water nuisance and water on the street the most. It can be seen that for all three neighbourhoods the measures lowering the garden, infiltration crate and pervious pavement are the most effective.

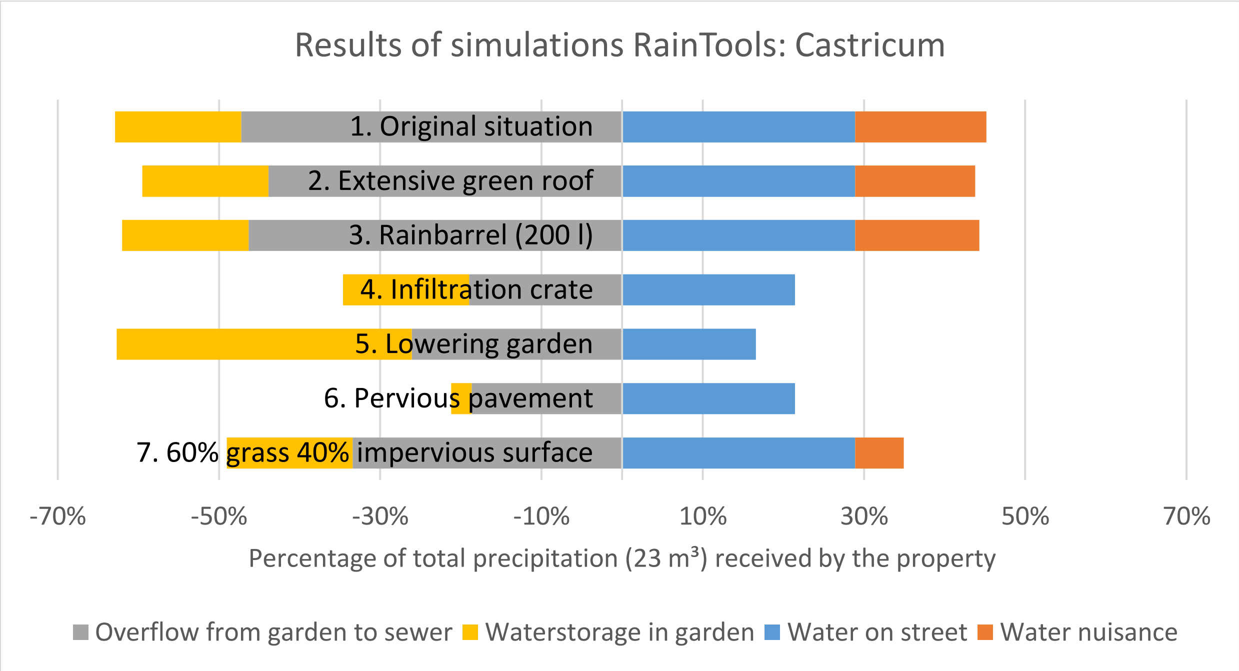

Figure 25. Results of simulations in RainTools for the 'average property' in the selected neighbourhood of Castricum

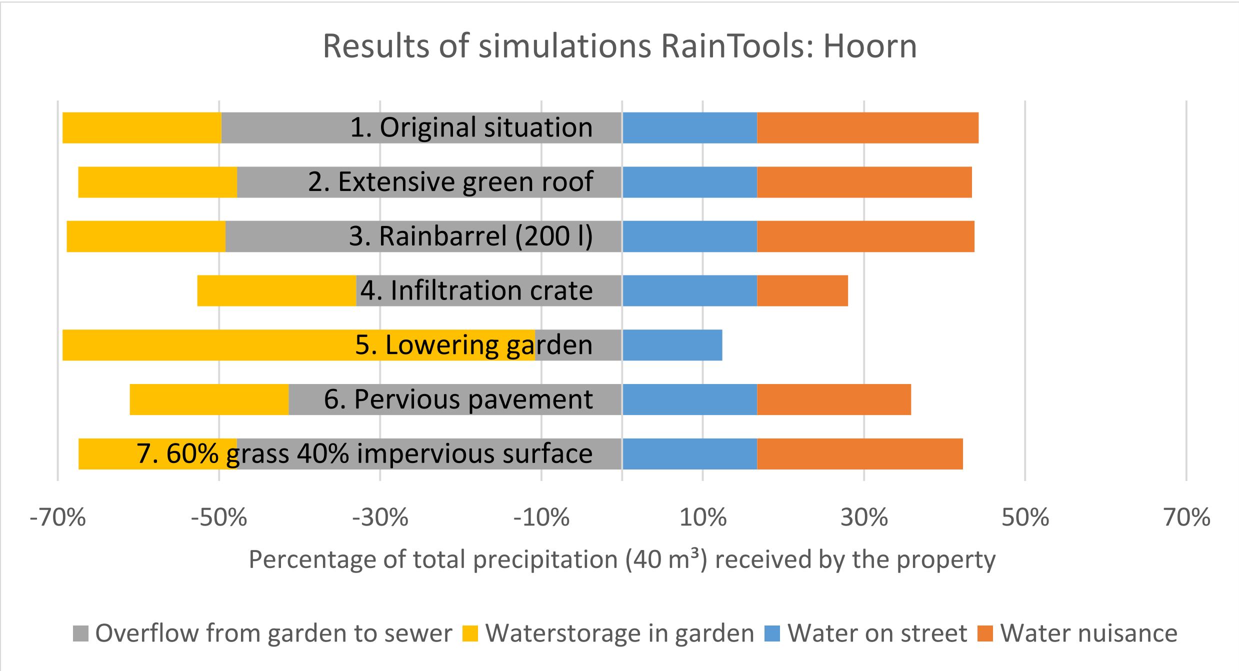

Figure 26. Results of simulations in RainTools for the 'average property' in the selected neighbourhood of Hoorn

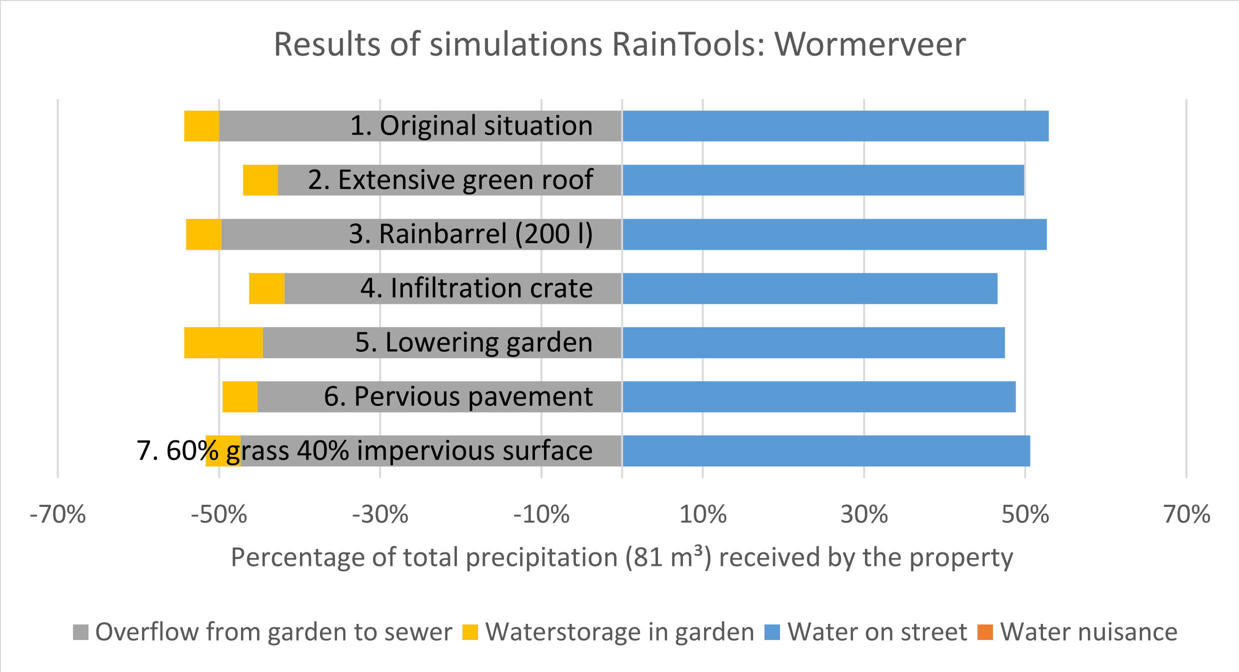

Figure 27. Results of simulations in RainTools for the 'average property' in the selected neighbourhood of Wormerveer

4. Discussion & Conclusion

4.1 Summary and reliability of findings

In this section the results for each sub question will be discussed, as well as the reliability of these results. The reliability is determined by assessing the uncertainties and limitations with regard to the used methods, data and obtained results.

4.1.1 Waterlabel

1. *What kind of method is used to calculate the Waterlabels, and what are the advantages and disadvantages of this method for determining the rainwater retention capacity of properties?*

To find out what kind of method was used to calculate the Waterlabels, information from Nelen & Schuurmans was used (L. Coppens, personal communication, March 6, 2017). The method was evaluated by examining the different components and calculating several Waterlabels manually. With regard to determining the rainwater retention capacity, the method has several disadvantages. To start with, the soil type is not taken into account, while the characteristic hydraulic conductivity and porosity of a soil determine the amount of infiltration possible (Hendriks, 2010). Furthermore, the groundwater level is not included in the method, while this determines how much water can be stored in the soil. A high groundwater level will result in less available storage compared to a low groundwater level. Incorporating these components would greatly improve the estimation of the rainwater retention capacity of the property. These findings correspond with the study of Boon et al. (2016), which recommended these improvements as well. Based on these recommendations, Nelen & Schuurmans is currently developing an improved method, in which soil type and groundwater level are incorporated (L. Coppens, personal communication, March 6, 2017).

When developing an improved method, the aim should be to keep a balance between a realistic representation of the water retention of a property and the purpose of informing people in order to improve water awareness. It cannot be assumed that everyone visiting the Waterlabel website knows the soil type and groundwater level of their property. In other words, when these components are incorporated into the method, the details should already be filled out on the website. This will keep the Waterlabel understandable for a layman, maintaining the potential of the Waterlabel to improve the water awareness. To determine the groundwater level of each property on forehand might be difficult in urban areas, since the level can differ substantially due to underground tunnels or parking garages (Stichting RIONED, 2017a). A recommendation would be to derive the groundwater level from the freeboard, the difference between the surface water level and the ground level, since this gives an indication of the groundwater level (K. Bruin-Baerts, personal communication, February 14, 2017; Moors et al., 2012).

With regard to the reliability of the results, it can be assumed that these are reliable enough for the purpose of this study. The calculation method was obtained from Nelen & Schuurmans, which co-developed the Waterlabel and calculated the labels for HHNK.

2. Is there a correlation between the spatial pattern of the Waterlabel and that of pluvial flood risk?

From the scatter plot and the correlation analysis it became clear that there is a negative relationship between the Waterlabel and mean water depth. This indicates that properties with a lower Waterlabel (e.g. F or G) have a larger mean water depth in a buffer of 10 meters compared to properties with a higher Waterlabel. This is in line with the statement on the Waterlabel website, that properties with a low Waterlabel increase the risk of pluvial flooding in their direct environment during extreme precipitation events (Waterlabel, 2017). However, it must be taken into account that the correlation, although significant, is very weak.

In addition, several uncertainties can be identified with regard to these results. To start with, uncertainties are present in the calculated Waterlabels and obtained pluvial flood risk. Furthermore, the methods used in the GIS and SPSS analyses might have influenced the reliability of the results.

Starting with the Waterlabel, uncertainties are caused by the assumptions made by Nelen & Schuurmans, as mentioned in chapter 3.1. Firstly, the amount of green space was derived from aerial photographs, however, the algorithm used for this could not make a distinction between grass or a green sheet. Additionally, for everything that was not green it was assumed to be impervious pavement, while this could also be pervious surface such as gravel. Furthermore, Nelen & Schuurmans assumed that neither a rain barrel nor a façade garden was present, since these details were unknown. Lastly, it was assumed that all roofs discharge the storm water to the type of sewer system that was closest to the property, since it was unknown whether roofs are disconnected from the sewer system or not.

To evaluate the effect of these limitations and assumptions, the change in Waterlabel was calculated for the average properties of the three selected neighbourhoods in chapter 3.2. In table 3 it can be seen how the Waterlabel changes for respectively; 5 square metres more green (pervious surface) in the back- or front yard, the presence of a façade garden or rain barrel and a change in discharge of storm water from the roof to the garden instead of to the combined sewer system. It shows that a small change in amount of green space, which is used to simulate the effect of potential errors made by the algorithm, does not influence the Waterlabel. The presence of a façade garden or rain barrel results in a maximum change of one class, and the shift to discharging storm water into the garden has by far the largest influence on the Waterlabel. However, it is assumed that only a small part of the properties has disconnected their drainpipes to let the storm water infiltrate into their garden. Therefore, the calculated Waterlabels are considered reliable enough for this study.

	Castricum	Hoorn	Wormerveer
Original situation	**F**	**D**	**G**
5 m² extra green backyard	**F**	**D**	**G**
5 m² extra green front yard	**F**	**D**	**G**
Façade garden	**E**	**D**	**F**
Rain barrel (200 l)	**E**	**D**	**F**
Discharge to garden instead of combined system	**D**	**C**	**C**

Table 9. Change in Waterlabel for 5 square metres extra green surface, the presence of a facade garden or rain barrel, and the change in type of discharge.

To determine the spatial pattern of the pluvial flood risk, the water depth map from the 'Klimaatatlas' was used, since no pluvial flood risk map was available. This map has several limitations, which might have influenced the reliability of the results. The map was composed by modelling the flow of water during a precipitation event of 100 mm in two hours. To model this flow, the elevation map was used as basis. Infiltration into the soil and drainage by the sewer systems was not incorporated, while these processes could influence the water depth.

According to expert judgement of HHNK, the water depth map gives a decent indication of the areas where problems might, or already, occur with regard to pluvial flooding (M. Lamers, personal communication, July 25, 2017). They state that infiltration during an extreme precipitation event can be neglected and the effect of the sewer system depends on the type of sewer system in place. On the other hand, expert judgement of RIONED indicates that incorporating the effect of sewer systems is crucial to determine which locations are prone to pluvial flooding (H. van Luijtelaar, personal communication, July 30, 2017). With the method of current water depth map, it is unknown what the effect of the sewer system is. Sewer systems can reduce the water depth by draining the water, however they can also increase the water depth when the system overflows due to overcapacity (M. Lamers, personal communication, July 25, 2017). Moreover, it is recommended to incorporate by all means the drainage by sewer systems into an improved water depth map. Adding infiltration will improve the reliability of the water depths even more, however, the effect of sewer systems is larger and therefore more important. Such an improved map will result in more realistic water depths and therefore an improved identification of the focus areas.

With regard to the methods used, some limitations have to be taken into account. For the correlation analysis a sample of approximately 9000 buffers from urban areas was used. To determine if this sample size is representative for the whole management area of HHNK, further research is needed.

4.1.2 Private Adaptation

3. In which areas is private adaptation most needed, based on the Waterlabel and pluvial flood risk?

By combining the low Waterlabels (G) and a water depth of 25 cm or more, which was used as the definition of a high pluvial flood risk, 17 streets (focus areas) were identified where adaptation is most needed. However, several uncertainties with regard to the data used have to be taken into account. As mentioned above, the identification of focus areas is influenced by the water depth map from the ‘Klimaatatlas’. Since in this map drainage by the sewer system is lacking, the water depths might differ from reality.

Even though the water depths are not completely accurate the map gives an indication of locations where problems might occur. The obtained results in this study can be used to identify cities with no focus areas and cities with a lot of focus areas. This gives an indication for HHNK on which cities to focus, and thus with which municipalities to cooperate to stimulate private adaptation. From the twelve cities evaluated, in the following cities multiple focus areas were identified; Den Helder, Hoorn, Edam-Volendam, Beverwijk and Zaandam. At all of these locations problems have occurred in the past with regard to extreme precipitation. The locations Den Helder, Hoorn and Edam-Volendam are in line with past experiences in 1998 and 2008 according to HHNK, and several newspaper articles (''Wateroverlast in kop van Noord-Holland, 2008''; ''Wateroverlast in Noord-Holland na hevige stortbuien'', 1998). Additionally, problems occurred in Zaandam and Beverwijk in 2014, when a precipitation event of 95 mm in two hours caused the flooding of tunnels, basements and roads (HHNK, 2015; Tauw, 2015)

Another option to identify focus areas, could be to combine the Waterlabels with the extensive analysis of the water system currently executed by HHNK. This analysis models the functions of the water systems (e.g. sewers, water pump stations, etc.) in case of extreme precipitation, to identify in which areas problems might occur. If problem areas from this analysis overlap with areas with low Waterlabels, the potential of private adaptation could be explored.

4. *Which measures are most effective in reducing the pluvial flood risk at three selected locations within the management area of HHNK?*

To determine the most effective private adaptation measures, three streets were selected from the previously identified focus areas. With these three streets simulations with six different adaptation measures were executed in RainTools, to visualize the effect on the risk of pluvial flooding. It became clear that the three most effective measures in the selected neighbourhoods were: lowering of the garden, implementation of an infiltration crate and replacing impervious pavement with pervious pavement. This is in line with the results from Stichting RIONED (2015), which also indicated that lowering the garden could significantly improve the water buffering capacity of a property. Additionally, they stated that impervious pavement contributed to pluvial flooding which corresponds with the positive result for the permeable pavement. With regard to infiltration crates it is recommended to determine the right size, since an upscaling of 4 to 8 cubic metres did not have any added value in the example of Stichting RIONED (2015).

From the results in chapter 3 it became clear that an extensive green roof and a rain barrel are the most ineffective adaptation measures. These results are confirmed by several studies. For example, Broks & Luijtelaar (2015) stated that in general a green roof is less effective compared to other measures such as infiltration crates or lowering of the garden. The effect might be more larger when green roofs are implemented on a large scale, or in case infiltration is barely possible due to a low permeability of the soil. The small water retention capacity of a rain barrel results in its low effectivity. In addition, in practice rain barrels are not frequently emptied, which results in an even smaller storage when extreme precipitation events happen.

Best effort was used in the simulations to represent reality in the best way possible, however, assumptions had to be made with regard to the sewer system capacity, infiltration rates and storage capacities of the different measures. Due to these assumptions the results give an indication of the most effective adaptation measures and cannot be assumed to completely represent reality. Obviously, the most accurate results would be obtained by conducting a pilot study in a neighbourhood prone to pluvial flooding. However, in practice such study is rather complicated, since it is not possible to obligate people to implement certain private adaptation. Furthermore, to determine the effectivity of measures, extreme precipitation events should happen during the pilot and these events cannot be planned. Therefore, it is recommended to use RainTools, since it has proven to be an appropriate simulation tool. Moreover, in the next version of RainTools it is possible to simulate a whole street instead of only one property, which increases the potential of this tool in the approach of private adaptation.

From the results it can be concluded that the most effective measures are not automatically the ones that improve the Waterlabel the most. For example, lowering the garden has proven to be an effective measure to reduce the risk of pluvial flooding. However, this measure cannot be incorporated into the current calculation method of the Waterlabel. This means that if one would lower their garden, this will not result in a better Waterlabel. This should be taken into account by Nelen & Schuurmans when developing an improved calculation method for the Waterlabel.

Another thing to keep in mind is that this approach is focused on determining the most effective measures, which are not automatically the most efficient measures. Determining the efficiency of measures is complex, since in most cases the exact costs and benefits are unknown (RIVM, 2011). However, by simulating the different measures in RainTools, the benefits can be defined as a reduction of pluvial flood risk. To connect a monetary value to a reduction in water depth on the street, the so-called 'Waterschadeschatter' could be used in future research. This tool is developed to estimate the damages to buildings, infrastructure and crops in case of a certain water depth (STOWA, 2013). To identify the benefits, one could determine the difference in water depth before and after implementation of adaptation measures, and calculate the difference in damages with the 'Waterschadeschatter'. This approach could also indicate if investing in private adaptation by HHNK or municipalities is efficient or that public adaptation measures are a better option.

4.2 Conclusion

''To what extent can improvement of the rainwater retention capacity on private properties, expressed by the Waterlabel, contribute to the reduction of pluvial flood risk in urban areas of the management area of HHNK?''

From the results it shows that implementation of private adaptation measures can actually reduce the risk of pluvial flooding. However, determining the exact contribution of private adaptation to the reduction of pluvial flood risk remains a scientific challenge. The extent of the effect of private adaptation is region specific and depends on the scale of implementation as well. Taking into account the reliability of the results and the limitations in the data that was used, it is concluded that further research is needed to provide a complete answer to the main question of this study. It is therefore recommended to execute a more in-depth analysis for the area of HHNK, taking into account the given recommendations with regard to the methods and data used in this study. In addition, research should be executed with regard to the best approach in communication to and motivation of citizens.

4.3 Recommendations & Policy Implications

With regard to further research, it is recommended to upgrade the water depth map from the 'Klimaatatlas' by incorporating sewer system capacity and infiltration. This kind of map is already being developed by Nelen & Schuurmans for the city of Rotterdam, and an option could be to let Nelen & Schuurmans develop this for the urban areas in the area of HHNK as well. This will result in more realistic water depths and a better representation of pluvial flood risk. This improved map could then be used to re-do the correlation analysis, to see whether this results in a stronger correlation. Additionally, the ‘streamflow’ map from the ‘Klimaatatlas’ might be worthwhile to incorporate in further research, since this map visualizes 'pathways' of the flow of water over the ground surface. In a way, this represents the underlying process of the water depth map. This map can be used to identify where the water in the problem areas originates from, and adaptation measures could then be recommended to the these upstream areas as well. Since the exact contribution of private adaptation to the reducing of pluvial flooding is still unknown, it is recommended to also consider a more in-depth analysis of the possible options in case of pluvial flood risk. One should not create a tunnel vision towards private adaptation. In other words, public adaptation measures should be evaluated as well, to make a substantiated decision with regard to the chosen approach. For example, the method of Koukoui et al. (2015) focuses on the adaptation of sewer systems and their effect during extreme precipitation events.

Next to the Waterlabel, several other tools and methods are available with regard to private adaptation to extreme precipitation. Which tool is optimal, depends on the goal that aims to be achieved. To raise the water awareness, the Waterlabel has the most potential since it is easy to understand and can be compared to already known energy label (Energielabel, 2017). When the goal is to make a first indication of possible adaptation options, more general tools such as the ‘Climate App’ or the ‘Adaptation Support Tool’ are recommended (van der Ven et al., 2016). If a specific neighbourhood is already identified as problem area, RainTools can be used. Since one can use this tool to accurately evaluate the functioning of different measures on a small scale, due to the extensive water balance approach incorporated into the simulations. Van Luijtelaar (RIONED) also stated that they are planning to develop a more simplistic tool for people without hydrologic knowledge, in order to make the tool more approachable. It might be promising to combine the detailed RainTools with the Waterlabel to determine the most effective measures for several types of properties. These measures could then be recommended to people when they visit the Waterlabel website, to improve effective adaptation.

Even though numerous tools are available with regard to adaptation, and their results are improving by ongoing developments, one should not lose sight of common sense. The risk of increasingly complex models is that one assumes that the reliability of the results increases as well (Vergroesen et al., 2013). It is therefore recommended to combine tools and models with knowledge of the area and experience from past events. In addition, it is recommended to look before you leap, and to define a clear goal and a division of responsibilities before starting any project, communication or cooperation.

Furthermore, it is recommended to involve or consult other organizations in the process of adaptation as well. HHNK has extensive knowledge with regard to the water systems, which could be combined with additional knowledge of municipalities or other organisations about other aspects that influence adaptation to extreme precipition. For example, Albers et al. (2015) stated that bringing urban planners and water manager together is important to reduce the risk of water nuisance. Additionally, HHNK could learn from similar projects executed by other water authorities. For example, the water authority 'Hoogheemraadschap Schieland en Krimpenerwaard' in Rotterda composed the 'Programma Wateroverlast Rotterdam', with a similar aim as HHNK. This program focuses on storing rainwater within the city and improving the water awareness of citizens and companies (Klerk & Bals, 2016).

Involving research institutes or universities might be promising as well, since knowledge and skills could be combined and monitoring of adaptation could be improved (Albers et al., 2015). According to Runhaar et al. (2011), 60 percent of the municipalities is working on water nuisance, but with the main focus on the sewer system. This indicates the potential for HHNK to start the conversation with municipalities to look further than just sewer systems. In this conversation the Waterlabel could contribute to widening the perspective of municipalities with regard to adaptation.

With regard to the communication, further research is needed to find out what is the best way to improve water awareness and to motivate people to take action. This last aim has proven to be quite difficult, as stated by Ramaker (2016), only a small percentage of the people will be stimulated to take action based on the Waterlabel alone. This statement is supported by the fact that the energy label, which was initiated to stimulate people to reduce their electricity use, has shown that behavioural change is not easily accomplished. Schilder et al. (2016) stated that the transition to energy use reduction in households is moving rather slow, even though the energy label was already developed in 2012. To prevent that the same thing happens with the Waterlabel, good thought should be given to the way it will be used in communication to stimulate adaptation.

Learning from different approaches could be profitable as well, for example the division in tax rates between wastewater and storm water in Germany (Baulinks, 2017). Since 2010 wastewater and storm water should not be mixed anymore, which means that all new build houses should be connected to separate sewer system or buffer the storm water on the property itself. For the already existing houses, a fee is charged for every cubic metre of storm water discharged to the sewer system, based on the roof surface and amount of impervious surface of the property. In this way, people are financially motivated to infiltrate and store as much rainwater as possible. Another approach increasing used by municipalities throughout the Netherlands, is to obligate people to disconnect the drain pipes from the sewer system and store the storm water on the property itself (Ammelrooy, 2017). This is comparable to the German approach, and puts the responsibly of discharging storm water at the citizens. In the current situation municipalities in the Netherlands can decide for themselves whether to compel disconnection of drainpipes. Since costs are associated with disconnection, this might lead to unequal costs between citizens of different municipalities. It is therefore recommended that guiding national policies are composed with regard to the disconnection of drainpipes. Thereby, thought should be given to the question if disconnection all properties is sustainable on the long term. If precipitation events keep getting more extreme, would buffering on private properties not lead to more damage than when the sewer systems overflow onto the streets or surface waters once in a while?

In summary, it is recommended to exchange knowledge between different projects, cooperate with different organisations, in order to exchange knowledge and skills. To accomplish successful private adaptation the aim should be to make adaptation a mutual goal, of both governmental organizations as well as citizens and private parties (Rovers et al., 2015). An effort should be made to reduce the gap between the public and private domain, which might improve the motivation of citizens to participate in initiatives of governmental organisations, such as HHNK.

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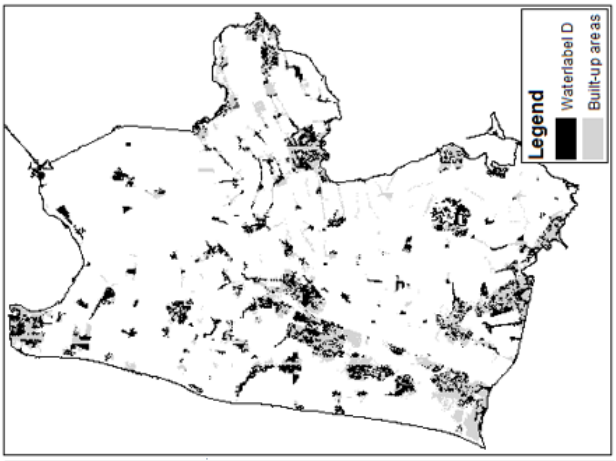
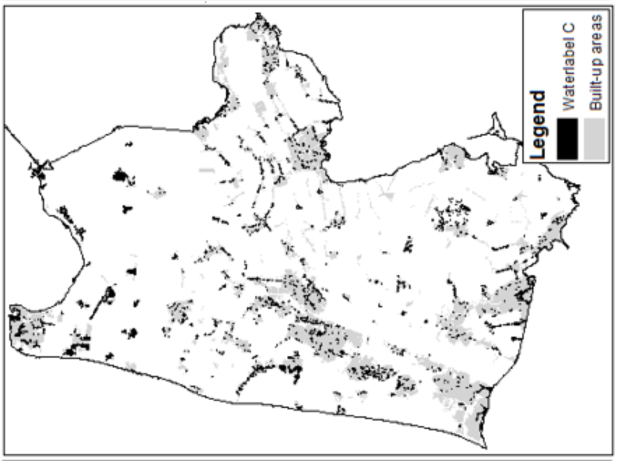
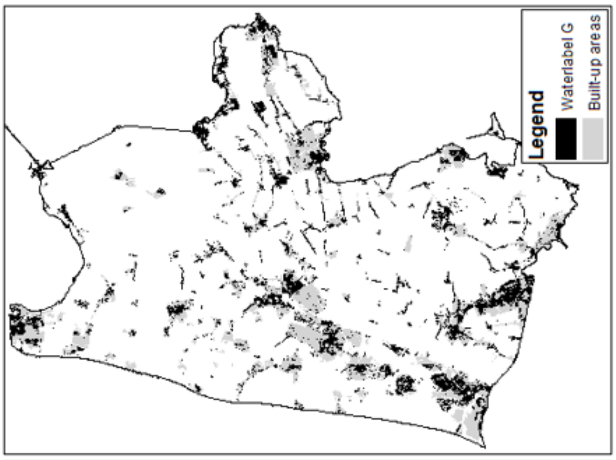
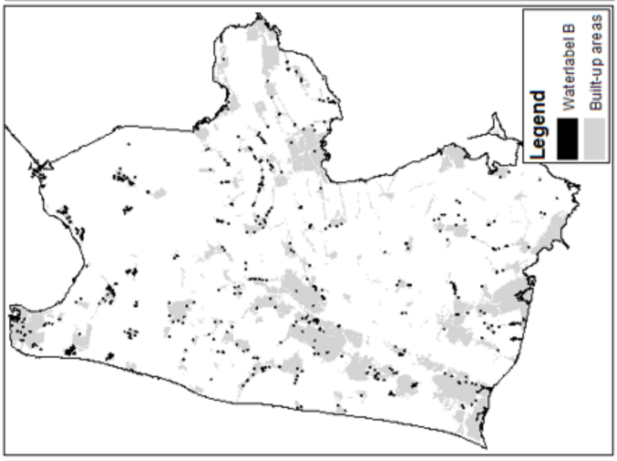
6. Annexes

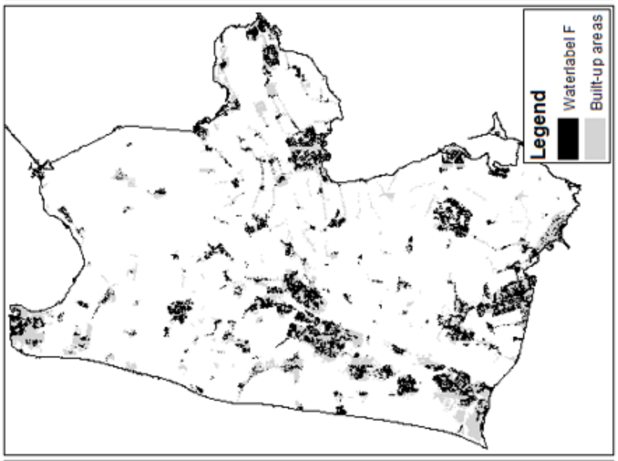
6.1 Annex 1: Spatial pattern of the different Waterlabels in black and white

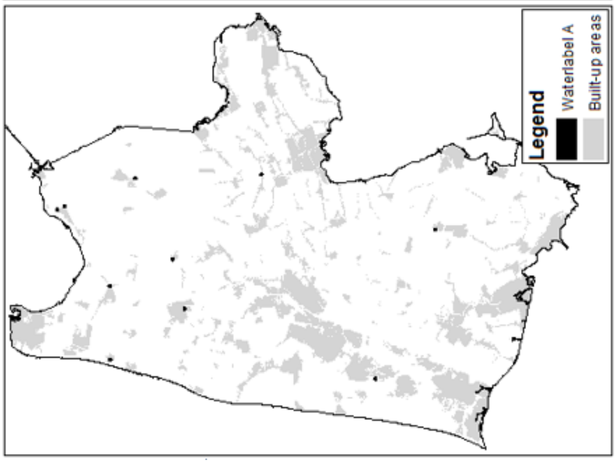


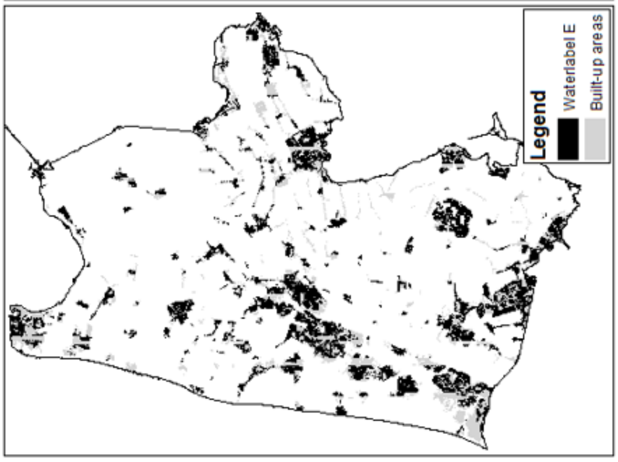




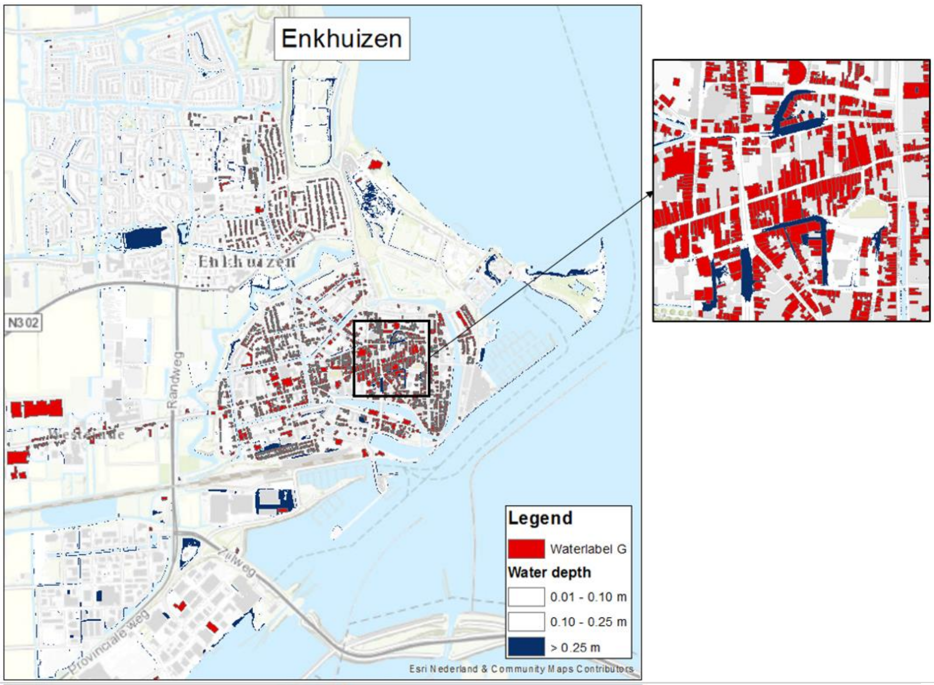


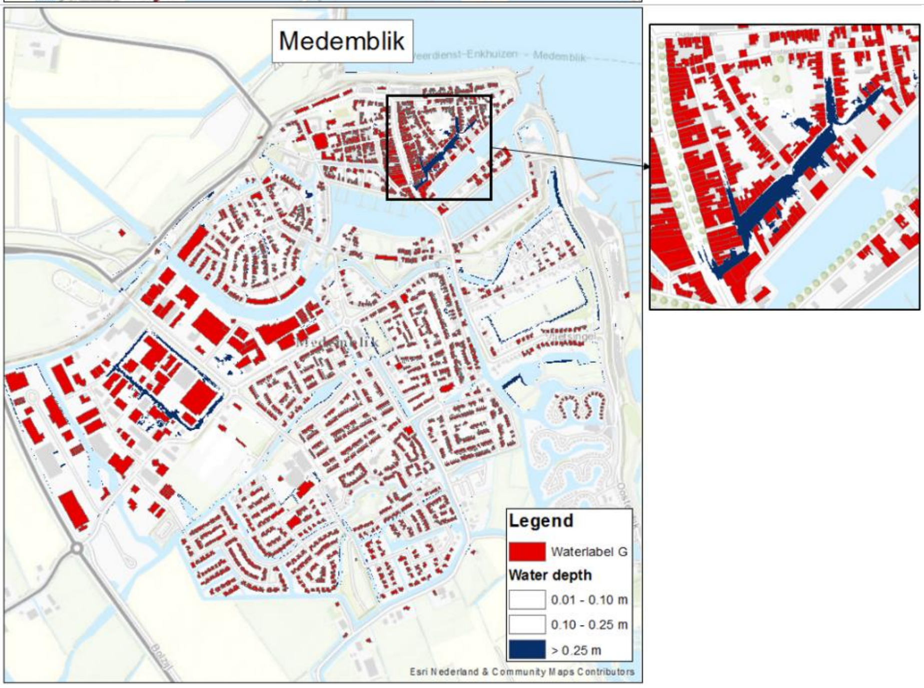


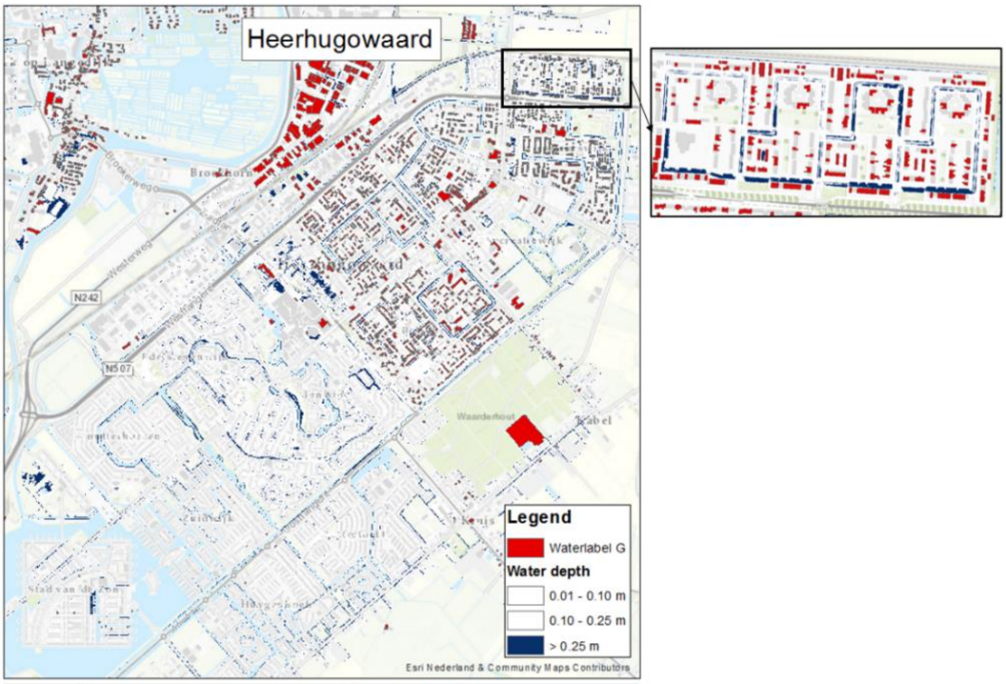




6.2 Annex 2: Focus areas






Heerhugowaard
N242
N507
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Waterlabel G
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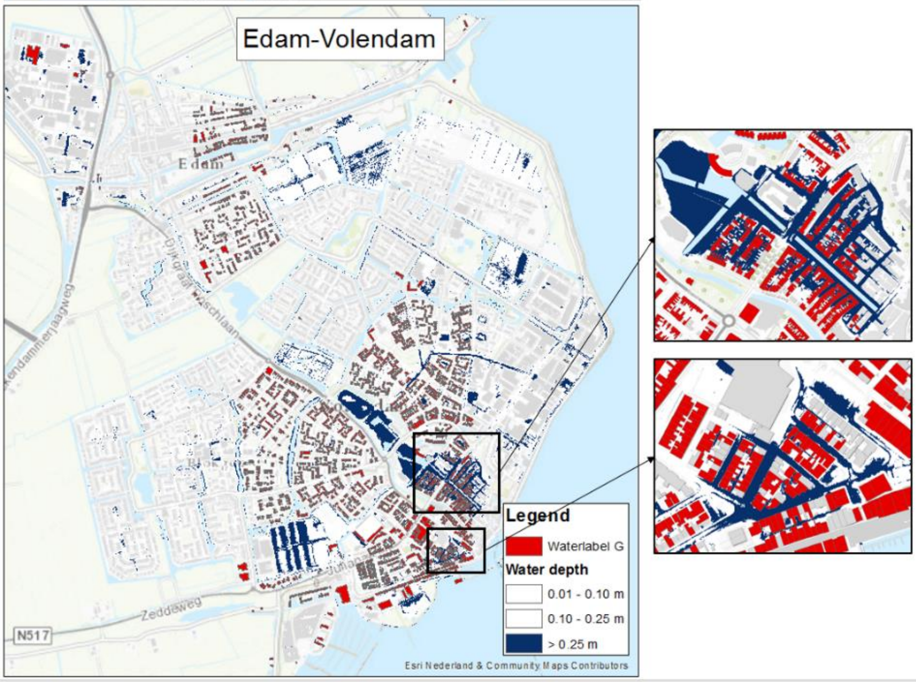
0.01 - 0.10 m
0.10 - 0.25 m
> 0.25 m
Esri Nederland & Community Maps Contributors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Edam
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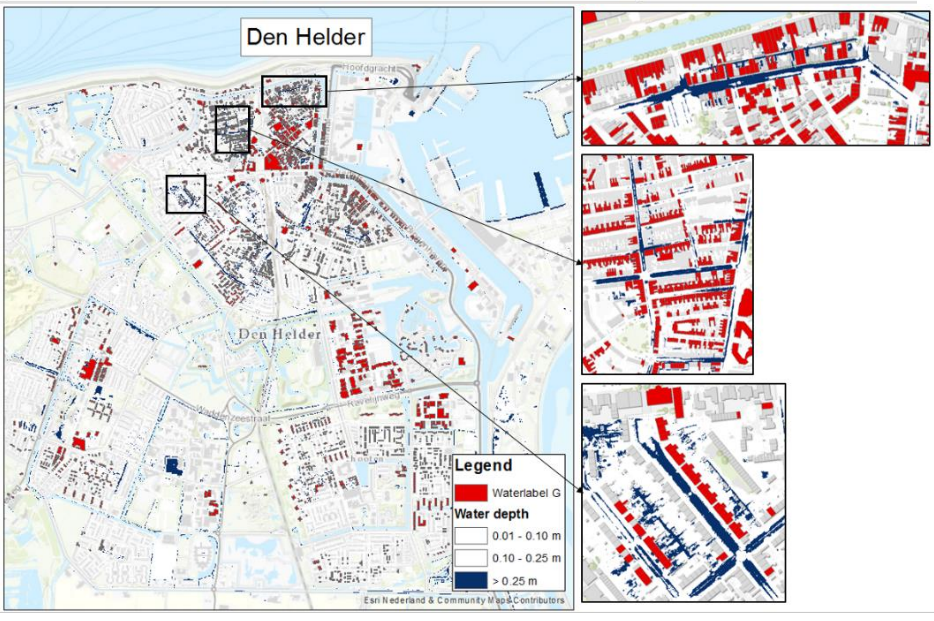
Esri Nederland & Community Maps Contributors


Den Helder
Den Helder
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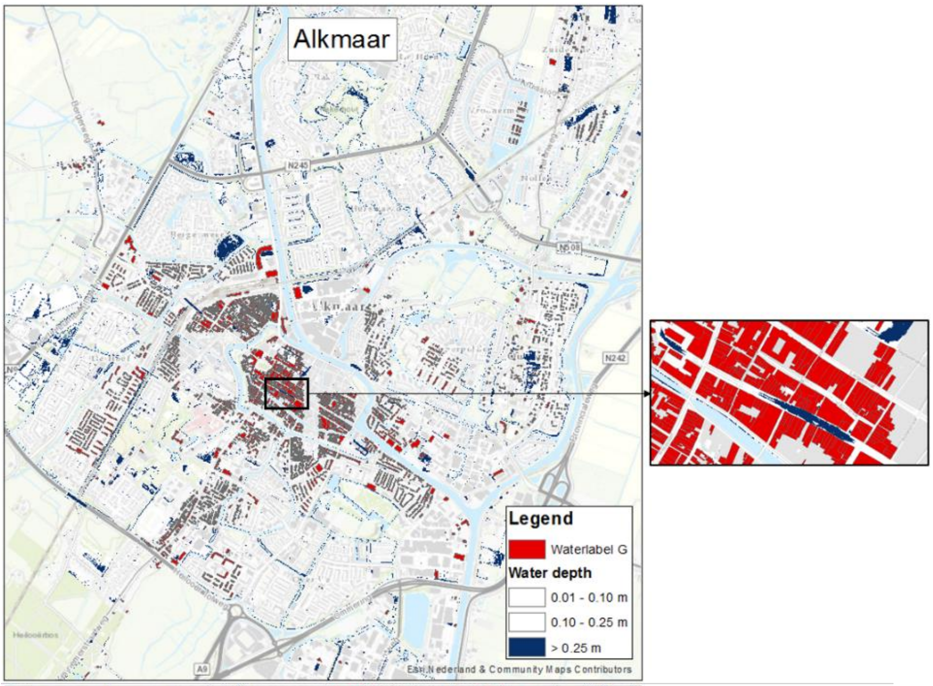
Esri Nederland & Community Maps Contributors



Alkmaar
Legend
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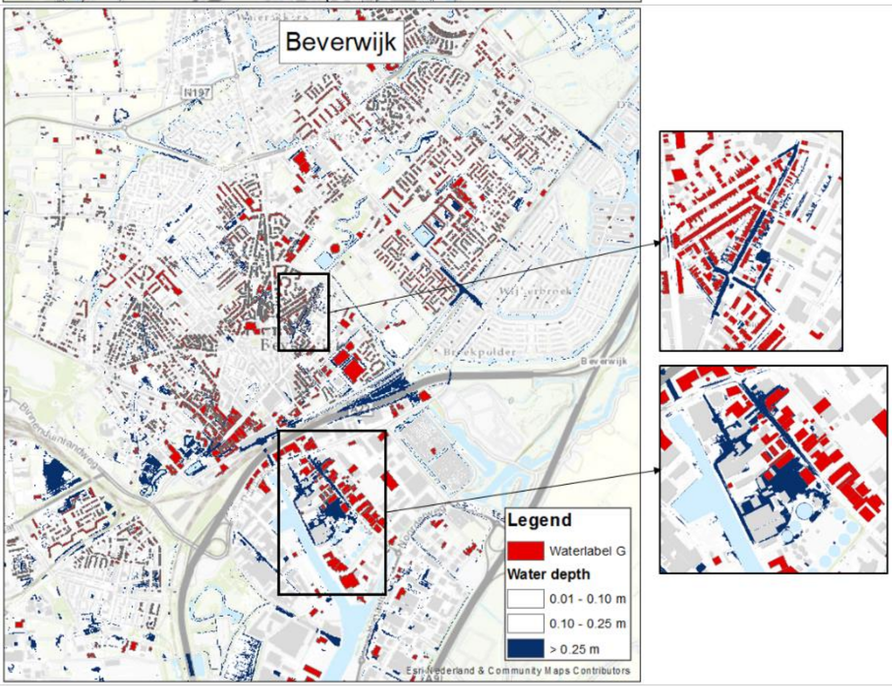
Esri Nederland & Community Maps Contributors



Beverwijk
Legend
Waterlabel G
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