Applicability of a hydraulic modelling tool in the urban planning process aiming at climate proof urban environments

MSc Thesis

by

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Utrecht University

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Supervision

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Abstract

Institutions, like the Intergovernmental Panel on Climate Change, investigated and examined climate change trying to understand and prevent its consequences. Agreements made include using instruments and measures to accommodate excessive rainfall, due to climate change, in order to prevent urban environments prone to flooding. As a result, water-robust and climate proof Dutch urban environments in 2050 is an example of mitigated action undertaken by the government in the Delta Plan Spatial Adaptation.

Present-day, it remains unclear how and when urban planners establish climate change strategies and measures such that urban planning designs result in adequate plans and layouts. Consequently, the purpose of this research was to determine the applicability of the hydraulic modelling instrument 3Di in urban planning processes and the feasibility of moving the evaluation of urban planning designs on water management forwards in the urban planning process (and how 3Di could play a role herein) in order to build climate proof urban environments.

Theory on urban planning processes and interviews with professionals revealed that there is potential to embed water management in the first three phases of the urban planning process as long as water management is considered urgent, actors are willing to consider it and that barriers are overcome. The interviews revealed that professionals think that a hydraulic model could help addressing the importance of water management in urban planning.

To this end, a case study was performed by evaluating the urban planning design of the Olympia district in Almere on water management with 3Di. Flood modelling, using three normative rainfall events, generated high resolution results (e.g. water depths and the time-period of inundation) that provided insight in flood prone locations and functioning of the water system. The results played an important role in work sessions and revealed that new overarching insights concerning the maximum time-period locations can be inundated. These results and the insights gained in work sessions led to substantiated motives, from a water management perspective, to change the urban planning design.

Based on the research results, recommendations for sensitivity analyses of 3Di-input and general additions to the basic principles of 3Di were given. More research is needed on the return period of rainfall events and a framework and a single comprehensive definition for climate proof should be established. Also, more in depth research is needed on the effects of embedding water management at the early stages of the urban planning process.

List of abbreviations

AHN2	Algemene Hoogtekaart Nederland 2 *(Dutch Digital Elevation Map)*
BOFEK2012	Bodemfysische Eenhedenkaart 2012 *(Dutch soil physics map 2012)*
CBS	Centraal Bureau voor de Statistiek *(Dutch Central Statistical Office)*
DEM	Digital Elevation Model
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
KNMI	Koninklijk Nederlands Meteorologisch Instituut *(Royal Dutch Meteorological Institute)*
MBZK	Ministerie van Binnenlandse Zaken en Koninkrijksrelaties *(Ministry of the Interior and Kingdom Relations)*
MEZ	Ministerie van Economische Zaken *(Ministry of Economic Affairs)*
MIM	Ministerie van Infrastructuur en Milieu *(Ministry of Infrastructure and the Environment)*
NAP	Normaal Amsterdams Peil *(Dutch Ordnance System)*
WADI	Water Afvoer Door Infilratie *(Water Discharge by Infiltration)*

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1 | Introduction

To strengthen a water robust and weather resistant (re)development of the urban environment, the Delta Plan Spatial Adaptation is compiled as part of the Delta Program of 2018 (MIM & MEZ, 2016). The Delta Plan aims at cooperation between governmental authorities, businesses and civil organizations in order to achieve climate proof and water robust urban environments. Moreover, the urban environment in the Netherlands needs to be resilient and climate proof in 2050 in order to accommodate excessive rainfall due to climate change. Besides, an agreement to be established in the Delta Plan includes which instruments and measures are used by these organizations to reach climate proof urban environments (MIM & MEZ, 2016).

Climate change causes various risks. Therefore the Royal Dutch Meteorological Institute (KNMI) translated the research outcome of the 2013 report of the Intergovernmental Panel on Climate Change (IPCC) into four future scenarios for the Netherlands (KNMI, 2015). These scenarios predict that temperatures will rise, sea level rise continues and precipitation intensities will increase (KNMI, 2015). Up to now, the majority of studies have focused on the identification and quantification of the identified risks and on which adaptive measures may be taken (Runhaar et al., 2012). However, the process of how urban planners establish climate change strategies and measures such that urban environments can cope with it still remains to be investigated (Runhaar et al., 2012). Also, a gap is present between the provided knowledge by experts in the water domain and the knowledge demanded by multiple practitioners outside this domain. Simulation models are recognized as useful tools to reduce this gap (Leskens, 2015).

1.1 Problem description

The Delta Plan Spatial Adaptation in the Netherlands emphasizes the awareness of a changing climate and the additional risks for the urban environment. Governmental institutions agreed upon (re)building climate proof urban environments and nowadays many urban planning projects arise from this agreement. The research will address a case study of an urban planning project (initiated by the municipality of Almere) in the city of Almere (a description of the case study is provided in section 3.1).

Within the area to be developed, the Olympia district at Almere, mitigation actions are planned aiming to drain rainwater above ground as much as possible. The following objectives were determined by the municipality of Almere in case of excessive rainfall events:

1. Residences are not affected by surpluses of drained rainwater;
2. Roads remain accessible (especially for emergency traffic);

3. Critical water depths at parking lots and in infiltration zones[1] are avoided.

However, it is unclear whether the current urban planning design fulfils the objectives, to date and in the future. The hydraulic modelling tool 3Di, which simulates the flow of water and provides realistic flooding simulation by coupling the sewage and surface system and using innovative methods to ensure short calculation times and high resolution output-data (Casulli, 2008; Stelling, 2012; Van Dijk, 2011; Volp et al., 2013), is a useful instrument to test the design on whether it achieves to fulfil these objectives; if this is not the case, the model output can then be used for a revision of the urban planning design of the Olympia district so that excessive rainwater is discharged in a safe and responsible manner.

Furthermore, this research is also conducted to evaluate whether 3Di could be used earlier in the urban planning process as a water assessment tool; to date a review of the urban environment on water management is mainly incident driven despite agreements made within the Delta Plan. Final urban planning designs are tested on water management after which the design will be modified. Potential benefits might be gained in new construction projects if water management demands are considered in an earlier stage in the design process, because it is easier to alter a preliminary design.

Yet, Runhaar et al. (2012) concluded that it remains unclear how urban planners establish climate change strategies and measures such that urban planning designs result in adequate plans and layouts. Therefore it is useful to explore how urban planning developers deal with climate change and excessive rainfall events, and to what extent they integrate water management in the urban planning process. At the request of the internship company, Nelen & Schuurmans, it is investigated whether urban planners and other professionals in the water domain are willing to use 3Di. At the same time Nelen & Schuurmans wants to know if their product is adequate in its present performance, or that investments are necessary to improve the applicability of their product.

1.2 Previous work done on the problem

With regard to climate adaptation and urban planning Uittenbroek et al. (2012) created a conceptual model to enhance how climate adaptation is understood by actors and integrated into urban planning policies. They attempted to understand barriers that hamper integration processes, and examined strategies to overcome barriers and that create opportunities. Subsequently, a comparative analysis between two Dutch case studies (related to urban planning) was performed to illustrate the value of their model. Despite the fact that both cases were not representative but rather illustrative, it became clear that integrating climate adaptation into processes does not always result into immediate actions. Barriers and opportunities complicate achieving a climate proof situation. Therefore, actors need to apply strategies focused on making deliberate decisions and synergies which consider present-day and future impacts of climate change (Uittenbroek et al., 2012).

Leskens et al. (2014) evaluated whether decision-makers would accept using an interactive modelling tool to improve urban water management decision-making. They concluded that

[1] In Dutch these zones are called Water Afvoer Door Infiltratie (in short WADI) which stands for Water Discharge by Infiltration. In this research the term WADI will be used to indicate these zones.

short computation times, realistic visualizations, and the simple adaptable interface of 3Di were seen as essential characteristics of the model for adopting the use of 3Di in planning sessions.

Yet, there is still unknown in climate adaptation. Using a hydraulic modelling tool in the urban planning process could help in the transition towards climate proof urban environments. Hydraulic models are useful instruments to explore and apply strategies that could interpret and prevent future urban flooding due to increasing rainfall intensities as predicted in the KNMI climate scenarios. The question rises how applicable such models are and how they can be embedded in the urban planning process in order to reach climate proof urban environments.

1.3 Aim and research questions

The aim of this study was to determine the applicability of a hydraulic modelling tool in the urban planning process in order to build climate proof urban environments. By conducting research into urban planning processes, this thesis also aims to test the feasibility and successes of moving the evaluation of an urban planning design on water management forwards in urban planning processes. The additional question rises if and how 3Di could play a role herein.

The over-arching research question is:

'To which extent can water management evaluation of an urban planning design be applied sooner in urban planning processes by using 3Di modelling in order to (re)design a climate proof Dutch urban environment?'

The sub-questions are:

1. *How are urban planning processes traditionally shaped and executed in the Netherlands?*

2. *What barriers do professionals, which are involved in urban planning processes, experience when water management evaluation of an urban planning design is carried out earlier in an urban planning processes?*

3. *How useful are 3Di results in urban planning processes and in which format?*

4. *What measures must be included in the urban planning design of the Olympia district to safely discharge large quantities of rainwater via the surface?*

5. *How do professionals who are involved in urban planning processes, look at the evaluation of urban planning designs on water management when this is performed at an early stage of urban planning processes?*

1.4 Outline

This research continues with the relevant concepts and theories on climate change adaptation in legislation and the Dutch urban planning processes in Chapter 2. The research methodology is defined in Chapter 3 with a description of the case study of this research, the interviews conducted with professionals in the urban planning process, the 3Di-model and the rainfall events used for urban flood modelling. This chapter also elaborates on the methods for data analysis. In Chapter 4 the results are presented. Chapter 5 performs an evaluation of the methods used and the results gained followed by the implications of this research and recommendations. Finally, the research is concluded with answers to the research question in Chapter 6.

2 | Covering climate change adaptation in legislations and processes

This chapter explains the relevant theory on climate change and legislative adaptation followed by theory on (water management in) urban planning processes and the relations between the urban planning processes and the demanded requirements of 3Di and urban planning designs.

2.1 Climate change and legislative adaptation

KNMI has provided four scenarios for temperature, precipitation and sea level rise towards the end of this century for the Netherlands (Figure 2-1). The four scenarios are: G_H (moderate temperature rise, large change in atmospheric circulation pattern), G_L (moderate temperature rise, small change in atmospheric circulation pattern), W_H (high temperature rise, large change in atmospheric circulation pattern) and W_L (high temperature rise, small change in atmospheric circulation pattern). The overall precipitation changes in winter concern an increase in rainfall and extreme rainfall. For the summer period, the intensity of extreme rainfall will increase (KNMI, 2015). On average, all scenarios predict one to two degrees of warming for 2050. Figure 2-2 indicates that per degree of warming, the hourly intensity of extreme rainfall events increase by approximately 12%.

The scenarios should be considered to ensure water safety in the Netherlands. The Dutch conception of 'flooding does not occur in the Netherlands' is disproven by modern water safety policies that focus on the possibility of serious flood events. Hence, besides flood prevention,

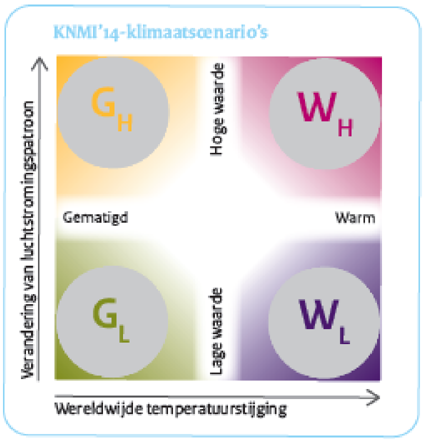

Figure 2-1. Four climate scenarios for the Netherlands (KNMI, 2015).

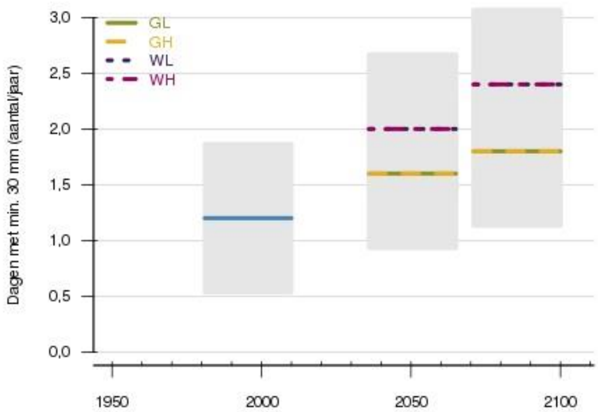

Figure 2-2. Annual mean number of days with a minimum of 30 mm precipitation per year. The historic value is presented in blue, the WL/WH scenarios in purple/pink and the GL/GH scenarios in green/yellow (source: KNMI).

more attention is given to water safety in spatial planning (Van Rijswick, 2014).

The Dutch Constitutional Law (Article 21) states that the government is obliged to provide a safe living environment for every Dutch citizen. Therefore, the Dutch Water Law is created to ensure proficient water management in the Netherlands. In its place, the Dutch Water Law understands water management as the responsibility of the government with the focus on flood prevention and where possible the limitation of flooding (Van Rijswick, 2014). Subsequently, Article 2.8 of the Dutch Water Law states that standards for surface water flooding are to be determined and should differ per land use. Also, by provincial regulation the flood standard for urban environments, concerning surface waters not managed by the government, determines that the maximum acceptable chance of flooding is equal to once every 100 years. A standard frequently used with respect to climate change is that the urban environment should be able to cope with an excessive rainfall event of 60 millimeters an hour. Furthermore, in the Netherlands a formal water assessment evaluates whether water management interests are included in urban planning, and therefore it is legally anchored in current and future legislation (Van Rijswick, 2014).

In the Delta Program the standards mentioned above come more into practice since several measures and facilities are incorporated herein (Van Rijswick, 2014). The Delta Program sets the goal (and includes proposals) that the urban environment in the Netherlands needs to be resilient and climate proof in 2050 in order to accommodate excessive rainfall due to climate change, but it does not provide a framework and a definition of when municipalities are considered to be resilient and climate proof. Thus, decision-makers and actors cannot fall back on one single comprehensive definition for resilience or being climate proof and need to rely on research. For example, Morecroft et al. (2012) defined that becoming resilient to climate change means that the vulnerability of e.g. urban environments to climate change should decrease.

2.2 Water management in urban planning processes

As Van Rijswick (2014) concluded, in the Netherlands a formal Water Assessment is used to evaluate urban planning on including water management interests. Moreover, decision makers, water managers and the contracting authority of an urban development project are all involved in the Water Assessment, which influences the final design of the concerned project. As experiences prove, water systems (e.g. water courses, dikes and canals as part of an urban plan) require space and therefore require attention in urban planning. It is more difficult to react against water instead to integrate water management in urban planning policies (Meire et al., 2003). Public authorities should take responsibility in restricting flooding and the resulting damage for inhabitants. However, the construction of climate proof and water robust urban environments is nowadays the responsibility of the private sector and to a high degree of the public sector (Mees, 2014). In order to comply with the aim to reach climate proof urban environments in 2050, this research investigates how water management is and should be embedded in the urban planning process since many urban planning projects arise from this aim.

2.2.1 Urban planning processes

Urban planning has been applied to monitor the proposed changes in the urban environment (Meyer et al., 2008). Urban environments have been growing in complexity, and more stakeholders need to be involved in urban planning which has a negative effect on e.g. the quality of urban planning projects (MBZK, 2011). Urban planning ensures that:

- clear objectives and arrangements are made;
- private and public functions are adjusted to each other;
- the interests of every stakeholder is involved and adjusted to each other;
- cooperation between stakeholders is ensured.

With urban planning multiple functions (e.g. living, working, infrastructure and recreation) are combined into a new developed urban environment. In general, urban planning processes comprise several phases (Figure 2-3): a (pre) exploratory phase, urban planning phase, realisation phase and management & maintenance phase (MBZK, 2011). Activities in the first three phases result in a structure for the final urban planning design. This research only focuses on the first three phases as they only concern the construction of an urban planning design and, moreover, the research objective is to find out to what extent a water management evaluation of urban planning designs can be applied sooner in urban planning processes.

In the pre-exploratory phase of an urban planning process, it is determined which incentive started a new urban planning project (e.g. more residences needed or urban flooding occurred) and how the project should be carried out in order to design a correct urban plan (or maybe there are other and better alternatives). The incentives and ambitions of the involved parties are investigated to combine them into a substantiated vision for an urban plan with concept project-borders. From there, the aim of the project area and the goals that should be accomplished are defined which comprise themes like the prevention of urban flooding or the realisation of residences. The end-product of this phase is normally a project plan with objectives and requirements (MBZK, 2011).

The exploratory phase provides time and space for an in-depth analysis of the project area, resulting in final borders of the project area. Discussed in this phase is what different ambitions the involved parties have and what the desired urban plan is in relation to the financial boundary conditions for the project. Therefore, concept images of the future urban plan and a preliminary allotment plan are created to ensure that the ambitions and desires are secured. Furthermore, market operators (e.g. building contractor) are approached for their participation in the next phases (MBZK, 2011).

In the urban planning design phase it is investigated how the desired ambition and objectives of the area is guaranteed. This phase is an iterative process in which the project team (in most cases) needs to 'calculate and draw' possible designs with eventually a final design. As soon as it becomes clear that the initial ambitions and objectives are hard to realise or combine even these need to be adjusted (MBZK, 2011). Subsequently, in the last two phases the project is realised based on the final urban planning design (realising the intended ambitions) and after completion the project is maintained (utilizing and preserving the realised ambitions).

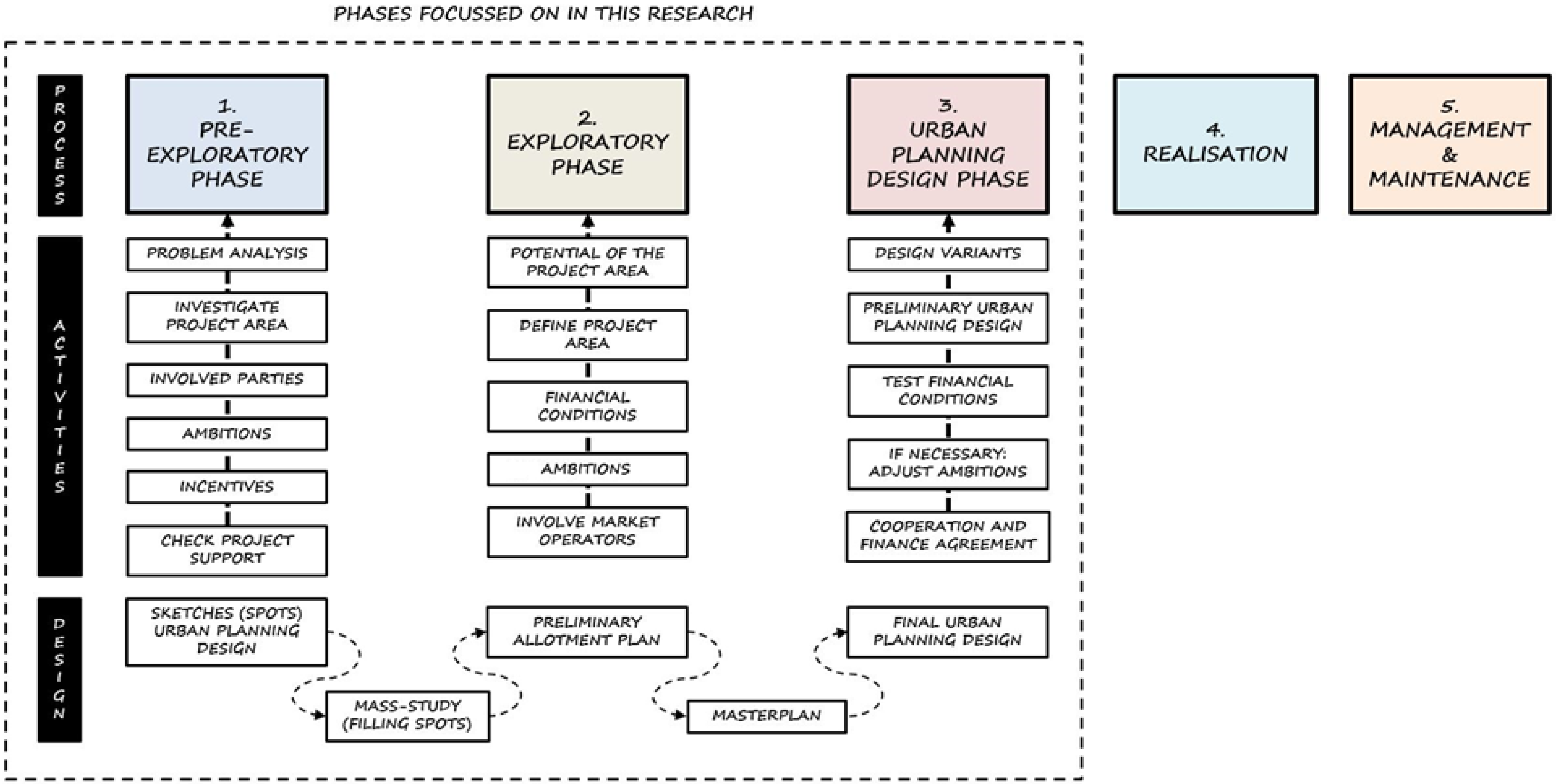

Figure 2-3. Scheme of the process phases, activities and design products of the urban planning processes.

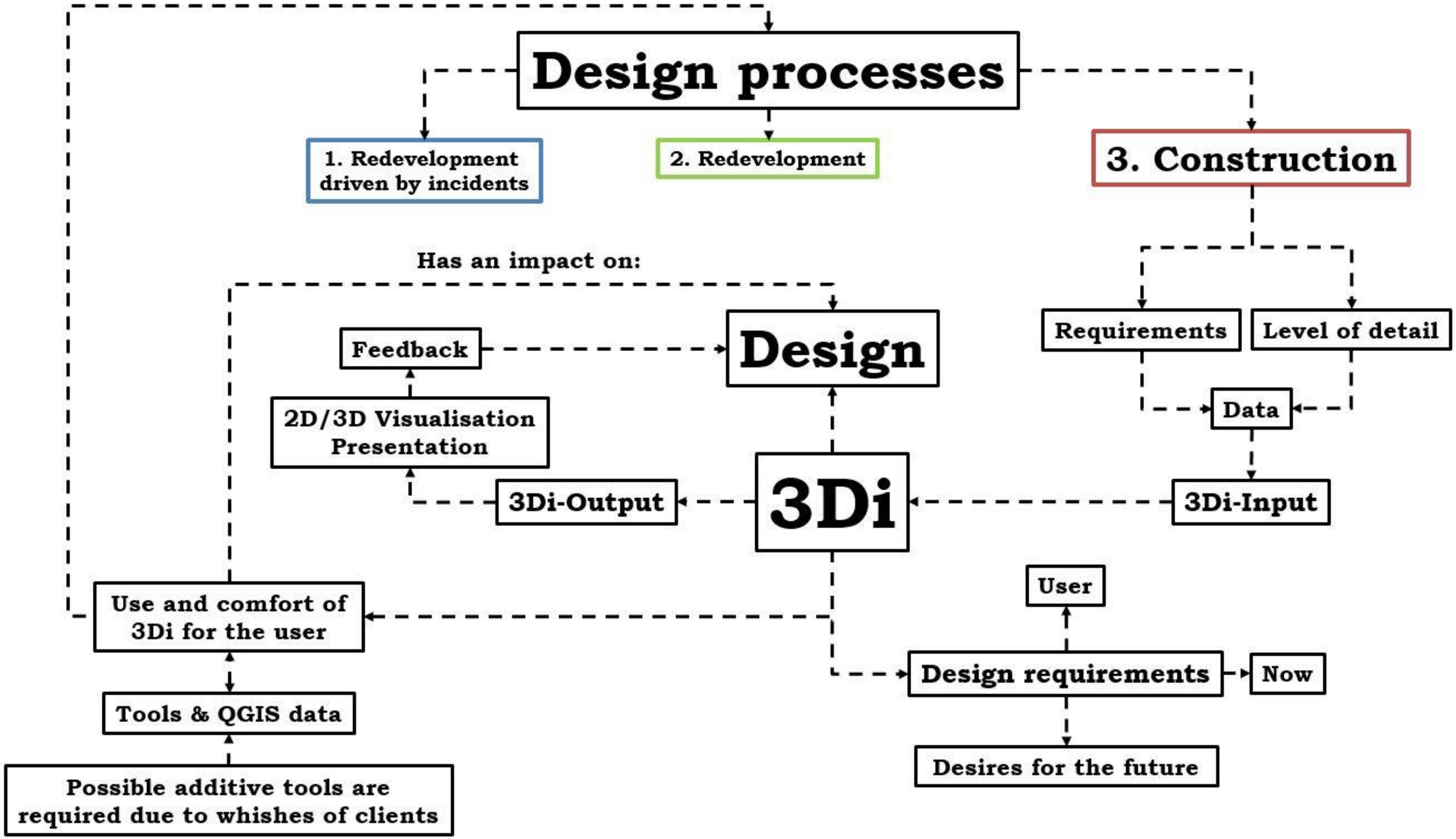

Figure 2-4. Relations between the urban planning processes and the requirements 3Di and urban planning designs demand (created in a work session on 12 January 2017 with the supervisors at Nelen & Schuurmans).

2.2.2 Relation between urban planning processes and the requirements of 3Di

Figure 2-4 presents the relation between urban planning processes and the requirements 3Di and urban planning designs demand. The scheme shows that design processes have three initiators that form the origin and start of the design process:

- redevelopment driven by incidents (e.g. as a result of heavy rainfall events);
- redevelopment (e.g. due to changing functions);
- construction (e.g. expanding the amount of residences of a city).

It is expected that water management can be applied in an earlier stage of construction projects; therefore this research focuses on the process of urban construction projects. Figure 2-4 shows that, in order to evaluate an urban planning design on water management by using 3Di, the data put into 3Di depends on the requirements of the construction plan and the level of detail. The 3Di-output is presented to the client in a work session from which feedback provides input for a final urban planning design with a proper and resilient water system. However, if 3Di is hard to use or can only be used in combination with in-depth knowledge of hydraulic models it could have an impact on the final design. Tools and other QGIS data-formats could help to prevent this and therefore 3Di related visions and feedback from professionals is valuable information. Hence, the demanded design requirements by the client, for the present and/or future (e.g. climate change) conditions, affect the whole process and how 3Di should be applied.

3 | Methods

Interviews with professionals were conducted to gain in-practice information on water management in urban planning processes. The interview methods and the analysis of the interviews are explained in this chapter. To examine if water management can be applied earlier in the urban planning process, a case study in Almere was performed and a 3Di-model was created to verify if the designed water system functions properly. Therefore, this chapter also describes what the basic principles of 3Di are, which data is put in the model, the output of the 3Di-model and how the data is analysed. First a description of the study area is provided as this defined the methods used.

3.1 Study area: Olympia district west

The case study is situated in Almere (Figure 3-2). According to CBS, Almere grew to a total of about 202.000 inhabitants in July 2017 and it is one of the fastest growing Dutch cities. In order to deal with the increasing amount of inhabitants, urban development in Almere Poort was already assigned in Almere's Structure Plan of 1983. With Almere Poort, the city of Almere is expanding towards the west and is connected with the agglomeration of big cities in the Netherlands (Gemeente Almere, 2007). The Olympia district west is one urban area yet to be constructed. In this area functions like shopping, living and offices are combined into a new urban environment. The interesting design criterion for this urban environment is that rainwater should be discharged via the surface as much as possible (Figure 3-1) without installing a new domestic sewage system. Therefore, this area is suited as a case study for this research.

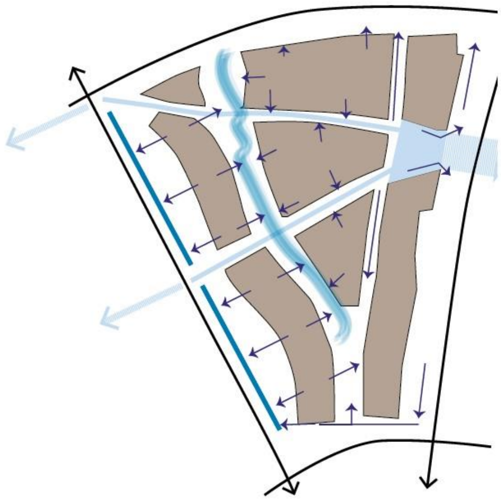

Figure 3-1. Intended rainwater discharge system in the Olympia district.

3.1.1 Location

The Olympia district west is located at the far southwest side of the city centre. The district is closed in by the railroad on the east side and the recently constructed project of Almere DUIN in the west. The highway A6 can be found south of the district. In section 3.5.2 an in-depth overview of the Olympia district west is provided by showing the urban planning design.

3.1.2 Physical characteristics

Almere lies in the polder area of Flevoland, which was created in the mid-twentieth century. The polder area, in which Almere is situated, is called Southern Flevoland polder and was created in 1968. The ground level of the polder is 2 to 5 meters lower than the water level of IJsselmeer Lake. The polder substrate consists mainly of clay with a low permeability and therefore this area is interesting when it comes to infiltration zones in urban planning areas. Underneath the (on average) three meters[2] thick surface clay layer sandy deposits occur.

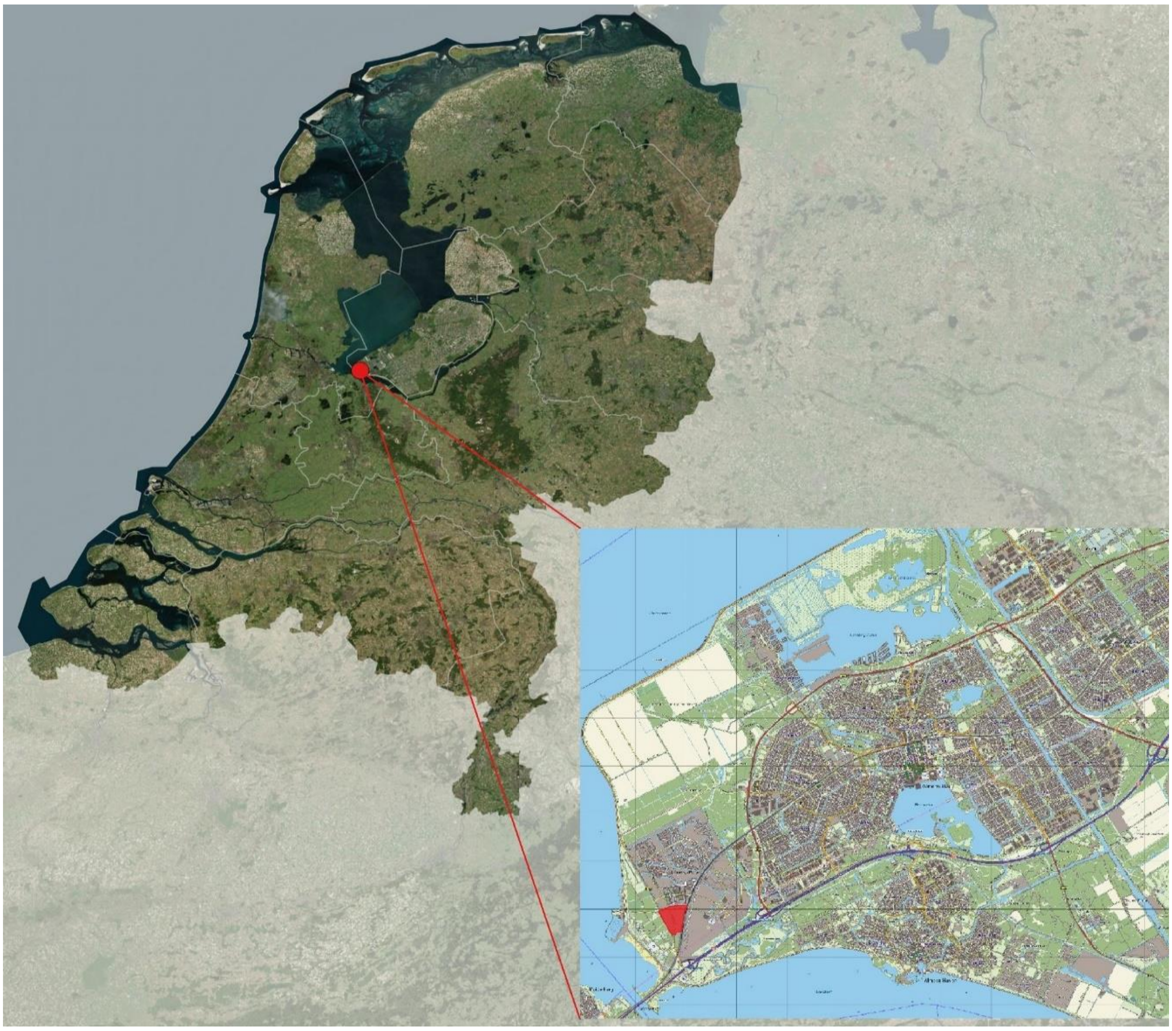

Figure 3-2. Map of the Netherlands (created with QGIS) with the city of Almere highlighted with a red dot. In the small map of Almere, the Olympia district west is indicated in red. Source: http://www.amazing-holland.nl/assets/almeremap.jpg

3.1.3 Organizational and governance structure

The municipality of Almere consist of two governing bodies: the town council and the executive board. The town council consists of elected representatives who are chosen by the inhabitants of Almere and provides a framework for policies. The executive board consists of the mayor and aldermen and their primary purpose is to conduct national policy and decisions taken by the town council. All provisional legislation needs to proceed through these bodies before it is approved and applicable for the municipality of Almere.

[2] Information retrieved on 22 August 2017 from https://www.dinoloket.nl/ondergrondmodellen

3.2 Case study approach

The urban environment of the Olympia district will be developed as a dune landscape and rainwater is drained above ground as much as possible. A progressive urban planning design combined with the polder area of Almere asks for a progressive approach to evaluate the water system of the urban planning design. The following approach was set up:

Inventory phase and first work session: In this phase the required information on the (sub)surface water drainage was gathered and analysed. The different information layers and subgrids in 3Di are explained in paragraph 3.5.2. Further, design criterions that had to be concerned were addressed and discussed in a first work session with the project team of the municipality of Almere. The output of this session further defines the input for the 3Di-model (section 3.7).

Model build and test phase: In this phase, using the feedback and the design criterions that had to be concerned from the first work session, the 3Di-model was generated. The coupling of the 1D sewage system and the 2D surface system was analysed and validated. The water system in the urban planning design was tested with the three rainfall scenarios described in section 3.6. The 3Di-model output and the analysis of the output are described in section 3.5.3 and section 3.8.

Second work session: The results of the first phases were presented in a second work session to the landscape planners, water managers and urban water consultants involved in this project. The design criterions that had to be concerned (as determined in the first work session) were discussed and made visible in a digital environment. By doing so, the results and insights in the water system at the three rainfall events were presented as clear as possible. Also, the opinions of the professionals present was detected on topics like acceptable maximum time of inundation (section 3.7).

3.3 Conducting interviews on urban planning processes and 3Di

Background information on how urban planning processes currently are executed, which stages the process consist of and which activities should be accomplished was gathered by performing a literature study (as discussed in the previous chapter). Expectations are that there are differences between these processes as described in literature and in practice. Therefore, additional interviews with a small group of professionals involved in urban planning processes were performed to obtain clarity on how urban planning processes are executed in practice. The so called '3Di-kennisdag[3]', hosted by Nelen & Schuurmans and other parties, offered a chance to get in touch with potential candidates to conduct an interview with. Additional candidates and their contact information were obtained via colleagues at Nelen & Schuurmans.

Most professionals were acquainted with the work of Nelen & Schuurmans or even collaborated with Nelen & Schuurmans. The selection of professionals was based on the difference in backgrounds they have, the institution they work at and which position they take. Hereby, work patterns and experiences of these professionals were determined and it should clarify how

[3] This day was held midway March and was organized for clients and people that were interested to work with 3Di, to follow workshops and to share knowledge on 3Di (www.3Di.nu/3di-kennisdag/).

they incorporate and intercept water management in the urban planning process they are involved in.

An interview guide was set up to ensure interview consistency and that in every interview the same questions were asked about the day-to-day work process and experiences of the professionals. The questions have been divided into three subjects that relate questions (the interview guide with all questions is presented in Annex I) to:

- Urban construction projects,
- Urban (re)development projects;
- Urban planning projects that arise from incidents like floods.

The interviews were recorded to prevent the loss of key information during the interview. Afterwards, the interviews were played back and the answers were written down for analysis.

3.4 Data analysis interviews

The semi-structured interviews were encrypted in order to systematically analyse the output. The output includes for example in what stage of the urban planning process different professionals are involved, how they consider water management and what they think of using information from 3Di model results.

First, the questions asked have been translated into multiple statements for the reason that they could be subdivided into three main themes to encrypt the interviews. Next, a simple format of the open encrypting method was used, which means that the entire interview was read and certain responses were labelled to indicate to which theme it belongs to. The main themes consist of statements on urban planning processes, communication and information necessities in urban planning processes, and 3Di. The statements were reviewed per interviewee on whether the interviewee identify themselves (e.g. to identify their realm of thought or work patterns) with the concerned statement or not. By doing so the interviews were encrypted and analysed, and an overview of the outcome of the interviews was created.

3.5 Hydraulic model

To put the evaluation of an urban planning design on water management more into practice, a case study with a hydraulic modelling tool was performed for the new urban construction project: the Olympia district. Urban flood analyses can be performed with different kind of models. Van Dijk (2011) concluded that there are broadly three types of urban flood models that can be used for urban flood analyses:

- Surface analysis tools based on GIS;
- 1D/1D dual drainage models;
- 1D/2D dual drainage models.

Which model should be used depends for example on the aim of the research, the availability of data and the purpose of the model. For a realistic flooding simulation, the sewage and surface system should be coupled (1D/2D) (Van Dijk, 2011). In such models the sewage system is represented by the flow of water in one direction and the flow of water in the surface system can take place in the x and y-direction.

The 3Di consortium of the Delft University of Technology, Deltares, Stelling Hydraulics and Nelen & Schuurmans developed detailed hydraulic modelling software with the resulting hydraulic modelling tool 3Di. The program calculates surface water flow at a high resolution over a large area (Nelen & Schuurmans, 2016). Water flow over the surface is traditionally calculated with conceptual models based on concepts like a linear reservoir or time of concentration which inappropriately simulate urban flooding due to limited capacity of the methods (Maksimovic et al., 2009). Therefore, 3Di is a very complete method available since it is a physically based model in which physical processes are simulated as best as possible to stay close to reality (Hunter et al., 2008). In order to handle this information and to simulate these processes, the program uses multiple techniques and assumptions.

3.5.1 Basic principles 3Di

The basic principle of 3Di is that it uses computational grids (with square cells) and information layers, in which the computational grids are detached from the information layers. Therefore, unlike other models (e.g. SOBEK and Delft3D), the computational grids do not use the resolution size of the information layer for computation (Stelling, 2012; Volp et al., 2013). One advantage is that 2D water flow is simulated accurately and relatively fast. In each cell of the computational grid the internal water balance is calculated and the interaction between the neighbouring cells for each time step. Grids can be adjusted locally to model water buffers or other flood defences in more detail and contain high-resolution information on processes such as the surface level, the infiltration capacity of the soil and flow resistance (the different subgrids are listed in 3.5.2) (Nelen & Schuurmans, 2016).

In the 3Di-model, the surface flow following after rainfall is based on the Saint-Venant 2D shallow water equations consisting of the continuity equation and momentum equations:

$$\frac{\partial h}{\partial t} + u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} = 0 \qquad \text{Continuity equation}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial \zeta}{\partial x} + \frac{c_f}{h}u\|u\| = 0 \qquad \text{Momentum equation in x-direction}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial \zeta}{\partial y} + \frac{c_f}{h}v\|u\| = 0 \qquad \text{Momentum equation in y-direction}$$

where h is the water depth, ζ is the water level above the plane of reference (NAP), u and v are the depth averaged velocities, g is the gravitational acceleration, $\|u\|$ denotes the velocity magnitude, and cf is a dimensionless friction function (Stelling, 2012).

In the 3Di-model links are made between 1D (e.g. surface water, sewage system) elements and the ground surface in 2D. Connecting 1D and 2D ensures that water flows are exchanged between the streets and the sewage system, but also in the other direction. This may occur when the sewage system is fully saturated in case of extreme rainfall events. Besides, precipitation can infiltrate into the soil based on Darcy's Law. 3Di also considers surface friction (Figure 3-3), evaporation and interception of precipitation at surface level can be extracted (via the DEM-subgrid, Annex II).

The 3Di-model neglects the interaction of the saturated and unsaturated zone and the deeper situated soil layers. Park et al. (2011) and Hayashi & Farrow (2014) concluded that deep groundwater flow becomes of more importance when measured over large timescales (e.g.

days/years). In this research, rainfall events with a total duration of only an hour were used. Therefore, boundary conditions were included like the maximum infiltration capacity, the infiltration rate and the initial water level to simulate the process of the soil becoming saturated.

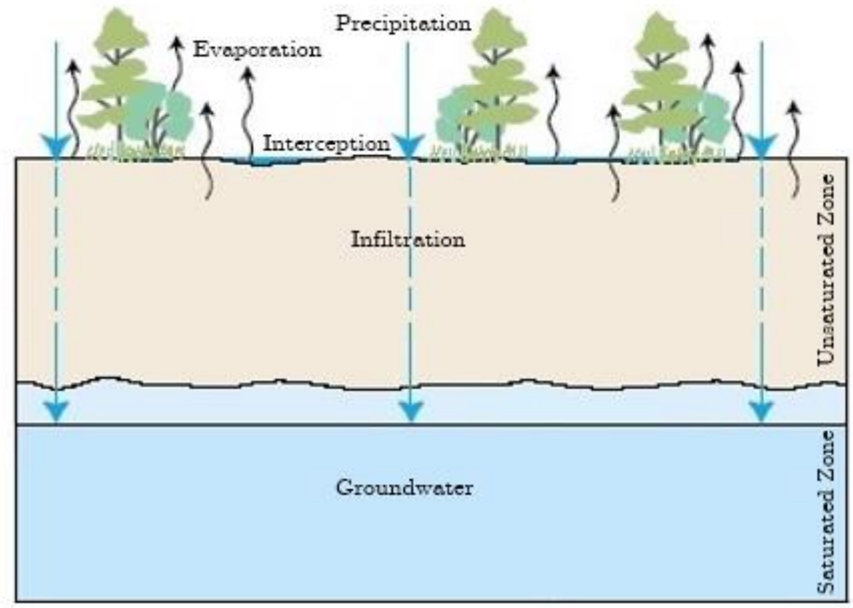

Figure 3-3. Schematisation of processes in 3Di.

3.5.2 Model input

The different subgrid layers that were generated, collected and adjusted in a GIS environment (program used: QGIS) are listed below. The subgrids, used in the 3Di-model of the Olympia district, contain a resolution-size of 0.2 x 0.2 m in GeoTiff format.

Digital Elevation Model (DEM): When modelling water flows in existing areas, an adjusted AHN2 (made by Nelen & Schuurmans) is used in which cars and trees are removed. However, the Olympia district in Almere consists of an open sand surface since the urban planning project is not in construction yet. Consequently, the AHN2 does not provide correct elevation data of the future situation as input for the 3Di-model. Therefore, a correct elevation map of the future situation (Figure 3-4) was established and provided by a specialist at the Amsterdam University of Applied Sciences. In this model, the present-day original surface level has been measured with a drone, and subsequently, the new surface levels, derived from the urban planning design, have been superimposed over the original surface level. However, small errors have been found (residence floor levels were missing, +5 cm in relation to the surrounding area) and therefore the DEM was altered manually.

Sewage system: A network of sewage and rainwater discharge pipes, manholes, pumping stations and overflows was created. The sewage design for the Olympia district is not a traditional combined sewage system, because the rainwater drainage system is disconnected from the domestic sewage system, with the result that rainwater cannot enter the sewage system and vice versa. Rainwater is discharged through the drainage system (Figure 3-5) and overflows were created that are connected to the surface water.

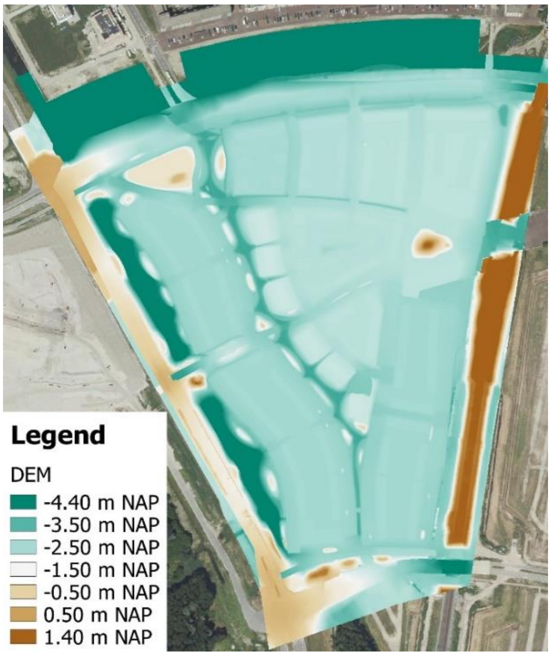

Figure 3-4. DEM subgrid Olympia district.

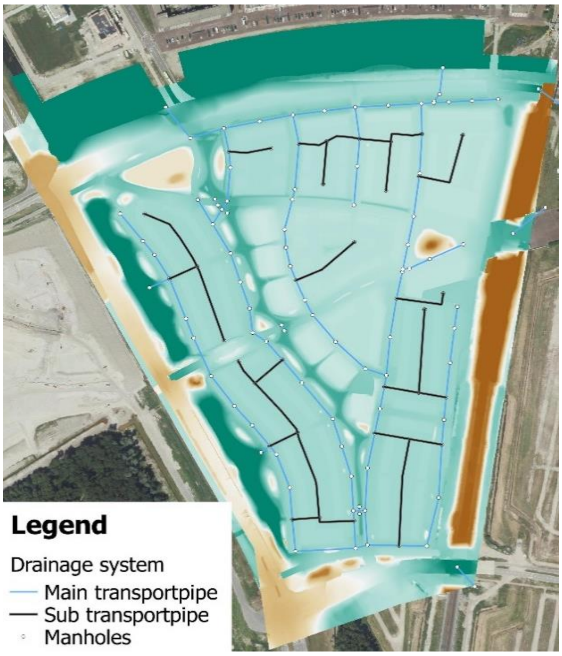

Figure 3-5. Drainage system Olympia district.

Ground surface type: Contains information on the future ground surface type (Figure 3-6). This information was provided by the municipality of Almere and adjusted to a QGIS format. Residences, different pavement types and courtyards were included in the ground surface type map and with this data processes like infiltration and surface friction were modelled.

Infiltration: This information was derived from a combination of the ground surface type per cell and soil type (retrieved from BOFEK2012). The height of the infiltration rate (mm/day) depends on the permeability of the ground surface type. As a first estimated guess the next

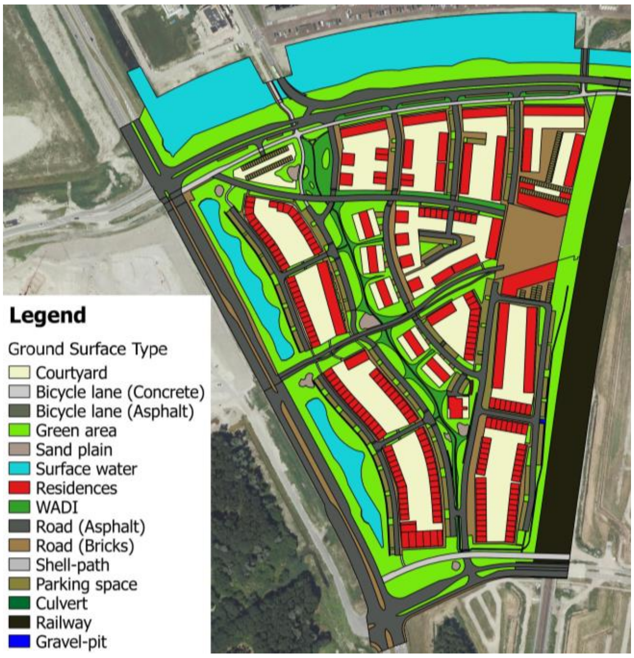

Figure 3-6. Ground surface type subgrid Olympia district.

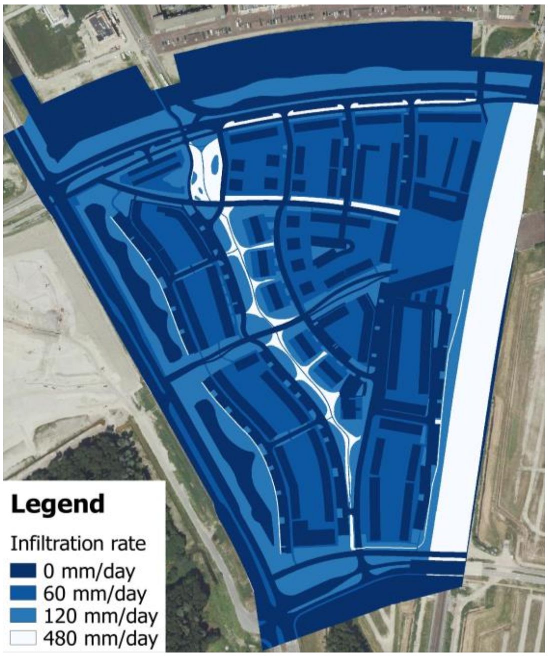

Figure 3-7. Infiltration subgrid Olympia district.

parameters were used: impervious (0), semi-permeable (0.5) or permeable (1). The infiltration rate is multiplied by one of the three infiltration factors per type of permeability (Figure 3-7).

Figure 3-8. Surface friction subgrid Olympia district.

Figure 3-9. Initial water level subgrid Olympia district.

Surface friction: This subgrid contains information on the surface friction (see Figure 3-8). The surface friction and the corresponding friction coefficient were derived from the ground surface type data. This subgrid must be incorporated and generated separately, due to that water is slowed down more (friction) by vegetation than by e.g. roads.

Initial water level: Subgrid with information on the reference water level of the surface water in the area. In reality (and in the urban planning design) surface water is present, which is modelled as the initial water level. As Figure 3-9 shows, in the model the initial water level of the surface water was set on -4.40 m NAP and the rest of the project area was set on -10.00 m NAP. This means that in the concerned computational grid cell, the initial water level (which is -10.00 m NAP) was set on the lowest surface level.

3.5.3 Model output

A 3Di-model produces high resolution and detailed output in relative small computation times, despite the high amounts of information that is put in the model (3Di consortium, 2014). With the output, grids with a spatial distribution of the water depth for the concerned rainfall event were produced. The water depth grid was visualized as the water depth per pixel (given relative to the DEM) at a certain time step or as the maximum water depth per pixel at various time steps. In the first case the time step is fixed (e.g. t = 5 min) and returns the water depth at that time step, where in the last case the water depth is fixed (the maximum value) and returns the maximum water depth measured in that pixel at a certain time step. Moreover, the output also includes the flow velocity between grid cells for each time step. Flowlines were generated (derived from the DEM) to determine the origin of rainwater on the streets and in which direction it flows as they represent the path of water towards the lowest points in the

DEM. Furthermore, drainage areas were obtained. When multiple flowlines end at the same location their origin was recovered which determines the boundary of a drainage area.

3.6 Rainfall events

Flood modelling with the 3Di-model of the Olympia district was performed with a simulation driven by three rainfall events (using three rainfall events is acknowledged in the European Flood Directive (2007/60/EC)). The events concerned are listed in Table 3-1.

Table 3-1. Overview of the rainfall events modelled with the 3Di-model of the Olympia district.

Rainfall event [-]	Intensity [mm/h]	Recurrence time [year]	Duration of rainfall event [h]
1. - 'bui02'	10,5	0.25	1:15
2. - 'bui08'	19,8	2	1
3. - 'bui60'	60	100	1

RIONED (2004) defined several normative rainfall events (based on KNMI statistics) to analyse scenarios with water on the streets and for the design of water robust urban environments in the Netherlands. The total duration per rainfall event is determined as the average duration of all events selected from the data-series that are more extreme (in terms of the amount of precipitation in 15 minutes) than the recurrence time. Most rainfall events are long-lasting (little difference in intensity over time) with only few high intensity peaks which are not interesting for hydraulic modelling. Consequently, only the period in which 85% of the total amount of precipitation is fallen is taken into account which decreases simulation times (RIONED, 2004). The rainfall events (Table 3-1) were used to create output with the 3Di-model. The events are spatially uniform which means that rain is falling over the complete project area with the same intensity. Anyhow, the events are not uniform over time due to a peak in the event. A rainfall-peak (maximum duration is 10 minutes) is added as it puts more stress on the model than a uniform scenario because of higher quantities of rainwater in a shorter period of time (RIONED, 2004).

The first simulation was a rainfall event with an intensity of 10.5 mm in 1 hour and 15 minutes. RIONED (2004) defined that this is a normative rainfall event, called 'bui02', which occurs four times per year. The next simulation was an event of 19.8 mm in 1 hour ('bui08') that occurs once every two years (Figure 3-10 shows the progression of the rainfall event). 'Bui08' is the minimum design criterion for sewage systems in the Netherlands and the Dutch sewage systems should be capable to process this event.

The last simulation was a rainfall event of 60 mm with the duration of 1 hour ('bui60'). In this research, this particular rainfall event was selected (in consultation with the municipality of Almere) as a climate stress test for the urban planning design of the Olympia district. The event is a representation of a potential rainfall scenario. Though, the mentioned recurrence times are expected to decrease as a result of climate change. Overall changes in these recurrence times were investigated and underlined by Lenderink et al. (2011), but they based their conclusions on rainfall records for the period 2000-2011.

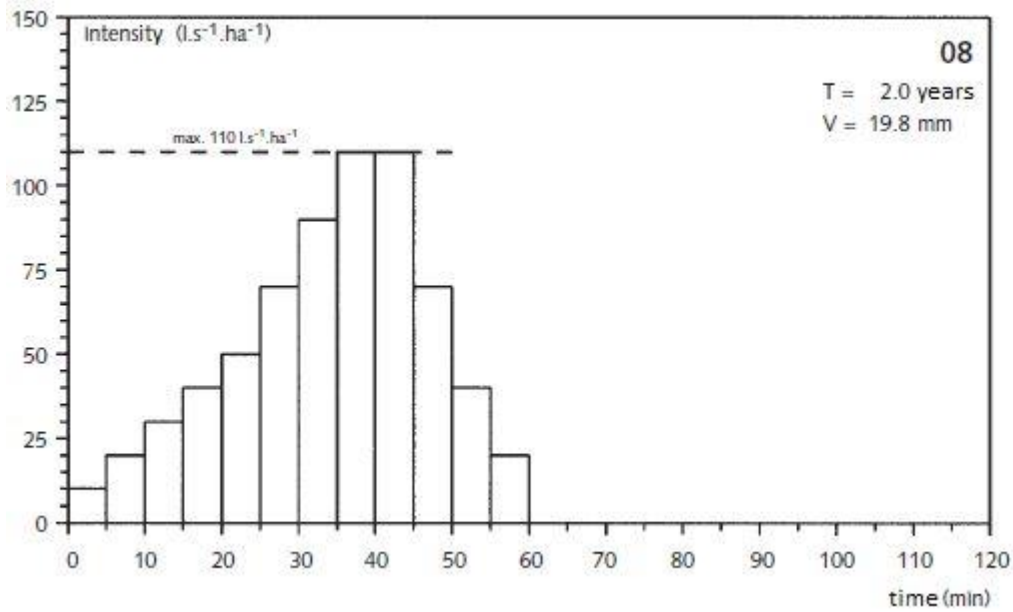

Figure 3-10. Progression of rainfall event 'bui08' as defined by RIONED (2004).

3.7 Design criterions to evaluate the urban planning design

The urban planning design was evaluated on fulfilling the design objectives:

- Residences are not affected by surpluses of drained rainwater;
- Roads remain accessible;
- Critical water depths at parking lots and in WADI's are avoided.

Also, in the first work session (section 3.2), additional water management related design criterions and general questions were added to the objectives. These criterions and questions were included to perform an in depth evaluation of the water system in the urban planning design. The main design criterions and questions are listed below (Annex III provides a full summarized description).

Design criterions

- The disconnected sewage system for rainwater is a final solution for water to flow out of the Olympia district;
- The three tunnels under the railway track all contain a pumping station which are connected to the surface water.
- Special interest for the railway track and multiple WADI's with high infiltration capacities;
- The WADI's are connected with each other by a so-called 'Permeoblok' and is in fact a tube with a permeable surface on top.
- Certain parts of the WADI's are assigned to remain wet for a longer period.

Questions

- Flowlines; how does water flow and does it flow according expectations?
- Is the storage capacity of the WADI's sufficient to store the 60 mm/h rainfall event?
- At which rainfall event is the central WADI's tipping over point deployed (water can flow over the road towards the surface water) at the north side of the project area?

Furthermore, discussions with and between the professionals in the second work session led to the acceptable maximum time of inundation that are presented in Table 3-2.

3.8 Data analysis output related to 3Di

The model output was used to analyse whether the designed water system in the Olympia district functions adequately. The first objective, residences are not affected by surpluses of drained rainwater, was examined by a spatial analysis of the maximum interpolated water depth at certain time steps in the three rainfall events. Residences prone to flooding were determined by placing the water depth layer over the ground surface type layer. A residence was prone to flooding if the water depth layer covered the residence ground surface type. In each water depth layer, 1.5 cm water depths were made invisible, because these water depths:

- are reached simple in the rainfall events;
- are less important as they have little effect on water in the residences;
- might be the result of small interpolation errors.

Besides, water depths at different pixels are exaggerated due to higher water depths in the surrounding pixels with the result that for every pixel an average value is returned. Thus, a small water depth will eventually be higher.

Road-accessibility and the prevention of critical water depths were assessed by a spatial analysis of the maximum interpolated water depth at certain time steps in the three rainfall events. Because roads should remain accessible (especially for emergency traffic) and critical water depths should be avoided, three categories were defined: inaccessible, partly accessible and accessible. Roads and other locations become inaccessible when a water depth of 20 cm or more is reached, partly accessible at water depths between 10 and 20 cm and are accessible at water depths below 10 cm.

Data containing information on the network of roads in the Netherlands was not present for the Olympia district (the district currently exists of sand plains). Therefore, statistics of the amount of pixels in one of the three categories were used to examine the relation between the intensity of a rainfall event and the percentage of the project area that becomes inaccessible.

Table 3-2. Overview of the analysed water problem locations in the preliminary urban planning design of the Olympia district.

ID	Ground surface type	Max. water depth	Acceptable maximum time of inundation		
			10 mm/h	20 mm/h	60 mm/h
1.	WADI	0.78 m	24 – 48 hours	24 – 48 hours	24 – 48 hours
2.	Bicycle lane	0.60 m	15 minutes	30 minutes	24 hours
3.	Green zone	0.27 m	6 hours	12 hours	24 hours
4.	Bicycle tunnel	0.58 m	15 minutes	30 minutes	1 hour

Furthermore, four water problem locations were analysed. Graphs were created by retrieving data from the 3Di plugin in QGIS, which presents the relationship of the water level at the concerned location over the total simulation time. The locations (indicated with a star in Figure 3-11) are selected on the ground surface type and the maximum water depth that is reached at the location for the different rainfall events (Table 3-2). For these locations it was examined whether the acceptable maximum time of inundation was within the pre-set limit or exceeded and would cause nuisance for passers-by or inhabitants.

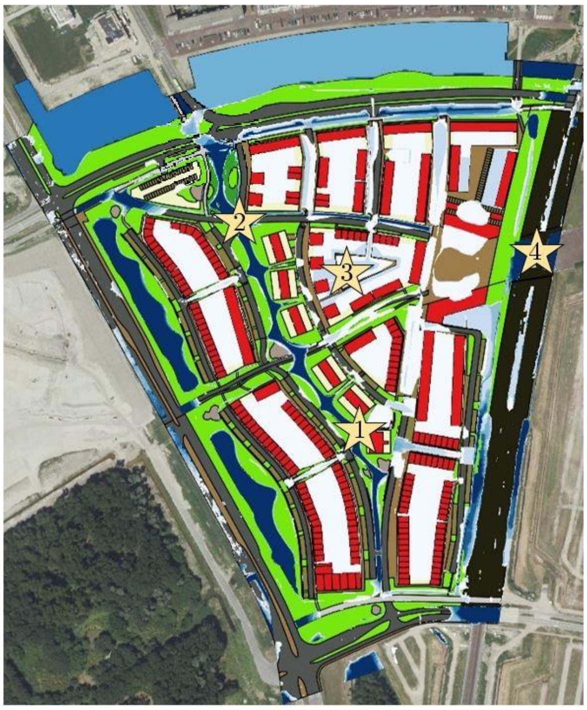

Figure 3-11. Overview of the selected locations with water problems at the Olympia district.

The total time that a location remained inundated was determined using two methods. In the first method, data from the 3Di-plugin in QGIS showing the water height progression over the time period of the rainfall event, was translated into the right format to work with in Excel. However, the total simulation time of the model was set at 240 minutes. In this time period most locations did not drain completely and water was still found. Therefore, data series were extrapolated from the moment that the water depth decreases with a constant rate and no water flows are observed between the water problem location and the surrounding areas. The assumption here is that from this moment onwards the water depth decreases due to infiltration (also the water table is neglected). The slope of the data-line is used to calculate the water depth over time. To check the validity of this method, also a calculation by hand was performed. The same moment in the data series (as previously described) was used, since the assumption is that water infiltrates by the location's infiltration rate. From this moment, the difference between the water height at that time step (h_x in m) and the surface level (h_0 in m) is divided by the infiltration rate (I) in meters per day times 24 hours:

$$T = \frac{-(h_0 - h_x)}{(\frac{I}{1000})} * 24$$

4 | Results

Results of flooded and unaffected residences, road-accessibility, critical water depths and the analysis of the water problem locations are presented in this chapter. These results are created based on the 3Di-model output. Also the results of the interviews are presented.

4.1 Flooding patterns

4.1.1 Flooded residences

The evaluation of flooded and unaffected residences at different rainfall events is performed with the maximum interpolated water depths for the different rainfall events. The result is that flooded residences only emerge in the event of 60 mm/h. Therefore, the maximum water depth reached at the 60 mm/h rainfall event is presented in Figure 4-1. All events are also presented in Annex IV. As seen in Figure 4-1, the residences closest to the square in front of the railway station are affected by water depths below 5 cm. These residences are indicated in red and the unaffected residences in white (Figure 4-2).

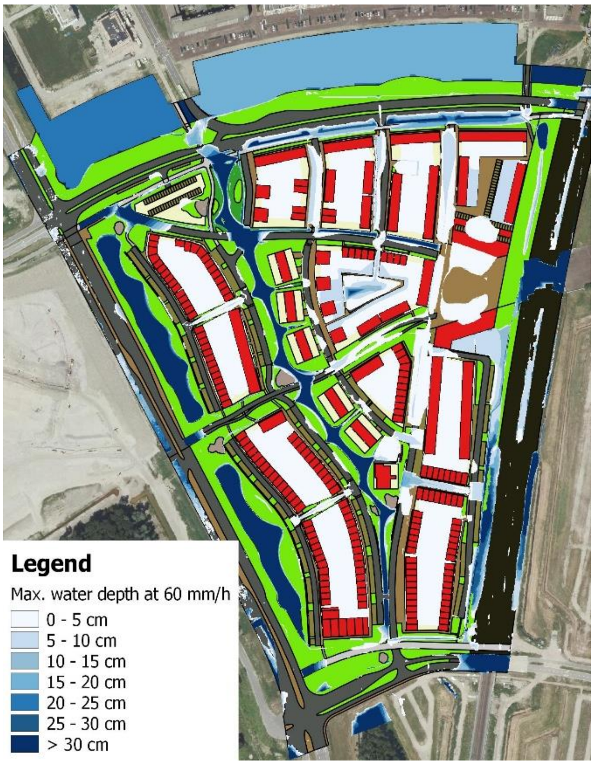

Figure 4-1. Maximum water depth at 60 mm/h.

Figure 4-2. Flooded residences at 60 mm/h.

4.1.2 Road-accessibility and critical water depths

The accessibility of the roads is derived from the maximum water depth at the different rainfall events (Figure 4-3). The roads, bicycle lanes, parking lots and pavements are selected upon which the maximum water depth is projected. Accessible road-parts and locations are indicated with a green colour, yellow areas are roads and locations that are more difficult to access, but emergency vehicles are still able to pass. A red colour indicates that a part of the road or location is inaccessible and water depths of 20 cm and higher are reached.

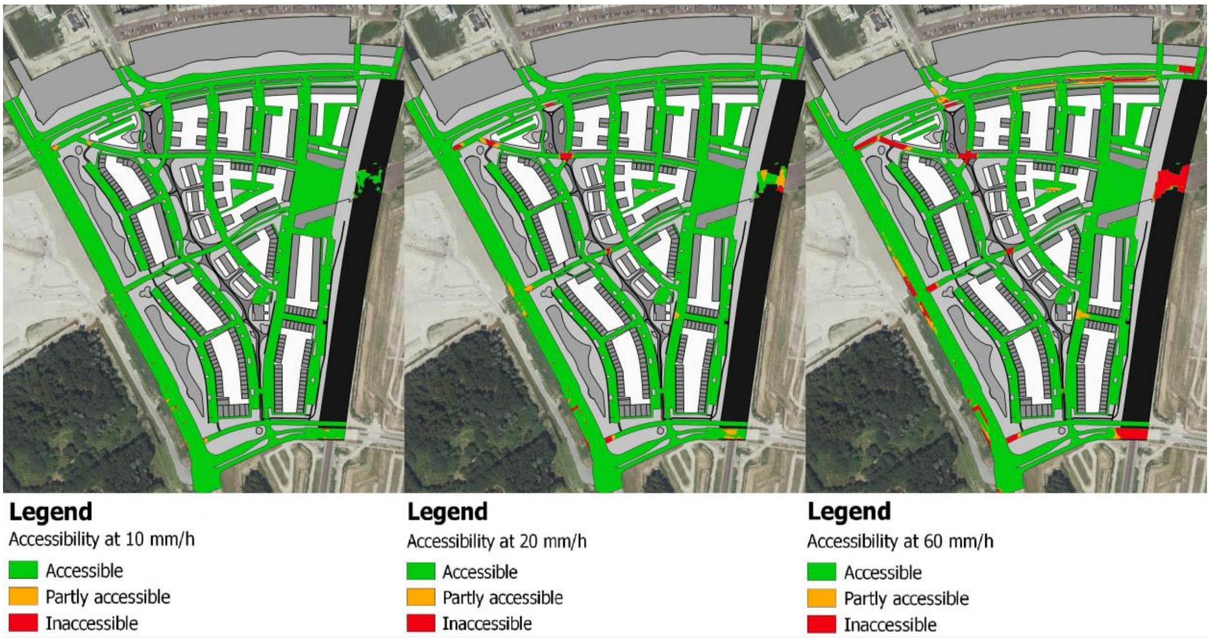

Figure 4-3. Accessibility and critical water depths Olympia district per rainfall event.

Critical water depths are detected at several locations in the project area (Figure 4-3). In the rainfall event of 10 mm/h critical water depths hardly occur. Figure 4-4 shows that 0.2% of the highlighted area becomes inaccessible. Few locations in the 20 mm/h rainfall event are indicated as inaccessible (percentage of inaccessibility increased to 1%), but are of less hindrance as the locations are mostly bicycle lanes and pavements. More critical water depths are reached (5.2% of the highlighted area becomes inaccessible) in the 60 mm/h rainfall event: now tunnels and road-parts are inundated with water depths of more than 20 cm. Thus, accessibility becomes a greater problem at the extreme rainfall event of 60 mm/h.

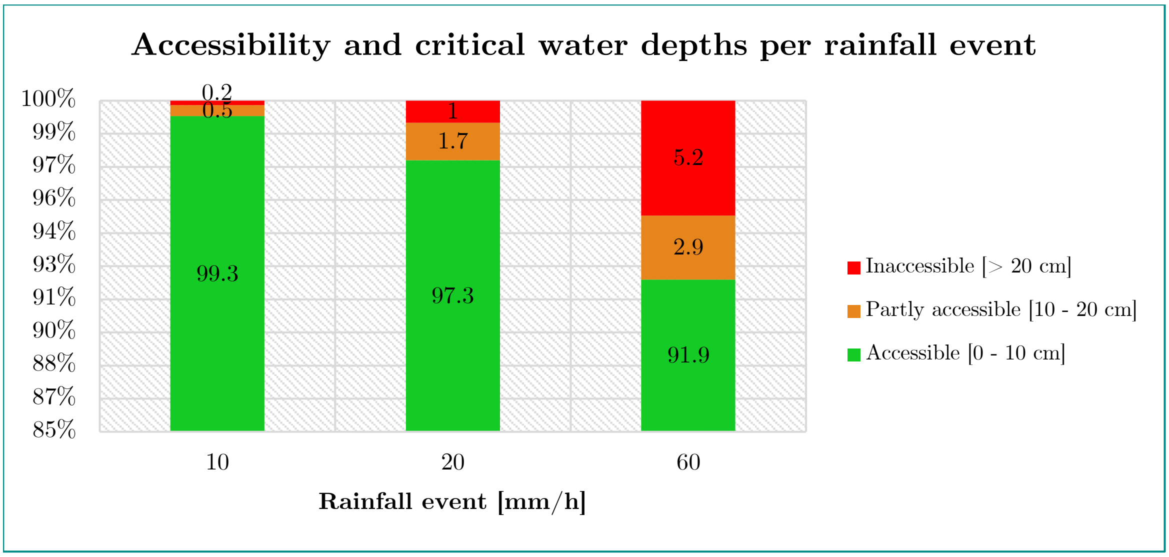

Figure 4-4. Distribution of the accessibility and critical water depths per rainfall event.

4.1.3 Drainage areas and tipping point central WADI

Figure 4-5 shows the drainage areas divided into six classes. The total drainage areas connected to the different classes are presented in Table 4-1. It becomes clear that the difference between the total surface and the connected flow area is the highest for the 'gravel pit' and the smallest for 'surface water'. The negative difference for the class 'other' is declared by the fact that the surface is lost to the other classes.

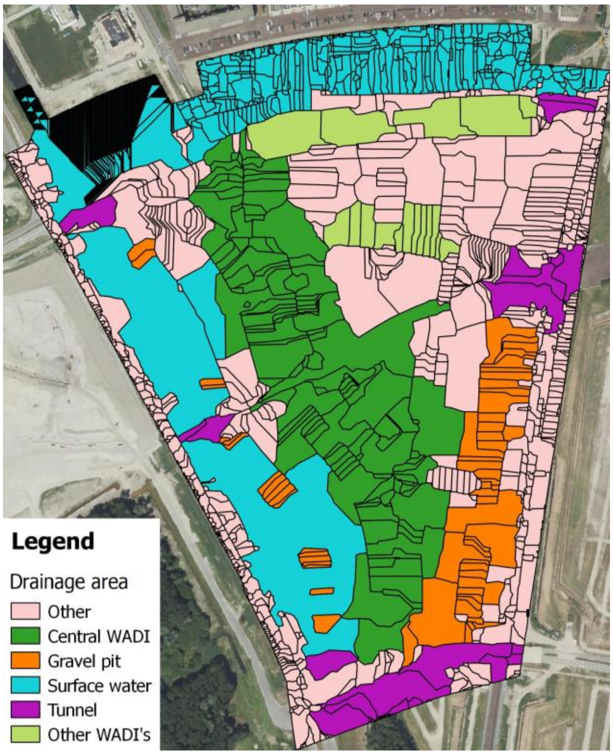

Figure 4-5. Drainage areas in the Olympia district derived from the DEM.

Figure 4-6 shows the height-volume relationship of the water level in the central WADI and the amount of precipitation to determine at which rainfall event the tipping over point, where water can flow over the road towards the surface water, at the north side of the WADI is used. The lowest point in the WADI is -3.7 m NAP and the tipping over point is at -3.2 m NAP. The figure shows that at a rainfall event of 24.5 mm, water flows over the tipping point towards the surface water. What should be noted is that infiltration and the time component both are neglected in this graph and therefore the rainfall event could in practice turn out higher than a rainfall event of 24.5 mm.

Table 4-1. Drainage areas in relation to the designed total surface.

Class	Total surface [m²]	Total drainage area connected [m²]	Total increase or decrease [-]
Central WADI	11320	47570	+ 4,20
Gravel pit	880	17130	+ 19,47
Surface water	30280	58280	+ 1,92
Tunnel	5110	12880	+ 2,52
Other WADI's	1370	11740	+ 8,57
Other	176050	77410	- 0,44

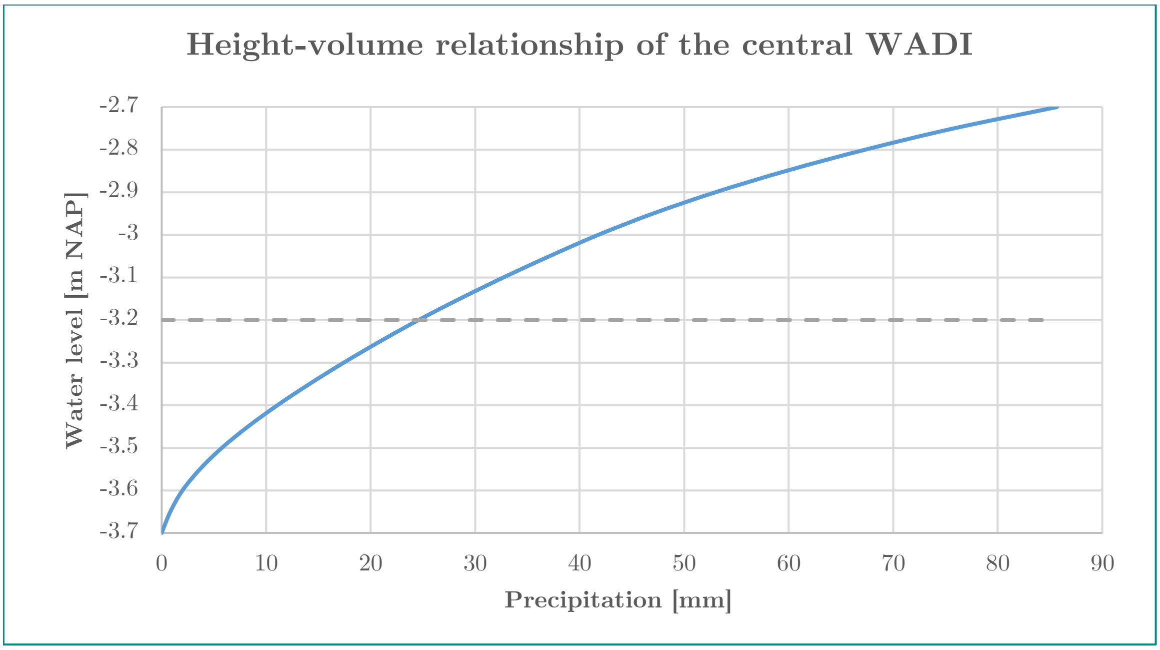

Figure 4-6. Relationship between the water level in the central WADI and the amount of precipitation that falls.

4.1.4 Locations with water problems

Four locations with water problems in the urban planning design of the Olympia district were analysed. For every location the water height progression is shown per rainfall event with the results presented in Figure 4-7, 4-8 and 4-9. The dotted lines show the 10 mm/h rainfall events, the dash lines show the 20 mm/h rainfall events and the solid lines show the 60 mm/h rainfall events.

The water height progression for the rainfall event of 10 mm/h (Figure 4-7, red dotted line) increases at 15 minutes after the start of the rainfall event due to the intensity increase of the rainfall. After 112 minutes, the water height on the surface reaches a maximum of 23 cm (37 minutes after the end of the rainfall event). The fact that the maximum water height is not reached during the rainfall event is granted to the surrounding area at higher surface levels that contributes to this location. From 112 minutes, the water height decreases slowly because of the area's infiltration capacity of 480 mm/day. The location remains inundated for approximately 11 hours at the least and approximately 15 hours at the most, which is below the acceptable maximum time of inundation (Table 4-2).

The water height progression at location 2 shows different trends (yellow dotted line). An explanation is that the surface level of location 2 is higher than location 1. Second, again the water height increases slowly the first 15 minutes but lower maximum water heights are observed (4 cm after 51 minutes). When the simulation ends, at location 2 little water is on the streets but it takes longer to infiltrate due to a lower infiltration capacity. The location remains inundated for approximately 3 hours, so the acceptable maximum time of inundation is exceeded.

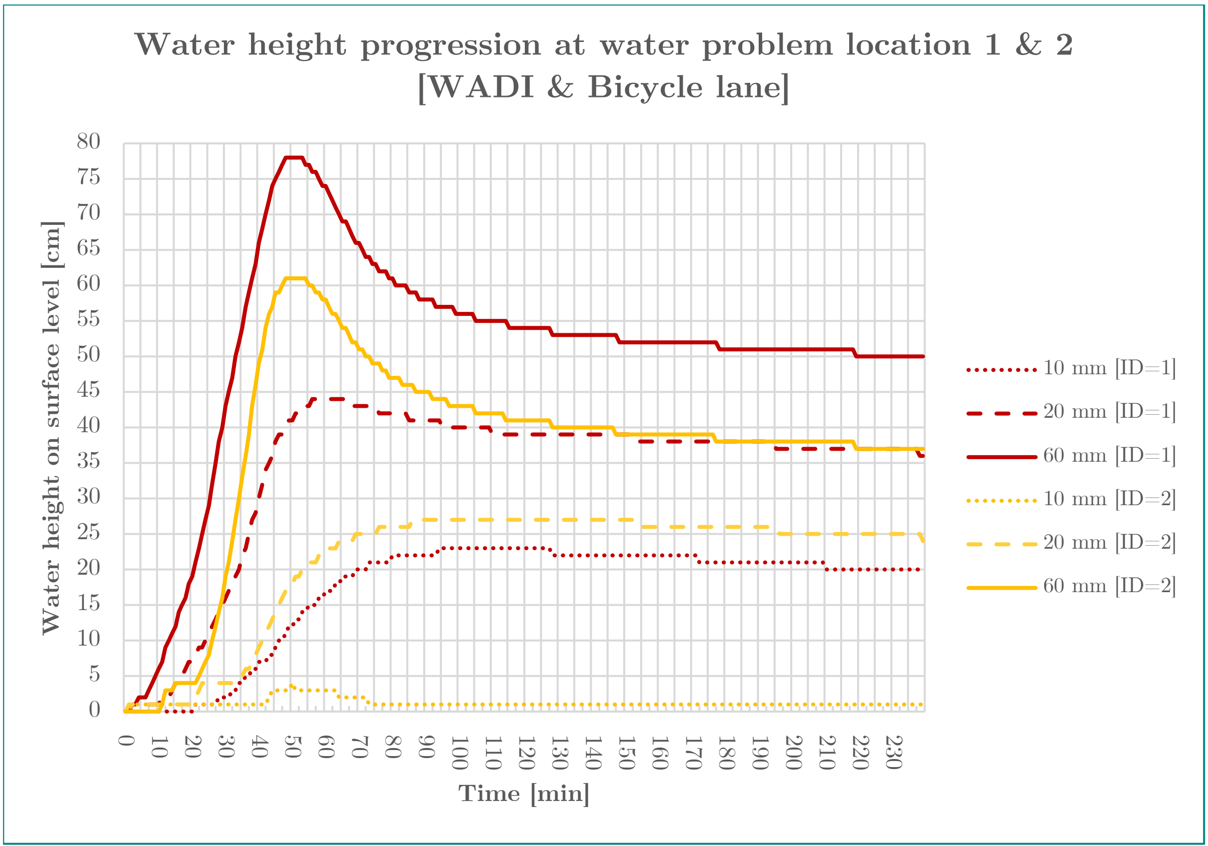

Figure 4-7. Water height progression over the time period of the three rainfall events for water problem location 1 & 2.

Table 4-2. Overview of the actual time of inundation per location and per rainfall event. [4]

ID	Rainfall event	Infiltration capacity	Time of inundation [3Di plugin data in Excel]	Time of inundation [by hand]	Exceedance acceptable max. time of inundation
1.	10 mm/h	480 mm/h	15.25 hours	10.79 hours	No
	20 mm/h		30.15 hours	19.06 hours	No
	60 mm/h		40.81 hours	25.87 hours	No
2.	10 mm/h	0 mm/h	3.1 hours	-	Yes
	20 mm/h		21.52 hours	-	Yes
	60 mm/h		30.68 hours	-	Yes
3.	10 mm/h	120 mm/h	80.65 hours	48.70 hours	Yes
	20 mm/h		50.62 hours	56.58 hours	Yes
	60 mm/h		36.57 hours	57.81 hours	Yes
4.	10 mm/h	0 mm/h	3.77 hours	-	Yes
	20 mm/h		4.37 hours	-	Yes
	60 mm/h		6.37 hours	-	Yes

[4] Both methods to calculate the time of inundation are discussed in section 5.1.3. Location 2 and 4 are not calculated by hand as there is no infiltration capacity.

Analysing the 20 mm/h rainfall event for location 1 and 2, it is observed that the water height increases immediately. Location 1 reaches a maximum water height of 44 cm after 62 minutes. First the water height decreases rapidly and from approximately 110 minutes the water heights at both locations decrease at a similar pace by infiltration rate. Location 1 remains inundated for approximately 19 hours at the least and approximately 30 hours at the most for the 20 mm/h rainfall event. Location 2 has a similar water height progression except from the first 36 minutes due to the surface level difference. This location reaches its maximum water height (27 cm) after about 110 minutes. Location 2 remains inundated for approximately 22 hours, so the acceptable maximum time of inundation is exceeded.

The rainfall event of 60 mm/h shows different trends at both locations. Logically, water heights increase more rapidly and almost start to increase at the start of the rainfall event (the water height of location 2 significantly increases a few minutes later than location 1). The maximum water heights (78 cm and 61 cm) are reached at 49 minutes while the rainfall event continues for 11 more minutes. Location 1 remains inundated for approximately 28 hours at the least and approximately 41 hours at the most for the 60 mm/h rainfall event, which is not within the limit of 24 hours. Location 2 exceeds the acceptable maximum time of inundation (of 24 hours) by approximately 7 hours.

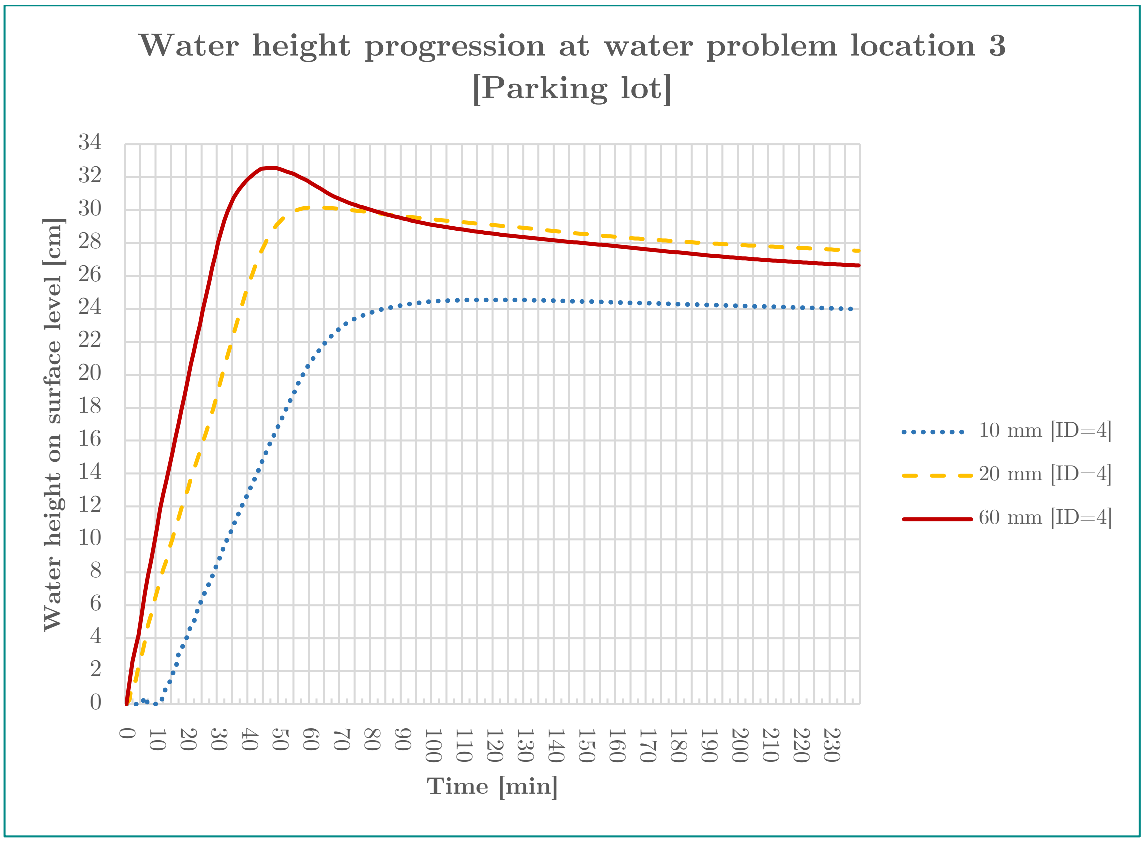

Figure 4-8. Water height progression over the time period of the three rainfall events for water problem location 3.

Figure 4-8 shows the water height progression over the time period of the three rainfall events for location 3. During the 10 mm/h rainfall event, the water height does not increase much in the first ten minutes (the line shows a small bump, probably due to a simulation error), after which it increases rapidly until it reaches the maximum water height of 25 cm after 106 minutes. At this location both calculations show that the acceptable maximum time of inundation is exceeded enormously. This is undesirable since the close-by parking lots also remain inundated for a long time. As a result, the cars parked here will be damaged in a rainfall event that could take place 4 times per year.

During the 20 mm/h rainfall event the water height increases immediately and reaches a maximum of 30 cm after 53 minutes. Also, in this event the acceptable maximum time of inundation is exceeded by far.

The increase in water height, in the 60 mm/h rainfall event, shows almost similar trends as the 20 mm/h rainfall event, except that the water height increases more quickly. The maximum water height of 33 cm is reached after 45 minutes. The rainfall event progresses for another 15 minutes with a lower intensity. Further, the acceptable maximum time of inundation is exceeded even more than the previous events.

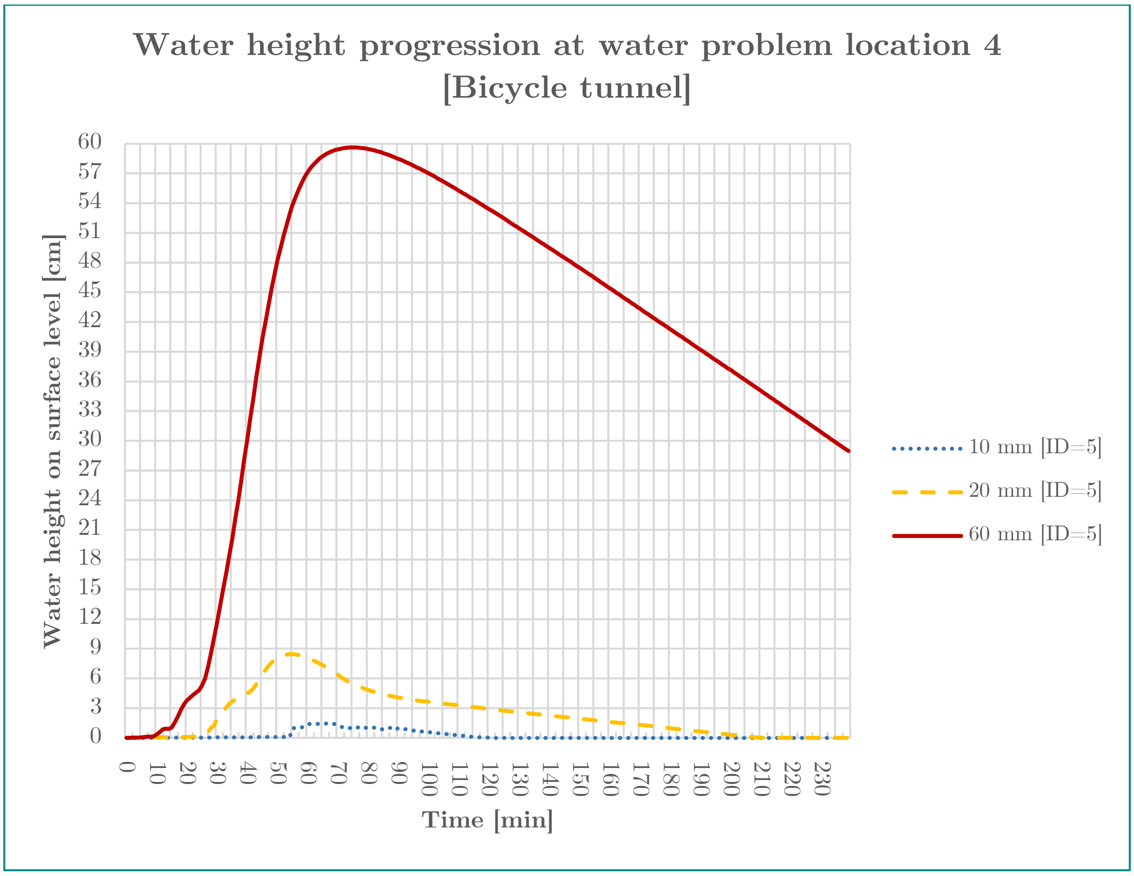

Figure 4-9. Water height progression over the time period of the three rainfall events at water problem location 4.

The increase in water height is minimal for the 10 mm/h rainfall event for location 4 (Figure 4-9). The maximum water height of 1.4 cm is reached after 61 minutes. The water height at this location is low due to a pumping station which pumps water out of the tunnel. The acceptable maximum time of inundation is exceeded, but since the maximum water height is slightly higher than the surface level it does not result in hindrance. Though it might be inconvenient for the people who walk, but cyclists are still able to pass.

The water height in the 20 mm/h rainfall event increases after approximately 25 minutes to a maximum water height of 8 cm after 55 minutes. Again the acceptable maximum time of inundation is exceeded and results in more hindrance than the previous rainfall event.

The water height in the 60 mm/h rainfall event increases after 10 minutes and reaches its maximum (60 cm) after 76 minutes. The effect of the pumping station becomes clear when analysing the water height progress after 76 minutes. Since the pumping station pumps out water with a steady pace, the location only remains inundated for approximately 6 hours which is rather short compared to the other locations. Still, the acceptable time of inundation is exceeded and therefore pump capacity should be increased.

4.2 Urban planning processes and water management in practice

As mentioned before, interviews were conducted to clarify how urban planning processes are executed in practice and to obtain information on work patterns and experiences of the professionals interviewed. The interview results are presented in Table V-1 to V-3 (Annex V) and explained in detail in the next sections.

4.2.1 Urban planning processes

The following results, related to the urban planning process theme, can be derived from the answers provided by the interviewees:

- *Professionals in the position of landscape planner or public space designer are involved in the pre-exploratory phase of the urban planning process.*

- *Consultants and interviewees at a management position enter the process in the exploratory phase.*

- *Consultants and interviewees at a management position stay longer in the process than landscape planners and public space designers.*

After the design phase the project has to be realised and managed. In these last phases, landscape planners and public space designers are not needed anymore.

- *Two out of eight professionals interviewed do think there are differences to be found in the urban planning process of urban construction projects and urban redevelopment projects.*

One interviewees opinion was that the difference is that the process is more simplified in urban construction projects, because the end-use of the area changes in these projects (e.g. from agriculture to an urban environment). Therefore, it less difficult to reserve space for water in the project, where in redevelopment projects more research needs to be done on how every component fits in the urban planning design (custom fit). Another interviewee added that more knowledge of the water system is needed and more professionals need to discuss about the design plan, which makes the process more complicated.

- *Every interviewee provides products in a 2D format (e.g. drawings on paper) and some even provide digital products in a 3D format (e.g. AutoCAD drawings in 3D).*

- *Almost every interviewee needs to consider water management.*

Traditionally most landscape planners and public space designers needed to integrate surface water in the urban planning design (surface area of approximately 7% of the total project area). Since several years climate change creates awareness that the urban environment should be climate proof. As a result, urban water management became more important over time and inspired to create innovative urban planning designs (it became a design criterion). However, the way professionals consider and integrate water management in the urban planning process differs per location because it is dependent on who is involved (e.g. political preferences, type of municipality or the civil servant involved).

4.2.2 Communication and information necessities in urban planning processes

The following results, related to the communication and information necessities in urban planning processes, can be derived from the answers provided by the interviewees:

- *The professionals interviewed agree that there is a need for a hydraulic modelling tool in the urban planning process.*

With a hydraulic modelling tool information is well sorted and very comprehensible. Moreover, a model only has to be set up once and could be used for other purposes than merely water management.

- *Every professional thinks it is desirable to evaluate urban planning designs on water management.*

Both in urban construction projects as in urban redevelopment projects. Evaluating urban planning designs on water management could prevent flooded residences or other unwanted situations.

- *Five out of eight professionals interviewed think that the need for a hydraulic modelling tool is higher in urban redevelopment projects.*

The opinions are that these projects are more complex and so is the accompanying water management issue.

- *Almost every interviewee thinks that 3Di is a useful instrument to evaluate an urban planning design on water management.*

3Di delivers output with a high resolution and can be adjusted rather simple. Another main advantage of 3Di is that it connects 1D and 2D flow and therefore includes complete water systems with the result that water management issues can be prevented as much as possible in advance.

- *Six out of eight professionals think that 3Di is more applicable within urban redevelopment projects.*

In these projects, the main structure of the urban environment needs to be considered. On that account, 3Di can produce a custom fit which makes it more applicable in this process.

- *Every interviewee but one thinks that the process of urban planning projects will be more efficient because more information is digitally generated with tools like 3Di.*

An instrument like 3Di translates complex situations and problems into more understandable matter, even for professionals outside the water domain. In practice, water problems are prevented more and the duration of the project decreases if 3Di is implemented at the right moment.

4.2.3 Professionals on the hydraulic modelling tool 3Di

The following results, related to 3Di, can be derived from the answers provided by the interviewees:

- *Only consultants use a hydraulic modelling tool and from the instruments available, they use 3Di.*

Landscape planners and public space designers do not have the acquired knowledge to work with 3Di. In general, they also do not have to work with hydraulic modelling tools.

- *Other professionals than those who use 3Di believe that they are going to build their own 3Di-model.*

This could be related to that some professionals only use the output of 3Di and make use of the applications within 3Di. Moreover, consultants do not think they are going to build the model itself (hydraulic modelling is a speciality) although it could be useful to have hydraulic modelling expertise in-house.

- *Three out of eight professionals interviewed think that the main function of 3Di is that it is a communication and visualization instrument.*

On small scales (e.g. evaluating the urban planning design of the Olympia district with 3Di on water management), 3Di is useful for professionals inside the water domain (or for the professionals that are involved with the work done within the water domain) as a communication tool, because it provides high detailed information on the hydrological regime in urban environments. On bigger scales (e.g. municipal development plans), 3Di is a powerful visualisation tool to persuade decision-makers, without any hydrologic or water management knowledge, that there are water management problems and that they need to act.

- *Every professional expressed the need for additives in 3Di and the need to immediately change the output of 3Di in interactive work sessions.*

Landscape planners and public space designers go through a process of constantly changing concept urban planning designs and exploring possibilities. These professionals believe that the downside of 3Di is that e.g. surface levels cannot be adjusted immediately to see the effect of the adjustment on the functioning of the water system. Therefore, the usability decreases since you always have to back to a GIS-environment which is time consuming.

- *The specialist from the Amsterdam University of Applied Sciences was the only interviewee that gave answers that did not match the statements in this table or did not agree with them.*

5 | Discussion

This chapter discusses whether the methods used and results created are reliable. Furthermore, the implications of this research are discussed.

5.1 Evaluation of the methods

5.1.1 General remarks on the basic principles of 3Di

Although 3Di contains a high level of physical and spatial detail, still some processes are not included in 3Di. The unsaturated zone and groundwater tables are not accounted for in 3Di (soon to be added). When rainwater infiltrates into the soil it disappears out of the model and thus is not added to the groundwater table. However, this process is only interesting when simulated over long time-periods and for projects in which infiltration of water to groundwater is necessary.

Also, at the start of a rainfall event simulation a 3Di-model assumes that the water can infiltrate with maximum capacity; this might be true for the months (e.g. July) with low groundwater tables, but is not realistic for the months (e.g. January) with a high groundwater table. In the latter situation, the model might over-estimate infiltration rates, and hence underestimates surface water depths.

5.1.2 Limitations due to model boundaries

Due to the model boundaries (result of project borders), the 3Di-model underestimates the inflow of rainwater (either via overland flow or through the water system that has an open connection with other areas) from the surrounding areas. As a result, more water could accumulate on the streets in the Olympia district. Since the Olympia district is to be situated in a polder with average elevation level of -2.50 m NAP and the surrounding urban environment of Almere DUIN is higher, steps need to be taken to prevent water flow from Almere DUIN to the Olympia district.

5.1.3 Calculating inundation times of the water problem locations

Uncertainties and inaccuracies are to be found in both methods to evaluate water problem locations as differences among the time periods of inundation have been observed.

In 3Di the amount of wet pixels within a computational grid cell (4m x 4m) is calculated. In the calculation by hand, the wet surface is overestimated because the assumption is made that the complete computational grid cell is wet. Therefore, water can infiltrate with a constant rate over a larger area while in practice the wet surface becomes smaller over time and therefore the total volume that can infiltrate also decreases.

In the data from the 3Di-plugin, the amount of wet pixels and the corresponding volume decrease over time. However, both are still overestimated at some locations (e.g. large times of inundation are calculated at location 3) as the total simulation time is 4 hours and the amount of wet pixels and the total volume are not calculated after 4 hours. When a location remained inundated after 4 hours, the data series have been extrapolated to estimate the total time of inundation. However, data-extrapolation still overestimates the decrease of the amount of wet pixels and the corresponding volume. In practice, the results should reveal shorter times of inundation, so longer simulation times would reveal more precise outcomes.

Furthermore, infiltration rates of other ground surface types within the same computational grid cell are neglected when calculating inundation times by hand. For the whole grid cell, one infiltration rate is used while parts of the grid cell contain other infiltration rates. Finally, the soil becoming saturated and other processes that get water out of the system (e.g. evaporation) are also neglected in the calculation by hand.

5.1.4 Interviewing professionals

The interviews gained insight on the interpretations, experiences and beliefs of multiple professionals (with different backgrounds) within the urban planning process. As six out of the eight professionals interviewed had experiences with hydraulic models (in special 3Di) this research is somewhat biased. Perhaps if professionals without knowledge of 3Di were interviewed other insights were gained. Although, the professionals interviewed do have a better understanding of how hydraulic models should work (and what need to be included).

5.2 Evaluation of the results

5.2.1 Remarks on the accessibility results

Analysing the outcome regarding accessibility, it became clear that most inaccessible roads and locations (the pixels counted at that location) are a result from small errors in the DEM. Outside sources (other than Nelen & Schuurmans) generated the DEM, by flying over the Olympia district with a drone from which data could be translated to a GIS-environment. The downside is that at e.g. bushes have not been removed from the DEM and some data points were missing. Adjusting the DEM by interpolation (to close gaps or smoothen the surface) still resulted in unrealistic values at certain locations that are to be found back in the results. Thus, the DEM should be correct as this forms the basis for the output 3Di generates.

Furthermore, the objective of this urban planning design is that rainwater is discharged via the surface without causing nuisance or damage. Differences in the surface level are designed deliberately and therefore it is argumentative that these roads and locations remain inundated and inaccessible for a longer period. The municipality of Almere mentioned that future inhabitants should be conscious of a changing climate and how their living environment handles e.g. extreme rainfall events, because water on the streets will occur more frequently as this originates from the urban planning design.

5.2.2 Remarks on the outcome of the interviews

An evaluation of the interview results revealed remarkable outcomes. As previously noticed, the specialist from the Amsterdam University of Applied Sciences was the only interviewee that gave answers that did not match the statements related to 3Di or did not agree with them at all. This outcome is related to that the interviewee does not necessarily has to consider water management (only had to in the urban planning process of the Olympia district) and does not work with hydraulic models.

Another remark is that most professionals interviewed (those that immediately want to adjust the output of 3Di in work sessions to see the effects of their changes) want to include the possibility that e.g. surface levels can be adjusted immediately to see the effects with 3Di. Since 3Di is a hydraulic modelling instrument and not a design tool, it is perhaps unwanted to include this feature in 3Di. On the contrary, an older version of 3Di contained this feature but was removed after some time. However, this feature will be added again with high priority in the current version.

5.2.3 Water management at the early stages of the urban planning process

Dealing with climate change in urban environments (e.g. evaluating urban planning designs on water management) asks for adaptation strategies which professionals in urban planning processes need to consider and apply. Implementing and developing adaptation strategies in these processes is difficult as many barriers like conflicting interests, ambiguous responsibilities and conflicting time scales of the actors involved are experienced by professionals (Biesbroek et al., 2011; Uittenbroek et al., 2012). Efforts of implementing adaptation strategies frequently have been reactive as they are based on extreme rainfall events that resulted in floods (Amundsen et al., 2010). Due to the many barriers, climate change adaptation strategies are hard to implement.

Including water management at an early stage of the urban planning process also revealed to be complex. Water management is considered as less important and lacks urgency (e.g. financial gains are considered more important) and therefore is included at the end of the decision-making process which makes it harder to embed water management in the urban planning process. Embedding it in as a design criterion for urban planning designs for example (e.g. to discharge rainwater via the surface as done at the Olympia district) ensures that water needs to be discussed and evaluated by the involved actors. Clear process-arrangements could ensure that the right actors are involved at the right moment and the interest of every actor involved is considered. However, including water management at an early stage of the urban planning process also depends on the willingness (e.g. some professionals think that there is no need to consider water management) to include water management versus the role of the involved actors as personal opinions or beliefs could differ from each other resulting in misunderstanding and disagreement between actors. Also the kind of organization, different political backgrounds, different knowledge levels and the involvement of new technology (like 3Di) could have an effect on embedding water management at the early stages of the urban planning process.

In addition, climate proof urban environments are created and urban flooding is decreased if urban planning policies and practices are changed. Policies are only shaped differently if local-scale pioneering and experimentation is continued following bottom-up initiatives (Zevenbergen et al., 2008). The creation of the Delta Plan Spatial Adaptation 2018, as part of the Delta Program, and the Dutch Environmental Law 2018 (the so-called 'Omgevingswet 2018') are examples of initiatives for transformation that reached higher levels of governance as both contain policies and proposals to develop e.g. water robust urban environments. Both acts are expected to ensure that adaptation strategies are considered by all actors involved in climate proofing Dutch urban environments

5.3 Implications

In this research a hydraulic model is used to evaluate a preliminary urban planning design on water management. Hydraulic models are normally used to recreate an actual intensive rainfall event which led to water problems and are not frequently used as an evaluation method to test the water system in a non-existent urban plan that has the objective to drain water above ground as much as possible. This last concept is relatively new and has not been carried out much. Applying 3Di as an evaluation method for an urban plan turned out to be useful. With the 3Di-model, points of concern and locations with water problems have been detected and an in depth analysis has been performed to derive the origin and cause of them. The urban plan for the Olympia district can be redesigned in an urban environment that complies with the design objectives, with the result that future water problems are prevented. As a result, 3Di seems very applicable in the design phase of an urban planning process and could be used earlier in the process if the need for such a hydraulic modelling tool is addressed.

The three rainfall events that were used to evaluate the water system in urban planning design of the Olympia district are events that use the present-day knowledge and insights in climate change. Literature and consulting agencies in water management frequently use the 60 mm/h rainfall event as a 'stress test' to test whether the urban planning design can discharge these amounts of rainwater.

This research indicated that there is a need for a framework and guidelines as professionals are still browsing for the right track towards climate proof urban environments. As not every municipality has to deal with the same problems (e.g. sloping areas are not to be found in every municipality, but sloping areas have much influence on the flow of water over the streets), it is hard to define one overall definition for being climate proof and to check when an urban environment is considered to be climate proof. Yet, it becomes clear that the current urban environments are not resistant to climate change and therefore a framework and guidelines maybe could help in the transition towards climate proof urban environments.

5.4 Recommendations for further research

The recommendations that follow from this research are recommendations related to improving 3Di and recommendations related to climate proof urban environments and water management at the early stages of the urban planning process.

Sensitivity analysis on 3Di-model input

Chapter 3 mentions that the height of the infiltration rate depends on the permeability of the ground surface type. In the 3Di-model of the Olympia district, a first estimated guess of the permeability per ground surface type (impervious, semi-permeable and permeable) was used as input parameters to determine the infiltration rate and the surface friction coefficient. As these parameters highly influence the output generated with 3Di, it is recommended to perform a sensitivity analysis on these parameters and their influence on the model output. It is recommended that real-time data is used as reference material.

Basic principles of 3Di

As described before, the period prior to the rainfall event simulation is not included in 3Di-models. Water depth results based on 3Di could be underestimated as the assumption is made that water can infiltrate with maximum capacity at the start of simulation which is inaccurate for the months with high groundwater tables. It is recommended to conduct further research on the effects of including the period leading up to simulation runs as an initial condition on the output generated with 3Di-models.

Next, it is recommended to perform in-depth research on simply adjusting surface levels in a 3Di-model (nowadays you need to go back to a GIS-environment) in work sessions, because if water accumulates on the surface it could be very useful to change an urban planning design immediately. Expected is that much time is needed to further develop 3Di into an instrument that is capable of the function mentioned above and it should be noted that, by adding more functions to 3Di, more needs are created. This may be unwanted.

Climate proof urban environments

Due to global warming, worldwide precipitation extremes have been observed more often which is acknowledged by research and literature (Lehmann et al., 2015; O'Gorman, 2015). In the Netherlands, increasing precipitation intensities and extreme rainfall events are also predicted by the four KNMI climate change scenarios (KNMI, 2015). However, as the return periods of precipitation events are very important in designing climate proof urban environments (e.g. selecting the accurate rainfall event for a stress test of the urban planning design), they are still highly uncertain. Therefore, more research is needed on the effects of the return periods like the research of Barbero et al. 2017 in which they observed that hourly extremes are less sensitive to global warming than daily extremes. Furthermore, many actors within the urban planning process are in need for guidelines as there is no framework developed for one single integral approach of developing climate proof urban environments and no overall definition of climate proof. Establishing a framework and a single comprehensive definition for climate proof ensures that actors follow the same steps in the process (and uses the same principles) in climate proof urban environments.

Water management at the early stages of the urban planning process

Literature pointed out that it is complex to embed climate adaptation and therefore water management in the urban planning process. In addition, the interviews with the professionals revealed that water management needs to obtain a 'value' (or some kind of urgency) before it is considered important. More research is needed on how to embed water management at the early stages of the urban planning process by awarding it more urgency and importance, e.g. using water management as a design criterion as applied in the urban planning process of the Olympia district, and how the professionals involved in the process respond to it (evaluate the interactive work sessions in which the output of 3Di is presented and discussed with the professionals involved).

6 | Conclusion

The main research question, addressed in this thesis was:

'To which extent can water management evaluation of an urban planning design be applied sooner in urban planning processes by using 3Di modelling in order to (re)design a climate proof Dutch urban environment?'

Urban planning processes exist of five phases in which many activities need to be carried out to reach and maintain a suitable urban planning design. There is potential to embed water management in a pre-exploratory phase as water management can be combined with several activities like the problem analysis and ambition check. However, water management is only to be combined with these activities as long as it is considered important and taken seriously.

However, actors experience barriers like conflicting interests, conflicting time-scales, the willingness to innovate versus their role and the lack of trust in new technology which complicates the progress of (re)designing climate proof Dutch urban environments. Moreover, the absence of a clear comprehensive definition for climate change and a framework with directives with fixed instructions that municipalities need to consider in climate proofing the urban environments provides space for own interpretations and influences from e.g. politics. But awareness is slowly progressing and confirmation is found in the light of climate change, the increasing intensive rainfall events and the resulting urban flooding.

Flood prevention investments and evaluating urban planning designs on water management, using 3Di modelling, should be applied in advance as research costs are (in most cases) only a small fraction of the total project budget and result in lower or even no flood-damage costs.

In depth analyses of the urban planning design of the Olympia district in Almere proved that 3Di is a very useful hydraulic modelling tool to simulate and test the effects of the design objective of maximized rainwater discharge via the surface. The three simulated rainfall events revealed that certain locations remain inundated for longer times than anticipated for and in the 60 mm/h rainfall event some residences are prone to flooding. The 3Di-results played an important role in work sessions as it provided insights in e.g. local (design) shortcomings of the urban planning design and new overarching insights concerning the maximum time-period locations can be inundated.

Due to the previous mentioned design criterion, actors needed to consider water management with the effect that a 'climate-proof analysis' of the urban planning design needed to be conducted with 3Di. The points of concern in the urban planning design (from a water management perspective) are solved with measures like raising pump capacities and raising surface levels of residences which ensure that large quantities of water are discharged safely or are to be found at desirable locations.

However, the possibilities of 3Di and the output it creates is still in progress and needs improvement according to professionals involved in the urban planning process, but they think that 3Di is an appropriate tool to perform a water management evaluation of an urban planning design and that it should be embedded in the urban planning process. Uncertainty is present on if water management is ever considered urgent and taken seriously resulting in the evaluation of urban planning designs on water management at an early stage of the urban planning process. Therefore, further research is recommended on the evaluation of urban planning designs on water management.

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Annex I

Interview Guide
Thesis Water Science and Management

'Applicability of a hydraulic modelling tool in the urban planning process aiming at climate proof urban environments'

1. Introductie

Ik ben tweedejaars student van de master Water Science and Management aan de Universiteit Utrecht. Per januari 2017 ben ik bij Nelen & Schuurmans gestart met het schrijven van mijn scriptie ter afronding van mijn Master. Met mijn scriptie doe ik onderzoek naar de toepasbaarheid van een hydrologisch model programma (zoals het programma 3Di dat mede ontwikkeld is door Nelen & Schuurmans) binnen het stedelijk ontwerpproces. Een veranderend klimaat en de daaropvolgende overheidsrichtlijnen zorgen ervoor dat er bewuster met onze stedelijke leefomgeving moet worden omgegaan zodat excessieve regenbuien opgevangen kunnen worden op plaatsen waar dat wenselijk is. Situaties van water overlast zijn niet langer indicenten, maar beginnen met enige regelmaat vaker voor te komen. Vandaar dat mijn onderzoek zich richt op hoe een hydrologisch model programma, waarbij er ondergrondse en bovengrondse waterstromen meegenomen kunnen worden, een rol kan spelen in het stedelijk ontwerpproces zodat steden klimaatbestendig worden ingericht. Meestal is het toetsen van het stedelijk gebied op water management reactief; gedreven door voormalige incidenten, maar de toetsing vindt ook plaats in projecten in het kader van herontwikkeling en nieuwbouw. Aangezien u betrokken bent en een rol speelt in een stedelijk ontwerpproces ben ik geinteresseerd in uw werkproces en ervaringen om inzicht te verkrijgen in hoe stedelijke ontwerpprocessen normaliter worden uitgevoerd, wanneer u in het stedelijke ontwerpproces ingeschakeld wordt en hoe het onderdeel water door u wordt opgevangen en ingevuld.

2. Uw gegevens

- Naam :
- Organisatie :
- Functie :
- Aantal jaren in deze functie :

3. Vragen

Het toetsen van het stedelijk gebied op water management is vaak gedreven door incidenten, herontwikkeling en nieuwbouw projecten. Om inzicht te verkrijgen in deze stedelijke ontwerpprocessen zijn de vragen per proces onderverdeeld.

1. Ontwerpproces van nieuwbouw projecten

- Hoe ziet een ontwerpproces voor een nieuwbouw project eruit?

- Wat is uw rol binnen een dergelijk ontwerpproces?

- Hoe houdt u rekening met het onderdeel water? Is dat bijv. een percentage waar u rekening mee dient te houden vanuit een bestemmingsplan?

- Welke producten levert u aan?

- Is uw manier van werken anders in vergelijking tot andere instanties?

- Hoe denkt u dat stedelijke ontwerpprocessen in de toekomst zullen worden ingevuld door strengere richtlijnen en wetswijzingen?

Communicatie en informatie behoefte bij nieuwbouw projecten

- Is het in een stedelijk ontwerpproces wenselijk om het stedelijk ontwerp te evalueren op water management? Tevens bij nieuwbouw projecten?

- Welke elementen zijn benodigd om het aangeleverde stedelijk ontwerp op water management te evalueren?

- Wat vindt u van het hydrologisch model programma 3Di (na het zien van videomateriaal) als instrument voor een evaluatie van een stedelijk ontwerp op water management?

- Hoe zou u 3Di in uw werkproces zien en hoe zou u gebruik willen maken van het programma?

- Denkt u dat het ontwerpproces meer geautomatiseerd gaat worden zodat het proces efficienter verloopt? Zou 3Di daarin een uitkomst kunnen bieden?

Visualisatie en interactiviteit bij nieuwbouw projecten

- Denkt u dat er behoefte is aan een hydrologisch model instrument als 3Di in een stedelijk ontwerpproces bij nieuwbouw? Wat is uw behoefte daarin?

- Heeft 3Di toevoegingen nodig om het voor u een bruikbaar instrument te maken?

- Op welke manier ziet u graag de uitkomsten van een hydrologisch model instrument aan u gepresenteerd worden?

- Welke ingrepen zou u zelf in de uitkomsten willen doen en welke mate van interactiviteit zou u graag zien? Wat verwacht u zelf te moeten kunnen (nu en in de toekomst) en verwacht u dat u straks zelf een 3Di-model moet maken?

2. Ontwerpproces van herontwikkelingsprojecten

- Hoe ziet een ontwerpproces voor een herontwikkelingsproject eruit?
- Wat is uw rol binnen een dergelijk ontwerpproces?
- Hoe houdt u, binnen een herontwikkelingsproject, rekening met het onderdeel water?
- Welke producten levert u aan?
- Is uw manier van werken anders in vergelijking tot andere instanties?

Communicatie en informatie behoefte bij herontwikkelingsprojecten

- Is het in een herontwikkelingsproject wenselijk om het stedelijk ontwerp te evalueren op water management?
- Welke elementen zijn benodigd om het aangeleverde stedelijk ontwerp op water management te evalueren?
- Hoe zou u 3Di in uw werkproces zien en hoe zou u gebruik willen maken van het programma?

Visualisatie en interactiviteit bij herontwikkelingsprojecten

- Denkt u dat er behoefte is aan een hydrologisch model instrument als 3Di in een stedelijk ontwerpproces bij herontwikkeling? Wat is uw behoefte daarin?
- Heeft 3Di toevoegingen nodig om het voor u een bruikbaar instrument te maken?
- Op welke manier ziet u graag de uitkomsten van een hydrologisch model instrument aan u gepresenteerd worden?
- Welke ingrepen zou u zelf in de uitkomsten willen doen en welke mate van interactiviteit zou u graag zien? Wat verwacht u zelf te moeten kunnen (nu en in de toekomst) en verwacht u dat u straks zelf een 3Di-model moet maken?

3. Ontwerpproces van incident gedreven projecten

- Hoe ziet een ontwerpproces voor een incident gedreven project eruit?
- Wat is uw rol binnen een dergelijk ontwerpproces?
- Hoe houdt u, binnen een incident gedreven project, rekening met het onderdeel water?
- Welke producten levert u aan?
- Is uw manier van werken anders in vergelijking tot andere instanties?

Communicatie en informatie behoefte bij incident gedreven projecten

- Is het in een incident gedreven project wenselijk om het stedelijk ontwerp te evalueren op water management?
- Welke elementen zijn benodigd om het aangeleverde stedelijk ontwerp op water management te evalueren?
- Hoe zou u 3Di in uw werkproces zien en hoe zou u gebruik willen maken van het programma?

Visualisatie en interactiviteit bij incident gedreven projecten

- Denkt u dat er behoefte is aan een hydrologisch model instrument als 3Di in een stedelijk ontwerpproces gedreven door incidenten? Wat is uw behoefte daarin?
- Heeft 3Di toevoegingen nodig om het voor u een bruikbaar instrument te maken?
- Op welke manier ziet u graag de uitkomsten van een hydrologisch model instrument aan u gepresenteerd worden?
- Welke ingrepen zou u zelf in de uitkomsten willen doen en welke mate van interactiviteit zou u graag zien?

Annex II

Additional information that can be extracted and calculated by 3Di.

Interception: Up to date, it is not possible to insert and perform simulations with an interception subgrid in 3Di. However, the interception can be extracted from the rainfall event and calculated (based on the ground surface type subgrid) by 3Di. Interception in normal terms is the amount of water that is intercepted by e.g. objects or vegetation. Water stored on the surface level flows into the closest sewer pipe when the maximum amount of interception is reached.

Annex III

Opmerkingen Inrichtingsplan Olympiakwartier west

1. Tunnels onder de Poortdreef door. Gemaal niet aanwezig.
2. Verlaging (incl. maatregelen t.b.v. erosie preventie) in de Demetrius Vikelaslaan welke is aangesloten op de WADI (+/- 10 cm lager). Onbekend is bij welke bui de WADI gebruik zal maken van deze verlaging.
3. Uitwisseling van water tussen de WADI's. Vindt plaats d.m.v Permeoblokken.
4. Drie stuwen in WADI.

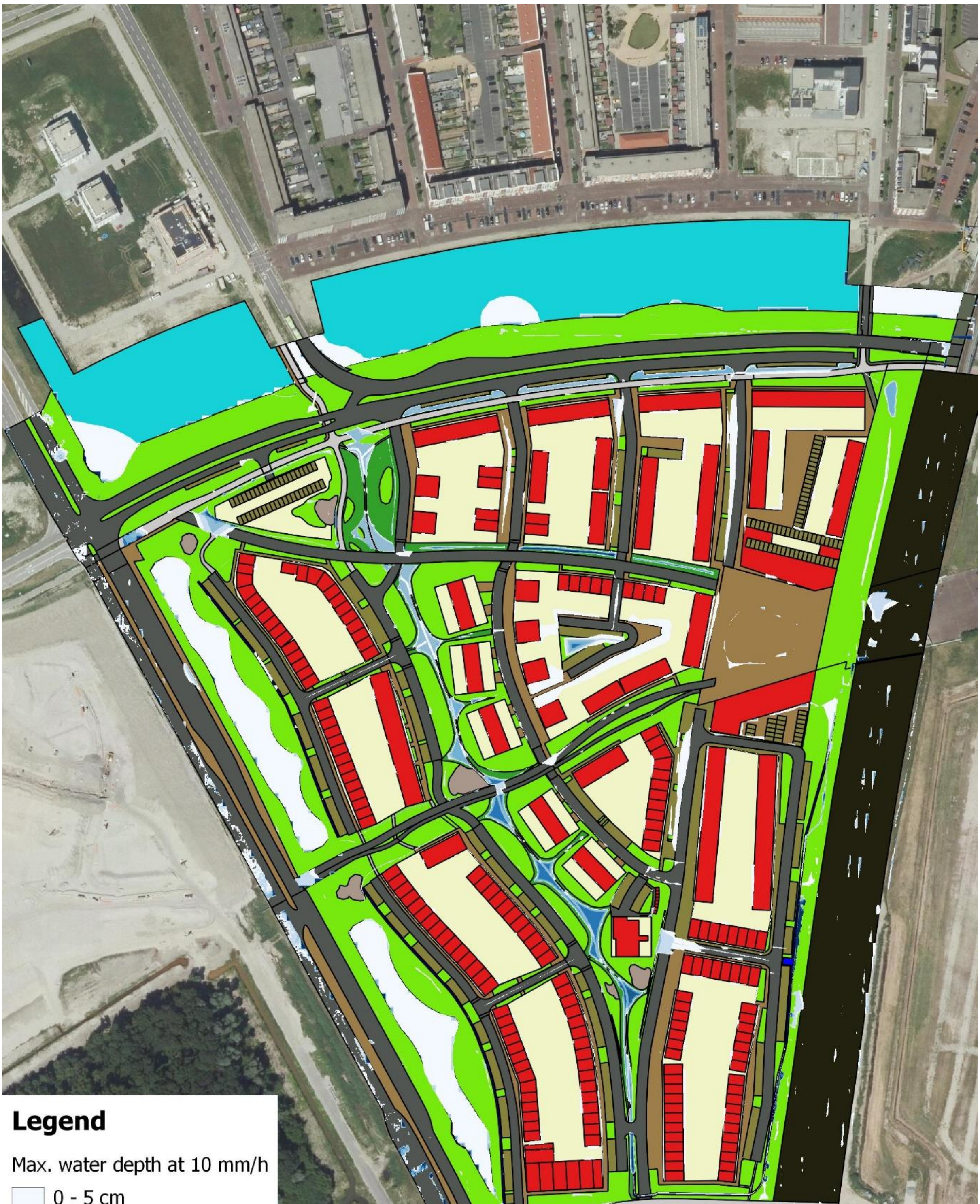
5. Situering grindkoffers i.c.m. grastegel ‘Greenston’. Liggen lager dan het maaiveld.
6. Tunnel onder het spoor door. RWA gemaal aanwezig, capaciteit wordt nog toegestuurd.
7. Tunnel onder het spoor door. Gemaal aanwezig, capaciteit wordt nog toegestuurd.
8. Verlaagd fietspad.
9. Is hier een greppel benodigd?
10. Hoe stroomt het water vanaf de panden/erven af richting de WADI? Dit is de vraag op meerdere locaties langs de centrale WADI; stroomgebiedenkaart, wat eindigt waar?
11. Wegverkanting richting het oppervlaktewater (incl. maatregelen t.b.v. erosie preventie).
12. Zijn er slokops in deze WADI benodigd? Het zou wellicht wenselijk zijn dat er water in de nabij gelegen busbaan komt te staan.
13. Deze locaties zijn potentiele knelpunten en behoeven extra aandacht.
14. Diepte WADI onbekend. Deze WADI loopt trapsgewijs af, dus de vraag: hoe diep met deze WADI zijn? Start vanaf het spoorgebouw en eindigt ongeveer bij punt 5.
15. Donkergroene delen zijn tot op heden indicatief en de lager gelegen delen van de WADI. Definitieve contouren en inhoud van de WADI’s zijn nog niet bekend. Geldt voor het gehele plangebied.
16. Lichtgroene delen, de uiterwaarden van de WADI: hoe vaak zullen deze onder water staan? Geldt voor het gehele plangebied.
17. Binnenpleinen van woonblokken: moeten deze oppervlakken worden afgewaterd? Tijdens de bouwrijp fase wordt de grond niet voorbelast.
18. Achterpaden bij woningen (vindt plaats bij elk bouwblok in het plangebied) zullen aangesloten worden op kolkleidingen. Deze kolkleidingen zullen weer worden aangesloten op het RWA.

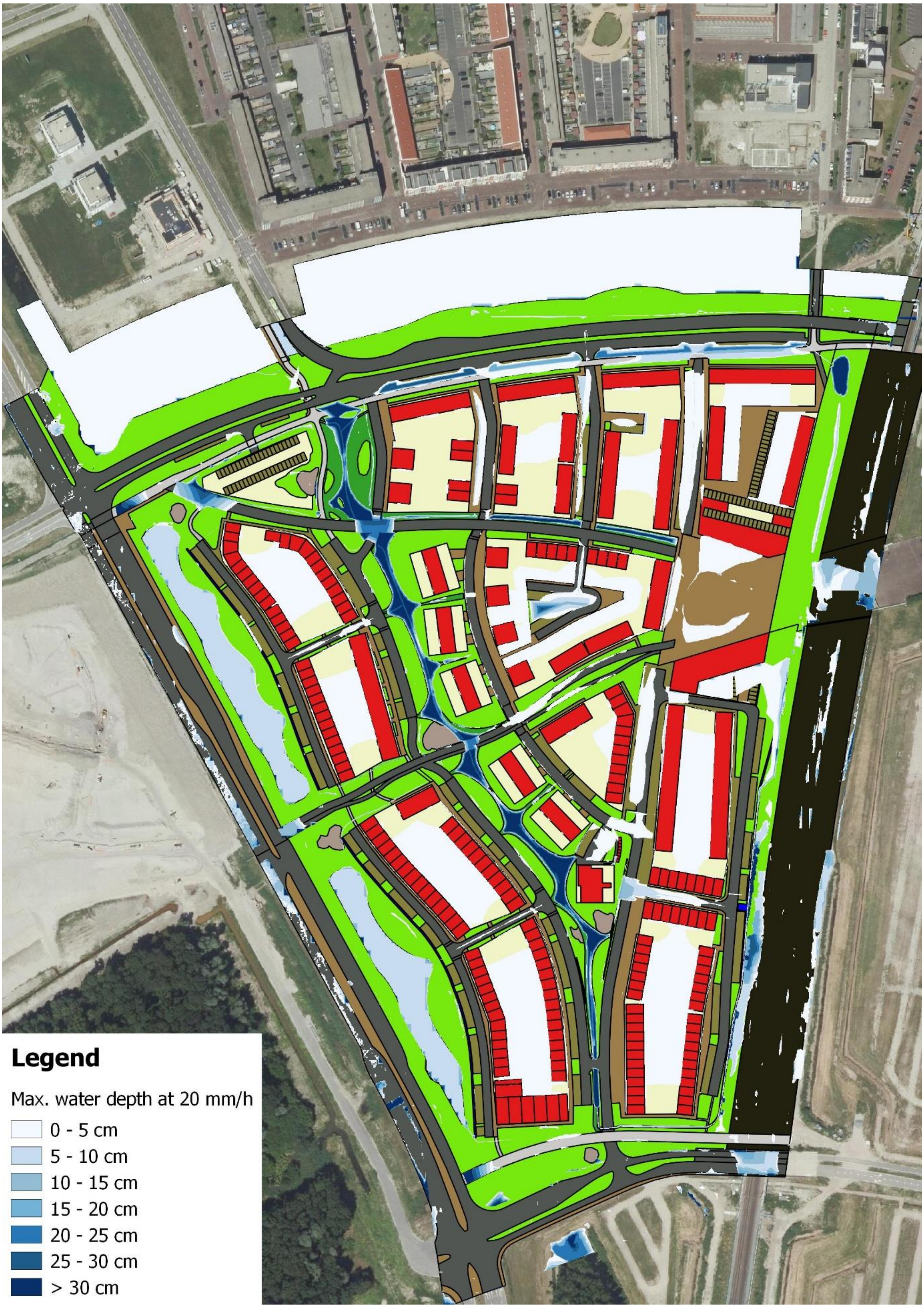
Algemene behoeften

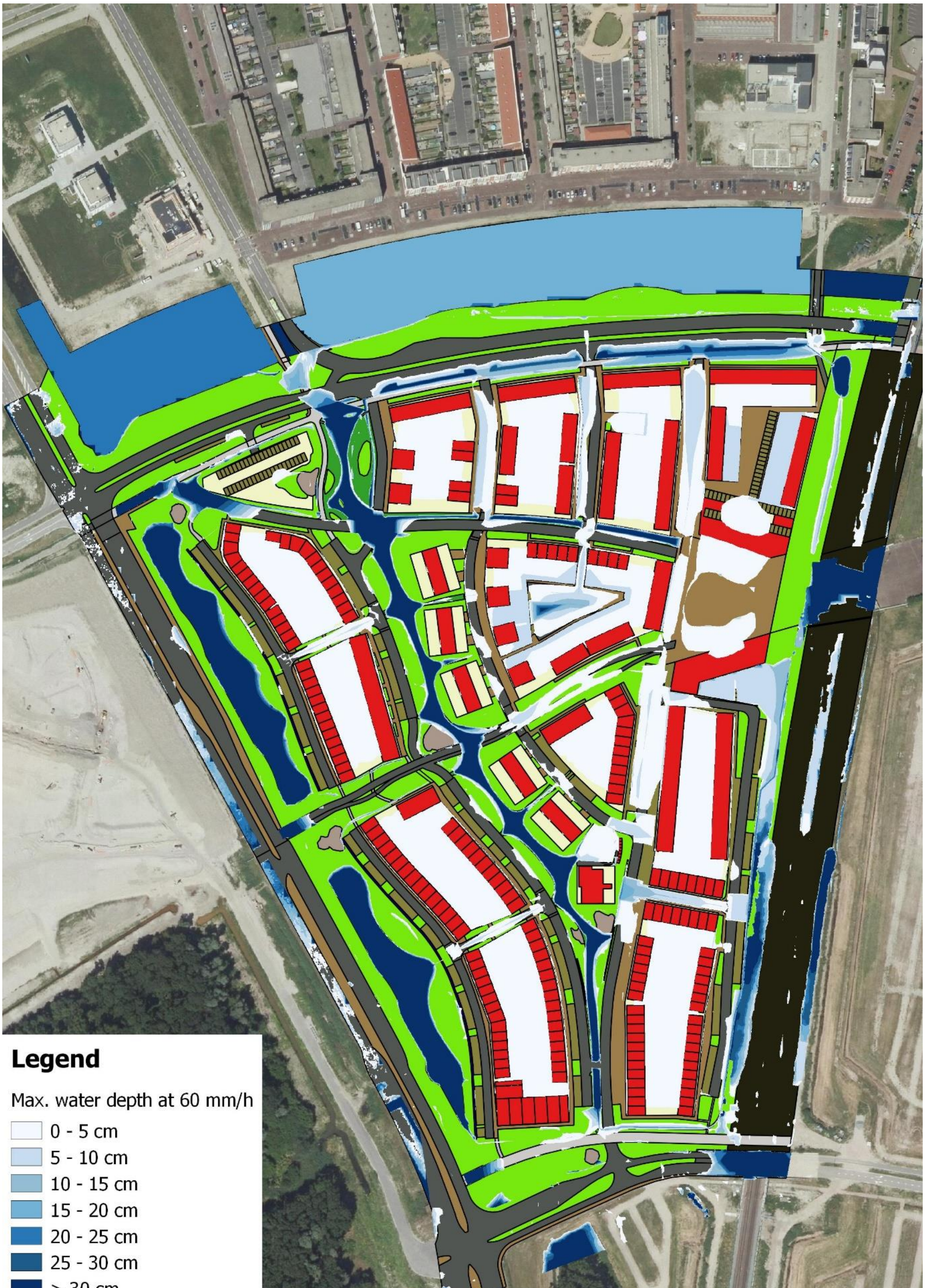
- Stroombanen van het gebied: hoe stroomt het en komt dit overeen met de verwachting?
- Inzicht in de bovengrondse afstroomgebieden.
- Afstemmen of er voldoende berging is in de lage (donker) groene WADI’s bij 60 mm/h.
- Doel bij 60 mm/h: geen water in de woningen. Deze bui is overeenkomstig is met voorgaande studies en informatie in de klimaatatlas.
- Bij welke neerslaghoeveelheid stroomt het water uit de WADI over de Demetrius Vikelaslaan (punt 2)?

Annex IV

Maximum water depth at the three rainfall events.


Legend
Max. water depth at 10 mm/h
0 - 5 cm
5 - 10 cm
10 - 15 cm
15 - 20 cm
20 - 25 cm
25 - 30 cm
> 30 cm


Legend
Max. water depth at 20 mm/h
0 - 5 cm
5 - 10 cm
10 - 15 cm
15 - 20 cm
20 - 25 cm
25 - 30 cm
> 30 cm


Legend
Max. water depth at 60 mm/h
0 - 5 cm
5 - 10 cm
10 - 15 cm
15 - 20 cm
20 - 25 cm
25 - 30 cm
> 30 cm

Annex V

The interview results are explained in section 4.2. This annex presents an overview of the results (Table V-1 to V-3). Per table, an overview is given of all statements that belong to one of the three themes as described in section 3.3 and 3.4. When the table indicates an X, this means that the professional interviewed gave an answer that positively matched the corresponding statement and the answer of the interviewee did agree with the statement. In case the answer did not match the statement or the interviewee did not agree with the statement, the table indicates a minus (-). Unfortunately, in some interviews the answers were not always persuasive to fit a statement or were missing entirely. In that case the table indicates an X.

Table V-1. Overview outcome interview statements related to urban planning processes.

INSTITUTION	Urban Planning Office		Municipalities			Water Board	Specialist	
	OKRA	BURO MA.AN	Almere	Amsterdam	Rotterdam	Water Board Hollands Noorderkwartier	Amsterdam University of Applied Sciences	Kadaster
POSITION STATEMENT	Project Leader & Landscape Planner	Owner & Public Space Designer	Landscape Planner	Landscape Planner & Public Space Designer	Urban Water Consultant	Senior Consultant Climate Proof	Lecturer BIM & Project manager	Project Leader Urban Redevelopment & Landscape Planner
Phase of entrance in the urban planning process	1	1	1	1	2	2	2	1
Involved up to and including the indicated phase in the urban planning process	3	3	3	3	5	5	3	3
There are differences between the urban planning process of an urban construction project and urban redevelopment project	-	-	-	-	-	X	-	X
I provide products in 2D	X	X	X	X	X	X	X	X
I provide digital products in 3D	-	X	X	-	-	X	X	-
I need to consider water management in the urban planning process	X	X	X	X	X	X	-	X

Table V-2. Overview outcome interview statements related to communication and information necessities in urban planning processes.

INSTITUTION	Urban Planning Office		Municipalities			Water Board	Specialist	
	OKRA	BURO MA.AN	Almere	Amsterdam	Rotterdam	Water Board Hollands Noorderkwartier	Amsterdam University of Applied Sciences	Kadaster
POSITION STATEMENT	Project Leader & Landscape Planner	Owner & Public Space Designer	Landscape Planner	Landscape Planner & Public Space Designer	Urban Water Consultant	Senior Consultant Climate Proof	Lecturer BIM & Project manager	Project Leader Urban Redevelopment & Landscape Planner
There is a need for a hydraulic modelling tool in urban planning processes	X	X	X	X	X	X	X	X
It is desirable to evaluate an urban planning design on water management in urban construction projects	X	X	X	X	X	X	X	X
It is desirable to evaluate an urban planning design on water management in urban redevelopment projects	X	X	X	X	X	X	X	X
The need for a hydraulic modelling tool in the urban planning process of urban redevelopment projects is higher than in urban construction projects	X	X	X	X	X	X	-	X

3Di is a useful instrument for the evaluation of an urban planning design on water management	X	X	X	X	X	X	X	X
3Di is more applicable within urban construction projects	X	-	X	-	X	-	-	-
3Di is more applicable within urban redevelopment projects	X	X	X	X	X	X	X	X
The process of urban planning projects will be more efficient because more information is digitally generated	X	X	X	X	X	X	X	X

Table V-3. Overview outcome interview statements related to 3Di.

INSTITUTION	Urban Planning Office		Municipalities			Water Board	Specialist	
	OKRA	BURO MA.AN	Almere	Amsterdam	Rotterdam	Water Board Hollands Noorderkwartier	Amsterdam University of Applied Sciences	Kadaster
POSITION / STATEMENT	Project Leader & Landscape Planner	Owner & Public Space Designer	Landscape Planner	Landscape Planner & Public Space Designer	Urban Water Consultant	Senior Consultant Climate Proof	Lecturer BIM & Project manager	Project Leader Urban Redevelopment & Landscape Planner
I use a hydraulic modelling tool	-	-	-	-	X	X	-	-
I use 3Di	-	-	-	-	X	X	-	-
3Di is more a communication and visualisation tool	-	X	X	-	-	X	-	-
I am going to build my own 3Di-model in the future	-	-	-	X	X	-	-	-
3Di needs additives	X	X	X	X	X	X	-	X
In work sessions, I want to adjust the output of 3Di immediately to see the effects of my alterations	X	X	X	X	X	X	-	X