Improving decision quality in urban storm water management projects

Floor Speet

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Content

Definitions of essential concepts

In this report the following definitions are used:

3Di system = An integrated water management model of the 3Di consortium that focuses on speed, accuracy, integration, interaction and information (Nelen & Schuurmans, 2014).

Alternative = one of the possibilities in a decision. In this research an alternative is a storm water measure, for example green roofs. An alternative can also be a combination of different measures.

Climate change = Future change in climate,. This research focuses especially on rainfall pattern changes due to climate change

Decision making process= the process in which stakeholders decide about a solution for a problem. In this research this is the decision about which measure will be taken for urban storm water. This contains the whole process, from initial problem till implementation.

Decision quality (DQ) = Quality of the process and input of information of the decision making process evaluated using framework, different from the quality of the outcome (Keisler, 2011).

Effects (of measures) = The effects of measures after implementation, in this research this especially focuses on a reduction of storm water

Flood simulation model = A representation or imitation of reality in which a flood is simulated

Integrated Water Resources Management (IWRM) = "a process which promotes the coordinated development of management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (Giupponi et al., 2006).

Mainstreaming = Combining climate change with other (socio-economic) drivers (Gersonius et al., 2012).

Public participation = The definition of public participation is the direct involvement of the public in decision making. Also, the term 'public involvement' or 'stakeholder participation' is sometimes used instead of public participation (Giupponi et al., 2006).

Rainproof = Urban storm water management project in Amsterdam executed by the municipality of Amsterdam and Waternet. The term 'rainproof' is defined as a situation in which the hindrance of storm water is acceptable for all stakeholders.

Storm water = Direct rainwater runoff

Urban storm water management project = A project where solutions for storm water in an urban environment are searched.

Urban resilience = the robustness and rapidity of a city as a system to react by adaptation or mitigation on, for example, flooding (Lu & Stead, 2013).

Urban flood = Floods that can have much impact on urban areas are categorized as urban floods, this includes both naturally occurring flood and human induced floods (Jha et al., 2012) Natural causes are fluvial, coastal, flash, pluvial and groundwater floods, human induced causes are a lack of drainage or sewage capacity, lack of permeability, malfunctioning drainage system or management and deficient land use planning (Jha et al., 2012). The duration is mostly from hours to days (Jha et al., 2012).

1. Introduction

The introduction describes the motivation, problem statement and hypothesis of the research.

1.1. Motivation of the research

The impact of floods in cities is relatively high because of the high density of people and concentration of economic activities (Heikkila & Huang, 2013). Urban flooding can have many of negative effects on for example housing, education and employment (Hammond et al., 2013). Because of this, cities should be more resilient for flooding, a city should be capable to adapt easily and rapidly to changes (Lu & Stead, 2013). Climate change so an increase of rainfall is an example of these changes.

Climate change and urbanization will lead to even more problems with urban flooding (Hammond et al., 2013). Climate change will affect rainfall patterns in the whole world, this will especially give problems in cities because of the high density of paved areas. Aspects of climate change can also be an advantage for cities possibly, more about this can be found in the literature review. Unfortunately, there is much uncertainty about the effects of climate change and storm water measures in cities (Arnbjerg-Nielsen et al., 2013). The worldwide urban population is expected to grow from 3,6 billion in 2011 to 6,3 billion in 2050. This will result in more impervious areas, increased urban runoff and higher exposure to flood hazard in cities (Hammond et al., 2013). Also in Amsterdam it is expected that the intensity of rainfall will increase in the future, on top of that the paved area will increase due to more dwellings (Uittenbroek et al., 2013).

In many cities around the world projects has started to increase the urban resilience (for changes as climate change), also in Amsterdam. The project Rainproof has started in January 2014 and it will contribute to both current storm water bottlenecks and mainstreaming of storm water strategy in the city in the future (Uittenbroek et al., 2013).

An important part of storm water management projects as Rainproof is the choice between possible measures, the assessment of the best alternative for the storm water problem. Decisions made in urban storm water management projects may rely on predictions of rainfall, the effects on the city and the expected effects of measures. These predictions can be made with a flood simulation model. More accurate and detailed predictions can lead to a higher decision quality.

Flood simulation models are increasingly detailed and quick because of increased possibilities with computers (Hammond et al., 2013). Frank Tibben and Anne Leskens are currently doing research about the decision making process and the use of models in flood disaster management and urban storm water management projects. They are both doing this research for the University of Twente (as respectively master thesis and PhD thesis) and Nelen & Schuurmans. No research about the effect of the use of these models for decision quality is done. Only research focusing on the process design is done, the process design is therefore seen as fixed in this research. Only the input can be changed, not for example the stakeholders involved.

1.2. Projects involved

The research will contribute to two projects, the 3Di program and the ‘rainproof’ project. This section describes these projects.

The municipality of Amsterdam is implementing the project ‘rainproof’ in the city. The project ‘rainproof’ in Amsterdam has started in January 2014 and will last 1,5 year. The aim of the project is to integrate a sustainable and profitable rainproof strategy in each new project in Amsterdam, called ‘mainstreaming’, but also handle current bottlenecks. This will be done by increasing knowledge and insights about the implications of extreme rainfall events and by integrating the concept rainproof in future projects (Uittenbroek et al., 2013). The project team decides not to formulate a clear definition of the concept Rainproof because this may raise unwanted responsibilities of the government or municipality. Furthermore, a part of the responsibility should be taken by inhabitants and other stakeholders of the storm water problem. Focus points of the project are stakeholder participation and solutions that are integrated with other projects in the city.

The 3Di Water management program is a research program of TU Delft, Deltares and Nelen & Schuurmans. The program develops web based applications for hydraulic computations. The program focuses on applications with a short calculation time, a high level of detail and visualization also for non-technical people (Nelen & Schuurmans, 2014). The program will yield the 3Di Water Management system, which is still under development and is nowadays only used for case studies. It is expected that it can be operationally for projects from April 2014.

This research will contribute to these projects by finding opportunities of integration of the 3Di system in the Rainproof project and proving a broad application of the 3Di system. The research will be carried out at Nelen & Schuurmans.

1.3. Problem statement and hypothesis

The implementation of the Rainproof project can possibly be improved by using a detailed flood simulation model as the 3Di system. One part of the project is the comparative assessment of different measures that will be implemented, the decision-making. This decision can be made by all stakeholders of the storm water problem in a city; governmental institutions, companies or inhabitants. In storm water management projects there is always uncertainty about the effects of measures, rainfall predictions and spatial characteristics (as for example the location of culverts). Because of this decisions are based on uncertain information what can lead to inferior decisions.

The problem is the uncertainty during the decision making process of urban storm water management projects.

The uncertainty in the decision making process can be split up in different parts. There is uncertainty in the boundaries of the project, the model used, input parameters and other information about the context, as expected changes in environment (Walker et al., 2003). Uncertainty is one of the elements of decision quality.

The decision making process can be divided in two parts, the decision and the outcome of the process. The decision is not the same as the outcome, good decisions can lead to bad outcomes. Whether a decision is good or bad can only be determined by the quality of the decision, not by the outcome. The outcome is only a future result that cannot be tested on quality (Howard, 1988). The quality of the decision can be maximized to increase the chance on a good outcome. A good outcome is what is desired from a decision making process (Mcnamee & Celona, 2008). Research about the use of flood simulation models in the decision making process including the process design is currently carried out. Therefore the following hypothesis is set up for this research:

A quick, detailed and interactive flood simulation model as the 3Di system can add value to decision making in urban storm water management projects by improving the decision quality.

2. Theoretical context

A summary of the most important conclusions of the literature review is given in this chapter. The frameworks in this chapter are used in the research proposal for categorization.

2.1. Decision making process

The decision making process is divided in the steps given in Figure 1.

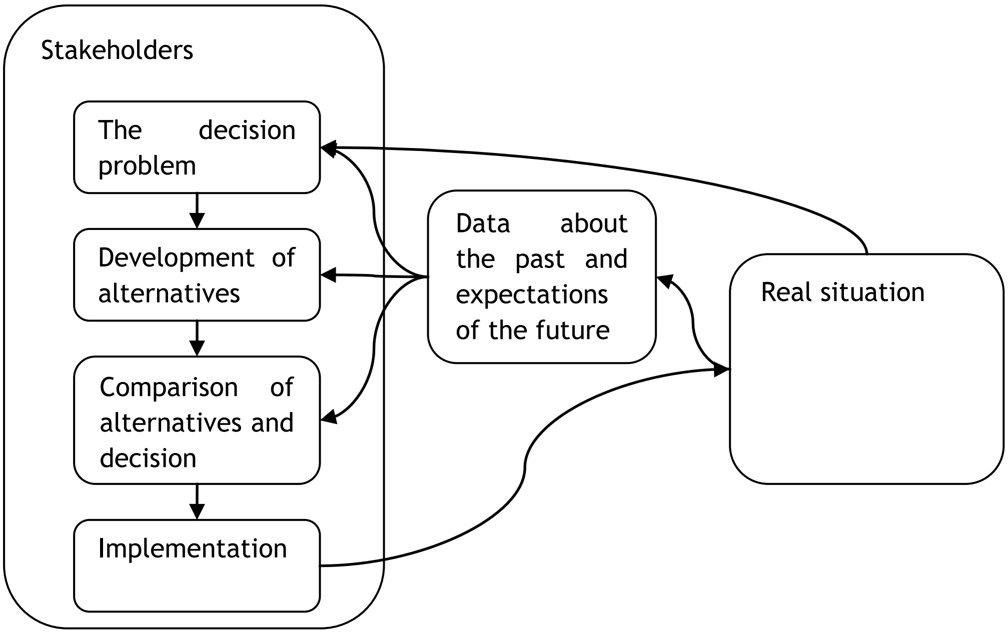

Figure 1: Representation of the decision making process (Bredenhoff-Bijlsma, 2010; Grünig & Kühn, 2009)

Another representation of the decision making process is given in Figure 2, from this view definitions of the decision quality are derived.

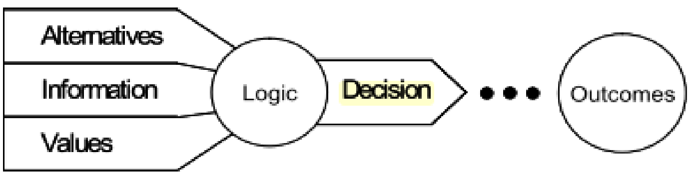

Figure 2: Representation of decision making process (Mcnamee & Celona, 2008)

2.2. Framework decision quality

Quality of decisions can be divided in six elements (Howard, 1988, 2007; Keisler, 2011; Mcnamee & Celona, 2008). The attributes of decision quality are presented as a chain (Figure 3) because they are intensively connected (Matheson & Matheson, 1998). With for example no information, it is not helpful if other attributes are well available.

Figure 3: Decision quality framework (Matheson & Matheson, 1998)

The decision quality elements in Figure 3 are further divided in sub elements from the literature, see also section 6.2. Not all of these elements can be influenced by models, the following elements and sub-elements can be influenced by models according to description of some models in the literature, see also section 6.2 (Al-Sabhan et al., 2003; Andreu et al., 1996; Frick & Hegg, 2011; Voinov & Bousquet, 2010). This are the decision quality elements (B) as clarified in Figure 5:

- Decision framing
    - A conscious perspective
- Information
    - Completeness and selection of data
    - Structure
    - Correctness and explicitness
    - Knowledge of uncertainty
- Logic
    - Reasoning clearly
    - Consequences of alternatives
- Commitment to action or implementation

3. Conceptual model

This section describes the objective, scope, research model and research questions.

3.1. Objective

The aim of the research is to evaluate the hypothesis by comparing a decision making process with using the 3Di system and without 3Di …

The hypothesis is: A quick, detailed and interactive flood simulation model as the 3Di system can add value to decision making in urban storm water management projects by improving the decision quality.

… and give advice about the way in which model information of a detailed, quick and interactive model as the 3Di system can be presented in the decision making process of an urban storm water management project to obtain an optimum decision quality by comparing the situation with and without the use of such a model.

3.2. Research scope

The research will be a theory-testing research because a hypothesis will be tested. In addition the research will be a design-oriented research, a design of the presentation of the 3Di system will be made for use in the decision making process

Decisions are defined as decisions between possible measures for addressing storm water problems, taken by either organizations or individual people. Only the aspects that can be changed by the 3Di system are taken into account, as can be found in section 2.2. The research will not involve the development of alternatives, but only the actual decision between given alternatives.

Only the aspects that can be affected by the 3Di system are taken into account for the decision quality. For example the stakeholders that are involved in the decision making process cannot be changed by the model, so will be considered as fixed. Only the aspect 'expectations' and therefore the aspect comparison of alternatives are affected (using the framework of the decision making process in section 2.1). The aspects problem definition and formulation of alternatives are also affected by the model or expectations, but are not included (see the paragraph above this paragraph)

For the evaluation of the added value of the 3Di system to decision making, a framework with six elements of decision making is used, see section 2.2.

The research does not focus on flood disaster management in which decisions have to be made in a very short time. Focus points of flood disaster management projects are emergency management and rehabilitation of floods (Akter & Simonovic, 2005), this is not the case for the Rainproof project. A similarity between urban storm water management projects and flood management projects is the involvement of stakeholders in the process.

Stakeholders of the decision making process in urban storm water management projects governmental organizations, as the municipality and Waternet, companies, but also inhabitants. The stakeholders of a specific project location depend on the scale of the problem and measure. In this research it is assumed that all sort of stakeholders will be involved in the decision making process.

3.3. Research object

The research object will be urban storm water management projects as rainproof. The project Rainproof in Amsterdam will be used as a test case. Both the mainstreaming and the bottleneck part of the project will be used.

Also the 3Di Water management system is a research object, this system will be evaluated for the use in the other research object.

3.4. Research model

To clarify the conceptual model, an overview is given in Figure 4.

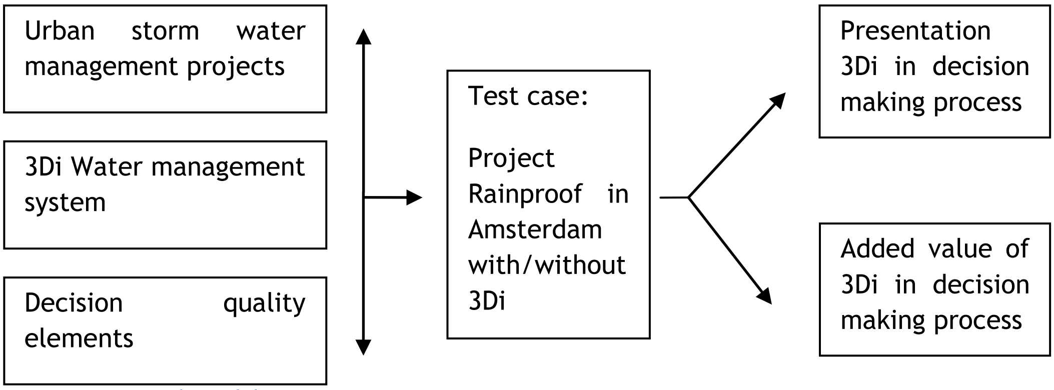

Figure 4: Research model

3.5. Research questions

The main question is:

How can detailed, quick and interactive models as the 3Di system improve the decision quality in urban storm water management projects as Rainproof in Amsterdam in comparison to the current situation of decision making in these projects?

The main question will be explained in parts:

How can ...

The 3Di system has many functionalities and is therefore probably too detailed to present as a whole to decision makers. A choice in presentation of the 3Di system should therefore be made, how can it be presented? Requirements of the decision support will be determined in sub question 1.

... detailed, quick and interactive models as the 3Di system ...

In comparison to older models or without using a model, the 3Di system is more detailed, quicker and more interactive.

... improve the decision quality ...

What elements of decision quality can be improved by the 3Di system? A first selection of the relevant decision quality elements is already made in section 2.2. A second selection will be done in sub question 2. The quantification of the elements will be done in sub question 3.

... in urban storm water management projects as Rainproof in Amsterdam ...

Characteristics of the Rainproof project and similar urban storm water management projects should be known to determine how the decision quality can be improved. These characteristics will be found with sub question 1.

... in comparison to the current situation of decision making in these projects?

Improvement can only be measured when the standard situation of decision making is known, so without the use of the 3Di system or other models. Research question 1 will answer this part of the main question, for a comparison with the current situation, first insight in this is needed.

The sub questions are given below, in Figure 5 an overview of the use of the decision quality elements is given. This is meant to clarify the different sections of the elements used in the proposal. DQ elements (A) are all elements (from the literature), DQ elements (B) are the elements selected in the literature review (so specified for models). DQ elements (C) are specified for 3Di and (D) can be improved by 3Di. Figure 6 visualizes the coherence between the sub questions, which sub question result is needed for other questions?

1. What is the current situation of decision making in urban storm water management projects and what are requirements for the input information?
2. What elements of Decision Quality (B) in projects as Rainproof can be affected by the 3Di system? (This will result in Decision Quality elements (C))
3. How can decision quality elements (C) for projects as rainproof be quantified and measured for the 3Di system and for a decision making process without the 3Di system?
4. How can 3Di-generated information be presented in the decision making process to increase the decision quality (C) using the quantification? (This will result in Decision Quality Elements (D))
5. Is the Decision Quality improved by using the 3Di system?

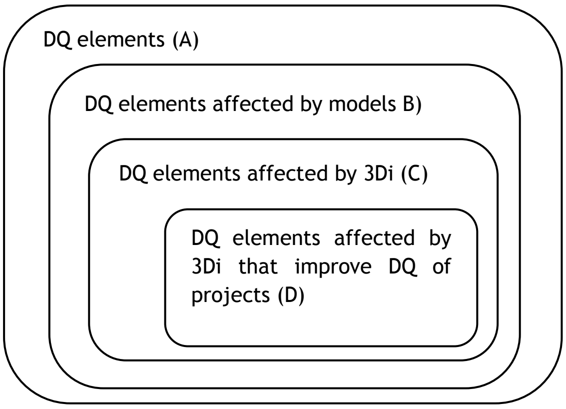

Figure 5: Overview of used decision quality elements. DQ elements (A) encloses (B), (B) encloses (C) etc.

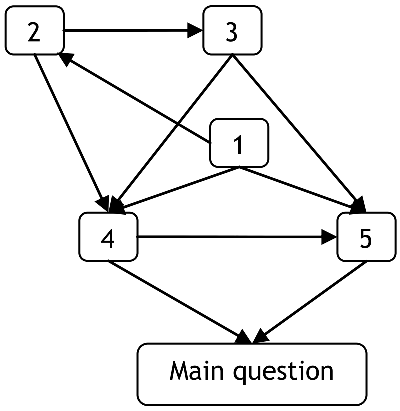

Figure 6: Coherence sub questions

4. Methodology

The method for each sub question is first described in words after which an overview figure (Figure 7) is given with a corresponding overview table (Table 1).

4.1. Answering sub and main questions

The sub questions answer together the main question: *How can detailed, quick and interactive models as the 3Di system improve the decision quality in urban storm water management projects as Rainproof in Amsterdam in comparison to the current situation of decision making in these projects?*

1. **What is the current situation of decision making in urban storm water management projects and what are requirements for the input information?**

Information will be obtained from:

- Literature and project reports
- Interviews with the project team if the written information is not sufficient

Results of this will be for both projects with (future) use of a model and without use of a model:

- Description of the steps in the decision making process to take into account all effects of decision quality elements, described following the division found in literature (Figure 1).
- Stakeholders involved in the decision making process in order to interview the right people and involve the right people in the workshop
- Requirements of information used in the decision making process to make sure the presentation of the model is applicable
- Presentation of the DQ elements (C) in the process to obtain knowledge necessary for the quantification

2. What elements of Decision Quality (B) in projects as Rainproof can be affected by the 3Di system? (This will result in Decision Quality elements (C))

Possibly not all elements of Decision Quality B can be affected by the 3Di system. To determine this for each element of DQ B the combination with the 3Di system will be investigated. Can a Decision Quality element be changed by 3Di, both in a positive or negative way?

For example, the possibilities of the 3Di system to affect the element 'logic' will be investigated by setting up a list of the 3Di system characteristics in which this can be done. If no characteristic or possibility in the 3Di system will affect the element 'logic', this element cannot be affected by the 3Di system.

Information from interviews is necessary to determine the effects of 3Di. Suggestions of improvement will be used of the current decision making process, for instance that more detailed maps can be helpful for the stakeholders.

3. How can decision quality elements (C) for projects as rainproof be quantified and measured for the 3Di system and for a decision making process without the 3Di system?

The decision quality elements that can be affected by the 3Di system should be quantified to conclude if the use of the 3Di system will improve the decision quality. Each element will be quantified; an example is the element 'uncertainty of the data'. This element will be split up in parameters for uncertainty of data that can be found in literature. A value will be given for the status of the elements in a way that it is applicable for projects as rainproof. Already a start for this is made in the literature review but this have to be adapted to the 3Di system.

4. How can 3Di-generated information be presented in the decision making process to increase the decision quality (C) using the quantification? (This will result in Decision Quality Elements (D))

Whether the decision quality can be improved depends on what can be improved in the decision process according to the stakeholders. This is investigated by interviewing the stakeholders for sub question 2. Besides that the decision quality can be improved on other point that can be concluded logically from the earlier questions. These questions determined how the decision quality elements can be measured and so can be concluded if certain use of the 3Di system increases the decision quality.

To answer this sub question the information from the interviews and project information will be combined with the quantification of the decision quality elements. The presentation of the 3Di system for the project should have the following requirements:

- fulfill the requirements of input (obtained from other projects)
- if possible fulfill the wishes/problems
- improve the decision quality optimal, so all possibilities of increased decision quality should be incorporated

The presentation of the 3Di system in the project will be evaluated with the workshop.

5. Is the Decision Quality improved by using the 3Di system?

If the decision quality is improved by the use of the 3Di system will be tested with a workshop and questionnaires. During the workshop a decision making process with and without the use of the 3Di system is simulated. When these two situations are compared, a conclusion can be drawn about the improvements. This will be done with the quantifications of the Decision quality elements. To get more detailed information from the workshop, a questionnaire will be held after the workshop.

4.2. Overview of methodology

This section describes an overview of the methodology in a flow diagram and table.

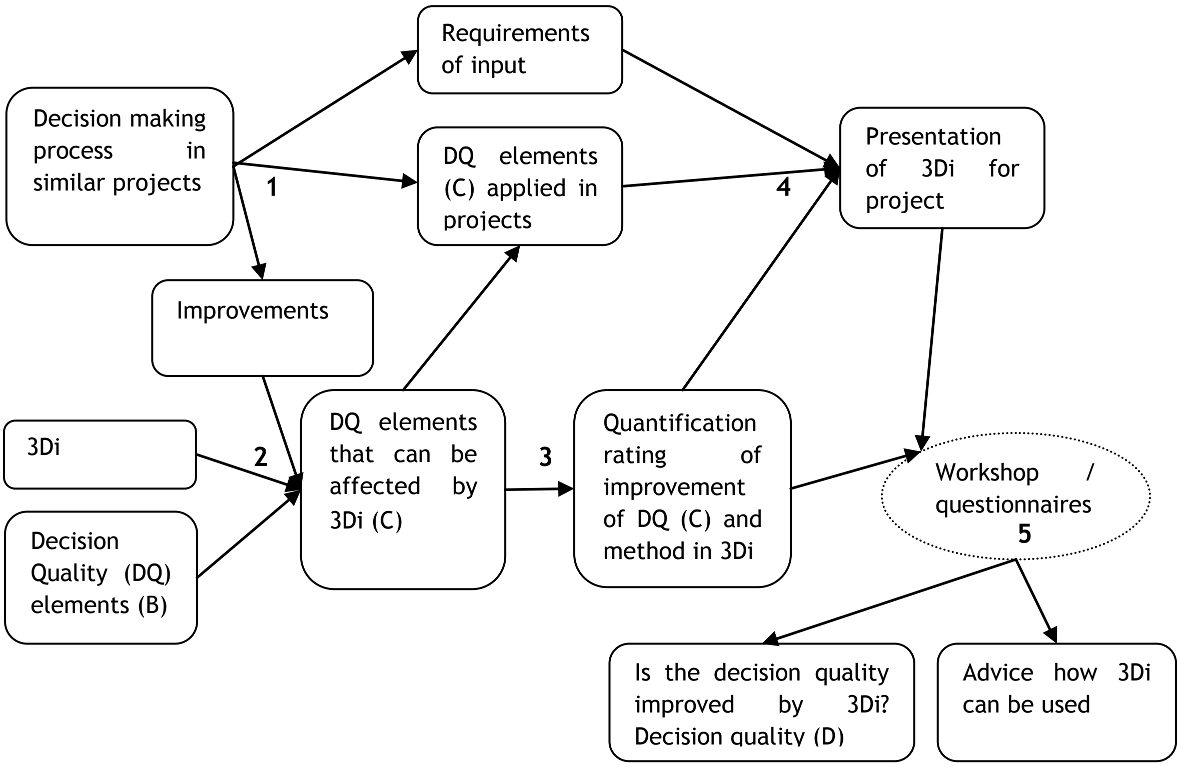

Figure 7: Overview of methodology

Nr.	Input	Informa-tion type	Output	Question	sub ques-tion
1	- Similar projects - Information about decision making process projects - DQ elements	Literature Interviews	- Requirements - problems/ wishes - DQ elements in process	What are requirements, problems and wishes of the input of similar projects? How are the DQ elements presented in the decision process of similar projects?	1 + 2
2	- DQ elements - 3Di - Improvements	Combi-nation Literature	DQ elements (C)	What DQ elements can be affected by 3Di ?	2
3	DQ elements	Literature Logic	- Quantification DQ elements	When is an element contributing to an improved DQ? How can this be	3

			- Presentation with 3Di	measured? And how can this be presented with 3Di?	
4	- Requirements of input - Wishes/problems input - Presentation of DQ elements in process - Quantification of DQ elements	Combi-nation	- Improvement possibilities with 3Di	With what presentation of 3Di can the decision quality optimal be improved?	4
5	- Presentation of 3Di - Quantification of DQ elements	Workshop Question-naires	- Evaluated possibilities with 3Di - main question	Is the decision quality really improved by the use of the presentation of 3Di? Are there any improvements to the representation of 3Di?	4 + 5

Table 1: Overview of the methodology

4.3. Research tools and projects

Interviews, a workshop and a questionnaire after the workshop will be held during the research.

4.3.1. Similar projects

Similar projects as the rainproof project have a combination of the following properties to make them comparable to Rainproof:

- In an urban environment
- Storm water problem (rainfall problems)
- Integrated (public participation)
- Recent
- Dealing with climate change
- Linked to spatial planning on the long term (mainstreaming)
- Located in the Netherlands

Projects used for comparison are chosen by practicality and comparability with the project Rainproof. Therefore mostly projects from the Netherlands will be evaluated:

- Rotterdam Waterplan 2 (Lijn43, 2013), an integrated program about water hindrance in the city of Rotterdam from the municipality and water boards.
- Casestudy West-Friesland (Nelen & Schuurmans, 2013a), a case about flood disaster management where a test with the 3Di system is done by Nelen & Schuurmans
- WATERgraafsmeer (Kennis voor klimaat, n.d.), an integrated and participatory project in Amsterdam focusing on water and climate change
- Rainproof Amsterdam

During the research process possibly other useful projects will be add to this list. All projects will be evaluated on the steps in the decision making process as defined in the literature review. Also already available information from the Rainproof project will be included in this evaluation.

4.3.2. Interviews

The interviews will be in-depths interviews. The interviews will be held with members of project teams of similar projects as rainproof to collect information about decision making processes in such projects. During an in-depth interview information about facts but also about opinions can be obtained (Yin, 2009), what is needed for the research.

4.3.3. Workshop

The workshop will be used to perform a multiple comparative case-study. The two cases are:

- A workshop with the standard situation of decision making
- A workshop with use of the 3Di system

The 3Di presentation will be evaluated by the two cases by comparing the process and results. These workshops will be done in collaboration with the project Rainproof in Amsterdam. The two workshops will have the same subject and area about which the decision has to be made, but a different group of stakeholders will be used. One group makes the decision in the standard way and one group with the representation of the 3Di system.

During the workshop a group of stakeholders will execute the decision making process between some alternatives for a case about urban storm water management. If possible, a real case will be used, for example a district of Amsterdam with bottleneck storm water problems will be used for this. If this is not possible, for example if the 3Di system is not yet representative enough, an example case will be used.

As input for the workshop the following information and decisions are needed:

- Location of the case, which district of Amsterdam will be used.
- Participants of the workshop, stakeholders of the project case will be invited, this can be inhabitants, people of the municipality or companies in the area.
- Alternatives for the storm water management problem of the case
- Representation of the alternatives in the 3Di system

The following aspects of the workshop will be documented:

- The presented value of each decision quality element
- The satisfaction and opinion about the decision making process of the participants
- Possible improvements of the presentation of the 3Di system in the decision making process

The external validity of the research can be small for a case study because only two cases are used (Verschuren & Doorewaard, 2007). Nevertheless, this research method is used because no projects executed with the 3Di system are available for analysis.

4.3.4. Questionnaires

After or during the workshop a questionnaire about the process will be held. The use of the model and standard situation will be tested on:

- Is the decision quality improved, so are better results for the DQ elements reached?
- Are there other positive or negative changes in the process?
- Are there any improvements possible for the presentation of the 3Di system, thinking about usability and easiness?

5. Planning

A planning is made for the execution of the research. The planning starts at the first week after the finalization of the research proposal.

Task nr.	Week from start	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22-24
	Date Monday of that week	10/3	17/3	24/3	31/3	7/4	14/4 (esater)	21/4 (easter)	28/4	5/5	12/5	19/5	26/5	2/6	9/6	16/6	23/6	30/6	7/7	14/7	21/7	28/7	
	Question 1																						
1	info similar projects and preparing interviews																						
2	interviews and processing																						
	Question 2																						
3	DQ elements B to C																						
4	Combination interviews																						
	Question 3																						
5	Quantification																						
	Question 4																						
7	improvements presentation with 3Di																						
	Question 5																						
8	prepare workshop + questionnaires																						
9	Workshop + questionnaires																						
10	Evaluation workshop																						
	Finishing																						
11	Writing chapters (see appendix for chapters)					A	3 A	3 4	4	4	5			B C 5 6	B C 5 6	B C 5 6	All chapters						
12	Meetings UT							1			2				3				4				
13	Finishing report																						
14	colloquium																						

Table 2: Planning of the research

The exact date of the meetings with the supervisors of the UT will be determined by email. The first meeting will be with both the supervisors from the UT and Nelen & Schuurmans and will take place after the 19th of April because of planned holidays. During the research process, tight contact will be kept with the supervisor from N&S, on average every week a short meeting will be held.

6. Literature review

In the literature review some subjects from the research will be explained. These questions will be answered in the literature review:

- What are elements of the decision making process and what is decision quality?
- What is written about decision quality in projects as Rainproof?
- What is the 3Di system and how does it work?
- What is written about using models in projects as Rainproof?

6.1. Decision making process

Many different representations of the decision process are described in literature. Bredenhoff-Bijlsma (2010) describes two extreme models for the decision making process, the rounds model and the phase model. The phase model is an analytical representation of the decision making process in which a clear beginning and end is defined(Hommes, 2008). A complex participatory decision making process can better be defined as a rounds model in which different decision making rounds are passed. Actors can contribute each round and can change the content and directions of the total process (Hommes, 2008).

The categorization of the phase model is used in this research to make a clear overview of the steps in the decision making process. The rounds model is not divided in clear steps. The phase model of Bredenhoff-Bijlsma (2010) and Hommes (2008) is combined with the representation of Grünig & Kühn (2009). This results in the representation in Figure 8.

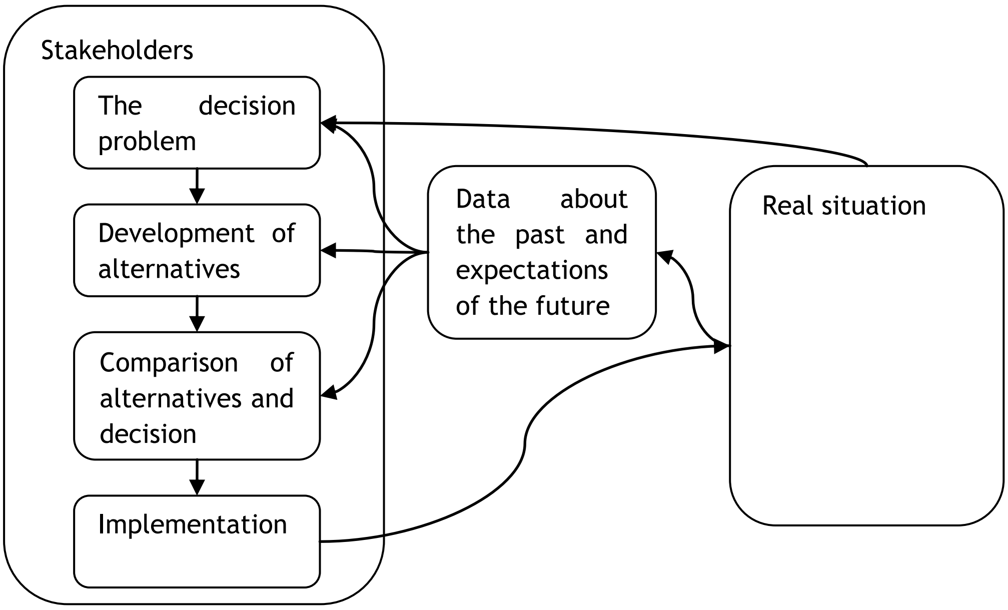

Figure 8: Representation of the decision making process (Bredenhoff-Bijlsma, 2010; Grünig & Kühn, 2009; Hommes, 2008)

Necessary information about projects similar to rainproof can be described by the framework of the representation of the decision process (Figure 8); real situation, data and expectations, stakeholders and the four steps; the problem, the alternatives, the comparison and the decision and implementation. In these elements of the process the characteristics of urban resilience will be included.

To find improvements of decisions for urban storm water management projects knowledge about projects in the past or current projects is needed. What is/was the outline of the decision process and what was important. Because spatial planning is increasingly trying to account for climate change and urban resilience (Lu & Stead, 2013) characteristics of urban resilience for these projects will be used. Lu & Stead (2013) identified six characteristics of urban resilience, these are important for increasing the resilience of a city by urban planning. The characteristics should be included in decisions for increased urban resilience. These characteristics should be incorporated in one or more steps of the decision making process in Figure 8 to obtain a resilient city;

- Attention to the current situation to maintain the current status of the environment (Important for the real situation)
- Attention to trends and future threats, as for example climate change (Important for the real situation and expectations)
- Ability to learn from previous experience to use this knowledge again in similar situations (Important for the development of alternatives and comparison and decision)
- Ability to set goals, as indicator of the willingness to act (Important for the decision problem and implementation)
- Ability to initiate actions (Important for the implementation)
- Ability to involve the public (Important for the stakeholders)

All characteristics should also get attention at the stakeholders, because they have to carry out the actions. The book 'Water policy in the Netherlands' (Huitema et al., 2009) distinguishes five main goals of public participation for water management, what is also an important issue in projects as Rainproof:

- **Awareness raising** of the issue in mind of the water manager, for example about the risk of flooding at a specific location (Useful for the attention to the current situation and predictions)
- **Improving decisions** so solutions are workable and acceptable by the public (Useful for the comparison of alternatives and the stakeholders)
- **Increasing legitimacy of decision-making** so the acceptance and support of the public will be higher (Useful for the stakeholders and the implementation)
- **Increasing accountability of decision-making** so the policy makers seems more transparent and responsive to the problems of the public (Useful for the implementation, problem definition and stakeholders)
- **Collective learning or social learning** so all stakeholders learn how to deal with conflicting interests and views, if succeeding ending with a collective vision. This can result in managing something together (Giupponi et al., 2006). (Useful for the stakeholders and comparison and decision)

6.1.1. Real situation

The decision problem is made from an analysis of the real situation and predictions of the future. Attention to the current situation to maintain the current status of the environment is also an important characteristic of a resilient city (Lu & Stead, 2013).

Water safety in Amsterdam

Nowadays Amsterdam is relatively safe for flooding because of the following aspects but this will change because of climate change impacts (DHV et al., 2012):

- The sluice Ijmuiden, and the Markermeerdijk and Lekdijk satisfy the standards (almost)
- A large part of Amsterdam is located high (above NAP)
- The historic city dykes protect a large part of the city centre and the hinterland
- In the Watergraafsmeer is a defense located that can be closed
- In the most important watercourses are emergency defenses constructed that prevent flooding of the polder if a regional defense breaks

6.1.2. Data and expectations

Attention to trends and future threats is a very important characteristic of urban resilience (Lu & Stead, 2013). When this is not noticed, no adaptation can be done and projects have only effects on the short term. Trends and future threats are important for the formulation of the problem, formulation of alternatives and the comparison of alternatives. These trends can be determined by use of a model or other interpretation of data.

Most conclusions on climate change focus on an increase of average temperature of the earth and the rise of sea level, but also other changes will occur. For the Netherlands this will be more extreme rainfall events in the summer, with an increase of the average sum of rainfall with 5-27% in 2050. In the winter the sum of rainfall will increase with 4-14 % in 2050. Also the intensity of rainfall events will increase due to climate change, more millimeter rainfall per hour. For 2100 these percentages will be even higher (Dorland & Jansen, 2007). Other changes that can occur to cities are increased water level in the Ijsselmeer and inland waterways, changes in winds and storms, increased peak discharge of river during the winter and a possible higher groundwater table because water cannot flow away (Aerts et al., 2006; Drunen et al., 2009). This will possibly affect Amsterdam not so much because of the sluice system around the city.

Points of interest according to DHV et al. (2012) of the flood risk in Amsterdam are:

- The crowded deep polders in the city can flood easily when the sluices mentioned above fail. A flooding of these polders can lead to spreading of chemicals (Westelijk Havengebied), damage on vital infrastructure (as RWZI, the A2 and the hospital AMC)
- The historic dyke is going diagonal through Amsterdam and is built-up

Recently the locations that are most vulnerable for flooding in Amsterdam were determined. This was done with an analysis with WOLK (a model from Tauw), whereupon the results were checked by field observations (Habes et al., 2014). An estimation of the part of Amsterdam that is most vulnerable for inundations can already be made with these results.

6.1.3. Stakeholders

Two extreme approaches of decision-making are the analytical (or classical, rational, linear, traditional, hierarchic, technocratic, top-down, intellectual, positivism) approach and the participatory approach (or interactive, communicative, adaptive, collaborative, consensus) (Hommes, 2008). The decision-making process of the Rainproof project is defined as a participatory approach.

The profits of public participation can be approached from different perspectives. Public participation can help to rectify shortcomings in policy decisions, but also to promote their own interest (Huitema et al., 2009). The integrated part of water management is more and more recognized as important, the role of public should be an integral component (Rauch et al., 2005).

There are several levels of public participation according to Giupponi et al. (2006) going from less involvement to much involvement:

- Information supply (public is provided with or has access to information)
- Consultation (public can react to plans)
- Co-thinking (discussions between public and government)
- Co-designing (public contributes actively to policy development)
- Co-decision making (public and government share decision making power)
- Self control (public acts independently).

According to team members of the rainproof project actors/inhabitants are very important in the project. The concept Rainproof is something that is different for everyone therefore the project will be an open proactive platform. Important is also that it is not only about public areas, but also about private areas, the rainfall problem is not only the problem of the government, the government satisfies the norms of drainage for this already. Rainproof will focus on integration of different disciplines and stakeholders, both the municipality, companies and private people (Uittenbroek et al., 2013). The construction of a green roof is an example of integration, the water management and livability are both increased and it can be located on the property of companies or inhabitants. The project team is trying to reach the highest level of involvement, self control.

No detailed documentation about the level of involvement in other projects can be found.

6.1.4. Decision process steps

Steps in the decision process are; the decision problem, development of alternatives, comparison of alternatives and decision and implementation. In the rounds model these steps are reiterative passed.

The decision problem, goal setting

During the goal setting process step the decision is defined and criteria for the result are set (Hommes, 2008). For the goal setting also knowledge about the current situation and the stakeholders is needed. An important aspect of setting the decision problem are the ability of the stakeholders to set goals (Lu & Stead, 2013). For the Rainproof project the goal is set by the project team and only specific goals, for example about which bottleneck in which district have to be chosen. A goal of the Rainproof project is to 'mainstream' storm water management, it should be normal to integrate storm water management in future projects. Besides that they aim to solve the most important storm water hindrance bottlenecks on short term.

Development of alternatives

The development of alternatives can be done by the project team or the stakeholders themselves. In the Rainproof project the alternatives are determined by the project team or experts and a decision between the given measures is done by less expert people. During the process stakeholders can bring up new alternatives.

It is not meant to implement large measures in the Rainproof project, but to integrate the concept in future projects. The urgency is not very high, but the city has to be prepared for rainfall related problems. Another important aspect of rainproof is integration of different disciplines, besides a solution for the rain problem measures can also contribute to other aspects of the city.

Integration is an important aspect of decision making in urban water management projects. Storm water troubles concern the drainage, but also aboveground disciplines (Kluck et al., 2013). Private and public buildings, roads, parks and tunnels can be affected (Kluck et al., 2013). Therefore alternatives should affect different disciplines.

Comparison of alternatives

A comparison of alternatives can be done with using a flood simulation model, but also on other fields of interest alternatives can be compared. With a model the effects of measures can detailed be determined. Different storm water management projects will use also different criteria for comparison.

A collective vision between the stakeholders is important to reach a collective decision, public participation will contribute to this. This will also ensure that a measure will be acceptable and executable (Huitema et al., 2009).

For the comparison of alternatives a representation of 3Di will be used for one workshop and the standard way of representation will be used for the other workshop.

Decision and implementation

According to Lu & Stead (2013) learning from previous experiences is very important for a resilient city. Therefore it is useful to look for projects in the past for the implementation of measures. Also the willingness of action of the stakeholders is important. Public participation can be important for these aspects because it improves the legitimacy and accountability of decision making (Huitema et al., 2009).

6.2. Decision quality

A more theoretical representation of the decision making process is the division between the decision and the outcome (see Figure 9). The decision is made by using information, values, alternatives and combine these with logic (Mcnamee & Celona, 2008). Howard (2007) and Keisler (2011)state also that decision and outcome is something different. It is desired to have a good outcome of the decision making process, but the quality of the outcome cannot be measured. Alternatives that were not chosen cannot be tested on quality and also future effects of the outcome are not known. Because the quality of the outcome cannot be determined, the quality of the decision should be determined to increase the chance on a good outcome (Howard, 2007; Keisler, 2011; Mcnamee & Celona, 2008).

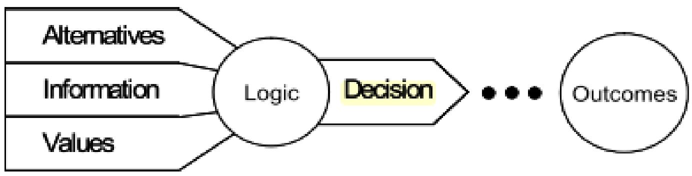

Figure 9: Representation of decision making process (Mcnamee & Celona, 2008)

Many different definitions of decision quality can be found in literature. Decision quality is defined as the opinion of the decision-makers about their satisfaction with the final decision (Wilson & Arvai, 2006). Decision quality as both the quality of analysis and the commitment to action is used by many authors (Howard, 1988; Mcnamee & Celona, 2008). Most authors make a distinction between six elements of decision quality. These elements can be divided further in sub elements, the six elements are the same according to the different articles but the sub elements differ (Howard, 1988, 2007; Keisler, 2011; Mcnamee & Celona, 2008). The sub elements of each author are combined to obtain one framework;

- Decision framing
    - A clear purpose (frequently expressed by a vision or mission statement and list of deliverables)
    - A defined scope (what is inside and outside the frame)
    - A conscious perspective (taken into account all relevant data, issues and concerns without limiting the perspective)
- Alternatives
    - Creative, are the alternative different from current situations
    - Complete
    - Achievable
    - Significantly different
    - Coherent
    - Compelling, to create motivation
- Information
    - Completeness and selection of data
    - Structure
    - Correctness and explicitness

    - Knowledge of uncertainty
- Values, clearness of preferences
- Logic of integration and evaluation, information, values and alternatives are combined well
    - Reasoning clearly, can the results be explained to an outsider
    - Consequences of alternatives for each criteria of the decision
- Commitment to action or implementation, possibility of execution

Each attribute can be seen from two perspectives, people and content. Content quality is obtained if the use of processes and tools results in a logical and justified decision. People quality is obtained when the right people are involved (Mcnamee & Celona, 2008).

In this research only the elements that can be affected by models are used. Therefore an analysis of some models used in the past is done, given in Table 3. Literature about models comparable to the 3Di system is used for this, see section 6.3.2. Possible relevant elements are selected with this, some elements will possibly not be relevant for the 3Di system, but this will be determined during the research.

Decision quality element	Sub element	D-PHASE (Frick & Hegg, 2011)	GIS-models (Al-Sabhan et al., 2003)	Participatory modeling (Voinov & Bousquet, 2010)	AQUATOOL (DSS) (Andreu et al., 1996)	Rainproof expectation
Decision framing	A clear purpose					
	A defined scope					
	A conscious perspective		X	X		X
Alternatives	Creative					
	Complete					
	Achievable					
	Significantly different					
	Coherent					
	Compelling					
Information	Completeness and selection of data	X	X	X	X	X
	Structure	X	X	X	X	X
	Correctness and explicitness	X	X	X	X	X
	Knowledge of uncertainty	X	X	X	X	X
Values	Values					
Logic	Reasoning clearly				X	X
	Consequences of alternatives				X	X
Commitment	Commitment to action or implementation	X				X

Table 3: Analysis of Decision Quality elements affected by a model in several projects

Decision framing - A conscious perspective
From the element decision framing only the consciousness of the perspective can be changed. Decision quality is only received if team members incorporate the total set of relevant data, issues and concerns (Mcnamee & Celona, 2008).

Information – Completeness and selection of data
If data is not appropriate selected, many time has to be spend by analyzing inappropriate available data or searching for necessary data (Mcnamee & Celona, 2008). Therefore the data set should be complete but not too extended.

Information - Structure
The information should be structured so everything can be understood and can be found easily.

Information - Correct and explicit
Is the information correct and detailed, are explicit values given instead of vague adjectives (Mcnamee & Celona, 2008). Also the basis of the data is important, where does it come from and is this a reliable source?

Information - Uncertainty
Knowing how well you know something is very important, this is especially the case for expectations about future events (Mcnamee & Celona, 2008). For projects related to climate change this is a very important element because they include many uncertainties about future changes.

Logic - Reasoning clearly
The logic of a reasoning can be measured by whether it can be explained to an intelligent outsider (Mcnamee & Celona, 2008). Can the reasoning be understood by someone that did not made the decision?

Logic - Consequences of alternatives
What are the consequences of the alternatives for each criterion used in the decision making? Can the consequences be logically explained?

Commitment to action or implementation
The commitment to action or implementation depends mainly on the enthusiasm of the stakeholders, are they motivated. Motivation is following from involvement and insight in the total process (Mcnamee & Celona, 2008).

First quantification of decision quality elements
These elements can be quantified with percentages according to Mcnamee & Celona (2008), the quality is perfect when 100% of all elements is reached.

	0%	50%	100%
Decision framing	No conscious perspective, scope and assumptions not stated Decision-makers not identified	List of issues, but not fully structured	Clear statements of scope etc and agreement of decision-makers
Information	Not knowing how much is known or what is important, ignoring uncertainty	Knowing information gaps and what is important; uncertainty quantified; interdependencies not explored	Knowledgeable and ready
Logic	Intuitive evaluation by each decision maker	Key sources of value identified; important uncertainties identified; dependencies not accounted for; logic incomplete and/or at insufficient level of detail	Reliable analysis and clear choice
Commitment to action	Lack of interest of key decision-makers; in-surmountable organizational hurdles; insufficient support	Active participation by the right people; commitment to achieve decision quality; commitment to "do it right the first time"; buy-in not yet pervasive in the organization	Buy-in from project team, decision board, and those affected by the decision; sufficient resources allocated to implement and make the decision stick

Table 4: Quantification of decision quality elements (Mcnamee & Celona, 2008)

6.3. Models and decision making tools

Models can be used to predict the impact of scenarios to discuss different strategies that can be taken. The advantage of models is that they can describe complex relationships and deal with large amounts of data. Models have been proven to be successful for creating awareness of measures for lay people and other stakeholders.

According to many authors models are not used always in decision making processes. Limitations in calculation time and flexibility of flood simulation models cause a lack of use of models. Another argument of not using a model is uncertainty about the model results. Therefore in some decision making processes rules of thumb are used rather than models (Leskens et al., 2014). The uncertainty of the model results is partly caused by miscommunication between scientists, who make the model, and the practitioners. On this can be anticipated by more collaboration between the scientists and the practitioners, the scientists have to listen better to the practitioners wishes and knowledge (Morss et al., 2005)

Disadvantages of decisions based on models are that scientific models are objective and can only be validated after the decision is implemented. Besides that, not all stakeholders will accept the results of the model. When participatory modeling is used, when modeling is done with a constant dialogue between stakeholders and experts, model results are seen as more relevant and reliable (Craswell et al., 2007).

6.3.1. 3Di Waterbeheer

The 3Di system is a new model developed by TU Delft, Deltares and Nelen & Schuurmans. 3Di Waterbeheer is an instrument that can visualize flooding processes in 3D and can calculate the effectiveness of measures (Ven, 2012). It is an instrument that can assist the designer with knowledge about expected damage and risks. The 3Di system focuses on a short calculation time, a high level of detail and visualization for also non-technical people (Nelen & Schuurmans, 2014). The model is still in the making and is nowadays only used for case studies, it is expected that it can be used for regular projects from April 2014.

The basic model of the 3Di system consists of combined information layers, as the AHN (actueel hoogtebestand Nederland), Basisregistratie Adressen en Gebouwen (BAG)) and TOP10 (topographic information) (Nelen & Schuurmans, 2014). Missing data as the exact location of dams are determined by combining the layers. Detailed layers with the infiltration, interception and resistance are made with this information. The 3Di system is with this information appropriate for rainfall-discharge modeling, flood calculations and groundwater modeling.

The model can be faster and more detailed because the calculation cells are determined with the quadtree method; square cells are divided in smaller square cells if more details are useful at that location (Stelling, 2012). In this way river banks are considered very detailed while plain areas with everywhere the same characteristics are seen as one cell.

The surface flow is calculated with the ontinuity and momentum equations of Saint-Venant; each step the amount of water that can flow to surrounding cells is calculated. Ground water flow is calculated with the equation of Darcy. Besides horizontal flow, also vertical flow is integrated in the model with a 1D-model (Nelen & Schuurmans, 2013b).

The basic model can be represented in different interfaces; Flood Early Warning System (for high water predictions), Lizard Flooding (for flood calculations), a 3D stereo viewer, 3Di information system (as showed in Figure 11). and 3Di Interactive (as showed in Figure 10) (Nelen & Schuurmans, 2014). Results can be presented with a 3D-viewer, but also in the 3Di system itself as a detailed map

Figure 10: Screenshot of 3Di Interactive (Nelen & Schuurmans, 2014)

Figure 11: Printscreen of the 3Di background system, with a map of Amsterdam Zuidoost

During the case study of the 3Di system in West-Friesland it became clear that the 3Di system is a useful instrument for detailed information. It was useful for flood risk scenarios and damage calculations (Nelen & Schuurmans, 2013a). The 3D-visualizations in the case study in West-Friesland were supporting the commitment of the stakeholders (Nelen & Schuurmans, 2013a)

The city of Rotterdam has a program 'Rotterdam Climate Proof'; the goal of this is to have a 100% climate proof Rotterdam in 2025. Therefore the Rotterdamse Adaptatiestrategie (RAS) is made and water is also an important part of this plan. The RAS is supported by Waterplan 2, another program of Rotterdam. The Waterplan 2 Rotterdam focuses on flood monitoring to predict future changes better. 3Di was used already as a test in this project, but no detailed information about the use can be found (Lijn43, 2013). Therefore this information should be obtained by interviews.

6.3.2. Other comparable models

Besides the 3Di system, other quick, detailed or interactive flood simulation models are also available. This information is used for selection of decision quality elements that can be affected by flood simulation models. Models found in literature are the D-PHASE model, hydrological models based on GIS, participatory modeling and Decision Support System AQUATOOL. Information about the models is used as input for Table 3.

The D-PHASE model made for the Alpine region is somehow comparable to the 3Di system. A part of the D-PHASE model is a web-based visualization platform. Besides that the model can made predictions of heavy rainfall and corresponding flooding events. Frick & Hegg (2011) concluded that the use of such a model can contribute to the aspects below. Some advantages are because the research was only done on short-term (Frick & Hegg, 2011).

- Increasing laypeople interest in meteorological and hydrological processes, because of increased knowledge and understanding
- Mutual understanding between end-users and forecasting services
- Confidence about situation analysis and decision making by stakeholders
- Availability of information
- Structure/overview of information
- Interpretation of information

Hydrological models with use of GIS can contribute also to the decision making according to Al-Sabhan et al (2003). They developed their own GIS- and web-based hydrological model that affected the decision making process by visualization of information, the understanding of the data and collaboration of team members (Al-Sabhan et al., 2003).

For participatory modeling, ‘the use of modeling in support of a decision-making process that involves stakeholders’ (Voinov & Bousquet, 2010), the model influences the decision quality also on some elements. Besides the elements of decision quality it contributes also to getting a common language between groups of stakeholders (Voinov & Bousquet, 2010).

AQUATOOL is a decision support system developed for decision making in complex river basins in Spain. It supports the decision making process by a computerized system. The system makes a part of the decision by using the input given by the stakeholders. The system affects amongst others the communication between team members, reducing the complexity of the decision and setting priorities (Andreu et al., 1996).

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