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DECISION -MAKING IN STORMWATER MANAGEMENT FOR DESIGNING INDUSTRIAL AREAS

BACHELOR CIVIL ENGINEERING THESIS

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Preface

This thesis report forms the end product of my graduation research to obtain my bachelor's degree in Civil Engineering. To do so, I performed research for Ska-pa for 10 weeks in the period from November 2023 until January 2024.

I could not have achieved this report without the involved supervision from Tom Coenen representing the University of Twente, and Johan Boxem from Ska-pa. Their guidance helped me stay on track and eventually produce my end product.

I would also like to thank my colleagues from Ska-pa, for giving me a feeling of comfort and welcomeness from the moment I started until the very last day. They were interested in my research and provided me with answers to my questions where possible.

Sincerely,

Joost Bisschop
Deventer, January 2024

Summary

Climate change is possibly the number one threat to society, and it is becoming increasingly dangerous at a rapid pace. Especially in largely paved areas such as industrial parks, these effects are becoming more apparent. Therefore, industrial parks form the scope of this study. The effects are seen everywhere, with rainfall becoming more extreme, and periods of droughts getting longer. More extreme rainfall results in increased pressure on the sewage systems. When the sewers have reached their maximum capacity, all of the water that needs to be processed subsequently is flooding streets, parking lots or even buildings. Periods of drought in the summer can reduce the groundwater levels by a dangerous amount. These two problems form the incentive of this research. Especially on largely paved areas, they become more apparent. Within paved areas, almost no water gets infiltrated into the ground, and almost all water ends up in the sewage systems.

Project developers need to include stormwater management techniques in their projects to assist with the battle against the effects of climate change. Currently, they can only make decisions based on their expertise or that of their colleagues. They lack a concise model, on which they can base their decisions, and where they can refer back to when explaining their choices to clients. The following research question supported by multiple sub-questions is addressed in this research:

'How could a Decision Support System (DSS) support the decision-making process of stormwater management in the design of industrial areas?'

1. 'What are the key techniques in stormwater management for industrial areas?'
2. 'What are the most important criteria to assess the key techniques for developers of industrial areas?'
3. 'How do the techniques of stormwater management score on the determined criteria?'
4. 'What are the key combinations of techniques of stormwater management for industrial areas in different situations?'
5. 'How could a DSS look like that aims to support decision-makers with applying industrial stormwater management?'

A DSS is created, which includes the most relevant techniques regarding water quantity management. These techniques are found after performing a literature review, supported by expert interviews with project developers. The DSS includes the key criteria to test these techniques, ranging from water quantity criteria such as peak flow reduction and groundwater recharge, to more practical criteria such as space efficiency to maximize sellable meters and cost criteria. These criteria are determined in the same way as the techniques. Subsequently, the performances of the techniques on the criteria are determined again using a literature review. These values form the base performance values of the techniques. Since these values are not constant throughout different situations, different situational characteristics, such as groundwater level and soil type, form reduction factors which decrease the performance values when these variables become less favourable. This is what makes the DSS dynamic and adaptable to different situations. Different versions of the DSS are evaluated using case studies, where the final version is evaluated by a project developer on an ongoing project. The final product is formed by comprehensible tables and graphs to help with the problem of water quantity management in industrial parks. Project developers can use the DSS to make decisions between different solutions in water quantity management techniques.

Samenvatting

Klimaatverandering is mogelijk de meest prominente dreiging tot de samenleving waarvan de gevolgen gevaarlijker worden op een rap tempo. Deze gevolgen zijn voornamelijk zichtbaar op gebieden met hoge percentages verharde grond, zoals industriële gebieden. Industriële parken vormen dan ook het focus punt van dit onderzoek. De effecten van klimaatverandering zijn overal zichtbaar, waarbij stormen extremer worden, en periodes van droogte langer. Meer extreme stormen resulteren in een verhoogde druk op de rioolsystemen. Wanneer een riool zijn maximumcapaciteit bereikt, wordt al het water wat vervolgens in het riool terecht komt omgezet in de overstroming van straten, parkeerplaatsen of zelfs gebouwen. Periodes van droogte in de zomer kunnen de grondwaterstand verlagen tot een gevaarlijk niveau. Deze twee problemen vormen de beweegrede van dit onderzoek. In gebieden met veel verharde grond, wordt bijna geen water geïnfiltreerd in de grond, en bijna al het water komt in de rioolsystemen terecht.

Projectontwikkelaars zijn verplicht om watermanagement technieken in hun projecten te verwerken, om te helpen met het gevecht tegen de effecten van klimaatverandering. Momenteel kunnen projectontwikkelaars alleen beslissingen maken door gebruik te maken van hun eigen kennis en kunde, of dat van hun collega's. Zij missen een beknopt model, waar zij keuzes op kunnen baseren en waar zij naar toe kunnen refereren wanneer ze hun keuzes moeten uitleggen aan klanten. De volgende onderzoeksvraag gesteund door meerdere sub-vragen wordt behandeld:

'Hoe kan een 'Decision Support System' (DSS) assisteren in het besluitvormingsproces van stormwater management in het ontwerp van industriële gebieden?

1. 'Wat zijn de hoofdtechnieken als het gaat om stormwater management voor industriële gebieden?'
2. 'Wat zijn de meest belangrijke criteria om de hoofdtechnieken te toetsen voor ontwikkelaars van industriële gebieden?'
3. 'Hoe presteren de hoofdtechnieken op de gevormde criteria?'
4. 'Wat zijn de combinaties van technieken voor stormwater management van industriële gebieden die toepasbaar zijn in verschillende situaties?'
5. 'Hoe kan een DSS eruitzien die doelt op het assisteren van projectontwikkelaars bij het toepassen van industrieel stormwater management?'

Een DSS is ontwikkeld, die de meest relevante technieken behandeld als het gaat om water kwantiteit management. Deze technieken zijn gevonden na het uitvoeren van een literatuur onderzoek, ondersteund door expert interviews met project ontwikkelaars. De DSS bevat de nodige criteria om deze technieken te toetsen, variërend van criteria over water kwantiteit zoals piek stroom reductie en grondwateraanvulling, tot meer praktische criteria zoals ruimte efficiëntie om uitgeefbare meters te maximaliseren en criteria over kosten. Deze criteria zijn gevormd op een vergelijkbare manier als hoe de hoofdtechnieken zijn gevormd. Vervolgens zijn de prestaties van de technieken op de criteria bepaald wederom door een literatuur review. De waardes die hieruit voorkomen vormen de basiswaardes voor de technieken. Deze waardes zijn echter niet constant voor verschillende situaties. Hierom zijn verschillende locatie karakteristieken bepaald zoals grondwaterstand en grondtype, die omgezet worden in reductie factoren die de basiswaardes laten afnemen als situaties minder gunstig worden. Dit maakt de DSS dynamisch en aanpasbaar op verschillende situaties. De DSS is geëvalueerd op diverse projecten, waar hij uiteindelijk is geëvalueerd door een project ontwikkelaar op een huidig project. Het eindproduct van dit onderzoek wordt gevormd door overzichtelijke tabellen en grafieken die helpen met de water kwantiteit problemen. Project ontwikkelaars kunnen de DSS gebruiken om keuzes te maken tussen diverse water kwantiteit management technieken.

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1. Introduction

Within industrial areas, a large percentage of the area is paved. Industrial areas are seen as areas intended for larger companies with much freight traffic, while business parks are more suited for smaller companies (Schellenburg, 2020). Not only the pavements themselves but also the roofs of the buildings are generally impervious. Climate change is expected to increase the duration and magnitude of precipitation during the winter and result expectedly in more extreme peak rain showers in the summer (Stead, 2014). For the largely paved industrial areas, this could have problematic consequences. With the paved areas being unable to absorb water, flooding of the industrial parks becomes a risk when the sewage systems cannot handle the amount of water. The solutions to these extreme situations are often a part of the urban drainage system, which is seen as a combination of traditional systems (e.g., pipes, storage tanks) and green infrastructure practices. Green Infrastructure practices control the amount of rainwater runoff at the source, by absorbing a part of the water (Ng et al., 2023).

Apart from the consequences of climate change mentioned above, the climate also affects the groundwater level. During summer, the changes in precipitation patterns have resulted in lower groundwater levels which can increase drought events (Stead, 2014). Since a largely paved area disposes most of its water in surface water bodies or stormwater management facilities, the rainwater does not end up in the groundwater, and this could become too low.

These problems are also acknowledged by the Dutch government. To make sure area development projects account for among others water quantity, -quality and groundwater, project developers are obliged by law to perform a 'Watertoets', or 'Water test'. Project developers are required to involve water managers early on in the development as counsellors and they are required to declare their responsibilities towards water management. When a project developer has a plan for an area, the water managers can provide more information on the characteristics and what is (im)possible (Rijkswaterstaat, 2001).

The problems mentioned above become even more apparent since the amount of area used for industry in the Netherlands has increased by 200 square kilometres from 2013 to 2020. This is at the cost of land used for agriculture. With land use for agriculture decreasing, this available space is used mostly for built-up areas. This built-up area exists mostly out of paved areas with buildings and industrial areas (CBS, 2022). Since a largely paved area disposes its water in the sewage system, the rainwater does not end up in the groundwater. As a result, this level could become too low. With the amount of industrial area and the extreme peak showers together with the periods of drought increasing, water management becomes increasingly important for industrial areas.

The variety of directions in stormwater management results makes it difficult for developers and designers to decide how and where to implement which solution. Furthermore, the application of stormwater management is not a constant set of techniques. When the risk of flooding is higher, a green roof could be more suitable since it holds the water on its own and slowly evaporates it. When the risk of drought is more relevant, a wadi could be preferred. Developers and designers of such industrial parks currently lack the tools to select the appropriate solutions concerning stormwater management, which is also stated by project developers. Currently, decision-makers can only make decisions based on their past experiences and knowledge from the work field.

To support designers and developers of industrial areas to more comprehensively include water management in design considerations, this research develops a Decision Support System (DSS) that allows designers and developers to better align specific water management measures with characteristics and contextual factors of a particular industrial area.

This report will guide you through the research and development process using the Design Science Research Methodology (DSRM). This methodology uses activities, which are steps to take to eventually end up with your desired end product. These activities are used as the backbone of this report. The remainder of the report is structured as follows. In section 3.1 the objectives for the solution, which is the DSS developed in section 3.2, are stated. The DSS is subsequently demonstrated and evaluated using several cases in section 3.3 and the final product is presented and explained in section 3.4.

2. Research approach

In this chapter, the research approach is stated. This exists out of the research objective- and questions which state what the purpose of this research is and which questions will need to be answered to achieve this purpose. Subsequently, the research methodology is explained which forms the backbone of this report.

2.1. Research objective and -questions

The objective of this research is the development of a DSS to assist developers in the design of industrial areas with selecting the appropriate measures for minimizing flooding and groundwater drought. I aim to develop this DSS by analysing the known techniques on their strengths and weaknesses and testing these on two cases using the method of design science research. The goal of the DSS is to help developers of industrial areas with applying stormwater management techniques and eventually explaining the choices made to possible clients. The scope of this report regarding stormwater management is limited to water quantity, more specifically peak flow reduction and groundwater recharge.

To successfully carry out the research objective, the following research question will be answered:

'How could a DSS support the decision-making process of stormwater management in the design of industrial areas?'

The main research question will be addressed by answering 5 sub-questions. First, we need to know what stormwater management techniques are currently being used, and which of them are suitable for industrial areas. This results in the following sub-question:

1. *'What are the key techniques in stormwater management for industrial areas?'*

To evaluate the application of the techniques in industrial areas, the criteria on which the techniques are evaluated have to be set up. To determine this, it is important to know which problems they are trying to solve, and how their capability to dissolve these problems could be evaluated. Furthermore, criteria outside of the scope of water retention will be evaluated as well (e.g., costs, maintenance, etc.). This leads to the following sub-question:

2. *What are the most important criteria to assess the key techniques for developers of industrial areas?'*

To eventually provide a clear overview of each technique and its capabilities, each criterion should have different levels of application (e.g., technique A has a water retention ability of 'x' and therefore falls into the 'good water retention' category). The techniques will be evaluated on these criteria, with each technique performing on a certain level for each criterion. Therefore, the following sub-question is formed:

3. *'How do the techniques of stormwater management score on the determined criteria?'*

This research question will dive deeper into how stormwater management is applied. First, individual techniques were determined which are suitable for industrial stormwater management. Subsequently, they will be evaluated on their effectiveness in different situations (e.g., flood- or drought prevention). Combinations of the techniques can be determined for each situation in which they are most effective. This leads to the following sub-question.

4. *'What are the key combinations of techniques of stormwater management for industrial areas in different situations?'*

To eventually reach the research objective, the DSS itself has to be developed. The insights gathered in the previous sub-questions have to be processed into a clear system. This is processed in the sub-question stated below. Figure 1 shows the visualisation of how the different sub-questions eventually answer the main question.

5. *'How could a DSS look like that aims to support decision-makers with applying industrial stormwater management?'*

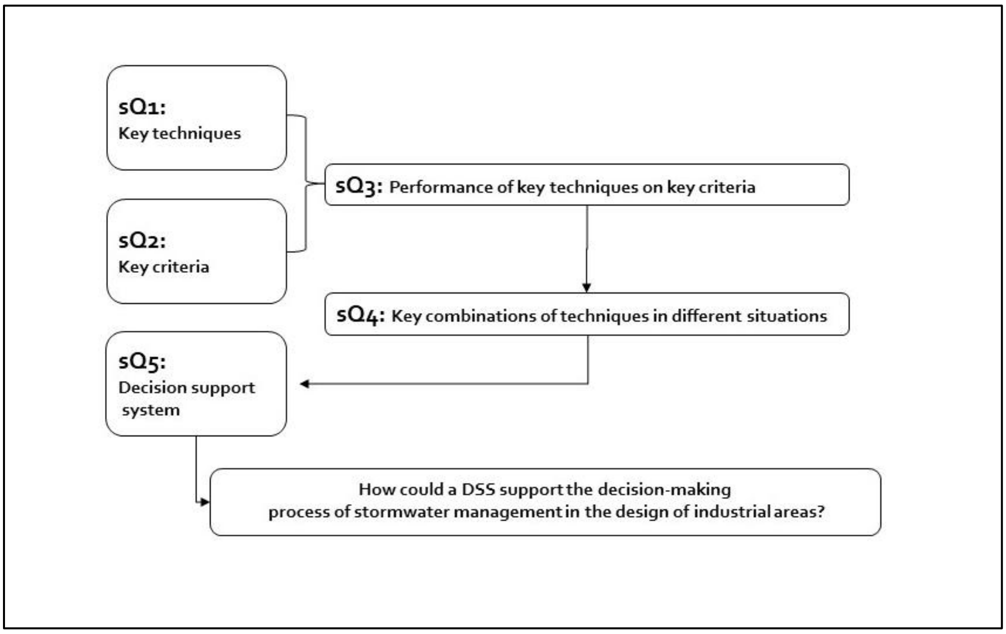


Figure 1: Visualisation of the research questions

2.2. Research methodology

For this study, the Design Science Research Methodology (DSRM) is used (Figure 2) based on Peffers et al. (2007). DSRM is understood to solve organizational problems by designing a system that is updated by a feedback loop that evaluates the system on cases in practice. This method is used mainly because of its iterative design. Designing a DSS itself without testing its competence in cases is insufficient. The DSS must be beneficial for developing companies of industrial areas. Therefore, the DSS is evaluated using previous- and current industrial projects. This type of iterative design makes this method suitable for this research.

As shown in Figure 2, there are multiple possible research entry points. Since this study started with a problem definition, the research entry point is in this case a Problem-Centred Initiation. As indicated by the Process Iteration loop, the design of the DSS is constantly evaluated in the evaluation phase. The results from this evaluation are again processed in the design & development phase. The process iteration loop also goes from the communication phase, but this falls outside the scope of this study. Given the iterative nature of this approach, the objectives can be re-defined if the evaluation demands this. The DSRM process consists, as shown in Figure 2, of various activities. Each activity is, related to the various research questions (RQs) from the previous section individually explained in the following part.

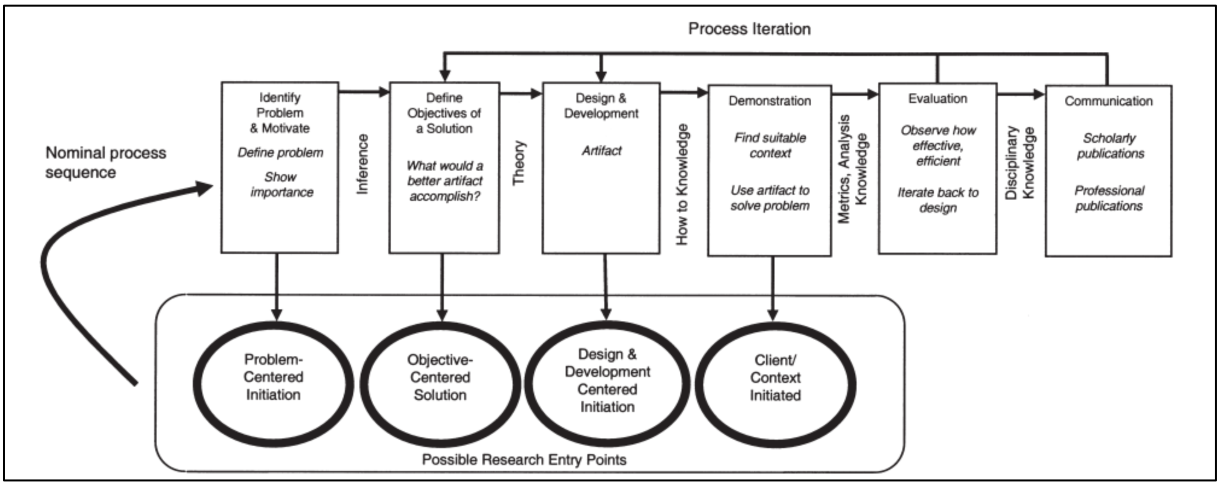


Figure 2: DSRM process model (Peffers et al., 2007)

Activity 1: Problem Identification and Motivation

In this activity, the research problem was defined, and the justification of a solution for this problem was stated. The latter is done to convince the researcher and the audience of the report to go further with the solution and accept its results.

A general problem identification has been described in the Introduction section. The main purpose of this activity is to substantiate the reasoning behind performing research on a certain topic. This has already been done by analysing current literature and defining a research gap to eventually state a problem definition. Project developers have been interviewed to gain insight into their stance on the problem and this has been added to the problem statement.

Activity 2: Define the objectives for a solution

Activity 2 has taken the solution justification from Activity 1 and formed this into possible and feasible objectives for our DSS. The research objective is stated in the Research objective section and is explained in more detail in section 3.1.

Activity 3: Design and development

In this activity, the artefact which in this case is the DSS, is created. This activity includes the desired functionality and the architecture of the DSS. This involves its actual design. This activity includes the processing of the research questions, which is further explained subsequently. The following methods are applied to structure this activity. This activity is performed in section 3.2.

The general insights for this activity are acquired through a literature review. For this, mainly Scopus and Google Scholar were used. Google Scholar was used for the more general literature to gain fundamental knowledge on the subject. For more specific literature, a Scopus keyword search was preferred. Grey literature was used to obtain knowledge on more unknown principles and the state of the techniques in practice. Types of grey literature which were used are policy papers from governments, NGOs specialised in water management and climate adaptation or product information on climate adaptive solutions. The literature review resulted in approximately 35 scientific papers, 20 policy documents and 20 documents from NGOs and other relevant organisations. Furthermore, several cases are studied to validate the DSS. The data extracted from the literature was presented in such a way that it has a new contribution to the existing data. How the sub-questions are answered is seen below.

To gain knowledge of the key techniques in stormwater management (sQ1), a literature review was performed. The subject of stormwater management is heavily researched, but not essentially for industrial areas. Therefore, the key techniques that came out of the literature review were evaluated on their capability to work for industrial areas. First, a general overview of the applicable techniques is shaped. Subsequently, a keyword search has provided more specific information on each of the techniques.

For the more general overview of the techniques, a higher amount of hits, around 150, was accepted since such an overview is a broader research field. The more relevant results were analysed based on their title and abstract. To obtain knowledge on the techniques, search queries included keywords such as Green Infrastructure (GI) and Low Impact Development (LID) since these terms are umbrella terms of multiple techniques that are relevant to stormwater management. Grey literature was used to gain further knowledge of the known techniques and discovered techniques that have not come up in the academic literature.

When a general overview of the techniques was determined, each technique was further researched, again with keyword searches. Since this is a more specific search field, around 50-100 hits were accepted, and the titles and abstracts were analysed to determine the relevant papers. To make sure only relevant papers are studied, papers from before the year 2010 were studied.

To address sQ2, the evaluation criteria needed to be determined. The first research method for this was a literature review. The relevant facets of stormwater management were researched, and the corresponding evaluation criteria were set up. This exists out of their technical and practical competencies. Literature was used to understand how the techniques determined in sQ1 could be evaluated on their technical competence. This was based mostly on their water retention capabilities. A literature review on comparison between the performance of stormwater management techniques was used to gain insight into the comparison criteria. Keyword searches are used, and around 50-100 hits are the aim. The titles and abstracts are again analysed.

For the practical competencies, expert interviews were held with the managing employees of our case organisation Ska-pa to determine what they find important when it comes to applying stormwater management to industrial areas. The technical competencies were also questioned, to make sure they covered the needs of Ska-pa.

For sQ3, the techniques determined in sQ1 were further researched. This was done using a literature review. The performance of the techniques in the criteria points determined in sQ2 has been determined. When the performance of each technique in each of the criteria points was determined, categories, or levels, of the criteria could be set up. This is done by first quantifying all performance values of each technique on each criterion. Out of this, a logical grade distribution was made where each technique is fairly graded, and differences between performances resulted in a logical distinction in grade level. This level is a range of values in which a technique could score, with a higher grade meaning a more preferred level of performance.

The keyword searches exist out of the combination of a technique and the performance criteria. To obtain knowledge of the most recent data on performance, data since 2015 is evaluated first. When this data is not sufficient, data from 2010-2015 is evaluated. Since this is a specific search field, between 20 and 50 hits is acceptable.

To answer sQ4, mainly the answers to the sub-questions stated in the section above were used partially supported by the literature review. sQ3 provided information on the strengths and weaknesses of the key techniques. Based on their strengths, the techniques were grouped to serve most effectively in different situations.

First, the different situations for which stormwater management is needed were determined. These situations mainly existed out of groundwater drought and flooding hazards. To combine the techniques for each situation, the performance from each technique was considered (already determined in sQ3). In different situations, the techniques have different performances. The DSS automatically shows the set of techniques suitable for a specific situation based on their performance. The user is subsequently able to select the desired technique from the set of possible solutions, because of the DSS.

sQ5 uses the output from the other sub-questions as its input. This could be supported by both insights from the expert interviews and literature on the principle of a DSS.

Activity 4: *Demonstration*

After having designed the DSS, its effectiveness and usability can be demonstrated. For this research, the method for the demonstration activity is a case study. Ska-pa has performed several projects on industrial areas in the past, and these cases are used to see how the DSS would be used and whether it was effective. The results of this are processed in the next activity.

The time frame of this research is limited. The DSS is evaluated on two industrial areas and one set of fictive situations. First, 'Ossebroeken bedrijvencentrum' in the province of Drenthe is used to evaluate the DSS in the earlier stage to make sure the development of the DSS is on the right track. This business park project was executed by the predecessor of Ska-pa, 'Credo Integrale Planontwikkeling'. The second case study is held on 3 fictive cases, with a positive situation, a more difficult situation and one with mixed characteristics. The third evaluation is done using a current project about an industrial area in Boekelo, near Enschede. This project is used as the final evaluation case since this evaluates the most complete version of the DSS. The project is currently being designed and developed, and is, therefore, the most relevant. This case is evaluated in more detail by a member of the development team of this project. In conclusion, the DSS is evaluated in the following cases in this order:

1. Ossebroeken bedrijvencentrum;

The case of Ossebroeken Bedrijvencentrum is mainly used to gain insight into the choices that project developers make and compare these choices to what the DSS would have recommended. The evaluation of this case was early on in the research, to make sure that the development of the DSS was on a good track.

2. Three fictive situations;

A more complete version of the DSS is evaluated on three fictive situations, with favourable, unfavourable and mixed locational characteristics. This is done to see how the DSS reacts to situations with significant differences in terms of locational characteristics. The sensitivities in the model appear because of this method.

3. Boekelo industrial area.

The final case evaluation uses the ongoing project development of the Boekelo industrial park. This is done in collaboration with a project development professional at Ska-pa, to gain insight into what developers find important and pay attention to.

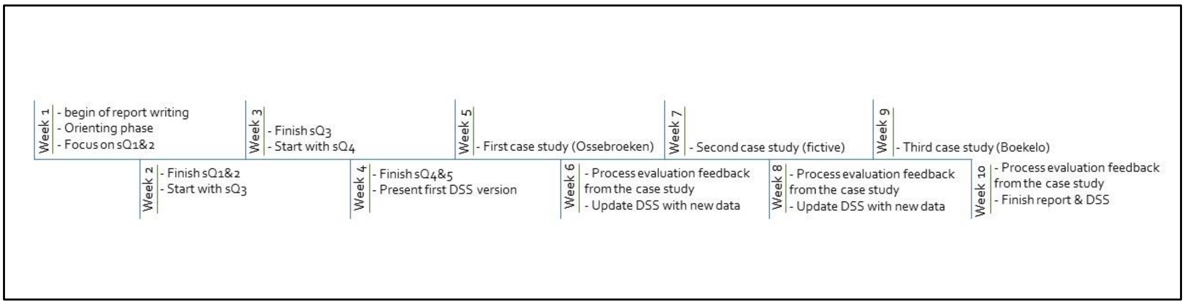


Figure 3: Research timeline

Activity 5: ***Evaluation***

The evaluation activity looks at the previously determined objectives in Activity 2 and sees whether the objectives are achieved when comparing them to the results determined in the previous activity. Furthermore, the results are evaluated by the managing employees of Ska-pa. After the evaluation, the feedback could be processed by re-doing activity 3 to try and improve the effectiveness of the DSS. The explanation of both activities 4 & 5 is seen in section 3.3.

Activity 6: Communication

The final activity comprises the communication phase. This is in the case of this study the processing of the DSRM process in the research report as a main structure. The final product of this study is the DSS which supports decision makers with industrial stormwater management. The results are presented in a detached model file which is usable on its own. This activity furthermore provides information on how the end product could fit in practice and the research field. See section 3.4 for the presentation of this activity.

3. Results

The activities mentioned in the methodology section are elaborated in this section of the report. Following the problem identification and motivation in the Introduction section, the solution objectives are stated below. The DSS is designed and developed in the third activity, and subsequently evaluated using several cases in activities 4 and 5. After the evaluations, the final product is presented in the final activity.

3.1. Activity 2: Define objectives for a solution

As explained previously, the risk of flooding and groundwater drought is increasing. This is also acknowledged by project developers, who are obliged to take responsibility for water management in area development projects. The DSS will need to help project developers with making choices in water management. When the water test is performed and the stormwater management is not deemed sufficient, industrial area developers must make decisions based on the result of the water test. The DSS will help with making decisions and explaining these decisions to the clients they sell the area to.

To do so, it is important to create a DSS which showcases the techniques and their competencies in an understandable way. Furthermore, it should show in what situations which techniques are best applicable. For example, if the development plan does not sufficiently recharge groundwater, it should be improved by implementing technique A/B. The user can choose between technique A or B, by showing their competencies on the assessment criteria. The DSS is sufficient when the user can explain their choices regarding water management in the design phase by referring to the DSS. To do so, the DSS should be comprehensible and adaptable to different location characteristics. In other words, it should be clear which techniques are applicable in which situation. In summary, the DSS must meet the following criteria:

1. The DSS should identify and recommend techniques to optimize water quantity management in industrial areas;
2. The DSS should prioritize techniques which not only enhance water quantity management but also maximize the number of sellable meters;
3. The DSS should be usable on its own;
4. The DSS should be comprehensible for project developers with a sufficient level of knowledge on this topic;
5. Project developers should be able to make choices between different techniques based on the DSS;
6. Project developers should be able to use the DSS to explain their choices made regarding water management for the design of industrial parks;
7. The DSS needs to incorporate location-specific characteristics to ensure custom-made recommendations for different projects;
8. The DSS needs to be expandable and adaptable when new techniques are discovered or when performance values change;
9. The DSS should be aesthetically pleasing.

3.2. Activity 3: Design and development

The contents of the design and development activity are explained below. These contain the steps around establishing the answers to all of the sub-questions. This includes the establishment of the key techniques and -criteria and the performance quantifications and qualifications of the techniques. Eventually this results in the design of the DSS.

3.2.1. Key techniques

When performing a literature review on the known stormwater management (SWM) techniques, it becomes apparent that most of the modern techniques follow the principles of Green Infrastructure (GI) and Low Impact Development (LID). LID plays a big role in SWM and is a concept that takes away pressure from the sewage systems. What all implementations of LID have in common is that they limit impermeable surfaces (Zhao & Meng, 2020). GI practices work with nature to reduce stormwater runoff and water quality. The GI practices can reduce the urban flooding risk by delaying the lag time of the runoff, due to the water infiltrating the soil. Vegetation can increase evapotranspiration because of vegetation uptake, further decreasing the stormwater runoff (Li et al., 2019).

The key techniques are separately discussed below (see Appendix 1: Key techniques for more information on how these techniques were determined).

Wadi

A wadi, which stands for '*Water Afvoer Drainage en Infiltratie*', meaning Water Disposal Drainage and Infiltration, is a gravel and sand-filled trench which can retain and infiltrate stormwater. They are a type of swale system and are the most applied Green Infrastructure practice in the Netherlands (ClimateScan, 2023). Figure 4 shows the schematic overview of a wadi system.

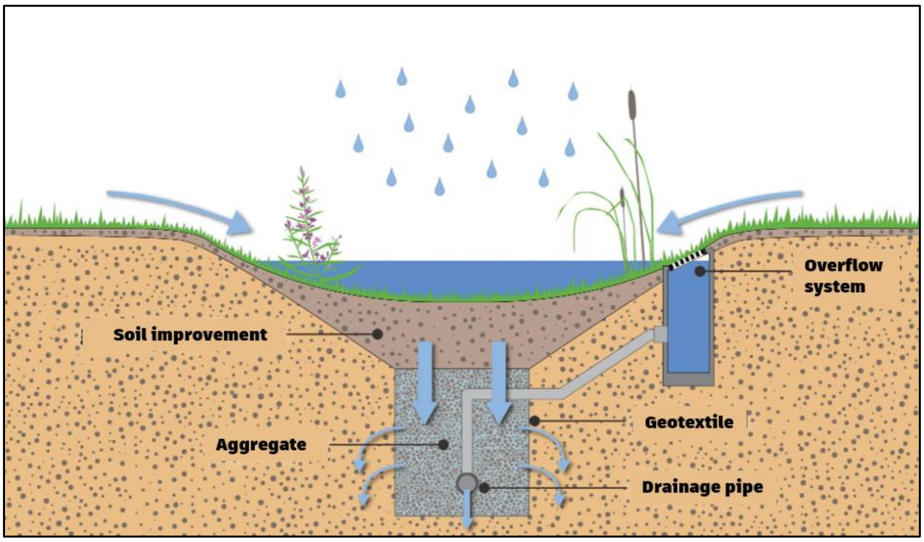


Figure 4: Schematic overview wadi system (Rainproof, 2023e)

The infiltration/drainage pipe can infiltrate the water in the soil or redirect the water to areas with better infiltration capacity or lower groundwater levels. The overflow system is connected to the infiltration- or drainage pipe and is used when the water level in the wadi reaches the level of the overflow system. When the overflow system is also full, the wadi functions as an above-ground discharge system, and the water is disposed of via the sewage system or to surface water (Rainproof, 2023e).

Rainproof (2023e) states that wadis are in particular applicable in areas with a low groundwater level. Therefore, it could be that other techniques are more suited for areas with a high groundwater level. Figure 5 shows the groundwater levels throughout the Netherlands. It can be seen that the east of the Netherlands has a significantly lower groundwater level compared to the west of the Netherlands.

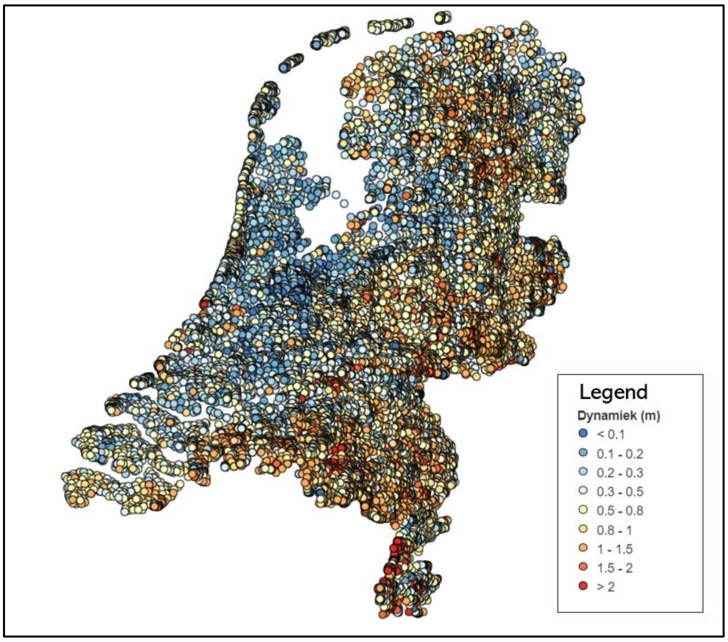


Figure 5: Groundwater levels in the Netherlands (GrondwaterTools, 2023)

(Blue) Green roofs

Green roofs are normal roofs, with a layer of vegetation added to increase the sponge effect of buildings and cities. The roofs exist out of a vegetation layer, substrate layer, drainage layer and protection layer. Depending on the situation, a filter layer could be added. A distinction can be made between extensive- and intensive green roofs. Extensive roofs are the most applied type of green roof and are the thinnest type of green roof. It exists out a thinner substrate layer, to supply soil for mostly sedum, which is possibly supplemented with grasses and herbs. Sedum is used since it can hold a lot of water and can withstand drought properly. Intensive roofs have a larger variety of vegetation and can retain more water because of it. The vegetation could exist of among other types, bushes, and trees. The downside of intensive roofs is that they are significantly more expensive and heavier. Therefore, this study will focus on the extensive roofs. Green roofs are also often implemented in the Netherlands (ClimateScan, 2023). The roofs can provide insulation for the buildings, which could be seen as a secondary benefit. This works through the use of heat by the vegetation to evaporate the water (Rainproof, 2023a). Blue-green roofs work similarly to green roofs but have an extra water basin to retain water. Regular blue-green roofs are also called retention roofs, and polder roofs are more advanced with a dynamic release valve which uses weather forecasts (Rainproof, 2023c). In this report, the focus has been put on the retention roofs since they are more cost-effective.

Permeable pavements

Permeable pavement is pavement where water can infiltrate into or next to the bricks. Where water on regular pavement ends up in the sewage system, permeable pavement allows it to infiltrate the ground, or get delayed discharged to the sewage system or to surface water (Schoenmaker, 2020). The schematic overview of a permeable pavement system is seen in Figure 6.

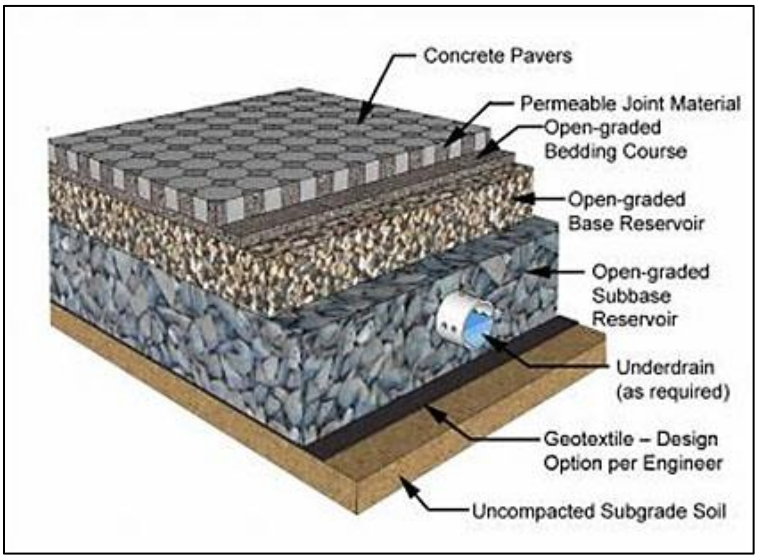


Figure 6: Schematic overview of permeable pavement system (State of California, 2018)

Rockwool

Rockwool is a system made entirely out of circular rockwool. The rockwool can absorb up to 95% of its volume with water within 15 minutes, which is subsequently infiltrated into the soil. The Rockwool is filled from the bottom side, and the air inside the system escapes via a ventilation channel. Because of this, the rockwool can quickly absorb the water. The water infiltrates the soil, and within 24 hours the system can be used again. (Rockwool B.V., 2022). See Figure 7 for a schematic overview of a rockwool system.

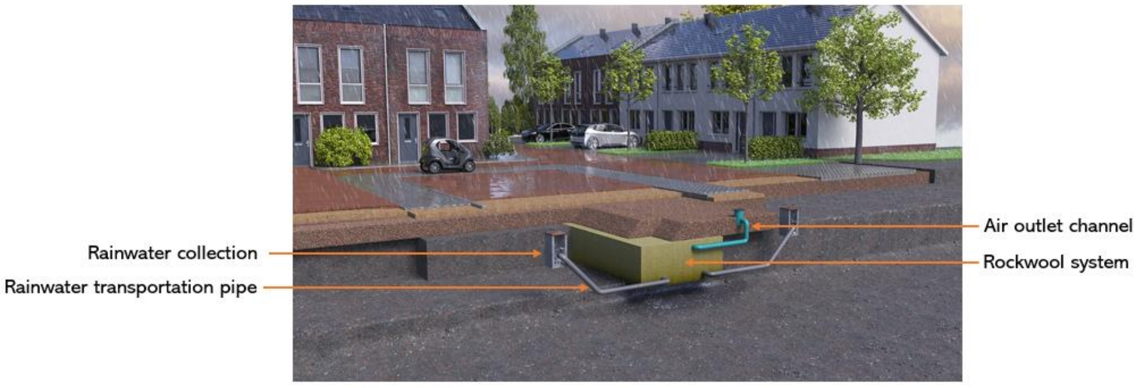


Figure 7: Rockwool system (Rockwool B.V.)

Infiltration crates

Infiltration crates can retain a significant amount of rainwater and subsequently infiltrate it into the ground. The crates are for example applicable below parking lots and roads. The crates should be placed in areas without a high groundwater level, otherwise, they are already placed in the water and that makes them ineffective. The main benefit of infiltration crates is that there is almost no space needed above ground to apply them. However, it might be hard to apply them around cables and pipes in the ground. Furthermore, there is a risk of clogging in the crates due to excess material which flows with the rainwater. Therefore, a geotextile layer is applied (Rainproof, 2023b). The system of infiltration crates is illustrated in Figure 8.

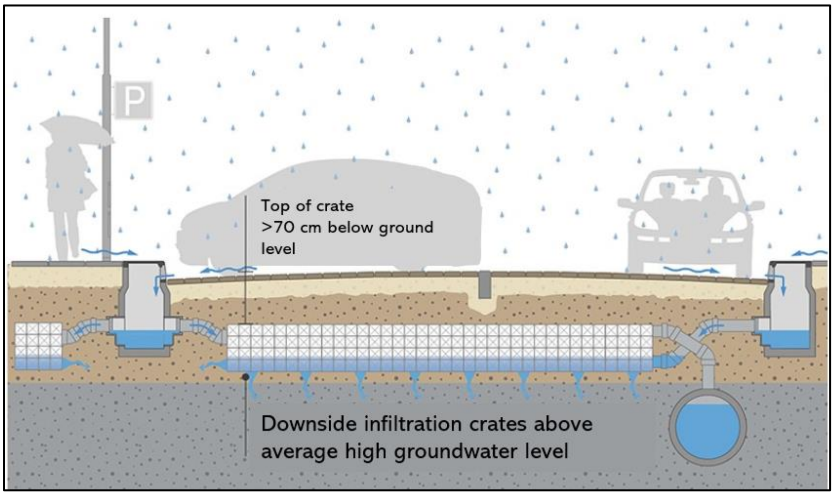


Figure 8: Schematic drawing of infiltration crates (Rainproof, 2023b)

Rainwater tanks

Rainwater tanks can be used to supply non-potable water and reduce runoff simultaneously. Conventional rainwater tanks are only used for water supply. When they are full, they are unable to further reduce runoff. Passive release systems include a stormwater detention volume with a slow-release discharge outlet. Rainwater is released when the water level is above the outlet. At last, active systems use forecasts to predict the inflow and use it to balance water supply and stormwater management. The different systems are seen in Figure 9.

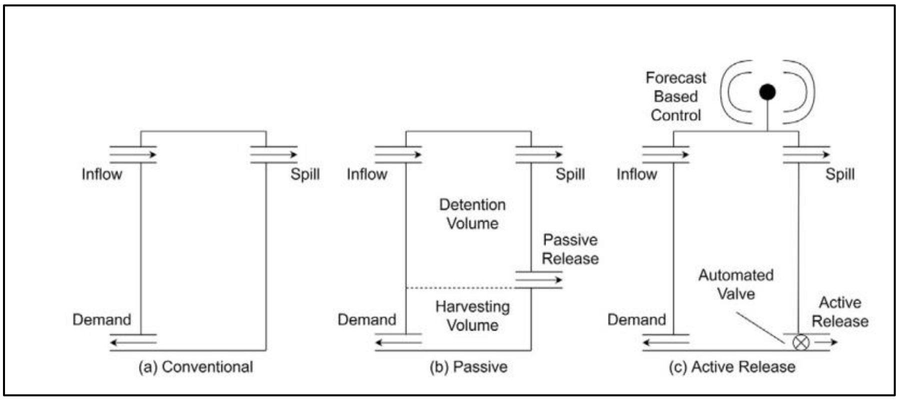


Figure 9: Conventional, Passive and Active Rainwater Harvesting Systems (Quinn et al., 2021)

Ponds

Stormwater ponds are constructed basins designed to capture and store stormwater runoff (Minnesota Pollution Control Agency, 2022). There are two kinds of ponds; retention ponds, and detention ponds. Retention ponds are designed for the permanent storage of water in large ponds. Detention ponds are designed to store water for a limited period (one or two days) after heavy rainfall (Nasr & Shmroukh, 2020). Figure 10 shows the simplified difference between detention- and retention basins. Retention basins are often larger, to prevent overflow whereas detention basins can discharge via the outlet to prevent overflow from happening.

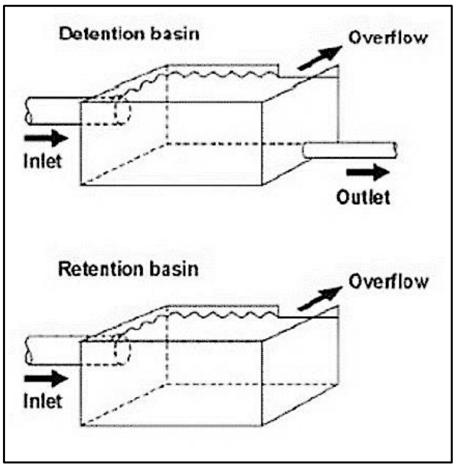


Figure 10: Simplified difference detention- and retention basin (SSWM)

3.2.2. Assessment criteria

Based on the previous section, we know the main techniques that can be used to support water management in industrial areas. To make the right decisions for specific parameters, we need to know which individual or combination of techniques is suitable for a specific situation. In this section, the process of determining the assessment criteria is discussed.

Ska-pa acknowledges the risk of flooding and groundwater drought. Furthermore, the number of sellable meters is of great importance, therefore the methods need to be space efficient. To test the ability to reduce flooding, criteria regarding volume reduction are relevant. This includes the percentage of peak flow (Li et al., 2017). Furthermore, the ability to recharge groundwater is important. As explained in the problem statement, the number of sellable meters is of importance for project developers. Therefore, the gradation in which they limit these meters is an important criterion. Furthermore, Ska-pa has stated that implementation costs as well as life-cycle costs are important.

The scope of this research is limited to water quantity rather than water quality. For water quantity, flood protection and groundwater drought prevention were found to be the most relevant criteria in times of climate change. Peak flow reduction and groundwater recharge were determined as the key criteria. These two criteria are seen in this research as the criteria which should be prioritized. Expert interviews with Ska-pa brought attention to mainly space efficiency and the ability to reuse water, where space efficiency is seen as one of the more important criteria by Ska-pa. Subsequently, greenery and capital/life cycle costs were added since greenery was found to often go hand in hand with Green Infrastructure techniques, and costs need to be realistic to make a project feasible. Each criterion is explained separately below.

Peak flow reduction

Peak flow management is closely related to flood management. They are often mentioned in the same sentence when talking about urban water management. Since a peak flow is the maximum rate of discharge during a storm, this amount is most likely to cause the damage. The solutions are therefore assessed based on the percentage of the peak flow they can process and therefore do not end up in the sewage system. In the Netherlands, there are multiple design storms. They range from return periods of ¼ to 10 years (RIONED, 2019). Where available, data was taken with a return period of 10 years (T10 storm). If not, data is used closest to a T10 storm and the results get evaluated on whether it would be a realistic value for a T10 storm. This does mean that there is some uncertainty in this criterion since not all techniques could be evaluated on a T10 storm. It is assumed that techniques outside of (blue) green roofs also need to process water outside of the water that falls directly on its surface since water can flow via impermeable surfaces to these solutions.

The peak flow reduction will be assessed on a scale of 0 to 8, with steps of 1. This scale was determined process-wise to eventually provide a clear distinction in grading between different techniques while simultaneously grouping techniques with similar performance values. It was kept in mind to create a logical distribution with logical steps, in this case of 10%. How the grades are distributed can be seen in Table 1. The distribution of the grades is based on the quantified performances of the techniques, and out of this, a linear distribution was made. This was done by comparing the different performances of the techniques and assessing fair grades for each of them, while also keeping in mind that new techniques could be added.

Table 1: Peak flow reduction grade distribution

Grade	Minimum (%)	Maximum (%)
0	0	19
1	20	29
2	30	39
3	40	49
4	50	59
5	60	69
6	70	79
7	80	89
8	90	100

Groundwater recharge

The ability to recharge the groundwater is of great importance. Due to climate change, periods of drought have increased. The stormwater management techniques therefore should be able to help keep the groundwater level on a steady level. Urbanization, where industrial- and business parks are a part of, is expected to reduce groundwater recharge. To mitigate this, stormwater management techniques are used through distributed stormwater infiltration (Bhaskar et al., 2018). The solutions are assessed on their ability to infiltrate a peak storm into the ground which is again expressed in a percentage. The downside of this method is that the less extreme, longer parts of storms are not considered who do help with groundwater recharge. When a solution has a longer amount of time to infiltrate the storm into the soil, it might not benefit the peak part of the storm, but it could benefit the rest of the storm significantly. The grade distribution is seen in Table 2 and was determined similarly as for the peak flow reduction.

Table 2: Groundwater recharge grade distribution

Grade	Minimum (%)	Maximum (%)
0	0	19
1	20	29
2	30	39
3	40	49
4	50	59
5	60	69
6	70	79
7	80	89
8	90	100

Space efficiency

As previously mentioned, the number of sellable meters is important. Techniques that take up too much area, such as wetlands, are therefore not feasible. When a technique is more space efficient by redeveloping non-permeable areas such as roads or roofs into climate adaptive solutions while maintaining the same functionality, it will be evaluated higher. Space efficiency has been seen to be more important for areas with a high number of sellable meters which is defined as above an average of 74% (Verwoerd & Zuidema, 2015). Therefore, the space efficiency grades are higher in the DSS when the development area has an above-average percentage of sellable meters. The grade distribution is seen in Table 3.

Table 3: Space efficiency grade distribution

Grade (below/above 74%)	Explanation
0	Should not be applied
1/2	Has a significant impact on sellable meters
2/4	Still considered a significant impact on sellable meters, but is still seen as applicable
3/6	Does impact the sellable meters, but is not significant
4/8	Does not impact sellable meters, makes use of necessary area components (roads, roofs etc.) and makes them climate-adaptive

Ability to reuse water

A benefit of certain stormwater management techniques could be that a certain amount of water is retained and could be reused for non-potable uses. The range in grades for this criterion range from 0 for no water reuse, to 8 for a high amount of water reuse. A high amount of water reuse would mean that for example an office building could be provided with enough water to flush toilets and other non-potable water practices. Furthermore, an uncertainty in the amount of water a technique can provide will result in a lower grade.

Greenery

A benefit of certain Green Infrastructure practices is the increased biodiversity by applying more greenery. This is not the main focus point of this study, but it is a welcome benefit. As explained in the future chapters regarding case evaluations, certain criteria weigh heavier in different types of industrial areas. In the Introduction, it was explained that a distinction can be made between industrial- and business parks. In the first case evaluation, it became clear that business parks could value the green aesthetic sometimes at the expense of sellable meters. This is most likely because companies often need to host clients and greenery could improve their image. Therefore, for business parks the greenery criterion weighs heavier, and for industrial areas the space efficiency criterion ways heavier. This distinction is expressed in the amount of sellable meters. Business parks are expressed as parks with below average number of sellable meters (74%), and therefore industrial parks are expressed as parks with above average number of sellable meters. The grade distribution is seen in Table 4.

Table 4: Greenery grade distribution

Grade (above/below 74%)	Explanation
0	Does not add greenery whatsoever
1/2	Barely any greenery
2/4	Might add some greenery but nothing significant
3/6	Adds greenery, but might not add much to the aesthetic
4/8	Adds greenery which benefits biodiversity and aesthetic

Capital costs

For a real estate management company, such as Ska-pa, the capital- and installation costs are of great importance. They need to be able to sell a development plan to their clients, and with too high capital costs this becomes difficult. The techniques should be effective in terms of flood reduction and groundwater recharge, but their implementation should also be feasible in terms of capital costs. The capital costs should however not be seen as main criteria point, since often development companies can obtain compensation for applying climate adaptive solutions. Both of the cost criteria will be expressed in €/m^3. Both of the cost criteria will not be scaled, since the costs are often difficult to compare between different types of techniques. Therefore, only the quantified values will be shown.

Life cycle costs

Besides capital costs, the life cycle costs are also important. The clients need to be able to use the techniques without having to spend too much money on maintenance. Furthermore, a technique might provide insulation or water for non-potable uses which could decrease the costs over time. This could be determined by measuring the demand for non-potable water together with the yield. This can determine the cost savings done by collecting rainwater for non-potable water uses.

3.2.3. Performance of the techniques on the criteria

Table 5 and Table 6 show the overview of the performances of the techniques on the quantifiable- and qualifiable criteria respectively. Some techniques have multiple performances when their performance is dependent on the situation of the project. This is further explained in Appendix 2: Solutions assessments. These performance values are the basis of the DSS and using these values the sets of techniques in different situations can be determined, and the DSS can be made. The first version of the DSS is seen in Appendix 3: Versions of the DSS.

For the peak flow reduction criterion, techniques which include overflow mechanisms are assumed to not be influenced by locational characteristics since they can dispose of excess water to these overflow systems. Furthermore, retention ponds are assumed to have a constant performance value due to their large size while they do not have overflow mechanisms. Groundwater recharge is more dependent on the locational characteristics. Where possible, values were obtained via the literature, and otherwise values were assumed based on comparison with other techniques and the overall nature of a technique. For (blue)-green roofs the groundwater recharge depends heavily on the method of discharging excess water. When this is disposed of to a retention area it can contribute to groundwater recharge, but when it is disposed of to a sewer it will not contribute to groundwater recharge. The effect of locational characteristics is processed in reduction factors. All techniques have been assessed a base value, and specific reduction factors for the groundwater level- and soil type criteria. The base values are the performance values in ideal situations, and they get multiplied by reduction factors when situations become more unfavourable. The table below shows the base values in case of favourable situations (sandy soil and low groundwater level).

Table 5: Performance evaluation for quantifiable criteria

Solution	Peak flow reduction (0-8)	Groundwater recharge (0-8)	Capital costs (€/m^3)	Maintenance costs (€/m^3)
Wadi	7	7	67.00	1.23
Green roofs	4	1	750.00	80.00
Blue-green roofs	6	3	1275.00	176.00
Permeable pavements	6	6	575.00	22.25
Rockwool	8	8	1000.00	190.50
Infiltration crates	7	7	595.00	238.00
RWH systems	7	0	1900.00	0 (with net benefit)
Retention ponds	8	3	60.00	3.60
Detention ponds	8	0	60.00	3.60

Table 6: Performance evaluation of qualifiable criteria, scaled (0-8)

Solution	Space efficiency (above 74%)	Space efficiency (below 74%)	Water reuse	Greenery (above 74%)	Greenery (Below 74%)
Wadi	6	3	0	4	8
Green roofs	8	4	0	3	6
Blue-green roofs	8	4	4	3	6
Permeable pavements	8	4	0	0	0
Rockwool	8	4	0	0	0
Infiltration crates	8	4	2	0	0
RWH systems	8	4	8	0	0
Retention ponds	0	0	8	1	2
Detention ponds	4	2	8	1	2

3.3. Activity 4&5: Demonstration and evaluation

In this section, the case studies will be performed. This exists out of both the demonstration- and evaluation activities. During the demonstration activity, the cases will be explained and during the evaluation activity, the insights that are gathered during the case studies will be discussed.

3.3.1. Case 1: Business centre Ossebroeken

The first version of the DSS will be a more simplified version of the eventual DSS, in the form of a table as seen in Appendix 3: Versions of the DSS. The left side shows the techniques discussed, and the top side shows the assessment criteria.

Activity 4: demonstration

As discussed previously, both versions of the DSS will be evaluated on a case study. For version 1, the case used is the project 'Ossebroeken bedrijvencentrum'. A general overview is presented in Figure 11.

Figure 11: General overview Ossebroeken bedrijvencentrum (GoogleEarth, 2022) (G-Kracht)

The following stormwater management techniques were applied:

- Left side was heightened (approximately 1 meter) as a water barrier;
- The top right side has a retention pond with grass shores;
- There are grassed areas with trees throughout the area which act as a green buffer;
- The curbs used are also grassed, as seen in Figure 12.

Figure 12: Grassed curbs in Ossebroeken Bedrijvencentrum (GoogleEarth, 2022)

When looking at the location of Ossebroeken in Figure 17, the soil type is sandy, and it is a business park (so no industry which would increase the risk of clogging) which means permeable pavements and stormwater ponds are possible. There is no data on the groundwater level for the exact location, but the measurements done around the area found the groundwater level to be medium to low. Therefore, wadis are also applicable.

Ponds were not discussed in the first instance due to their size. However, a retention pond was applied in this case by stretching it out across the entire right side as seen in Figure 13. Therefore, they are discussed in detail. It has to be considered that this pond was already present before the area was developed, as seen in satellite images from 2005 in Figure 14. It therefore might not have been the first choice for the developers to implement a pond.

Figure 13: Retention pond Ossebroeken Bedrijvencentrum (GoogleEarth, 2022)

Figure 14: Satellite image Ossebroeken Bedrijvencentrum 2005 (GoogleEarth, 2005)

Activity 5: evaluation

For the assessment, Figure 14 is taken as the area before development and Figure 11 as the general aim of the area. It makes sense to keep the retention pond since it is an effective stormwater management method, and it does not limit the sellable meters by much due to its stretched-out shape. The curbs, such as in Figure 12, could be (partially) replaced by wadis. This would increase the number of sellable meters, since wadis are deeper and have improved soil characteristics with drainage pipes, resulting in less area needed for the same water management benefits as with a grassed curb. Since permeable pavements are prone to pressure from traffic, it might not be wise to implement permeable pavements on the main roads. On a more business-focused scope, the parking lots and driveways could be replaced by permeable pavements. Furthermore, Rockwool, infiltration crates, rainwater harvesting tanks and (blue) green roofs could be applied for the business buildings. The latter do not apply to all buildings due to their possibly angled roofs. However, when acting as a developer in the design phase, these buildings could have been built with a flat roof if the idea was to implement (blue) green roofs. Implementing a detention pond would not be a logical choice since there is already a retention pond present.

It is not logical to implement all the applicable techniques. It is simply not necessary to do so. When taking financial matters such as possible subsidies into account, it is better to implement a technique on a larger scale than a few techniques on a smaller scale. Therefore, choices have to be made. It might be of importance for the businesses located in the area to have a green entrance for possible clients and overall aesthetic. Therefore, biodiversity is a factor to take into consideration. It makes sense to apply wadis in the shape of a curb and possibly add plants to the wadis. Having wadis as curbs and a retention pond, the water retention is possibly already sufficient. When businesses are interested in the reuse of water for non-potable purposes, blue-green roofs or rainwater harvesting systems might be applied.

When looking back at the solution requirements stated in chapter 3.1, this first version does not meet each requirement. It does however meet a few. For example, it does include the peak flow reduction- and groundwater recharge criteria, together with the sellable meters criterion. However, the model still lacks the ability to use it on its own. When this state of the DSS would be handed over to a project developer, he would not be able to make decisions without additional information. Therefore, he also could not explain the choices made to clients. This version of the DSS also does not include location-specific characteristics, which also is a requirement. At last, the model is not expandable, and its aesthetic could be improved.

Out of the assessment of the case, a few notes can be considered for the next version of the DSS:

- Businesses in business parks value a green entrance and -aesthetic, while this is less important for industrial areas. Therefore, a distinction should be made between the two;
    - To make this an objective characteristic, the distinction will be made between above- and below-average percentage of sellable meters of 74% (Verwoerd & Zuidema, 2015).
- The above-mentioned note also brings the criterion of sellable meters into perspective. In business parks, this might be neglected more quickly to improve the aesthetic. For industrial areas, the sellable meters will be maximized more likely;
- The criterion 'biodiversity' should be called 'greenery', since biodiversity does not include the aesthetic which covers the scope of the criterion better;
- The area might already include stormwater management techniques pre-development; they have to be considered in the decision-making process.

3.3.2. Case 2: three different fictive situations

The next version of the DSS is similar to the first one but more advanced. It considers several location characteristics and adapts the criteria depending on these characteristics. The second version of the DSS takes groundwater level, soil type, the difference between above- and below-average percentage of sellable meters and distance to surface water into account. Furthermore, the (blue) green roofs now have different types of systems in the DSS, with different methods of processing excess rainwater. The layout was also improved by applying a more logical colour scaling method and adding more general headings to make it more comprehensive. Furthermore, quantified performance values were added in columns to showcase where certain grades are based on. Lastly, several criteria have been studied in more detail and therefore some values have changed. In the second evaluation, three fictive industry parks will be discussed to see how the DSS reacts. The fictive cases exist out of favourable-, difficult, and mixed situations. By evaluating cases from both extremes of the spectrum and a case which combines both, insight is gathered into how the DSS reacts to extreme situations and where its sensitivities can be found.

Activity 4: demonstration (favourable situation)

In the first fictive situation, the most favourable characteristics will be taken:

- Groundwater level: low (>1.5m);
- Soil type: sand;
- Above-/Below 74% sellable meters: below;
- Distance to surface water: low (<1km);
- Excess (blue) green roof water retained and infiltrated.

The resulting versions of the DSS are all seen in Appendix 3: Versions of the DSS. It can be seen that for the peak flow reduction, almost all techniques perform in a similar range. The performances for the groundwater recharge criterion are significantly further apart. When looking at the combination of these two criteria, rockwool infiltration blocks perform the best scoring the highest grade in both categories (4 out of 4). Infiltration crates and wadis both perform good as well, scoring 3.5 out of 4 for both categories.

Activity 4: demonstration (difficult situation)

In the second fictive situation, the most difficult characteristics will be taken:

- Groundwater level: high;
- Soil type: clay;
- Above-/Below 74% sellable meters: Above;
- Distance to surface water: high;
- Excess (blue) green roof water disposed to sewer.

Overall, the differences in the groundwater recharge performances become larger compared to the previous case, and differences in peak flow reduction also become more apparent. The best-performing technique remains the wadi, scoring the same as in the positive situation. It has to be considered that with more difficult situation characteristics, the wadi most likely has to dispose some of its water to the sewer. Furthermore, rockwool continues to work properly. Several techniques can reduce the peak flow significantly but are not able to recharge the groundwater. This does make sense given the fact that the groundwater level is already high, and it therefore cannot be recharged.

Activity 4: demonstration (mixed situation)

In the third fictive situation, mixed characteristics will be taken:

- Groundwater level: medium;
- Soil type: peat;
- Above-/Below 74% sellable meters: below;
- Distance to surface water: medium;
- Excess (blue) green roof water to overflow, which is connected to the sewer.

As expected, the results from this case can be placed somewhere between the results of the previous two cases. Again, the wadi scores the best together with the rockwool infiltration blocks. Furthermore, infiltration crates do have significant impacts on peak flow reduction and groundwater recharge.

Activity 5: evaluation

When looking at the solution requirements in chapter 3.1 and comparing it to the first version of the DSS, the second version performs significantly better. The usability on its own is improved, but still not sufficient. The headers in the DSS are more self-explanatory and the quantified performance value columns help with understanding where grades come from. However, there still lacks a dedicated tab in which the overall idea behind the DSS is explained together with the techniques and criteria. This goes hand in hand with the criteria regarding the decision between techniques and the explanation to clients. Furthermore, locational characteristics were added, and the overall aesthetic was improved. The DSS is expandable, but this system could be improved.

Out of the fictive cases, it became clear that especially the groundwater recharge is sensitive to the locational characteristics in the DSS. This makes sense, since when soil is saturated with water or is very impermeable, the water has to be disposed of elsewhere and therefore does not end up in the groundwater, but it does reduce the peak flow. Several techniques are in general more sensitive to locational characteristics. These are mostly the more space-efficient methods since they are applied often below ground or pavement, making them interact more with the soil surrounding themselves. Especially the performance of infiltration crates and permeable pavements are sensitive to location characteristics.

When comparing the three cases, it became clear that the groundwater recharge was only dependent on the soil type, and not the groundwater level. This is not a realistic representation of reality, since when a soil is fully saturated with water it cannot absorb as much water as when it is not saturated. Therefore, in the new version of the DSS, the groundwater recharge depends on soil type as well as groundwater level. This is done by giving each technique a variable reduction factor for soil type and groundwater level and multiplying both with a starting value which is the value in an ideal situation. The variable reduction factors are given a value of 1 when the situation is ideal (low groundwater level or sandy soil) and for example, 0.5 when a situation is very difficult (high groundwater level or clay soil). When both reduction factors are unfavourable, the starting value is multiplied by a factor of 0.25 (0.5 times 0.5).

In the second version, the DSS was not usable without having this report with it. This has been changed after the second evaluation. Several tabs have been added to the Excel file, which explains the overall use of the DSS, the techniques which are evaluated and the explanation behind the scoring system. This makes the DSS usable on its own, without having to use this report.

3.3.3. Case 3: Industry park Boekelo

The final case study is of a currently developed industrial area in Boekelo, Enschede. A general overview can be seen in Figure 15. When comparing the third version to the second version of the DSS, it might seem that not much has changed but this is not the case. As stated in the evaluation activity of the previous cases, the usability of the model has been improved by adding tabs which include a general introduction and explanations of the techniques and criteria. The resulting DSS is presented in Appendix 3: Versions of the DSS.

Activity 4: demonstration

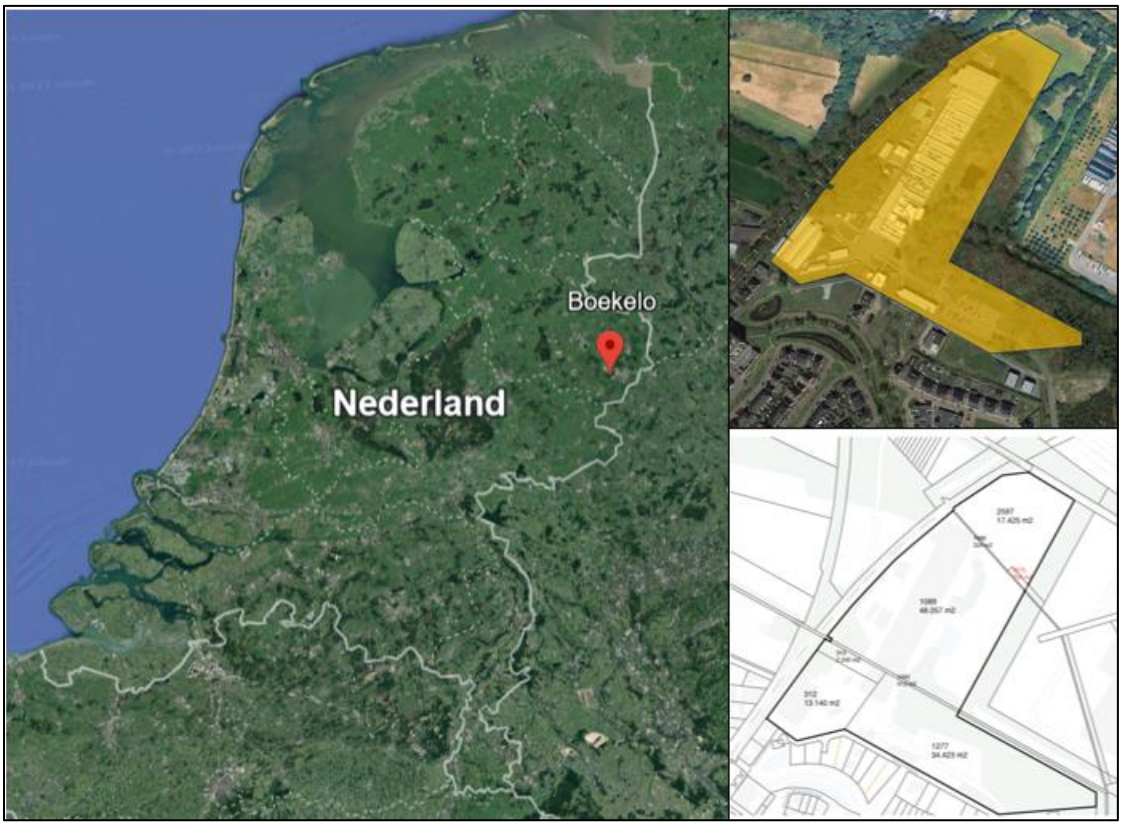


Figure 15: General overview of Boekelo case study (GoogleEarth, 2022) (Harmsel, 2023)

The soil type in Boekelo is assumed to be sand, based on Figure 17. Furthermore, the groundwater level is medium (Grondwater Tools, 2023) and the distance to surface water is low (below 1km). Since the groundwater level is relatively low and the soil type is favourable, the excess green roof water is assumed to infiltrate the soil. The maximum building percentage of each lot is 70% (Harmsel, 2023), and therefore the percentage of sellable meters is assumed to be below the average of 74%.

Activity 5: evaluation

The third version of the DSS is almost sufficient and at least partially meets all the requirements from the solution requirements stated in chapter 3.1. The usability of the model was significantly improved. Several tabs were added. First, a general introduction tab which includes the motivation behind the model and a general explanation of how the model works. Furthermore, this tab includes an explanation of how the model can be expanded. Furthermore, a tab explaining the techniques and one explaining the criteria were added. This helped users get an idea of how the model works and where it is based on. Since the usability of the model on its own was improved, the ability to make- and explain choices was also improved. The comprehensibility of the model could be improved by making the scales of all criteria equal. For the final case, a member of the development team for this project will evaluate the DSS. The member will try and use the model and provide feedback on the usability of the model. The following points of feedback were given:

- The overall usability of the model was sufficient, but some knowledge of the subject was needed. The model would be usable on its own, but improvements could still be made;
- The locational characteristics were deemed logical;
- It would be favourable to be able to sort the techniques based on the criteria of the user's choice;
- In the case of the industrial area in Boekelo, the policy says that the amount of impermeable ground translates to a certain amount of retention. This amount of retention translates to an amount of retention capability of a technique, which results in a certain amount of costs. Ideally, the DSS would include a criterion about costs per cubic meter which translates to a total retention cost per criterion.

Changes made before the final version

The first point of criteria was resolved by adding the tabs explaining the techniques and criteria points. The project developer did not have the version including these tabs when he first looked at the model, but when shown these tabs he stated that this would resolve the unclarity of the model. For the final version, all scales were changed to a range from 0 to 8 with steps of 1 instead of 0.5 for more clarity. Furthermore, cells in which the user should provide input were marked with a red colour. A clear explanation of how the model can be expanded is also added. The cost criteria are no longer scaled since it is difficult to compare different types of techniques based on a cost scale. The groundwater recharge criterion is now more realistic by having added reduction factors for both soil type and groundwater level. The final point of feedback was processed by adding a retention calculation in which the user can determine the amount of retention required by filling in the amount of impermeable area within the industrial park together with the required retention depth. This eventually results in a retention costs column, which is calculated by the price per cubic meter and the retention calculations. The DSS has been divided into two parts; a comprehensive version, and a detailed version. The comprehensive version is the main end product of this research, and the detailed version functions as a clarification behind the comprehensive version. The DSS now only presents the scaled performances of the techniques, together with the total retention costs. The detailed version shows all of the columns including the quantified performances and the costs per cubic meter. The DSS has been elaborated by enabling the user to select a prioritized criterion, which subsequently presents the performance of each technique in a comprehensive bar chart. This partially processes the third point of feedback. At last, a contents tab was added together with colour-coded tabs to enable the user to navigate to a tab by simply clicking on its name in the content tab and notes are added throughout the file to help the user.

3.3.4. Final DSS version

The final version, as presented in the subsequent chapter, is evaluated in this section. All of the changes made which are stated in the previous section are applied in this version.

Evaluation

In chapter 3.1, the solution requirements for the DSS were discussed. They were formed out of the problem identification and motivation activity, and together with the research questions they formed the end product in the shape of the DSS as seen in chapter 3.4. When looking at the DSS, it includes all of the listed requirements.

The first and second requirements were included by answering the first three sub-questions. In these sub-questions, the key techniques were identified and were subsequently evaluated on the identified key criteria. These criteria included, among others, peak flow reduction, groundwater recharge and space efficiency. Peak flow reduction and groundwater recharge were found to be the key criteria to evaluate water quantity management, and space efficiency was found to be the logical choice to evaluate the ability to maximize sellable meters.

Requirement 3 was realised by adding several tabs which explain the use of the DSS, and how the results should be implemented. The techniques were explained, together with the key criteria and the corresponding scoring system. (Appendix 3: Versions of the DSS). This makes it usable on its own, without having to use this report.

Requirement 4 is about the clarity and comprehensibility of the DSS. This was realised by adding clear and comprehensive headers throughout the model, together with making clear where the user should make choices or add information him- or herself. This requirement is partially met by meeting requirement 3, since improving the usability on its own also improves the comprehensiveness of the model.

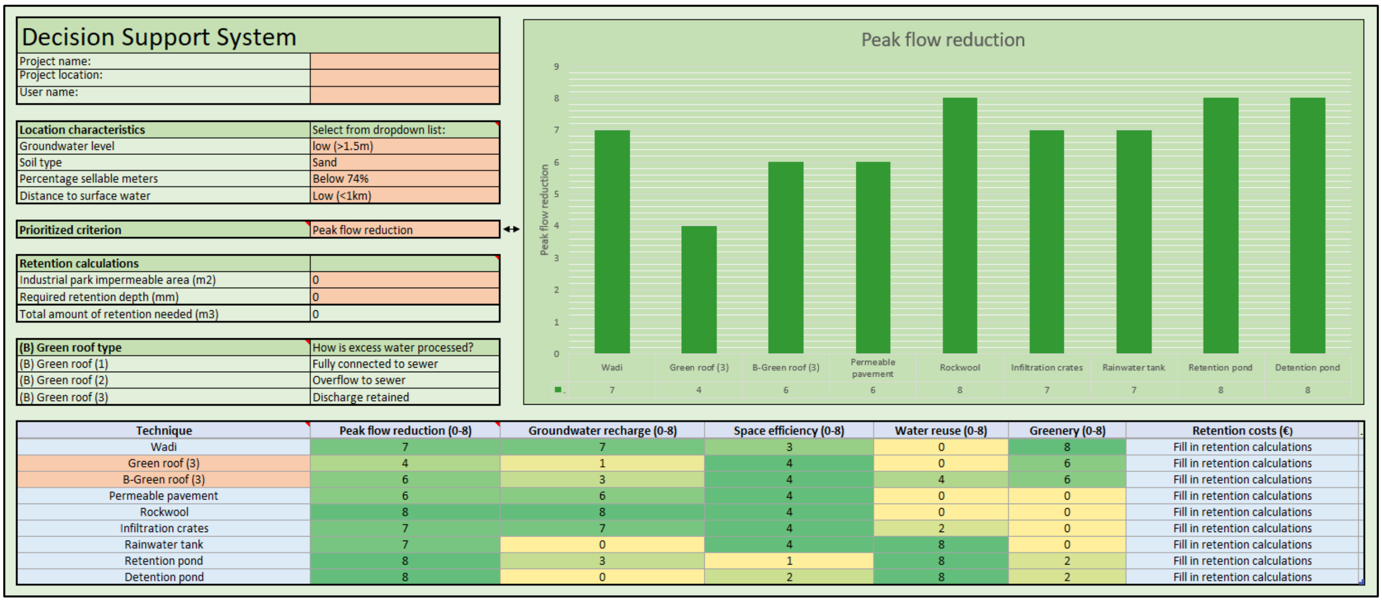
Requirements 5 and 6 were realised by answering sub-questions 4 and 5 together with implementing the previous requirements. Sub-questions 4 and 5 were answered to find suitable techniques in specific situations, which was eventually translated into the DSS. The previous requirements provided the needed clarity to make choices between different techniques, and to use the DSS in explaining the choices made to clients.

Requirement 7 was also partially answered by sub-question 4 about the suitable techniques in specific situations. The locational characteristics were used to make the DSS dynamic and location-specific.

Requirement 8 was realised by clearly explaining how to expand the DSS. The explanation is seen in the introduction tab in Appendix 3: Versions of the DSS. At last, the overall aesthetic is sufficient due to a comprehensive colour scheme and colour scales. The DSS has a clear colour scheme throughout all tabs.

3.4. Activity 6: Communication

The final version of the DSS is presented below in Figure 16. It is supported by multiple tabs. The introduction tab and the detailed version of the DSS table can be seen in Appendix 3: Versions of the DSS. The tabs including the explanations of the techniques and criteria are similar to that included in this report, as seen in sections 3.2.1 and 3.2.2. The user should provide information in the cells which are made red, and could subsequently decide between techniques based on the criteria columns. The user can select a prioritized criterion, which will show the performance values of each technique in the bar graph. The DSS is developed following the DSRM paradigm. The DSS and this accompanying report were developed to assist project developers in the design phase of industrial parks with applying stormwater management solutions.



Decision Support System

Project name:	
Project location:	
User name:	

Location characteristics	Select from dropdown list:
Groundwater level	low (>1.5m)
Soil type	Sand
Percentage sellable meters	Below 74%
Distance to surface water	Low (<1km)

Prioritized criterion	Peak flow reduction

Retention calculations	
Industrial park impermeable area (m2)	0
Required retention depth (mm)	0
Total amount of retention needed (m3)	0

(B) Green roof type	How is excess water processed?
(B) Green roof (1)	Fully connected to sewer
(B) Green roof (2)	Overflow to sewer
(B) Green roof (3)	Discharge retained

Technique	Peak flow reduction (0-8)	Groundwater recharge (0-8)	Space efficiency (0-8)	Water reuse (0-8)	Greenery (0-8)	Retention costs (€)
Wadi	7	7	3	0	8	Fill in retention calculations
Green roof (3)	4	1	4	0	6	Fill in retention calculations
B-Green roof (3)	6	3	4	4	6	Fill in retention calculations
Permeable pavement	6	6	4	0	0	Fill in retention calculations
Rockwool	8	8	4	0	0	Fill in retention calculations
Infiltration crates	7	7	4	2	0	Fill in retention calculations
Rainwater tank	7	0	4	8	0	Fill in retention calculations
Retention pond	8	3	1	8	2	Fill in retention calculations
Detention pond	8	0	2	8	2	Fill in retention calculations

Figure 16: Final version of the DSS

The research performed in this report was essentially done for the case organisation Ska-pa. The DSS is presented to them, and they can decide whether to keep it for themselves, publish it publicly or perform further research. The end product is produced for Ska-pa but can be used by other industrial park developers as well.

4. Discussion

The problem as stated in the introduction, was in the broadest sense about climate change. When reducing the scope more and more, climate change is reduced to water management problems, which is reduced to problems regarding water quantity, which is reduced to the problem specifically on paved areas and eventually it is reduced to the decision-making process of water quantity management in the design of industrial areas. This DSS could help the designers and developers of industrial areas by applying the most suitable techniques in specific situations. When applying the correct techniques in a specific situation, the risk of flooding can be reduced, and the groundwater drought can be minimized. Furthermore, designers and developers could explain and argue their choices regarding water management to clients.

This research investigated how a DSS could help designers and developers of industrial areas with applying stormwater quantity management to projects. This was done using multiple literature reviews, partially supported by expert interviews. What became clear during this research, was that it is difficult to quantify certain performance values, since they depend heavily on locational characteristics and weather conditions. The effect of these variables was often not quantified in the literature and therefore often had to be assumed. The effect of locational characteristics was processed in the DSS using the literature where possible and was otherwise quantified by comparing the effect on performance values with that of other techniques which were quantified in the literature. This results in the first shortcoming of this research and more specifically the DSS. Certain values cannot be verified using literature and are based purely on assumptions. This means that the DSS holds a relatively high level of uncertainty. The effect of weather conditions was mainly minimized by looking for Dutch literature as much as possible, often in grey literature such as governmental policy papers. This was not always possible, in that case, literature from countries with similar climates to the Dutch climate was taken where possible.

This research had to be performed in approximately 10 weeks. This could be seen as a short amount of time, and therefore the scope of this research had to be small with clear boundaries. This was therefore reduced to water quantity management for specifically industrial areas. By only focusing on water quantity management, water quality management which often goes hand in hand is neglected. This could mean that when project developers would look at the broader picture of both water quantity- and quality management, they would not select techniques based on this research based on their performance regarding water quality management.

To evaluate the DSS, several cases were used to test the performance of the DSS in reality. These were deemed very helpful. The first case was a business centre, which had already been developed for a few years. This helped to get insight into which choices project developers make, and which of these choices should be processed in this research and DSS. The second selection of cases were all fictive situations with different characteristics. This helped with getting insight into the sensitivities of the DSS, which resulted in the change of certain performance values and how they are determined in the DSS. At last, the third case was an industrial area, which is currently being developed. The DSS was evaluated by a project developer actively working on this project, which shows the capability of the DSS in a realistic situation. To go through the model together with someone active in this work field, was useful. It showed how a project developer thinks and what was missing to make the DSS complete. Insights were gathered into how the cost criterion could be redeveloped into a cost per cubic meter of retention capability, to make the criterion more relevant. Furthermore, it was stated that it would be useful to see the techniques sorted on criteria values of the user's choice. This was not possible to do in this timeframe, and therefore another solution was chosen which tries to solve the same problem. This could be seen as a shortcoming, and in a future development of this model the sorting system could be implemented.

As stated by project developers, there is a lack of research done on the scope of water management for industrial areas. This was later confirmed by doing a literature analysis, where there was a clear shortage of academic papers in this scope. The DSS and this report fall within these practical- and research gaps. However, the gap is not completely covered by this research. Water management is a broad concept and therefore this research was limited to water quantity management. The gap between water quality management and the other facets of water management is still present in industrial parks. Within the broader subject of project development, the DSS could be applicable for other projects than industrial parks but it would need to be expanded and altered. For the development of an apartment complex, different criteria and techniques would be relevant compared to industrial parks. The layout of the DSS and a significant amount of data would be usable in the broader subject of project development.

5. Conclusion

Looking back at the research objective stated in section 2.1, the aim of this research was mainly to assist developers with stormwater management in designing industrial areas. The risk of flooding and groundwater drought is increasing, and with that the need for climate adaptive project developments, more specifically the development of industrial parks. The DSS developed in this research reached this objective. This was done by selecting the relevant techniques to evaluate on the prioritized criteria. Because of this, developers can refer back to a concise model which is not too elaborate and generally comprehensible. The techniques were evaluated on cases with different locational characteristics, which has made the DSS dynamic by making it adaptable to situations. The user can provide information on these locational characteristics of a project site, and the DSS automatically shows the performance values of each technique in a comprehensible table. The user can furthermore select the prioritized criterion, and this shows the performance of each technique on this criterion in a clear graph.

This was reached by answering the research questions stated in section 2.1 and following the DSRM methodology explained in section 2.2. What became clear during the process of answering these questions, firstly was that some techniques might look like the most suitable at first glance, but when altering the locational characteristics they become significantly less applicable. For example, a green roof is not sensitive to soil characteristics such as groundwater level and soil type. A wadi has a high grade for groundwater recharge in favourable conditions. When these conditions become less favourable, the groundwater recharge reaches a level even below that of green roofs. This fact put the performances of the techniques in perspective and brought light to the effects of the locational characteristics. Furthermore, the cases discussed in the demonstration and evaluation activities brought light to the choices that project developers make. Within the subject of water management in designing industrial areas, or all project developments for that matter, there is no objective right or wrong purely based on water management criteria. For example, with a business park such as in the Boekelo case (section 3.3.1), a significant amount of greenery was added throughout the area. This was also at the expense of sellable meters while this criteria was stated to be one of the most important criteria within the subject. Different types of industrial parks therefore require different types of decision making.

6. Limitations and future research

In the discussion of this research, several shortcomings of the end product were stated. This leads to the following suggestions for future research:

Verification of quantified performance values

As stated in the conclusion, several performance values are based on assumptions rather than literature or experiments. To increase the reliability of the model, further research should be done on these performance values. This is also the case for the effect of locational characteristics, which also often had to be assumed. This could be done with an additional literature review when new data is available, or to be more precise experiments could be done to see the performances of the different techniques.

Effect of weather conditions

The effect of weather conditions within a year also significantly impacts the performance values. For example, when a year is considered to be wet, the groundwater is significantly higher, and ponds could be already full when another storm hits. This means that it cannot process any more water and is therefore ineffective. This effect should be studied in the future. The most logical method to research this effect is to experiment with different durations of storms and different levels of soil saturation.

Expand the research with water quality management

The subject of water management could roughly speaking be divided into two parts; water quantity management and water quality management. The scope of this research is the first, and therefore water quality management is neglected. In future research, this study should be expanded with water quality management, to make sure that techniques which neglect water quality are not selected and the overall quality of water has a higher priority. This could be studied similarly to this study.

Combinations of techniques

Sometimes, techniques could be combined to form the most suitable solution. For example, a wadi could be applied together with a rockwool system to form a solution. This is currently not processed in the DSS, but it could be worth to research in the future. The effects of combining techniques are most likely not studied in literature and therefore should be studied via experiments.

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Appendices

Appendix 1: Key techniques

GI and LID applications are often placed into two categories; infiltration-based- and retention-based techniques. Infiltration-based techniques are described as techniques that restore baseflows through the recharging of subsurface flows and groundwater. Retention-based techniques are described as techniques that reduce the outflow by retaining stormwater (Eckart et al., 2017).

To gain insight into the known techniques, literature on different SWM techniques has been studied. Table 7 and Table 8 show the retention-based and infiltration-based techniques respectively, together with which reference acknowledges which technique.

Table 7: Retention-based SWM techniques

	Retention-based			
	Ponds	(Blue) Green roofs	Rainwater harvesting	Wetlands*
(Nasr & Shmroukh, 2020)	x	x		x
(Li et al., 2019)		x		
(Eckart et al., 2017)	x	x	x	x
(Shojaeizadeh et al., 2021)	x			x
(Mosleh et al., 2023)		x	x	x

Table 8: Infiltration-based SWM techniques

	Infiltration-based									
	Swale systems	Infiltration trench	Bioretention /rain garden	Sand filters	Permeable pavements	Infiltration basin	Vegetated filter strip	Wetlands*	Tree box	Dry well
(Nasr & Shmroukh, 2020)	x		x		x			x	x	
(Li et al., 2019)			x		x					
(Eckart et al., 2017)	x	x	x	x	x					
(Shojaeizadeh et al., 2021)	x	x	x	x	x	x	x	x	x	x
(Mosleh et al., 2023)	x		x	x	x		x	x		

*: Wetlands have both infiltration- and retention-based capabilities.

To leave the very specific techniques out, only techniques which are acknowledged multiple times will be discussed further. Below the techniques are described briefly.

Ponds

Stormwater ponds exist out of wet and dry ponds. Wet ponds, or retention ponds, are designed for the permanent storage of water in large ponds. Dry ponds, or detention ponds, are designed for storing water for a limited period (one or two days) after heavy rainfall (Nasr & Shmroukh, 2020). Subsequently, the water leaves the system via an outlet. Due to the larger size of retention ponds, detention ponds might be more suited for industrial areas when there is a limited amount of area available.

(Blue) Green roofs

Green roofs exist out of three layers: a vegetation layer, a growing medium layer and a storage or drainage layer. Green roofs can either be extensive or intensive, with extensive roofs being used more often due to their lighter weight, lower costs, and less need for maintenance.

Green roofs can reduce and delay the peak flow significantly. When rain enters a green roof system, it is at first partially intercepted by the vegetation layer. The rest of the water enters the medium, substrate layer. The water subsequently leaves the system via the drainage mat through filtration onto the building top. The retained rainwater is evaporated back into the atmosphere through vegetation (Li et al., 2019). The absorption in the medium layer together with the evapotranspiration through vegetation results in a delay in peak flow (Shafique et al., 2018). Green roofs can be beneficial for industrial areas since it is a space-efficient method to reduce and delay stormwater runoff. Space efficiency is especially beneficial for industrial areas since it increases the sellable meters.

Blue green roofs have an extra storage layer which helps with storing more water to prevent flooding. The water retained could subsequently be used for domestic purposes such as toilet flushing and washing of surfaces (Shafique et al., 2018). Furthermore, green roofs can function as insulation for buildings reducing the costs for cooling during the summer (D'orazio et al., 2012).

Rainwater harvesting

Rainwater harvesting, or RWH, collects and stores roof runoff in storage tanks. The runoff can subsequently be used for non-potable sources in among others the industrial sector. RWH reduces the load on stormwater piping systems, which in turn can prevent flooding (Vargas, 2009). Retention tanks can be used to supply water for non-potable purposes, as well as manage the runoff volume (Burns et al., 2015).

Wetlands

Wetlands are vegetated systems where rainwater can flow through. The soil, vegetation and microorganisms in the wetlands can retain water and remove/reduce pollutants in the water (Nasr & Shmroukh, 2020).

Swale systems

Swale systems are channels filled with flood-resistant vegetation and are designed to control stormwater through infiltration and filtration. They are often used to enhance traditional curbs and gutters for the transportation of stormwater runoff (Eckart et al., 2017). This makes them applicable to industrial areas as well, by replacing the traditional curbs with swale systems.

Infiltration trench

Similar to swale systems, infiltration trenches are also open channels. The channel is made of gravel, which is underlain by a geotextile fabric and covered with vegetated soil. They use storage and filtration to delay stormwater runoff (Eckart et al., 2017). Most often runoff from impermeable surfaces is piped into the trenches (Toran & Jedrzejczyk, 2017).

Bioretention area

Bioretention areas consist of multiple layers of vegetation, together with several storage and filter layers and possibly an underdrain. The vegetation serves as a peak flow and runoff volume reducer through evapotranspiration, and it delays the runoff via soil infiltration (Li et al., 2019).

Sand filter

Sand filters are used primarily for stormwater quality management and are therefore outside the scope of this study.

Permeable pavements

Permeable pavements usually consist of a permeable pavement surface, underlain by a storage bed and optionally an underdrain system. The system can reduce stormwater runoff and recharge groundwater by infiltrating the water into the storage bed and subsequently the groundwater (Li et al., 2019). By replacing regular pavements with permeable pavements, you do not waste space on stormwater management, which is beneficial to project developers from the viewpoint of sellable meters.

Vegetated filter strip

Vegetated filter strips are vegetated surfaces designed to treat runoff flow. The strips slow down stormwater and provide infiltration into the underlying soil. They are suited for roof runoff and small parking lots, but heavier flows might overwhelm the system (USEPA, 2021). To account for the heavier flows, swale systems and infiltration trenches might be more suited to the development of industrial areas.

Street trees

Increasing the urban tree density can help with reducing runoff through interception, evapotranspiration and infiltration (Nasr & Shmroukh, 2020). Since trees are a standard implementation in development projects they will not be further discussed.

Swale systems, infiltration trenches, bioretention areas and vegetated filter strips are all types of wadis in the Netherlands. Therefore, they will not be discussed separately. Street trees are a stand application and therefore not relevant to study in more detail. Wetlands are deemed not to be a realistic technique due to their large size. Stormwater ponds were added after the first evaluation case since that project used a retention pond.

Out of these techniques, the following will be evaluated by the DSS:

- Green roof;
- Blue Green roof;
- Permeable pavements;
- Rainwater tanks;
- Retention ponds;
- Detention ponds.

Together with the following techniques which are often applied in the Netherlands:

- Wadi;
- Rockwool;
- Infiltration crates;
- Rainwater tanks.

Appendix 2: Solutions assessments

In this appendix, the explanations behind the performance values given in section 3.2.3 are stated. Each technique is assessed separately below.

Wadi

Bioswales, which are also wadis, were analysed by Regier & McDonald (2022). Two bioswales were tested, but one of the swale systems was not working properly. The other bioswale reduced the total volume by 51%, and the peak reduction by 94.3%, and they were overall deemed effective in removing volume and delaying runoff. These numbers were based on 47 rainfall events on a farm in Milwaukee. The runoff was collected from pavements and buildings. Furthermore, Purvis et al. (2019) concluded that a bioswale reduced peak flow by 89% based on 39 rainfall events. Overall, the volumetric and flow mitigation was deemed positive. According to Boogaard and Wentink (2005), the annual rainfall runoff could be infiltrated into the ground (and is therefore reduced) by 85% when the wadi is emptied within 24 hours. 24 hours is often taken as a design target in the Netherlands. All 3 of these experiments have relatively similar results all being in the 90% +/- 5% range. To be cautious, 85% will be taken as the value for peak flow reduction.

As explained in chapter 3.2.1 which explains the principle of wadis, wadis are sensitive to high groundwater. It is assumed not to affect the peak flow reduction, but the literature is not always in agreement about this. Wentink (2022) states that wadis are applicable in areas with high groundwater levels and clay soil, while Blauw Groen Vlaanderen states that wadis should not be applied in areas with permanently high groundwater levels. High groundwater is assumed to affect the groundwater infiltration and not the peak flow reduction. The wadi system could dispose of water to surface water or a sewage system, and by doing this still reduces the peak flow, but not recharging the groundwater. For low groundwater levels, the groundwater recharge is assumed to be equal to the peak flow reduction of 85%. Rujner et al. (2018) Found that at a low initial moisture level, swale systems were able to reduce volume by 82% (comparable to 85%). When the initial moisture level was high, this was reduced to 15%. Assuming that wadi systems can dispose of this difference to surface water or sewage systems, the difference in groundwater level is taken to only affect the groundwater recharge. Therefore, a factor of 0.20, which is approximately the same factor as 82% to 15%, is taken as a multiplication factor for when the groundwater level is high. When the groundwater level is medium, a factor of 0.60 is taken (between 1 and 0.20). For the effect of soil type on the groundwater recharge, wadis were compared to other techniques such as permeable pavements, infiltration crates and rockwool infiltration blocks. Since water can sit in a wadi significantly longer than permeable pavements and infiltration crates, it is assumed that soil type has less of an effect on the groundwater recharge for wadis compared to these techniques. This is because the water has a longer amount of time to infiltrate the soil. Rockwool systems are stated to be able to withstand lower permeable soil very well, and therefore wadis are assumed to fall somewhere in between infiltration crates and rockwool systems in terms of the effect of soil on the groundwater recharge. Therefore, (river) clay gets a factor of 0.5, peat and loess a factor of 0.75 and sand a factor of 1.

Apart from peak flow reduction and -delay, the ability to recharge the groundwater is also important to reduce the risk of drought. Wentink (2022) who performed research for Tauw which is a Dutch consultancy- and engineering firm, found that wadis contribute to both peak flow delay and infiltration in the groundwater. He found that in practice, only 15% of the time wadis contain water and they can retain water within 12 to 24 hours after a storm 80% of the time. Most municipalities in the Netherlands find an infiltration capacity of 0.5m/day sufficient for wadis, but often 0.3m/day is deemed sufficient since wadis are engineered gardens, and not regular grassed strokes (Bouwmeester, 2023).

Provincie Gelderland and Rainproof (2023e) both estimate the costs to be around €5.00 per square meter. Provincie Noord-Brabant (2023) states that the excavation of the soil is rather expensive, and therefore estimates the cost around €20.00 per square meter. Both Provincie Gelderland and Noord-Brabant provided estimates specifically for business parks. Since Provincie Noord-Brabant specifically mentions the excavation, it is more certain that this cost value includes all necessary components. Boogaard and Wentink (2005) state that wadis are generally between 30 and 50 centimetres. Since a wadi is not rectangular, a value of 30cm will be assumed as depth. This results in a capital cost of 67 €/m^3. For maintenance costs, Rainproof (2023e) assume a maintenance cost of €0.37/m^2. This comes down to a maintenance cost of €1.23/m^3.

(Blue) Green roofs

Provincie Gelderland performed research on several GI techniques in business parks. Among other things, both water drainage and -retention scored 3 out of 3 for (blue) green roofs. Li and Babcock Jr (2014) performed a literature review on among others the peak flow reduction of green roofs. They found that all studies concluded a peak flow reduction of at least 45%, with 5 out of 8 studies even reaching around 80% peak flow reduction which is most likely for intensive roofs. Gids Duurzame Gebouwen (2016) states that the peak flow reduction can range between 50% for extensive roofs, to 70% for intensive roofs. Assuming that only extensive roofs are realistic for industrial parks, 50% is taken as a peak flow reduction rate. Blue green roofs can ameliorate peak flow reduction by adding a storage basin below the green roof. Depending on the storage depth, the peak discharge reduction can be increased by 38.6% for a storage depth of 2.9cm, 58.2% for a depth of 4.3 cm, and 78.2% for a depth of 5.9 cm compared to a regular green roof. Assuming that a depth of 5.9 cm is unrealistic for the same reason an intensive roof is unrealistic, the peak flow reduction for a blue-green roof can be between 70% and 80% (Martin & Kaye, 2020).

Green roofs are less suitable for groundwater recharge since it is a more closed system not directly connected to the groundwater. The delay in peak flow does provide the rainwater with additional time to infiltrate the groundwater. For (blue) green roofs, it depends on where the roof discharge is going. It is possible to connect it to some kind of retention technique, with or without an overflow mechanism, or directly connected to the sewer system. Broks and Luijtenaar (2015) performed an analysis of the performance of green roofs in these 3 situations, for 3 more regular storms, and 2 extreme storms. When the discharge is directly connected to the sewer, no water is infiltrated into the ground. When there is an overflow system present, it differs depending on among others the retention volume.

For the 3 situations, the following values will be taken for runoff infiltration:

- Situation 1: Directly connected to sewer: 0%;
- Situation 2: Overflow connected to sewer: 20% for T10 storm (storm with 10-year return period);
- Situation 3: Discharge connected to retention area: 28% for T10 storm.

These simulations were run with the smallest connected retention volumes since larger retention volumes are less likely since they would impact the number of sellable meters for industrial sites. Blue-green roofs can retain 20% more of the peak flow due to their basin. This is assumed to add 20% to the infiltration in situation 3, and 10% in situation 2.

For industrial areas, green roofs are well suited. The roofs are already present, and therefore applying green roofs does not limit the number of sellable meters. However, the downside of this is that it does not improve the green aesthetic.

According to Arcadis et al. (2021), the costs of extensive green roofs range from a minimum of €42.00 to €50.00, to a maximum of €80.00 to €120.00 per square metre. Since this is a rather large range, €75.00 per square meter will be taken since this is between the minimum and maximum range given and is also taken as the average value of an extensive green roof by Homedeal (2023). Green roofs have an average retention depth of 10cm (Green roof technology, 2023). This results in a capital cost of 750 €/m^3. Maintenance costs vary between €6.00 and €8.00 per square metre, or 80.00 €/m^3 when €8.00 is taken as the maintenance cost per square meter.

Witteveen+Bos (2017) analysed the costs of two types of blue-green roofs; retention roofs and polder roofs. Polder roofs are similar to retention roofs but have dynamic release valves. The costs were €1275 and €2100 per cubic meter for the retention roof and polder roof respectively. We assume that retention roofs are more realistic since they are more cost-effective. The maintenance costs were stated to be around €176.40 per cubic metre for both the retention- and polder roof.

Permeable pavement

The peak flow reduction depends heavily on the size of the storage thickness. Zhu et al. (2019) performed research on several storage thicknesses, and found the following peak flow reductions which were formed after simulating storms with recurrence periods of 5-, 10-, 20- and 30 years:

- 15 cm storage: 52.94% reduction;
- 20 cm storage: 70.59% reduction;
- 25 cm storage: 82.35% reduction;
- 30 cm storage: 94.12% reduction.

According to Struyk Verwo Infra BV the thickness of the fundament of a parking lot area should be 20 to 25 cm. To account for possible setbacks, the peak reduction of 20cm will be taken as the general value for peak flow reduction (rounded to 70% in the DSS). For partial infiltration, it is assumed that half of the water is infiltrated, and half of the water is disposed to some kind of surface water. Since the half that is disposed to the surface water does not contribute to the groundwater recharge, the reduction factor for the soil type effect on groundwater recharge is 0.5 for partial infiltration. Furthermore, the reduction factor is 0 for complete disposal to a sewer system. The effect of groundwater level could be compared to values of other techniques. When comparing it to infiltration crates, permeable pavements are placed closer to the surface level and are therefore less sensitive to high groundwater levels. The effect of higher groundwater levels is assumed to be similar to the effect on wadis. Wadi systems are placed deeper into the ground but also have a significantly longer time to dispose of the water. Assuming that these two facts balance each other, the reduction factors 0.2 and 0.6 will be taken as values for high- and medium groundwater levels.

Permeable pavements do not limit sellable meters, since there is no extra space needed for making the pavement permeable. The effectiveness of the permeable pavement is dependent on the soil type. This depends on the K-factor, which is the permeability expressed in m/s or m/day. When the K-factor is below 0.5m/day, it is not wise to let water infiltrate the soil. Figure 17 shows where in the Netherlands what kind of permeable pavement is applicable, depending on the soil type. It shows that the west of the Netherlands is not suited for permeable pavement, but in the east of the Netherlands, with more sandy soil, permeable pavements are applicable. The pavements are often designed to withstand a storm of 16.2mm/10min. Due to unavoidable maintenance, often a safety factor of 2 is considered for the infiltration capacity.

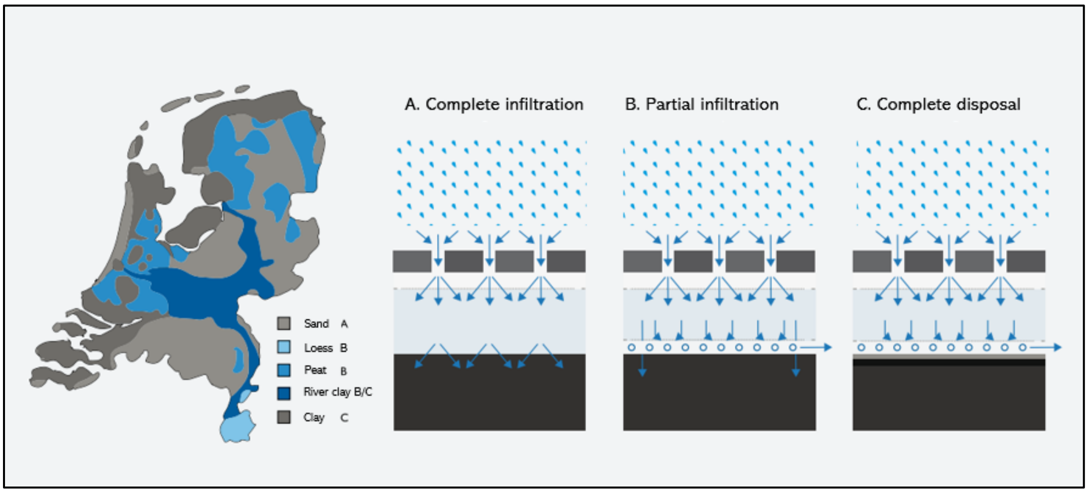

Figure 17: Suitability of permeable pavements according to the soil type in the Netherlands (Struyk Verwo Infra BV)

However, it is stated that applying permeable pavements on industrial areas might not be suitable due to the chance of clogging due to pollution and too high pressure from traffic. This has to be taken into account since there is a difference between an industry and a business park (Struyk Verwo Infra BV).

Imran et al. (2013) stated that permeable pavements are a good stormwater runoff management solution for among other industrial areas. It is a Sustainable Drainage System (SuDS) and helps with flood prevention and water scarcity. However, Razzaghmanesh and Beecham (2018) stated that the infiltration rates declined drastically even within 2 years of installation. This could mean that maintenance is apart from being a nuisance, also expensive. The costs of permeable pavements, without installation costs, vary between €40.00 and €100.00 per square meter for the more standard and more advanced pavements, respectively (Gardenlux, 2023). RIONED (2021b) assumes the total costs of applying permeable pavements to be approximately €115.00 per square meter. With a retention depth of 20cm, this comes down to €575/m^3. Furthermore, they determined the following maintenance costs:

- Sweep (1 to 6 times per year): €0.55 per m^2;
- Deep cleaning (once per 1 to 7 years): €2.25 per m^2;
    - Subsequent replenishing of seams: €0.55 per m^2.

Assuming having to sweep 3 times per year and performing deep cleaning every year, the maintenance costs come down to €4.45/m^2. This comes down to €22.25/m^3.

Underground infiltration systems

Underground infiltration systems are becoming more popular in the Netherlands. Examples of these systems include Rockwool infiltration blocks and infiltration crates. These systems are designed to store stormwater and subsequently slowly infiltrate the water in the ground. Rockwool is a type of infiltration block, which is the more modern version of infiltration crates.

This is better compared to infiltration crates since Rockwool is also effective in high groundwater areas, where infiltration crates are not. Urban areas are currently often filled with obstacles such as cables and pipes. Rockwool is applicable in these areas since the systems can easily be placed around them. Rockwool can absorb peak flows from storms with return periods ranging from 10 years to 100 years (Rockwool B.V.). Since the system can absorb water very fast together with it able to retain water from storms ranging from 10-year to 100-year return periods, 95% will be taken as a peak reduction value. Assuming the entire storm is infiltrated in the soil, 95% is also taken as the base value percentage of water infiltrated in the groundwater.

Hydrorock (2019) states that the time to empty the system is significantly shorter for the rockwool system compared to the crate system. This is due to the direct water pressure on the bottom which counteracts the infiltration. The costs of the Hydrorock rockwool systems vary around €1000 per cubic meter.

They work similarly to the rockwool systems but are more sensitive to the groundwater level. Furthermore, infiltration crates are more difficult to apply due to the nuisance of pipes and cables. The cost of infiltration crates is approximately €595.00 per cubic meter (RIONED, 2021a).

According to RIONED, the infiltration crates are also able to retain water in 95% of its volume. Since crates are not able to absorb water as quickly as rockwool and this limits the ability to process a peak flow, a value of 80% is taken for peak flow reduction and groundwater recharge. This is however an ideal situation because infiltration crates are more sensitive to soil type and groundwater level.

For both the rockwool system and the infiltration crates, soil type and groundwater level are a limiting factor. Due to the nature of rockwool, groundwater level is less of an issue since rockwool can absorb it very quickly. For infiltration crates, this is more of a limiting factor. The literature says that when the groundwater level is high, infiltration crates are not deemed effective. When a less permeable soil type is present such as clay, the groundwater recharge is also reduced. When the infiltration rate is not high enough, the systems are not able to release their water and it might have to be disposed of by the sewage system or surface water. Rockwool, which is a company which makes rockwool infiltration systems, states that rockwool systems have a higher infiltration area which makes it better compared to alternatives such as infiltration crates when it comes to soil infiltration (Rockwool B.V.). Therefore, the impact of less impermeable soil types is larger on infiltration crates compared to rockwool systems.

As seen in Figure 8, the infiltration crates should be placed at least 70 cm below the surface level. Since the groundwater level is seen as high from 50cm below the surface and above, it is assumed that with high groundwater, the recharge is 0 for infiltration crates. The reduction factor is therefore taken at 0. For medium groundwater, it is assumed to be approximately 0.5, to be in between the values of high- and low groundwater levels. For rockwool, the effect of groundwater level is less on the groundwater recharge performance. It is assumed to be comparable to the values of wadis, therefore 0.2 and 0.6 will be taken as reduction factor values for high- and medium groundwater levels respectively.

Therefore, the following peak flow reduction rates and groundwater recharge rates will be assumed:

- Effect high groundwater level on groundwater recharge: rockwool: 75%, infiltration crates: 30%;
- Effect medium groundwater level on peak flow reduction: rockwool: 85%, infiltration crates: 60%;
- Effect (river) clay on groundwater recharge: rockwool: 0.7, infiltration crates: 0.37;
- Effect loess/peat on groundwater recharge: rockwool: 0.9, infiltration crates: 0.75.

According to RIONED (2021a), the maintenance costs for infiltration crates are not known as of 2022 since infiltration crates are a relatively modern technique and have not been applied for a long time. Therefore, this value has to be assumed. It is assumed that the costs are in the range of permeable pavements since both have a geotextile layer which has to be deep cleaned which is the largest maintenance cost. Therefore, a value of €238.00/m^3 will be assumed. Rockflow states that the system needs to be deep cleaned every 2 to 3 years (Rockwool B.V.), and therefore is assumed to have slightly lower maintenance costs compared to infiltration crates. Therefore, a value of €190.50/m^3 is assumed.

Infiltration crates could be used for non-potable water purposes by pumping up the water when they are full. This is however heavily dependent on the weather conditions since the main function of the crates is to recharge the groundwater. The water can therefore only be used for non-potable purposes when the crates are full, and they need to be emptied to keep them functional. If they are full, they could provide more water compared to a blue-green roof. Otherwise, it is a very uncertain method of reusing water. Therefore, a grade of 2 out of 8 is awarded to infiltration crates.

Rainwater tanks

Since water supply is not the main focus point of this study, it is not relevant since it does not provide sufficient stormwater management. Two passive systems were studied (75% detention volume and 25% detention volume), together with the active system. The passive system with the highest detention volume was found to have the highest inflow control efficiency (Quinn et al., 2021).

Table 9: Median inflow control efficiencies (Quinn et al., 2021)

	1-hour storm	6-hour storm	24-hour storm
No system	0.03	0.03	0.05
Conventional	0.87	0.61	0.50
Passive (75% detention)	1.0	0.90	0.87
Passive (25% detention)	1.0	0.77	0.74
Active	0.89	0.66	0.59

Since the main goal of this study is to provide flood- and drought protection, the passive system with 75% detention volume is seen as the most realistic. According to Table 9, this system can control 87% of the inflow for a T1.0 24-hour storm. This value is selected since it is most similar to a T10 storm, which is a minimum of 5 hours (RIONED, 2019). Therefore, 87% is taken as peak flow reduction. The groundwater recharge is only possible if the outflow is connected to a type of infiltration system. Otherwise, the outflow is likely slowly discharged to the sewage or surface water. Therefore, the groundwater recharge of the system itself is 0%.

Such dual-use Rainwater Harvesting (RWH) Systems, or "retention and throttle" RWH systems, are found to be able to provide up to 95% of non-potable water demands, while simultaneously controlling stormwater runoff during storms having return periods up to 1 in 100 years. The costs can vary depending on the tank size. It could range between €9,500 and €82,000 for 5 cubic meters and 100 cubic meters respectively. Per cubic meter, this ranges between €1,900 and €820. The RWH systems are most likely applied on a building scale and not a site/park scale. Therefore, the costs for 5 cubic meters are more realistic than the costs for 100 cubic meters.

For small collection areas (<500 m²) and very large collection areas (>5000 m²), it is uncertain whether RWH systems result in a positive net benefit. For medium (500 – 2000 m²) and large (2000 – 5000 m²), the results were positive (Table 10) (Fredenham et al., 2020).

Table 10: Net benefit of RWH systems dependent on collection areas (Fredenham et al., 2020)

Collection area	Total net benefit (*1000)
Small (<500 m²)	-€3,50 – €95
Medium (500 – 2000 m²)	€7 – €370
Large (2000 – 5000 m²)	€1,20 – €350
Very large (>5000 m²)	-€3,50 - €870

In terms of water reuse, the rainwater tanks can provide a high amount of water and significantly more than any other technique together with the ponds. Therefore, they are rewarded with the maximum grade.

Ponds

Provincie Gelderland states that open water, which is similar to a retention pond, scores for both water retention and water drainage a 3 out of 3 grade. In terms of costs, they scored 1.5 out of 3. Retention ponds are often larger compared to detention ponds since they need to store the water permanently.

Detention ponds only temporarily retain water and discharge it so it can retain the next storm event. Modern systems use weather forecasts to be able to retain the water as long as possible. Rainproof (2023d) analysed detention ponds and scored the construction costs and maintenance costs to both be 2 out of 3. Furthermore, they stated that if a pond has to process polluted water from busy roads and parking lots, it might have to be closed off by foil and this stops direct infiltration into the ground. Therefore, ponds in industrial areas are less applicable.

Retention ponds were studied by Miller (2006) in the United States, processing water from a 35 ha area, where 82% ended up in the retention pond. The study found that the retention ponds infiltrated approximately 40% of the water into the ground. Furthermore, Natural Water Retention Measures (2015) states that detention basins are not designed to allow water infiltration, and therefore it will be assumed to be 10%. The peak flow reduction rate of retention ponds heavily depends on the rainfall characteristics of that period. Morgan et al. (2007) found that the peak flow reduction for a single rainfall event was around 94%, but it decreased to 69% when there were sequential storm events. This is most likely due to the lack of water outlets. Apart from the infiltration into the ground, the only outlet is overflow. Since most of the other techniques were evaluated on single storm events 94% will be taken as the rate, but the decrease in peak flow reduction has to be considered when there are sequential storm events. For detention ponds, there is no exact data on the peak flow reduction. Assuming it is somewhere between wadis and retention ponds, 90% is taken as the value for peak flow reduction. This is done since detention ponds have similarities with wadis in the fact that they have discharge mechanisms, and with retention ponds in the larger overall basin size.

The costs for detention- and retention ponds vary between €16.2/m^3 and €32.4/m^3 depending on size and the type of pond, where detention ponds are often cheaper (United States Environmental Protection Agency). These values are from 1997, so after applying inflation rates, this comes down to an approximate range of €30/m^3 to €60/m^3. For both types of ponds, a value of €60/m^3 is assumed, since smaller ponds are more expensive and on industrial sites large ponds are not realistic. According to USEPA, the maintenance costs for ponds are between 3% and 6% of the construction costs. This comes down to €3.60/m^3 when assuming 6%.

Ponds are also suitable for water reuse. This is however more difficult to implement compared to rainwater harvesting tanks since ponds are not placed directly next to the office buildings when looking at it from a business scale. Therefore, the water has to be redirected to the buildings to make it usable. When this is possible, the ponds are large basins which can provide a large amount of non-potable water. Therefore they are also both graded with an 8 out of 8.

Appendix 3: Versions of the DSS

DSS case 1

Technique	Peak flow reduction	Groundwater recharge	Sellable meters	Water reuse	Biodiversity	Capital costs	Maintenance costs	Comments
Wadi	2	2	0,5	0	2	3	3	Less suitable in high groundwater
Green roof	3	1	1	0	1	2	2	
Blue green roof	3	1	1	1	1	1	1	
Permeable pavement	1,5	2	1	0	0	1,5	1	Only suitable in sandy soil & not for industry
Rockwool	2	3	1	0	0	1	2	
Infiltration crates	2	2	1	0	0	2	2	Less flexible around cables and pipes
Rainwater tank	1	1	1	2	0	1	2	
Retention pond	2	2	0	0	1	1,5	1,5	Depending on size, not on industrial areas
Detention pond	3	1,5	0,5	0	1	2	2	Depending on size, not on industrial areas

Positive situation case 2

Decision Support System	
Project name:	Positive situation
Project location:	
User name:	Joost Bisschop

Technique	Peak flow reduction (0-4)	Peak flow reduction (%)	Groundwater recharge (0-4)	Groundwater recharge (%)	Space efficiency (0-3)	Water reuse (0-2)
Wadi	3,5	85	3,5	85	1	0
Green roof (3)	2	50	0,5	28	1,5	0
B-Green roof (3)	3	70	1,5	48	1,5	1
Permeable pavement	3	70	3	70	1,5	0
Rockwool	4	95	4	95	1,5	0
Infiltration crates	3,5	80	3,5	80	1,5	0
Rainwater tank	3,5	87	0	0	1,5	2
Retention pond	4	94	1,5	40	0	0
Detention pond	4	90	0	10	0,5	0
Add new technique in cell above ↑		Add value in cell above ↑		Add value in cell above ↑	Add value in cell above ↑	Add value in cell above ↑

Location characteristics	Select from dropdown list:
Groundwater level	low (>1.5m)
Soil type	Sand
Percentage sellable meters	Below 74%
Distance to surface water	Low (<1km)

(B) Green roof type	Select in technique column
(B) Green roof (1)	Fully connected to sewer
(B) Green roof (2)	Overflow to sewer
(B) Green roof (3)	Discharge retained

Water reuse (0-2)	Greenery (0-3)	Capital costs (0-3)	Capital costs (€/m2)	life cycle costs (0-3)	Maintenance costs (€/m2)	Comments
0	1,5	3	20	3	0,37	
0	1	2	75	2	7	Limits other uses of roof, adds insulation
1	1	0,5	153	0,5	21,17	Limits other uses of roof, adds insulation
0	0	1,5	115	2,5	4,45	
0	0	3	21	2,5	4	
0	0	3	12,5	2,5	5	Less flexible around cables and pipes
2	0	0	1900/m3**	3	0	Maintenance costs 0 due to net benefit
0	0,5	2,5	50	2,5	3	Peak flow reduction sensitive to wet year
0	0,5	2,5	50	2,5	3	
Add value in cell above ↑	Add value in cell above ↑		Add value in cell above ↑		Add value in cell above ↑	

**no m2 value

Difficult situation case 2

Decision Support System

Project name:	Difficult situation
Project location:	
User name:	Joost Bisschop

Technique	Peak flow reduction (0-4)	Peak flow reduction (%)	Groundwater recharge (0-4)	Groundwater recharge (%)	Space efficiency (0-3)	Water reuse (0-2)
Wadi	3,5	85	3,5	85	2	0
Green roof (1)	2	50	0	0	3	0
B-Green roof (1)	3	70	0	0	3	1
Permeable pavement*	3	70	0	0	3	0
Rockwool	3	75	2,5	65	3	0
Infiltration crates*	1	30	1	30	3	0
Rainwater tank	3,5	87	0	0	3	2
Retention pond	4	94	1,5	40	0	0
Detention pond*	4	90	0	10	1	0
Add new technique in cell above ↑		Add value in cell above ↑		Add value in cell above ↑	Add value in cell above ↑	Add value in cell above ↑

*Excess water disposed to sewer

Location characteristics	Select from dropdown list:
Groundwater level	high (<0.5m)
Soil type	Clay
Percentage sellable meters	Above 74%
Distance to surface water	High (>2.5km)

(B) Green roof type	Select in technique column
(B) Green roof (1)	Fully connected to sewer
(B) Green roof (2)	Overflow to sewer
(B) Green roof (3)	Discharge retained

Greenery (0-3)	Capital costs (0-3)	Capital costs (€/m2)	life cycle costs (0-3)	Maintenance costs (€/m2)	Comments
1,5	3	20	3	0,37	
1	2	75	2	7	Limits other uses of roof, adds insulation
1	0,5	153	0,5	21,17	Limits other uses of roof, adds insulation
0	1,5	115	2,5	4,45	
0	3	21	2,5	4	
0	3	12,5	2,5	5	Less flexible around cables and pipes
0	0	1900/m3**	3	0	Maintenance costs 0 due to net benefit
0,5	2,5	50	2,5	3	Peak flow reduction sensitive to wet year
0,5	2,5	50	2,5	3	
Add value in cell above ↑		Add value in cell above ↑		Add value in cell above ↑	

**no m2 value

Mixed situation case 2

Decision Support System

Project name:	Mixed situation
Project location:	
User name:	Joost Bisschop

Technique	Peak flow reduction (0-4)	Peak flow reduction (%)	Groundwater recharge (0-4)	Groundwater recharge (%)	Space efficiency (0-3)	Water reuse (0-2)
Wadi	3,5	85	3,5	85	1	0
Green roof (2)	2	50	0,5	20	1,5	0
B-Green roof (2)	3	70	1	30	1,5	1
Permeable pavement	3	70	1	35	1,5	0
Rockwool	3,5	85	3,5	85	1,5	0
Infiltration crates	3	75	2,5	60	1,5	0
Rainwater tank	3,5	87	0	0	1,5	2
Retention pond	4	94	1,5	40	0	0
Detention pond	4	90	0	10	0,5	0
Add new technique in cell above ↑		Add value in cell above ↑		Add value in cell above ↑	Add value in cell above ↑	Add value in cell above ↑

Location characteristics	Select from dropdown list:
Groundwater level	medium (0.5-1.5m)
Soil type	Peat
Percentage sellable meters	Below 74%
Distance to surface water	Medium (1-2.5km)

(B) Green roof type	Select in technique column
(B) Green roof (1)	Fully connected to sewer
(B) Green roof (2)	Overflow to sewer
(B) Green roof (3)	Discharge retained

Greenery (0-3)	Capital costs (0-3)	Capital costs (€/m2)	life cycle costs (0-3)	Maintenance costs (€/m2)	Comments
1,5	3	20	3	0,37	
1	2	75	2	7	Limits other uses of roof, adds insulation
1	0,5	153	0,5	21,17	Limits other uses of roof, adds insulation
0	1,5	115	2,5	4,45	
0	3	21	2,5	4	
0	3	12,5	2,5	5	Less flexible around cables and pipes
0	0	1900/m3**	3	0	Maintenance costs 0 due to net benefit
0,5	2,5	50	2,5	3	Peak flow reduction sensitive to wet year
0,5	2,5	50	2,5	3	
Add value in cell above ↑		Add value in cell above ↑		Add value in cell above ↑	

**no m2 value

DSS case 3

Decision Support System	
Project name:	Verzetslaan Boekelo
Project location:	Boekelo, Enschede
User name:	Joost Bisschop

Technique	Peak flow reduction (0-4)	Peak flow reduction (%)	Groundwater recharge (0-4)	Groundwater recharge (%)	Space efficiency (0-3)	Water reuse (0-2)
Wadi	3,5	85	3,5	85	1	0
Green roof (2)	2	50	0,5	20	1,5	0
B-Green roof (2)	3	70	1	30	1,5	1
Permeable pavement	3	70	3	70	1,5	0
Rockwool	3,5	85	4	95	1,5	0
Infiltration crates	3	75	3,5	80	1,5	0
Rainwater tank	3,5	87	0	0	1,5	2
Retention pond	4	94	1,5	40	0	0
Detention pond	4	90	0	10	0,5	0

Add new technique in cell above ↑ Add value in cell above ↑ Add value in cell above ↑ Add value in cell above ↑ Add value in cell above ↑

Location characteristics	Select from dropdown list:
Groundwater level	medium (0.5-1.5m)
Soil type	Sand
Percentage sellable meters	Below 74%
Distance to surface water	Low (<1km)

(B) Green roof type	Select in technique column
(B) Green roof (1)	Fully connected to sewer
(B) Green roof (2)	Overflow to sewer
(B) Green roof (3)	Discharge retained

Technique	Greenery (0-3)	Capital costs (0-3)	Capital costs (€/m2)	life cycle costs (0-3)	Maintenance costs (€/m2)	Comments
Wadi	1,5	3	20	3	0,37	
Green roof (2)	1	2	75	2	8	Limits other uses of roof, adds insulation
B-Green roof (2)	1	0,5	153	0,5	21,17	Limits other uses of roof, adds insulation
Permeable pavement	0	1,5	115	2,5	4,45	
Rockwool	0	3	21	2,5	4	
Infiltration crates	0	3	12,5	2,5	5	Less flexible around cables and pipes
Rainwater tank	0	0	633	3	0	Maintenance costs 0 due to net benefit
Retention pond	0,5	2,5	50	2,5	3	Peak flow reduction sensitive to wet year
Detention pond	0,5	2,5	50	2,5	3	

Add value in cell above ↑ Add value in cell above ↑ Add value in cell above ↑

DSS final version

DSS introduction

This Decision Support System (DSS) is designed specifically for project developers to select water management solutions for the design of industrial areas. The DSS is made dynamic by enabling the user to select location specific characteristics which in turn change the performance values of the techniques. The techniques are evaluated on 7 different criteria. The header above the criteria shows the range of possible grade values shown between brackets next to the criterion name. Each criterion is colour scaled, which makes it easy to compare the performance of each technique, where the greener, the better. Furthermore, the quantifiable criteria have a quantified column next to the grade column to show the user where grades are based on. The cells in red should be filled in by the user, the rest of the cells are automatically generated.

Adding a new technique? When the user wants to expand the DSS with a new technique, he could do so by first filling in the name in the technique column in a cell with *"new technique"* dispalyed in it (first unhide the rows below the DSS table). Subsequently, the user is able to fill in quantifiable values in columns D, F, G, H & I which the user first has to unhide. The 'GR Base value' column is the quantified performance value for a favourable situation. GR Soil & GR Level are the factor columns which decrease the base values when situations get more unfavourable. The factor columns can be filled in similar to the rest of the column, which could be a constant factor value when groundwater level and soil type do not effect the groundwater recharge, or a cell value in the shape of *'=IF(C22="high (<0.5m)";0,2;IF(C22="medium (0.5-1.5m)";0,6;1))'* When the groundwater recharge is dependent on groundwater level in this example. Columns J, K & L are qualitative performance values, and could be filled in using the explanation of grades under the 'DSS criteria' tab. Columns M & N are again quantitative values, and lastly column O could be filled in when there are relevant comments (only in detailed version).

Technique	Peak flow reduction (0-8)	Peak flow reduction (%)	Groundwater recharge (0-8)	Groundwater recharge (%)
Wadi	7	85	7	85
Green roof (3)	4	50	1	28
B-Green roof (3)	6	70	3	48
Permeable pavement	6	70	6	70
Rockwool	8	95	8	95
Infiltration crates	7	80	7	80
Rainwater tank	7	87	0	0
Retention pond	8	94	3	40
Detention pond	8	90	0	10

GR base value	GR level	GR soil	Space efficiency (0-8)	Water reuse (0-8)	Greenery (0-8)	Capital costs (€/m3)	Retention costs (€)	Life cycle costs (€/m3)
85	1	1	3	0	8	67	Cell C21 = 0	1,23
28	1	1	4	0	6	750	Cell C21 = 0	80,00
48	1	1	4	4	6	1275	Cell C21 = 0	176,00
70	1	1	4	0	0	575	Cell C21 = 0	22,25
95	1	1	4	0	0	1000	Cell C21 = 0	190,50
80	1	1	4	0	0	595	Cell C21 = 0	238,00
0	1	1	4	8	0	1900	Cell C21 = 0	0,00
40	1	1	1	0	2	60	Cell C21 = 0	3,60
10	1	1	2	0	2	60	Cell C21 = 0	3,60