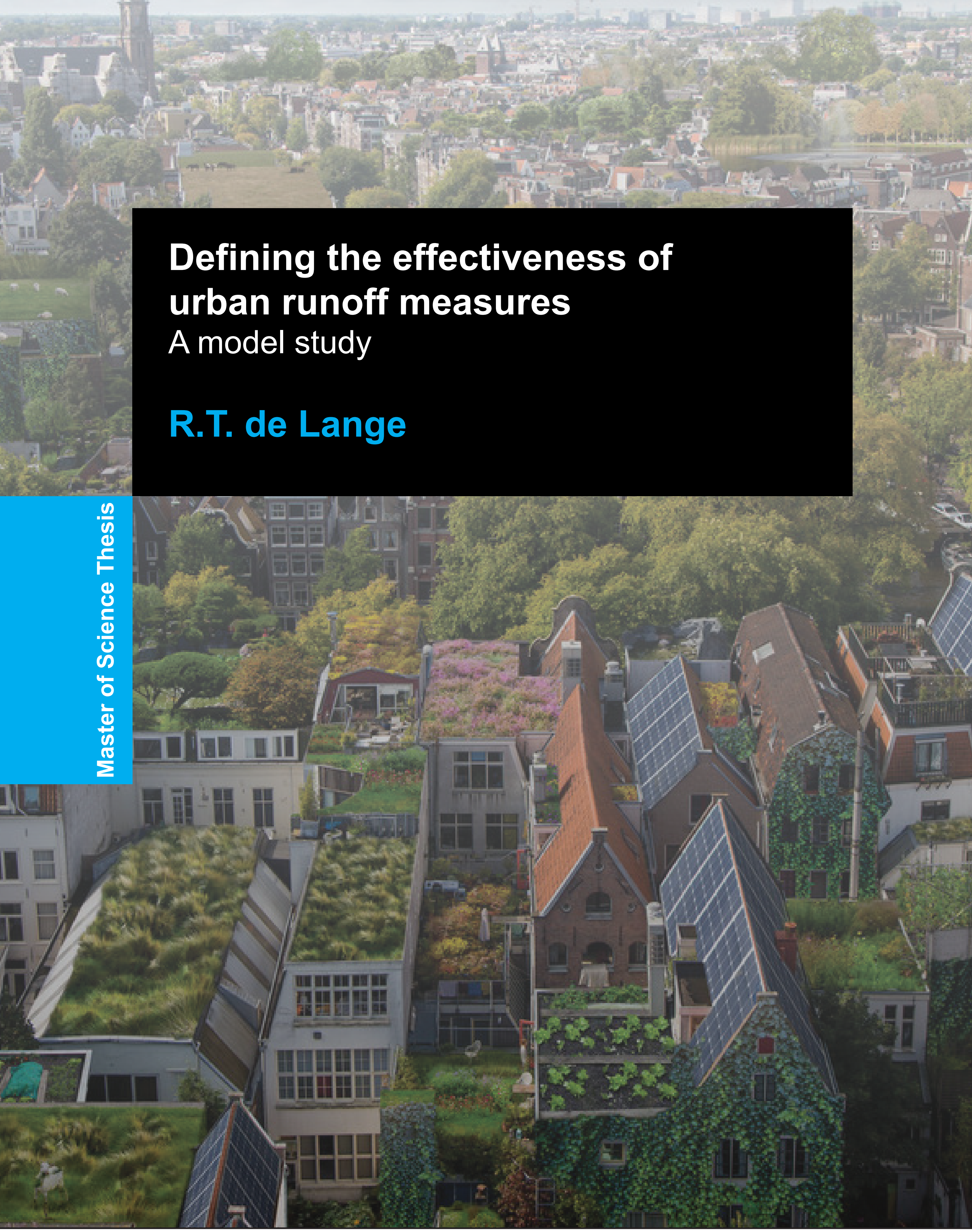

Defining the effectiveness of urban runoff measures

A model study

R.T. de Lange

Master of Science Thesis

Delft University of Technology

Deltares
Enabling Delta Life

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Defining the effectiveness of urban runoff measures

A model study

by

RT. de Lange

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at the Delft University of Technology,

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Preface

This research is conducted as a master's thesis of Water Resources Engineering at the Delft University of Technology. In this research, a model study is performed about defining the effectiveness of urban runoff measures. The project is carried out in cooperation with the TU Delft and Deltares.

This thesis forms the end of my academic journey at the Delft University of Technology. Last year in September I started this project at Deltares and TU Delft. Luckily Deltares had a spot for me to get to know the company and to learn more about the field of research. Unfortunately, the pandemic situations got worse, and we had to work from home. However, I did enjoy the last couple of months and learned a lot from this project. This thesis made me even more enthusiastic about water problems and their solutions, and I hope to continue my professional career in this field of work.

I would like to thank my main supervisor Frans van de Ven, for giving me the opportunity of doing this thesis at Deltares and for his guidance and valuable feedback throughout the project. I really appreciate our biweekly meetings and the time you took to read my draft reports. It helped me a lot.

I would like to thank my company supervisor Toine Vergroesen for all the time that you had available to help me. When I would call, you always picked up and helped me through my problems. Thanks for your very valuable insights about modelling and how to interpret results. I also learned that I yet still have a lot to learn! Thanks for everything.

I would like to thank Markus Hrachowitz and Jeroen Langeveld for their time and constructive feedback. Although we haven't met in person during this project, I learned a lot from you. With your feedback during the kick-off, mid-term and green light, I improved myself and learned a lot about both modelling and the uncertainties of data and models. I guess writing and doing research are not my most developed skills, but I learned a lot about these subjects with your feedback.

I want to thank Evelien, my roommates, old roommates, and friends from Laga and Rosmalen for the fun times to forget a little bit about the current pandemic and to help me through tough moments.

At last, I want to thank my sister and parents for helping me through the whole journey of university. The last couple of months were quite hectic, but you were always there to help me through the difficult times and enjoyed the fun times with me.

RT. de Lange
Rotterdam, June 2021

Abstract

Recent studies have reported an increase of heavy precipitation events [32] and an increase of urbanisation in 2030 [39]. With both climate change, population growth and urbanisation in mind, cities worldwide are exposed to a variety of challenges. These challenges have led to the increasing importance of urban climate adaptation.

Urban climate adaptation is generally attained — in a hydrological perspective – by implementing stormwater management techniques, such as grey, blue and green adaptation measures. Implementing such multi-functional adaptation measures touches on the interests of many stakeholders who need to work together to find resilient and suiting solutions in urban climate adaptation. To facilitate this cooperation, Deltares developed the Adaptation Support Tool (AST). The AST is an interactive online tool used to explore which adaptation measures can be implemented in the area and review the effectiveness of the measures. The AST defines eight different performance indicators to compare the effectiveness of these urban runoff reduction measures, among which the runoff volume reduction factor. This factor is defined as the rate at which a specific adaptation measure increases the return time of the extreme runoff event. This factor is determined by the underlying model of the AST, the Urban Water Balance Model (UWBM).

The Urban Water Balance Model (UWBM) has the benefit of using long times series instead of single precipitation events (design storms) as input to determine the effectiveness of measures; antecedent conditions for every extreme event are therefore known. Including antecedent conditions into the calculation of the effectiveness of measures gives a more thorough inside into the performance of said measures. Currently, the UWBM is only determining the runoff volume reduction factor. At the same time, the literature shows the importance of analysing the effectiveness of measures using both flow peak reduction and storage peak reduction. Exploration of the possibility to implement these two reduction factors into the UWBM forms the challenge of this study. Therefore the following research question has been formulated for this thesis:

> *Research question 1: How can the effectiveness of urban runoff reduction measures in a project area be defined and quantified when these are modelled for runoff volume reduction, flow peak reduction and storage peak reduction?*

Most adaptation plans will include a combination of measures, which makes it preferable to convert the calculated factor from the measure areas to a factor for the whole project area. Therefore an additional research question has been formulated for this thesis:

> *Research question 2: How can this effectiveness be defined for a combination of different adaptation measures in a project area instead for a single measure and how can this effectiveness be expressed in performance indicators for the whole area?*

Based on the method used for the calculation of the runoff volume reduction factor, in this study, a new method is proposed for calculating both the flow- and storage peak reduction based on long time series. For the flow peak reduction analysis, the flow peaks of the uncontrolled runoff out of the measure area are analysed instead of the runoff volume. While for the storage peak reduction analysis, the peaks in the open water storage are analysed. The data are plotted together with their estimated return times on a semi-logarithmic graph to prove that indeed a factor can be assessed from these data. To answer the second research question, a method of converting the flow peak reduction factor of the measure area to the whole project area is proposed.

In this study, 29 measures are analysed, from which five are analysed more thoroughly. These 5 measures are selected based on their emptying mechanism, either regulated discharge, evaporation, infiltration, or

combining these three. Two scenarios are used as input: scenario 1 "Dutch climate" where 30 years of precipitation and evaporation data from KNMI of the station De Bilt is used, and scenario 2 "Tropical climate" where the rainfall data of scenario 1 is used multiplied by 3 and the evaporation multiplied by 2.This to mimic tropical conditions and verify the conclusions for conditions beyond the Netherlands. Graphical analysis is carried out of all the graphs to validate the conclusions.

The results show that, in addition to a runoff volume reduction factor, also the flow peak reduction factor can be empirically determined based on the proposed method. The composed graphs of the flow peaks indicate a linear increase in return time due to implementing an adaptation measure. Besides, scenario 2 shows higher confidence in the presence of a flow peak reduction factor, where the linear increase is observed more clearly. A storage peak reduction factor, however, is not substantiated with the proposed method. The composed graphs show unstable results which could not be used for calculating a continuous storage peak reduction factor. The results show mostly a linear increase in the lower regions of the storage peaks, but in the higher regions, the linear increase is not substantiated. Measures with runoff to Open Water and Groundwater showed unstable results due to their emptying mechanism and how they are defined within the UWBM.

The analysis of the results of the conversion of the effectiveness of the measure area to the whole project area show the feasibility of conversion. Manually fitting the peak reduction graphs was needed for substantiating this conversion. A conversion equation is proposed to convert the flow peak reduction factor over the measure area to a factor over the whole project area. The new equation is used to analyse two neighbourhoods. The results show that the flow peak reduction factor and the runoff volume reduction factor can give the user valuable insight into the effectiveness of the applied adaptation measures.

Key findings

- **A flow peak reduction factor can be empirically determined based on the proposed method in this study.**
- **A storage peak reduction factor can not be empirically determined based on the proposed method in this study. It is recommended to do more research into the analysis of the storage peaks using time series, since it can give an extra insight into the effectiveness of measures.**
- **Converting the found flow peak reduction factor for the measure area to the project area with multiple interventions is substantiated with a proposed equation. However, it is recommended to do more research into the conversion equation to be used in the Adaptation Support Tool (AST).**
- **By determining the flow peak reduction factor together with the runoff volume reduction factor, the effectiveness of urban runoff reduction measures in a project area can be quantified and used to compare alternative solutions for their effectiveness in flood risk reduction. The added flow peak reduction factor gives a more thorough insight into this effectiveness of measures.**

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1
Introduction

About 55.3% of the world's population lived in urban settlements in 2018, and this number is expected to increase to 60% in 2030 [39]. At the same time, global warming is likely to reach 1.5 °C between 2030 and 2052 [32]. Besides, IPCC and KNMI forecast with a high confidence an increase of heavy precipitation and an increase of frequency of droughts in several regions ([25], [32]). With both climate change, population growth, and urbanization in mind, cities worldwide are exposed to a variety of challenges. These challenges have led to the increasing importance of urban climate adaptation.

Urban climate adaptation is generally attained - in a hydrological perspective - by implementing stormwater management techniques, for example, traditional 'grey' adaptation measures and innovative blue-green adaptation measures [43]. Examples of grey measures are concrete structures, drainpipes, or pumping stations. Blue-green measures are sustainable blue and green infrastructure that use the underlying ecosystem functions to deliver multiple benefits to adapt to extreme events. These functions are water flow regulation and runoff mitigation, urban temperature regulation, and moderation of environmental extremes [14]. Examples of blue-green measures are green roofs and urban wetlands [43].

Implementation of such multi-functional adaptation measures touches on the interests of many stakeholders. That is why stakeholders with different backgrounds need to work together to find resilient and suitable solutions in urban climate adaptation. To facilitate in this cooperation, Deltares developed the Adaptation Support Tool (AST) [10]. The AST is an interactive online tool used to explore which adaptation measures can be implemented in the area and review the effectiveness of the measures. The tool can be used by both experts and non-experts and makes the planning of climate adaptation measures more collaborative and easy to understand for non-specialists. With the help of the AST, different climate adaptation options can be compared for a project area. The AST includes 62 blue, green, and grey adaptation measures [42].

The AST defines eight different performance indicators to compare the effectiveness of these climate adaptation measures, which are [9]:

- Storage Capacity created by the measure
- Runoff volume reduction factor for extreme storms
- Estimated increase in annual evaporation in the project area
- Estimated increase in annual groundwater recharge in the project area
- Estimated water quality improvement in terms of reduced loads of nutrients, sediment, and their absorbed pollutants and pathogens.
- Number of cool spots (>200 m2) that is created
- Construction costs
- Maintenance costs

The first four indicators are calculated with the help of an underlying model, the Urban Water Balance Model (UWBM). The UWBM is a conceptual multi-reservoir model, written in Python language and released in 2019 by Deltares [11]. This model simulates the dominant hydrological processes of an urban system, where long historical rainfall data is used as input to take different antecedent conditions into account. The schematic overview of the UWBM is given in Figure 1.1. As shown in the Figure, the model is comprised of different reservoirs and fluxes going in and out of the system. The defined boundaries are the atmosphere, water outside the project area, deep groundwater, and wastewater treatment plant. An example of the definition of water outside of the project area is a pump that pumps the water out of a polder into another system.

A vital aspect of the UWBM is that it gives the user a first insight into the vulnerability of the system and the differences in implementing different urban runoff measures. To this purpose, four performance indicators are calculated within the model to define the effectiveness of the implemented urban runoff measures being storage capacity, the runoff volume reduction factor, evaporation, and groundwater recharge in the projected area. With these indicators, the effectiveness of urban runoff measures can be evaluated in chosen hypothetical rainfall situations as input. The model is conceptual, and many parameters are set to default values for different types of urban areas and their subsurface. Because this model plays a central role in this study, it is more thoroughly described and explained in chapter 2.

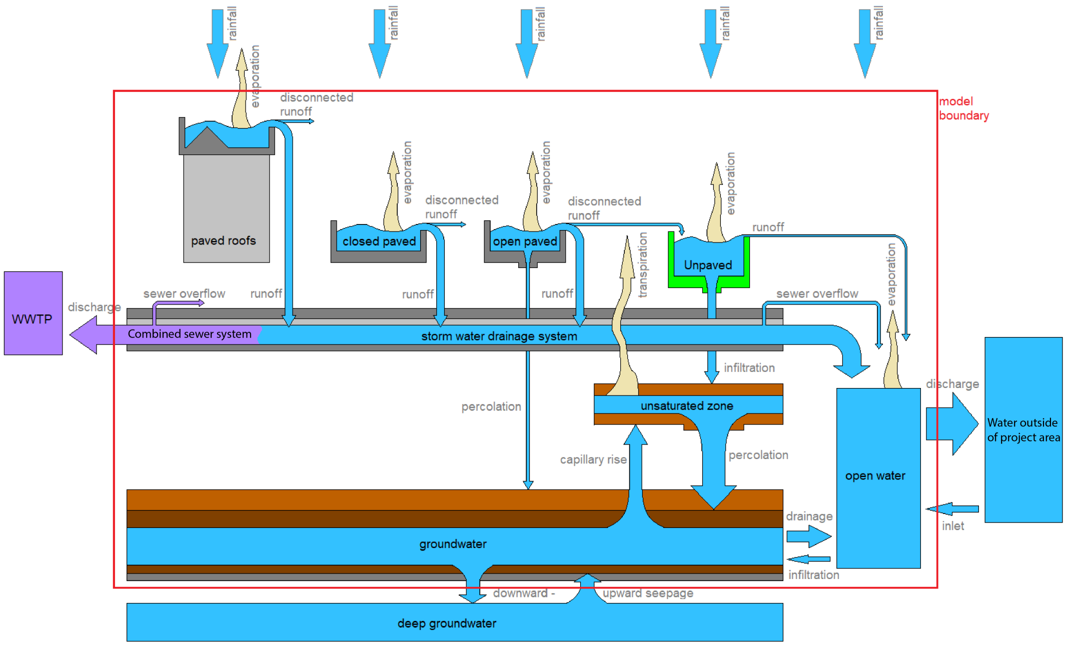


Figure 1.1: Conceptual representation of the Urban Water Balance Model [10]

As the UWBM can determine four performance indicators, this study is focused on the runoff volume reduction factor since the method of determining this factor can be used to define other factors. The runoff volume reduction factor was studied by Zhang [45]. This factor is defined as the rate at which a specific adaptation measure increases the return time of the runoff. For example, if the return time of an extreme runoff event is changed from once every two years to once every four years by implementing a measure, the runoff volume reduction factor is 2.

The model now calculates this factor for every single measure separately over the area of the applied measure and not for the whole project area. Most adaptation plans will include a combination of measures. A way to quantify the cumulative effect in terms of the performance indicators is required. This cumulative effect is determined by a post-processing step where the factor of the measure is calculated for the whole project area. Based on this whole project area factor, different implemented measures can be combined to one single runoff volume reduction factor for the whole project area. A more detailed description of the runoff volume reduction factor can be found in chapter 2.

The method of empirically calculating the runoff volume reduction factor — based on time series and calculating the return time of events — is a method that can be adopted for other new performance indicators. This study focuses on the possible development of a reduction factor for flow peaks and storage peaks to gain a more thorough insight into the effectiveness of urban runoff measures.

Using time series as input

According to literature, the most widely used performance indicators for the effectiveness of urban runoff measures are peak discharge reduction, runoff volume reduction, the runoff coefficient, and time to peak [37]. When calculating these performance indicators, several studies use single (design) rainfall events ([6], [28], [29]). The use of single rainfall events in models can often give a wrongful insight into the effectiveness of a measure since it ignores the antecedent conditions of the system. Several studies observed that antecedent conditions can have a large impact on runoff and peak attenuation ([2],[22], [31], [36]). Modeling urban runoff measures performance using time series as input can thus be advantageous since the antecedent conditions are incorporated in this method.

The Urban Water Balance model uses time series to model the effectiveness of urban runoff measures, including the runoff volume reduction factor [8]. This factor is a convenient indicator of the effectiveness of urban runoff measures regarding the volume of runoff. The UWBM now analyses the runoff volume, but in literature, the flow peaks and inundation of the system are also used as performance indicators which can be implemented in the UWBM.

Flow peak reduction

Besides runoff volume, current increases in impervious surfaces and urbanization result in higher stormwater runoff peaks [35]. In most literature, the peak runoff reduction is calculated based on single rainfall events ([6], [15], [19], [23], [27]). The UWBM currently does not analyze the modelled peak runoff. The flow peak reduction can give the user a more complete insight into the performance of measures and the volume reduction. Defining a peak runoff reduction factor which defines the rate at which the measure increases the return time of the peak runoff, is a new way of defining the effectiveness of urban runoff measures.

An example of the importance of incorporating flow peaks into the analysis is shown in Figure 1.2. The Figure shows hydrographs of the outfall depth for an existing urban neighborhood of Cost Rica and the hydrograph after a blue-green measure is implemented, computed by Khan et al. [23]. The graphs show differences in runoff peak reduction values and runoff volume reduction values. For example, Figure 1.2a shows a small precipitation event before a heavier precipitation event where the peak runoff will occur. What can be seen in the Figure is that the blue-green measure can store the incoming rainfall at first. However, the second heavier precipitation event is only slightly lower than the existing situation. The normative peak is almost as high as the old normative peak. A second example is Figure 1.2c. Initially, the measure can cope with the first precipitation peak. However, when the storage capacity of the measure is probably full, the outflow shows little differences and similar flow peaks. Another example is Figure 1.2e. This Figure shows a full reduction of the first two peaks, but the normative peak is only reduced by a small amount. Thus, the volume reduction is quite high for this measure, but the normative peak is still quite high and can cause problems downstream. This Figure thus gives an insight into the importance of modeling antecedent conditions and the use of runoff peak reduction indicators for evaluating the effectiveness of measures.

Storage peak reduction

Figure 1.1 shows that most fluxes in the urban water balance will flow towards the Open Water of the system, after which it will be either discharged to the water outside of the project area or evaporated. Analyzing the storage volumes in this reservoir will give the user valuable insight into the performance of a measure since an over-filled reservoir will indicate the inundation of the whole system.

Several studies have evaluated the effectiveness of urban runoff measures to mitigate urban inundation in the urban watershed ([21], [44], [46]). These studies used distributed models like the Storm Water Management Model (SWMM) and used single precipitation events as input. The different method of the UWBM — using time series and looking at the return time of the events — can give a better insight into the effectiveness of the urban runoff measure. In this case, looking at the storage peaks in the Open Water gives the user the insight of the impact on inundation by the measure.

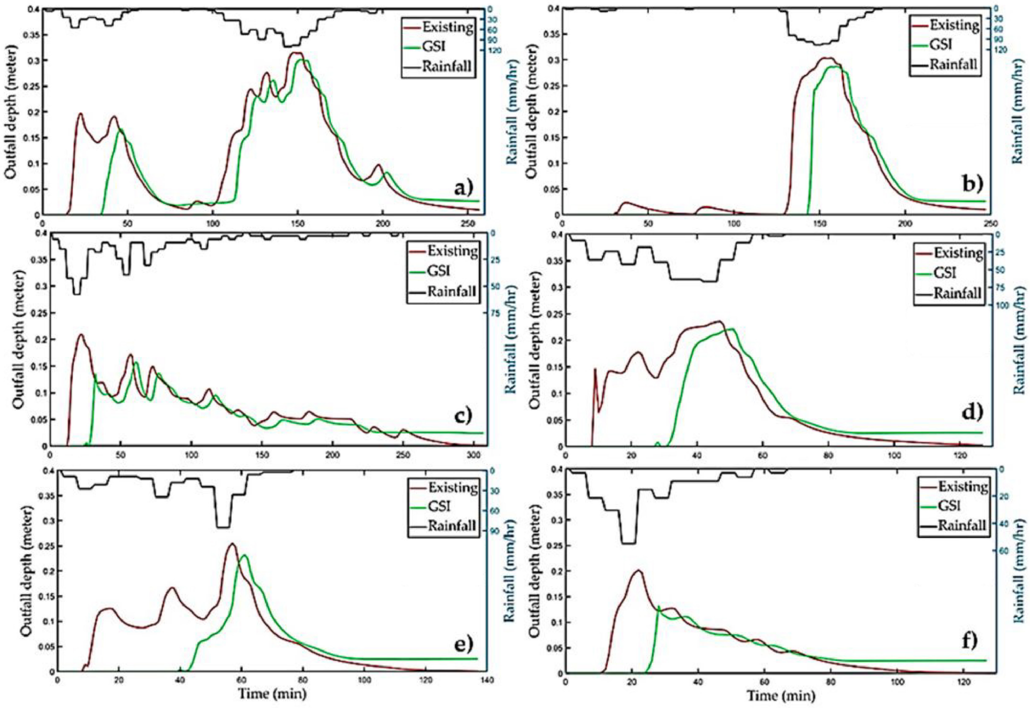


Figure 1.2: Rainfall-runoff response hydrographs of existing conditions and after implementation of Green Stormwater Infrastructure. [23]

1.1. Research objective

The benefit of the present Urban Water Balance Model (UWBM) is thought to be that one can model a project area using time series of precipitation (and potential evaporation) as input. However, it is currently unknown if the method of calculation of the runoff volume reduction factor can be adapted to calculate a flow peak or storage peak reduction factor. If these two factors can be calculated, it would make the interpretation and decision process using the AST more thorough and precise. Thus, this research aims to determine if the flow peak reduction and storage peak reduction due to the implementation of blue-green-grey adaptation measures can be defined by a factor when modeling the project area with an urban water balance model based on time series. In addition, a post-processing step is currently used to get a single runoff volume reduction factor for the whole project area with several implemented measures. Hence if a flow peak reduction and storage peak reduction factor can be found for implementing a single adaptation measure, the second goal of this study is to research if it possible to combine several measures in an area and return a single flow peak reduction and storage peak reduction factor.

1.2. Research Questions

Based on the foregoing the following research questions are formulated for this study: The main research question holds:
"How can the effectiveness of urban runoff reduction measures in a project area be defined and quantified when these are modelled for runoff volume reduction, flow peak reduction, and storage peak reduction?"

The second research question is defined as:
"How can this effectiveness be defined for a combination of different adaptation measures in a project area instead of for a single measure, and how can this effectiveness be expressed in performance indicators for the whole area?"

1.3. Reading guide

This report is structured as follows: the "Introduction" which presents the research motivation, problem statement, research objective and the research question is given in Chapter 1. The "Theoretical Background" is discussed in Chapter 2. Then, the "Methodology" will be discussed in Chapter 3. Chapter 4 will discuss the results of this research. At last, the "Discussion" and "Conclusions and Recommendations" are given in chapters 5, 6 respectively.

2
Theoretical Background

2.1. Urban Water Balance Model

The Urban Water Balance Model (UWBM) is a lumped conceptual multi-reservoir model developed by Deltares [11]. In 2019 Deltares released the UWBM. This model, written in Python, simulates the dominant hydrological process of an urban system, where long historical rainfall data is used as input to take different antecedent conditions into account. Besides, model building and calculations take less time with the UBWM than other more detailed hydrological and hydraulic models (e.g., SWMM, SOBEK, D-Hydro).

A vital aspect of the UWBM is that it gives an initial insight into the vulnerability of the system and the differences in implementing different urban runoff measures. As discussed in the introduction, the model returns four performance indicators to define the effectiveness of the implemented urban runoff measures: Storage capacity, Runoff volume reduction factor, evaporation, and groundwater recharge.

First, the study introduces the model framework. After which, the different performance indicators are discussed. Then, the third section will discuss the calculation of the runoff volume reduction factor. At last, the current calculation of the local measure factor to the whole project area factor is discussed.

2.1.1. Model framework

The UWBM describes the most dominant urban water flows and associated water resources. Figure 2.1 shows the defined storage areas and fluxes in the model. The model divides the urban area into five types:

1. Paved area above surface level (Paved Roof);
2. Paved area at the surface level (Closed Paved);
3. Open paved area at the surface level (Open Paved);
4. Unpaved area at surface level (Unpaved);
5. Surface-water below surface level (Open Water).

Besides these five components, there are three components distinguished below the surface level. These three components are in connection with the four components above surface level:

1. Unsaturated Zone
2. Shallow Groundwater
3. Sewer System (Combined sewer system or stormwater drainage system.)

At last, the model has three boundaries where water exchanges to external systems:

1. Atmosphere (Rainfall and potential evaporation)
2. Deep groundwater (seepage from shallow groundwater to deep groundwater)
3. Water outside of the project area & wastewater treatment plant (Combined sewer system discharges water to a wastewater treatment plant or excess water on the surface water is pumped out of the system)

The input components needed for the model are precipitation, potential evaporation of open water, and reference crop evaporation. The user can define the time step of the data. The preparation of this data is discussed in Chapter 3: Methodology.

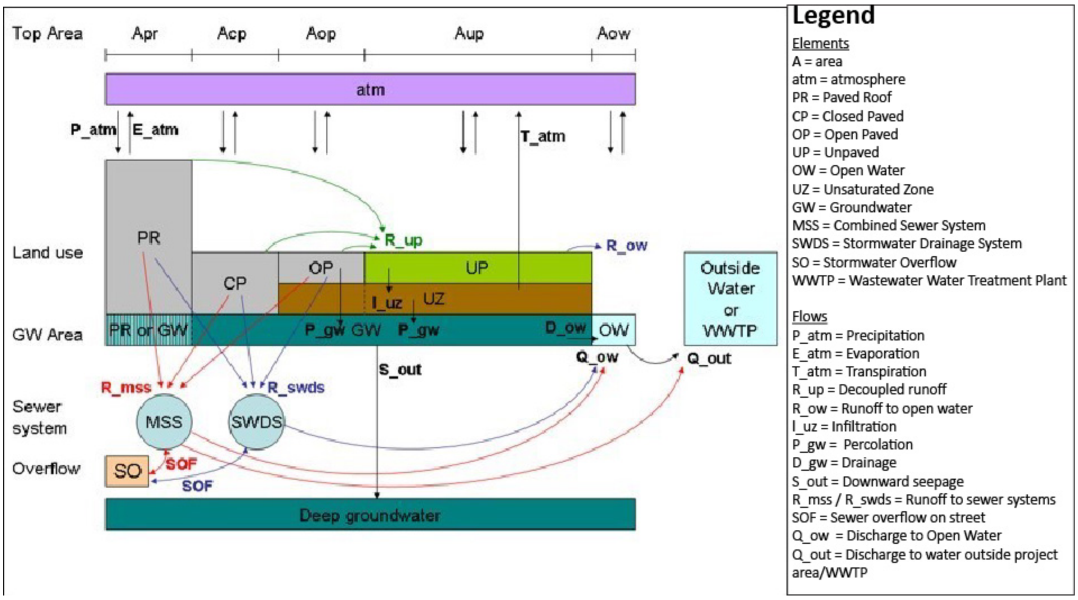


Figure 2.1: Schematic overview of the Urban Water Balance Model [11]

2.1.2. Assumptions

The model takes several assumptions, which are discussed below.

- The model ignores internal routing; there is no time incorporated for water to move between reservoirs. The model is applicable at the neighbourhood scale, and using the model at a large spatial scale may be questionable. To this point, the time step of the model has to be chosen accordingly. The time step has to sufficiently large to be able to neglect routing. If the time step is chosen as seconds, the assumption of neglecting routing may be questionable. The time step has to be sufficiently short to give a fair insight into the rainfall-runoff process and the model's storage reservoirs behaviour of the project area. Usually, in fast-responding urban systems, a time step of one hour chosen.
- The model needs representative and long time series (i.e. 30 years) of precipitation and potential evaporation. Besides, relevant estimates of the properties of the project area are needed to get a reliable estimate of the average behaviour and the behaviour of extremes.
- Only rainfall is considered as precipitation i.e. no irrigation is considered in the model. Precipitation is instantaneously at the beginning of each time step.
- The precipitation gets intercepted, where first the water evaporates and then infiltrates.
- Calculated water flows and storage volumes are expressed in depth (mm) per area for a component.
- The model conserves water quantity for the entire model, i.e., no water is lost. However, water flow is limited by three aspects: the available water volume, the available storage and the transport capacity.

- When calculating the runoff volume reduction factor, only uncontrolled runoff is incorporated in the calculations. Controlled runoff does add to the total runoff, but the influence is assumed to be small.

2.1.3. Implementation of measures: Measure module

This research focuses on pluvial flooding, which is defined as rain-related flooding. Pluvial flooding usually occurs following short, intense or prolonged rainfall events that can not be handled by either the storage capacity or the drainage capacity of the urban water system [20]. To manage the existing and future flood risks, urban climate adaptation measures are applied.

The Urban Water Balance Model (UWBM) can model 62 different adaptation measures, including grey, blue and green measures. The UWBM can implement a measure in the modelled study area and determine the four performance indicators, among which the runoff volume reduction factor. The calculation of this factor is discussed in section 2.2. To define a measure in the model, first the layer system of the measures is described, after which the definition of effective depth is discussed.

Layer system

Every measure is defined by parameters that the user can set for up to three storage layers and their related flows. Generally, measures can be chosen as a 1-layer, 2-layer or 3-layer structure. The 3-layer structure is shown in figure 2.2 together with its water balance.

- The 1-layer structure contains only the interception layer (1). These types of measures create storage and allow for evaporation.
- The 2-layer structure contains the interception layer (1) and the bottom storage layer (3). Within the bottom storage layer, the user can define evapotranspiration, percolation to groundwater and controlled runoff. Controlled runoff is runoff volume stored in the measure that can be discharged in a controlled way.
- The 3-layer structure consists of the interception layer (1), the top storage layer (2) and the bottom storage layer (3) as depicted in Figure 2.2. The top storage layer acts as a growing medium that encourages evapotranspiration. An example of a 3-layer system is a green roof.

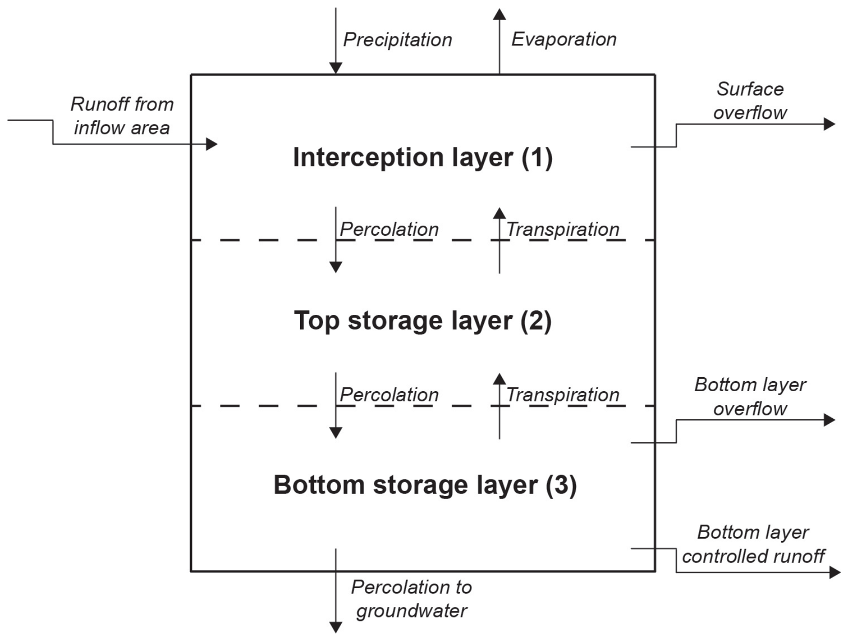


Figure 2.2: Definition of the measure in the UWBM, containing 3 layers. The user can choose the amount of layers to implement.

Effective depth
To calculate the different performance indicators, the user can define the design depth of the measure, the reservoir where the measure is implemented (e.g., Paved Roof and Open Paved) and the measure inflow factor. Then, based on these three parameters, the effective depth of the measure is calculated. Both the measure inflow factor and the effective depth calculation are explained in more detail in the following.

The measure inflow factor is the fraction between the measure inflow area and the area of the measure itself. For example, if the measure area is 10 m^2 and the measure inflow area is 100 m^2, the measure inflow factor is 10.

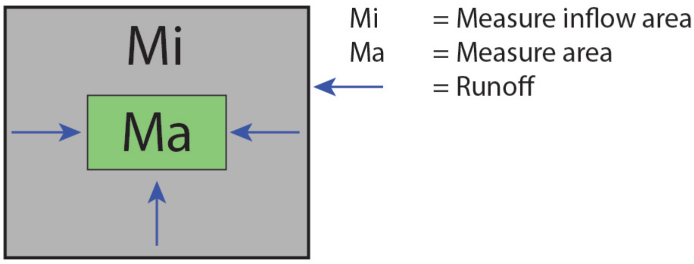


Figure 2.3: Measure inflow area and measure area

Every measure is defined with a so-called effective depth, calculated with equation 2.1, where the user defines the depth of the measure. Alternating the effective depth makes it possible for the user to assess different possibilities for implementing the measure.

$$ED = \frac{d_{Meas} * A_{Meas}}{A_{meas_{inflow}}} \tag{2.1}$$

where:

ED	= Effective depth $[mm]$
d_{Meas}	= Depth of the measure as: measure design depth * void ratio $[mm]$
A_{Meas}	= Area of the measure $[m^2]$
$A_{meas_{inflow}}$	= Inflow area of the measure $[m^2]$

Assumptions
With implementing the measure module, the next assumptions are taken:

- The whole area where the measure is implemented (e.g. Open Paved, Paved Roof) is assumed to be the measure inflow area. For example, if a measure is implemented in a Paved Roof area of 100 m^2 and the inflow factor is 10, the measure area is 10 m^2 and the measure inflow area is 100 m^2.
- The measures are simplified by defining them as a 3-layer system. It is assumed that the function of the measure can be approached using this method.

2.1.4. Performance Indicators of measures

The UWBM is usually used to calculate four performance indicators that indicate the effectiveness of the implemented urban runoff measures: Storage capacity, average annual groundwater recharge, average annual evaporation and the runoff volume reduction factor ([42], [9]).

Storage capacity

The storage capacity of a catchment is the maximum water volume that the area can contain. The available storage of the area is filled during a rainstorm, either partly or entirely. Then, the stored water needs to be removed, which takes time depending on different processes, e.g., outflow, evaporation and pumping. Therefore, depending on the time and outflow/pumping capacity, the available storage for the next rainstorm can be less than the storage capacity of the area, as the reservoir(s) are not yet empty.

The required storage capacity can be estimated using a Storage Discharge Frequency (SDF) -Curve, using the existing or future stormwater discharge capacity. The SDF curve plots the discharge capacity of the entire area against the storage capacity over the entire area for a specific return period as shown in Figure 2.4. The different data points on this graph are retrieved by running the model for varying discharge capacities from the open water to the external area. When the discharge capacity and normative return time of exceedance of a runoff event are known, the area's required storage capacity can be determined. For example, if the area has a low discharge capacity, a high storage capacity is required and vice versa.

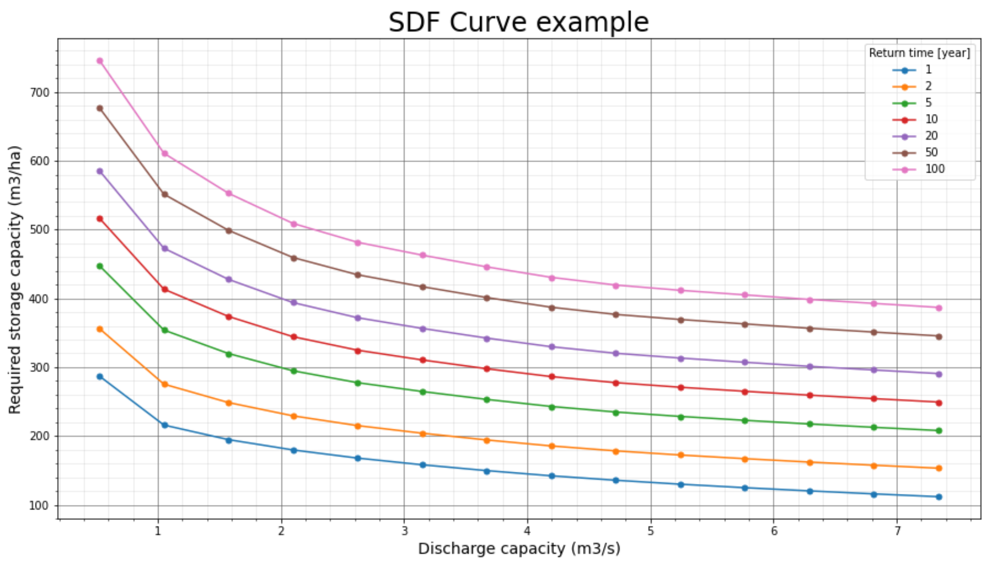


Figure 2.4: Storage Duration Frequency curve for different return periods.

Evapotranspiration

Change in expected annual average evapotranspiration is used as a performance indicator since it indicates cooling of the area. More evaporation means a decrease in heat. Evapotranspiration is defined as evaporation from the surface- and intercepted water and water that plants transpire. More water evaporates and transpires if the area is greener and bluer, which increases cooling. Hence, blue and green measures contribute to this indicator.

Groundwater recharge

Expected change in annual average groundwater recharge is a performance indicator since it is relevant in areas sensitive to land subsidence. Increased groundwater recharge raises groundwater levels, which can slow down land subsidence. Another effect of groundwater recharge is that it enhances the availability of water for vegetation during dry periods.

Runoff volume reduction factor

The runoff volume reduction factor is an empirical relationship found by [45], and it defines how a particular measure alters the return time of an event-based runoff depth. For example, a runoff that currently is exceeded once every two years can be changed by applying an urban runoff measure into a runoff that is exceeded once every three years [8].

The assessment of this factor is based on the output that the UWBM generates. For the runoff volume reduction factor, the uncontrolled runoff discharged by the implemented measure is analysed. The uncontrolled runoff is the runoff that is generated when the storage capacity is exceeded, which results in surface runoff. Besides this, a baseline uncontrolled runoff assessed. This baseline uncontrolled runoff is the uncontrolled runoff out of the area when there is no measure implemented.

An example of a fragment of the output of the UWBM is given in Figure 2.5. Here, the UWBM was used to model an Urban wetland in a specific area for 30 years on an hourly based time series. The figure shows a half-day of this output and shows the outflow of the urban wetland where different effective depths of this measure are applied. The reduction in runoff caused by an increasing effective depth of the measure is visible.

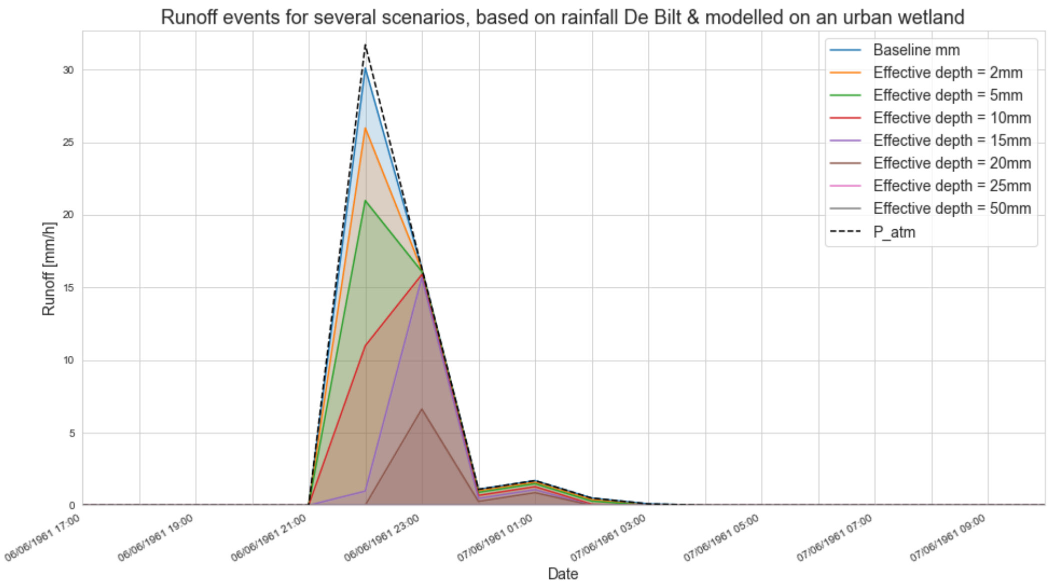


Figure 2.5: Example of the output of the UWBM, where the runoff is shown for several effective depths of an urban wetland.

Based on these kind of long datasets, Zhang [45] described that the change in return periods due to the implementation of a measure can be defined by a constant factor. This constant factor is the runoff volume reduction factor. The assessment procedure of the runoff volume reduction factor is discussed in the next section.

2.2. Calculation of the runoff volume reduction factor

The calculation of the runoff volume reduction factor consists of 5 steps [8], which are shown in Figure 2.6.

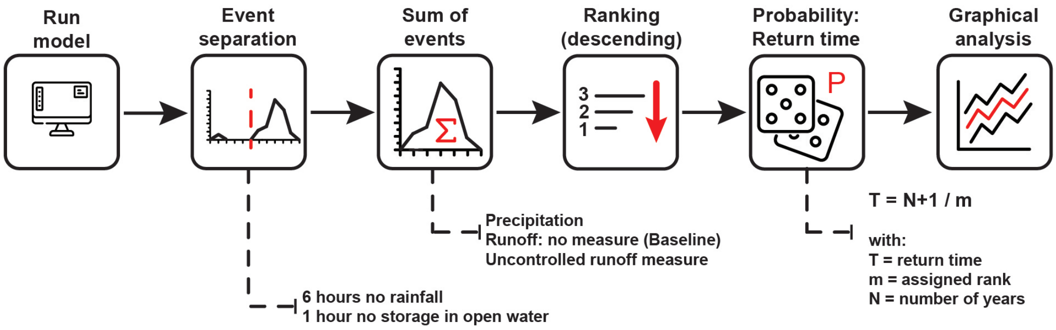


Figure 2.6: Six steps needed to calculate the runoff volume reduction factor

1. Running the UWBM: First, the model will be run with a baseline run without a measure implemented. Afterwards, the model is used again, including a measure implemented with varying effective depths defined by the user. The precipitation, open water level and chosen uncontrolled runoff is stored for the baseline run. The uncontrolled runoff of the different effective depths of the measure is also stored to be analyzed in the next steps.
2. Event separation based on the baseline run:
    - Rainfall events are separated by six consecutive hours with no precipitation. Each rainfall event ends when the next rainfall event starts.
    - Storage events are separated by a single time step with no storage in the open water reservoir. Each storage event ends when the next storage event starts.
    - The total event separation combines both the storage and rainfall events. A detailed description is given in Appendix C.
    - The event separators as defined by the combined rainfall and storage events are applied for the periods of all the runoff events.
3. Calculation: The sums of event-based rainfall depth, event-based baseline runoff depth, and event-based uncontrolled runoff depth are calculated.
4. Ranking & probability: The data is ranked by arranging them in descending order of magnitude. The probability of exceedance of each rank number is calculated using the Weibull formula [7] $\left(P = m/(N+1);\right.$ where m is the assigned rank and N number of years$\left.\right)$. The corresponding return period is then calculated using $(T = 1/P)$.
5. Visual presentation: The results are plotted on a semi-logarithmic graph, where the runoff depth is plotted against the $\log^{10}$ of the corresponding return period.
6. Steps 3-5 are repeated for various effective depths of the measure.
7. Graphical analysis: Figure 2.7 shows an example of the semi-logarithmic graph that is used for graphical analysis. A linear shift of the line on the y-axis can be observed, *implying that a measure with a certain effective depth increases the return time of a certain runoff depth by a constant factor.* The factor is calculated by dividing the return time of the applied measure by the return time of the baseline scenario. To calculate the factor of the measure for every effective depth, the average of the factors is calculated for a predefined set of runoff depths. This factor is only applicable for the measure inflow area. Section 2.3 discusses the derivation of the factor for the entire project area.

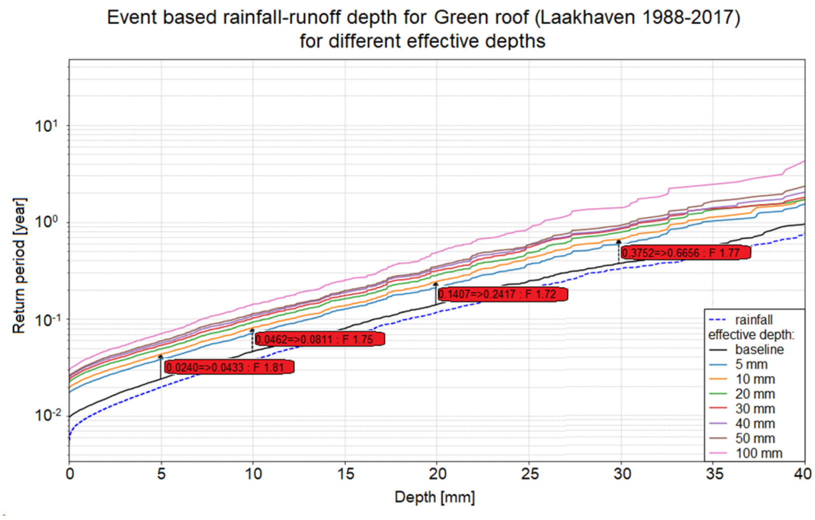


Figure 2.7: Example of the usage of the plot used for calculation of the runoff volume reduction factor. [8]

2.3. Measure factor to project factor

The runoff volume reduction factor calculated in the UWBM is only applicable for the area where the runoff is affected by the measure, i.e. the measure inflow area. Urban planners are interested in knowing the impact of the runoff volume reduction of the measure in the total project area. Therefore the runoff volume reduction factor of the measure inflow area is transformed into a reduction time factor for the total project area.

The area is divided into a paved area and the rest of the area, i.e. unpaved area. It is assumed that the measures are applied to the paved area only. The rest of the area will most likely also produce some rainfall-runoff, but this fraction is generally much less and slower than produced by the paved area. Figure 2.8 presents a schematization of an urban project area with size T. The green square represents the area of inflow to the measure, the grey area is the paved area, and the yellow area is the rest of the area.

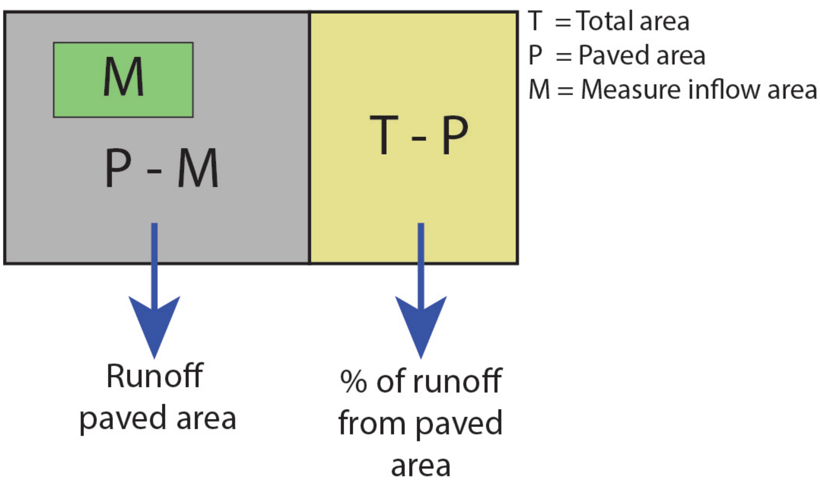


Figure 2.8: Schematization of an urban project area with size T.

For a given single measure, the following formula is defined by Zhang and Deltares ([8], [45]) to transform the resulting runoff volume reduction factor of the measure inflow area to the runoff volume reduction factor of the project area:

$$F_{tot} = \frac{A_p * \exp(\frac{A_{mi} * \ln(F_{meas})}{A_p}) + \frac{Perc_{RA}}{100} * (A_{tot} - A_p)}{A_p + \frac{Perc_{RA}}{100} * (A_{tot} - A_p)} \tag{2.2}$$

Where:

F_{tot} = Factor for total area
F_{meas} = Factor for measure inflow area
A_{tot} = Total area
A_p = Paved area
A_{mi} = Measure inflow area
$Perc_{RA}$ = Runoff from the rest of the area, estimated as the percentage of the runoff
= from paved area.

Now, this equation can be used to determine the factor of several measures to a combined factor for the total project area. The formula is then formulated as:

$$F_{tot} = \frac{A_p * \exp(\frac{\sum_n^{i=1}(A_{mi_i} * \ln(F_{meas_i}))}{A_p}) + \frac{Perc_{RA}}{100} * (A_{tot} - A_p)}{A_p + \frac{Perc_{RA}}{100} * (A_{tot} - A_p)} \tag{2.3}$$

Where:

i = Counter, from 1 to N
N = Number of applied measures

2.3.1. Derivation of the project area factor

The conversion of the measure factor to the project area factor is based on the use of the graph of the runoff depth and return period on a semi-logarithmic graph. The semi-logarithmic graph where the runoff volume reduction factor is based on, e.g. the one in figure 2.9 can be simplified by straight lines when the extremely small events are ignored.

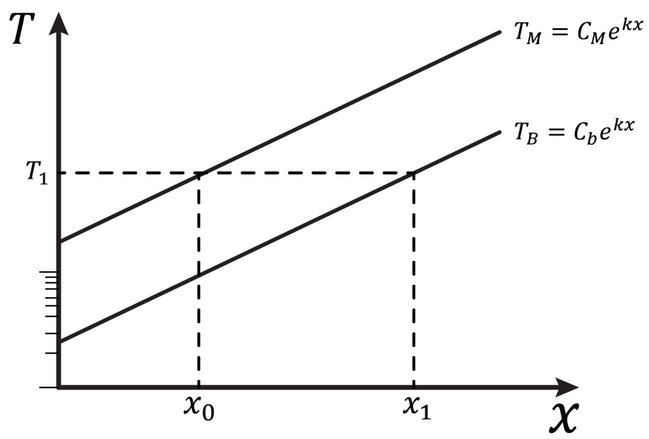


Figure 2.9: Simplified graph of runoff depth and return period in a semi-logarithmic graph [45]. x denotes the runoff depth, T denotes the return time, T_M and T_B denote the approximate fits for the graph of the measure and the entire area under baseline situation respectively.

Based on this Figures 2.8 and 2.9, Zhang [45] assumed that the curves obtained by the plotting position method roughly approximate straight lines. The runoff volume reduction return time can thus be defined as:

$$T = C_1 * e^{C_2 * x},$$
$$x = \frac{1}{C_2} * ln\frac{T}{C_1} \tag{2.4}$$

Since it is known that the approximation curves of the measure inflow area and the entire area under baseline situation are roughly parallel, C_2 is equal in both cases, and T_M and T_B can be defined as:

$$T_M = C_M * e^{kx},$$
$$T_B = C_B * e^{kx} \tag{2.5}$$

The runoff volume reduction factor is calculated as the factor of the measure inflow area divided by the factor of the entire area. Therefore, the runoff frequency reduction factor can be defined as:

$$f = \frac{T_M}{T_B} = \frac{C_m * e^{kx}}{C_b * e^{kx}} = \frac{C_M}{C_B} \tag{2.6}$$

In Figure 2.9, return time T_1 is determined by $T_1 = C_m * e^{kx_0} = C_b * e^{kx_1}$. Based on this equation, the definition for x_1 is determined:

$$C_m * e^{kx_0} = C_b * e^{kx_1}$$
$$\frac{C_m}{C_b} * e^{kx_0} = e^{kx_1}$$
$$\ln f + kx_0 = kx_1$$
$$x_1 = x_0 + \frac{1}{k}\ln f(x_0 > 0) \tag{2.7}$$

The runoff value for the baseline case over the entire area is always $\frac{1}{k}\ln f$ larger than the runoff value over the measure inflow area when the measure is applied. Let us consider the runoff over the entire area under the situation where the measure is applied $x_t tot$. This can be calculated using the following equation:

$$x_{tot} = \frac{x_0 * M + x_1 * (A - M)}{A} = \frac{(x_1 - \frac{1}{k}\ln f) * M + x_1 * (A - M)}{A} = \frac{x_1 * M - \frac{1}{k}\ln f * M + x_1 * A - x_1 * M}{A}$$
$$x_{tot} = \frac{\frac{1}{k}\ln f * M + x_1 * A}{A}$$
$$x_{tot} = x_1 - \frac{M}{A} * \frac{1}{k}\ln f \tag{2.8}$$

For any given return time T, the runoff value over the entire area is reduced by the measure with $\frac{M}{A} * \frac{1}{k}\ln f$. Figure 2.10 shows an increase of return time of the runoff over the entire area under the situation where the measure is applied. Based on this knowledge, the runoff frequency reduction factor over the entire area can be defined.

It is known that $T_1 = C_b * e^{kx} = C_{tot} * e^{kx}$ and $T_1 = T_{tot}$, $x = x_1 - \frac{M}{A}\frac{1}{k}\ln f$. This gives:

$$f_{tot} = \frac{T_1}{T_B} = \frac{C_B e^{kx_1}}{C_B * e^{k\left(x_1 - \frac{M}{A}\frac{1}{k}\ln f_{meas}\right)}} = e^{\frac{M}{A}\ln f_{meas}} \tag{2.9}$$

where:

f_{tot} = Runoff volume reduction factor over the entire area with the applied measure [-]
f_{meas} = Runoff volume reduction factor over the measure inflow area.
A = Entire area $[m^2]$
M = Measure inflow area $[m^2]$

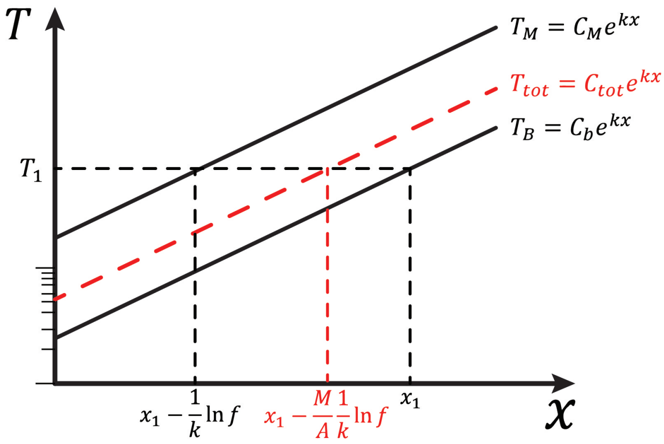


Figure 2.10: Simplified graph of runoff depth and return period in a semi-logarithmic graph [45]. "x" denotes the runoff depth with x_1 the runoff depth for the whole area under baseline situation. T denotes the return time where T_M and T_B denote the approximate fits for the graph of the measure and the entire area under the baseline situation, respectively. T_{tot} is the curve for the runoff averaged over the entire area under the situation with the applied measure. M is the measure inflow area, A is the total area, and f is the runoff volume reduction factor of the measure over the measure inflow area.

Equation 4.1 is based on an area that consists of the measure inflow area and the rest of the area. However, what if the entire area only contains unpaved land surface? Deltares [8] adapted equation 4.1 to an equation where both the unpaved area and open water are included. Let us consider the entire area based on Figure 2.8. Uncontrolled runoff in the rest of the area (T-P) is possible due to hortonian overland flow (exceedance of infiltration capacity of the soil [17]) and saturation overland flow (combination of precipitation intensity and duration and runoff from higher areas saturating the soil and raises the water table to the surface [13]).

Therefore Deltares [8] proposed the new equation to calculate the runoff volume reduction factor based on the total area composed of paved area, unpaved area and open water:

$$F_{tot} = \frac{A_p * \exp(\frac{A_{mi} * \ln(F_{meas})}{A_p}) + \frac{Perc_{RA}}{100} * (A_{tot} - A_p)}{A_p + \frac{Perc_{RA}}{100} * (A_{tot} - A_p)} \tag{2.10}$$

Where:

F_{tot} = Factor for total area
F_{meas} = Factor for the measure inflow area
A_{tot} = Total area
A_p = Paved area
A_{mi} = Measure inflow area
$Perc_{RA}$ = Runoff from the rest of the area, estimated as the percentage of the runoff
= from paved area.

2.3.2. Combining multiple measures

Often multiple different measures will be applied in an urban area. Therefore, it is desirable to combine these multiple measures with different runoff return time factors to one single return time factor for the project area. Deltares researched this and found that equation 2.10 can be changed to the following:

$$F_{tot} = \frac{A_p * \exp(\frac{\sum_{n}^{i=1}(A_{mi_i} * \ln(F_{meas_i})}{A_p}) + \frac{Perc_{RA}}{100} * (A_{tot} - A_p)}{A_p + \frac{Perc_{RA}}{100} * (A_{tot} - A_p)} \tag{2.11}$$

Where two parameters are added:

i = Counter, from 1 to N
N = Number of applied measures

3
Methodology

Using the Urban Water Balance Model (UWBM) as introduced in chapter 2 the following methodology is proposed to answer the research questions. A new method is proposed to analyse both the flow peaks of the measure and the storage peaks of the measure and the whole system. Instead of looking at the runoff volumes, this study takes a look at the estimated runoff peaks like the ones in Figure 2.5 and resulting peaks in the stored volumes in the receiving open water. This new method is first tested on a simple reservoir model before implementation into the UWBM, for which consult Appendix D. Based on the method described in section 2.3 a conversion for the flow peak factor from measure factor to project area factor is analysed. Based on this conversion, the project factor for a combination of measures can be defined . Based on this conversion, two areas are modelled and the results are analysed to review the functionality of the found factors.
The last sections of this chapter discusses the inputs to the model. The input parameters are defined, with the area parameters containing the distribution of paved and unpaved areas. The choice of urban climate adaptation measures as input for the model is defined. The input forcings are defined: Precipitation and evaporation. The analysed output is the uncontrolled runoff out of the measure and the storage in the open water.

3.1. Flow peak- & storage peak reduction factor method

The proposed method of calculating both the flow peak reduction factor and the storage peak reduction factor is discussed in this section. The method is based on the same method as the calculation of the runoff volume reduction factor (discussed in section 2.2), but the third step of this method is changed.

3.1.1. Flow peak factor

The flow peak reduction factor is calculated by locally analysing the uncontrolled runoff of a measure. The reduction in peak runoff caused by an increase of the effective depth of a measure is determined. The example of a fragment of the output of the UWBM is given in figure 3.1. This figure indicates for a single event the following: the peaks for every effective depth of the applied measure, the peak of the precipitation and the peak of the baseline scenario. Increasing the effective depth results in a decrease in the uncontrolled runoff. The proposed method uses 30 years of input data instead of one single event. An example of a single event is shown in Figure 3.1.

To analyse if it is possible to deduct a flow peak reduction factor for a measure for several events, a similar method is used as is used for the calculation of the runoff volume factor discussed in section 2.1 [8]. However, the third step of this method is changed in this study (indicated in Figure 3.2), where instead of the sum of the runoff of the events, the peak of the events is determined.

Steps 1 & 2 are the same as discussed in section 2.2, where running the model for different effective depths

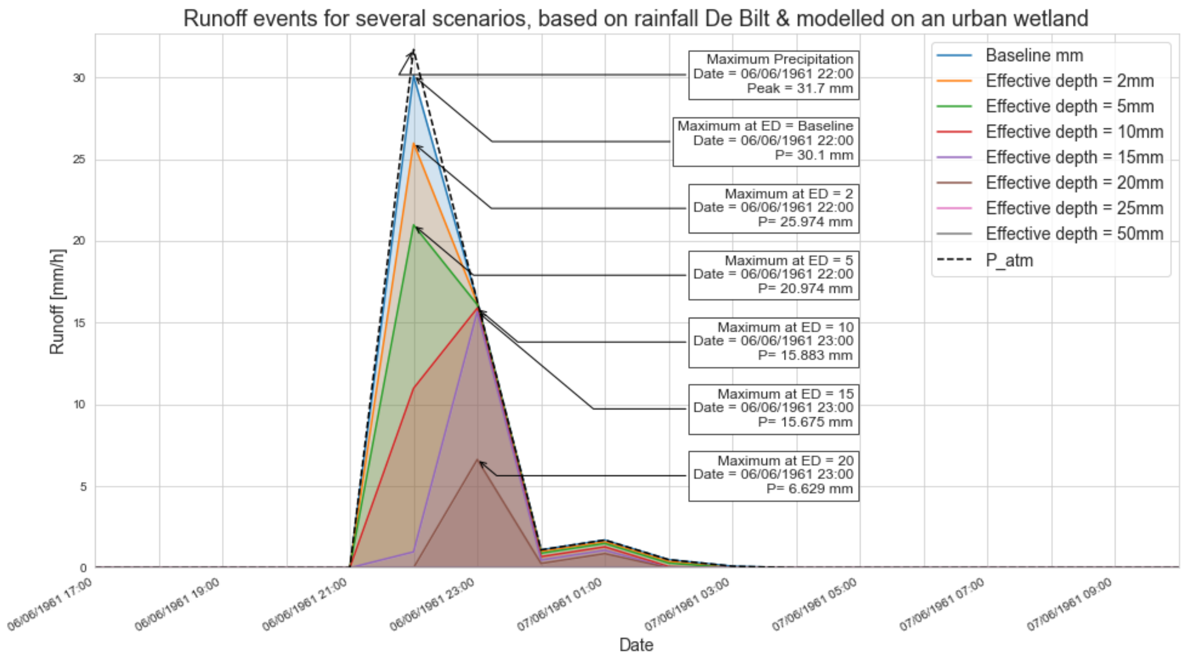


Figure 3.1: Several runoff scenarios for an increase of effective depth of an Urban Wetland. For a higher Effective Depth (ED), a lower peak runoff is observed.

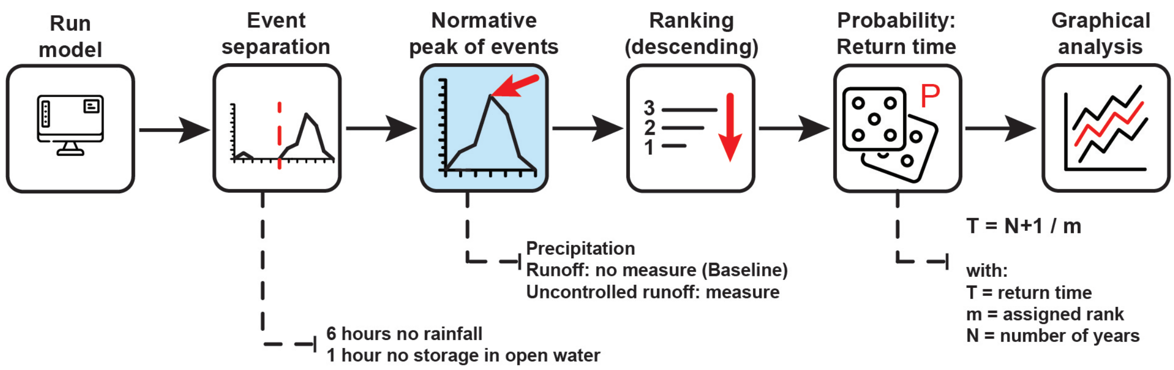


Figure 3.2: Proposed changed method to analyse a possible flow peak reduction factor.

of the measure and event separation is performed. Step three, however, is changed. During step 3, the calculation step, the **peaks** of the event-based rainfall depth, event-based baseline runoff depth, and event-based uncontrolled runoff depth are calculated.

Step 4 then ranks the peak data by arranging them in descending order of magnitude and calculating their corresponding return period. Steps 5 is the similar to the runoff volume reduction factor method, where the visual presentation is performed by constructing a semi-logarithmic graph of the results with flow peaks against the corresponding return period. Step 6, where steps 3-5 are repeated for various effective depths of the measure, is also carried out.

The last step, step 7, is the graphical analysis. As done with the calculation of the runoff volume reduction factor, the graphical analysis is performed. The graph is analysed to see if there is again a linear shift in the semi-logarithmic graph. To calculate the factor of the measure for every effective depth, the average of the factors of the changes of return periods is calculated for a set of peak values. The factor is calculated by dividing the return time of the flow peak of the applied effective depth by the return time of flow peak of the baseline scenario. The calculation is done with steps of 1 mm/h with excluding the 10 highest data points.

3.1.2. Storage peak factor

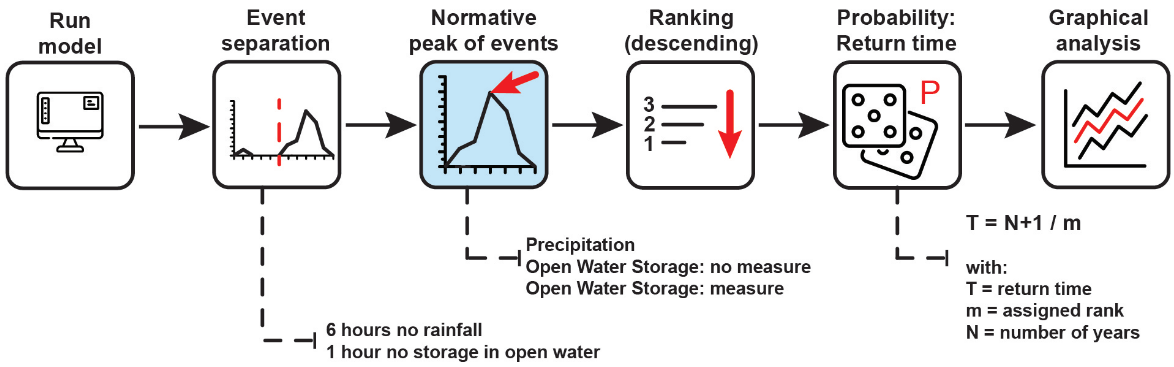


Figure 3.3: Proposed changed method to analyse a possible storage peak reduction factor.

The method to calculate the storage peak factor strongly resembles the method of the flow peak factor calculation. The difference is the data that is analysed in step 3 of the method, where the peaks of the **open water storage** are analysed instead of the peaks of the runoff out of the measure. Step three consists of storing the event-based rainfall depth, event-based baseline maximum open water storage volume, and event-based maximum open water storage volume for every effective depth of the measure. Also for the storage peak factor the average of the factors of the changes of return periods is calculated for a set of peak values. The factor is calculated by dividing the return time of the graph of the applied effective depth by the return time of the baseline scenario. The calculation is done with steps of 5 mm with excluding the 10 highest data points.

The open water storage is calculated as follows:

$$OWL_{stor}(t) = (OWL_{Target} - OWL(t)) * \frac{A_{OW}}{A_{tot}} \tag{3.1}$$

With:

$OWL_{stor}(t)$ = Open water level storage at time step t $[m^3/ha]$
OWL_{Target} = Predefined open water target level. $[m-SL]$
$OWL(t)$ = Open Water Level at time step t. $[m-SL]$
A_{OW} = Area of the Open Water $[m^3]$
A_{tot} = Total area of the project $[ha]$

3.2. Measure factor to whole project factor: Flow peak reduction

The conversion from the measure factor to a factor for the whole project area is only done for the flow peak reduction factor. The storage peak reduction is already an analysis for the whole area since the open water of the area is analysed instead of the uncontrolled runoff out of the measure.

To analyse if the flow peak reduction factor for the measure area can be converted to the factor for the whole project area, this study needs to prove that the same steps conducted in subsection 2.3.1 can be applied for the flow peak reduction.

The semi-logarithmic graph output for every measure are manually fitted to review if a conversion from measure factor to project factor is possible. For the method of conversion to be valid, the semi-logarithmic graph of the peak runoff reduction is fitted with equation 3.2 and also presented in Figure 3.4. If a fit can be found for all measures and the fits are parallel for every measure, the measure factor to the whole project factor is converted using the following steps.

$$T = C_1 * \exp^{kx} + C_2 \tag{3.2}$$

Where:

T = Return time of the runoff
C_1 = A constant, defined differently for every implemented effective depth of the measure.
k = Constant that determines the slope of the fitting graph.
C_2 = Constant to fit the curvature of the plot.

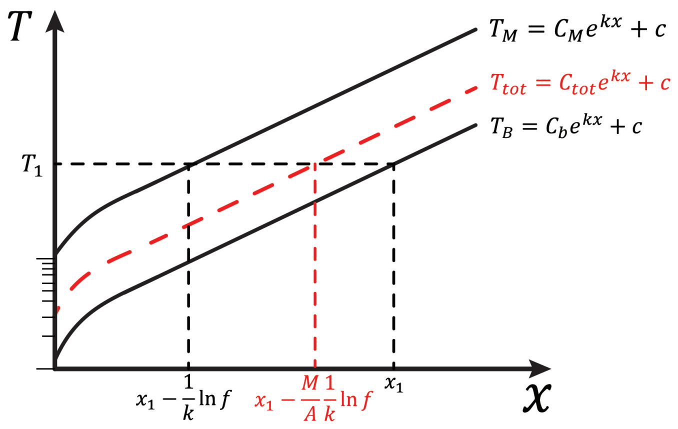


Figure 3.4: Fitting equations for the conversion of measure factor to whole project factor. T_M, T_{tot} and T_B represent the return times for the measure inflow area, total area and baseline scenario for the total area respectively. x_1 is the peak flow at a certain return time T_1. k is the parameter that denotes the slope of the graph and f is the flow peak factor over the measure inflow area.

Equation 3.2 has the extra constant C_2 with respect to the method described in subsection 2.3.1. However, if the graphs are parallel in all cases, the constant C_2 is the same for both the baseline and the measure inflow area, and the same conversion equation can be deducted:

$$\begin{aligned} T &= C_1 * e^{C_2 * x} + C_3, \\ x &= \frac{1}{C_2} * ln \frac{T - C3}{C_1} \end{aligned} \tag{3.3}$$

$$\begin{aligned} T_M &= C_M * e^{kx} + c, \\ T_B &= C_B * e^{kx} + c \end{aligned} \tag{3.4}$$

Using this knowledge, the definition of the flow peak over the measure inflow area is defined as:

$$\begin{aligned} C_m * e^{kx_0} + c &= C_b * e^{kx_1} + c \\ \frac{C_m}{C_b} * e^{kx_0} + c - c &= e^{kx_1} \\ \ln f + kx_0 &= kx_1 \\ x_1 &= x_0 + \frac{1}{k} \ln f (x_0 > 0) \end{aligned} \tag{3.5}$$

Since the equation for the flow peak over the measure inflow area (Equation 3.5) is the same as for the runoff volume over the measure inflow area (Equation 2.8), the same steps are taken to deduct the equation for the conversion of the flow peak factor over the measure inflow area to the flow peak factor over the project area:

$$x_{tot} = x_1 - \frac{M}{A} * \frac{1}{k} \ln f \tag{3.6}$$

For any given return time T, the flow peak value over the entire area is reduced by the measure with $\frac{M}{A} * \frac{1}{k} \ln f$. The peak flow reduction factor over the entire area can now be defined as:

$$f_{tot_{peak}} = \frac{T_1}{T_B} = \frac{C_B e^{kx_1}}{C_B * e^{k\left(x_1 - \frac{M}{A}\frac{1}{k}\ln f_{meas}\right)}} = e^{\frac{M}{A}\ln f_{meas}} \tag{3.7}$$

where:

$f_{tot_{peak}}$ = Flow peak reduction factor over the entire area with the applied measure [-]
f_{meas} = Flow peak reduction factor over the measure inflow area.
A = Entire area [m^2]
M = Measure inflow area [m^2]

As discussed in section 2.3, the conversion equation 3.7 does not include the unpaved area, where the runoff of the unpaved area can be significant. However, in equation 2.10 the parameter $Perc_{RA}$ is introduced, which is the runoff from the rest of the area, estimated as the percentage of the runoff from paved area. This parameter can not be used to convert the flow peak factor since this parameter uses the sum of the runoff from unpaved & paved area and not the peaks.

Therefore, $Perc_{PA}$ is introduced, defined as the peaks from the rest of the area. The calculation of $Perc_{PA}$ is as follows:

$$Perc_{PA} = \left(frac_{UP} * (1 - \frac{infilcap_{UP}}{1000})\right) * 100 \tag{3.8}$$

Where:

$Perc_{PA}$ = Peaks from the rest of the area [%]
$frac_{UP}$ = Predefined fraction of unpaved area
$infilcap_{UP}$ = Predefined infiltration capacity of unpaved area [mm/d]

This introduced parameter is a significant assumption and is used to give a first insight into the flow peak reduction factor usage over a whole project area.

Based on this newly introduced parameter, the measure to project conversion can be defined together with combining measures with the following equation, based on equation 2.11:

$$F_{tot} = \frac{A_p * \exp(\frac{(A_{mi} * \ln(F_{meas})}{A_p}) + \frac{Perc_{PA}}{100} * (A_{tot} - A_p)}{A_p + \frac{Perc_{PA}}{100} * (A_{tot} - A_p)} \tag{3.9}$$

Where:

F_{tot} = Factor for total area
F_{meas} = Flow peak factor for the measure inflow area
A_{tot} = Total area
A_p = Paved area
A_{mi} = Measure inflow area
$Perc_{PA}$ = Peaks from the rest of the area

Based on this equation, the equation of combining multiple measures is defined.

$$F_{tot} = \frac{A_p * \exp(\frac{\sum_{n}^{i=1}(A_{mi_i} * \ln(F_{meas_i})}{A_p}) + \frac{Perc_{PA}}{100} * (A_{tot} - A_p)}{A_p + \frac{Perc_{PA}}{100} * (A_{tot} - A_p)} \tag{3.10}$$

Where:

i = Counter, from 1 to N
N = Number of applied measures

3.3. Neighbourhood parameters

For the model to run, it needs parameters of the neighbourhood's properties as input. This section will discuss the different neighbourhoods defined to test the factors for different types of neighbourhoods.

Eight neighbourhoods are defined based on the study performed by Kleerekoper [24]. 20 Different neighbourhoods in the Netherlands are analysed on their classification, area distribution — Paved Roof, Closed Paved, Open Paved, Unpaved and Open Water—and other parameters. Based on these 20 neighbourhoods, eight theoretical neighbourhoods are defined for use in the Adaptation Support Tool, as discussed in table 3.1. Two of the neighbourhoods are selected in this study: Residential Housing and Post-war garden city low-rise.

Neighbourhood	pr_frac	cp_frac	op_frac	up_frac	ow_frac
Residential housing	26.0%	14.3%	42.8%	14.0%	3.0%
Post-war garden city low-rise	14.5%	10.4%	31.1%	40.0%	4.0%
Garden town	19.7%	11.8%	35.5%	27.7%	5.3%
Sub-urban expansion - Vinex	10.5%	13.6%	40.9%	29.5%	5.5%
Community neighbourhood	15.0%	10.4%	31.1%	39.5%	4.0%
Historical city block & pre-war city block	45.3%	10.2%	30.5%	11.0%	3.0%
Post-war garden city high-rise	15.7%	11.3%	33.8%	35.0%	4.3%
High-rise city centre	42.5%	24.5%	24.5%	8.0%	0.5%

Table 3.1: Land use percentages of the eight defined neighbourhoods

The percentages of land use of the neighbourhoods are given in the table. For full parameters consult Appendix A.

For the analysis of the flow peak factor and storage peak factor, only one neighbourhood will be used to run the model: Residential Housing. This area is chosen as it has relatively average values of fractions of land use. The total area that is applied in this study is 14.5 hectares, as the area of the model can not be taken too big for the assumptions taken in the Urban Water Balance Model (UWBM). To analyse the conversion of the measure factor to project factor, two neighbourhoods are used: The residential housing area and the Post-war garden city low-rise. These areas show high differences in fractions of areas and are therefore used for testing the conversion.

3.4. Applied urban climate adaptation measures

The Adaptation Support Tool (AST) defines 62 measures, from which this study chooses to analyse 29 of them. Section 2.1.3 discusses how measures are defined within the Urban Water Balance Model (UWBM). The chosen measures have a function to decrease pluvial flooding and can be analysed using the method of changing their effective depths. The 29 different measures analysed in this study are presented in the table below. A full description of all the measures is given in Appendix B.

All the defined measures in table 3.2 are analysed in this study. However, this report will discuss only five of these applied measures. The measures are subdivided into three types of measures based on their emptying mechanisms: Infiltration, Evaporation and Regulated discharge. This report will highlight five measures that are using either one of these mechanisms or two of them combined:

1. Underground storage tank (Regulated discharge)
2. Extensive green roof (Evaporation)
3. Infiltration boxes (Infiltration)
4. Urban wetland (Regulated discharge & Evaporation)
5. Bioswale (Infiltration & Evaporation)

Table 3.2: 29 Measures defined within the Adaptation Support Tool (AST) and modelled within the Urban Water Balance Model (UWBM).

Measure name	**Measure name**
Bioretention cell	Lowering part of terrace
Bioswale	Permeable pavement (storage)
Deep groundwater infiltration	Private green garden
Ditches	Rain barrel
Drainage/Infiltration/Transport (DIT) drains	Rain garden
Extensive green roofs	Rainwater detention pond (wet pond)
Gravel layers	Rainwater storage below buildings
Green roofs with drainage delay	Retention soil filter
Hollow roads	Systems for rainwater harvesting
Infiltration boxes	Underground storage
Infiltration fields and strips with surface storage	Urban wetland
Infiltration shaft	Use of groundwater (aquifer storage and recovery)
Infiltration trench	Water roof
Intensive green roofs	Water square
Lowering part of garden	

3.4.1. Underground storage tank (Regulated discharge)

The underground storage tank is designed to store excess runoff in their storage during wet periods. The basic idea of an underground storage tank is to create additional underground storage volume for rainwater buffering during wet periods without taking much space at the surface level. The underground storage tank is a 2-layer structure, where the bottom storage layer is the main body of the storage tank, where controlled runoff empties the system at a defined constant discharge rate. It is assumed that the entire storage is emptied within 48 hours. The underground storage tank is implemented in the Closed Paved area, with an inflow factor of 30.

3.4.2. Extensive green roof (Evaporation)

A green roof is a roof of a building covered with plants, generally with a substrate layer and a small drainage layer placed over the waterproofing membrane. If rainfall exceeds the storage capacity of the measure, the water is discharged to the sewer system. The storage of the soil layer is only emptied by gradual evapotranspiration. Hence intensive green roofs are primarily dependent on the antecedent conditions regarding their performance.

The UWBM defines both intensive and extensive green roofs, where extensive green roofs have a thinner substrate layer [40]. Extensive green roofs are thus less effective in rainwater buffering than the intensive green roofs [3]. The extensive green roof is defined as a 3-layer structure in the UWBM, added on the Paved Roof area with an inflow factor of 1.

3.4.3. Infiltration boxes (Infiltration)

An infiltration box is an underground facility that offers storage that is able to buffer rainwater for short spaces of time, after which the water can be infiltrated into the ground [40]. Mainly, synthetic boxes and bulbs are used because they are light and offer a high storage capacity. In the UWBM, the infiltration box is defined as a 2-layer structure and is defined in the Open Paved area. The bottom storage layer has a drainage delay controlled runoff. Overflow is discharged to the sewer system. the infilrtation boxes have an inflow factor of 30.

3.4.4. Urban Wetland (Regulated discharge & Evaporation

An urban wetland is an artificially created wetland. The urban wetland increases the area's storage capacity and has a function of purification of water [3]. Urban wetlands also increase biodiversity. The flow regime in urban wetlands is less dynamic than natural wetlands due to artificial control. The urban wetland is defined as a 2-layer structure and is defined in the Closed Paved. The bottom storage layer is defined with a controlled runoff to represent drainage at a delayed pace. The Urban Wetland has an inflow factor of 10.

3.4.5. Bioswale (Infiltration & Evaporation)

A bioswale is a ditch where vegetation and a porous bottom and an underdrain are applied [40]. The bioswale consists of two layers: A top layer with enhanced soil with plants and a lower layer consisting of gravel, scoria and clogging-proof baked clay pellets packed in geotextile. Below the second layer, a drainage pipe is situated, which is connected to the sewer system. The bioswale is implemented as a 3-layer structure and is implemented in the Open Paved area and has an inflow factor of 10.

3.5. Input data

The UWBM needs input data that is downloaded and prepared. For the model to run, hourly precipitation and evaporation data are used. Hourly precipitation data from De Bilt is retrieved from the KNMI website [26]. The data downloaded is from $01-01-1991\ 01:00$ until $02-01-2021\ 00:00$. Based on this data, two scenarios are defined, which is discussed in a later section.

The evaporation data can be calculated using data from the KNMI website. Hourly temperature and global radiation are downloaded to calculated the reference evaporation using Makkink. Some pre-processing is needed for the downloaded data, as it has to be in the correct format for the UWBM to read. This pre-processing step is done using python, where the code is presented in Appendix E.

3.5.1. Calculating evaporation based on Makkink

The KNMI website does not have hourly data available of the evaporation, only daily data. This is why the evaporation data is calculated based on other data that the KNMI provides and the method that KNMI uses to calculate the daily evaporation data. The calculation of the hourly evaporation is done using the Makkink formula ([12],[33], [34]):

$$ET_{Makkink} = 0.65\frac{s}{s+\gamma} * \frac{R_c}{\rho\lambda} \tag{3.11}$$

Where:

$$\lambda = (2501 - 2.375 * T) * 1000 \tag{3.12}$$

$$\gamma = 0.0646 + 0.00006 * T \tag{3.13}$$

$$s = \frac{7.5 * 237.3}{(237.3+T)^2} * \ln 10 * e_s \tag{3.14}$$

$$e_s = 0.6107 * 10^{\frac{7.5*T}{237.3+T}} \tag{3.15}$$

$ET_{Makkink}$	= Reference evaporation	$[mh^{-1}]$
R_c	= net radiation on Earth's surface	$[Jh^{-1}m^{-2}]$
s	= slope of the vapor curve	$[kPa°C^{-1}]$
γ	= psychometric constant	$[kPa°C^{-1}]$
ρ	= density of water (= 1000 kg/m^3)	$[kg/m^3]$
λ	= latent heat of evaporation	$[Jkg^{-1}]$
T	= Temperature	$[°C[$

Based on these equations, the evaporation is calculated for every time step by using the temperature and net radiation on Earth's surface, which is downloadable from the KNMI website. The open water evaporation is calculated using the calculated reference evaporation. For grass, this is assumed as $\frac{1}{0.9} * E_{Makkink}$ ([12], [33]).

The calculated accumulated yearly Makkink evaporation based on equation 3.11 is compared with the evaporation given by the KNMI (daily evaporation) for validation. It is observed that the difference of this yearly evaporation is, on average, below 10 mm. When checking differences based on daily evaporation values, the difference is a maximum of 0.1 mm every day.

3.5.2. Scenario 1: Dutch climate

Two scenarios are developed to analyse the flow peak- and storage peak factor to validate the method for different climates. Scenario 1 is a dutch climate, and scenario 2 is a tropical climate. Scenario 1 as the dutch climate is modelled using 30 years of hourly precipitation measured at De Bilt (1991-2001) [26] and the calculated evaporation using the equations mentioned above. This scenario thus simulates a mild dutch climate where the neighbourhood is under moderate stress compared to scenario 2.

3.5.3. Scenario 2: Tropical climate

Due to the lack of available hourly data in tropical areas, the second scenario is developed to simulate a tropical area based on the hourly precipitation of De Bilt. Scenario 2 takes the 30 years of hourly precipitation measured at De Bilt (1991-2021) multiplied by 3, where the evaporation from scenario 1 is multiplied by 2. This will simulate a tropical area where the yearly precipitation is roughly 2400 mm, and evaporation is 1000 mm. Scenario 2 has an increased stress on the urban climate and the aim is that the measures can not store all the rainfall coming into the system.

3.6. Methods for analysis

Based on the previously discussed methods, this study analyses the output data of the UWBM to answer the research questions. The following outputs are selected for analysis:

1. Single neighbourhood modelled, 29 implemented measures and 2 scenarios:
   (a) 29 Flow peak semi-logarithmic graphs
   (b) 29 Storage peak semi-logarithmic graphs
2. Multiple area analysis, 2 neighbourhoods (Residential housing & Post-war garden city low-rise, 29 implemented measures:
   (a) For every neighbourhood and measure the flow peak reduction factor and project factor for a varying effective depth.

This report will only highlight 5 of the 29 measures since these are based on the main emptying mechanisms of all the measures. The 29 measures are chosen since they all have different input parameters and this method also has to work for all the implemented measures in the UWBM. For all results consult Appendices G, H, I and J.

The constructed graphs are used to graphically analyse if a continuous linear shift in the graph can be observed to answer the main research question. *With continuous linear shift is meant that the distance between the curves in vertical direction is nearly the same for every peak.* Besides analysing the graph, the factors are calculated to evaluate the linear shift in the graph or to substantiate interesting observations mathematically.

Factor calculation

Calculating the factors is done by dividing the return time of the applied measure by the return time of the baseline scenarios for a particular range of the graph. This particular range is selected by ignoring the ten highest data points of the data set.
The range of the flow peaks used is generally $2-18 mm/h$ for scenario 1 and $5-60 mm/h$ for scenario 2 with steps of $1 mm/h$. The maximum range is based on taking the last ten observations of events. For all effective

depths, this is a return time of ± 3 years. The range of the storage peaks is $50-800mm$ for scenario 1 and $50-4000mm$ for scenario 2 with steps of $5mm$. An example of how this factor is calculated is shown in Figure 3.5.

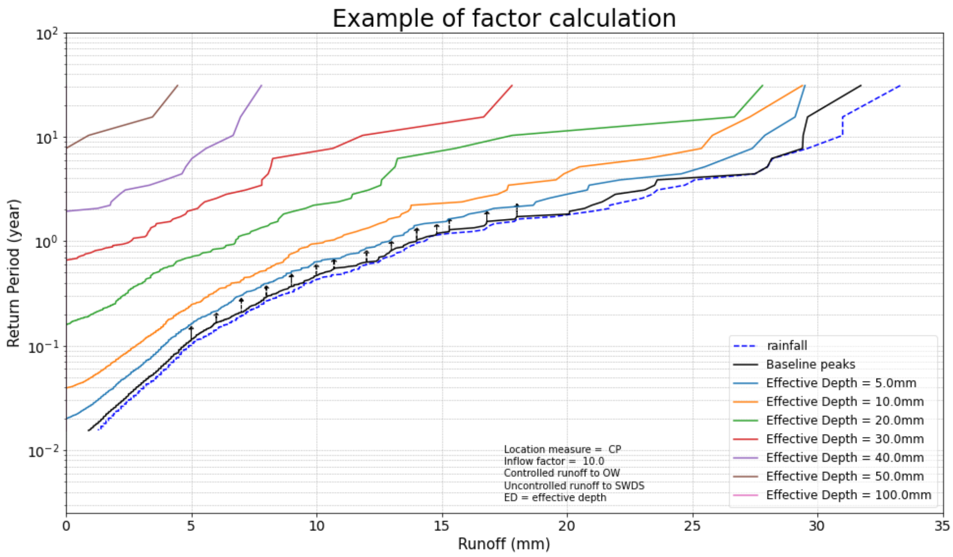


Figure 3.5: Factor calculation shown in the semi-logarithmic graph. The black dashed lines represent the factor calculation points, where the return time of the applied measure is divided by the return time of the baseline scenario.

Conversion from measure factor to project area factor

To answer the second research question, the graphs of every measure is analysed and fitted using code in Python to analyse if there is a conversion possible from measure inflow area to project area. To analyse if the conversion equation is correctly implemented and its implications, two areas are modelled and analyse both the runoff volume reduction factor and the flow peak reduction factor.

3.7. Flow chart of activities

The next flowchart is presented which shows the steps taken to answer the research questions:

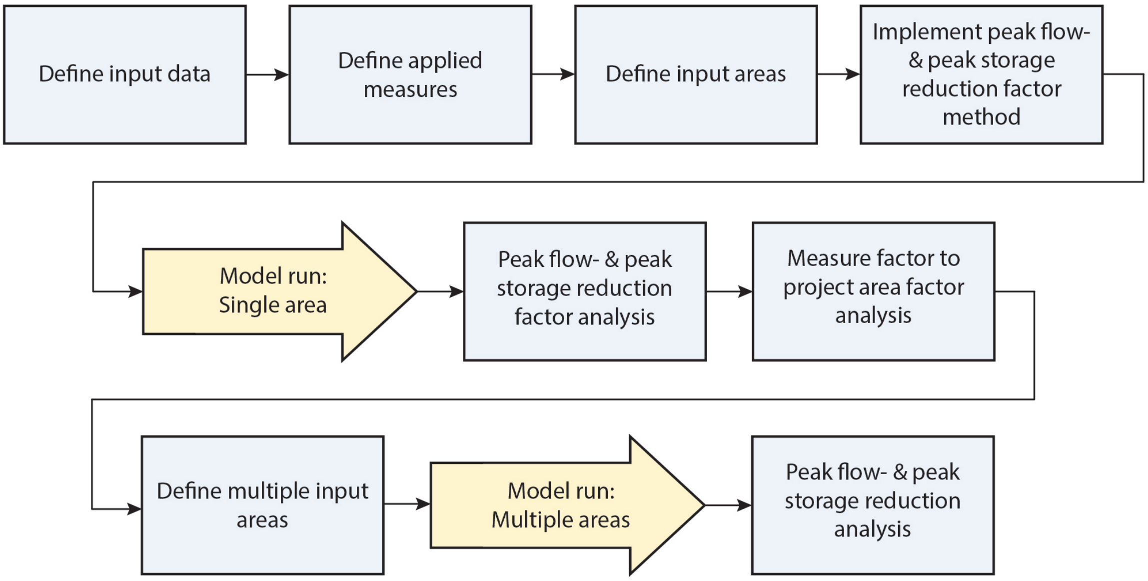


Figure 3.6: Methodology flowchart

The methodology proposed for this study consists of the following steps:

1. Define input data for the Urban Water Balance Model. The UWBM needs precipitation and evaporation data as input. Two scenarios are developed: a scenario with moderate yearly rainfall (800 mm/year) and one scenario that simulates a tropical area with heavy rainfall (2400 mm/year).
2. Define the applied measures for analysis of the proposed method. The model can evaluate 60 different measures, but this study will select 29 of them for analysis.
3. Run the model is to define the input area or so-called neighbourhood. By defining the neighbourhood, the user defines the fractions of Paved area, unpaved area and surface water, and other parameters.
4. Propose of the new method of analysing peak flows out of the measure and the peak storage in the system. The proposed method is based on the calculation of the runoff volume reduction factor.
5. Run the model for the 29 different measures on one single implemented area.
6. After running the model, analyse if it is possible to find a factor in the peak flows and the peak storages using the proposed method. This is done by analysing all the measures on their performance.
7. Analyse if the conversion of the measure factor to project area factor is possible for the peak flow reduction if the factor is found. If a conversion from measure factor to project area factor is found, the last phase of the research is started.
8. Define multiple input areas. Additional to the single input area defined in an earlier step, one extra input area is defined to analyse the found conversion of measure factor to project area factor for different areas.
9. The model is run for the 29 different measures on the two different implemented areas defined in the previous step.
10. The last step is to analyse the peak flow reduction and peak storage reduction of the different areas.

4 Results

Based on the methods discussed in chapter 3, the results are presented in this chapter. For two scenarios, a dutch climate and a tropical climate, flow peak- and storage peak graphs are presented of five measures. The five different measures are compared, after which the results of the conversion of measure factor to project area factor are presented. At last, a multiple area analysis is done where the conversion equation is tested on two neighbourhoods.

4.1. Flow peaks

As discussed in the method section, 29 measures are modelled based on a Dutch and a Tropical scenario. The dutch scenario uses input data of 30 years of precipitation downloaded from KNMI of De Bilt (1991-2021). The tropical scenario uses the precipitation of the dutch scenario multiplied by 3 and the evaporation multiplied by 2. Based on a defined neighbourhood — Residential housing — a semi-logarithmic graph can be constructed for the flow peaks.

Five of the 29 implemented measures are discussed — the underground storage tank, extensive green roof, infiltration boxes, urban wetland and the bioswale —, which are selected based on their emptying mechanisms. For the other results of this study about the flow peaks, consult appendices G and H.

4.1.1. Underground storage tank: Regulated discharge

The underground storage tank has the emptying mechanism of regulated discharge. Figure 4.1 presents the resulting semi-logarithmic graph based on the proposed method. The underground storage increases the return time of the flow peaks when increasing the effective depth. However, when implementing effective depths of $> 10mm$, the events become more incidental and more irregularities show in the graphs. The effective depth of 50 mm shows only three modelled uncontrolled runoff events with a high return time.

Figure 4.1 shows a constant increase of return time in the lower regions of the y-axis (return times) compared to the baseline scenario. The events are not incidental but show a precise line with low offset. When looking at the effective depth of 20 mm, the linear increase is visible up until roughly a peak of ± 7 mm/h, where after the events get incidental and the constant change in return time is less visible. At a return time of roughly $> 1year$, the events of all effective depths become more incidental and the graphs unstable. For an effective depth higher than 20 mm, the uncontrolled runoff events are highly incidental and deducting a linear increase of the return time is hard. There are no events determined for the effective depths of 50 and 100 mm, where the measure has no uncontrolled runoff.

When scenario 2 is implemented with higher precipitation, the underground storage tank shows more uncontrolled flow peaks as compared to scenario 1 as shown in Figure 4.2. Instead of the effective depth of 50

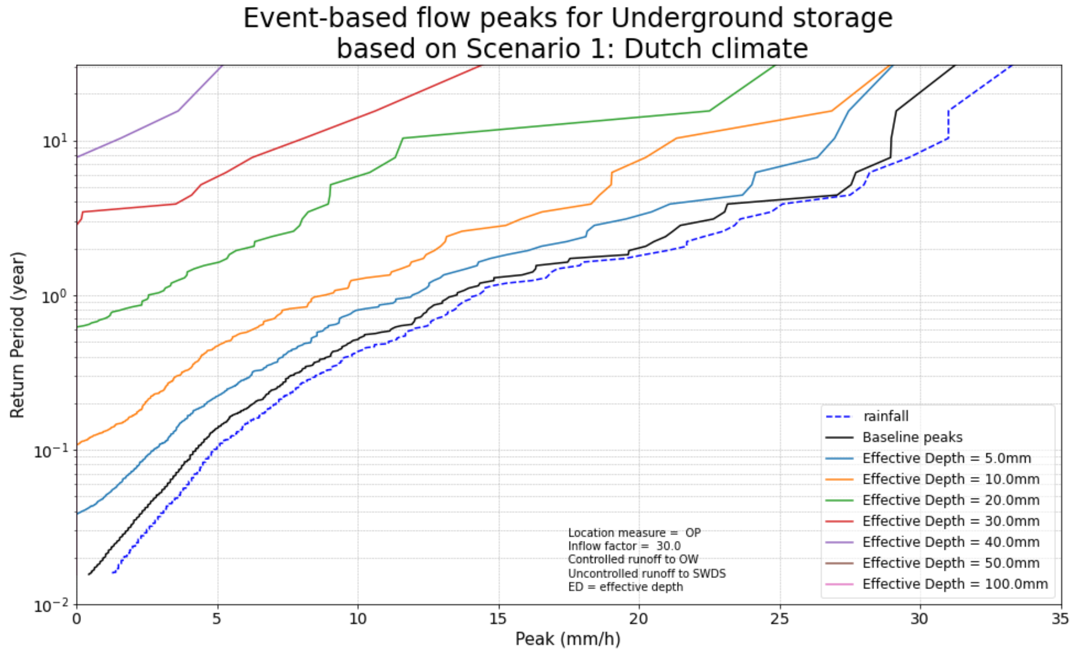


Figure 4.1: Event-based flow peaks for underground storage tank for the neighbourhood residential housing. Plot based on 30 years of input data downloaded from KNMI. The effective depths of 50 & 100 mm are not plotted since they have no events and uncontrolled runoff modelled.

	Eff. depth	**Event-based flow peaks for Scenario 1 [mm/h]**													
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**14**	**16**	**18**	**Avg**
Underground storage	5 mm	2.19	2.07	1.93	1.61	1.56	1.48	1.47	1.59	1.55	1.5	1.35	1.41	1.35	1.57
	10 mm	5.03	4.51	3.83	3.4	3.13	2.88	2.58	2.54	2.45	2.46	2.36	inf	inf	3.07
	20 mm	25.4	19.91	16.53	11.79	10.96	9.85	9.29	inf	inf	inf	inf	inf	inf	14.8
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

Table 4.1: Flow peak factor calculation for the underground storage measure based on scenario 1, where for every effective depth the factor is calculated over different event-based flow peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined". This is a selection of the results, full results are presented in Appendix H

and 100 mm showing no uncontrolled runoff, now all the effective depths show uncontrolled runoff from the measure. The events are less incidental; only the effective depth of 100 mm returns few events (±10) with a high offset. Again, for the return times of $> 1 year$, the overall plot is roughly unstable with several offsets in the graphs.

Tables 4.1 and 4.2 present the calculated flow peak reduction factors for the varying effective depths. Table 4.1 shows that only for effective depths of 5, 10 and 20 mm the flow peak factor can be calculated. The table shows that the flow peak factor is already less visible for the effective depth of 20 mm, where the factor is 25.4 and 9.29 at the flow peaks of 2 mm/h and 8 mm/h, respectively. This indicates a less visible constant increase of return time.
Therefore, it is interesting to look at the results for scenario 2 at table 4.2. This table shows that for scenario 2 the constant increase of return time is more visible for the effective depths of 20 mm than scenario 1. Moreover, the effective depths of 30 mm and 40 mm show low changes in return time over the increase of event-based flow peaks. The effective depth of 50 mm shows more uncertainty in a constant increase in return time due to fluctuations in the calculated factors.

For both scenarios, the underground storage shows a constant increase in return time of the flow peak due to the implementation of a measure. For scenario 2 this constant increase is more visible than in scenario 1.

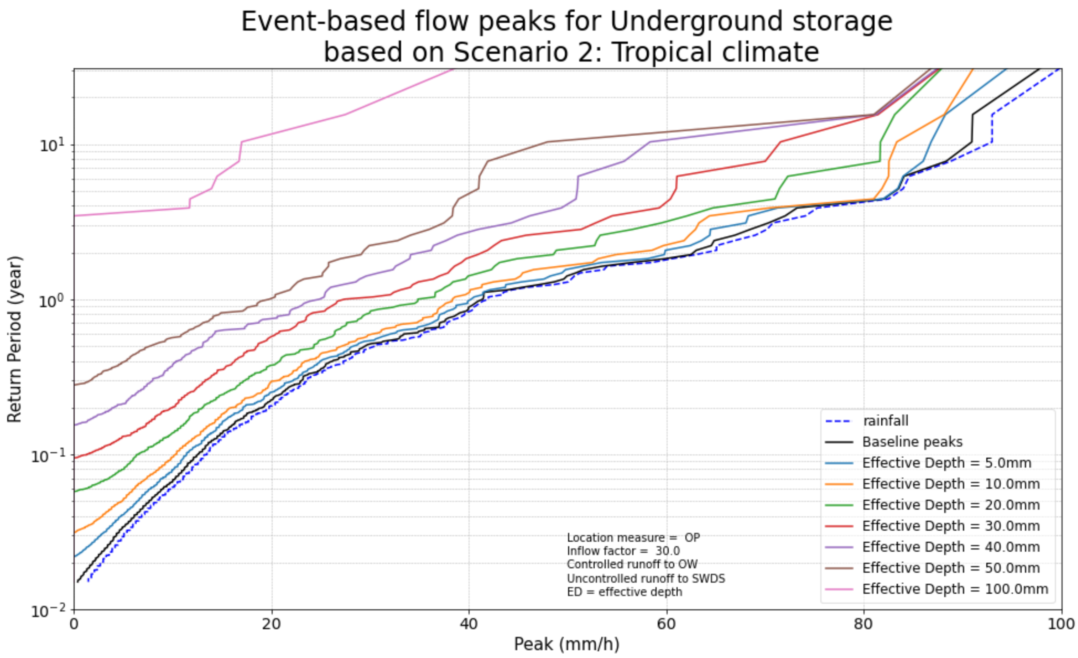


Figure 4.2: Event-based flow peaks for an underground storage tank for the neighbourhood residential housing. Plot based on 30 years De Bilt precipitation data, multiplied by 3.

	Eff. depth	**Event-based flow peaks for Scenario 2 [mm/h]**											
		5	**10**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**Avg**
Underground storage	5 mm	1.2	1.19	1.12	1.13	1.05	1.07	1.1	1.09	1.1	1.05	1.13	1.11
	10 mm	1.49	1.44	1.31	1.26	1.15	1.16	1.24	1.17	1.17	1.16	1.22	1.24
	20 mm	2.35	2.06	1.68	1.55	1.59	1.61	1.59	1.55	1.49	inf	inf	1.68
	30 mm	3.84	3.01	2.56	2.36	2.01	2.08	2.08	2.14	inf	inf	inf	2.43
	40 mm	6.22	5.6	3.35	2.85	2.78	3.21	inf	inf	inf	inf	inf	3.87
	50 mm	11.54	8.51	4.52	3.98	4.32	inf	inf	inf	inf	inf	inf	5.94
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

Table 4.2: Flow peak factor calculation for the underground storage measure based on scenario 2, where for every effective depth the factor is calculated over different event-based flow peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined". This is a selection of the results, full results are presented in Appendix H.

4.1.2. Extensive green roof: Evaporation

The extensive green roof is a 3-layer structure where evaporation is the underlying controlled emptying mechanism. Therefore, emptying depends on evaporation only, which means it takes more time to empty the storage than emptying the underground storage tank.

Figure 4.3 shows the result of the method of plotting the flow peak reduction. All the effective depths have uncontrolled runoff for the defined events. When increasing the effective depth, the return time of the flow peaks also increases. The higher effective depths of $> 20mm$ show a slight divergent slope compared to the baseline scenario. The graphs become unstable at higher peaks and return times, and the events become more incidental than at lower effective depths. The divergent slope of the graphs can be explained by the fact that if a higher effective depth is applied, the measure can store more rainfall which results in lower uncontrolled runoff peaks. The divergent shape is substantiated by Table 4.3. For example, the effective depth of 40 mm shows an increase in the flow peak factor from 2.79 to 9.55 for 2 mm/h and 8 mm/h, respectively. This indicates a diverging shape of the graph. This increase in the factor is also observed for effective depths of $> 30mm$.

However, it seems that for the low peaks (0-5 mm/h), there is a linear increase in return time for every effective depth. This is explained by the fact that the storage of the higher effective depths will remain full for more extended periods. This is due to the evaporation and uncontrolled runoff being the only fluxes that empty the green roofs. Logically, when the storage capacity is higher, the storage will remain fuller compared to lower storage capacities concerning lower storage capacities since evaporation is the same for every effective depth. When the storage remains fuller, the storage of the green roof will mostly already be (partly) filled when a precipitation event occurs, and more uncontrolled runoff occurs than, e.g., an underground storage tank.

When modelling based on scenario 2 with higher precipitation events, the return times for every scenario are lower as compared to scenario 1, as shown in figure 4.4. The different graphs of the effective depths follow the same shape with a comparable slope. This visual observation is substantiated by Table 4.4, where the flow peak factors are calculated for every effective depth. Putting the system under higher pressure shows the linear increase of return time more clearly, where the change of the flow peak factor for the effective depth of 100 mm is only from 2.26 to 2.95 for the flow peaks of 5 m/h and 40 mm/h respectively. This shows that the linear increase, i.e. the flow peak factor is more visible for the tropical climate.

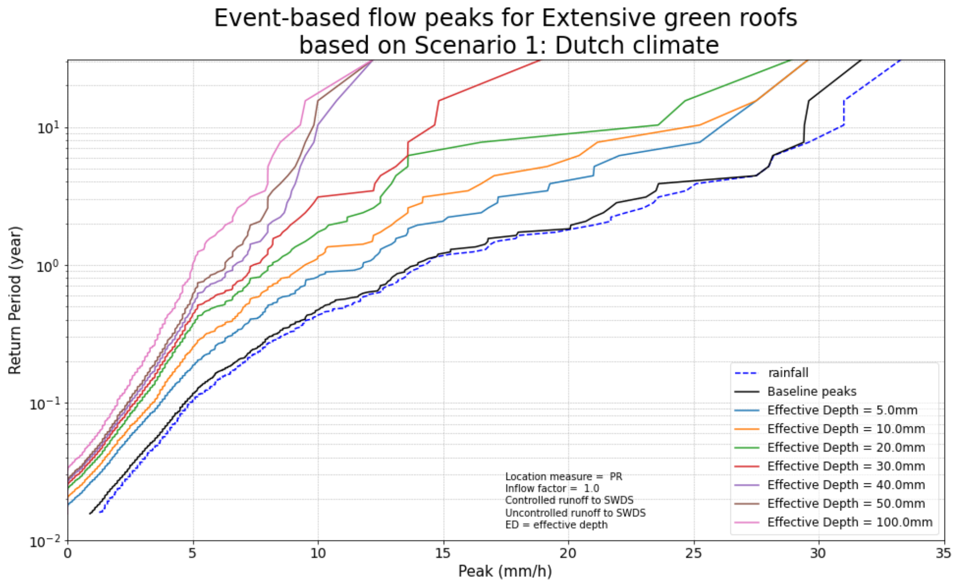


Figure 4.3: Event-based peak flow for an extensive green roof for the neighbourhood residential housing. Plot based on 30 years of input data downloaded from KNMI.

	Eff. depth	Event-based flow peaks for Scenario 1 [mm/h]													
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**14**	**16**	**18**	**Avg**
Extensive green roof	5 mm	1.66	1.64	1.65	1.6	1.59	1.66	1.69	1.66	1.74	1.67	1.88	1.74	inf	1.69
	10 mm	1.96	1.91	2.07	2.17	2.11	2.28	2.28	2.33	2.44	2.28	2.66	inf	inf	2.26
	20 mm	2.32	2.48	2.82	3.18	3.00	3.08	3.18	3.54	3.67	3.92	inf	inf	inf	3.17
	30 mm	2.60	2.76	3.19	3.76	3.65	3.70	4.20	5.43	6.60	inf	inf	inf	inf	3.99
	40 mm	2.79	3.04	3.61	4.45	4.54	5.10	6.18	9.68	inf	inf	inf	inf	inf	4.92
	50 mm	2.97	3.28	3.97	5.24	5.31	6.73	9.55	inf	inf	inf	inf	inf	inf	5.29
	100 mm	3.87	4.52	6.07	8.61	10.3	13.1	inf	inf	inf	inf	inf	inf	inf	7.75

Table 4.3: Flow peak factor calculation for the extensive green roof based on scenario 1, where for every effective depth the factor is calculated over different event-based flow peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined". This is a selection of the results, full results are presented in Appendix H.

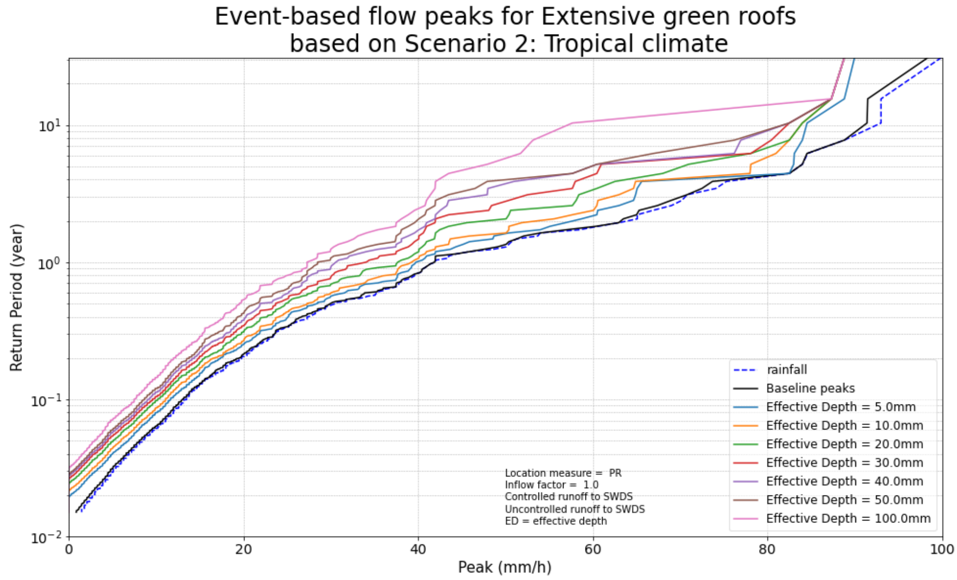


Figure 4.4: Event-based peak flow for an extensive green roof for the neighbourhood residential housing. Plot based on 30 years De Bilt precipitation data, multiplied by 3.

	Eff. depth	**Event-based flow peaks for Scenario 2 [mm/h]**												
		5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**Avg**
Extensive green roof	5 mm	1.28	1.25	1.18	1.18	1.16	1.13	1.16	1.22	1.15	1.2	1.09	1.2	1.17
	10 mm	1.40	1.36	1.30	1.26	1.28	1.19	1.26	1.28	1.3	1.21	1.23	1.31	1.27
	20 mm	1.57	1.53	1.42	1.46	1.49	1.38	1.49	1.43	1.63	1.54	1.51	inf	1.49
	30 mm	1.72	1.64	1.57	1.62	1.59	1.55	1.74	1.76	1.95	inf	inf	inf	1.69
	40 mm	1.83	1.77	1.69	1.77	1.74	1.82	2.02	2.05	inf	inf	inf	inf	1.85
	50 mm	1.91	1.88	1.84	1.99	1.88	2.14	2.20	2.46	inf	inf	inf	inf	2.04
	100 mm	2.26	2.26	2.19	2.5	2.36	2.48	2.80	2.95	inf	inf	inf	inf	2.46

Table 4.4: Flow peak factor calculation for the extensive green roof based on scenario 2, where for every effective depth the factor is calculated over different event-based flow peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined". This is a selection of the results, full results are presented in Appendix H.

4.1.3. Infiltration boxes: Infiltration

The measure infiltration boxes is based on the emptying mechanism of infiltration. Figure 4.5 shows the result of analysing the flow peaks of infiltration boxes. For this measure, a constant increase in return time for varying flow peaks occurs when increasing the effective depth of the measure. For scenario 1, the flow peak events show more irregularities for a return time of > 1 year. The events are incidental for the infiltration box with an effective depth above 20 mm, and the graph shows more offsets than at lower effective depths. Figure 4.5 strongly resembles the semi-logarithmic graph of Figure 4.1. The infiltration boxes have little observed events for effective depths of > 40 mm.

When looking at lower peaks with the effective depths of ≤ $20mm$, the graphs show a similar pattern compared to the baseline scenario. Especially from ± 5 mm/h to 10 mm/h for the baseline scenario and effective depths of 5 & 10 mm. Table 4.5 shows this by looking at the change of the peak flow factors: For the effective depths of 5 & 10 mm, the factor does not change much (± 1.5 and 4 respectively) for an increasing flow peak. However, for the effective depths of > 20 mm, the linear increase is less visible, and therefore the factor is also less visible.

When modelling the measures based on scenario 2, every effective depth's return times are lower than the return times of scenario 1. The graphs also follow the same shape and slope of the baseline scenario. This is substantiated by Table 4.6, where the calculated flow peak factor does not change more than 1.5 for the implemented infiltration boxes with an effective depth of < $50mm$. The effective depth of 100 mm shows a slight change in the factor over the increase of the flow peaks, which can also be observed in the graph of figure 4.6. The graph of 100 mm is one where the events are more incidental when compared to the lower applied effective depths. For this measure, the constant increase is also clearly visible.

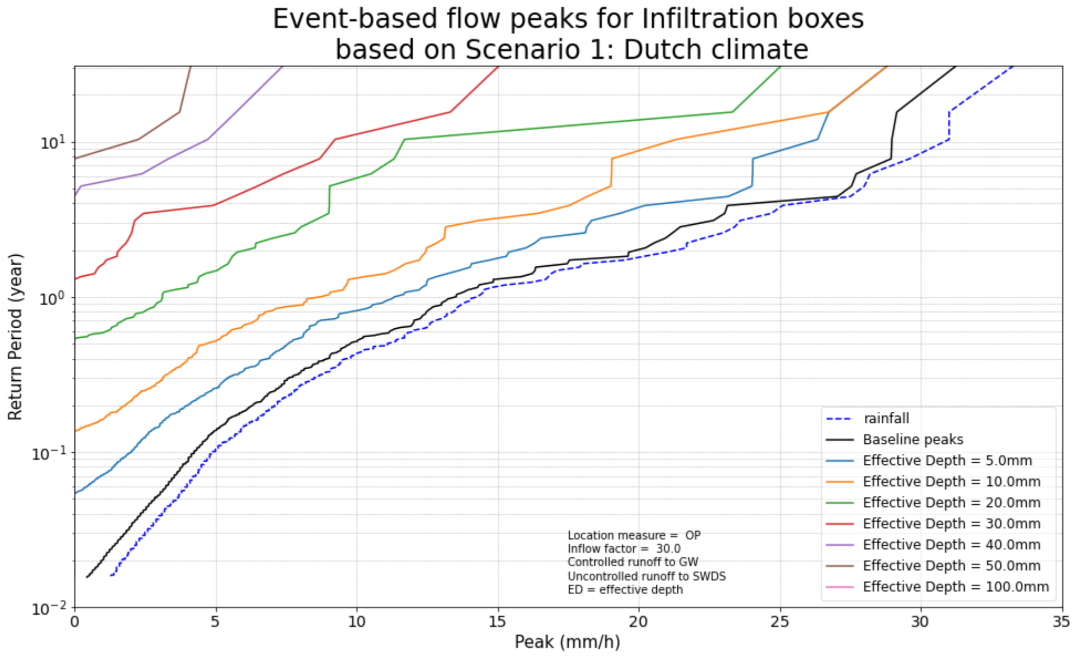


Figure 4.5: Event-based peak flow for an infiltration boxes for the neighbourhood residential housing. Plot based on 30 years of input data downloaded from KNMI.

	Eff. depth	**Event-based flow peaks for Scenario 1 [mm/h]**													
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**14**	**16**	**18**	**Avg**
Infiltration boxes	5 mm	3	2.77	2.3	1.87	1.82	1.73	1.68	1.78	1.58	1.63	1.39	1.5	1.47	1.80
	10 mm	6.45	5.34	4.51	3.76	3.57	3.34	2.73	2.57	2.56	2.51	inf	inf	inf	3.53
	20 mm	22.2	17.6	13.3	10.7	10.9	9.75	8.63	inf	inf	inf	inf	inf	inf	13.28
	30 mm	76.15	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	76.15
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

Table 4.5: Flow peak factor calculation for the infiltration boxes based on scenario 1, where for every effective depth the factor is calculated over different event-based flow peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined". This is a selection of the results, full results are presented in Appendix H.

	Eff. depth	**Event-based flow peaks for Scenario 2 [mm/h]**												
		5.0	**10.0**	**15.0**	**20.0**	**25.0**	**30.0**	**35.0**	**40.0**	**45.0**	**50.0**	**55.0**	**60.0**	**Avg**
Infiltration boxes	5 mm	1.3	1.3	1.22	1.18	1.17	1.1	1.1	1.12	1.09	1.12	1.05	1.13	1.15
	10 mm	1.64	1.51	1.37	1.33	1.27	1.15	1.23	1.29	1.19	1.17	1.16	1.32	1.29
	20 mm	2.17	1.97	1.68	1.65	1.49	1.47	1.55	1.44	1.55	1.49	inf	inf	1.62
	30 mm	2.92	2.34	2.08	2.04	1.79	1.77	1.92	1.92	2.07	inf	inf	inf	2.04
	40 mm	3.57	2.98	2.67	2.52	2.17	2.22	2.52	2.65	inf	inf	inf	inf	2.59
	50 mm	4.4	3.57	3.14	2.81	2.64	2.96	2.95	3.06	inf	inf	inf	inf	3.10
	100 mm	9.24	6.9	5.47	4.59	4.8	4.81	inf	inf	inf	inf	inf	inf	5.68

Table 4.6: Flow peak factor calculation for the infiltration boxes based on scenario 2, where for every effective depth the factor is calculated over different event-based flow peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined". This is a selection of the results, full results are presented in Appendix H.

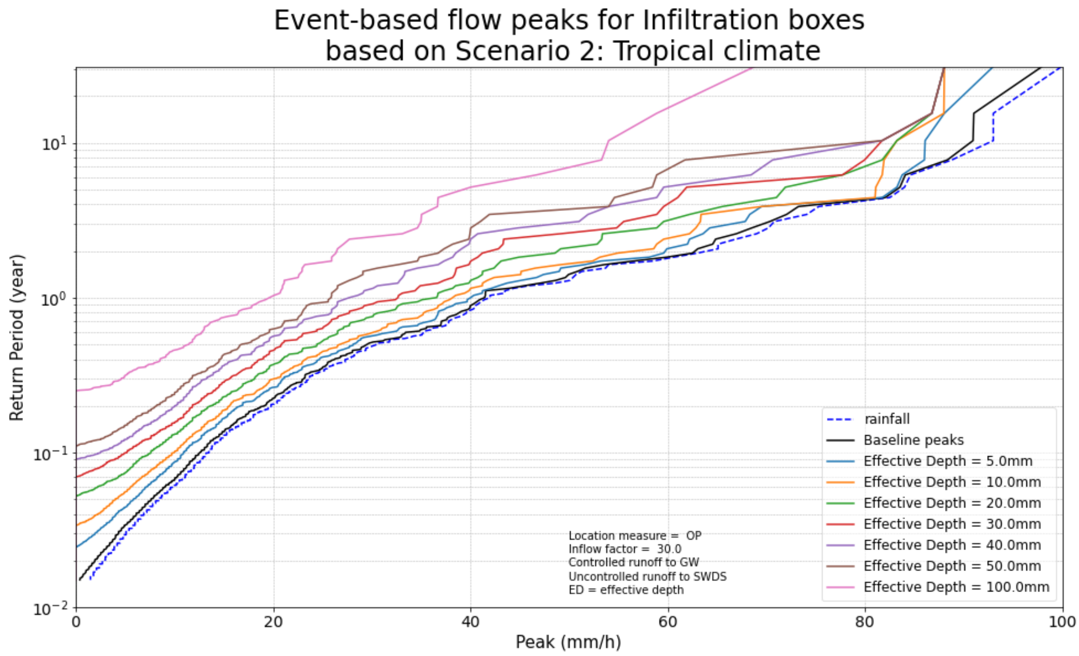


Figure 4.6: Event-based peak flow for an infiltration box for the neighbourhood residential housing. Plot based on 30 years De Bilt precipitation data, multiplied by 3.

4.1.4. Urban wetland: Regulated discharge & evaporation

The urban wetland has an emptying mechanism based on regulated discharge & evaporation. Figure 4.7 shows the results for the analysis of the peak flows of the urban wetland. Overall, the measure's implementation with a varying effective depth increases of return time of the uncontrolled runoff. The shape of the different graphs with varying effective depths are similar. At the higher effective depths of $> 20mm$, events become more incidental, and the offsets of the graph increase. This output is comparable to the output of the infiltration boxes and underground storage. Table 4.7 shows the factor calculation for scenario 1. The table shows that for the effective depths of 5 & 10 mm, the factor calculation shows stable results where the factors don't show high differences for an increase in flow peaks. This indicates a constant increase in return time due to the implementation of the urban wetland. However, the constant increase of return time becomes less visible for the effective depths above 10 mm, where the events are more incidental.

Figure 4.8 presents the output of the implementation of scenario 2 for the urban wetland. The results show a linear increase in return time by implementing the urban wetland. Furthermore, compared to other effective depths, the effective depth of 100 mm returns high return times, and little events are defined. Table 4.8 shows the factor calculations, which shows the apparent constant increase of return time over the range of flow peaks. Calculating the flow peak factor shows that the factor is less visible for the effective depth of 100 mm, where the factor changes from 40.6 to 19.0 for 5 mm/h and 15 mm/h, respectively. However, the factor results are stable for the other effective depths, and the constant increase of return time can be substantiated.

	Eff. depth	**Event-based flow peaks for Scenario 1 [mm/h]**													
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**12**	**14**	**16**	**18**	**Avg**
Urban wetland	5 mm	1.59	1.5	1.52	1.41	1.29	1.46	1.34	1.4	1.36	1.37	1.38	1.36	1.25	1.38
	10 mm	2.75	2.53	2.44	2.14	2.04	2.03	1.84	2.1	2.03	2.11	2.16	1.85	inf	2.13
	20 mm	10.0	8.96	7.96	6.09	5.2	5.54	4.9	5.19	4.76	inf	inf	inf	inf	6.30
	30 mm	34.1	25.1	21.6	17.2	15.8	inf	inf	inf	inf	inf	inf	inf	inf	22.8
	40 mm	98.4	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	98.4
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

Table 4.7: Flow peak factor calculation for the urban wetland based on scenario 1, where for every effective depth the factor is calculated over different event-based flow peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined". This is a selection of the results, full results are presented in Appendix H.

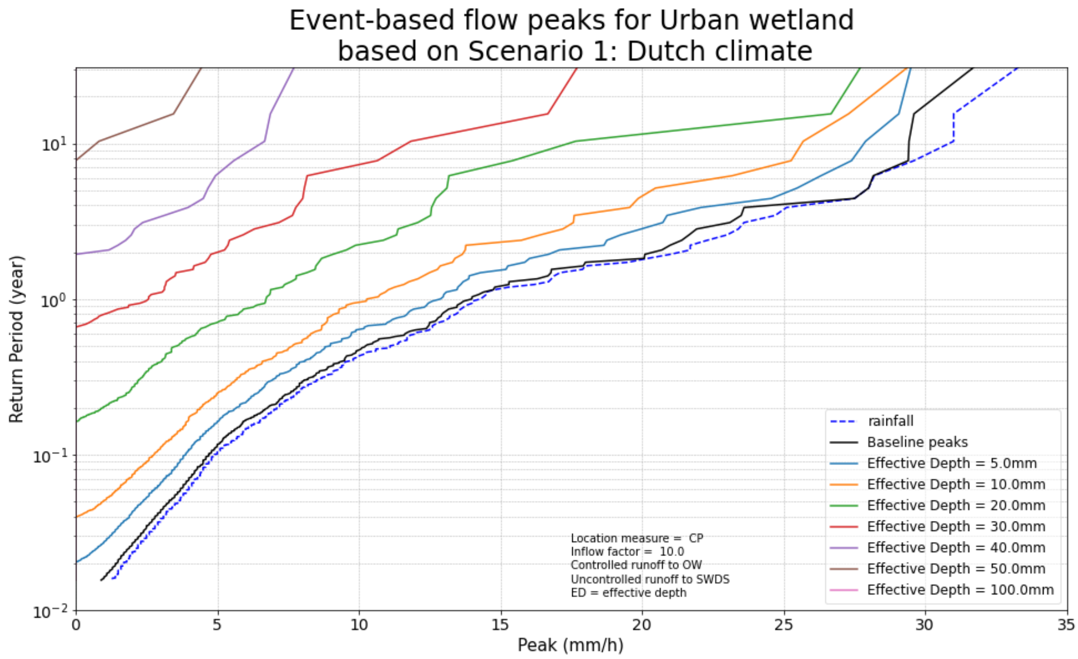


Figure 4.7: Event-based peak flow for an urban wetland for the neighbourhood residential housing. Plot based on 30 years of input data downloaded from KNMI.

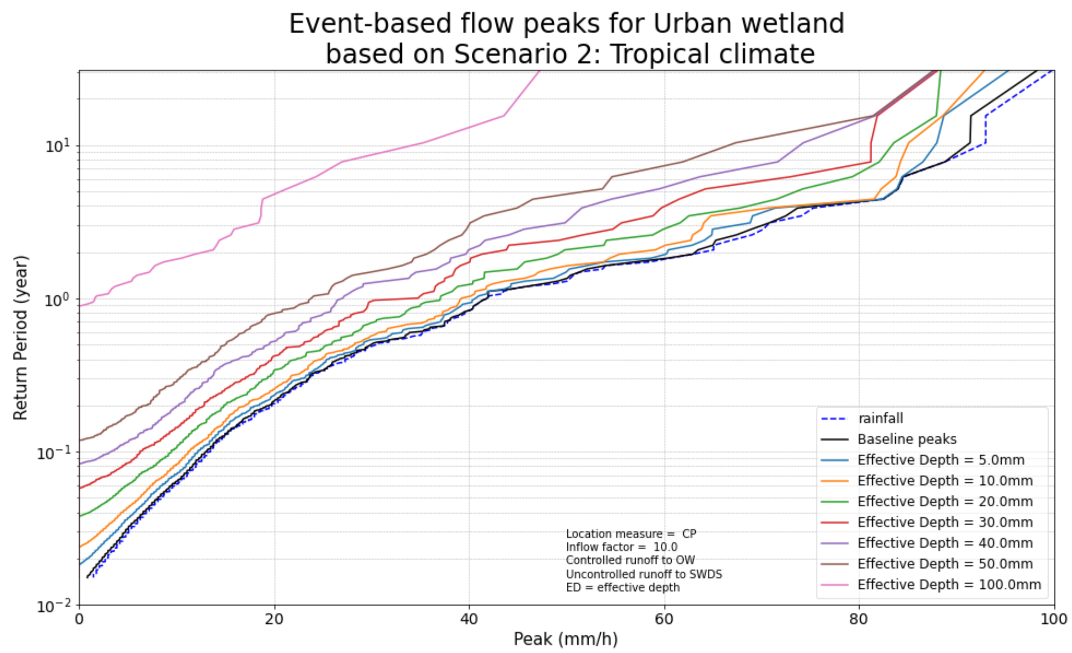


Figure 4.8: Event-based peak flow for an urban wetland for the neighbourhood residential housing. Plot based on 30 years De Bilt precipitation data, multiplied by 3.

	Eff. depth	Event-based flow peaks for Scenario 2 [mm/h]												
		5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**Avg**
Urban wetland	5 mm	1.18	1.11	1.11	1.09	1.09	1.07	1.06	1.12	1.08	1.11	1.05	1.06	1.09
	10 mm	1.37	1.29	1.2	1.2	1.21	1.13	1.13	1.23	1.14	1.21	1.13	1.21	1.19
	20 mm	1.95	1.65	1.54	1.59	1.39	1.38	1.47	1.48	1.34	1.54	1.46	inf	1.49
	30 mm	2.68	2.25	1.95	1.97	1.75	1.91	1.7	2.06	1.93	1.82	inf	inf	1.94
	40 mm	3.68	3.09	2.84	2.46	2.32	2.52	2.46	2.49	inf	inf	inf	inf	2.61
	50 mm	5.49	4.47	3.80	3.74	3.12	2.96	3.11	inf	inf	inf	inf	inf	3.66
	100 mm	40.6	28.2	19.0	inf	inf	inf	inf	inf	inf	inf	inf	inf	27.7

Table 4.8: Flow peak factor calculation for the urban wetland based on scenario 2, where for every effective depth the factor is calculated over different event-based flow peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined". This is a selection of the results, full results are presented in Appendix H.

4.1.5. Bioswale: Infiltration & evaporation

The bioswale has an emptying mechanism based on infiltration and evaporation. Figure 4.9 shows the semi-logarithmic graph for the bioswale for scenario 1. This graph is significantly different from the other graphs shown earlier in this section. When implementing the bioswale with an effective depth of 5 mm, a significant constant vertical shift of return time compared to the baseline is observed. A minor shift upwards is visible to the effective depth of 10 mm from the graph of 5 mm. Every effective depth of $> 10mm$ shows the same results for the return time of the uncontrolled runoff. The graphs have the same shape, where it looks like there is some maximum to the uncontrolled runoff. When carefully analysing the water balance of the bioswale, this result is explained. The bioswale has a certain defined infiltration capacity on the interception layer (storage layer 1). Every effective depth has a resulting surface flow due to the interception storage capacity and the exceeded infiltration capacity. When increasing the effective depth of the measure — i.e. increasing the bottom storage layer —, at one point the bottom storage layer of the measure is big enough to store the infiltration coming in. However, surface flow from the interception layer is not changed by the effective depth, which means that the surface flow from the measure is always the same. This results in the same results for the effective depths $> 10mm$. This is also shown mathematically in Table 4.9, where the same flow peak factors are shown for the measures $> 10mm$. The effective depth of 20 mm shows some minor differences in the factor for the flow peaks of 2-4 mm/h compared to the higher effective depths. The effective depths $< 10mm$ have bottom storage (storage layer 3) overflow occurring besides the interception overflow, which results in lower return times of the uncontrolled runoff.

When scenario 2 is applied as shown in 4.10, the same pattern can be observed where there seems to be an upper limit to the return period of the bioswale. However, the effective depth of $20mm$ can now also be distinguished and overflows more often than the higher effective depths. The return times for every effective depth have a constant increase of return time of the flow peaks, but there — again — seems to be a maximum. This indicates that using higher effective depth in the bioswale does not necessarily mean lower uncontrolled runoff, according to the UWBM. When looking at Table 4.10, the effective depths show different results for the flow peak factor for flow peaks from 5-20 mm/h, where after the effective depths of > 20mm again have the same results, since there is only interception overflow occurring.

	Eff. depth	Event-based flow peaks for Scenario 1 [mm/h]													
		2.0	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**	**9.0**	**10.0**	**12.0**	**14.0**	**16.0**	**18**	**Avg**
Bioswale	5 mm	5.8	4.87	3.83	3.27	3.3	3.15	2.89	2.8	2.5	2.81	2.4	inf	inf	3.31
	10 mm	12.6	11.31	7.92	6.01	5.56	5.3	4.53	4	3.96	inf	inf	inf	inf	6.54
	20 mm	20.6	16.9	12.4	9.52	7.9	6.62	5.45	4.51	3.96	inf	inf	inf	inf	9.24
	30 mm	21.1	17.4	12.8	9.52	7.9	6.62	5.45	4.51	3.96	inf	inf	inf	inf	9.38
	40 mm	21.6	17.9	12.8	9.52	7.9	6.62	5.45	4.51	3.96	inf	inf	inf	inf	9.48
	50 mm	21.6	17.9	12.8	9.52	7.9	6.62	5.45	4.51	3.96	inf	inf	inf	inf	9.48
	100 mm	21.6	17.9	12.8	9.52	7.9	6.62	5.45	4.51	3.96	inf	inf	inf	inf	9.48

Table 4.9: Flow peak factor calculation for the bioswale based on scenario 1, where for every effective depth the factor is calculated over different event-based flow peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined". This is a selection of the results, full results are presented in Appendix H.

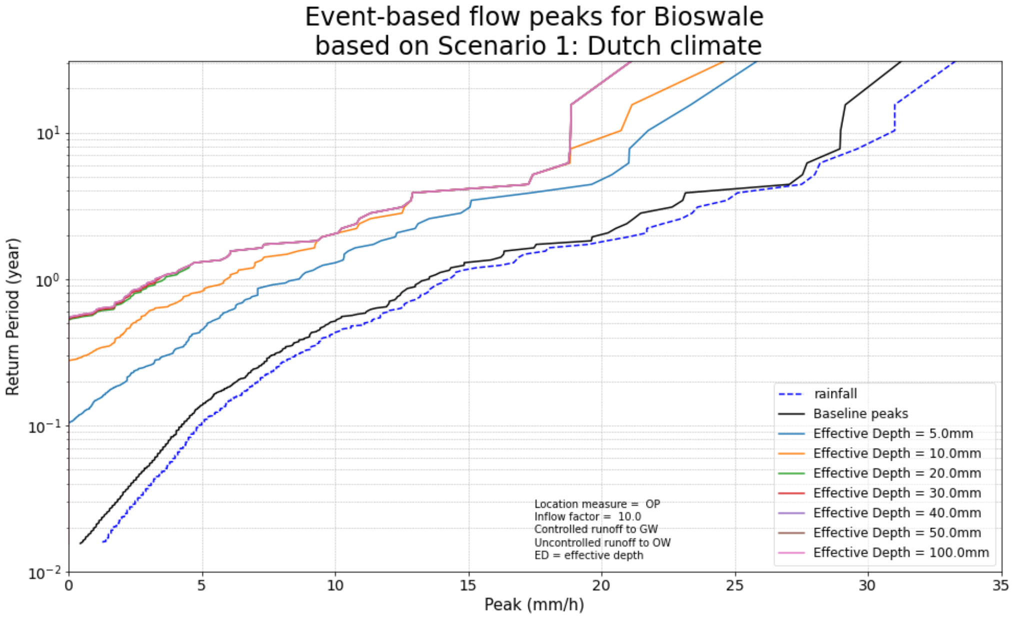


Figure 4.9: Event-based peak flow for a bioswale for the neighbourhood residential housing. Plot based on 30 years of input data downloaded from KNMI.

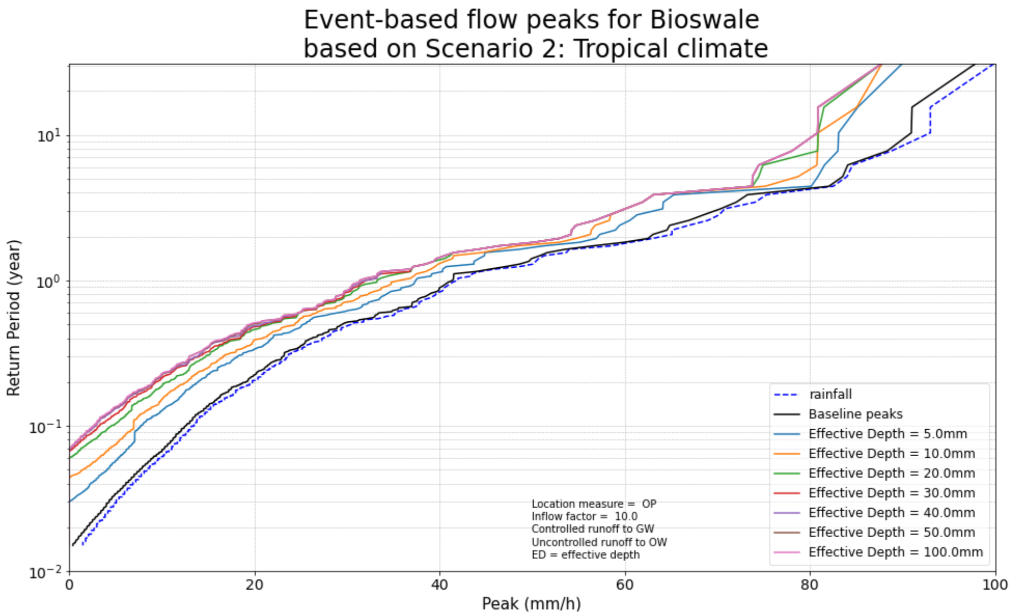


Figure 4.10: Event-based peak flow for a bioswale for the neighbourhood residential housing. Plot based on 30 years De Bilt precipitation data, multiplied by 3.

	Eff. depth	**Event-based flow peaks for Scenario 2 [mm/h]**												
		5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**Avg**
Bioswale	5 mm	1.67	1.9	1.65	1.5	1.35	1.2	1.36	1.28	1.32	1.19	1.09	1.36	1.39
	10 mm	2.18	2.28	1.83	1.74	1.55	1.38	1.57	1.47	1.33	1.24	1.17	inf	1.59
	20 mm	3.03	2.81	2.24	2.05	1.71	1.53	1.75	1.56	1.41	1.29	1.44	inf	1.84
	30 mm	3.52	3.19	2.37	2.14	1.71	1.61	1.81	1.62	1.41	1.29	1.44	inf	1.93
	40 mm	3.85	3.35	2.51	2.17	1.71	1.65	1.88	1.62	1.41	1.29	1.44	inf	1.98
	50 mm	3.93	3.4	2.54	2.24	1.71	1.66	1.88	1.62	1.41	1.29	1.44	inf	2.00
	100 mm	3.96	3.43	2.57	2.28	1.71	1.66	1.88	1.62	1.41	1.29	1.44	inf	2.01

Table 4.10: Flow peak factor calculation for the bioswale based on scenario 2, where for every effective depth the factor is calculated over different event-based flow peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined". This is a selection of the results, full results are presented in Appendix H

4.2. Storage peaks

Based on the proposed method in Section 3.1, the storage peaks of five measures are analysed. This section presents the results for the underground storage tank, extensive green roof, infiltration boxes, urban wetland and the bioswale. For the other results of the storage peaks in this study, consult appendices I and J.

4.2.1. Underground storage tank: Regulated discharge

Figure 4.11 presents the computed semi-logarithmic graph of the underground storage based on scenario 1: Dutch climate. For the varying effective depths, the graphs start at roughly the same origin. When looking at the storage peaks of 0-200 mm, the differences between the effective depths start to show. However, the graphs show no constant increase of return time and have different shapes. An interesting observation is that an increase in the effective depth of the measure does not necessarily increase the return time of the storage peaks. When carefully analysing the water balance of the underground storage, it is observed that the controlled runoff from the measure to open water has a strong influence on the open water storage. The controlled runoff is defined by the storage capacity divided by 48 hours (since the time step for this calculation is hours). Thus, when the measure storage is increased by increasing the effective depth, the controlled runoff is also increased. This implies that the controlled runoff will be very high for a high effective depth at a certain point.
For example, consider an underground storage tank with an effective depth of 100 mm and an effective depth of 50 mm with an inflow factor of 30. The runoff capacity will be $30 * 100/48 = 62.5\ mm/h$ & $30 * 50/48 = 31.25 mm/h$ respectively. When the storage capacity does not exceed 1500 mm for both tanks, the controlled runoff from the storage tank of 100 mm will be twice as high as the controlled runoff from the storage tank of 50 mm. This results in a faster increase of the Open Water for the underground storage tank of 100 mm.

Table 4.11 presents the results of the possible storage peak factors of the underground storage tank for a varying effective depth. The table shows a decrease in storage peak factor, i.e. return time, due to the increase of the effective depth for effective depths of > 10 mm in the lower regions of the storage peaks. The table also shows that at the higher regions of the storage peaks, an increase of effective depths results in a higher storage peak factor again. This can be observed more clearly for scenario 2.

Figure 4.12 presents the results for the implementation of scenario 2: Tropical climate. This graph seems to show a constant increase in return times, but also, in this scenario, the increase of the effective depth does not necessarily result in an increase in return time of the storage peaks. In the lower storage peaks of $0-600 m^3/ha$, the graph of an effective depth of 100 mm shows low return times due to the controlled runoff to OW being relatively high. Interesting to see is that for more extreme events, the linear increase seems to 'return'. At the lower storage peak events of scenario 2 the graphs show lower return times for higher effective depths. However, at around a storage peak of 4000 mm, an increase of effective depth increases return time. The visual observations are substantiated by the mathematical results presented in Table 4.12. The table shows that the storage peak factor — i.e. the return time — decreases for the effective depths of > 10 mm in the lower regions of the storage peaks. However, from a storage peak of > 1000 mm, the storage peak factor, i.e. the return time, increases for an increase of effective depth, except the effective depth of 100 mm.

	Eff. depth	**Event-based storage peaks for Scenario 1 [mm]**													
		50	**60**	**70**	**80**	**90**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**Avg**
Underground storage	5 mm	1.63	1.66	1.65	1.62	1.57	1.53	1.42	1.35	1.33	1.22	1.18	1.22	1.16	1.33
	10 mm	1.9	2.13	2.23	2.37	2.45	2.53	2.06	2.12	1.57	1.44	1.66	1.85	inf	1.89
	20 mm	1.66	1.8	1.98	2.11	2.23	2.34	3.49	3.81	2.95	2.8	inf	inf	inf	3.06
	30 mm	1.4	1.51	1.64	1.76	1.87	1.93	2.94	3.63	4.03	inf	inf	inf	inf	3.10
	40 mm	1.25	1.33	1.41	1.48	1.56	1.62	2.28	3.09	3.49	inf	inf	inf	inf	2.66
	50 mm	1.15	1.2	1.25	1.31	1.37	1.4	1.87	2.58	2.79	3.91	inf	inf	inf	2.39
	100 mm	1	1.04	1.04	1.03	1.06	1.06	1.13	1.34	1.4	1.34	1.78	inf	inf	1.38

Table 4.11: Storage peak factor calculation for the underground storage measure based on scenario 1, where for every effective depth the factor is calculated over different event-based storage peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined".

The underground storage tank shows no constant increase of the return time of varying storage peaks for scenario 1, but scenario 2 shows a certain constant change. However, the return time is not increasing for an increase of effective depth, which one would expect. Besides, the constant change in return time is only visible starting from a particular point in the graph at around ± 500 mm. Scenario 1 shows an unstable graph with no constant increase in return time of the storage peaks. The graph is unstable due to how the measure is now defined inside the model and in practice, where an emptying time of 48 hours is required.

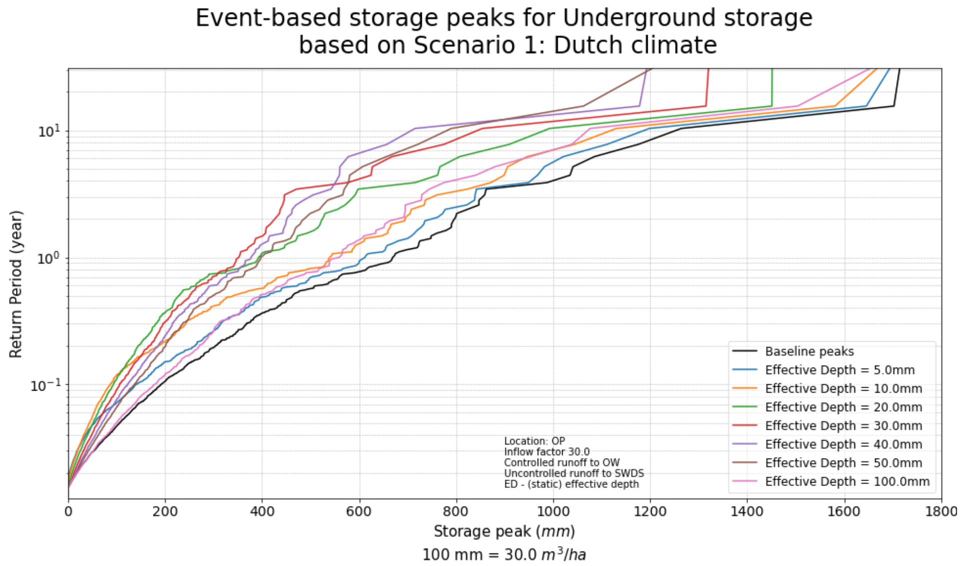


Figure 4.11: Event-based peak storages for an underground storage tank for the neighbourhood residential housing. Plot based on scenario 1: 30 years of input data downloaded from KNMI.

	Eff. depth	**Event-based storage peaks for Scenario 2 [mm]**																	
		50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**Avg**
Underground storage	5 mm	1.19	1.18	1.15	1.13	1.12	1.12	1.1	1.11	1.09	1.09	1.04	1.04	1.04	1.07	1.04	1.01	1.01	1.06
	10 mm	1.23	1.35	1.34	1.29	1.28	1.27	1.25	1.22	1.2	1.21	1.11	1.17	1.11	1.14	1.07	1.02	1.02	1.13
	20 mm	1.18	1.32	1.42	1.53	1.61	1.63	1.56	1.51	1.47	1.48	1.31	1.38	1.33	1.29	1.26	1.22	inf	1.31
	30 mm	1.13	1.24	1.34	1.4	1.52	1.6	1.63	1.7	1.73	1.73	1.62	1.6	1.46	1.39	1.44	1.41	inf	1.49
	40 mm	1.1	1.2	1.26	1.32	1.4	1.49	1.49	1.53	1.56	1.6	1.82	1.76	1.59	1.67	1.6	1.52	inf	1.63
	50 mm	1.07	1.14	1.2	1.25	1.33	1.38	1.41	1.43	1.44	1.49	1.8	1.87	1.74	1.81	1.69	1.56	inf	1.67
	100 mm	1.01	1.03	1.05	1.06	1.08	1.09	1.11	1.13	1.13	1.12	1.19	1.32	1.47	1.36	1.41	1.32	inf	1.31

Table 4.12: Storage peak factor calculation for the underground storage measure based on scenario 2, where for every effective depth, the factor is calculated over different event-based storage peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined".

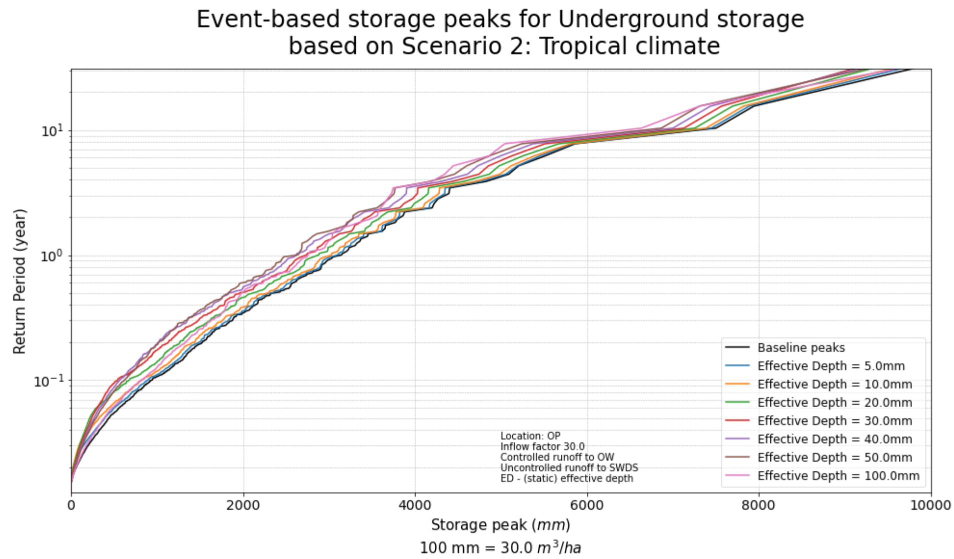


Figure 4.12: Event-based peak storages for an underground storage tank for the neighbourhood residential housing. Plot based on scenario 2.

4.2.2. Extensive green roof: Evaporation

Figures 4.13 and 4.14 present the semi-logarithmic graph of the storage peaks of an applied extensive green roof in a residential housing area. The graphs of the applied effective depths start at identical origins and follow the same line, where the graphs start to show differences after particular points. When the water balance of the measure and open water is analysed, it is observed that these differences are due to the capacity of the measure. When the effective depth is increased, overflowing occurs later with higher precipitation events due to the higher storage capacity of the measure. Subsequently, the lower effective depths in the graph have a lower return time from the point where the measure overflows. The graphs have a constant increase of the return time compared to the baseline scenario when the measure overflows, however only in a certain range of the graphs. This is substantiated if the storage peak factor is calculated between the storage peaks of 50 - 600 mm as shown in Table 4.13. The table shows an increase in storage peak factor when increasing the effective depth. In addition, the factors show a slight increase of the factor for higher storage peaks. The table shows that the factors of the different effective depths start at roughly the same origin, which substantiates the graphical analysis that there is no continuous constant increase of the return time of the storage peak of the implemented effective depth with respect to the baseline scenario.

For scenario 2 the identical structure of the graphs is observed, where they have roughly the same origin and shape, and at an increasing storage peak, they start showing differences in return time. The return times of the varying effective depths are closer to each other due to the higher precipitation used as input, resulting in a more frequent overflow of the measure. Also, for this scenario, the return time increases linearly after the measure overflows and shows different storage peaks' return times. The results of the storage peak factor calculation between the storage peaks of 50 – 4000 mm are presented in Table 4.14. The table shows more clearly that the different graphs have the same origin at a factor of around 1.11. The differences in the storage peak factors that occur are shown in the table for an increasing storage peak.

The return time only has a constant shift in the vertical directions for both scenarios starting from a particular point starting from around 50 mm. This can be explained by the fact that when the measure overflows — which is different for the varying effective depths — the open water storage increases due to the extra discharge coming into the reservoir. A measure with a lower effective depth overflows more quickly, which results in a lower return time of the peak storage in the open water. With both the graphical and mathematical analysis in mind, the increase of return time is not linear, and a constant factor can not be substantiated.

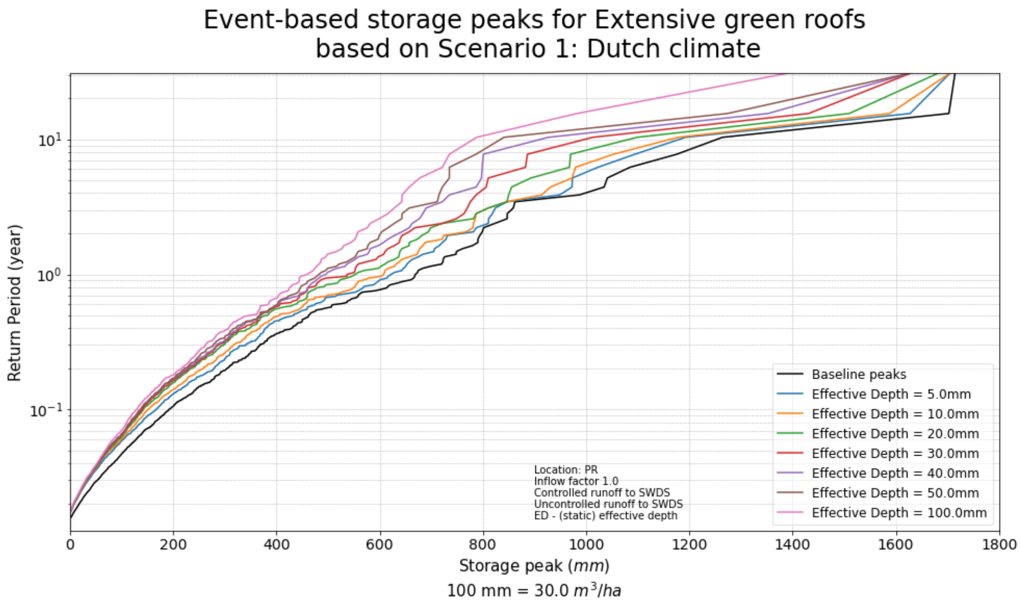


Figure 4.13: Event-based peak storages for an extensive green roof for the neighbourhood residential housing. Plot based on scenario 1: 30 years of input data downloaded from KNMI.

	Eff. depth	Event-based storage peaks for Scenario 1 [mm]													
		50	**60**	**70**	**80**	**90**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**Avg**
Extensive green roofs	5 mm	1.21	1.24	1.25	1.25	1.27	1.25	1.23	1.22	1.24	1.19	1.18	1.27	1.08	1.22
	10 mm	1.25	1.3	1.31	1.31	1.31	1.29	1.33	1.35	1.34	1.24	1.25	1.53	inf	1.34
	20 mm	1.27	1.31	1.34	1.36	1.36	1.34	1.5	1.58	1.53	1.48	1.47	1.93	inf	1.54
	30 mm	1.28	1.33	1.36	1.39	1.4	1.38	1.55	1.64	1.59	1.66	1.77	2.01	inf	1.66
	40 mm	1.29	1.34	1.37	1.41	1.41	1.4	1.6	1.68	1.62	1.83	2.15	inf	inf	1.74
	50 mm	1.29	1.34	1.38	1.42	1.43	1.4	1.61	1.77	1.62	1.95	2.54	inf	inf	1.79
	100 mm	1.32	1.39	1.44	1.49	1.51	1.5	1.71	1.97	1.83	2.49	inf	inf	inf	2.00

Table 4.13: Storage peak factor calculation for the extensive green roof based on scenario 1, where for every effective depth the factor is calculated over different event-based storage peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined".

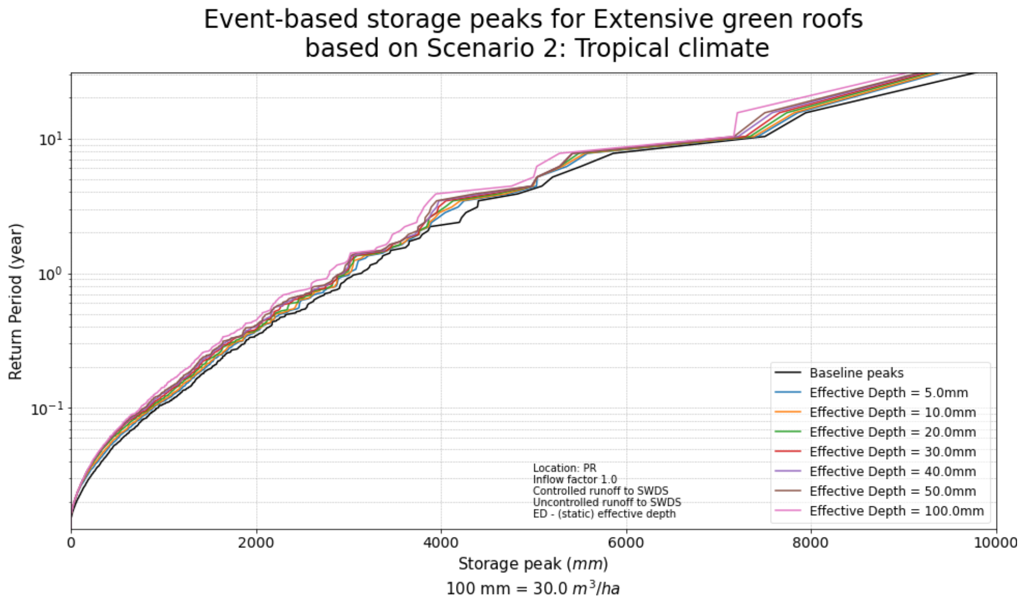


Figure 4.14: Event-based peak storages for an extensive green roof for the neighbourhood residential housing. Plot based on scenario 2.

	Eff. depth	Event-based storage peaks for Scenario 2 [mm]																	
		50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**Avg**
Extensive green roof	5 mm	1.11	1.13	1.11	1.1	1.09	1.1	1.09	1.09	1.07	1.08	1.05	1.08	1.07	1.18	1.05	1.05	inf	1.09
	10 mm	1.11	1.15	1.14	1.15	1.14	1.15	1.14	1.13	1.12	1.12	1.07	1.11	1.09	1.19	1.08	1.06	inf	1.11
	20 mm	1.12	1.15	1.17	1.19	1.2	1.21	1.21	1.2	1.19	1.18	1.1	1.18	1.09	1.22	1.13	1.06	inf	1.15
	30 mm	1.12	1.15	1.18	1.2	1.23	1.24	1.23	1.23	1.21	1.22	1.15	1.21	1.11	1.25	1.17	1.11	inf	1.19
	40 mm	1.12	1.15	1.19	1.2	1.23	1.26	1.25	1.24	1.22	1.24	1.2	1.25	1.16	1.28	1.26	1.12	inf	1.22
	50 mm	1.12	1.16	1.19	1.2	1.24	1.26	1.25	1.25	1.24	1.25	1.23	1.28	1.19	1.28	1.32	1.12	inf	1.24
	100 mm	1.12	1.16	1.19	1.21	1.25	1.28	1.27	1.27	1.25	1.27	1.33	1.38	1.3	1.39	1.38	1.32	inf	1.34

Table 4.14: Storage peak factor calculation for the extensive green roof based on scenario 2, where for every effective depth, the factor is calculated over different event-based storage peaks. "Inf" indicates that there are too few events to calculate the factor, which means that the factor is "undefined".

4.2.3. Infiltration boxes: Infiltration

The results of the analysis of the storage peaks in the Open Water for the infiltration boxes in shown in Figure 4.15. For scenario 1, the infiltration boxes show a similar pattern for the extensive green roofs: the graph all share an identical origin, and at the low storage peaks, the graphs are the same. The graphs start to show differences from a certain storage peak and higher, starting from the low effective depths. After this difference is visible, the graph also shows a linear increase in return time compared to the baseline storage peaks. The storage peak factor calculations for storage peaks of 50-600 mm are presented in Table 4.15. The graphs share the same shape at the lower storage peaks visible in this table, where the factors are the same at a storage peak of 50 & 60 mm for the effective depths of > 5 mm. The graph and table of scenario 1 show that the increase of return time is linear for the varying effective depths for scenario 1. However, this linear increase is not always visible, which means that the linear increase is not continuous.

Scenario 2 gives some remarkable results, where for the higher storage peaks, the scenarios for applied measures have lower return times than the baseline scenario as shown in Figure 4.16 and Table 4.16. The water balance of the open water shows a very high increase of runoff from the groundwater and unpaved reservoir for high precipitation events. This increase in runoff is due to increased controlled runoff to the groundwater from the measure during high precipitation events. For higher precipitation events, the groundwater gets filled faster for higher effective depths, where at some point, the groundwater level is at ground level. When controlled runoff comes to groundwater or unpaved after this point, it results in fast runoff directly into the Open Water. The results of a lower return time compared to the baseline scenario is also shown in Table 4.16 where the factors are calculated below 1 for high storage peaks.

In the lower regions of storage peaks, the output is comparable to the results for the extensive green roof: The graphs of the varying effective depths have the same origin and are the same for the low storage peaks. When increasing the storage peaks, the effective depths branch off.
Scenario 2 shows lower return time increases, but the mechanism seems to be the same: from certain storage peaks, the graph branches off and takes the same slope as the baseline peaks. The graphs get more unstable from a storage peak of $\pm 2000mm$ and show a less linear increase with irregularities.

The infiltration boxes show a linear increase in return times starting from different storage peaks for the varying effective depths. Thus, this linear increase is not continuous, which means that also, for this measure, a linear storage peak factor can not be substantiated.

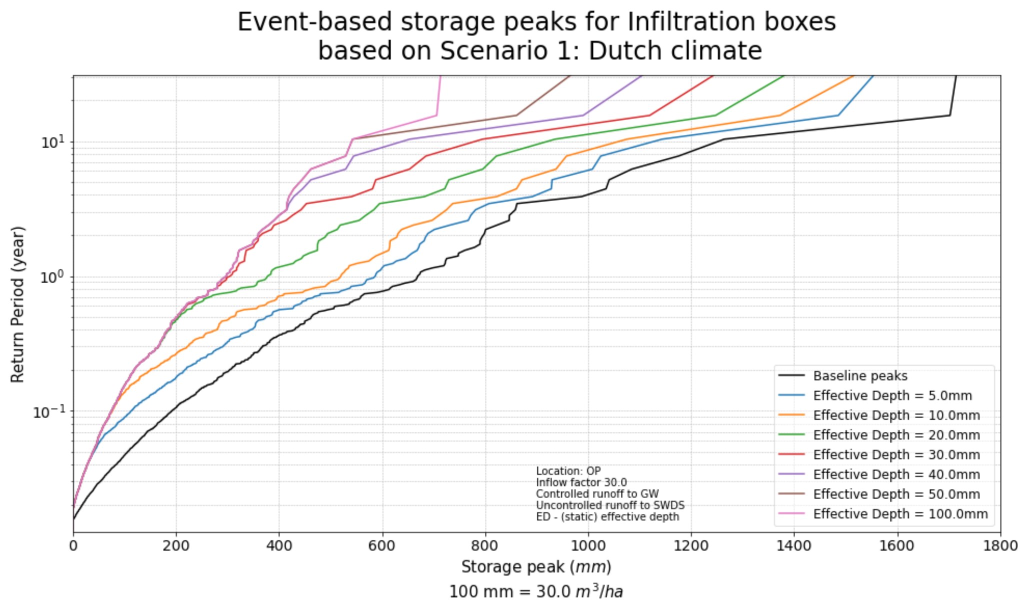


Figure 4.15: Event-based peak storages for infiltration boxes for the neighbourhood residential housing. Plot based on scenario 1: 30 years of input data downloaded from KNMI.

	Eff. depth	Event-based storage peaks for Scenario 1 [mm]													
		50	**60**	**70**	**80**	**90**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**Avg**
Infiltration boxes	5 mm	1.97	2.03	2	1.94	1.97	1.91	1.67	1.66	1.54	1.32	1.49	1.91	inf	1.62
	10 mm	2.22	2.43	2.59	2.75	2.9	2.93	2.5	2.42	1.94	1.6	1.91	inf	inf	2.24
	20 mm	2.21	2.43	2.6	2.82	3.05	3.29	4.46	3.86	3.2	3.72	inf	inf	inf	3.60
	30 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.01	6.76	inf	inf	inf	inf	4.63
	40 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.69
	50 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.69
	100 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.69

Table 4.15: Storage peak factor calculation for the infiltration boxes based on scenario 1, where for every effective depth the factor is calculated over different event-based storage peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined".

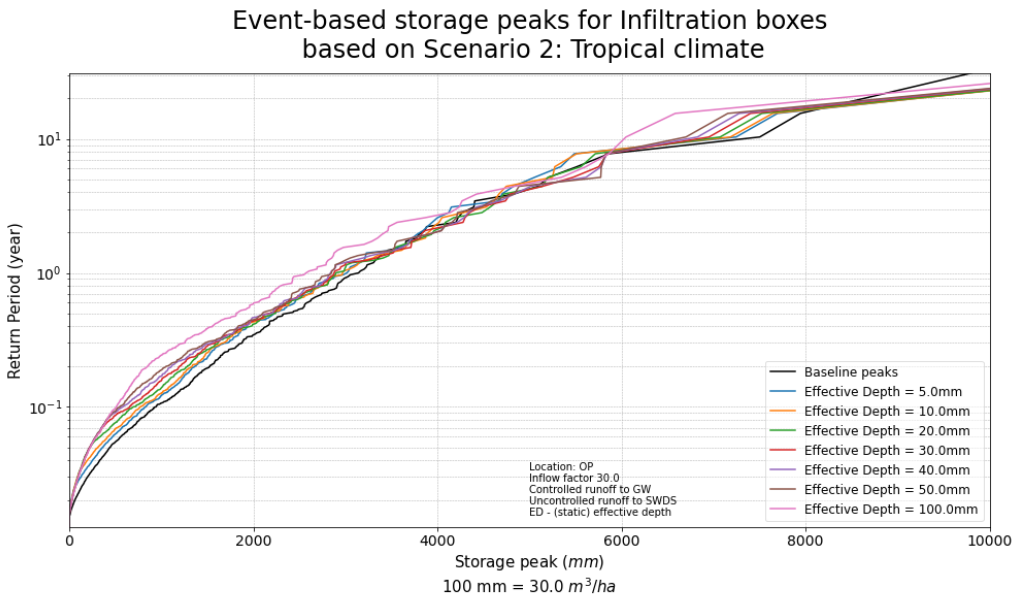


Figure 4.16: Event-based peak storages for infiltration boxes for the neighbourhood residential housing. Plot based on scenario 2.

	Eff. depth	Event-based storage peaks for Scenario 2 [mm]																	
		50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**Avg**
Infiltration boxes	5 mm	1.26	1.25	1.21	1.19	1.18	1.18	1.18	1.17	1.14	1.15	1.13	1.19	1.27	1.24	1.07	0.99	inf	1.15
	10 mm	1.26	1.39	1.37	1.33	1.32	1.32	1.28	1.26	1.24	1.25	1.18	1.3	1.25	1.21	1.14	0.96	1.03	1.17
	20 mm	1.24	1.37	1.48	1.55	1.57	1.54	1.48	1.43	1.4	1.39	1.3	1.38	1.2	1.2	1.19	0.96	0.93	1.22
	30 mm	1.22	1.35	1.45	1.54	1.6	1.64	1.66	1.65	1.6	1.58	1.47	1.46	1.27	1.27	1.27	0.94	0.95	1.27
	40 mm	1.21	1.34	1.43	1.54	1.6	1.67	1.7	1.72	1.71	1.67	1.59	1.51	1.35	1.28	1.3	0.98	0.89	1.32
	50 mm	1.21	1.33	1.42	1.52	1.6	1.67	1.68	1.73	1.72	1.71	1.76	1.57	1.3	1.4	1.35	0.99	0.89	1.38
	100 mm	1.21	1.33	1.41	1.5	1.58	1.63	1.66	1.7	1.77	1.78	2.27	1.98	1.71	1.78	1.69	1.52	inf	1.75

Table 4.16: Storage peak factor calculation for the infiltration boxes based on scenario 2, where for every effective depth, the factor is calculated over different event-based storage peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined".

4.2.4. Urban wetland: Regulated discharge & evaporation

The results of the urban wetland are shown in Figure 4.17. Again, the origin starts at the same level for every graph. For small precipitation events, all the applied effective depths of the measure can store the amount of rainfall coming in. The smallest modelled storm event will have a required storage of zero for all the effective depths as this event is negligible in size. The effective depths of 5 & 10 mm show differences from the other effective depths rather quickly but then have the same slope as the baseline scenario with a linear increase.

The calculations of the possible storage peak factor are given in Table 4.17. The results indicate the same as the previously discussed measures. The varying effective depths share the same shape and origin for low storage peaks, but at some point, show differences due to the overflowing of the measure. Also for this measure, the increase in return time of the storage peaks is non-continuous constant.

The urban wetland is modelled based on scenario 2, and the storage peaks are analysed. The results are shown in Figure 4.20. A decrease in return time is observed compared to scenario 1, and a smaller difference in return times for the varying effective depths. However, there still is a constant increase of return times of the storage peak starting from a certain storage peak, and the varying effective depths show a very similar graph, also in the higher regions of the storage peaks.

Table 4.18 shows the calculations of the storage peak factor of scenario 2. This Table shows that the factors start at the same point (1.07) and start to show differences for an increase of storage peaks. Subsequently, for scenario 2 the increase of return time is not continuous constant.

The results for the urban wetland show a non-continuous vertical shift of the return time for both scenarios based on the graphical and mathematical analysis. This will be discussed further in the Discussion.

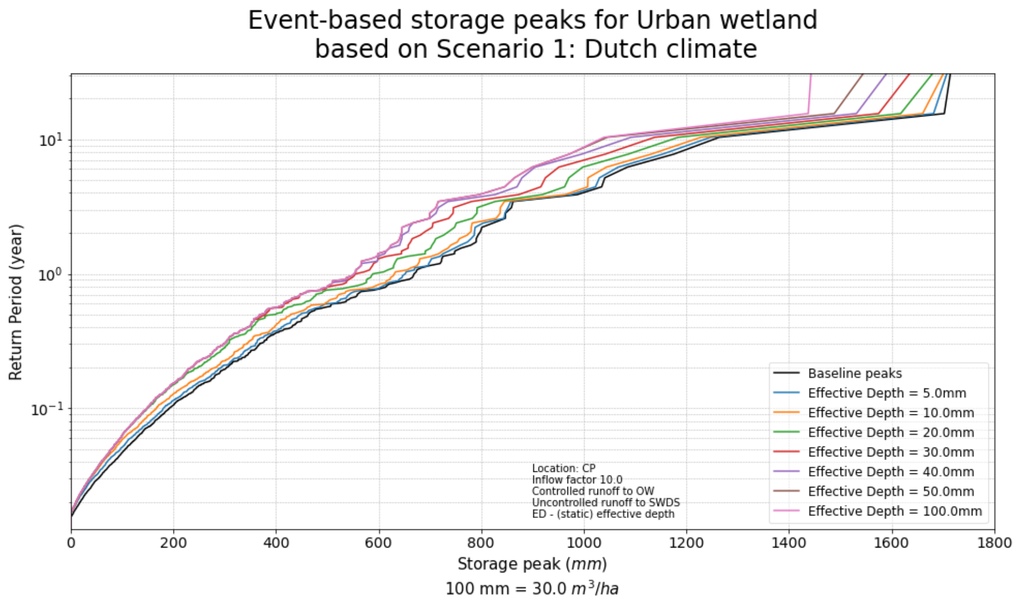


Figure 4.17: Event-based peak storages for an urban wetland for the neighbourhood residential housing. Plot based on scenario 1: 30 years of input data downloaded from KNMI.

	Eff. depth	Event-based storage peaks for Scenario 1 [mm]													
		50	60	70	80	90	100	200	300	400	500	600	700	800	Avg
Urban wetland	5 mm	1.09	1.1	1.12	1.13	1.12	1.09	1.09	1.07	1.03	1.05	1.01	1.07	1.1	1.07
	10 mm	1.18	1.21	1.23	1.22	1.25	1.25	1.21	1.16	1.14	1.09	1.08	1.16	1.15	1.17
	20 mm	1.21	1.25	1.27	1.29	1.32	1.34	1.42	1.44	1.37	1.33	1.32	1.34	inf	1.38
	30 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.53	1.4	1.68	1.88	inf	1.53
	40 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.76	inf	inf	1.58
	50 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.84	inf	inf	1.60
	100 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.84	inf	inf	1.60

Table 4.17: Storage peak factor calculation for the urban wetland based on scenario 1, where for every effective depth the factor is calculated over different event-based storage peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined".

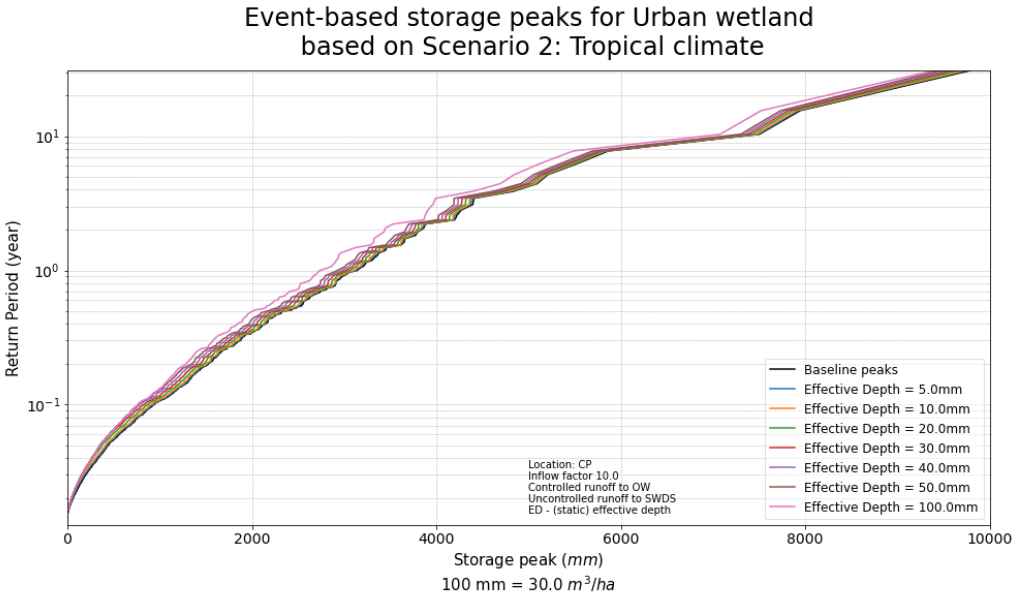


Figure 4.18: Event-based peak storages for an urban wetland for the neighbourhood residential housing. Plot based on scenario 2.

	Eff. depth	Event-based storage peaks for Scenario 2 [mm]																	
		50	100	150	200	250	300	350	400	450	500	1000	1500	2000	2500	3000	3500	4000	Avg
Urban wetland	5 mm	1.05	1.05	1.04	1.03	1.03	1.03	1.02	1.03	1.03	1.02	1.01	1.01	1.01	1.01	1.01	1	1	1.02
	10 mm	1.07	1.09	1.08	1.07	1.07	1.07	1.06	1.05	1.05	1.04	1.02	1.02	1.02	1.03	1.02	1.01	1.01	1.03
	20 mm	1.07	1.1	1.12	1.12	1.12	1.14	1.14	1.14	1.11	1.12	1.05	1.08	1.05	1.09	1.05	1.02	1.02	1.08
	30 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.18	1.17	1.17	1.08	1.16	1.11	1.12	1.07	1.03	1.02	1.12
	40 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.16	1.23	1.15	1.19	1.11	1.05	1.03	1.16
	50 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.22	1.31	1.25	1.25	1.15	1.13	1.04	1.20
	100 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.23	1.36	1.44	1.34	1.5	1.45	inf	1.33

Table 4.18: Storage peak factor calculation for the urban wetland based on scenario 2, where for every effective depth the factor is calculated over different event-based storage peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined".

4.2.5. Bioswale: Infiltration & evaporation

Figure 4.19 shows the storage factor plots of the bioswale. The varying effective depths share the identical origin and shape for low storage peaks from 0-±50 mm. From a storage peak of 50 mm, the differences between the effective depths are visible. Implementing the effective depth of 5 mm shows a significant increase in return time compared to the baseline situation. This increase resembles the peak factor plot of Figure 4.9. When the effective depths return different return times for an increase in storage peak, the graphs show a constant increase in return time for varying storage peaks compared to the baseline scenario.

Scenario 2 shows earlier differences in return times for the different effective depths. The graphs show a low linear increase in return time in the lower regions of the return periods. The graph gets highly unstable for the higher return times, where the storage peaks of effective depths even show lower return times than the baseline scenario. This result resembles the result of the infiltration boxes. The controlled runoff of the bioswale is to the groundwater reservoir. The explanation of this phenomenon seems to be the same as for the infiltration boxes: an increase of controlled runoff to the groundwater reservoir from the measure. This increase in runoff to the groundwater results in a direct overflow of the groundwater and unpaved reservoir, which then directly ends up in the open water.

Tables 4.19 and 4.20 substantiated the above discussed findings. The factor starts at the same origin for the different effective depths, and an increase in storage peaks results in differences in return time for the varying effective depths. Thus, the increase in return time is not continuous.

The bioswale shows a constant increase in return time for both scenarios in some areas of the graph. However, this constant increase is — just as for the other measures — not continuous, and thus, a continuous factor is not substantiated.

	Eff. depth	**Event-based storage peaks for Scenario 1 [mm]**													
		50	**60**	**70**	**80**	**90**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**Avg**
Bioswale	5 mm	2.22	2.43	2.62	2.75	2.77	2.68	2.32	2.34	1.92	1.78	2.22	inf	inf	2.24
	10 mm	2.21	2.43	2.6	2.82	3.05	3.29	3.33	3.28	2.4	2.71	3.15	inf	inf	3.01
	20 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.99	4.15	3.36	3.82	inf	inf	inf	3.69
	30 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.99	4.15	3.37	4.16	inf	inf	inf	3.75
	40 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.99	4.15	3.37	4.16	inf	inf	inf	3.75
	50 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.99	4.15	3.37	4.16	inf	inf	inf	3.75
	100 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.99	4.15	3.37	4.16	inf	inf	inf	3.75

Table 4.19: Storage peak factor calculation for the bioswale based on scenario 1, where for every effective depth the factor is calculated over different event-based storage peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined".

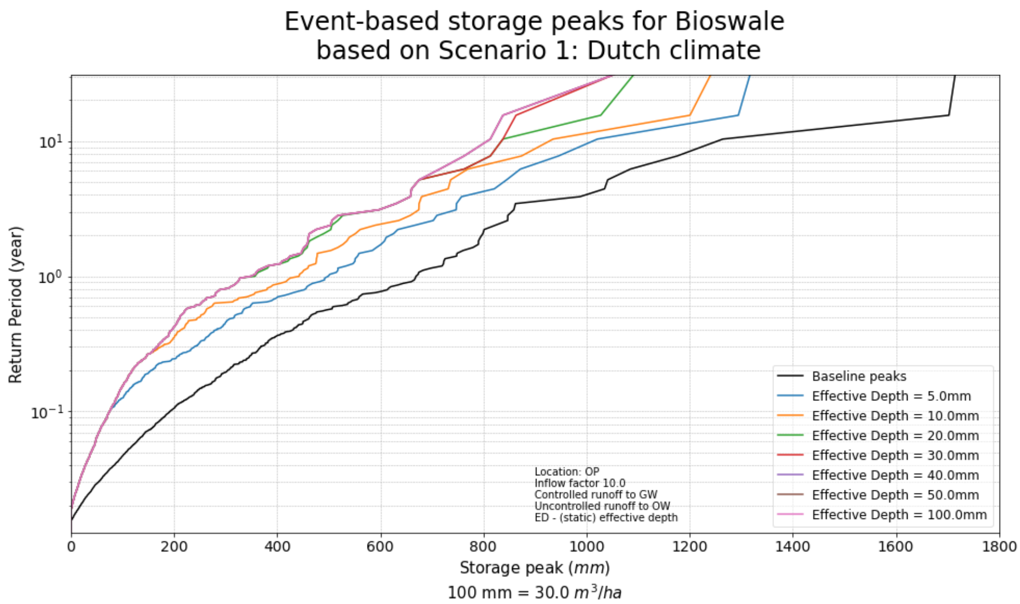


Figure 4.19: Event-based storage peaks for a bioswale for the neighbourhood residential housing. Plot based on scenario 1: 30 years of input data downloaded from KNMI.

	Eff. depth	Event-based storage peaks for Scenario 2 [mm]																	
		50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**Avg**
Bioswale	5 mm	1.25	1.34	1.32	1.3	1.33	1.32	1.31	1.29	1.28	1.29	1.31	1.4	1.19	1.34	1.25	1.06	0.97	1.25
	10 mm	1.24	1.39	1.48	1.49	1.48	1.47	1.46	1.44	1.39	1.37	1.46	1.49	1.27	1.35	1.32	0.99	0.97	1.30
	20 mm	1.23	1.37	1.46	1.52	1.58	1.66	1.62	1.62	1.63	1.64	1.64	1.57	1.36	1.49	1.3	1.14	0.95	1.40
	30 mm	1.23	1.36	1.46	1.52	1.58	1.65	1.62	1.66	1.68	1.71	1.71	1.61	1.42	1.51	1.36	1.21	0.91	1.47
	40 mm	1.23	1.36	1.45	1.51	1.58	1.65	1.61	1.65	1.67	1.7	1.75	1.61	1.41	1.54	1.54	1.21	1.02	1.50
	50 mm	1.23	1.36	1.45	1.51	1.58	1.65	1.61	1.65	1.67	1.7	1.79	1.61	1.41	1.58	1.61	1.21	1.05	1.52
	100 mm	1.23	1.36	1.45	1.51	1.58	1.65	1.61	1.65	1.67	1.7	1.79	1.63	1.41	1.58	1.61	1.21	1.05	1.53

Table 4.20: Storage peak factor calculation for the bioswale based on scenario 2, where for every effective depth the factor is calculated over different event-based storage peaks. "Inf" indicates that there are too little events to calculate the factor, which means that the factor is "undefined".

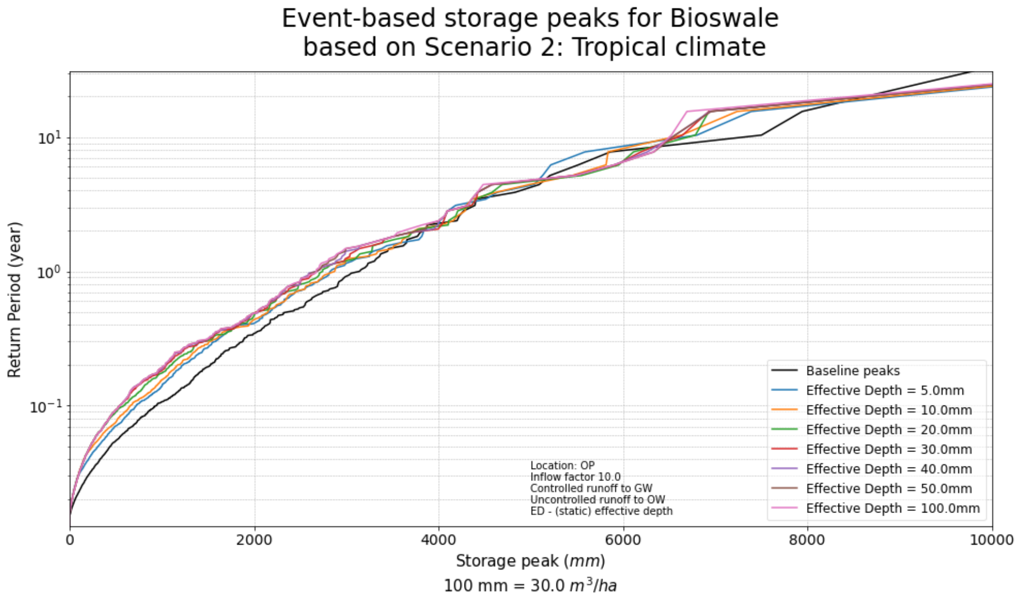


Figure 4.20: Event-based storage peaks for an urban wetland for the neighbourhood residential housing. Plot based on scenario 2.

4.3. Comparison of the five measures

4.3.1. Flow peaks

The flow peak reduction analysis shows differences for the different measures that are implemented.

The Underground storage, infiltration boxes, and urban wetland show a significant increase of return time for scenario 1. Where for all three, no uncontrolled runoff occurs — and thus no runoff events are defined — for an applied effective depth of 100 mm. On the other hand, the extensive green roofs and bioswale show uncontrolled runoff for all the applied effective depths. Moreover, applying a higher effective depth results in a lower increase of return time than the other three measures. This difference is due to the emptying mechanisms of the measures and how the parameters are defined within the model. The extensive green roofs always show uncontrolled runoff since the emptying mechanisms depend solely on evaporation. When looking at the water balance of the extensive green roofs, the storage of the measure is filled for many of the time steps. Since the evaporation is not enough to cope with the rainfall coming in, even the applied effective depth of 100mm will overflow, and the return time of the flow peaks will differ less for all the effective depths. The other measures are able to store and discharge the incoming water in a better way since they can either infiltrate or pump the water out of the measure.

An interesting result is observed when comparing the bioswale and infiltration boxes, having an emptying mechanism by infiltration. The bioswale returns uncontrolled runoff for all the applied effective depths. The infiltration boxes show a high return time increase and no uncontrolled runoff for the effective depth of 100 mm. This difference is explained by the fact that the bioswale is defined as a 3-layer measure structure, and the infiltration boxes are defined as a 2-layer structure. When looking at the water balance of both measures, the bioswale shows both surface runoff and bottom storage runoff, where the infiltration boxes only show bottom storage runoff. The difference between the two measures is that the bioswale has a lower infiltration capacity of the interception layer (83.3 mm/h) than the infiltration boxes (41666 mm/h). The infiltration capacity of the bioswale is exceeded due to the inflow factor of 10, where a precipitation of event of 10 mm results in 100 mm flowing into the bioswale. This results in surface flow out of the bioswale. The infiltration boxes never have surface flow and only have runoff out of the bottom layer.

For all measures, scenario 2 gives a clearer insight into the fact that there is a continuous flow peak factor that can be determined. For all measures, the tropical scenario shows lower return times as a whole, but the measures overflow more frequently, which shows the constant increase of the flow peaks more clearly. Also, for scenario 2, the bioswale is very effective when implementing an effective depth of 5 mm. However, the urban wetland, infiltration boxes, and underground storage surpass the effectiveness of the bioswale for higher effective depths. The bioswale has a maximum peak flow reduction factor of ± 2, where these measures surpass the factor of two for an effective depth of 40 mm. From this point on, the bioswale has higher surface runoff than the uncontrolled runoff out of the other measures and is less effective.

The most effective measures are the measures with regulated discharge (Underground storage and urban wetland). The second most effective are the infiltration measures (infiltration boxes and bioswale) and the least effective is the extensive green roof. Meaning, the measure's effectiveness partly depends on the emptying mechanism of the measure and antecedent conditions.

With both scenario 1 and scenario 2 in mind, the continuous factor for the flow peak reduction can be substantiated.

4.3.2. Storage peaks

The results of the storage peaks are compared for the five different implemented measures.

In general, all measures show an increase in return time of the storage peaks due to the measure's implementation. For scenario 1, the infiltration boxes are most effective together with the bioswale when comparing the five different measures. The underground storage and urban wetland follow as second effective and the extensive green roof is the least effective. In other words, the infiltration measures perform the best, the regulated discharge second best and the evaporation only measures perform the worst. However, the results show instability of the different measures, which will be discussed in the next paragraphs.

The bioswale and infiltration boxes show inconsistent results where the return time of the applied effective depths of the measure becomes lower than the baseline scenario for high storage peaks. This is due to the emptying mechanism of both measures. The controlled runoff of both measures is to the groundwater reservoir, which overflows when controlled runoff is high for longer periods. This result is only observed for the tropical scenario with both measures. The higher pressure on the area with more extreme precipitation events results in the groundwater storage being filled up for the higher precipitation events, which does not happen (or not as extreme) in the Dutch climate.

Furthermore, the underground storage shows irregularities where an increase of effective depth decreases return time. This is undesirable, and after investigation, this is due to how the measure is modelled in the UWBM. The measures with controlled runoff to Open Water have this result because this controlled runoff is increased together with the increase of the storage capacity of the measure.

Interestingly, for the extensive green roof, infiltration boxes, urban wetland, and bioswale, the increase in return time is not continuous but seems constant from some point in the graphs. However, all the graphs start at the same origin, which is logical but unreliable to determine where the continuous constant increase of the return time starts.

The results show that a possible flow peak reduction factor is there, but this factor is not continuous and can not be reliably calculated. Moreover, measures that discharge into Groundwater and Open Water show irregularities in their results.

4.4. Measure factor to whole project factor

In this study a method is presented to convert the found reduction factor of the measure area to a reduction factor of the whole project area. The method that is proposed requires fitting of the semi-logarithmic graphs to substantiate a conversion equation. Based on the presented method, the semilograthmic graphs are manually fitted using the equation $T = C_1 * \exp^{kx} + C_2$.

Figure 4.21 shows the fitting procedure for the flow peaks of an Urban Wetland. This fitting procedure is done for all the 29 implemented measures for the flow peaks of both scenario 1 and scenario 2.

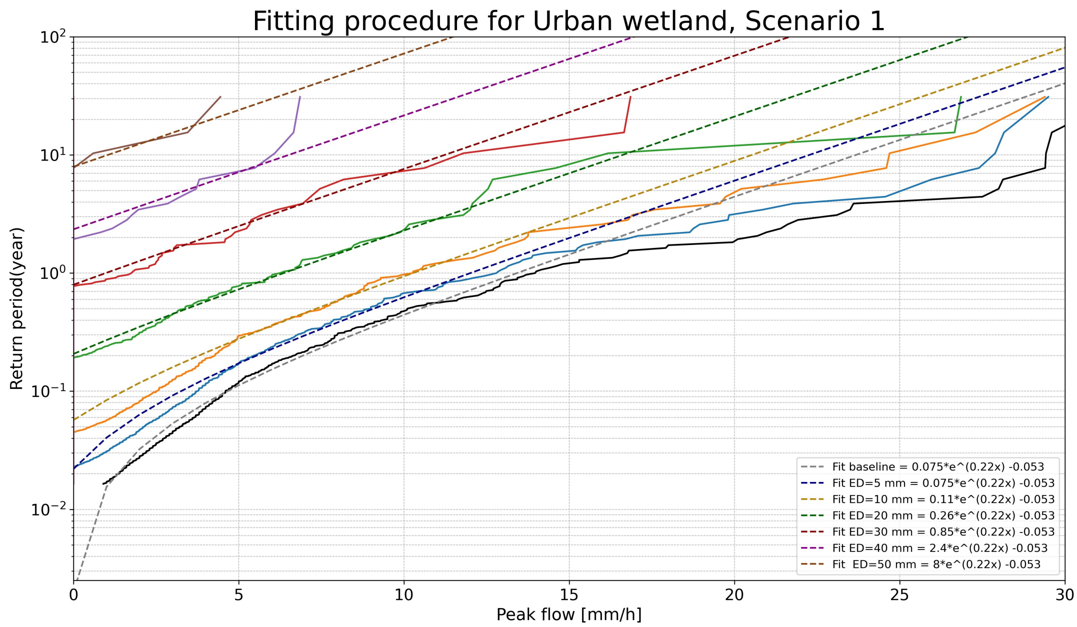


Figure 4.21: Fitting procedure on the urban wetland for scenario 1. The dashed lines show the fits for the different effective depths.

Using the proposed equation the graph can be closely fitted for the urban wetland. However, it is not a 100 % fit, especially for the effective depths of 5 and 10 mm. In the higher regions of the return times, above 1 *year*, the fit is off. Though, this is in the regions where the events become incidental and fewer measurements are plotted. Hence, the uncertainty of the events there is much larger. Besides, this region is also not where the flow peak factor is calculated. Only in the more stable regions, the factor is calculated. Using this fit, it is concluded that the lines are parallel, and the conversion of the measure factor to the whole project area factor can be defined — for application of one single measure — with the following equation (as discussed in section 3.2).

$$f_{tot_{peak}} = \frac{T_1}{T_B} = \frac{C_B e^{kx_1}}{C_B * e^{k\left(x_1 - \frac{M}{A}\frac{1}{k}\ln f_{meas}\right)}} = e^{\frac{M}{A}\ln f_{meas}} \tag{4.1}$$

where:

$f_{tot_{peak}}$ = Flow peak reduction factor over the entire paved area with the applied measure [-]
f_{meas} = Flow peak reduction factor over the measure inflow area.
A = Entire area $[m^2]$
M = Measure inflow area $[m^2]$

This equation does not include the unpaved area of the project area. Based on the proposed method, the conversion of the factor of the measure inflow area to the whole project area can be defined with equation 4.2.

$$F_{tot} = \frac{A_p * \exp(\frac{(A_{mi} * \ln(F_{meas})}{A_p}) + \frac{Perc_{PA}}{100} * (A_{tot} - A_p)}{A_p + \frac{Perc_{PA}}{100} * (A_{tot} - A_p)} \tag{4.2}$$

Where:

F_{tot}	= Factor for total area
F_{meas}	= Flow peak factor for the measure inflow area
A_{tot}	= Total area
A_p	= Paved area
A_{mi}	= Measure inflow area
$Perc_{PA}$	= Peaks from the rest of the area

Based on this equation, the equation of combining multiple measures is defined.

$$F_{tot} = \frac{A_p * \exp(\frac{\sum_{n}^{i=1} (A_{mi_i} * \ln(F_{meas_i})}{A_p}) + \frac{Perc_{PA}}{100} * (A_{tot} - A_p)}{A_p + \frac{Perc_{PA}}{100} * (A_{tot} - A_p)} \tag{4.3}$$

Where:

i	= Counter, from 1 to N
N	= Number of applied measures

4.5. Multiple area analysis

The conversion of the flow peak reduction factor is tested on the two proposed neighbourhoods for the 29 different measures as discussed in section 3.3. The two proposed neighbourhoods are Residential Housing and Post-war garden city. The conversion equation discussed in the previous section is implemented into the UWBM. The model is run to get the flow peak reduction factor and the runoff volume reduction factor for every measure for a varying effective depth. The results for the five selected measures are discussed in this section. The full results for all measures are given in Appendix K.

To analyse if the conversion of the flow peak factor is functioning, the five earlier introduced measures are discussed: Underground storage, Infiltration boxes, Extensive green roofs, Urban wetland and Bioswale.

Tables 4.21 and 4.22 present the calculated project area factors for the flow peaks of the Residential housing neighbourhood and Post-war garden city, respectively. For this analysis, the "inf" factor of the measure is converted to a factor of a 1000 before the conversion of the measure factor to the project area factor. The maximum factors are thus different for the different areas. For the neighbourhood residential housing, the maximum flow peak reduction factor is 34.4, where there is no uncontrolled runoff modelled for this measure with applied effective depth. For the Post-war garden city, the maximum factor is 40.6, where there is no uncontrolled runoff modelled for the measure with the applied effective depth.

Residential Housing: Peak flow reduction factor

	Effective depth:						
Measure	**5 mm**	**10 mm**	**20 mm**	**30 mm**	**40 mm**	**50 mm**	**100 mm**
Bioswale	1.45	1.82	2.5	2.89	3.23	3.51	3.6
Extensive green roofs	1.19	1.33	1.43	1.54	1.6	1.72	1.89
Infiltration boxes	1.18	1.43	1.71	1.87	2.16	2.42	3.76
Underground storage	1.22	1.69	3.76	10.5	34.4	34.4	34.4
Urban wetland	1.06	1.15	1.38	1.72	2.12	3.23	3.23

Table 4.21: Results of the flow peak reduction factor over the whole project area for the Residential Housing area.

Post-war Garden City: Peak flow reduction factor

	Effective depth:						
Measure	**5 mm**	**10 mm**	**20 mm**	**30 mm**	**40 mm**	**50 mm**	**100 mm**
Bioswale	1.63	2.42	3.25	3.47	3.47	3.48	3.5
Extensive green roofs	1.14	1.23	1.31	1.38	1.42	1.5	1.61
Infiltration boxes	1.28	1.74	3.17	5.05	8.54	17.4	40.6
Underground storage	1.27	1.75	4.31	17.6	40.6	40.6	40.6
Urban wetland	1.06	1.14	1.37	1.71	2.11	3.26	3.26

Table 4.22: Results of the flow peak reduction factor over the whole project area for the Post-war Garden City.

The results show different flow peak reduction factors when comparing the neighbourhoods. The bioswale, infiltration boxes and underground storage show increases in return time for the post-war garden city compared to the residential housing. Different parameters can explain this increase. The post-war garden city has a lower fraction of Open paved area than the residential housing, on which the measures are implemented. Moreover, the post-war garden city has a higher infiltration capacity, resulting in a higher effectiveness of the bioswale and infiltration boxes. Moreover, the differences can be explained because the post-war garden city has a total of 44% of unpaved area, but the residential housing only has 14% of unpaved area, which influences the conversion equation. The infiltration boxes show the highest difference of flow peak reduction factor when comparing residential housing to the post-war garden city. The earlier mentioned fraction of unpaved and the emptying the emptying mechanism of the infiltration boxes being infiltration can explain this: The measure can store water and discharge controlled runoff.

The results of the runoff volume reduction factor are given in Tables 4.23 and 4.24. For the runoff volume reduction factor, we observe the same trend of the results as for the flow peak reduction factor. The bioswale, infiltration boxes, underground storage and bioswale have a higher runoff volume reduction factor for the post-war garden city than residential housing. However, the peak flow reduction factor of the urban wetland is roughly the same for both neighbourhoods where the runoff volume reduction factor increases. This indicates that the post-war garden city can reduce more runoff in volume but is not necessarily reducing the flow peaks. The differences indicate that using both the flow peak reduction factor and the runoff volume reduction factor can give a more thorough insight into the effectiveness of measures.

	Residential Housing: Runoff volume reduction factor						
	Effective depth:						
Measure	**5 mm**	**10 mm**	**20 mm**	**30 mm**	**40 mm**	**50 mm**	**100 mm**
Bioswale	1.79	2.33	3.57	4.55	5.35	5.91	6.72
Extensive green roofs	1.15	1.2	1.26	1.29	1.32	1.35	1.45
Infiltration boxes	1.35	1.54	1.83	2.08	2.29	2.51	3.65
Underground storage	1.44	2.24	5.14	11.05	19.83	34.81	35.07
Urban wetland	1.11	1.23	1.55	1.9	2.32	2.84	3.27

Table 4.23: Results of the runoff volume reduction factor over the whole project area for the Residential Housing area.

	Post-war Garden City: Runoff volume reduction factor						
	Effective depth:						
Measure	**5 mm**	**10 mm**	**20 mm**	**30 mm**	**40 mm**	**50 mm**	**100 mm**
Bioswale	2.34	3.51	5.42	6.38	6.49	6.59	6.71
Extensive green roofs	1.13	1.16	1.21	1.24	1.25	1.27	1.35
Infiltration boxes	1.77	2.43	4.03	6.36	9.79	14.18	46.5
Underground storage	1.58	2.58	5.86	13.42	25.45	46.5	46.5
Urban wetland	1.12	1.26	1.6	2	2.49	3.09	3.6

Table 4.24: Results of the runoff volume reduction factor over the whole project area for the Post-war Garden City. A factor of 46.5 implies that the factor is infinite, i.e. there is no uncontrolled runoff for this measure with the selected effective depth.

5 Discussion

This research aims to define a flow peak- and storage peak reduction factor based on modelling systems in the Urban Water Balance Model (UWBM) using long time series. Because the model describes these factors over the measure area, the second goal of this study is to investigate the possibility of converting this measure factor to a whole project area factor and combining this factor for a combination of measures.

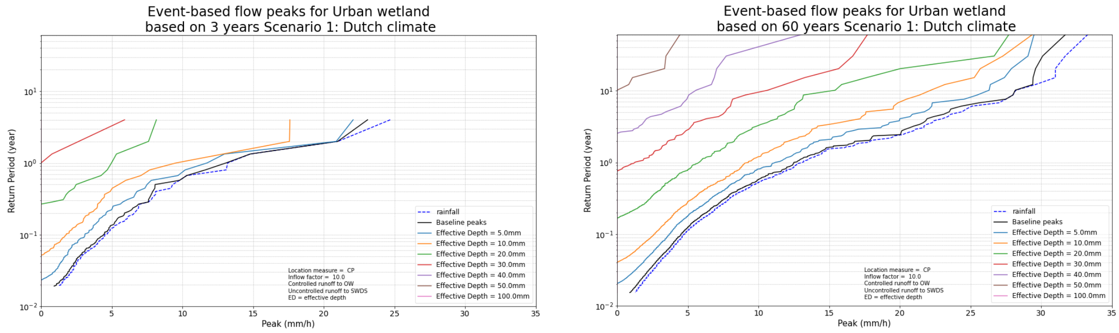
To the first purpose, a calculation method is introduced to quantify the so-called Flow Peak Reduction factor and the Storage peak Reduction Factor based on the same calculation method for determining the Runoff Volume Reduction factor, already being part of the UWBM. Using 29 urban climate adaptation measures — of which five are more thoroughly analysed in this report — with two scenarios being a dutch- and tropical climate, the size of the change in return time due to the implementation of a measure is analysed. It turned out that the Flow Peak Reduction factor can be defined for the proposed method with all the quantified parameters and used input data. However, the Storage Peak Reduction factor can not be defined by a continuous factor. Furthermore, this research determines a conversion for the measure factor to the whole project area factor for the flow peak reduction factor based on finding a flow peak reduction factor. In this study, the established conversion equation is tested on two neighbourhoods, which shows the functionality of this analysis. Based on these findings, defining the effectiveness of urban runoff measures can be improved by analysing the flow peaks when modelling a project area with an urban water balance model based on time series. Furthermore, this new factor will give the user a more thorough insight into the differences in the measures' effectiveness. This chapter presents the discussion of the flow peak- and storage peak reduction factor, the measure to project conversion and the limitations of the model and the data.

Flow peak reduction factor

The composed graphs of the Flow Peaks (Chapter 4, section 4.1) indicate an increase in return time which is constant over the varying flow peaks when an adaptation measure is implemented. This indicates that defining a continuous Flow Peak Reduction factor is possible based on the proposed method. Although the Flow Peak Reduction Factor is substantiated, some remarks should be made regarding limitations and thoughts. These limitations are related to the way the factor is calculated, the climate scenarios, the definition of 'infinite' and the applied type of urban runoff measure.

Factor calculation

The factor calculation excludes the ten highest ten data points from the calculation, which are the return times of 3 years and higher. This way, the factor calculation does not incorporate the more unstable part of the graph. However, based on the calculation of the flow peak reduction factor of the lower regions, we know the factor is applicable for the higher return times. For example, if a peak flow factor is considered 2, the measure changes a return time of 1 in 30 years into 1 in 60 years. The same measure also changes an event of 1 in 1 year into 1 in 2 years. The uncertainty of calculating the factor lies within the input data. Using a lengthier data set results in more events and data points, where the graph becomes more defined, and the incidental events occur for the high return times. If an input time series of 3 years is implemented, as shown in Figure 5.1a, the results are more jerky when compared to if time series of 60 years are used as shown in Figure 5.1b. For both plots, the linear increase — i.e. the peak flow reduction factor — is visible. However, for the 60 years of input time series, this factor is more clearly visible because more events are defined, and events of 1 in 3 years happen more often in a data series of 60 years. If one applied a time series of, e.g., a 1000 years, the factor would be visible up until even higher regions of return times because the data set is much larger. However, if a too long data series is chosen, time would be of influence where the model would take too long to model the implemented project area. Therefore, the time series of 30 years is chosen in this study, showing the reduction factor with acceptable accuracy.



(a) Peak flows for using 3 years of data.

(b) Peak flows for using 60 years of data.

Figure 5.1: Semi-logarithmic graphs representing the peak flows of an Urban Wetland when modeled based on Scenario 1: Dutch climate for 3 years (2018-2021) (a) and for 60 years (1961-2021) (b).

Visibility of a continuous factor

The constant increase in return time of the flow peaks is visible for the dutch climate scenario and the tropical climate scenario. However, the tropical scenario shows a more clear linear increase in return time. This is mainly due to the measures overflowing more frequently, which results in more defined events — i.e., more data points— which makes the factor more visible. Scenario 2 returns lower return times compared to scenario 1, because the measures will overflow more often.This results in more data points, a more fluid line and more certainty of the events.

Definition of "infinite"

Sometimes the flow peak reduction factor of high applied effective depths is defined as "infinite". This indicates that the model (with 30 years of input of rainfall and evaporation) shows no uncontrolled runoff modelled from the measure. However, this does not indicate that the effectiveness of the applied effective depth is infinite. This study uses time series of 30 years. However, more extreme events could happen beyond the available length of the time series, which may result in uncontrolled runoff from the measure. An 'infinite' factor should therefore be interpreted as 'undefined'. Before converting the measure factor to project factor, this 'infinite' factor is changed to a factor of 1000, where after conversion, a maximum factor can be represented for the neighbourhood.

Bioswale results

Regarding the peak flow reduction, the bioswale shows remarkable results, where there is a maximum to the effectiveness of the bioswale when increasing the effective depth. This maximum effectiveness is explained by the way the bioswale is defined within the model. The bioswale has both surface runoff and bottom storage runoff. However, at some point, the effective depth of the bioswale is big enough that there is no overflow occurring in the bottom storage layer of the bioswale. At this point, there is only surface runoff occurring in the measure, which does not change when changing the effective depth of the measure. The surface runoff is the limiting factor which is how the bioswale is currently set up in the model and results in a 'maximum' peak flow reduction factor.

Storage peak reduction factor

In this study it is researched if a storage peak reduction factor can be defined based on using the UWBM using time series. The results gave unstable trends in the composed graphs, in the sense that the increase in the return time of the storage peaks is not constant in the lower regions of the graph but is constant from a particular point. For some measures, this constant increase in return time was also not the case for the higher regions of the graph. In particular, measures with runoff to Open Water and Groundwater showed unstable results, which can be explained by the emptying mechanism. Based on the findings of this study, some remarks should be made about the measures with controlled runoff to Open Water and Groundwater and the potential of the method.

Measures with controlled runoff to Open Water and Groundwater

The study shows that the measures defined with controlled runoff to Open Water (e.g., the Underground storage) have unstable results. This is due to the definition of the measure in the Urban Water Balance Model (UWBM). The storage of the measure is influenced by the way the measure is emptied by controlled runoff. For the underground storage, the controlled runoff capacity is increased together with the increase of the effective depth. Mostly, the time that the storage needs to be emptied is set to 48 hours. Resulting, increasing the storage of the measure results in a higher controlled runoff. This indicates a higher impact of the controlled runoff on the Open Water if the effective depth is increased. More runoff going to the open water results in a decrease in return time of the storage peaks in the open water. Besides this, the study shows that measures that discharge their controlled runoff onto the groundwater show an unstable figure in the higher regions of the peak storage. Sometimes even where the applied measures return lower return times than the return times of the baseline scenario. This is possibly due to the controlled runoff from the measure to the groundwater at higher precipitation events, making the groundwater reach its storage capacity. If this storage capacity is reached, the extra incoming runoff will directly discharge to the open water, increasing the open water storage.

Potential of the method

The proposed method of analysing the return time of the storage peaks does show potential in defining a more thorough definition of the effectiveness of urban runoff measures. The resulting graphs of this method resemble the SDF curve, which is already used within the model. Therefore this study recommends more research into the storage peak reduction factor to see if, after more post-processing, an indicator can be found about the storage peaks within the system. Currently, the storage factor depends on the controlled runoff that the user defines for the measure. Some measures are now defined with the storage being emptied in 48 hours, which means that by changing the effective depth of the measure i.e. the storage, two changes are applied for analysis instead of one. Therefore it is recommended to analyse the possibility to define the controlled runoff differently within the model.

Measure factor to project area factor conversion & combining measures

Concerning this study's second goal —the conversion of the effectiveness of the measure to the whole project area, and determination of the effectiveness of a combination of measures— a fitting procedure is carried out to convert the measure factor to project area factor. After fitting, using equation 4.2 the measure factor can be converted to a project area factor. With the help of this method, this study can calculate the flow peak factor for two different areas to test the functionality and implications of this flow peak factor (Chapter 4, section 4.5). The results show that the flow peak factor can give a more thorough insight into the effectiveness of urban runoff measures in the area. The sections below describe the findings and limitations of the analysis of the conversion of the measure factor to project factor and the combination of measures.

Assumption of $Perc_{PA}$

The study made a significant assumption in calculating the $Perc_{PA}$, where this is now calculated based on the fraction of unpaved area and infiltration capacity. The equation 3.8 has high uncertainty in the scenario where the unpaved fraction of the area is 1. This is presented in Table 5.1 where $Perc_{PA}$ is calculated for different theoretical scenarios. What can be observed in the table is that if the whole area is unpaved, $Perc_{PA}$ would still be 54%, which means that the unpaved peaks are 54% of the paved peaks. This is not correct since there is no paved area. This study uses the $Perc_{PA}$ in areas with less than 40 % paved areas, which makes the equation acceptable to use in this study. However, this study recommends more research into this factor due to the uncertainty of the equation. An example of an alternative is to use the storage coefficient at the target level and infiltration capacity as a proxy of the unpaved peak contribution. However, this has to be researched more thoroughly to effectively implement in the Urban Water Balance Model (UWBM) and Adaptation Support Tool (AST).

Table 5.1: Different calculated percentage of the peaks from the Unpaved area.

	Fraction Unpaved [-]	**Infiltration capacity Unpaved [mm/d]**	**Perc_PA [%]**
Normal area	0.4	460	21.6
No Unpaved area	0	460	0
All Unpaved area	1	460	54

Fitting procedure

The fitting procedure shows that the fits are not exact. However, the fit is assumed to be correct since the fit is close to the graph in the lower regions of the peak flows. Based on the fit in the lower regions of the flow peaks, the linear increase can also be substantiated for the higher regions where the events are incidental. This study recommends analysing lengthier time-series data with more extreme values to test if the fitting procedure still holds.

Combination of measures

The combination of measures is incorporated in a way that the measures first have to be implemented in the area separately, where after they are combined by using the proposed equation 4.3. However, the measures may overlap in the project area, which is currently not incorporated into the model and calculations.

Limitations of the model and data

Of course, some remarks should be made concerning the Urban Water Balance Model (UWBM) itself. These remarks are related to three kinds of input data: Precipitation & Evaporation, Measures and Neighbourhoods, and calibration.

Input data

Precipitation & Evaporation

The input forcing data of the model is hourly precipitation data from De Bilt and calculated evaporation based on measured data at De Bilt. Calculation of evaporation using the Makkink equation is an approximation of the reference evaporation and will differ from the real-life evaporation that occurred per time step. Several studies have analysed the Makkink formula and compared the formula to the Penman-Monteith formula, where the main trend is that the Penman-Monteith can give a better estimate of the reference evaporation than Makkink [12]. However, the evaporation is currently also calculated with the Makkink formula by KNMI, which makes it possible to compare the calculated evaporation of this study with the calculated evaporation of the KNMI. Therefore, the calculated yearly evaporation in this study is compared to the yearly evaporation calculated by KNMI, which shows a difference of 20 mm, which is deemed acceptable.
Scenario 2 "Tropical climate", is constructed by multiplying the precipitation of scenario 1 "Dutch climate" by 3 and multiplying the evaporation by "2". This data set is used to mimic a tropical scenario with heavy

precipitation events. The reason why the data of scenario 1 is used to define data of the tropical scenario is due to the lack of hourly data of a tropical climate.

Measures

The parameters of the measures can be changed by the user of the UWBM. The used parameters in this study are delivered by Deltares as set for application in the Adaptation Support Tool [9]. The measures are defined using a 3-layer structure. The principle of using this 3-layered structure with several input parameters is to mimic the measures' predominant functionality. The used parameters and this structure have a closed water balance and the dominant hydrological processes are incorporated. However, the user should look carefully into the emptying mechanism of each measure. This mechanism is now a set parameter, for example, the controlled runoff of the underground storage tank, which is emptied within two days or infiltration of the infiltration boxes. The effectiveness of the measures is largely determined by the emptying mechanism as shown by the results. The controlled runoff has strong influence on the storage of the measure and with that the uncontrolled runoff of the measure. The resulting graphs of the five discussed measures show clear differences of effectiveness due to their different emptying mechanisms. However, it is recommended to do a thorough sensitivity analysis of the input parameters. The parameters chosen in this study are based on the expert judgement of Deltares.

Neighbourhoods

The neighbourhoods are defined within the model by parameters that the user can change. This study used parameters that are delivered by Deltares that were based on the study of Kleerekoper [24]. The data does take several assumptions that are discussed in this paragraph. Typically a neighbourhood has different types of roofs, but the model assumes that there is only one type of roof. For the neighbourhood, a soil- and crop type need to be selected. Both soil- and crop type of the neighbourhood are assumed to be one uniform over the area, while both may differ in real life in a single project area.
Using this model on a large spatial scale may be questionable due to the spatial heterogeneity of the urban environment. This is why this study applied an area of 14.5 hectares for calculating the factors. This ensured that the assumption of neglecting internal routing is substantiated. Besides, this study uses hourly data, which is long enough to ignore the internal routing still.
The user must define the unpaved/paved distribution carefully. This is because the amount of paved or unpaved area influences the runoff into and from the measure. This is why this study chose to base the neighbourhoods based on Kleerekoper [24].

Calibration

The model is currently not calibrated due to both lack of data of systems before and after implementation of urban runoff measures and the difficulty of retrieving such data. Models like SOBEK use water levels for calibration, but the UWBM needs both volumes and fluxes in an urban environment to calibrate the model since it is a conceptual multi-reservoir model. Based on this calibration, the confidence of the data can be improved. However, calibration is not of high importance in this model since the model gives the user a first insight into the effectiveness of different adaptation measures. The model is used to compare between different measures and which is best to implement in the area.

6

Conclusions & Recommendations

6.1. Conclusions

This research aims to determine if a flow peak reduction and storage peak reduction due to the implementation of blue-green-green adaptation measures can be defined by a factor when modelling the project area with an urban water balance model based on time series. The second goal is to determine whether the effectiveness of a combination of urban runoff reduction measures can be calculated and expressed for a whole project area. The research questions are answered.

How can the effectiveness of urban runoff reduction measures in a project area be defined and quantified when these are modelled for runoff volume reduction, flow peak reduction and storage peak reduction?
To analyse the possibility of defining a flow peak reduction and storage peak reduction, this study proposed a new method to obtain the return times of the peaks using time series. Based on the findings, it is concluded that the effectiveness can be defined when the urban runoff reduction measures are modelled for runoff volume reduction and flow peak reduction. However, the storage peak reduction factor is not a continuous factor which does not support the calculation of the factor using this method. The results show that the proposed method does not substantiate a storage peak reduction factor. Thus the effectiveness of urban runoff reduction measures can not be defined and quantified by a storage peak reduction. Using the found flow peak reduction factor, the effectiveness of urban runoff reduction measures in a project area can be defined and quantified more thoroughly together with the runoff volume reduction factor.

"How can this effectiveness be defined for a combination of different adaptation measures in a project area instead for a single measure and how can this effectiveness be expressed in performance indicators for the whole area?"
The conversion of the effectiveness of the measure area to a performance indicator for the whole area is done by using the same method is used as for the runoff volume reduction factor. The results show the possibility of converting the flow peak factor of the measure inflow area to the factor of the whole area. However, an assumption for an important parameter is made, making the final equation's reliability uncertain but acceptable in this study. This study concludes that the flow peak effectiveness for a combination of different adaptation measures in a project area can be defined using the proposed equation. However, more research is needed about this conversion.

6.2. Recommendations

The proposed method can produce the flow peak reduction factor to gain a more thorough insight into the modelled effectiveness of urban runoff measures in theory. However, this study concluded that a storage peak reduction factor is not substantiated using this proposed method. Besides, the conversion of the measure factor to the project factor is still based on some major assumptions. Therefore, this study recommends:

- to do more research into the storage peak reduction factor. The results show that a linear increase of the storage peak reduction exists but is not continuous and needs more thorough research. The graphs of the storage peaks strongly resemble the SDF curve, which could be a possible way to analyse the storage peaks based on long time series and return times.
- to analyse the way the urban runoff reduction measures are defined within the Urban Water Balance Model, which discharge their controlled runoff into the open water. Currently, the measures are defined to be empty in two days. A suggestion is to define the pump capacity based on the storage of the measure during the current time step.
- to analyse how the urban runoff reduction measures can be defined within the Urban Water Balance Model that discharge their controlled runoff into the groundwater. Currently, there results are unstable for the higher precipitation events and must be investigated more thoroughly.
- to do more research into the conversion of the measure factor into the project factor since the calculation is based on a major assumption about the percentage of peaks that is generated by the unpaved area. The influence of the peaks of the unpaved area compared to the paved area must be analysed more thoroughly.
- to research if it is possible to calibrate the model for several urban runoff reduction measures. Therefore, volumes and fluxes of the reservoirs are necessary, which are generally parameters that are hard to determine and quantify.

Appendices

A

Neighbourhood parameters

Neighbourhood	Post-war garden city low-rise (ov)	Garden town (ov)	Residential housing (ov)	Sub-urban expansion - Vinex (ov)	Community neighbourhood (ov)	Historical city block & pre-war city block (ov)	Post-war garden city high-rise (ov)	High-rise city centre (ov)
pr_frac	0.145	0.196667	0.26	0.105	0.15	0.453333	0.156667	0.425
cp_frac	0.10375	0.118333	0.1425	0.13625	0.10375	0.101667	0.1125	0.245
op_frac	0.31125	0.355	0.4275	0.40875	0.31125	0.305	0.3375	0.245
up_frac	0.4	0.276667	0.14	0.295	0.395	0.11	0.35	0.08
ow_frac	0.04	0.053333	0.03	0.055	0.04	0.03	0.043333	0.005
soiltype	5	17	17	17	5	5	17	5
croptype	1	1	1	1	1	1	1	1
infilcap_up	480	120	120	120	480	480	120	480
infilcap_op	10.9	2.73	2.73	2.73	10.9	10.9	2.73	10.9
storcap_ow	1030	1030	1030	1030	1030	1030	1030	1030
gwl_t0	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
down_seepage_flux	0.25	0.083	0.083	0.083	0.25	0.25	0.083	0.25
vc	1000	1000	1000	1000	1000	1000	1000	1000
w	50	50	50	50	50	50	50	50

B
Description of the applied measures

Measure	Description
Bioretention cell	A bioretention cell is a excavated depression in the ground planted with tolerant plant species to collect stormwater. It is typically designed to infiltrate, store and treat runoff for a particular area, through sedimentation, filtration, adsorption, and other natural processes.[5] The measure is applied on Open Paved area as a 3-layer structure.
Bioswale	A bioswale is a ditch where vegetation and a porous bottom and an underdrain are applied. The bioswale consists of two layers: A top layer with enhanced soil with plants and a lower layer consisting of gravel, scoria and clogging-proof baked clay pellets packed in geotextile. Below the second layer a drainage pipe is situated which is connected to the sewer system. The bioswale is implemented as a 3-layer structure and is implemented in the Open Paved area.
Deep groundwater infiltration	Deep groundwater infiltration infiltrates water into deep water aquifers. These aquifers are used as a source of drinking water. This measures facilitates in sustainable use of these aquifers.The measure is applied on Open Paved area as a 2-layer structure.
Ditches	Ditches are small channels that serve as temporary rainwater transportation, retention, and infiltration. This measure can be integrated into already green space or to the roadside. The ditches need extra space and maintenance. The measure is applied on Open Paved area as a 2-layer structure.
Drainage/Infiltration/Transport (DIT) drains	The DIT drain is a preforated horizontal pipe wrapped with geotextile. It is used to drain the ground, it allows water to infiltrate and it transports water. The measure is normally used if there isn't enough room for infiltration ditches or the ground has an insufficient permeability factor. The measure is applied on Open Paved area as a 2-layer structure.
Extensive green roofs	A green roof is a roof of a building covered with plants, generally with a substrate layer and a small drainage layer placed over the waterproofing membrane. If rainfall exceeds the storage capacity of the measure, the water is discharged to the sewer system. The storage of the soil layer is only emptied by gradual evapotranspiration, hence intensive green roofs are largely dependent on the antecedent conditions regarding their performance. The UWBM defines both intensive and extensive green roofs, where extensive green roofs have a thinner substrate layer [40]. Extensive green roofs are thus less effective in rainwater buffering than the intensive green roofs [3]. The extensive green roof is defined as a 3-layer structure in the UWBM, added on Paved Roof area.
Gravel layers	A gravel layer is a layer or shaft underground that is packed with gravel. The rainwater is allowed to infiltrate into the ground. Sometimes gravel layers are combined with DIT drains. The measure is applied on Open Paved area as a 2-layer structure.
Green roofs with drainage delay	A green roof is a roof of a building covered with plants, generally with a substrate layer and a small drainage layer placed over the waterproofing membrane. If rainfall exceeds the storage capacity of the measure, the water is discharged to the sewer system. The storage of the soil layer is only emptied by gradual evapotranspiration, hence intensive green roofs are largely dependent on the antecedent conditions regarding their performance. An extra feature added to this measure is drainage delay: The measure drains to the unsaturated zone, where the drainage is delayed. The measure is applied on Paved Roof area as a 3-layer structure.
Hollow roads	Hollow roades are concaves in the road that increase water capturing and drainage capacity. The roads allow water to be stored on the road and drain. The measure is applied on Closed Paved area as a 2-layer structure.
Infiltration boxes	An infiltration box is an underground facility that offers storage that is able to buffer rain water for short spaces of time, after which the water can be infiltrated into the ground [40]. Mostly, synthetic boxes and bulbs are used because they are light and offer a high storage capacity. In the UWBM the infiltration box is defined as a 2-layer structure and is defined in the Open Paved area. The bottom storage layer has a drainage delay controlled runoff and overflow is discharged to the sewer system.

Measure	Description
Infiltration fields and strips with surface storage	This measure are ditches or fields added next to paved area to temporarily store and infiltrate runoff. The water is partially filtered by the gravel and vegetation of the measure before it infiltrates. Permeability of the ground plays an important role for this measure. The measure is applied on Open Paved area as a 2-layer structure.
Infiltration shaft	Infiltration shafts are vertical facilities that allow rainwater to infiltrate more quickly. The measure is applied on Open Paved area as a 2-layer structure.
Infiltration trench	Infiltration trenches create temporary subsurface storage and enhance natural storage capacity of the ground. These trenches are shallow excavations with rubble or stone [38]. The measure is applied on Open Paved area as a 2-layer structure.
Intensive green roofs	As discussed for the extensive green roofs, a green roof is a roof of a building covered with plants, generally with a substrate layer and a small drainage layer placed over the waterproofing membrane. The intensive green roofs are thicker and can support a wider variety of plants than extensive green roofs. However, they are heavier and require more maintenance. The measure is applied on Paved Roof area as a 2-layer structure.
Lowering part of garden	By lowering a part of the garden it is possible to create extra storage or infiltration capacity. This measure also adds to a cooling effect of the area. The measure is applied on Unpaved area as a 2-layer structure.
Lowering part of terrace	Lowering part of terrace increases storage capacity of the area, because more depth is available to retain precipitation and buffer runoff. Water is drained in a controlled manner. The measure is applied on Closed Paved area as a 2-layer structure.
Permeable pavement (storage)	Permeable pavement is pavement that is made of porous material that is able to absorb rainfall. Water is either stored in the top layer or in the layer below which is the foundation. This measure also has a filtering mechanism as it can trap suspended solids and iflter pollutants from the water. The measure is applied on Open Paved area as a 2-layer structure.
Private green garden	Private green gardens are able to greatly influence the urban perceived temperature, control of the water and urban micro-climate. The measure is applied on Open Paved area as a 2-layer structure.
Rain barrel	The rain barrel is a storage barrel/tank that is very simple to install. Mostly, the measure catches runoff from roofs. The stored precipitation is mostly used for irrigation. Generally the rain barrels aren't designed large and an overflow is needed. The measure is applied on Paved Roof area as a 2-layer structure.
Rain garden	The rain garden is similar to a biorention cell where it is a depressed area in the landscape that collects rain water and allows it to infiltrate into the ground. The measure is applied on Open Paved area as a 2-layer structure.
Rainwater detention pond (wet pond)	Rainwater detention ponds are able to capture precipitaiton and allow it to drain off slowly. One drawback of this measure is that the water quality of the water is less easy to control. The measure is applied on Open Paved area as a 2-layer structure.
Rainwater storage below buildings	This measure is storing rainwater below buildings such as parking garages. It is possible to add relatively large volumes of storage, but it asks for additional costs and planning. The measure is applied on Paved Roof area as a 2-layer structure.
Retention soil filter	A retention soil filter is artificially created zones where the soil is able to filter or prufiy surface water. The measure is applied on Open Paved area as a 2-layer structure.

Measure	Description
Systems for rainwater harvesting	Systems for rainwater harvesting are most commonly used on roofs, where the water is captured. Mostly the water is used for purposes other than drinking water e.g. flushing the toilet or watering the garden. The system reduces the runoff to the sewer system and decreases the need for locally provided water supply. The measure is applied on Paved Roof area as a 2-layer structure.
Underground storage	The underground storage tank is designed to store excess runoff in their storage during wet periods. The underground storage tank creates additional underground storage volume for rainwater buffering during wet periods. The measure does not take up much space at the surface level. The underground storage tank is a 2-layer structure, where the bottom storage layer empties the measure with controlled runoff at a defined constant discharge rate. It is assumed that the full storage is emptied within 48 hours. The underground storage tank is implemented in the Closed Paved area as a 2-layer structure.
Urban wetland	An urban wetland is an artificial created wetland. By implementing a urban wetland the user can both increase the storage capacity of the area together with a water purification function. Urban wetlands also increase biodiversity. The flow regime in urban wetlands is less dynamic than natural wetlands due to artificial control. The urban wetland is defined as a 2-layer structure and is defined in the Closed Paved. The bottom storage layer is defined with a controlled runoff to represent drainage at a delayed pace.
Use of groundwater (aquifer storage and recovery)	Using groundwater is possible for activities like flushing toilets and irrigating plants. However, in many cases withdrawing groundwater can accelerate salinisation or reduce calcium-rich seepage which is undesirable. The measure is applied on Open Paved area as a 2-layer structure.
Water roof	Water roofs are flat roofs that are able to buffer precipitation by situating the overflow at a slightly higher level. The rainwater is drained of at a delayed pace by usage of narrow drainpipes. The measure is applied on Paved Roof area as a 1-layer structure.
Water square	A water square is a public space that is able to achieve rainwater retention. These measures are generally used in inner-city areas with little room for water buffers. The water square fills up when there is high precipitation event. The measure is applied on Open Paved area as a 2-layer structure.

C
Event separation

During this thesis, the event separation of the Urban Water Balance Model (UWBM) is updated to present a more precise and correct approach of defining the events. The old separation was done by only looking at the precipitation data and separating the events when there are 6 hours of no precipitation. The updated method separates the event when two conditions are met: 6 hours of no precipitation and 1 hour of no storage.

The events are defined based on the outputs of the baseline run of the model. The data needed for event separation is:

- Precipitation
- Open water storage (Open water target level - open water level at time step t)
- Time step length

The first step is to determine the time step of the separation of the precipitation data. This is done using the code defined in listing C.1. The input of the time step is defined in seconds, which is why it is first divided by 3600. This method makes sure that if the time step of 1 day is implemented, the separation occurs in only one time step. Otherwise the separation would take 6 days of no precipitation, which makes no sense in this case.

```
tsize = timestep / 3600.
ttot = len(precipitation)
if tsize <= 1:
    tseprain = 6. / tsize
else:
    if tsize < 2:
        tseprain = 6.
    else:
        if tsize < 3:
            tseprain = 2.
        else:
            tseprain = 1.
```

Listing C.1: Timestep length definition

When the separation timestep is known, we can define the events of both the precipitation and storage. First, the precipitation events and storage events are defined separately. Afterwards, the combined events are defined by analaysing both event separations. The separation process is presented in the next figures.

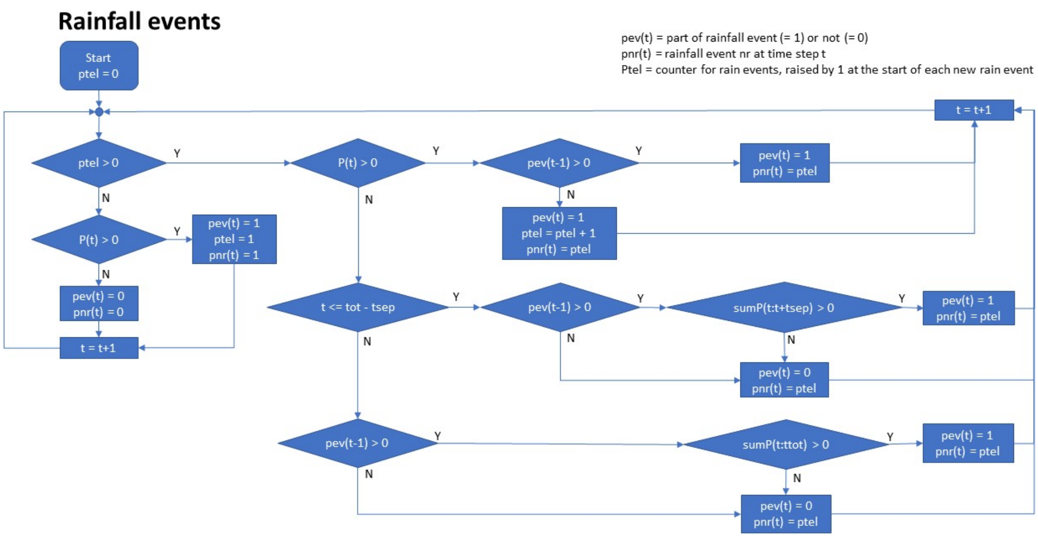


Figure C.1: Event separation of the precipitation events

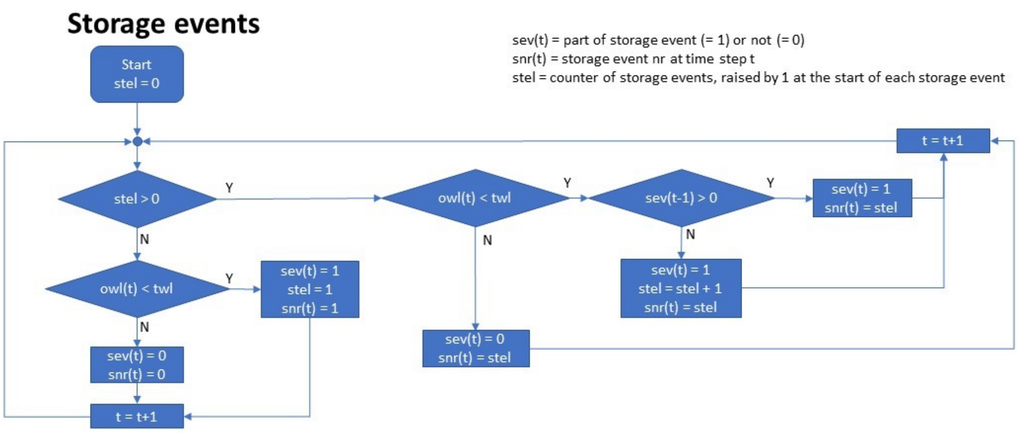


Figure C.2: Event separation of the storage events

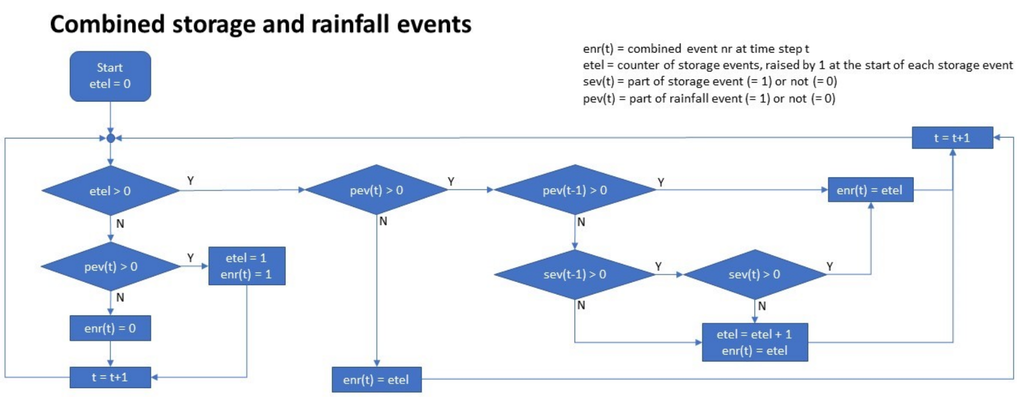


Figure C.3: Event separation of the combined events

In python, it is implemented as follows:

```python
def making_marks_prec(precipitation,timestep):
### SEPARATION OF RAINFALL EVENTS
# t         = time step number
# ttot      = total number of time steps
# ptel      = counter for rain events, raised by 1 at the start of each new rain event
# pev[t]    = part of rain event (value = 1), or not (value = 0)
# pnr[t]    = number of rain event, raised by 1 at the start of each new rain event

# # DETERMINE TSEPRAIN
    tsize = timestep / 3600.
    ttot = len(precipitation)
    if tsize <= 1:
        tseprain = 6. / tsize
    else:
        if tsize < 2:
            tseprain = 6.
        else:
            if tsize < 3:
                tseprain = 2.
            else:
                tseprain = 1.

# # START DEFINITION OF RAIN EVENTS
    ptel = 0
    pev = np.zeros_like(precipitation)
    pnr = np.zeros_like(precipitation)

    for i in range(len(precipitation)):
        if ptel == 0:
            #Determine start of the first rain event
            if precipitation[i] > 0:
                ptel = 1
                pev[i] = 1
                pnr[i] = 1
            else:
                pev[i] = 0
                pnr[i] = 0
        else:
            #all the other rain events
            if precipitation[i] > 0:
                if pev[i-1] > 0:
                    #Continuation of current rain event
                    pev[i] = 1
                    pnr[i] = ptel
                else:
                    #Start of new rain event
                    ptel = ptel + 1
                    pev[i] = 1
                    pnr[i] = ptel
            else:
                if i <= ttot - tseprain:
                    #Still sufficient time steps left to separate rain events
                    if pev[i-1]>0:
                        if sum(precipitation[int(i):int(i+tseprain)])>0:
                            # continuation of current rain event
                            pev[i] = 1
                            pnr[i] = ptel
                        else:
                            #Not part of rain event
                            pev[i] = 0
                            pnr[i] = ptel
                    else:
                            #Not part of rain event
                            pev[i] = 0
                            pnr[i] = ptel
                else:
                    if pev[i-1]>0:
                        #insufficient time steps left to separate rain events
                        if sum(precipitation[i : ttot]) > 0:
```

```
                            #continuation of last rain event
                            pev[i] = 1
                            pnr[i] = ptel
                        else:
                            # not part of last rain event
                            pev[i] = 0
                            pnr[i] = ptel
                    else:
                        pev[i] = 0
                        pnr[i] = ptel


    return pev, pnr

# END DEFINITION OF RAIN EVENTS

#DEFINITION STORAGE EVENTS
def making_marks_stor(precipitation, owl_stor):

### SEPARATION OF STORAGE EVENTS
# t         = time step number
# ttot      = total number of time steps
# stel      = counter for storage events, raised by 1 at the start of each new rain event
# sev[t]    = part of storage event (value = 1), or not (value = 0)
# snr[t]    = number of storage event, raised by 1 at the start of each new storage event
# seperation by 1 hour because of storage event

# # START DEFINITION OF RAIN EVENTS
    stel = 0
    sev = np.zeros_like(precipitation)
    snr = np.zeros_like(precipitation)
    for i in range(len(precipitation)):

        if stel == 0:
            #Determine start of the first rain event
            if owl_stor[i] > 0:
                stel = 1
                sev[i] = 1
                snr[i] = 1
            else:
                sev[i] = 0
                snr[i] = 0
        else:
            #all the other rain events
            if owl_stor[i] > 0:
                if sev[i-1] > 0:
                    #Continuation of current rain event
                    sev[i] = 1
                    snr[i] = stel
                else:
                    #Start of new rain event
                    stel = stel + 1
                    sev[i] = 1
                    snr[i] = stel
            else:
                sev[i] = 0
                snr[i] = stel


    return sev, snr

##END STORAGE EVENTS

#COMBINING PRECIPITATION EVENTS AND STORAGE EVENTS:
def making_marks(precipitation, timestep, owl_stor):

### SEPARATION OF combination EVENTS
# t         = time step number
# ttot      = total number of time steps
```

```
# stel       = counter for storage events, raised by 1 at the start of each new rain
    event
# sev[t]     = part of storage event (value = 1), or not (value = 0)
# snr[t]     = number of storage event, raised by 1 at the start of each new storage
    event
# seperation by 1 hour because of storage event

    pev = making_marks_prec(precipitation,timestep)[0]
    sev = making_marks_stor(precipitation,owl_stor)[0]
    etel = 0
    enr = np.zeros_like(precipitation)

    for i in range(len(precipitation)):
        if etel == 0:
            if pev[i] > 0:
                etel = 1
                enr[i] = 1
            else:
                enr[i] = 0
        else:
            if pev[i] >0:
                if pev[i-1]>0:
                    enr[i] = etel
                else:
                    if sev[i-1]>0:
                        if sev[i] > 0:
                            enr[i] = etel
                        else:
                            etel = etel +1
                            enr[i] = etel
                    else:
                        etel = etel + 1
                        enr[i] = etel
            else:
                enr[i] = etel

    return enr

###END RDL 20210503
```

Listing C.2: Timestep length definition

D

Simple reservoir model

To be able to quickly test the calculation of the peak runoff reduction coefficient, a simple reservoir model is set up. The definition of this model is presented in Figure D.1. The reservoir model is defined as a single storage reservoir, with four fluxes: P (Precipitation), E (Evaporation), $Q_{uncontrolled}$ (Uncontrolled runoff) and $Q_{controlled}$ (Controlled runoff). Besides the fluxes, a storage S is defined of the reservoir. Precipitation data is hourly data that is retrieved from the KNMI website [26]. The controlled runoff is a predefined daily runoff defined as 5 mm/day. The uncontrolled runoff can be infinite per time step, but only occurs when the storage is exceeded. Evaporation is defined at a standard daily value for simplicity at 3 mm/day for simplicity.

The water balance is defined as:

$$\frac{dS}{dt} = P(t) - E(t) - Q_{controlled}(t) - Q_{uncontrolled}(t) \tag{D.1}$$

With help of equation D.1 the storage of every time step t (hours) can be calculated.

The implementation of a measure is modelled by simply adding extra storage to the system. Logically, this should provide the system with more capacity to cope with higher intensity rainfall events with respect to the normal system. This should result in a higher controlled runoff and a lower uncontrolled runoff. The peaks of the uncontrolled runoff are expected to be lower, when antecedent conditions are favorable. Therefore, the peak runoff reduction factor can be calculated.

Using this simple reservoir model, the python code is tested before implemented in the UWBM.

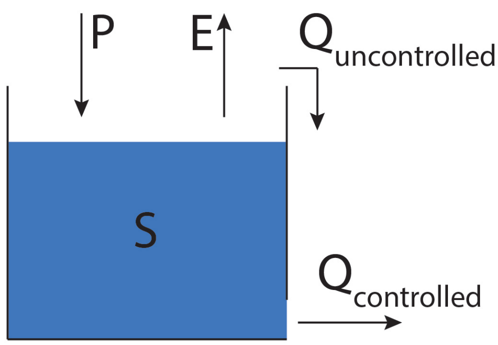


Figure D.1: Simple reservoir model used for testing the code for the determination of the peak runoff reduction factor. *P = Precipitation, E = Evaporation, S = Storage,* $Q_{uncontrolled}$ *= uncontrolled runoff,* $Q_{controlled}$ *= controlled runoff.*

E

KNMI Pre-Processing python script

```python
import pandas as pd
import numpy as np
import time
from pandas import read_csv
import matplotlib.pyplot as plt

filename = "KNMI_1991-2021_hourly_20210106.csv"
outputfile = "inputfile_UWB_30j_withrefgrass"
TypeET = "Makkink"

#Calculation of the Makkink Evaporation
def ET_mak(K,T):
    lambd = (2501 - 2.375*T)*1000 #J/kg
    gamma = 0.0646 + 0.00006*T #kPa/C
    es = 0.6107*10**((7.5*T)/(273.3+T))
    rho = 1000 #kg/m3
    s = ((7.5*237.3)/(237.3+T)**2) * np.log(10)*es
    K = Rn
    return (0.65*(s/(s+gamma))*K)/(lambd*rho) * 1000 #m/d to mm/d

#File to remove keys from a dataframe
def removekey(d, *keys):
    r = dict(d)
    for _ in keys:
        del r[_]
    return r

#function to read the .csv and store everything in a dataframe
def readfile (filename):
    data = pd.read_csv(filename, sep=',',skiprows=15,skipinitialspace=True)
    data = data.dropna() #skipped the rows until Q is defined
    dates = pd.to_datetime(data.YYYYMMDD, cache=True, format = "%Y%m%d")
    times = pd.to_timedelta(data.HH, unit='h')
    datetimes = dates + times
    data.insert(loc=0,column='date',value=datetimes)
    print (data)
    data = data.drop(['YYYYMMDD','HH','STN'],axis=1)
    #delete negative values and make precipitation in mm
    data['RH'] = data['RH'].replace(-1,0.25)
    data['RH'] = data['RH']*0.1 # 0.1 mm to 1 mm
    data['RH'] = data['RH'].astype(float)
    data['FH'] = data['FH']*0.1 # 0.1 m/s to 1 m/s
    data['FH'] = data['FH'].astype(float)
    data['T'] = data['T']*0.1 # 0.1 C to 1 C
    data['T'] = data['T'].astype(float)
    data['Q'] = data['Q']*10000 # J/cm2 to J/m2
    data['Q'] = data['Q'].astype(float)
    data['U'] = data['U']*0.01 # % to fraction
```

```python
    data['U'] = data['U'].astype(float)
    data = data.reset_index(drop=True)

#     dic = data.to_dict()
    return data

# Load in data
a = readfile(filename)

#Everything to a dictionary to make calculation faster
Rn = a['Q'].to_numpy()
T = a['T'].to_numpy()
h = a['U'].to_numpy()
u2 = a['FH'].to_numpy()
ET = [0]*len(u2)
ET_grass = [0]*len(u2)

#E_pot_ow is calculated by ET*1/0.9 based on documentation of Deltares and STOWA
outputfile = "inputfile_UWB_60j_20210516"
csvout = pd.DataFrame()
csvout['date'] = a['date']
csvout['P_atm'] = a['RH']

if TypeET == "Makkink":
    csvout['Ref.grass'] = a['ET']
    csvout['E_pot_OW'] = a['ET'] * (1/0.9) #Makkink to Penman according to STOWA
    verbetering act verdamping
#If evaporation is calced by Penman Monteith:
else:
    csvout['E_pot_OW'] = a['ET']
    csvout['Ref.grass'] = a['ET']* (0.9) #Penman to Makkink according to STOWA
    verbetering act verdamping

csvout.to_csv(outputfile+ '.csv',index=False)
```

Listing E.1: Code for Pre-Processing of the KNMI data

F

Graphical data analysis

In the field of water resources, often big data sets are used in computations using models, for example 30-year hourly data of precipitation can be used as an input to the UWM. Often graphs are used to visualize and analyse the data. These graphs provide visual summaries of the data and can provide a quick insight into the data [16]. Different methods can be used to establish these graphs, where in general the same four steps have to be taken. (i) First, the data has to be collected. After collecting the data, (ii)the data can be stored in different ways. (iii) When the data is stored, it can be visualized (using graphs) and (iv) with help of this visualization the probability distribution can be determined.

First, two probability distributions are discussed: the generalized extreme value distribution and the generalized logistic distribution. Afterwards, the methods for data visualisation are discussed.

F.0.1. Probability Distributions

There are several possibilities of using probability distributions within water resources. STOWA [1] uses two distributions to determine extreme rainfall in the netherlands: Generalized Extreme Value distribution and Generalized Logistic distribution. These distributions are three parameter distributions and are very useful in the field of hydrology.

Generalized Extreme Value distribution (GEV)

The Generalized Extreme Value distribution (GEV) is a parametric family of distributions and can be used to model the maxima in sample data. The GEV nests three main distributions: Gumbel (Type I), Fréchet (Type II) and Weibull (Type III) (Boudrissa et al. [4], Hosking et al. [18]). The GEV cumulative distribution function is given by Beersma et al. [1]:

$$F(x) = \begin{cases} \exp\left\{-\left[1-\kappa(\frac{x-\xi}{\alpha})\right]^{\frac{1}{\kappa}}\right\}, & \kappa \neq 0. \\ \exp\left(-\exp(-\frac{x-\xi}{\alpha})\right), & \kappa = 0. \end{cases} \tag{F.1}$$

Where:

- $\kappa = 0$ Gumbel (Type I)
- $\kappa < 0$ Fréchet (Type II)
- $\kappa > 0$ Weibull (Type III)

This distribution combines three parameters of limiting distributions for extreme values into one function [18]. The parameters are the location parameter (ξ), the scaling parameter (α) and the shape parameter (κ). The location parameter is equal to the average amount of precipitation that is exceeded once per year. The scaling parameter corresponds with the slope of the GEV Gumbel Plot i.e. how strongly the precipitation increases together with return time. The shape parameter κ=0, κ<0 and κ>0 correspond to Fisher-Tippett Types I, II, and III respectively. The distribution with $\kappa = 0$ is also known as the Gumbel distribution.

Generalized Logistic distribution (GLO)
The GLO distribution is a probability distrubtion with the same parameters (Location parameter ξ, scaling parameter α and shape parameter κ), but will give higher extreme values then GEV i.e. the probability of extreme values is higher for GLO with respect to GEV. The cumulative probability distribution is given by Beersma et al. [1]:

$$F_{GLO}(x) = \begin{cases} \left\{1 + \left[1 - \kappa(\frac{x-\xi}{\alpha})\right]^{\frac{1}{\kappa}}\right\}^{-1}, & \kappa \neq 0. \\ \left\{1 + \exp\left[-(\frac{x-\xi}{\alpha})\right]\right\}^{-1}, & \kappa = 0. \end{cases} \tag{F.2}$$

Where GLO with $\kappa = 0$ is also more known as a logistic distribution [1].

F.0.2. Data visualisation

The previous discussed probability distributions can be determined by ordering and visualising data in several ways. This section will discuss the use of plotting position and extreme value analysis, and Peak over Treshold analysis.

Plotting Position & Extreme Value Analysis
The plotting position is a way to describe data in an empirical cumulative distribution. The plotting position method is a suited method for the situation where the underlying probability of the data is unknown. The plotting position is made by ranking the data from smallest to largest. In case of a extreme value analysis, one can select the largest amount of precipitation or runoff in a time interval within a certain period [41]. In case of an annual maxima analysis, one choose the maximum value encountered in one year. The smallest value is assigned with a rank i = 1 and the biggest value is assigned with i=n, where n is the sample size of the data set. This data is then plotted along one axis, where the other axis is the "plotting position" axis. There are different types of plotting position formulas that can be used. The equations are based on a standard formula $p = (i - a)/(n + 1 - 2a)$ where p is the chance of non exceedance. The different equations are given in Table F.1.

Name	**a**	**formula**
Weibull (1939)	0	i / (n + 1)
Blom (1958)	0.375	(i - 0.375) / (n + 0.25)
Cunnane (1978)	0.4	(i - 0.4) / (n + 0.2)
Gringorten (1963)	0.44	(i - 0.44) / (n + 0.12)
Hazen (1914)	0.5	(i - 0.5) / n

Table F.1: Plotting position formulas ([7], [16])

The Weibull formula is a simple and commonly used formula in the field of hydrology, and also used by Deltares for determining the Runoff Factor [8]. After ranking the values, one can perform some fitting procedure e.g. regression. At last, the graph can be interpolated or extrapolated to determine the return period of the extreme value of interest. This interpolating and extrapolating is mostly done by modifying the scale of probability P that the plot of the cumulative distribution function of the variable appears as a straight line. This process is done by Deltares by calculating the return period of the data points (based on equation F.3) and changing the plot to a semi-logarithmic plot, where (almost) straight lines are returned as can be seen in Figure F.1. Generally, Gumbel paper probability paper is used [41], but also GEV (equation F.1) or the Pareto distributions can be used [30].

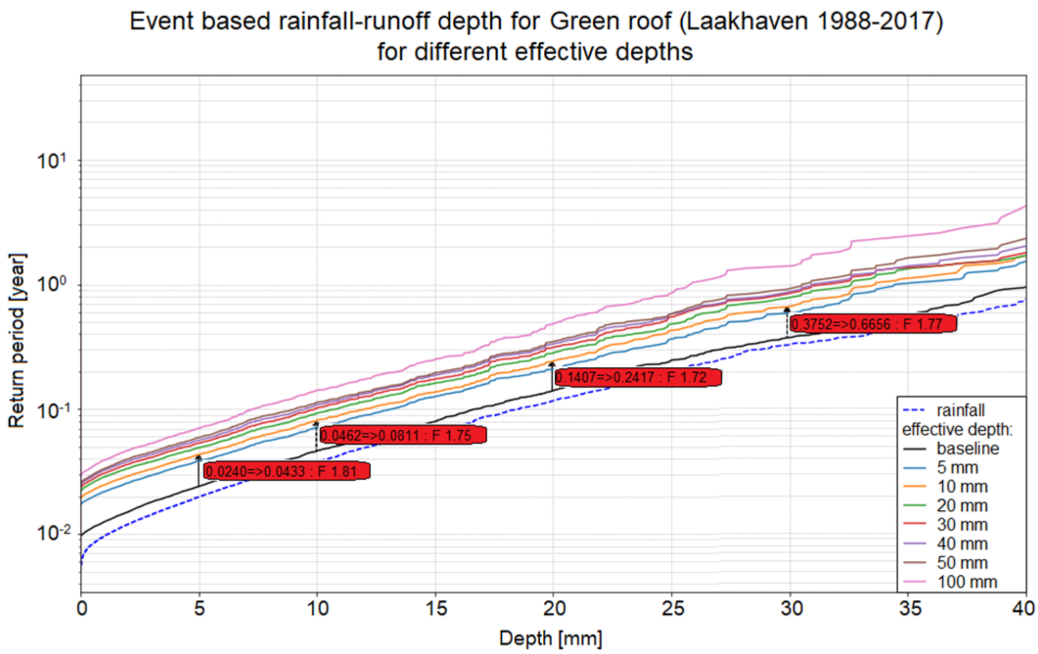


Figure F.1: Example of the usage of plotting position on a semi-logarithmic plot. [8]

The return time of exceedance of a certain data point can be calculated using the following simple equation [41]:

$$T = \frac{1}{1 - Pr(P(d) \leq H)} \tag{F.3}$$

With $Pr(P(d) \leq H)$ defined as the probability of that an amount of rainfall P falling within a time period d remains smaller than a certain value of H.

With help of plotting positions one can mainly compute three types of graphs: (i) comparing data to a Gaussian distribution (probability plot), (ii) comparing two or more data distributions (Q-Q plot) and (iii) to calculate frequencies of exceedance (using flow-duration curves) [16].

Probability Plot Probability plots are used to fit the data to a theoretical distribution e.g. normal, log normal or gamma distributions. A probability plot is constructed by plotting quantiles of sample data against quantiles of the chosen standardized theoretical distribution. An example of such a probability plot is given in Figure F.2. In this case, it can be concluded from the figure that the data plotted has a normal distribution.

Q-Q plot To directly compare two data sets, a quantile-quantile (Q-Q) plot can be used [16]. The Q-Q plots are similar to probability plots, but instead of comparing one data set to a theoretical distribution, two data sets are compared and plotted against each other. If both data sets are from the same distribution, the Q-Q plot will show a straight line.

Flow-Duration Curve The flow-duration curve shows the cumulative precipitation H that is exceeded in a time interval d every T years. The curve is composed by establishing for a number of periods the probability distribution of the extreme quantities of precipitation. First, the probability distribution is drawn using a quantile plot. Then, the x-percent point of this distribution has a return period of T, calculated with equation F.3. By plotting the x-percent point of all the distributions for $d_1 ... d_n$, the flow-duration curve can be acquired, as can be seen in Figure F.3.

On this curve both the precipitation of an area and the outflow of the area can be plotted. Since these duration

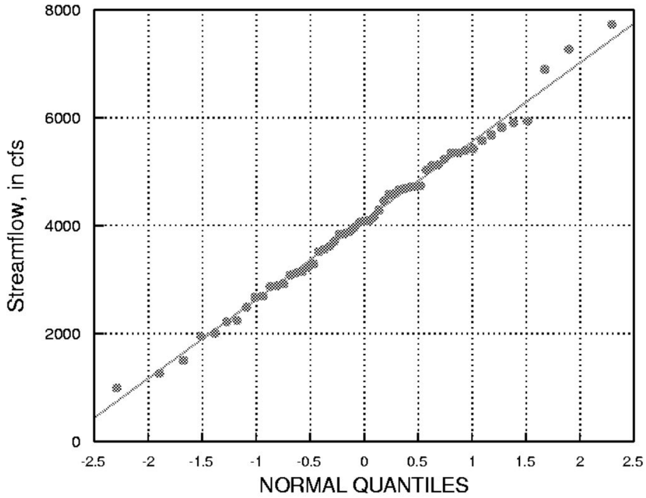
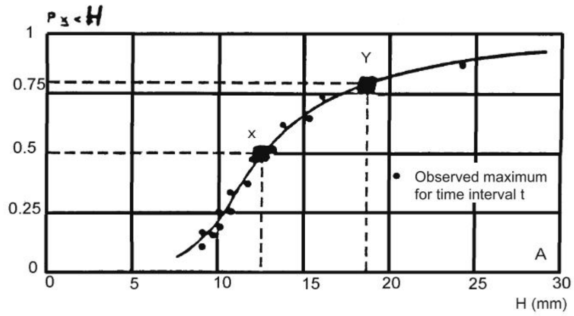
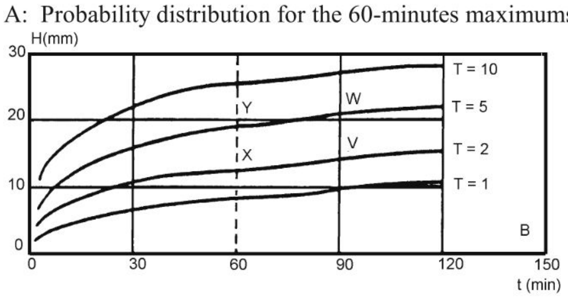


Figure F.2: Example of a probability plot. The data is compared to a normal distribution, where the plotting position formula of Cunnane is used. [16]



A: Probability distribution for the 60-minutes maximums



B: Duration curves with different return periods.

Figure F.3: Plots of the probability distribution and a duration curve. [41]

curves are made using a certain probability distribution, these probability distributions need to be explored more deeply. This will be discussed in the next section.

Peak over Treshold

The Peak over Treshold (PoT) determination is done by selecting peaks that are above a certain threshold. This method is different from the annual maxima method, because there are more data points chosen per year. Normally one can choose 2 or 3 data points per year, where annual maxima chooses only one. This analysis is done as follows [41].

First, the data is ordered and selected using the following three steps.

1. The periods for which the probability distribution will be determined are established ($d_1...d_i...d_n$);

2. The largest amount of precipitation or runoff in a time interval d_i within every storm of longer duration than d_i is selected. This data is sorted in increasing order of magnitude.
3. The number of times N that a certain threshold q is exceeded are determined with their values y_{ij}. If r years are available, N should be chosen that $N > 1.7r$.

Now that the data is known, the probability distributions can be determined. Usually, the number that the threshold is exceeded per year can be described as a Poisson-distribution. The extent in which the peaks exceed the threshold can be described as an exponential distribution. To calculate the probability of a peak having a certain magnitude can be done using the Gumbel cumulative probability distribution (equation F.4) or the GEV Gumbel Distribution (using $\kappa = 0$, equation F.5):

$$Pr\{x \leq y\} = \exp(-\exp(-y)) \tag{F.4}$$

$$Pr\left\{x \leq \frac{y-\xi}{\alpha}\right\} = \exp\left(-\exp(-\frac{y-\xi}{\alpha})\right) \tag{F.5}$$

The values y of the peak are re-scaled with help of the location parameter ξ and shape parameter α.

Estimating ξ and α can be done with use of the following equations:

$$\lambda = \frac{N}{r} \tag{F.6}$$

$$\frac{1}{\alpha} = \frac{\sum_{i=1}^{r}\sum_{j=0}^{n_i} y_{ij}}{N} - q \tag{F.7}$$

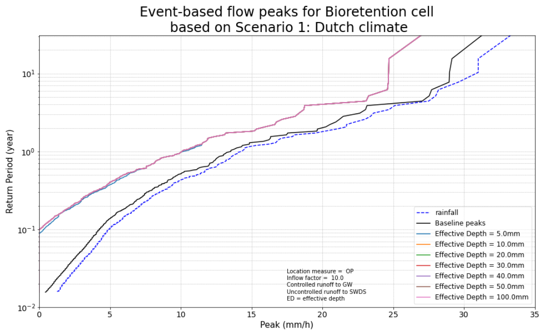
$$\xi = \frac{1}{\alpha}\ln\lambda \tag{F.8}$$

After calculation of the parameters, a complete computation of return periods can be performed. For example, at the 50 % point, the y-value is exceeded once per 2 years. This is calculated using equation F.3.

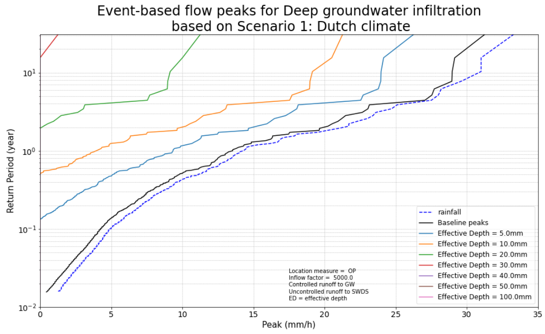
G

Graphical results of all measures: Flow peaks

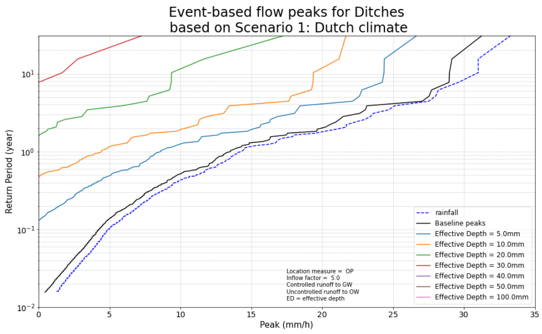
Scenario 1



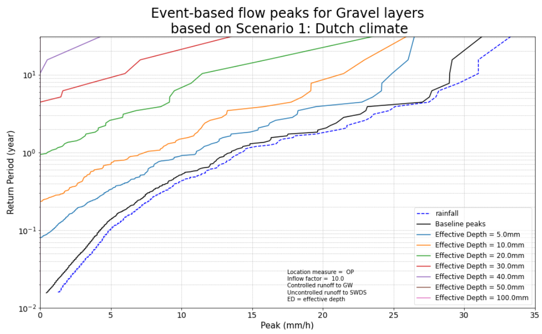
(a) flow peaks for the Bioretention cell.



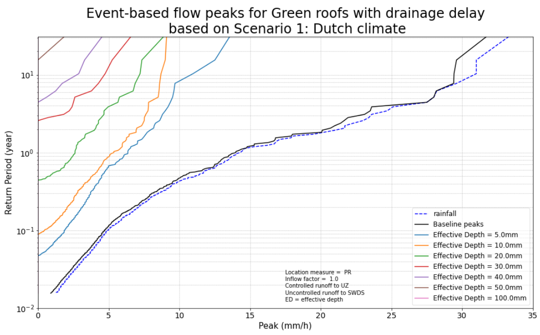
(b) Deep groundwater infiltration.



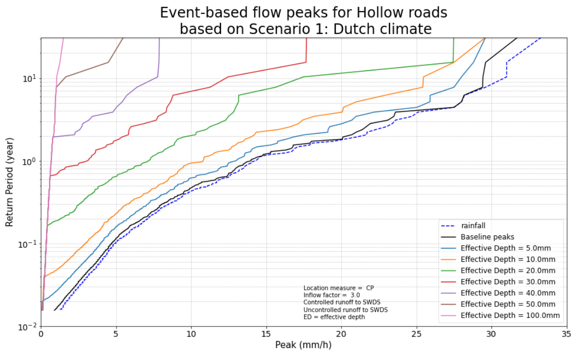
(c) Ditches



(d) Gravel layers

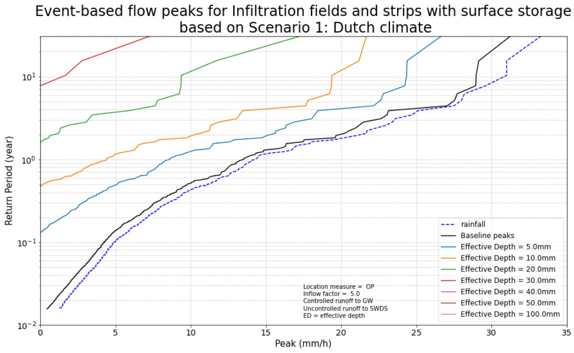


(e) Green roofs with drainage delay

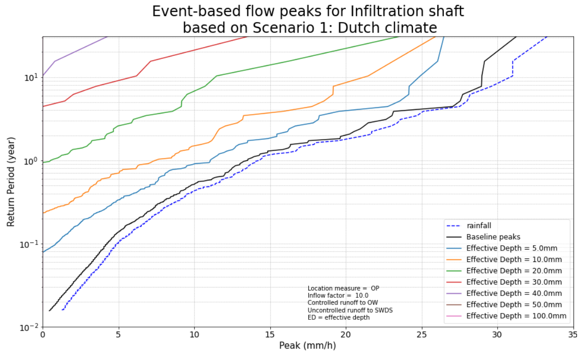


(f) Hollow roads

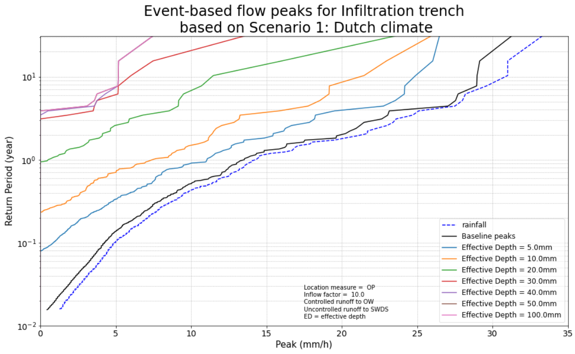
Figure G.1: Sub-figures representing the semi-logarithmic graphs for scenario 1 of the flow peaks in a residential area modelled in the Urban Water Balance Model.



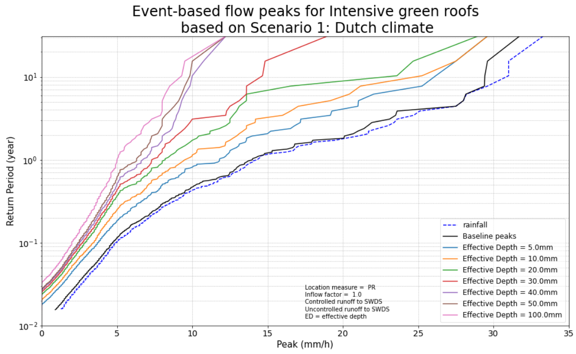
(a) Infiltration fields and strips with surface storage



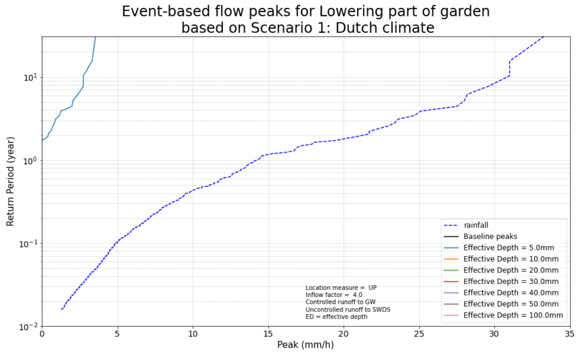
(b) Infiltration shaft



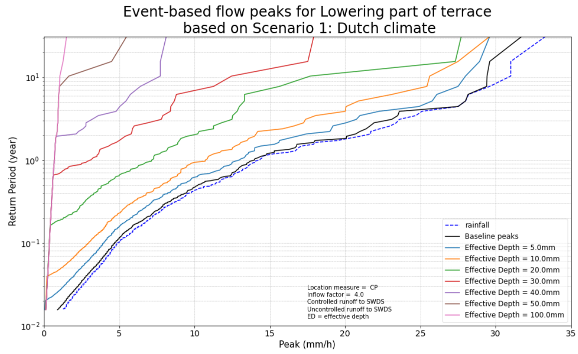
(c) nfiltration trench



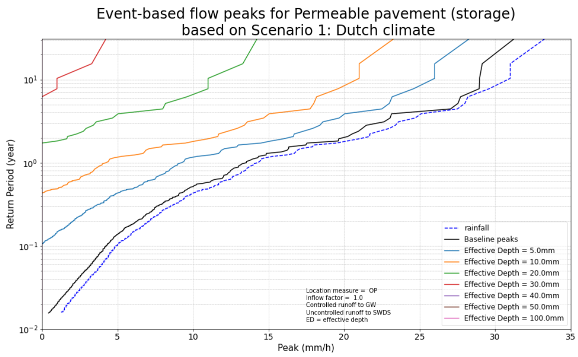
(d) Intensive green roofs



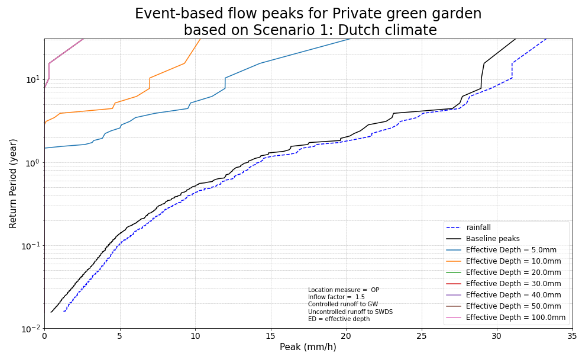
(e) Lowering part of garden



(f) Lowering part of terrace

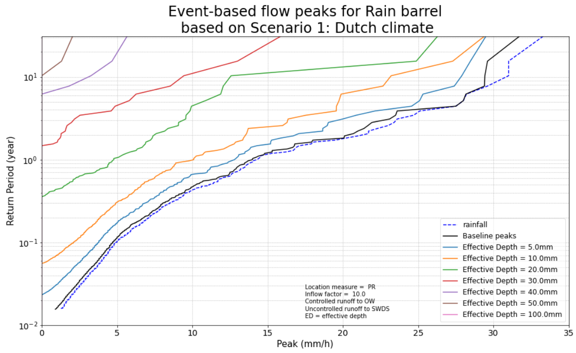


(g) Permeable pavement (storage)

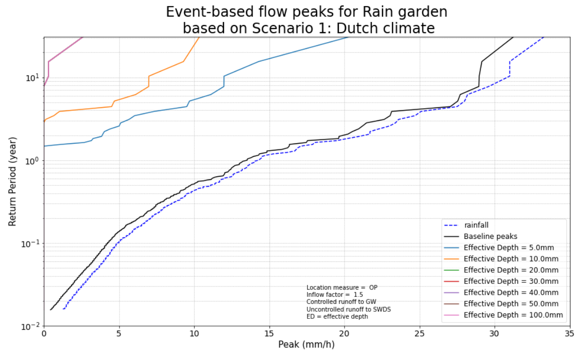


(h) Private green garden

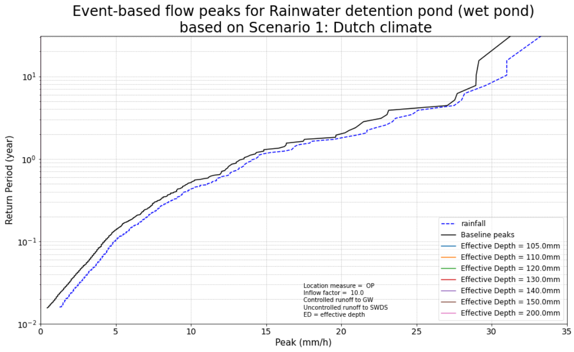
Figure G.2: Sub-figures representing the semi-logarithmic graphs for scenario 1 of the flow peaks in a residential area modelled in the Urban Water Balance Model.



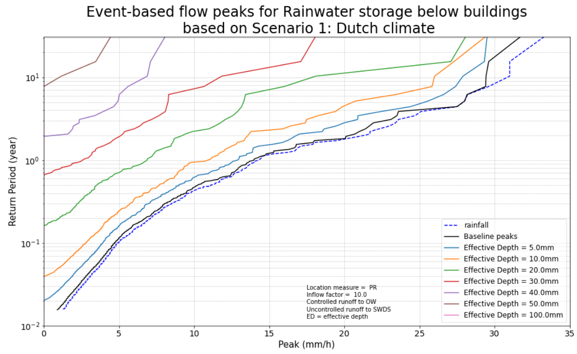
(a) Rain barrel



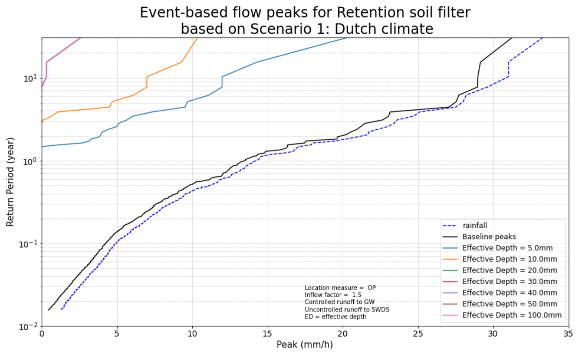
(b) Rain garden



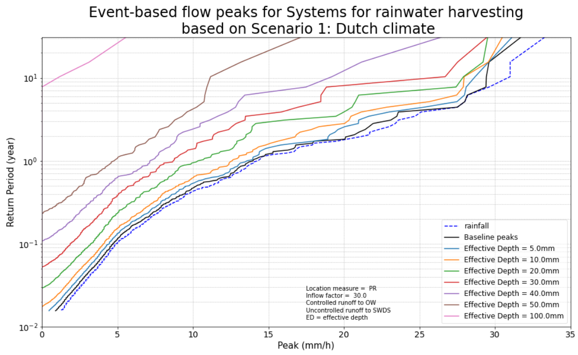
(c) Rainwater detention pond (wet pond)



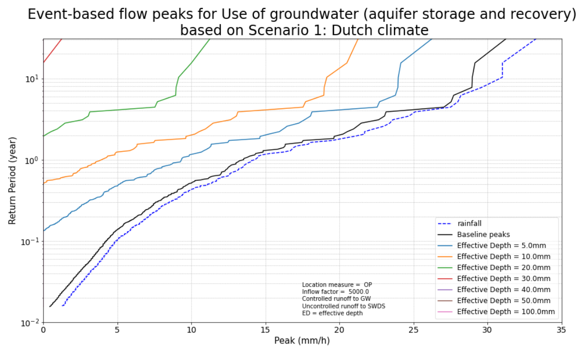
(d) Rainwater storage below buildings



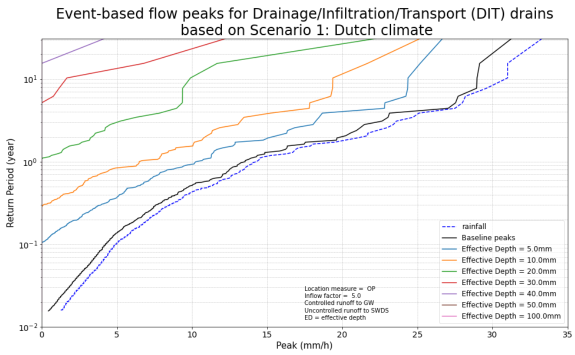
(e) Retention soil filter



(f) Systems for rainwater harvesting

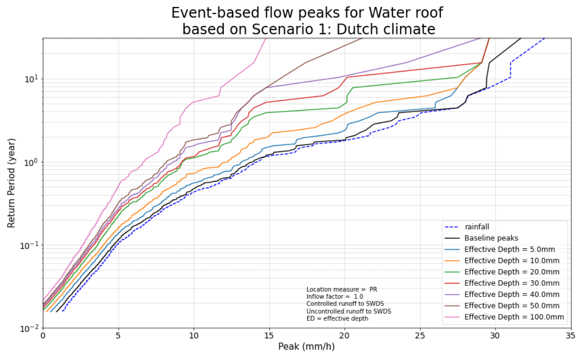


(g) Use of groundwater (aquifer storage and recovery)

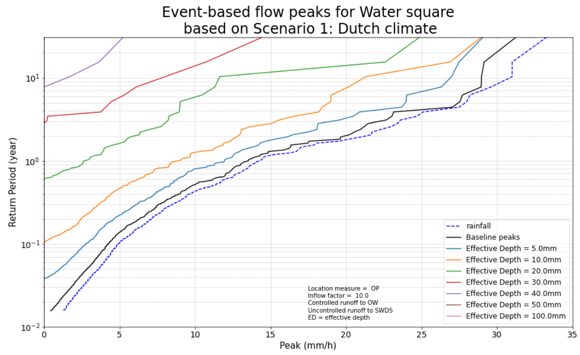


(h) Drainage/Infiltration/Transport drains

Figure G.3: Sub-figures representing the semi-logarithmic graphs for scenario 1 of the flow peaks in a residential area modelled in the Urban Water Balance Model.



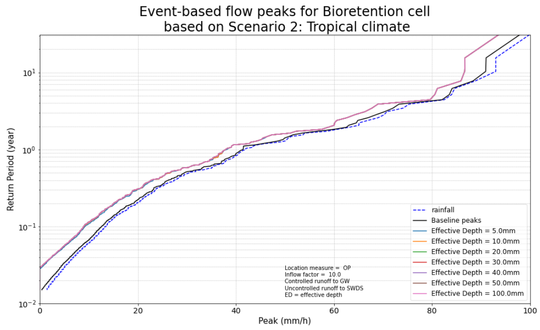
(a) Water roof



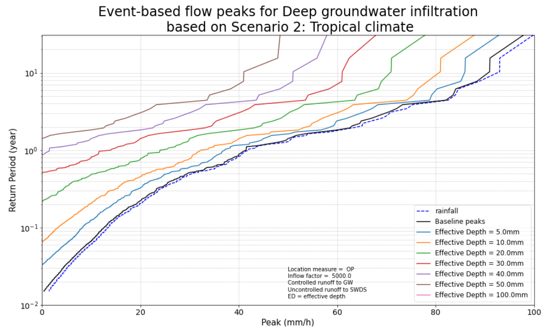
(b) Water square

Figure G.4: Sub-figures representing the semi-logarithmic graphs for scenario 1 of the flow peaks in a residential area modelled in the Urban Water Balance Model.

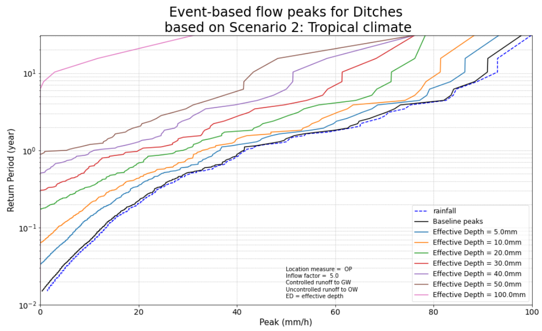
Scenario 2



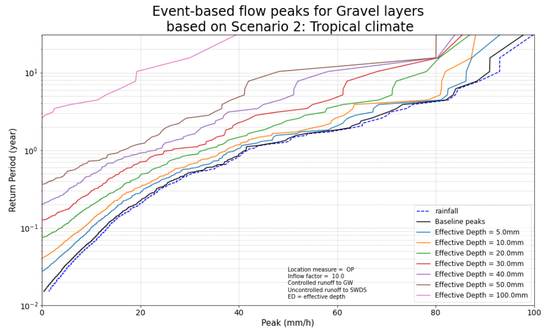
(a) Flow peaks for the Bioretention cell.



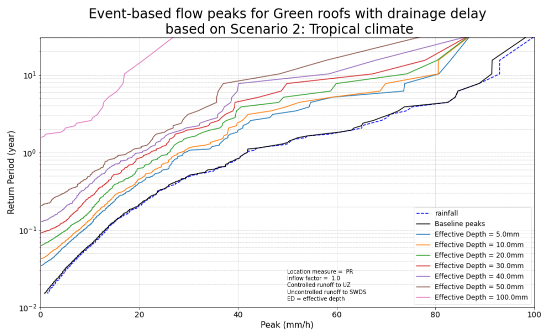
(b) Deep groundwater infiltration.



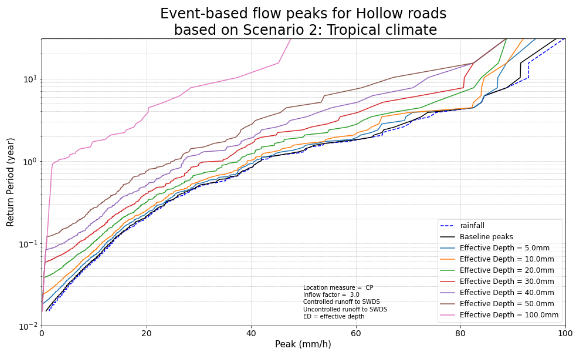
(c) Ditches



(d) Gravel layers

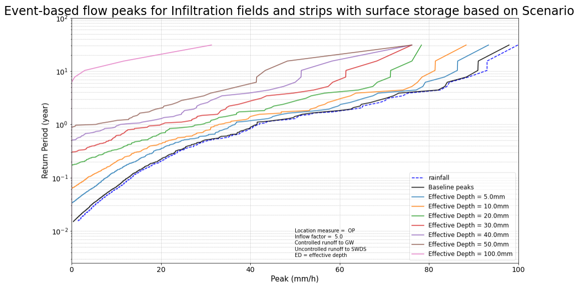


(e) Green roofs with drainage delay

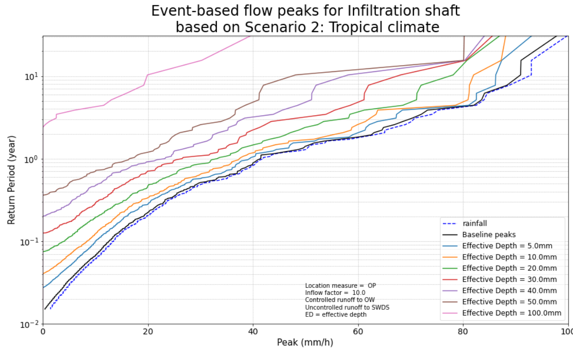


(f) Hollow roads

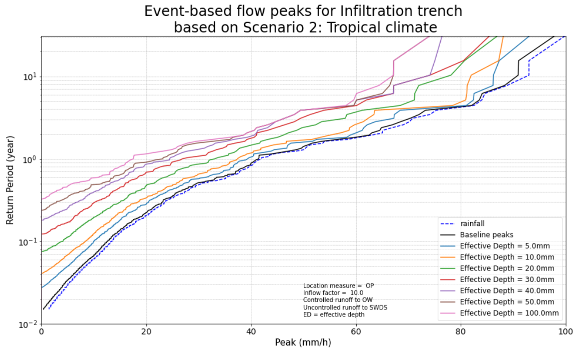
Figure G.5: Sub-figures representing the semi-logarithmic graphs for scenario 2 of the flow peaks in a residential area modelled in the Urban Water Balance Model.



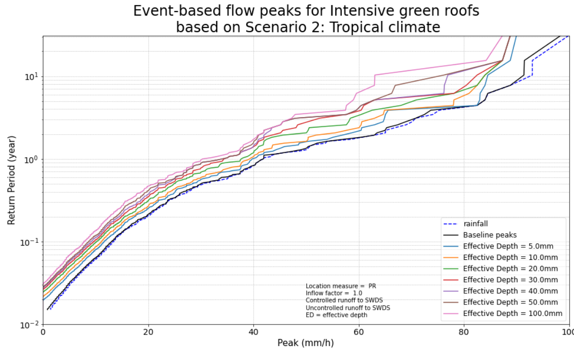
(a) Infiltration fields and strips with surface storage



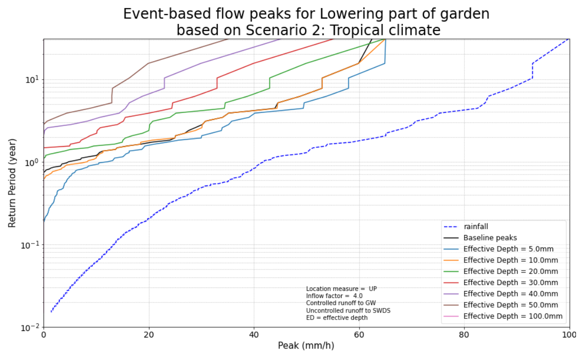
(b) Infiltration shaft



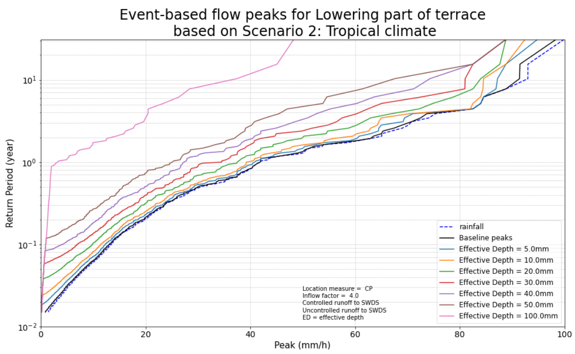
(c) nfiltration trench



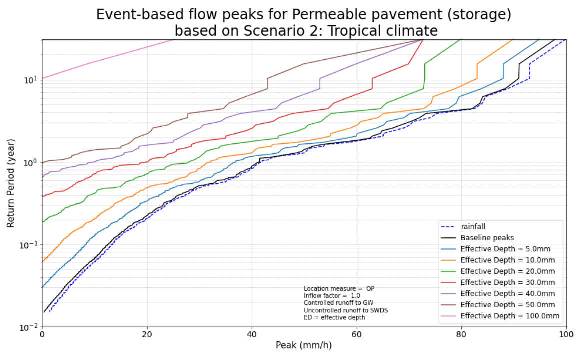
(d) Intensive green roofs



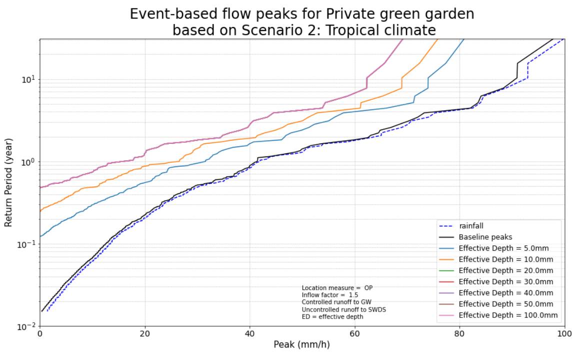
(e) Lowering part of garden



(f) Lowering part of terrace

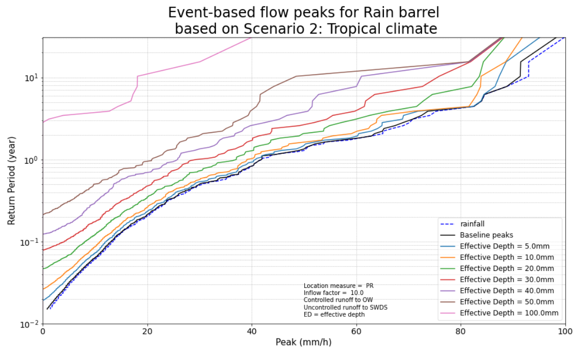


(g) Permeable pavement (storage)

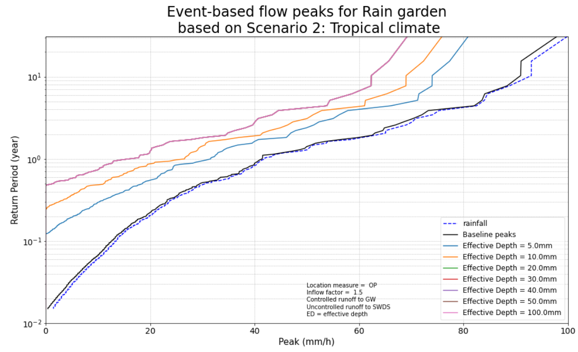


(h) Private green garden

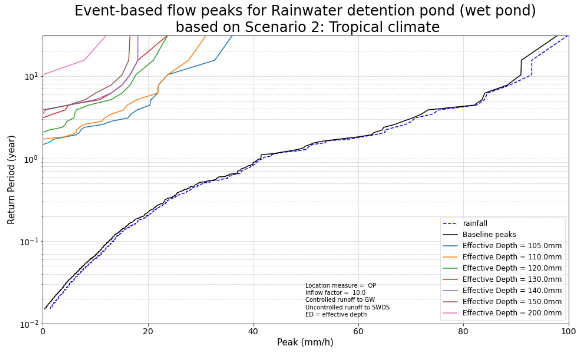
Figure G.6: Sub-figures representing the semi-logarithmic graphs for scenario 2 of the flow peaks in a residential area modelled in the Urban Water Balance Model.



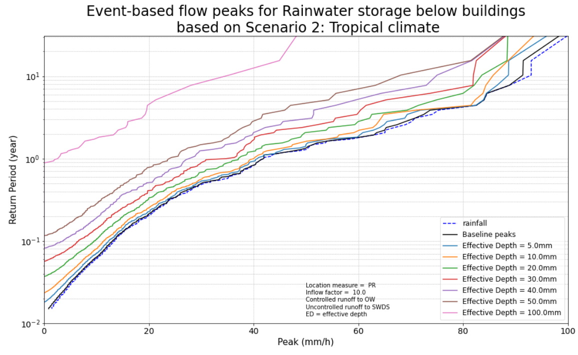
(a) Rain barrel



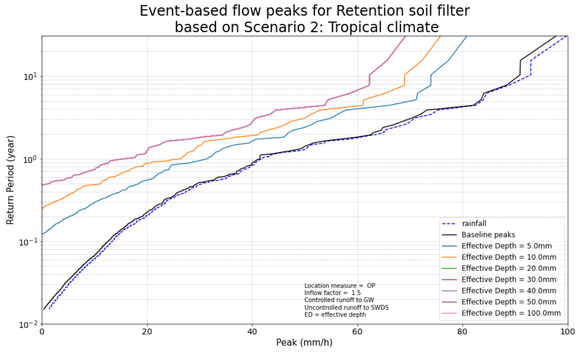
(b) Rain garden



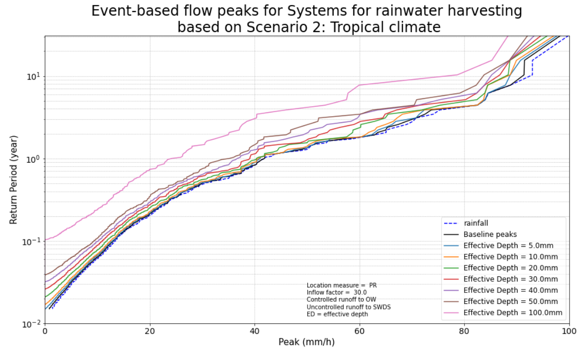
(c) Rainwater detention pond (wet pond)



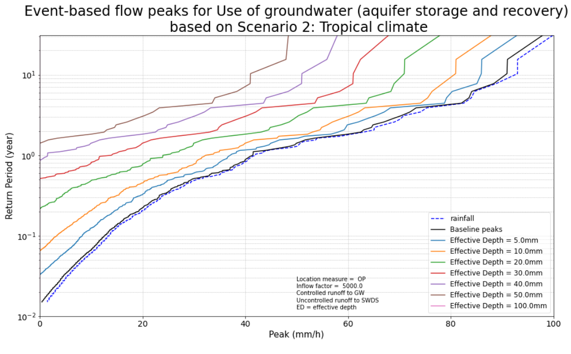
(d) Rainwater storage below buildings



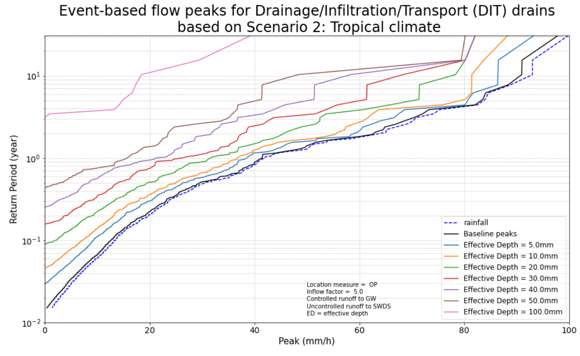
(e) Retention soil filter



(f) Systems for rainwater harvesting

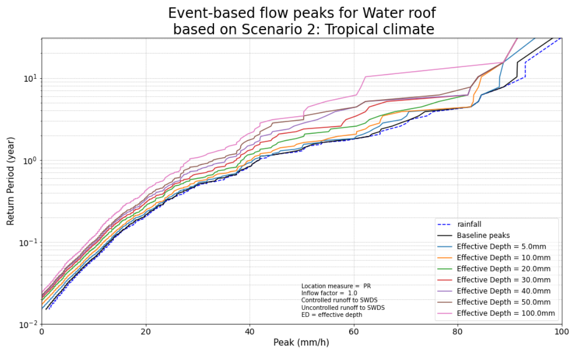


(g) Use of groundwater (aquifer storage and recovery)

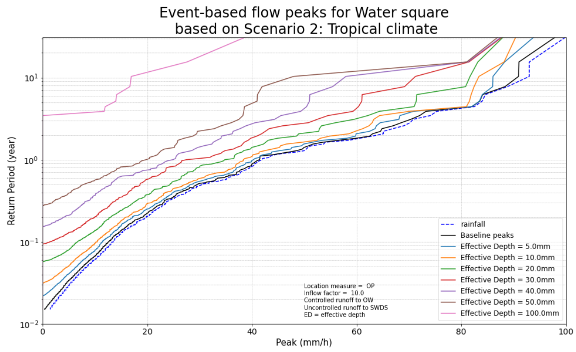


(h) Drainage/Infiltration/Transport drains

Figure G.7: Sub-figures representing the semi-logarithmic graphs for scenario 2 of the flow peaks in a residential area modelled in the Urban Water Balance Model.



(a) Water roof



(b) Water square

Figure G.8: Sub-figures representing the semi-logarithmic graphs for scenario 2 of the flow peaks in a residential area modelled in the Urban Water Balance Model.

H

Factor calculations: Flow peaks

This appendix describes the factor calculations for varying flow peaks from 2 to 20 mm/h for all the 29 implemented measures for scenario 1: Dutch climate. "inf" means infinity. However, this does not indicate that the effectiveness of the measure is infinite. The factor being "inf" occurs when a measure does not generate uncontrolled runoff. However, this occurs for the 30 years modeled in this study. For example, the Ditches of 30 mm show an infinite flow peak reduction factor for all flow peaks. Suppose one would select a lengthier time series (e.g., 100 or even 1000 years) with more intense rainfall events. In that case, the measure may now discharge uncontrolled runoff, which gives a flow peak reduction factor that is not infinite.

Scenario 1: Dutch climate

	Eff. depth	**Event-based flow peaks for scenario 1 [mm/h]**																
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**16**	**18**	**20**	**Avg**
Bioretention cell	5 mm	5.42	4.54	3.5	2.72	2.58	2.38	2.15	2.13	1.89	1.93	2.22	1.83	1.58	1.51	inf	inf	2.60
	10 mm	5.58	4.68	3.62	2.94	2.75	2.43	2.15	2.13	1.89	2	2.22	1.83	1.58	1.51	inf	inf	2.67
	20 mm	5.58	4.68	3.62	2.94	2.75	2.43	2.15	2.13	1.89	2	2.22	1.83	1.58	1.51	inf	inf	2.67
	30 mm	5.58	4.68	3.62	2.94	2.75	2.43	2.15	2.13	1.89	2	2.22	1.83	1.58	1.51	inf	inf	2.67
	40 mm	5.58	4.68	3.62	2.94	2.75	2.43	2.15	2.13	1.89	2	2.22	1.83	1.58	1.51	inf	inf	2.67
	50 mm	5.58	4.68	3.62	2.94	2.75	2.43	2.15	2.13	1.89	2	2.22	1.83	1.58	1.51	inf	inf	2.67
	100 mm	5.58	4.68	3.62	2.94	2.75	2.43	2.15	2.13	1.89	2	2.22	1.83	1.58	1.51	inf	inf	2.67
Bioswale	5 mm	5.8	4.87	3.83	3.27	3.3	3.15	2.89	2.8	2.5	2.87	2.81	2.5	2.4	inf	inf	inf	3.31
	10 mm	12.59	11.31	7.92	6.01	5.56	5.3	4.53	4	3.96	4.18	inf	inf	inf	inf	inf	inf	6.54
	20 mm	20.62	16.91	12.35	9.52	7.9	6.62	5.45	4.51	3.96	4.54	inf	inf	inf	inf	inf	inf	9.24
	30 mm	21.08	17.41	12.79	9.52	7.9	6.62	5.45	4.51	3.96	4.54	inf	inf	inf	inf	inf	inf	9.38
	40 mm	21.56	17.94	12.79	9.52	7.9	6.62	5.45	4.51	3.96	4.54	inf	inf	inf	inf	inf	inf	9.48
	50 mm	21.56	17.94	12.79	9.52	7.9	6.62	5.45	4.51	3.96	4.54	inf	inf	inf	inf	inf	inf	9.48
	100 mm	21.56	17.94	12.79	9.52	7.9	6.62	5.45	4.51	3.96	4.54	inf	inf	inf	inf	inf	inf	9.48
Deep Groundwater Infiltration	5 mm	7.03	5.71	4.25	3.46	3.07	2.59	2.46	2.31	2.26	2.3	2.38	1.97	1.61	1.64	inf	inf	3.07
	10 mm	19.54	15.49	11.73	9.05	7.27	6.56	5.41	4.48	3.91	4.18	inf	inf	inf	inf	inf	inf	8.76
	20 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Drainage/Infiltration/ Transport (DIT) drains	5 mm	5.74	4.58	3.54	2.68	2.65	2.36	2.32	2.1	1.81	1.87	2.18	1.95	1.6	1.56	inf	inf	2.64
	10 mm	12.81	11.24	8.41	6.13	4.8	4.29	3.85	3.7	3	3.56	3.9	inf	inf	inf	inf	inf	5.97
	20 mm	47.52	33.97	27.06	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	36.18
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Ditches	5 mm	7.16	5.93	4.59	3.56	3.15	2.64	2.71	2.75	2.43	2.3	2.37	1.95	1.6	1.68	inf	inf	3.20
	10 mm	19.07	14.95	10.94	8.43	6.94	6.45	5.36	4.46	3.72	3.72	inf	inf	inf	inf	inf	inf	8.40
	20 mm	79.12	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	79.12
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

	Eff. depth	Event-based flow peaks for scenario 1 [mm/h]																
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**16**	**18**	**20**	**Avg**
Extensive green roofs	5 mm	1.66	1.64	1.65	1.6	1.59	1.66	1.69	1.66	1.74	1.61	1.67	1.75	1.88	1.74	inf	inf	1.68
	10 mm	1.96	1.91	2.07	2.17	2.11	2.28	2.28	2.33	2.44	2.45	2.28	2.42	2.66	inf	inf	inf	2.26
	20 mm	2.32	2.48	2.82	3.18	3	3.08	3.18	3.54	3.67	3.63	3.92	inf	inf	inf	inf	inf	3.17
	30 mm	2.6	2.76	3.19	3.76	3.65	3.7	4.2	5.43	6.6	inf	inf	inf	inf	inf	inf	inf	3.99
	40 mm	2.79	3.04	3.61	4.45	4.54	5.1	6.18	9.68	inf	inf	inf	inf	inf	inf	inf	inf	4.92
	50 mm	2.97	3.28	3.97	5.24	5.31	6.73	9.55	inf	inf	inf	inf	inf	inf	inf	inf	inf	5.29
	100 mm	3.87	4.52	6.07	8.61	10.33	13.09	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	7.75
Gravel layers	5 mm	4.65	3.84	2.94	2.44	2.21	1.98	2.04	1.98	1.76	1.65	1.88	1.76	1.58	1.59	inf	inf	2.31
	10 mm	9.92	8.2	7	5.12	4.38	3.86	3.25	3.17	2.9	3.02	3.83	inf	inf	inf	inf	inf	4.97
	20 mm	40.94	29.31	21.8	18.93	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	27.75
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Green roofs with drainage delay	5 mm	3.98	4.15	5.03	5.81	5.19	6.14	6.69	9.32	inf	inf	inf	inf	inf	inf	inf	inf	5.79
	10 mm	6.86	7.73	7.4	7.6	8.03	9.89	15.65	inf	inf	inf	inf	inf	inf	inf	inf	inf	9.02
	20 mm	26.98	32.1	27.55	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	28.88
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Hollow roads	5 mm	1.5	1.44	1.45	1.38	1.29	1.36	1.31	1.33	1.32	1.23	1.33	1.23	1.3	1.32	1.22	inf	1.33
	10 mm	2.55	2.33	2.14	1.98	1.92	1.94	1.78	1.87	2	2	2.07	1.92	1.88	1.83	inf	inf	2.02
	20 mm	8.7	8.1	7.05	5.56	4.76	4.59	4.3	4.67	4.3	4.25	inf	inf	inf	inf	inf	inf	5.63
	30 mm	31.92	22.39	19.77	15.22	15.5	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	20.96
	40 mm	75.7	67.31	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	71.51
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Infiltration boxes	5 mm	3	2.77	2.3	1.87	1.82	1.73	1.68	1.78	1.58	1.61	1.63	1.55	1.39	1.5	1.47	inf	1.85
	10 mm	6.45	5.34	4.51	3.76	3.57	3.34	2.73	2.57	2.56	2.42	2.51	2.62	inf	inf	inf	inf	3.53
	20 mm	22.18	17.58	13.3	10.68	10.86	9.75	8.63	inf	inf	inf	inf	inf	inf	inf	inf	inf	13.28
	30 mm	76.15	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	76.15
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

	Eff. depth	**Event-based flow peaks for scenario 1 [mm/h]**																
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**16**	**18**	**20**	**Avg**
Infiltration fields and strips	5 mm	7.16	5.93	4.59	3.56	3.15	2.64	2.71	2.75	2.43	2.3	2.37	1.95	1.6	1.68	inf	inf	3.20
	10 mm	19.07	14.95	10.94	8.43	6.94	6.45	5.36	4.46	3.72	3.72	inf	inf	inf	inf	inf	inf	8.40
	20 mm	79.12	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	79.12
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Infiltration shaft	5 mm	4.61	3.82	2.93	2.44	2.2	1.97	2.04	1.97	1.76	1.63	1.87	1.76	1.58	1.59	inf	inf	2.30
	10 mm	9.86	7.96	6.98	5.11	4.33	3.77	3.25	3.12	2.9	2.86	3.82	inf	inf	inf	inf	inf	4.91
	20 mm	40.86	29.02	21.02	18.89	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	27.45
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Infiltration trench	5 mm	4.65	3.84	2.94	2.44	2.21	1.98	2.04	1.98	1.76	1.65	1.88	1.76	1.58	1.59	inf	inf	2.31
	10 mm	9.89	8.14	7	5.12	4.37	3.86	3.25	3.16	2.9	2.89	3.83	inf	inf	inf	inf	inf	4.95
	20 mm	40.94	29.3	21.8	18.93	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	27.74
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Intensive green roofs	5 mm	1.66	1.64	1.65	1.6	1.59	1.66	1.69	1.66	1.74	1.61	1.67	1.75	1.88	1.74	inf	inf	1.68
	10 mm	1.96	1.91	2.07	2.17	2.11	2.28	2.28	2.33	2.44	2.45	2.28	2.42	2.66	inf	inf	inf	2.26
	20 mm	2.32	2.48	2.82	3.18	3	3.08	3.18	3.54	3.67	3.63	3.92	inf	inf	inf	inf	inf	3.17
	30 mm	2.6	2.76	3.19	3.76	3.65	3.79	4.38	5.43	6.6	inf	inf	inf	inf	inf	inf	inf	4.02
	40 mm	2.78	3.04	3.61	4.45	4.54	5.1	6.18	9.68	inf	inf	inf	inf	inf	inf	inf	inf	4.92
	50 mm	2.95	3.28	4.01	5.34	5.47	6.73	9.55	inf	inf	inf	inf	inf	inf	inf	inf	inf	5.33
	100 mm	3.8	4.49	5.91	8.61	10.33	13.09	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	7.71
Lowering part of garden	5 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	10 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	20 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

	Eff. depth	**Event-based flow peaks [mm/h]**																
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**16**	**18**	**20**	**Avg**
Lowering part of terrace	5 mm	1.5	1.43	1.44	1.37	1.29	1.38	1.31	1.34	1.32	1.23	1.33	1.23	1.3	1.34	1.23	inf	1.34
	10 mm	2.53	2.33	2.15	1.98	1.92	1.94	1.78	1.87	2	2.01	2.07	1.91	1.89	1.82	inf	inf	2.01
	20 mm	8.7	8.1	7.05	5.56	4.74	4.57	4.31	4.67	4.32	4.17	inf	inf	inf	inf	inf	inf	5.62
	30 mm	31.81	22.39	19.83	14.81	15.5	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	20.87
	40 mm	76.02	67.31	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	71.67
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Permeable pavement (storage)	5 mm	5.94	5.13	3.81	3.14	2.65	2.49	2.25	2.42	2.26	2.12	2.16	1.84	1.52	1.41	1.5	inf	2.71
	10 mm	18.42	13.75	11.24	8.49	6.74	5.94	5.06	4.23	3.49	3.34	3.43	2.96	inf	inf	inf	inf	7.26
	20 mm	64.88	49.84	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	57.36
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Private green garden	5 mm	48.33	32.15	25.17	18.78	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	31.11
	10 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	20 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Rain barrel	5 mm	1.75	1.62	1.62	1.5	1.39	1.47	1.37	1.42	1.41	1.29	1.39	1.32	1.38	1.38	1.25	inf	1.44
	10 mm	3.61	3.25	2.98	2.65	2.36	2.61	2.39	2.49	2.11	2.23	2.12	2.02	2.33	1.94	inf	inf	2.51
	20 mm	20.09	15.42	11.05	9.11	7.54	7.92	7.36	6.94	inf	inf	inf	inf	inf	inf	inf	inf	10.68
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Rain garden	5 mm	48.33	32.15	25.17	18.78	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	31.11
	10 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	20 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

	Eff. depth	Event-based flow peaks for scenario 1 [mm/h]																
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**16**	**18**	**20**	**Avg**
Rainwater detention pond	5 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	10 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	20 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Rainwater storage below buildings	5 mm	1.48	1.49	1.4	1.4	1.29	1.44	1.32	1.38	1.32	1.26	1.32	1.29	1.37	1.25	1.26	inf	1.35
	10 mm	2.52	2.42	2.1	2.1	2.03	1.97	1.82	1.99	2.01	1.81	2.04	2.02	2.16	1.82	inf	inf	2.06
	20 mm	8.95	8.03	6.09	6.09	5.07	5.08	4.73	5.19	4.75	4.27	inf	inf	inf	inf	inf	inf	5.83
	30 mm	24.67	21.14	16.51	16.51	14.3	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	18.63
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Retention soil filter	5 mm	48.33	32.15	25.17	18.78	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	31.11
	10 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	20 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Systems for rainwater harvesting	5 mm	1.16	1.14	1.18	1.15	1.12	1.12	1.13	1.16	1.14	1.1	1.07	1.09	1.07	1.18	1	1.41	1.14
	10 mm	1.42	1.37	1.35	1.32	1.27	1.34	1.36	1.35	1.33	1.25	1.34	1.33	1.31	1.35	1.42	inf	1.34
	20 mm	2.19	2.04	1.99	2	1.93	2.05	1.91	2.09	2.02	1.94	2.07	2.13	2.58	inf	inf	inf	2.07
	30 mm	3.87	3.66	3.4	3.31	3.03	3.07	3.06	3.04	2.96	3.16	3.63	3.52	inf	inf	inf	inf	3.31
	40 mm	7.01	6.73	5.85	5.41	4.25	4.23	4.53	5.46	5.15	inf	inf	inf	inf	inf	inf	inf	5.40
	50 mm	15.04	14.5	11.22	9.27	7.47	8.35	8.33	inf	inf	inf	inf	inf	inf	inf	inf	inf	10.60
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Underground storage	5 mm	2.19	2.07	1.93	1.61	1.56	1.48	1.47	1.59	1.55	1.51	1.5	1.49	1.35	1.41	1.35	inf	1.60
	10 mm	5.03	4.51	3.83	3.4	3.13	2.88	2.58	2.54	2.45	2.31	2.46	2.38	2.36	inf	inf	inf	3.07
	20 mm	25.4	19.91	16.53	11.79	10.96	9.85	9.29	inf	inf	inf	inf	inf	inf	inf	inf	inf	14.82
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

	Eff. depth	**Event-based flow peaks for scenario 1 [mm/h]**																
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**16**	**18**	**20**	**Avg**
Urban wetland	5 mm	1.59	1.5	1.52	1.41	1.29	1.46	1.34	1.4	1.36	1.26	1.37	1.31	1.38	1.36	1.25	inf	1.39
	10 mm	2.75	2.53	2.44	2.14	2.04	2.03	1.84	2.1	2.03	2.02	2.11	2.02	2.16	1.85	inf	inf	2.15
	20 mm	10.03	8.96	7.96	6.09	5.2	5.54	4.9	5.19	4.76	4.35	inf	inf	inf	inf	inf	inf	6.30
	30 mm	34.08	25.05	21.6	17.21	15.82	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	22.75
	40 mm	98.36	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	98.36
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Use of groundwater	5 mm	7.03	5.71	4.25	3.46	3.07	2.59	2.46	2.31	2.26	2.3	2.38	1.97	1.61	1.64	inf	inf	3.07
(acquifer storage)	10 mm	19.54	15.49	11.73	9.05	7.27	6.56	5.41	4.48	3.91	4.18	inf	inf	inf	inf	inf	inf	8.76
	20 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Water roof	5 mm	1.19	1.18	1.21	1.19	1.16	1.19	1.15	1.2	1.18	1.14	1.2	1.12	1.15	1.2	1.17	1.3	1.18
	10 mm	1.4	1.4	1.41	1.39	1.4	1.51	1.5	1.54	1.53	1.5	1.54	1.53	1.76	1.73	1.49	inf	1.51
	20 mm	1.64	1.69	1.81	1.93	1.96	2.06	2.06	2.24	2.36	2.3	2.55	2.75	inf	inf	inf	inf	2.11
	30 mm	1.83	1.92	2.11	2.21	2.19	2.28	2.28	2.37	2.44	2.54	3.12	3.49	inf	inf	inf	inf	2.40
	40 mm	1.96	2.05	2.3	2.38	2.42	2.55	2.69	2.95	3.3	3.09	3.58	inf	inf	inf	inf	inf	2.66
	50 mm	2.07	2.21	2.56	2.78	2.78	2.9	3.09	3.3	3.88	3.67	4.19	inf	inf	inf	inf	inf	3.04
	100 mm	2.57	2.95	3.7	4.45	4.65	5.29	5.83	7.49	inf	inf	inf	inf	inf	inf	inf	inf	4.62
Water square	5 mm	2.2	2.04	1.93	1.61	1.59	1.49	1.48	1.58	1.55	1.5	1.55	1.48	1.35	1.4	1.35	inf	1.61
	10 mm	4.99	4.51	3.84	3.39	3.13	2.87	2.57	2.54	2.45	2.3	2.47	2.39	2.37	inf	inf	inf	3.06
	20 mm	25.11	20.03	16.44	11.81	10.95	9.81	8.83	inf	inf	inf	inf	inf	inf	inf	inf	inf	14.71
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

Scenario 2: Tropical climate

Measure	**Eff. depth**	**Event-based flow peaks for scenario 2 [mm/h]**																
		5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**20**	**30**	**40**	**50**	**60**	**Avg**
Bioretention cell	5 mm	1.6	1.6	1.57	1.53	1.62	1.64	1.52	1.5	1.46	1.42	1.39	1.36	1.13	1.3	1.14	1.13	1.43
	10 mm	1.65	1.64	1.63	1.59	1.67	1.7	1.58	1.52	1.53	1.45	1.44	1.38	1.13	1.3	1.14	1.13	1.47
	20 mm	1.66	1.65	1.64	1.6	1.7	1.73	1.61	1.53	1.53	1.45	1.45	1.38	1.13	1.3	1.14	1.13	1.48
	30 mm	1.66	1.65	1.64	1.6	1.7	1.73	1.61	1.54	1.54	1.45	1.45	1.38	1.13	1.3	1.14	1.13	1.48
	40 mm	1.66	1.65	1.64	1.6	1.7	1.73	1.61	1.54	1.54	1.45	1.45	1.38	1.13	1.3	1.14	1.13	1.48
	50 mm	1.66	1.65	1.64	1.6	1.7	1.73	1.61	1.54	1.54	1.45	1.45	1.38	1.13	1.3	1.14	1.13	1.48
	100 mm	1.66	1.65	1.64	1.6	1.7	1.73	1.61	1.54	1.54	1.45	1.45	1.38	1.13	1.3	1.14	1.13	1.48
Bioswale	5 mm	1.67	1.69	1.72	1.94	1.94	1.9	1.78	1.73	1.72	1.65	1.65	1.5	1.2	1.28	1.19	1.36	1.62
	10 mm	2.18	2.19	2.43	2.32	2.26	2.28	2.2	2.09	2.02	1.91	1.83	1.74	1.38	1.47	1.24	inf	1.97
	20 mm	3.03	2.98	3.13	2.9	2.81	2.81	2.62	2.45	2.39	2.27	2.24	2.05	1.53	1.56	1.29	inf	2.40
	30 mm	3.52	3.5	3.52	3.22	3.19	3.19	2.91	2.79	2.71	2.43	2.37	2.14	1.61	1.62	1.29	inf	2.67
	40 mm	3.85	3.71	3.69	3.33	3.27	3.35	3.02	2.86	2.74	2.48	2.51	2.17	1.65	1.62	1.29	inf	2.77
	50 mm	3.93	3.8	3.76	3.39	3.3	3.4	3.04	2.94	2.87	2.6	2.54	2.24	1.66	1.62	1.29	inf	2.83
	100 mm	3.96	3.83	3.81	3.43	3.35	3.43	3.07	2.96	2.9	2.6	2.57	2.28	1.66	1.62	1.29	inf	2.85
Deep Groundwater Infiltration	5 mm	1.84	1.83	1.81	1.84	1.89	1.88	1.75	1.75	1.68	1.56	1.54	1.46	1.17	1.31	1.15	1.31	1.61
	10 mm	3.58	3.5	3.35	3.16	3.12	3.1	2.92	2.81	2.61	2.46	2.32	2.03	1.51	1.59	1.26	inf	2.62
	20 mm	10.06	9.85	8.94	7.94	7.47	7.3	6.37	5.76	5.15	4.69	4.38	3.47	2.75	2.06	inf	inf	6.16
	30 mm	17.93	16.58	14.75	13.7	12.38	12.31	11.01	10.72	9.52	8.21	7.84	6.32	3.56	inf	inf	inf	11.14
	40 mm	33.44	30.13	26.63	24.09	22.06	21.31	18.99	17.24	15.52	13.41	12.29	8.18	inf	inf	inf	inf	20.27
	50 mm	49.33	44.2	38.86	33.54	30.21	27.57	23.85	21.09	19.83	17.6	17.59	inf	inf	inf	inf	inf	29.42
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Drainge/Infiltration/ Transport (DIT) drains	5 mm	1.61	1.62	1.61	1.55	1.59	1.69	1.54	1.53	1.52	1.39	1.42	1.34	1.13	1.3	1.13	1.18	1.45
	10 mm	2.29	2.25	2.21	2.09	2.06	2.1	1.97	1.91	1.89	1.88	1.78	1.6	1.29	1.42	1.2	inf	1.86
	20 mm	3.96	3.83	3.86	3.58	3.33	3.39	3.09	2.95	2.85	2.65	2.52	2.28	1.75	1.69	1.75	inf	2.90
	30 mm	6.46	6.26	5.91	5.6	5.18	5.2	4.64	4.42	4.41	4.12	3.85	3.36	2.17	2.78	inf	inf	4.60
	40 mm	10.53	9.83	10.07	9.26	9.08	8.53	7.94	7.41	7.13	6.35	5.89	4.23	3.64	inf	inf	inf	7.68
	50 mm	17.13	16.46	15.13	13.82	12.4	11.41	9.89	8.74	7.83	7.47	7.01	6.17	inf	inf	inf	inf	11.12
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Ditches	5 mm	1.93	1.96	2.01	1.95	2.02	2.05	1.91	1.84	1.79	1.61	1.6	1.55	1.18	1.33	1.18	1.26	1.70
	10 mm	3.42	3.35	3.21	3.04	2.98	3.01	2.81	2.73	2.49	2.39	2.25	1.95	1.5	1.58	1.25	inf	2.53
	20 mm	7.12	6.82	6.21	5.79	5.49	5.07	4.54	4.33	4.08	3.76	3.54	3.06	2.07	1.99	inf	inf	4.56
	30 mm	11.68	11.01	9.9	9.17	8.85	9.29	8.06	8.02	7.73	6.65	6.26	4.46	2.91	inf	inf	inf	8.00
	40 mm	21.05	19.4	17.87	16.07	14.46	14.07	12.76	11.25	10.02	8.58	7.81	5.76	4.92	inf	inf	inf	12.62
	50 mm	29.36	26.77	23.98	20.97	19.24	17.87	15.38	13.5	12.59	11.64	11.35	9.09	inf	inf	inf	inf	17.65
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

Measure	Eff. depth	Event-based flow peaks for scenario 2 [mm/h]																
		5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**20**	**30**	**40**	**50**	**60**	**Avg**
Extensive green roofs	5 mm	1.28	1.25	1.22	1.22	1.22	1.25	1.23	1.21	1.2	1.16	1.18	1.18	1.13	1.22	1.2	1.2	1.21
	10 mm	1.4	1.38	1.35	1.34	1.33	1.36	1.33	1.33	1.34	1.29	1.3	1.26	1.19	1.28	1.21	1.31	1.31
	20 mm	1.57	1.55	1.51	1.51	1.52	1.53	1.51	1.49	1.5	1.41	1.42	1.46	1.38	1.43	1.54	inf	1.49
	30 mm	1.72	1.69	1.64	1.64	1.65	1.64	1.61	1.6	1.64	1.55	1.57	1.62	1.55	1.76	inf	inf	1.63
	40 mm	1.83	1.8	1.73	1.74	1.75	1.77	1.73	1.75	1.77	1.67	1.69	1.77	1.82	2.05	inf	inf	1.78
	50 mm	1.91	1.89	1.84	1.85	1.89	1.88	1.85	1.86	1.89	1.77	1.84	1.99	2.14	2.46	inf	inf	1.93
	100 mm	2.26	2.24	2.15	2.21	2.26	2.26	2.29	2.28	2.27	2.17	2.19	2.5	2.48	2.95	inf	inf	2.32
Gravel Layers	5 mm	1.46	1.46	1.47	1.42	1.4	1.51	1.43	1.37	1.37	1.3	1.32	1.26	1.12	1.19	1.13	1.13	1.33
	10 mm	2.01	2.01	1.92	1.79	1.81	1.86	1.79	1.75	1.67	1.62	1.64	1.51	1.27	1.33	1.2	1.44	1.66
	20 mm	3.29	3.24	3.2	3	2.96	2.95	2.68	2.57	2.44	2.28	2.2	2.12	1.68	1.65	1.71	inf	2.53
	30 mm	5.05	4.88	4.75	4.59	4.41	4.4	4.07	3.8	3.69	3.55	3.51	3.16	2.11	2.54	inf	inf	3.89
	40 mm	8.61	8.56	7.87	7.44	7.61	7.29	6.52	6.18	6.08	5.56	5.3	4.1	3.06	inf	inf	inf	6.48
	50 mm	14.94	14.22	12.93	12.07	11.34	10.94	9.34	8.33	7.63	7.25	6.68	5.39	inf	inf	inf	inf	10.09
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Green roofs with drainage delay	5 mm	1.97	1.92	1.91	1.88	1.8	1.82	1.9	1.84	1.8	1.81	1.8	1.9	2.1	2.32	inf	inf	1.91
	10 mm	2.26	2.21	2.18	2.1	2.08	2.09	2.23	2.08	2.08	2.07	2.11	2.13	2.28	2.91	inf	inf	2.20
	20 mm	3.1	2.97	2.91	2.73	2.67	2.71	2.83	2.89	2.88	2.88	2.93	2.94	3.12	inf	inf	inf	2.89
	30 mm	4.14	4.05	4.02	4.07	4.08	4.14	4.07	3.99	3.91	3.85	3.96	3.98	3.91	inf	inf	inf	4.01
	40 mm	6.2	5.96	5.92	6.32	5.93	6.13	6.17	5.69	5.49	5.54	5.26	4.65	4.2	inf	inf	inf	5.65
	50 mm	9.73	9.19	8.38	8.26	7.87	7.78	7.96	7.02	7.09	7.03	6.39	5.35		inf	inf	inf	7.67
	100 mm	65.66	58.36	52.42	50.03	44.09	40.31	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	51.81
Hollow Roads	5 mm	1.15	1.14	1.13	1.14	1.12	1.12	1.09	1.09	1.1	1.08	1.1	1.08	1.07	1.12	1.1	1.05	1.11
	10 mm	1.34	1.3	1.29	1.3	1.25	1.29	1.28	1.24	1.21	1.19	1.2	1.18	1.13	1.23	1.2	1.18	1.24
	20 mm	1.87	1.79	1.76	1.65	1.59	1.64	1.61	1.56	1.55	1.49	1.48	1.48	1.38	1.47	1.47	inf	1.59
	30 mm	2.56	2.42	2.39	2.25	2.16	2.15	2.08	1.95	1.98	1.92	1.85	1.89	1.82	1.95	1.79	inf	2.08
	40 mm	3.48	3.24	3.12	2.9	2.88	2.88	2.78	2.71	2.72	2.59	2.61	2.38	2.38	2.29	inf	inf	2.78
	50 mm	4.98	4.73	4.49	4.23	4.27	4.24	4.06	3.74	3.65	3.41	3.49	3.53	2.9	inf	inf	inf	3.98
	100 mm	35.28	33.3	32.17	29.38	25.85	27.11	24.51	20.79	20.35	18.37	16.56	inf	inf	inf	inf	inf	25.79
Infiltration boxes	5 mm	1.3	1.31	1.3	1.26	1.26	1.3	1.29	1.28	1.25	1.17	1.22	1.18	1.1	1.12	1.12	1.13	1.22
	10 mm	1.64	1.63	1.58	1.51	1.5	1.51	1.47	1.46	1.42	1.34	1.37	1.33	1.15	1.29	1.17	1.32	1.42
	20 mm	2.17	2.19	2.11	2.01	1.96	1.97	1.87	1.85	1.79	1.67	1.68	1.65	1.47	1.44	1.49	inf	1.82
	30 mm	2.92	2.84	2.69	2.48	2.39	2.34	2.25	2.25	2.19	2.04	2.08	2.04	1.77	1.92	inf	inf	2.30
	40 mm	3.57	3.44	3.33	3.05	2.97	2.98	2.89	2.93	2.85	2.67	2.67	2.52	2.22	2.65	inf	inf	2.91
	50 mm	4.4	4.26	4.01	3.72	3.61	3.57	3.54	3.47	3.21	2.96	3.14	2.81	2.96	3.06	inf	inf	3.48
	100 mm	9.24	8.86	7.96	7.2	6.91	6.9	6.2	5.98	6	5.73	5.47	4.59	4.81	inf	inf	inf	6.60

Measure	**Eff. depth**	**Event-based flow peaks for scenario 2 [mm/h]**																
		5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**20**	**30**	**40**	**50**	**60**	**Avg**
Infiltration fields and strips	5 mm	1.93	1.96	2.01	1.95	2.02	2.05	1.91	1.84	1.79	1.61	1.6	1.55	1.18	1.33	1.18	1.26	1.70
	10 mm	3.42	3.35	3.21	3.04	2.98	3.01	2.81	2.73	2.49	2.39	2.25	1.95	1.5	1.58	1.25	inf	2.53
	20 mm	7.12	6.82	6.21	5.79	5.49	5.07	4.54	4.33	4.08	3.76	3.54	3.06	2.07	1.99	inf	inf	4.56
	30 mm	11.68	11.01	9.9	9.17	8.85	9.29	8.06	8.02	7.73	6.65	6.26	4.46	2.91	inf	inf	inf	8.00
	40 mm	21.05	19.4	17.87	16.07	14.46	14.07	12.76	11.25	10.02	8.58	7.81	5.76	4.92	inf	inf	inf	12.62
	50 mm	29.36	26.77	23.98	20.97	19.23	17.87	15.38	13.5	12.59	11.64	11.35	9.09	inf	inf	inf	inf	17.64
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Infiltration shaft	5 mm	1.46	1.45	1.47	1.41	1.4	1.5	1.43	1.37	1.37	1.3	1.32	1.25	1.12	1.18	1.13	1.13	1.33
	10 mm	2	2.01	1.91	1.78	1.81	1.85	1.78	1.74	1.65	1.6	1.64	1.51	1.26	1.33	1.2	1.42	1.66
	20 mm	3.29	3.19	3.2	2.99	2.95	2.94	2.67	2.56	2.44	2.28	2.16	2.1	1.68	1.65	1.69	inf	2.52
	30 mm	5.04	4.78	4.68	4.51	4.33	4.33	4.07	3.75	3.67	3.55	3.46	3.16	2.11	2.51	inf	inf	3.85
	40 mm	8.2	8.32	7.87	7.26	7.51	7.11	6.43	6.15	6.06	5.54	5.24	4.1	3.03	inf	inf	inf	6.37
	50 mm	14.82	14.21	12.68	11.55	11.3	10.59	9.31	8.32	7.61	7.25	6.68	5.35	5.01	inf	inf	inf	9.59
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Infiltration trench	5 mm	1.46	1.46	1.47	1.41	1.4	1.51	1.43	1.37	1.37	1.3	1.32	1.26	1.12	1.19	1.13	1.13	1.33
	10 mm	2.01	2.01	1.91	1.78	1.81	1.86	1.79	1.75	1.66	1.62	1.64	1.51	1.27	1.33	1.2	1.43	1.66
	20 mm	3.29	3.22	3.2	3	2.96	2.95	2.67	2.57	2.44	2.28	2.18	2.11	1.68	1.65	1.7	inf	2.53
	30 mm	5	4.84	4.72	4.55	4.27	4.4	3.99	3.63	3.47	3.36	3.31	3.08	2.1	2	inf	inf	3.77
	40 mm	7.41	7.36	6.72	6.11	6.16	5.96	5.3	5.01	4.73	4.36	4.14	3.85	2.54	2.13	inf	inf	5.13
	50 mm	10.06	9.71	8.71	7.73	7.34	7.34	6.27	5.69	5.15	5.06	4.69	4.08	3.04	2.42	inf	inf	6.24
	100 mm	13.67	13.02	11.52	10.09	9.2	8.87	7.62	7.01	6.23	6.17	5.9	5.14	3.2	2.42	inf	inf	7.86
Intensive green roofs	5 mm	1.28	1.25	1.22	1.22	1.22	1.25	1.23	1.21	1.2	1.16	1.18	1.18	1.13	1.22	1.2	1.2	1.21
	10 mm	1.4	1.38	1.35	1.34	1.33	1.36	1.33	1.33	1.34	1.29	1.3	1.26	1.19	1.28	1.21	1.31	1.31
	20 mm	1.57	1.55	1.51	1.51	1.52	1.53	1.51	1.49	1.5	1.41	1.42	1.46	1.38	1.43	1.54	inf	1.49
	30 mm	1.71	1.69	1.65	1.64	1.65	1.65	1.62	1.61	1.65	1.55	1.56	1.63	1.55	1.68	inf	inf	1.63
	40 mm	1.82	1.8	1.74	1.75	1.75	1.76	1.72	1.73	1.74	1.65	1.67	1.75	1.77	1.7	inf	inf	1.74
	50 mm	1.89	1.87	1.83	1.84	1.87	1.86	1.83	1.83	1.85	1.75	1.82	1.94	1.77	1.87	inf	inf	1.84
	100 mm	2.16	2.14	2.05	2.09	2.13	2.13	2.13	2.11	2.13	2.06	2.08	2.2	1.94	2.07	inf	inf	2.10
Lowering part of garden	5 mm	0.66	0.73	0.76	0.75	0.77	0.78	0.74	0.73	0.74	0.76	0.76	0.93	0.7	inf	inf	inf	0.75
	10 mm	0.92	0.91	0.9	0.87	0.9	0.93	0.96	1	1	1	1	1.06	0.92	inf	inf	inf	0.95
	20 mm	1.39	1.38	1.36	1.3	1.3	1.31	1.2	1.17	1.17	1.13	1.14	1.4	inf	inf	inf	inf	1.27
	30 mm	1.54	1.62	1.65	1.7	1.79	1.85	1.96	inf	inf	inf	inf	inf	inf	inf	inf	inf	1.73
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

Measure	Eff. depth	Event-based flow peaks for scenario 2 [mm/h]																
		5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**20**	**30**	**40**	**50**	**60**	**Avg**
Lowering part of terrace	5 mm	1.15	1.14	1.13	1.14	1.12	1.12	1.09	1.1	1.1	1.08	1.1	1.08	1.07	1.12	1.1	1.05	1.11
	10 mm	1.34	1.3	1.29	1.29	1.25	1.28	1.27	1.24	1.2	1.19	1.2	1.18	1.13	1.23	1.2	1.19	1.24
	20 mm	1.87	1.78	1.75	1.64	1.59	1.63	1.61	1.56	1.53	1.49	1.48	1.47	1.38	1.46	1.49	inf	1.58
	30 mm	2.54	2.42	2.38	2.25	2.15	2.14	2.07	1.95	1.97	1.91	1.84	1.86	1.77	1.97	1.79	inf	2.07
	40 mm	3.47	3.23	3.13	2.88	2.82	2.86	2.78	2.67	2.7	2.56	2.66	2.38	2.38	2.29	inf	inf	2.77
	50 mm	4.97	4.7	4.49	4.15	4.18	4.21	4.01	3.74	3.58	3.37	3.54	3.45	2.9	inf	inf	inf	3.95
	100 mm	34.82	33.18	31.91	29.38	25.85	27.08	24.43	20.69	19.82	17.75	16.26	inf	inf	inf	inf	inf	25.56
Permeable pavement (storage)	5 mm	1.81	1.78	1.85	1.79	1.88	1.95	1.82	1.71	1.69	1.53	1.5	1.5	1.12	1.31	1.17	1.13	1.60
	10 mm	3.77	3.69	3.45	3.29	3.15	3.05	2.95	2.81	2.65	2.58	2.45	2.17	1.62	1.45	1.27	inf	2.69
	20 mm	8.32	7.73	7.01	6.44	6.6	6.23	5.92	5.26	4.65	4	3.68	3.2	2.22	2	1.81	inf	5.00
	30 mm	13.87	13.61	12.89	11.48	10.84	10.79	9.84	8.83	7.83	7.11	6.65	4.47	3.4	2.88	inf	inf	8.89
	40 mm	25.21	22.73	20.5	17.68	16.4	15.05	13.47	11.91	10.6	9.36	8.73	7.14	4.97	inf	inf	inf	14.13
	50 mm	32.55	31.26	28.27	25.14	22.95	21.09	18.08	15.79	13.97	11.92	10.84	9.81	inf	inf	inf	inf	20.14
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Private green garden	5 mm	5.73	5.35	5.21	4.68	4.51	4.46	3.99	3.68	3.46	3.07	2.96	2.46	1.85	1.84	1.7	inf	3.66
	10 mm	10.6	10.05	9.6	8.83	8.04	7.29	6.27	6.1	5.76	4.96	4.85	3.9	2.79	2.15	inf	inf	6.51
	20 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	30 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	40 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	50 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	100 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
Rain barrel	5 mm	1.19	1.17	1.15	1.18	1.13	1.13	1.16	1.13	1.11	1.13	1.11	1.09	1.07	1.12	1.1	1.06	1.13
	10 mm	1.44	1.37	1.42	1.39	1.33	1.36	1.39	1.32	1.27	1.27	1.25	1.23	1.14	1.24	1.21	1.21	1.30
	20 mm	2.21	2.09	2.09	2.05	1.93	1.9	1.9	1.75	1.75	1.71	1.64	1.64	1.45	1.54	1.54	inf	1.81
	30 mm	3.47	3.25	3.08	2.92	2.9	2.74	2.6	2.61	2.51	2.47	2.4	2.24	2.02	2.06	inf	inf	2.66
	40 mm	5.33	4.92	4.75	4.82	4.63	4.67	4.73	4.37	4.41	4.48	4.33	3.27	2.69	3.13	inf	inf	4.32
	50 mm	9.88	9.1	8.87	8.41	7.89	7.89	7.29	6.52	6.07	5.66	5.73	4.48	3.92	inf	inf	inf	7.05
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Rain garden	5 mm	5.73	5.35	5.21	4.68	4.51	4.46	3.99	3.68	3.46	3.07	2.96	2.46	1.85	1.84	1.7	inf	3.66
	10 mm	10.6	10.05	9.6	8.83	8.04	7.29	6.27	6.1	5.76	4.96	4.85	3.9	2.79	2.15	inf	inf	6.51
	20 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	30 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	40 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	50 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	100 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98

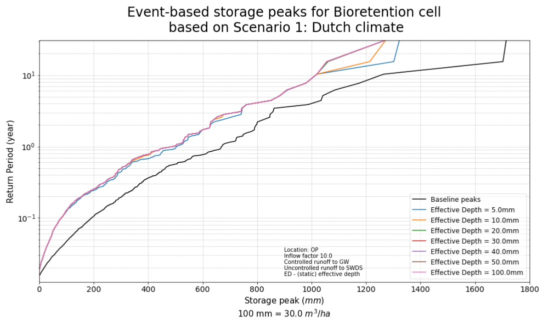
Measure	Eff. depth	Event-based flow peaks for scenario 2 [mm/h]																
		5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**20**	**30**	**40**	**50**	**60**	**Avg**
Rainwater detention pond	5 mm	64.73	54.77	49.6	46.18	45.35	41.13	37.76	32.63	inf	inf	inf	inf	inf	inf	inf	inf	46.52
	10 mm	65.27	55.88	52.04	53.28	49.14	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	55.12
	20 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	30 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	40 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	50 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Rainwater storage below buildings	5 mm	1.16	1.13	1.11	1.16	1.12	1.11	1.13	1.09	1.08	1.11	1.08	1.07	1.07	1.12	1.1	1.03	1.10
	10 mm	1.36	1.3	1.31	1.31	1.24	1.27	1.3	1.24	1.21	1.21	1.18	1.19	1.12	1.2	1.21	1.21	1.24
	20 mm	1.93	1.82	1.77	1.71	1.63	1.64	1.7	1.58	1.53	1.52	1.51	1.57	1.36	1.48	1.54	inf	1.62
	30 mm	2.65	2.54	2.48	2.34	2.24	2.22	2.17	2.14	2.09	1.97	1.94	1.93	1.78	2.04	1.81	inf	2.16
	40 mm	3.65	3.34	3.26	3.13	3.02	2.99	3.03	2.83	2.8	2.8	2.8	2.41	2.49	2.49	inf	inf	2.93
	50 mm	5.4	5.08	4.73	4.8	4.64	4.43	4.49	4.04	3.8	3.81	3.63	3.69	2.96	inf	inf	inf	4.27
	100 mm	40.53	36.04	33.87	33.77	29.86	27.76	25.52	21.59	19.42	18.9	17.71	inf	inf	inf	inf	inf	27.72
Retention soil filter	5 mm	5.73	5.35	5.21	4.68	4.51	4.46	3.99	3.68	3.46	3.07	2.96	2.46	1.85	1.84	1.7		3.66
	10 mm	10.6	10.05	9.6	8.83	8.04	7.29	6.27	6.1	5.76	4.96	4.85	3.9	2.79	2.15	inf	inf	6.51
	20 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	30 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	40 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	50 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
	100 mm	17.09	16.17	14.37	12.84	11.88	11.11	10.42	9.53	9.07	7.85	7.21	5.57	3.53	3.14	inf	inf	9.98
Systems for rainwater harvesting	5 mm	1.05	1.04	1.04	1.04	1.05	1.05	1.04	1.03	1.02	1.01	1.03	1.02	1.02	1.07	1	1	1.03
	10 mm	1.12	1.11	1.1	1.1	1.09	1.09	1.08	1.08	1.08	1.06	1.08	1.07	1.05	1.08	1.05	1	1.08
	20 mm	1.27	1.24	1.23	1.23	1.21	1.21	1.2	1.19	1.17	1.16	1.17	1.18	1.11	1.15	1.15	1.3	1.20
	30 mm	1.47	1.41	1.4	1.39	1.34	1.38	1.4	1.33	1.31	1.32	1.26	1.29	1.22	1.37	1.25	inf	1.34
	40 mm	1.7	1.64	1.63	1.6	1.51	1.54	1.56	1.45	1.42	1.44	1.41	1.39	1.28	1.53	1.52	inf	1.51
	50 mm	2.01	1.86	1.85	1.76	1.66	1.69	1.74	1.63	1.63	1.68	1.61	1.63	1.5	1.76	1.91	inf	1.73
	100 mm	4.72	4.53	4.28	4.09	3.78	3.74	3.73	3.42	3.41	3.38	3.31	3.48	2.93	inf	inf	inf	3.75
Underground storage	5 mm	1.2	1.19	1.22	1.16	1.17	1.19	1.18	1.18	1.18	1.12	1.15	1.12	1.05	1.1	1.1	1.13	1.15
	10 mm	1.49	1.53	1.5	1.41	1.42	1.44	1.4	1.38	1.36	1.27	1.33	1.31	1.15	1.24	1.17	1.22	1.35
	20 mm	2.35	2.37	2.32	2.13	2.07	2.06	1.94	1.97	1.91	1.79	1.77	1.68	1.59	1.59	1.49	inf	1.94
	30 mm	3.84	3.55	3.32	3.19	3.16	3.01	2.95	2.79	2.73	2.62	2.58	2.56	2.01	2.08	inf	inf	2.89
	40 mm	6.22	6.19	5.87	5.67	5.41	5.6	5.31	5.12	4.74	4.67	4.62	3.35	2.78	inf	inf	inf	5.04
	50 mm	11.54	11.29	10.55	9.59	8.91	8.51	7.55	7.07	6.71	6.11	5.99	4.52	4.32	inf	inf	inf	7.90
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

Measure	Eff. depth	Event-based flow peaks for scenario 2 [mm/h]																
		5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**20**	**30**	**40**	**50**	**60**	**Avg**
Urban wetland	5 mm	1.18	1.15	1.14	1.17	1.12	1.11	1.14	1.11	1.1	1.11	1.11	1.09	1.07	1.12	1.11	1.06	1.12
	10 mm	1.37	1.31	1.34	1.33	1.25	1.29	1.32	1.25	1.21	1.23	1.2	1.2	1.13	1.23	1.21	1.21	1.26
	20 mm	1.95	1.85	1.78	1.73	1.64	1.65	1.71	1.6	1.55	1.55	1.54	1.59	1.38	1.48	1.54	inf	1.64
	30 mm	2.68	2.6	2.51	2.36	2.27	2.25	2.21	2.14	2.12	2	1.95	1.97	1.91	2.06	1.82	inf	2.19
	40 mm	3.68	3.38	3.3	3.15	3.05	3.09	3.09	2.92	2.85	2.94	2.84	2.46	2.52	2.49	inf	inf	2.98
	50 mm	5.49	5.16	4.74	4.81	4.68	4.47	4.53	4.06	3.9	3.81	3.8	3.74	2.96	inf	inf	inf	4.32
	100 mm	40.57	38.52	34.7	33.97	30.69	28.19	25.78	22.25	20.27	18.82	19	inf	inf	inf	inf	inf	28.43
Use of groundwater (acquifer storage)	5 mm	1.84	1.83	1.81	1.84	1.89	1.88	1.75	1.75	1.68	1.56	1.54	1.46	1.17	1.31	1.15	1.31	1.61
	10 mm	3.58	3.5	3.35	3.16	3.12	3.1	2.92	2.81	2.61	2.46	2.32	2.03	1.51	1.59	1.26	inf	2.62
	20 mm	10.06	9.85	8.94	7.94	7.47	7.3	6.37	5.76	5.15	4.69	4.38	3.47	2.75	2.06	inf	inf	6.16
	30 mm	17.93	16.58	14.75	13.7	12.38	12.31	11.01	10.72	9.52	8.21	7.84	6.32	3.56	inf	inf	inf	11.14
	40 mm	33.44	30.13	26.63	24.09	22.06	21.31	18.99	17.24	15.52	13.41	12.29	8.18	inf	inf	inf	inf	20.27
	50 mm	49.33	44.2	38.86	33.54	30.21	27.57	23.85	21.09	19.83	17.6	17.59	inf	inf	inf	inf	inf	29.42
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf
Water roof	5 mm	1.1	1.08	1.08	1.08	1.09	1.09	1.07	1.05	1.05	1.05	1.08	1.07	1.02	1.11	1.05	1	1.07
	10 mm	1.21	1.19	1.17	1.16	1.17	1.19	1.17	1.17	1.16	1.13	1.14	1.14	1.11	1.18	1.2	1.13	1.16
	20 mm	1.35	1.33	1.31	1.31	1.31	1.31	1.31	1.31	1.32	1.28	1.29	1.29	1.19	1.4	1.42	1.41	1.32
	30 mm	1.47	1.44	1.42	1.42	1.42	1.45	1.43	1.43	1.46	1.4	1.41	1.41	1.35	1.58	1.74	inf	1.46
	40 mm	1.55	1.52	1.49	1.48	1.5	1.51	1.5	1.52	1.54	1.49	1.5	1.53	1.48	1.81	inf	inf	1.53
	50 mm	1.6	1.58	1.55	1.56	1.59	1.58	1.58	1.58	1.61	1.55	1.57	1.61	1.68	2.11	inf	inf	1.63
	100 mm	1.82	1.81	1.76	1.77	1.81	1.83	1.87	1.91	1.94	1.87	1.87	1.99	2.14	2.55	inf	inf	1.92
Water square	5 mm	1.2	1.2	1.22	1.17	1.17	1.19	1.19	1.19	1.18	1.13	1.14	1.12	1.06	1.1	1.1	1.13	1.16
	10 mm	1.5	1.54	1.5	1.42	1.42	1.44	1.4	1.38	1.37	1.27	1.33	1.31	1.15	1.24	1.16	1.23	1.35
	20 mm	2.35	2.37	2.33	2.14	2.07	2.08	1.95	1.97	1.93	1.79	1.77	1.68	1.59	1.59	1.49	inf	1.94
	30 mm	3.83	3.55	3.33	3.17	3.12	3.04	2.95	2.78	2.74	2.63	2.57	2.59	2.02	2.08	inf	inf	2.89
	40 mm	6.2	6.14	5.9	5.64	5.41	5.55	5.29	5.11	4.74	4.66	4.59	3.35	2.78	inf	inf	inf	5.03
	50 mm	11.54	11.26	10.38	9.57	8.91	8.52	7.45	7.05	6.7	6.09	5.99	4.53	4.35	inf	inf	inf	7.87
	100 mm	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf	inf

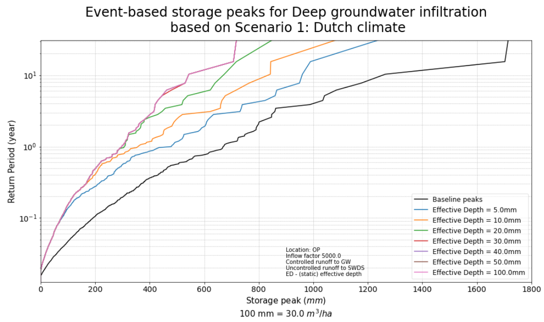
I

Graphical results of all measures: Storage peaks

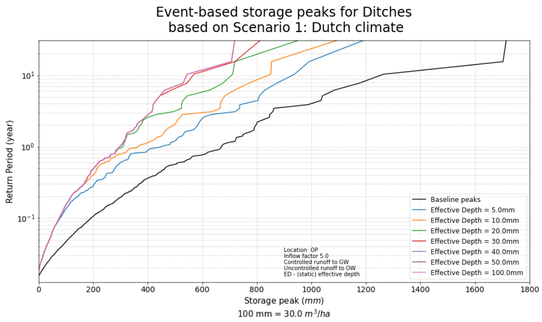
Scenario 1



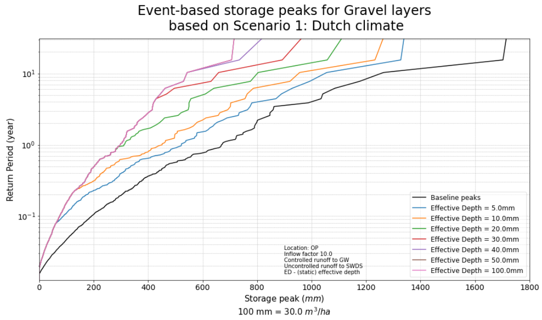
(a) Storage peaks for the Bioretention cell.



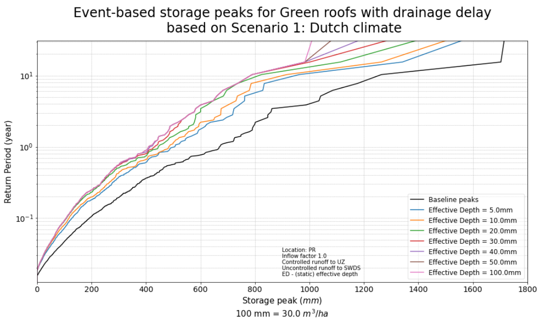
(b) Deep groundwater infiltration.



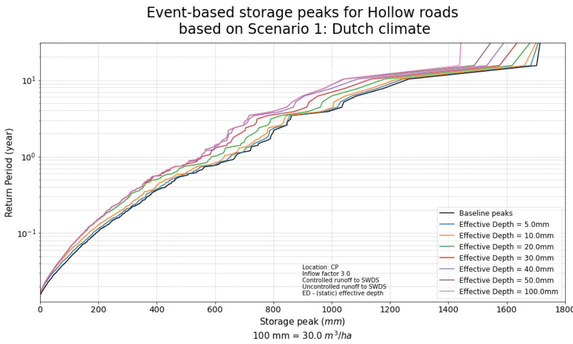
(c) Ditches



(d) Gravel layers

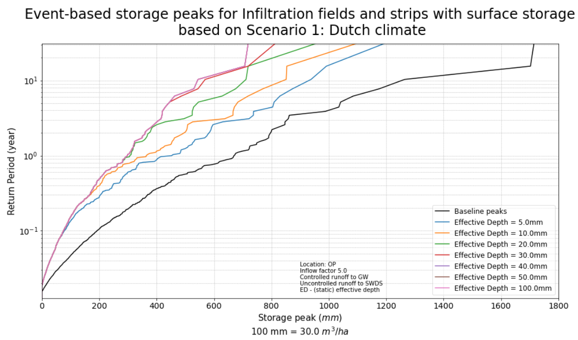


(e) Green roofs with drainage delay

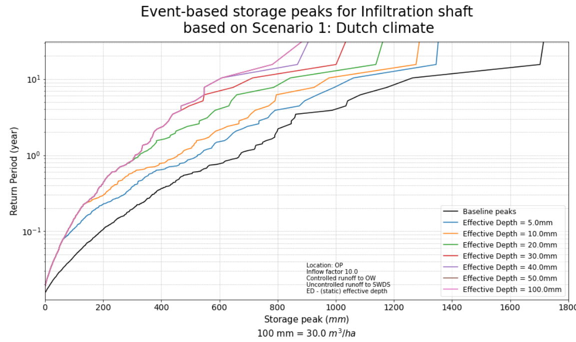


(f) Hollow roads

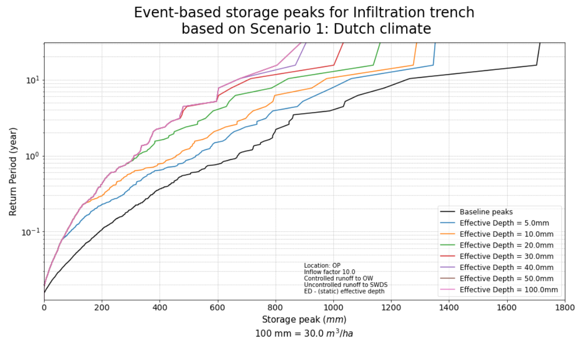
Figure I.1: Sub-figures representing the semi-logarithmic graphs for scenario 1 of the storage peaks in a residential area modelled in the Urban Water Balance Model.



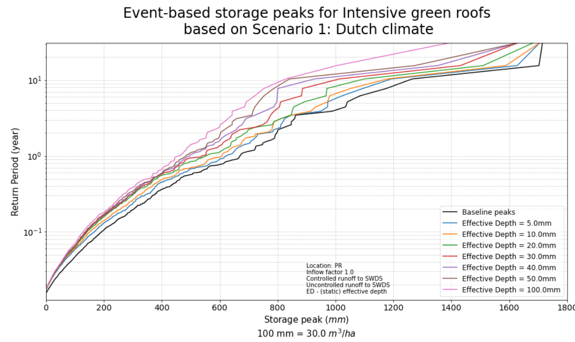
(a) Infiltration fields and strips with surface storage



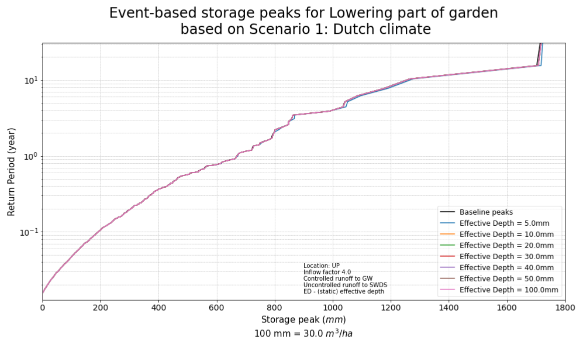
(b) Infiltration shaft



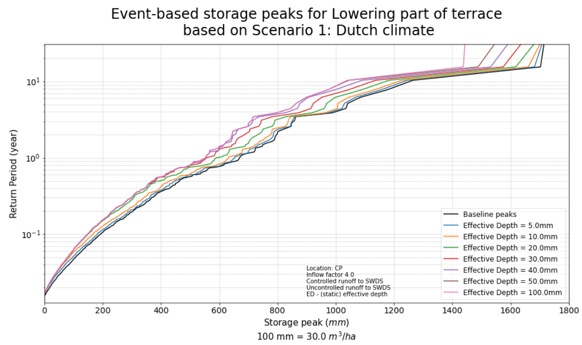
(c) nfiltration trench



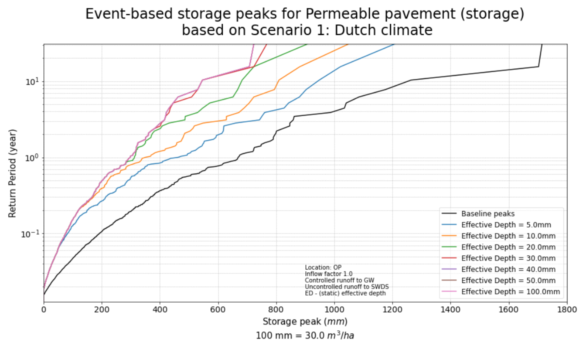
(d) Intensive green roofs



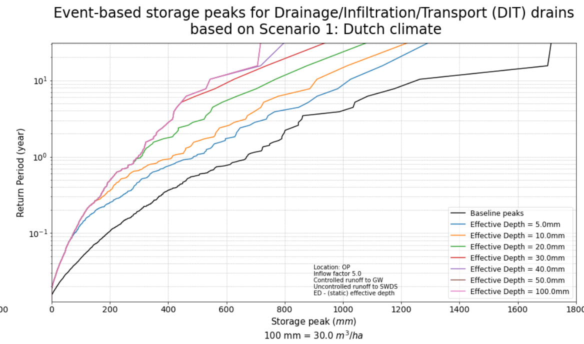
(e) Lowering part of garden



(f) Lowering part of terrace

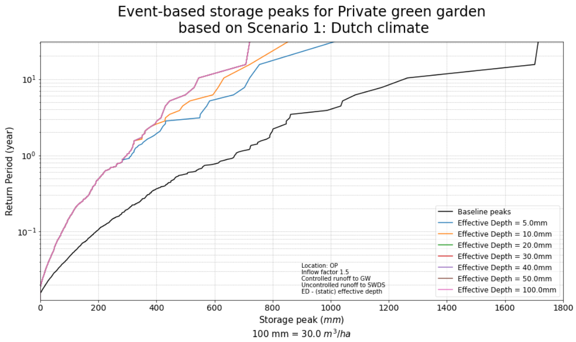


(g) Permeable pavement (storage)

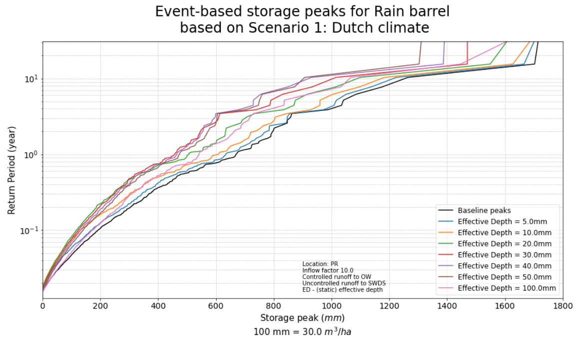


(h) Drainage/Infiltration/Transport drains

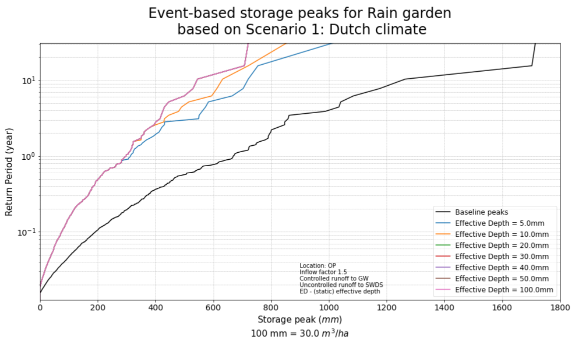
Figure I.2: Sub-figures representing the semi-logarithmic graphs for scenario 1 of the storage peaks in a residential area modelled in the Urban Water Balance Model.



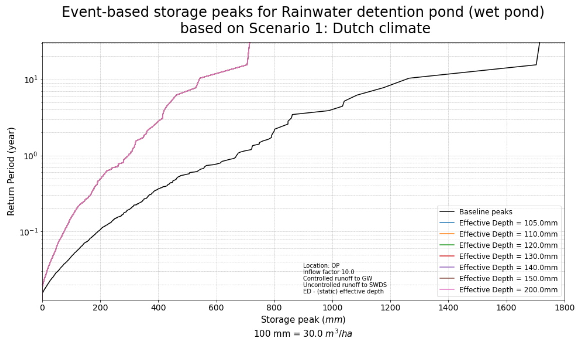
(a) Private green garden



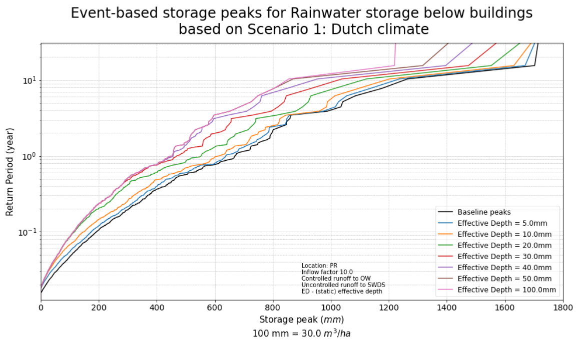
(b) Rain barrel



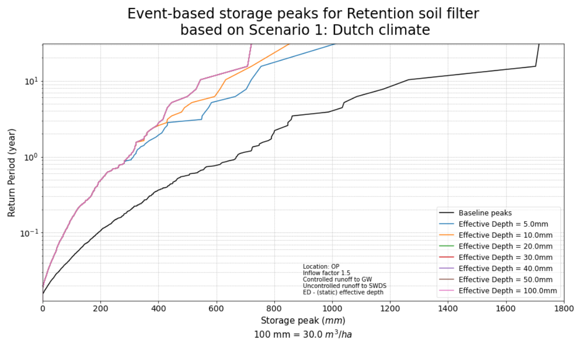
(c) Rain garden



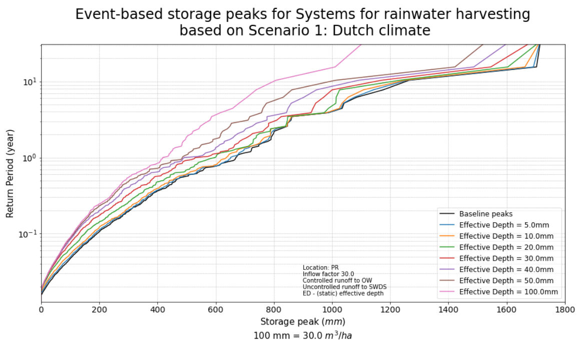
(d) Rainwater detention pond (wet pond)



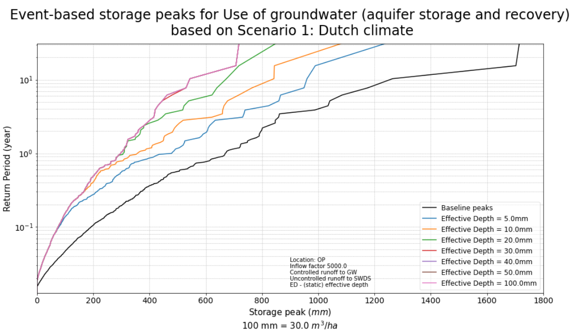
(e) Rainwater storage below buildings



(f) Retention soil filter

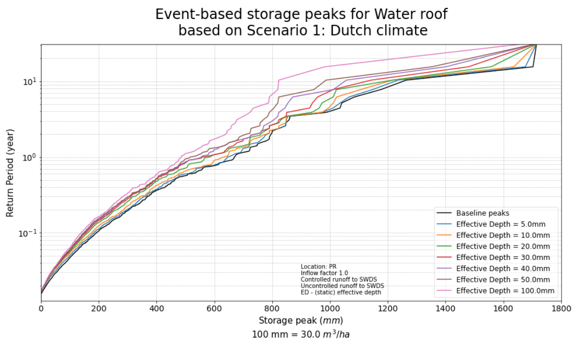


(g) Systems for rainwater harvesting

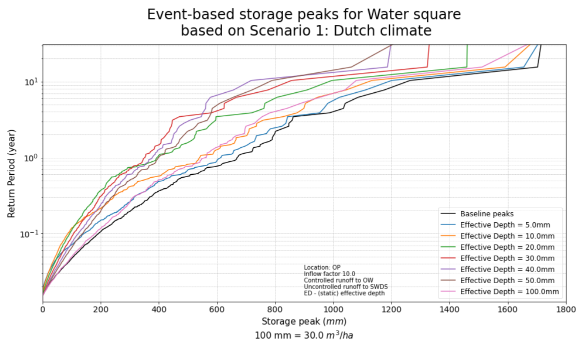


(h) Use of groundwater (aquifer storage and recovery)

Figure I.3: Sub-figures representing the semi-logarithmic graphs for scenario 1 of the storage peaks in a residential area modelled in the Urban Water Balance Model.



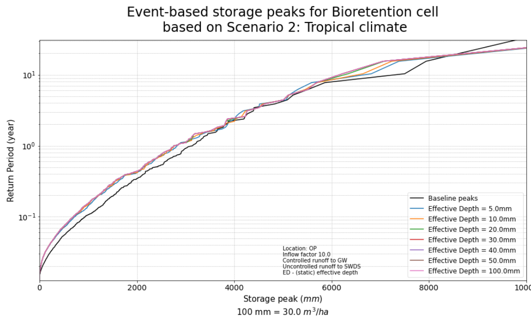
(a) Water roof



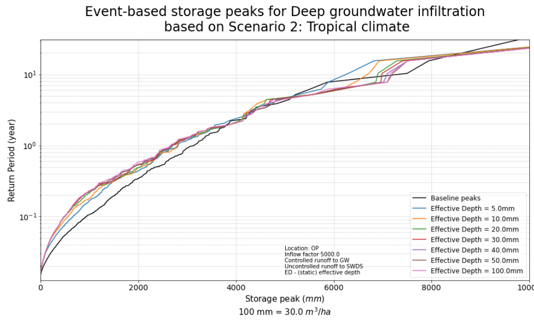
(b) Water square

Figure I.4: Sub-figures representing the semi-logarithmic graphs for scenario 1 of the storage peaks in a residential area modelled in the Urban Water Balance Model.

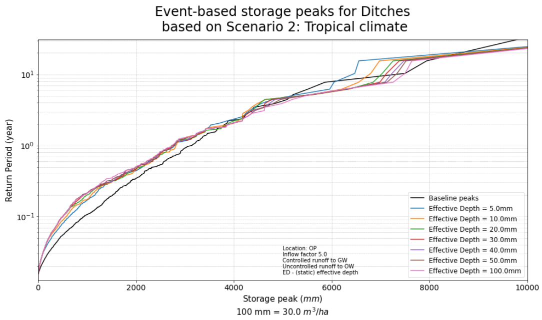
Scenario 2



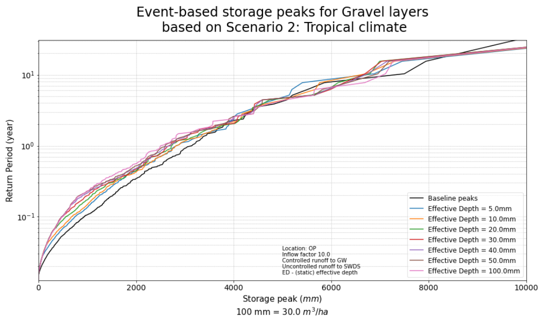
(a) Storage peaks for the Bioretention cell.



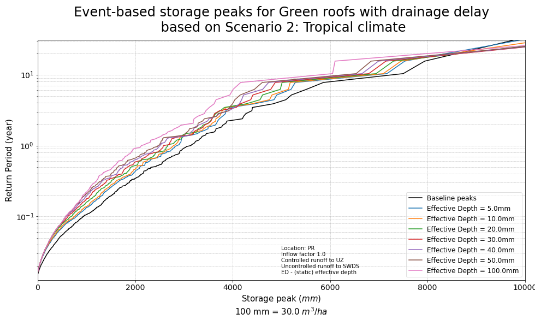
(b) Deep groundwater infiltration.



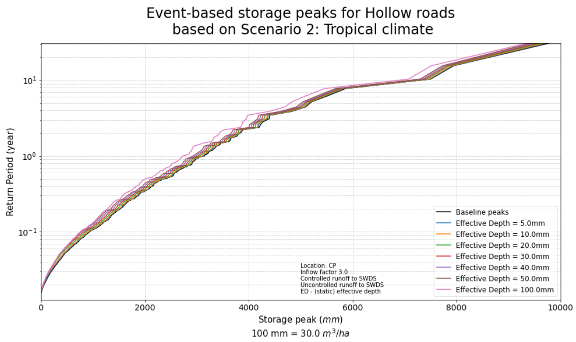
(c) Ditches



(d) Gravel layers

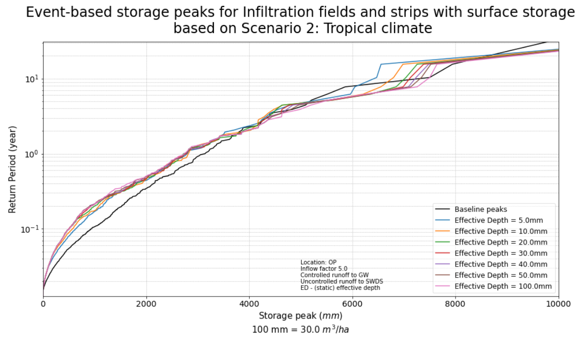


(e) Green roofs with drainage delay

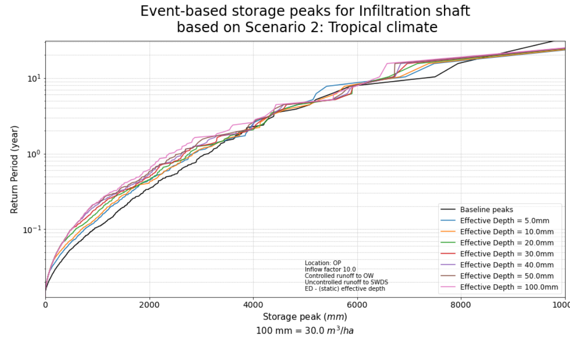


(f) Hollow roads

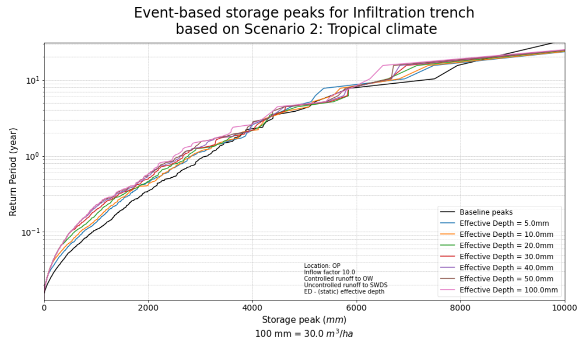
Figure I.5: Sub-figures representing the semi-logarithmic graphs for scenario 2 of the storage peaks in a residential area modelled in the Urban Water Balance Model.



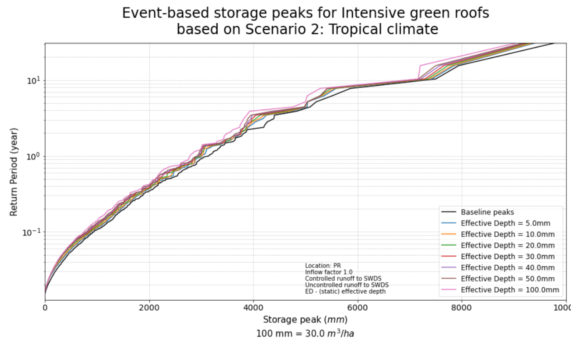
(a) Infiltration fields and strips with surface storage



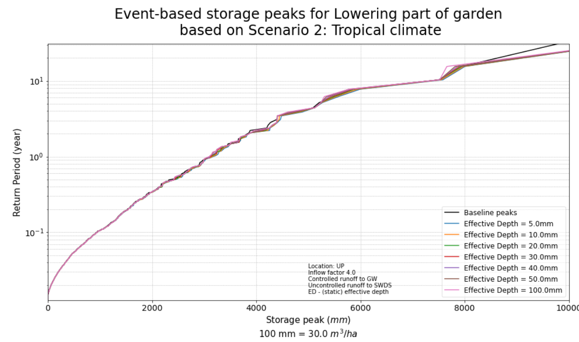
(b) Infiltration shaft



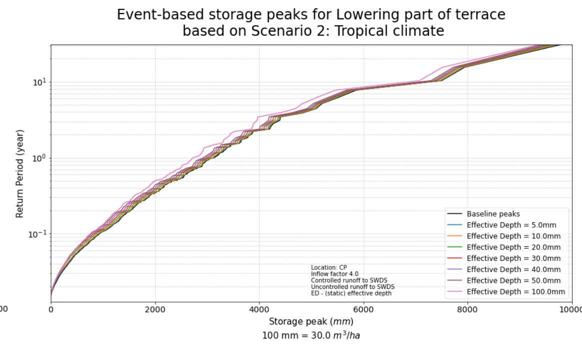
(c) Infiltration trench



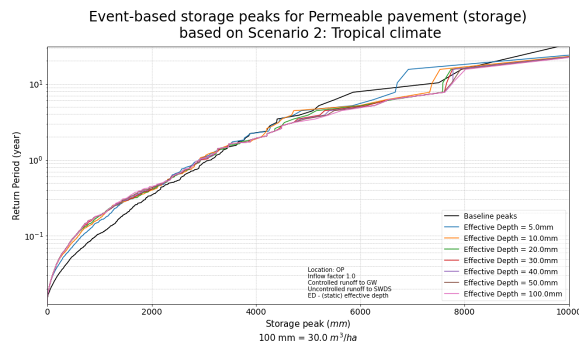
(d) Intensive green roofs



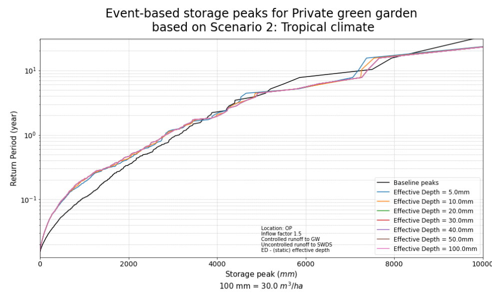
(e) Lowering part of garden



(f) Lowering part of terrace

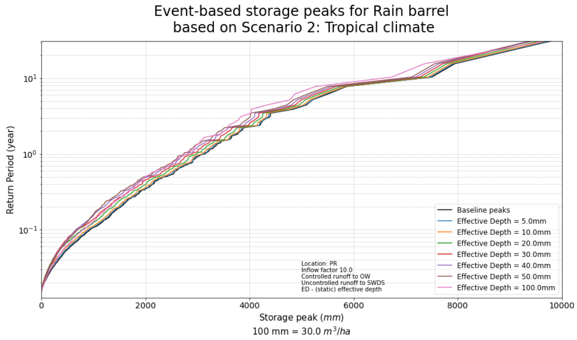


(g) Permeable pavement (storage)

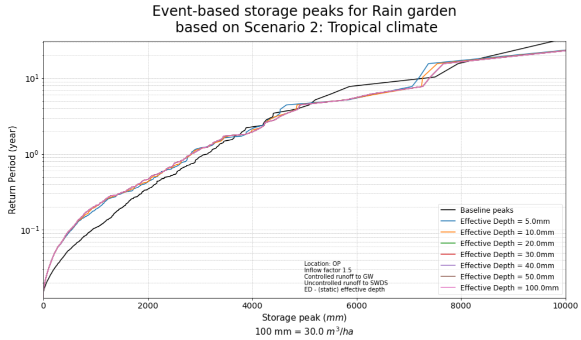


(h) Private green garden

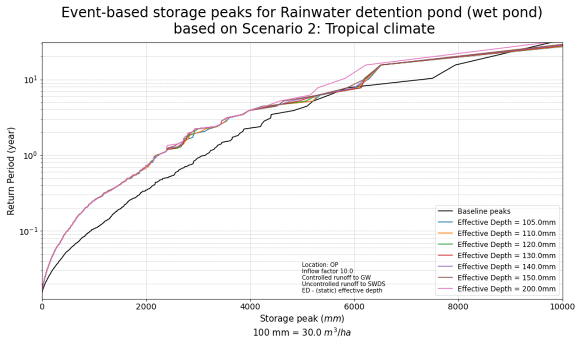
Figure I.6: Sub-figures representing the semi-logarithmic graphs for scenario 2 of the storage peaks in a residential area modelled in the Urban Water Balance Model.



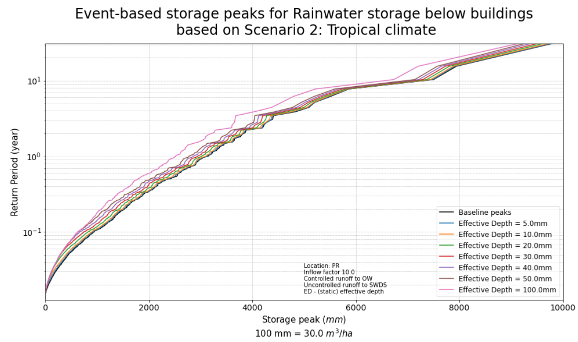
(a) Rain barrel



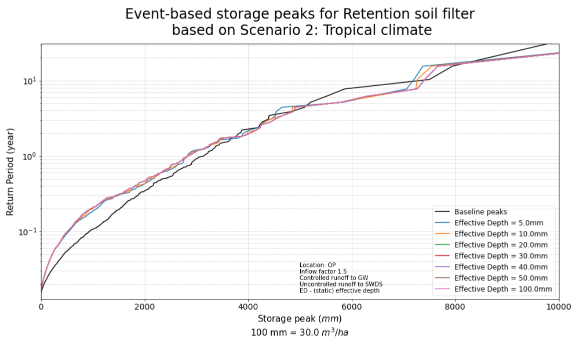
(b) Rain garden



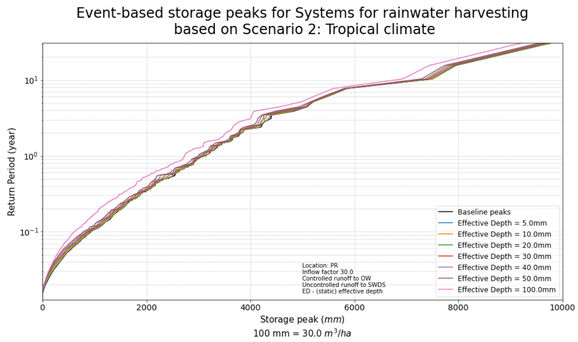
(c) Rainwater detention pond (wet pond)



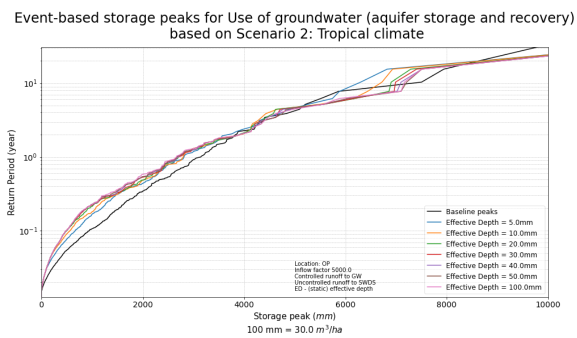
(d) Rainwater storage below buildings



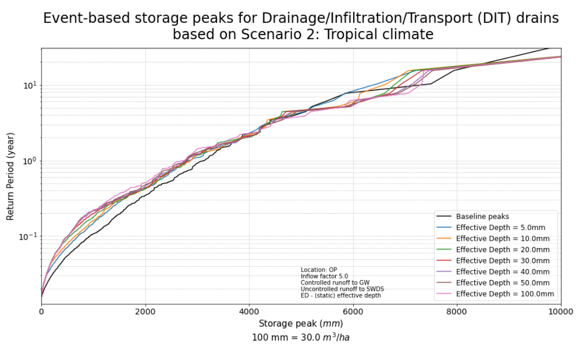
(e) Retention soil filter



(f) Systems for rainwater harvesting

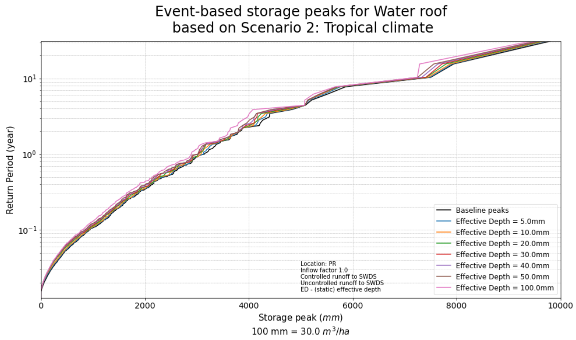


(g) Use of groundwater (aquifer storage and recovery)

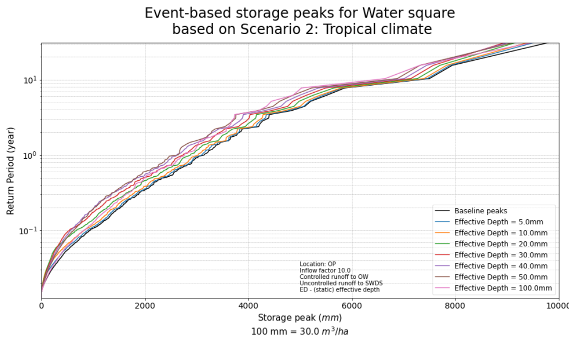


(h) Drainage/Infiltration/Transport (DIT) drains

Figure I.7: Sub-figures representing the semi-logarithmic graphs for scenario 2 of the storage peaks in a residential area modelled in the Urban Water Balance Model.



(a) Water roof



(b) Water square

Figure I.8: Sub-figures representing the semi-logarithmic graphs for scenario 2 of the storage peaks in a residential area modelled in the Urban Water Balance Model.

J

Factor calculations: Storage peaks

Scenario 1: Dutch Climate

	Eff. depth	Event-based storage peak for scenario 1 [mm]													
		50	**60**	**70**	**80**	**90**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**Avg**
Bioretention cell	5 mm	2.22	2.36	2.48	2.54	2.60	2.64	2.30	2.27	1.86	1.67	2.24	inf	inf	2.19
	10 mm	2.22	2.36	2.48	2.55	2.64	2.73	2.40	2.52	2.08	1.81	2.24	inf	inf	2.33
	20 mm	2.22	2.36	2.48	2.55	2.64	2.73	2.40	2.52	2.14	1.81	2.24	inf	inf	2.33
	30 mm	2.22	2.36	2.48	2.55	2.64	2.73	2.40	2.52	2.14	1.81	2.24	inf	inf	2.33
	40 mm	2.22	2.36	2.48	2.55	2.64	2.73	2.40	2.52	2.14	1.81	2.24	inf	inf	2.33
	50 mm	2.22	2.36	2.48	2.55	2.64	2.73	2.40	2.52	2.14	1.81	2.24	inf	inf	2.33
	100 mm	2.22	2.36	2.48	2.55	2.64	2.73	2.40	2.52	2.14	1.81	2.24	inf	inf	2.33
Bioswale	5 mm	2.22	2.43	2.62	2.75	2.77	2.68	2.32	2.34	1.92	1.78	2.22	inf	inf	2.24
	10 mm	2.21	2.43	2.6	2.82	3.05	3.29	3.33	3.28	2.4	2.71	3.15	inf	inf	3.01
	20 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.99	4.15	3.36	3.82	inf	inf	inf	3.69
	30 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.99	4.15	3.37	4.16	inf	inf	inf	3.75
	40 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.99	4.15	3.37	4.16	inf	inf	inf	3.75
	50 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.99	4.15	3.37	4.16	inf	inf	inf	3.75
	100 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.99	4.15	3.37	4.16	inf	inf	inf	3.75
Deep Groundwater Infiltration	5 mm	2.22	2.43	2.55	2.66	2.83	2.94	2.62	2.86	2.37	2.07	2.48	2.87	inf	2.55
	10 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.88	4.04	3.22	4.32	inf	inf	inf	3.67
	20 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	4.92	inf	inf	inf	inf	inf	4.62
	30 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	40 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	50 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	100 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
Drainge/Infiltration/ Transport (DIT) drains	5 mm	2.22	2.41	2.53	2.59	2.65	2.76	2.38	2.4	2.07	1.88	2.25	inf	inf	2.28
	10 mm	2.21	2.43	2.59	2.81	3.04	3.29	3.38	3.39	2.55	2.82	3.28	inf	inf	3.10
	20 mm	2.21	2.42	2.57	2.81	3.04	3.28	4.67	4.91	4.86	inf	inf	inf	inf	4.51
	30 mm	2.21	2.42	2.57	2.81	3.04	3.28	4.67	5.34	inf	inf	inf	inf	inf	4.67
	40 mm	2.21	2.42	2.57	2.81	3.04	3.28	4.67	5.34	inf	inf	inf	inf	inf	4.67
	50 mm	2.21	2.42	2.57	2.81	3.04	3.28	4.67	5.34	inf	inf	inf	inf	inf	4.67
	100 mm	2.21	2.42	2.57	2.81	3.04	3.28	4.67	5.34	inf	inf	inf	inf	inf	4.67
Ditches	5 mm	2.21	2.41	2.53	2.63	2.77	2.89	2.7	3.1	2.42	2.12	inf	inf	inf	2.65
	10 mm	2.21	2.43	2.59	2.81	3.04	3.29	3.79	4.04	3.15	3.63	inf	inf	inf	3.57
	20 mm	2.21	2.43	2.58	2.81	3.04	3.29	4.67	4.91	inf	inf	inf	inf	inf	4.56
	30 mm	2.21	2.43	2.58	2.81	3.04	3.29	4.67	5.34	inf	inf	inf	inf	inf	4.67
	40 mm	2.21	2.43	2.58	2.81	3.04	3.29	4.67	5.34	inf	inf	inf	inf	inf	4.67
	50 mm	2.21	2.43	2.58	2.81	3.04	3.29	4.67	5.34	inf	inf	inf	inf	inf	4.67
	100 mm	2.21	2.43	2.58	2.81	3.04	3.29	4.67	5.34	inf	inf	inf	inf	inf	4.67

	Eff. depth	Event-based storage peak for scenario 1 [mm]													
		50	**60**	**70**	**80**	**90**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**Avg**
Extensive green roofs	5 mm	1.21	1.24	1.25	1.25	1.27	1.25	1.23	1.22	1.24	1.19	1.18	1.27	1.08	1.22
	10 mm	1.25	1.3	1.31	1.31	1.31	1.29	1.33	1.35	1.34	1.24	1.25	1.53	inf	1.34
	20 mm	1.27	1.31	1.34	1.36	1.36	1.34	1.5	1.58	1.53	1.48	1.47	1.93	inf	1.54
	30 mm	1.28	1.33	1.36	1.39	1.4	1.38	1.55	1.64	1.59	1.66	1.77	2.01	inf	1.66
	40 mm	1.29	1.34	1.37	1.41	1.41	1.4	1.6	1.68	1.62	1.83	2.15	inf	inf	1.74
	50 mm	1.29	1.34	1.38	1.42	1.43	1.4	1.61	1.77	1.62	1.95	2.54	inf	inf	1.79
	100 mm	1.32	1.39	1.44	1.49	1.51	1.5	1.71	1.97	1.83	2.49	inf	inf	inf	2.00
Gravel layers	5 mm	2.23	2.43	2.39	2.39	2.41	2.35	2.17	2.03	1.78	1.59	1.98	2.11	inf	2.01
	10 mm	2.21	2.43	2.6	2.82	3.05	3.29	2.95	3.2	2.2	2.5	2.9	inf	inf	2.80
	20 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	4.9	4.65	4.48	inf	inf	inf	4.37
	30 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	40 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	50 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	100 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
Green roofs with drainage delay	5 mm	1.4	1.44	1.51	1.53	1.54	1.54	1.71	1.93	1.66	1.74	2.3	inf	inf	1.86
	10 mm	1.52	1.57	1.65	1.71	1.74	1.72	1.87	2.21	1.83	2.02	2.87	inf	inf	2.04
	20 mm	1.58	1.66	1.8	1.89	1.93	1.94	2.19	2.6	2.05	2.49	inf	inf	inf	2.30
	30 mm	1.58	1.66	1.81	1.9	1.95	1.97	2.34	2.83	2.21	3.06	inf	inf	inf	2.48
	40 mm	1.58	1.66	1.81	1.9	1.95	1.97	2.34	2.88	2.33	3.65	inf	inf	inf	2.59
	50 mm	1.58	1.66	1.81	1.9	1.95	1.97	2.34	2.88	2.46	3.65	inf	inf	inf	2.61
	100 mm	1.58	1.66	1.81	1.9	1.95	1.97	2.34	2.88	2.46	3.65	inf	inf	inf	2.61
Hollow roads	5 mm	1.09	1.1	1.12	1.13	1.11	1.1	1.08	1.07	1.03	1.05	1.02	1.05	1.09	1.07
	10 mm	1.18	1.21	1.23	1.22	1.25	1.25	1.21	1.16	1.16	1.08	1.08	1.16	1.15	1.17
	20 mm	1.21	1.25	1.27	1.29	1.32	1.34	1.42	1.45	1.37	1.33	1.32	1.34	inf	1.38
	30 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.53	1.4	1.68	1.88	inf	1.53
	40 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.76	inf	inf	1.58
	50 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.84	inf	inf	1.60
	100 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.84	inf	inf	1.60
Infiltration boxes	5 mm	1.97	2.03	2	1.94	1.97	1.91	1.67	1.66	1.54	1.32	1.49	1.91	inf	1.62
	10 mm	2.22	2.43	2.59	2.75	2.9	2.93	2.5	2.42	1.94	1.6	1.91	inf	inf	2.24
	20 mm	2.21	2.43	2.6	2.82	3.05	3.29	4.46	3.86	3.2	3.72	inf	inf	inf	3.60
	30 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.01	6.76	inf	inf	inf	inf	4.63
	40 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.69
	50 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.69
	100 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.69

	Eff. depth	Event-based storage peak for scenario 1 [mm]													
		50	**60**	**70**	**80**	**90**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**Avg**
Infiltration fields and strips	5 mm	2.21	2.41	2.53	2.62	2.77	2.89	2.7	3.1	2.42	2.2	inf	inf	inf	2.66
	10 mm	2.21	2.43	2.59	2.81	3.04	3.29	3.79	4.04	3.15	3.63	inf	inf	inf	3.57
	20 mm	2.21	2.43	2.58	2.81	3.04	3.29	4.67	4.91	inf	inf	inf	inf	inf	4.56
	30 mm	2.21	2.43	2.58	2.81	3.04	3.29	4.67	5.34	inf	inf	inf	inf	inf	4.67
	40 mm	2.21	2.43	2.58	2.81	3.04	3.29	4.67	5.34	inf	inf	inf	inf	inf	4.67
	50 mm	2.21	2.43	2.58	2.81	3.04	3.29	4.67	5.34	inf	inf	inf	inf	inf	4.67
	100 mm	2.21	2.43	2.58	2.81	3.04	3.29	4.67	5.34	inf	inf	inf	inf	inf	4.67
Infiltration shaft	5 mm	2.15	2.38	2.37	2.33	2.34	2.3	2.15	1.97	1.77	1.55	1.95	2.09	inf	1.96
	10 mm	2.15	2.38	2.49	2.72	2.91	3.12	2.8	2.98	2.14	2.16	2.79	inf	inf	2.68
	20 mm	2.15	2.38	2.49	2.72	2.91	3.12	4.07	4.34	4.38	4.29	inf	inf	inf	3.99
	30 mm	2.15	2.38	2.49	2.71	2.91	3.12	4.06	4.35	6.39	inf	inf	inf	inf	4.29
	40 mm	2.15	2.38	2.49	2.71	2.91	3.12	4.06	4.35	6.39	inf	inf	inf	inf	4.29
	50 mm	2.15	2.38	2.49	2.71	2.91	3.12	4.06	4.35	6.39	inf	inf	inf	inf	4.29
	100 mm	2.15	2.38	2.49	2.71	2.91	3.12	4.06	4.35	6.39	inf	inf	inf	inf	4.29
Infiltration trench	5 mm	2.13	2.34	2.37	2.32	2.34	2.3	2.14	1.97	1.77	1.56	1.95	2.08		1.96
	10 mm	2.12	2.34	2.46	2.65	2.86	3.09	2.79	2.98	2.14	2.16	2.79	inf	inf	2.67
	20 mm	2.12	2.34	2.46	2.64	2.85	3.09	3.99	4.31	4.38	4.28	inf	inf	inf	3.97
	30 mm	2.12	2.34	2.46	2.64	2.85	3.09	3.99	4.32	6.26	inf	inf	inf	inf	4.29
	40 mm	2.12	2.34	2.46	2.64	2.85	3.09	3.99	4.32	6.26	inf	inf	inf	inf	4.28
	50 mm	2.12	2.34	2.46	2.64	2.85	3.09	3.99	4.32	6.26	inf	inf	inf	inf	4.28
	100 mm	2.12	2.34	2.46	2.64	2.85	3.09	3.99	4.32	6.26	inf	inf	inf	inf	4.28
Intensive green roofs	5 mm	1.21	1.24	1.25	1.25	1.27	1.25	1.23	1.22	1.24	1.19	1.18	1.27	1.08	1.22
	10 mm	1.25	1.3	1.31	1.31	1.31	1.29	1.33	1.35	1.34	1.24	1.25	1.53	inf	1.34
	20 mm	1.27	1.31	1.34	1.36	1.36	1.34	1.5	1.58	1.53	1.48	1.47	1.93	inf	1.54
	30 mm	1.28	1.33	1.36	1.39	1.4	1.38	1.55	1.64	1.59	1.66	1.77	2.01	inf	1.66
	40 mm	1.29	1.34	1.37	1.41	1.41	1.4	1.6	1.68	1.62	1.83	2.08	inf	inf	1.74
	50 mm	1.29	1.34	1.38	1.42	1.43	1.4	1.61	1.77	1.62	1.95	2.41	inf	inf	1.78
	100 mm	1.32	1.39	1.44	1.49	1.51	1.5	1.71	1.97	1.83	2.49	inf	inf	inf	1.99
Lowering part of garden	5 mm	1	1	1	1	1	0.99	1	1	1	1	0.99	1	0.97	0.99
	10 mm	1	1	1	1	1	0.99	1	1	1	1	1	1	0.97	1.00
	20 mm	1	1	1	1	1	0.99	1	1	1	1	1	1	0.97	1.00
	30 mm	1	1	1	1	1	0.99	1	1	1	1	1	1	0.97	1.00
	40 mm	1	1	1	1	1	0.99	1	1	1	1	1	1	0.97	1.00
	50 mm	1	1	1	1	1	0.99	1	1	1	1	1	1	0.97	1.00
	100 mm	1	1	1	1	1	0.99	1	1	1	1	1	1	0.97	1.00

	Eff. depth	Event-based storage peak for scenario 1 [mm]													
		50	**60**	**70**	**80**	**90**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**Avg**
Lowering part of terrace	5 mm	1.09	1.1	1.12	1.13	1.12	1.1	1.08	1.07	1.03	1.05	1.01	1.05	1.09	1.07
	10 mm	1.18	1.21	1.23	1.22	1.25	1.25	1.21	1.16	1.16	1.08	1.08	1.16	1.15	1.17
	20 mm	1.21	1.25	1.27	1.29	1.32	1.34	1.42	1.45	1.37	1.33	1.32	1.34	inf	1.38
	30 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.53	1.4	1.68	1.88	inf	1.53
	40 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.76	inf	inf	1.58
	50 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.84	inf	inf	1.60
	100 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.84	inf	inf	1.60
Permeable pavement (storage)	5 mm	2.15	2.29	2.36	2.49	2.63	2.68	2.53	2.78	2.31	1.99	2.56	inf	inf	2.47
	10 mm	2.19	2.41	2.51	2.8	3.03	3.22	3.71	4.09	3.29	3.84	inf	inf	inf	3.54
	20 mm	2.18	2.41	2.51	2.8	3.03	3.22	4.65	4.62	6.5	inf	inf	inf	inf	4.52
	30 mm	2.18	2.41	2.51	2.8	3.02	3.22	4.65	5.33	inf	inf	inf	inf	inf	4.69
	40 mm	2.18	2.41	2.51	2.8	3.02	3.22	4.65	5.33	inf	inf	inf	inf	inf	4.62
	50 mm	2.18	2.41	2.51	2.8	3.02	3.22	4.65	5.33	inf	inf	inf	inf	inf	4.62
	100 mm	2.18	2.41	2.51	2.8	3.02	3.22	4.65	5.33	inf	inf	inf	inf	inf	4.62
Private green garden	5 mm	2.19	2.41	2.53	2.81	3.04	3.25	4.66	4.62	5.28	inf	inf	inf	inf	4.39
	10 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.69
	20 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	30 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	40 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	50 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	100 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
Rain barrel	5 mm	1.24	1.26	1.28	1.26	1.26	1.24	1.17	1.15	1.15	1.07	1.1	1.13	1.14	1.16
	10 mm	1.46	1.52	1.58	1.59	1.6	1.59	1.54	1.52	1.38	1.28	1.28	1.35	inf	1.42
	20 mm	1.42	1.49	1.55	1.65	1.75	1.74	2.12	2.37	1.99	1.7	1.83	inf	inf	1.98
	30 mm	1.35	1.4	1.46	1.53	1.62	1.62	1.98	2.45	2.06	2.38	inf	inf	inf	2.17
	40 mm	1.27	1.3	1.36	1.41	1.49	1.53	1.76	2.11	2.04	2.24	inf	inf	inf	2.00
	50 mm	1.18	1.22	1.28	1.32	1.37	1.39	1.58	1.98	1.85	2.05	inf	inf	inf	1.86
	100 mm	1.02	1.05	1.05	1.06	1.1	1.09	1.18	1.47	1.44	1.35	1.8	inf	inf	1.43
Rain garden	5 mm	2.19	2.41	2.53	2.81	3.04	3.25	4.66	4.62	5.28	inf	inf	inf	inf	4.39
	10 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.69
	20 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	30 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	40 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	50 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	100 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71

	Eff. depth	Event-based storage peak for scenario 1 [mm]													
		50	**60**	**70**	**80**	**90**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**Avg**
Rainwater detention pond	5 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	10 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	20 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	30 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	40 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	50 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	100 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
Rainwater storage below buildings	5 mm	1.18	1.2	1.21	1.21	1.18	1.17	1.14	1.1	1.09	1.06	1.04	1.14	1.14	1.13
	10 mm	1.41	1.43	1.45	1.47	1.47	1.44	1.38	1.32	1.33	1.22	1.26	1.21	1.17	1.31
	20 mm	1.51	1.57	1.66	1.74	1.8	1.81	1.93	2.14	1.66	1.48	1.71	1.84	inf	1.79
	30 mm	1.51	1.58	1.66	1.75	1.83	1.84	2.21	2.49	2.07	2.06	2.58	inf	inf	2.17
	40 mm	1.51	1.58	1.66	1.75	1.83	1.84	2.23	2.65	2.11	2.44	inf	inf	inf	2.31
	50 mm	1.51	1.58	1.66	1.75	1.83	1.84	2.23	2.65	2.11	2.67	inf	inf	inf	2.37
	100 mm	1.51	1.58	1.66	1.75	1.83	1.84	2.23	2.65	2.11	2.67	inf	inf	inf	2.37
Retention soil filter	5 mm	2.19	2.41	2.53	2.81	3.04	3.25	4.66	4.62	5.28	inf	inf	inf	inf	4.39
	10 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.69
	20 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	30 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	40 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	50 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
	100 mm	2.19	2.41	2.52	2.81	3.03	3.25	4.66	5.34	inf	inf	inf	inf	inf	4.71
Systems for rainwater harvesting	5 mm	1.05	1.05	1.06	1.07	1.07	1.06	1.05	1.05	1.02	1.05	1	1.13	1.07	1.05
	10 mm	1.14	1.16	1.18	1.18	1.17	1.15	1.15	1.11	1.08	1.07	1.05	1.18	1.13	1.12
	20 mm	1.32	1.34	1.38	1.37	1.36	1.35	1.35	1.32	1.31	1.21	1.32	1.19	1.14	1.31
	30 mm	1.45	1.49	1.55	1.54	1.6	1.59	1.65	1.67	1.56	1.62	1.46	1.54	inf	1.57
	40 mm	1.5	1.56	1.66	1.71	1.76	1.79	1.92	2.08	1.78	1.77	1.75	2.01	inf	1.86
	50 mm	1.54	1.6	1.72	1.79	1.86	1.86	2.21	2.47	1.98	1.91	2.29	inf	inf	2.13
	100 mm	1.55	1.61	1.73	1.83	1.91	1.91	2.33	2.81	2.31	3.27	inf	inf	inf	2.50
Underground storage	5 mm	1.63	1.66	1.65	1.62	1.57	1.53	1.42	1.35	1.33	1.22	1.18	1.22	1.16	1.33
	10 mm	1.9	2.13	2.23	2.37	2.45	2.53	2.06	2.12	1.57	1.44	1.66	1.85	inf	1.89
	20 mm	1.66	1.8	1.98	2.11	2.23	2.34	3.49	3.81	2.95	2.8	inf	inf	inf	3.06
	30 mm	1.4	1.51	1.64	1.76	1.87	1.93	2.94	3.63	4.03	inf	inf	inf	inf	3.10
	40 mm	1.25	1.33	1.41	1.48	1.56	1.62	2.28	3.09	3.49	inf	inf	inf	inf	2.66
	50 mm	1.15	1.2	1.25	1.31	1.37	1.4	1.87	2.58	2.79	3.91	inf	inf	inf	2.39
	100 mm	1	1.04	1.04	1.03	1.06	1.06	1.13	1.34	1.4	1.34	1.78	inf	inf	1.38

	Eff. depth	Event-based storage peak for scenario 1 [mm]													
		50	**60**	**70**	**80**	**90**	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**Avg**
Urban wetland	5 mm	1.09	1.1	1.12	1.13	1.12	1.09	1.09	1.07	1.03	1.05	1.01	1.07	1.1	1.07
	10 mm	1.18	1.21	1.23	1.22	1.25	1.25	1.21	1.16	1.14	1.09	1.08	1.16	1.15	1.17
	20 mm	1.21	1.25	1.27	1.29	1.32	1.34	1.42	1.44	1.37	1.33	1.32	1.34	inf	1.38
	30 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.53	1.4	1.68	1.88	inf	1.53
	40 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.76	inf	inf	1.58
	50 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.84	inf	inf	1.60
	100 mm	1.21	1.25	1.27	1.3	1.33	1.34	1.45	1.56	1.54	1.41	1.84	inf	inf	1.60
Use of groundwater (acquifer storage)	5 mm	2.22	2.43	2.55	2.66	2.83	2.94	2.62	2.86	2.37	2.07	2.48	inf	inf	2.55
	10 mm	2.21	2.43	2.6	2.82	3.04	3.29	3.88	4.04	3.22	4.32	inf	inf	inf	3.67
	20 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	4.92	inf	inf	inf	inf	inf	4.62
	30 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	40 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	50 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
	100 mm	2.21	2.43	2.6	2.82	3.04	3.29	4.67	5.35	inf	inf	inf	inf	inf	4.68
Water roof	5 mm	1.07	1.08	1.08	1.09	1.08	1.07	1.06	1.05	1.03	1.06	1.02	1.12	1.06	1.07
	10 mm	1.14	1.16	1.16	1.18	1.17	1.16	1.16	1.16	1.16	1.15	1.17	1.17	1.06	1.16
	20 mm	1.18	1.2	1.2	1.22	1.22	1.21	1.29	1.34	1.32	1.26	1.39	1.22	inf	1.30
	30 mm	1.2	1.21	1.22	1.24	1.25	1.25	1.37	1.43	1.4	1.48	1.39	1.5	inf	1.39
	40 mm	1.21	1.23	1.25	1.27	1.28	1.27	1.41	1.5	1.43	1.52	1.62	1.5	inf	1.45
	50 mm	1.21	1.25	1.27	1.29	1.3	1.29	1.47	1.52	1.43	1.66	1.71	1.68	inf	1.52
	100 mm	1.24	1.28	1.31	1.35	1.38	1.36	1.54	1.7	1.62	1.95	2.24	inf	inf	1.72
Water square	5 mm	1.62	1.64	1.64	1.62	1.57	1.52	1.42	1.34	1.33	1.22	1.18	1.25	1.15	1.32
	10 mm	1.9	2.13	2.21	2.36	2.45	2.52	2.04	2.12	1.57	1.44	1.65	1.68	inf	1.87
	20 mm	1.66	1.8	1.99	2.11	2.23	2.34	3.49	3.81	2.95	2.78	inf	inf	inf	3.05
	30 mm	1.4	1.51	1.64	1.76	1.87	1.93	2.94	3.64	4.03	inf	inf	inf	inf	3.10
	40 mm	1.24	1.33	1.4	1.47	1.55	1.6	2.25	3.09	3.49	inf	inf	inf	inf	2.66
	50 mm	1.14	1.19	1.24	1.3	1.36	1.39	1.87	2.58	2.77	3.92	inf	inf	inf	2.37
	100 mm	1	1.02	1.03	1.02	1.04	1.05	1.11	1.32	1.4	1.34	1.77	inf	inf	1.36

Scenario 2: Tropical climate

	Eff. depth	Event-based storage peak for scenario 2[mm]																	
		50	100	150	200	250	300	350	400	450	500	1000	1500	2000	2500	3000	3500	4000	Avg.
Bioretention cell	5 mm	1.25	1.34	1.32	1.3	1.33	1.32	1.31	1.29	1.28	1.29	1.31	1.4	1.19	1.34	1.25	1.06	0.97	1.26
	10 mm	1.24	1.39	1.48	1.49	1.48	1.47	1.46	1.44	1.39	1.37	1.46	1.49	1.27	1.35	1.32	1.04	0.97	1.29
	20 mm	1.23	1.37	1.46	1.52	1.58	1.66	1.62	1.62	1.63	1.64	1.64	1.57	1.36	1.49	1.3	1.15	0.95	1.31
	30 mm	1.23	1.36	1.46	1.52	1.58	1.65	1.62	1.66	1.68	1.71	1.71	1.61	1.42	1.51	1.36	1.22	0.91	1.32
	40 mm	1.23	1.36	1.45	1.51	1.58	1.65	1.61	1.65	1.67	1.7	1.75	1.61	1.41	1.54	1.54	1.22	1.02	1.32
	50 mm	1.23	1.36	1.45	1.51	1.58	1.65	1.61	1.65	1.67	1.7	1.79	1.61	1.41	1.58	1.61	1.22	1.05	1.32
	100 mm	1.23	1.36	1.45	1.51	1.58	1.65	1.61	1.65	1.67	1.7	1.79	1.63	1.41	1.58	1.61	1.27	1.05	1.32
Bioswale	5 mm	1.25	1.34	1.32	1.3	1.33	1.32	1.31	1.29	1.28	1.29	1.31	1.4	1.19	1.34	1.25	1.06	0.97	1.25
	10 mm	1.24	1.39	1.48	1.49	1.48	1.47	1.46	1.44	1.39	1.37	1.46	1.49	1.27	1.35	1.32	0.99	0.97	1.30
	20 mm	1.23	1.37	1.46	1.52	1.58	1.66	1.62	1.62	1.63	1.64	1.64	1.57	1.36	1.49	1.3	1.14	0.95	1.40
	30 mm	1.23	1.36	1.46	1.52	1.58	1.65	1.62	1.66	1.68	1.71	1.71	1.61	1.42	1.51	1.36	1.21	0.91	1.47
	40 mm	1.23	1.36	1.45	1.51	1.58	1.65	1.61	1.65	1.67	1.7	1.75	1.61	1.41	1.54	1.54	1.21	1.02	1.50
	50 mm	1.23	1.36	1.45	1.51	1.58	1.65	1.61	1.65	1.67	1.7	1.79	1.61	1.41	1.58	1.61	1.21	1.05	1.52
	100 mm	1.23	1.36	1.45	1.51	1.58	1.65	1.61	1.65	1.67	1.7	1.79	1.63	1.41	1.58	1.61	1.21	1.05	1.53
Deep Groundwater infiltration	5 mm	1.25	1.36	1.37	1.38	1.38	1.42	1.41	1.42	1.4	1.41	1.57	1.61	1.27	1.46	1.29	1.16	1.05	1.35
	10 mm	1.24	1.37	1.47	1.53	1.58	1.62	1.59	1.62	1.63	1.66	1.69	1.61	1.41	1.48	1.42	1.2	0.91	1.43
	20 mm	1.24	1.37	1.47	1.57	1.65	1.7	1.73	1.78	1.81	1.83	2.01	1.68	1.41	1.54	1.36	1.13	0.94	1.50
	30 mm	1.24	1.37	1.47	1.57	1.65	1.7	1.72	1.79	1.83	1.87	2.08	1.68	1.54	1.61	1.37	1.17	0.92	1.53
	40 mm	1.23	1.37	1.47	1.57	1.65	1.7	1.72	1.78	1.84	1.87	2.13	1.74	1.58	1.57	1.36	1.17	0.92	1.55
	50 mm	1.23	1.37	1.47	1.57	1.65	1.7	1.72	1.78	1.82	1.86	2.14	1.8	1.58	1.61	1.42	1.17	0.92	1.56
	100 mm	1.23	1.37	1.47	1.56	1.65	1.7	1.73	1.79	1.83	1.87	2.13	1.86	1.69	1.66	1.42	1.22	0.92	1.59
Drainage/Infiltration/ Transport (DIT) drains	5 mm	1.25	1.32	1.31	1.31	1.31	1.32	1.33	1.31	1.31	1.3	1.38	1.44	1.22	1.31	1.19	1.05	1.01	1.26
	10 mm	1.24	1.38	1.48	1.49	1.49	1.49	1.47	1.46	1.45	1.44	1.49	1.51	1.24	1.37	1.3	1.03	0.97	1.30
	20 mm	1.23	1.35	1.46	1.56	1.63	1.7	1.66	1.71	1.67	1.66	1.66	1.53	1.24	1.39	1.28	1.18	0.9	1.37
	30 mm	1.22	1.35	1.45	1.55	1.63	1.7	1.69	1.77	1.82	1.81	1.86	1.59	1.27	1.39	1.33	1.13	0.94	1.42
	40 mm	1.22	1.34	1.44	1.55	1.62	1.68	1.68	1.76	1.8	1.81	2.01	1.64	1.31	1.37	1.31	1.11	0.9	1.45
	50 mm	1.22	1.34	1.44	1.54	1.62	1.68	1.68	1.76	1.79	1.79	2.06	1.68	1.38	1.46	1.39	1.1	0.92	1.48
	100 mm	1.22	1.34	1.43	1.53	1.6	1.67	1.66	1.74	1.77	1.77	2.04	1.86	1.48	1.55	1.54	1.14	1.01	1.55
Ditches	5 mm	1.24	1.34	1.37	1.39	1.4	1.45	1.44	1.43	1.43	1.46	1.59	1.6	1.28	1.42	1.26	1.22	1.03	1.37
	10 mm	1.24	1.37	1.47	1.53	1.56	1.61	1.57	1.59	1.6	1.63	1.63	1.58	1.31	1.43	1.35	1.19	0.9	1.40
	20 mm	1.23	1.36	1.46	1.56	1.64	1.69	1.7	1.73	1.77	1.79	1.88	1.59	1.35	1.38	1.33	1.11	0.97	1.43
	30 mm	1.23	1.36	1.46	1.56	1.63	1.69	1.7	1.74	1.81	1.83	2	1.57	1.36	1.48	1.29	1.17	0.91	1.46
	40 mm	1.23	1.36	1.45	1.56	1.63	1.69	1.7	1.73	1.79	1.81	2.01	1.58	1.44	1.49	1.29	1.16	0.92	1.47
	50 mm	1.23	1.36	1.45	1.56	1.63	1.69	1.69	1.73	1.79	1.81	2	1.67	1.44	1.49	1.37	1.16	0.92	1.48
	100 mm	1.23	1.35	1.45	1.56	1.63	1.68	1.69	1.72	1.78	1.8	2	1.79	1.46	1.53	1.4	1.16	0.92	1.50

	Eff. depth	Event-based storage peak for scenario 2[mm]																
		50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**Avg.**
Extensive green roofs	5 mm	1.11	1.13	1.11	1.1	1.09	1.1	1.09	1.09	1.07	1.08	1.05	1.08	1.07	1.18	1.05	1.05	inf	1.09
	10 mm	1.11	1.15	1.14	1.15	1.14	1.15	1.14	1.13	1.12	1.12	1.07	1.11	1.09	1.19	1.08	1.06	inf	1.11
	20 mm	1.12	1.15	1.17	1.19	1.2	1.21	1.21	1.2	1.19	1.18	1.1	1.18	1.09	1.22	1.13	1.06	inf	1.15
	30 mm	1.12	1.15	1.18	1.2	1.23	1.24	1.23	1.23	1.21	1.22	1.15	1.21	1.11	1.25	1.17	1.11	inf	1.19
	40 mm	1.12	1.15	1.19	1.2	1.23	1.26	1.25	1.24	1.22	1.24	1.2	1.25	1.16	1.28	1.26	1.12	inf	1.22
	50 mm	1.12	1.16	1.19	1.2	1.24	1.26	1.25	1.25	1.24	1.25	1.23	1.28	1.19	1.28	1.32	1.12	inf	1.24
	100 mm	1.12	1.16	1.19	1.21	1.25	1.28	1.27	1.27	1.25	1.27	1.33	1.38	1.3	1.39	1.38	1.32	inf	1.34
Gravel layers	5 mm	1.26	1.3	1.28	1.25	1.26	1.28	1.27	1.25	1.25	1.25	1.27	1.36	1.28	1.32	1.22	1.04	1.04	1.24
	10 mm	1.24	1.39	1.47	1.46	1.43	1.44	1.41	1.4	1.36	1.35	1.38	1.47	1.23	1.31	1.27	1.03	0.95	1.28
	20 mm	1.23	1.37	1.47	1.56	1.66	1.74	1.67	1.67	1.65	1.64	1.62	1.55	1.3	1.47	1.33	1.16	0.9	1.40
	30 mm	1.23	1.35	1.45	1.55	1.64	1.73	1.74	1.81	1.87	1.87	1.86	1.6	1.36	1.44	1.37	1.2	0.91	1.50
	40 mm	1.22	1.35	1.45	1.54	1.64	1.71	1.72	1.79	1.87	1.9	2.02	1.69	1.39	1.56	1.45	1.18	inf	1.57
	50 mm	1.22	1.35	1.45	1.54	1.63	1.71	1.71	1.78	1.86	1.88	2.14	1.72	1.51	1.69	1.49	1.14	inf	1.62
	100 mm	1.21	1.34	1.43	1.53	1.62	1.7	1.7	1.76	1.82	1.85	2.15	1.91	1.62	1.85	1.65	1.24	1.07	1.71
Green roofs with drainage delay	5 mm	1.14	1.19	1.22	1.24	1.26	1.3	1.28	1.29	1.27	1.27	1.25	1.32	1.25	1.3	1.47	1.22	inf	1.28
	10 mm	1.16	1.22	1.26	1.27	1.31	1.33	1.33	1.34	1.3	1.34	1.3	1.43	1.35	1.42	1.49	1.26	inf	1.35
	20 mm	1.16	1.25	1.29	1.32	1.38	1.42	1.43	1.42	1.4	1.44	1.49	1.57	1.51	1.52	1.56	1.39	inf	1.47
	30 mm	1.16	1.24	1.3	1.33	1.4	1.45	1.46	1.5	1.46	1.49	1.65	1.77	1.7	1.58	1.49	1.38	inf	1.57
	40 mm	1.16	1.24	1.3	1.33	1.4	1.46	1.48	1.51	1.48	1.52	1.82	1.86	1.83	1.84	1.46	1.54	inf	1.70
	50 mm	1.16	1.24	1.29	1.33	1.39	1.46	1.48	1.51	1.49	1.55	1.96	2.02	1.93	1.91	1.52	1.64	inf	1.80
	100 mm	1.16	1.24	1.29	1.32	1.39	1.45	1.47	1.5	1.48	1.54	2.06	2.38	2.66	2.46	2.14	inf	inf	2.14
Hollow roads	5 mm	1.05	1.04	1.04	1.03	1.03	1.03	1.02	1.03	1.03	1.02	1	1.01	1.02	1.01	1.01	1.01	1	1.02
	10 mm	1.07	1.09	1.09	1.07	1.07	1.07	1.06	1.06	1.06	1.05	1.03	1.03	1.03	1.03	1.02	1.01	1.01	1.04
	20 mm	1.07	1.1	1.12	1.12	1.12	1.14	1.14	1.15	1.11	1.12	1.05	1.09	1.05	1.1	1.05	1.02	1.02	1.08
	30 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.17	1.18	1.1	1.17	1.12	1.15	1.07	1.03	1.03	1.12
	40 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.17	1.25	1.15	1.21	1.12	1.08	1.04	1.17
	50 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.22	1.31	1.27	1.26	1.18	1.14	1.04	1.21
	100 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.23	1.36	1.44	1.4	1.51	1.45	inf	1.33
Infiltration boxes	5 mm	1.26	1.25	1.21	1.19	1.18	1.18	1.18	1.17	1.14	1.15	1.13	1.19	1.27	1.24	1.07	0.99	inf	1.15
	10 mm	1.26	1.39	1.37	1.33	1.32	1.32	1.28	1.26	1.24	1.25	1.18	1.3	1.25	1.21	1.14	0.96	1.03	1.17
	20 mm	1.24	1.37	1.48	1.55	1.57	1.54	1.48	1.43	1.4	1.39	1.3	1.38	1.2	1.2	1.19	0.96	0.93	1.22
	30 mm	1.22	1.35	1.45	1.54	1.6	1.64	1.66	1.65	1.6	1.58	1.47	1.46	1.27	1.27	1.27	0.94	0.95	1.27
	40 mm	1.21	1.34	1.43	1.54	1.6	1.67	1.7	1.72	1.71	1.67	1.59	1.51	1.35	1.28	1.3	0.98	0.89	1.32
	50 mm	1.21	1.33	1.42	1.52	1.6	1.67	1.68	1.73	1.72	1.71	1.76	1.57	1.3	1.4	1.35	0.99	0.89	1.38
	100 mm	1.21	1.33	1.41	1.5	1.58	1.63	1.66	1.7	1.77	1.78	2.27	1.98	1.71	1.78	1.69	1.52	inf	1.75

	Eff. depth	Event-based storage peak for scenario 2[mm]																	
		50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**Avg.**
Infiltration fields and strips	5 mm	1.24	1.34	1.37	1.39	1.4	1.45	1.44	1.43	1.44	1.46	1.59	1.6	1.28	1.42	1.26	1.21	1.03	1.37
	10 mm	1.24	1.37	1.47	1.53	1.56	1.61	1.57	1.59	1.61	1.63	1.63	1.56	1.31	1.43	1.4	1.19	0.9	1.40
	20 mm	1.23	1.36	1.46	1.56	1.64	1.69	1.69	1.73	1.77	1.79	1.87	1.57	1.35	1.37	1.33	1.11	0.97	1.43
	30 mm	1.23	1.36	1.45	1.56	1.64	1.69	1.7	1.74	1.81	1.83	1.99	1.57	1.36	1.42	1.28	1.17	0.91	1.46
	40 mm	1.23	1.36	1.45	1.56	1.63	1.69	1.7	1.73	1.79	1.81	2.01	1.58	1.43	1.49	1.29	1.16	0.91	1.47
	50 mm	1.23	1.36	1.45	1.56	1.63	1.69	1.69	1.73	1.79	1.8	2	1.67	1.44	1.49	1.37	1.16	0.92	1.48
	100 mm	1.23	1.35	1.45	1.55	1.63	1.68	1.69	1.72	1.78	1.79	1.98	1.79	1.46	1.53	1.4	1.16	0.92	1.50
Infiltration shaft	5 mm	1.26	1.29	1.27	1.23	1.25	1.28	1.25	1.24	1.23	1.24	1.24	1.36	1.29	1.3	1.22	1.02	1.09	1.22
	10 mm	1.24	1.37	1.44	1.44	1.41	1.41	1.38	1.38	1.36	1.33	1.35	1.45	1.2	1.29	1.25	1.06	0.94	1.26
	20 mm	1.23	1.36	1.44	1.52	1.6	1.68	1.66	1.6	1.58	1.57	1.56	1.56	1.31	1.46	1.37	1.08	0.91	1.37
	30 mm	1.22	1.35	1.43	1.52	1.59	1.67	1.67	1.72	1.77	1.8	1.81	1.64	1.42	1.49	1.39	1.18	0.95	1.48
	40 mm	1.22	1.35	1.43	1.51	1.58	1.66	1.64	1.71	1.77	1.82	1.97	1.7	1.55	1.6	1.42	1.19	1.06	1.57
	50 mm	1.22	1.35	1.43	1.51	1.58	1.66	1.64	1.7	1.76	1.82	2.09	1.85	1.67	1.74	1.64	1.22	inf	1.64
	100 mm	1.22	1.34	1.43	1.51	1.58	1.66	1.64	1.68	1.75	1.81	2.12	2.01	1.78	1.97	1.81	1.35	inf	1.79
Infiltration trench	5 mm	1.25	1.29	1.27	1.23	1.25	1.28	1.26	1.24	1.23	1.24	1.24	1.36	1.29	1.3	1.22	1.02	1.11	1.23
	10 mm	1.24	1.37	1.44	1.44	1.41	1.42	1.39	1.39	1.36	1.33	1.35	1.45	1.2	1.32	1.25	1.06	0.95	1.27
	20 mm	1.23	1.36	1.43	1.52	1.6	1.67	1.67	1.61	1.59	1.58	1.58	1.58	1.33	1.46	1.37	1.07	0.95	1.38
	30 mm	1.22	1.35	1.42	1.52	1.59	1.66	1.66	1.72	1.76	1.8	1.81	1.68	1.44	1.5	1.39	1.18	0.96	1.49
	40 mm	1.22	1.35	1.42	1.51	1.59	1.65	1.66	1.71	1.75	1.81	1.98	1.73	1.57	1.58	1.42	1.19	inf	1.58
	50 mm	1.22	1.35	1.42	1.51	1.58	1.65	1.65	1.69	1.75	1.81	2.1	1.81	1.67	1.65	1.63	1.22	inf	1.62
	100 mm	1.22	1.35	1.42	1.51	1.58	1.65	1.65	1.7	1.75	1.81	2.1	1.84	1.67	1.86	1.68	1.27	inf	1.69
Intensive green roofs	5 mm	1.11	1.13	1.11	1.1	1.09	1.1	1.09	1.09	1.07	1.08	1.05	1.08	1.07	1.18	1.05	1.05	inf	1.09
	10 mm	1.11	1.15	1.14	1.15	1.14	1.15	1.14	1.13	1.12	1.12	1.07	1.11	1.09	1.19	1.08	1.06	inf	1.11
	20 mm	1.12	1.15	1.17	1.19	1.2	1.21	1.21	1.2	1.19	1.18	1.1	1.18	1.09	1.22	1.13	1.06	inf	1.15
	30 mm	1.12	1.15	1.18	1.2	1.23	1.24	1.23	1.23	1.21	1.22	1.15	1.21	1.11	1.25	1.17	1.11	inf	1.19
	40 mm	1.12	1.15	1.19	1.2	1.23	1.26	1.25	1.24	1.23	1.24	1.19	1.24	1.16	1.28	1.26	1.12	inf	1.22
	50 mm	1.12	1.16	1.19	1.2	1.24	1.26	1.25	1.25	1.24	1.25	1.23	1.26	1.19	1.28	1.32	1.12	inf	1.24
	100 mm	1.12	1.16	1.19	1.21	1.25	1.29	1.27	1.27	1.25	1.27	1.3	1.36	1.22	1.39	1.38	1.32	inf	1.33
Lowering part of garden	5 mm	0.99	1	1	0.99	1	0.99	0.99	1	0.99	1	0.99	0.99	0.99	0.96	0.95	0.97	0.93	0.97
	10 mm	0.99	1	1	0.99	0.99	0.99	0.99	1	0.99	1	0.99	0.99	0.99	0.97	1	0.98	0.93	0.97
	20 mm	0.99	1	1	0.99	0.99	0.99	0.99	1	0.99	1	0.99	0.99	0.99	0.98	1	0.98	0.93	0.98
	30 mm	0.99	1	1	0.99	0.99	0.99	0.99	1	0.99	1	0.99	0.99	0.99	1.04	1	0.98	0.94	0.99
	40 mm	0.99	1	1	0.99	0.99	0.99	0.99	1	0.99	1	0.99	0.99	1	1.04	1	0.98	0.94	0.99
	50 mm	0.99	0.99	1	0.99	0.99	0.99	0.99	0.99	0.99	1	0.99	0.99	1	1.04	1	0.98	0.96	0.99
	100 mm	0.99	0.99	1	0.99	0.99	0.99	0.99	0.99	0.99	1	0.99	0.99	1	1.04	1.02	0.98	0.98	1.00

	Eff. depth	Event-based storage peak for scenario 2[mm]																	
		50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**Avg.**
Lowering part of terrace	5 mm	1.05	1.05	1.04	1.03	1.03	1.03	1.02	1.03	1.03	1.02	1	1.01	1.02	1.01	1.01	1.01	1	1.02
	10 mm	1.07	1.09	1.09	1.07	1.07	1.07	1.06	1.05	1.06	1.04	1.03	1.03	1.03	1.03	1.02	1.01	1.01	1.04
	20 mm	1.07	1.1	1.12	1.12	1.12	1.14	1.14	1.15	1.11	1.12	1.05	1.08	1.05	1.1	1.05	1.02	1.02	1.08
	30 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.17	1.18	1.09	1.17	1.12	1.15	1.07	1.03	1.03	1.12
	40 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.17	1.24	1.15	1.2	1.12	1.06	1.03	1.16
	50 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.22	1.31	1.27	1.26	1.17	1.14	1.04	1.21
	100 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.23	1.36	1.44	1.39	1.51	1.45		1.33
Permeable pavement (storage)	5 mm	1.21	1.29	1.33	1.33	1.35	1.39	1.37	1.34	1.34	1.37	1.48	1.48	1.19	1.26	1.19	1.06	1	1.25
	10 mm	1.22	1.34	1.42	1.48	1.54	1.56	1.52	1.53	1.53	1.55	1.59	1.46	1.16	1.21	1.19	1.09	0.83	1.27
	20 mm	1.21	1.33	1.43	1.53	1.59	1.63	1.63	1.63	1.65	1.68	1.71	1.5	1.19	1.21	1.13	1.04	0.84	1.27
	30 mm	1.21	1.33	1.42	1.51	1.57	1.63	1.64	1.64	1.69	1.72	1.73	1.5	1.2	1.21	1.1	1.09	0.84	1.28
	40 mm	1.21	1.33	1.42	1.51	1.57	1.63	1.63	1.64	1.68	1.72	1.75	1.5	1.24	1.21	1.14	1.09	0.84	1.29
	50 mm	1.21	1.33	1.42	1.51	1.57	1.62	1.62	1.62	1.68	1.71	1.73	1.55	1.24	1.23	1.17	1.09	0.84	1.29
	100 mm	1.21	1.33	1.42	1.51	1.56	1.62	1.61	1.61	1.67	1.7	1.74	1.59	1.3	1.23	1.15	1.09	0.84	1.30
Private green garden	5 mm	1.22	1.35	1.46	1.55	1.62	1.65	1.64	1.67	1.67	1.71	1.75	1.55	1.24	1.24	1.3	1.1	0.95	1.35
	10 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.67	1.7	1.75	1.77	1.87	1.58	1.25	1.3	1.27	1.13	0.91	1.39
	20 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	30 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	40 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	50 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	100 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
Rain barrel	5 mm	1.11	1.09	1.07	1.06	1.07	1.06	1.05	1.05	1.05	1.03	1.01	1.02	1.02	1.02	1.02	1.01	1	1.03
	10 mm	1.14	1.19	1.19	1.16	1.14	1.15	1.13	1.14	1.11	1.12	1.05	1.07	1.05	1.1	1.05	1.02	1.01	1.07
	20 mm	1.13	1.2	1.24	1.27	1.3	1.35	1.33	1.31	1.26	1.26	1.16	1.25	1.14	1.19	1.12	1.03	1.03	1.17
	30 mm	1.11	1.17	1.21	1.24	1.29	1.36	1.37	1.39	1.39	1.41	1.29	1.37	1.31	1.28	1.16	1.2	1.11	1.27
	40 mm	1.09	1.15	1.18	1.21	1.25	1.31	1.32	1.33	1.33	1.34	1.43	1.45	1.41	1.34	1.33	1.32	inf	1.36
	50 mm	1.06	1.13	1.16	1.18	1.21	1.26	1.29	1.29	1.27	1.28	1.49	1.58	1.46	1.42	1.46	1.44	inf	1.42
	100 mm	1.02	1.04	1.06	1.07	1.09	1.11	1.14	1.15	1.16	1.15	1.2	1.32	1.46	1.38	1.45	1.33	inf	1.32
Rain garden	5 mm	1.22	1.35	1.46	1.55	1.62	1.65	1.64	1.67	1.67	1.71	1.75	1.55	1.24	1.24	1.3	1.1	0.95	1.35
	10 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.67	1.7	1.75	1.77	1.87	1.58	1.25	1.3	1.27	1.13	0.91	1.39
	20 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	30 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	40 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	50 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	100 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42

	Eff. depth	Event-based storage peak for scenario 2[mm]																	
		50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**Avg.**
Rainwater detention pond	5 mm	1.22	1.35	1.44	1.54	1.62	1.71	1.71	1.77	1.84	1.84	2.35	2.11	2	2.27	2.15	inf	inf	2.06
	10 mm	1.22	1.35	1.44	1.54	1.62	1.71	1.71	1.77	1.84	1.84	2.35	2.12	1.98	2.26	2.18	inf	inf	2.08
	20 mm	1.22	1.35	1.44	1.54	1.62	1.71	1.7	1.77	1.84	1.84	2.33	2.11	2.07	2.26	2.41	inf	inf	2.10
	30 mm	1.22	1.35	1.44	1.54	1.62	1.71	1.7	1.76	1.83	1.84	2.33	2.09	2.1	2.28	2.44	inf	inf	2.11
	40 mm	1.22	1.35	1.44	1.54	1.62	1.71	1.7	1.76	1.83	1.84	2.33	2.09	2.1	2.35	2.44	inf	inf	2.12
	50 mm	1.22	1.35	1.44	1.54	1.62	1.71	1.7	1.76	1.83	1.84	2.33	2.09	2.05	2.41	2.44	inf	inf	2.13
	100 mm	1.22	1.35	1.44	1.54	1.62	1.71	1.7	1.76	1.83	1.84	2.33	2.09	2.05	2.56	2.44	inf	inf	2.14
Rainwater storage below buildings	5 mm	1.09	1.07	1.06	1.05	1.06	1.05	1.04	1.04	1.04	1.03	1.01	1.01	1.01	1.02	1.01	1	1	1.02
	10 mm	1.13	1.16	1.15	1.12	1.11	1.12	1.09	1.11	1.08	1.09	1.04	1.04	1.03	1.08	1.03	1.01	1.01	1.06
	20 mm	1.15	1.22	1.25	1.25	1.25	1.27	1.25	1.24	1.21	1.2	1.1	1.16	1.11	1.14	1.07	1.03	1.03	1.13
	30 mm	1.15	1.22	1.27	1.29	1.34	1.39	1.37	1.37	1.34	1.31	1.21	1.28	1.22	1.22	1.14	1.08	1.04	1.22
	40 mm	1.15	1.22	1.27	1.29	1.35	1.41	1.4	1.42	1.42	1.42	1.34	1.37	1.35	1.32	1.23	1.22	inf	1.31
	50 mm	1.15	1.22	1.27	1.29	1.35	1.41	1.4	1.42	1.42	1.45	1.48	1.48	1.41	1.34	1.38	1.29	inf	1.40
	100 mm	1.15	1.22	1.27	1.29	1.35	1.4	1.4	1.42	1.42	1.45	1.69	1.79	1.73	1.82	1.73	1.56	inf	1.68
Retention soil filter	5 mm	1.22	1.35	1.46	1.55	1.62	1.65	1.64	1.67	1.67	1.71	1.75	1.55	1.24	1.24	1.3	1.1	0.95	1.35
	10 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.67	1.7	1.75	1.77	1.87	1.58	1.25	1.3	1.27	1.13	0.91	1.39
	20 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	30 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	40 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	50 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
	100 mm	1.23	1.35	1.45	1.55	1.62	1.67	1.68	1.72	1.76	1.78	1.94	1.6	1.34	1.37	1.25	1.16	0.85	1.42
Systems for rainwater harvesting	5 mm	1.04	1.03	1.02	1.02	1.02	1.02	1.01	1.01	1.02	1.01	1	1.01	1	1.01	1	1	1	1.01
	10 mm	1.07	1.06	1.05	1.04	1.05	1.04	1.04	1.03	1.03	1.02	1.01	1.01	1	1.04	1.01	1	1	1.02
	20 mm	1.11	1.12	1.12	1.1	1.11	1.1	1.08	1.07	1.06	1.07	1.03	1.04	1.02	1.07	1.01	1.01	1.02	1.05
	30 mm	1.13	1.17	1.16	1.17	1.17	1.17	1.14	1.14	1.14	1.12	1.07	1.07	1.05	1.09	1.03	1.02	1.04	1.08
	40 mm	1.14	1.2	1.22	1.22	1.22	1.23	1.21	1.22	1.19	1.18	1.1	1.13	1.11	1.11	1.05	1.02	1.07	1.12
	50 mm	1.15	1.22	1.25	1.26	1.27	1.29	1.29	1.29	1.25	1.25	1.15	1.22	1.12	1.19	1.1	1.04	1.1	1.17
	100 mm	1.16	1.23	1.28	1.31	1.38	1.43	1.44	1.46	1.45	1.48	1.6	1.6	1.55	1.46	1.39	1.3	inf	1.48
Underground storage	5 mm	1.19	1.18	1.15	1.13	1.12	1.12	1.1	1.11	1.09	1.09	1.04	1.04	1.04	1.07	1.04	1.01	1.01	1.06
	10 mm	1.23	1.35	1.34	1.29	1.28	1.27	1.25	1.22	1.2	1.21	1.11	1.17	1.11	1.14	1.07	1.02	1.02	1.13
	20 mm	1.18	1.32	1.42	1.53	1.61	1.63	1.56	1.51	1.47	1.48	1.31	1.38	1.33	1.29	1.26	1.22	inf	1.31
	30 mm	1.13	1.24	1.34	1.4	1.52	1.6	1.63	1.7	1.73	1.73	1.62	1.6	1.46	1.39	1.44	1.41	inf	1.49
	40 mm	1.1	1.2	1.26	1.32	1.4	1.49	1.49	1.53	1.56	1.6	1.82	1.76	1.59	1.67	1.6	1.52	inf	1.63
	50 mm	1.07	1.14	1.2	1.25	1.33	1.38	1.41	1.43	1.44	1.49	1.8	1.87	1.74	1.81	1.69	1.56	inf	1.67
	100 mm	1.01	1.03	1.05	1.06	1.08	1.09	1.11	1.13	1.13	1.12	1.19	1.32	1.47	1.36	1.41	1.32	inf	1.31

	Eff. depth	Event-based storage peak for scenario 2 [mm]																	
		50	**100**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**1000**	**1500**	**2000**	**2500**	**3000**	**3500**	**4000**	**Avg.**
Urban wetland	5 mm	1.05	1.05	1.04	1.03	1.03	1.03	1.02	1.03	1.03	1.02	1.01	1.01	1.01	1.01	1.01	1	1	1.02
	10 mm	1.07	1.09	1.08	1.07	1.07	1.07	1.06	1.05	1.05	1.04	1.02	1.02	1.02	1.03	1.02	1.01	1.01	1.03
	20 mm	1.07	1.1	1.12	1.12	1.12	1.14	1.14	1.14	1.11	1.12	1.05	1.08	1.05	1.09	1.05	1.02	1.02	1.08
	30 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.18	1.17	1.17	1.08	1.16	1.11	1.12	1.07	1.03	1.02	1.12
	40 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.16	1.23	1.15	1.19	1.11	1.05	1.03	1.16
	50 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.22	1.31	1.25	1.25	1.15	1.13	1.04	1.20
	100 mm	1.07	1.1	1.12	1.13	1.14	1.17	1.2	1.19	1.18	1.19	1.23	1.36	1.44	1.34	1.5	1.45		1.33
Use of groundwater (acquifer storage)	5 mm	1.25	1.36	1.37	1.38	1.38	1.42	1.41	1.42	1.4	1.41	1.57	1.61	1.27	1.46	1.29	1.16	1.05	1.35
	10 mm	1.24	1.37	1.47	1.53	1.58	1.62	1.59	1.62	1.63	1.66	1.69	1.61	1.41	1.48	1.42	1.2	0.91	1.43
	20 mm	1.24	1.37	1.47	1.57	1.65	1.7	1.73	1.78	1.81	1.83	2.01	1.68	1.41	1.54	1.36	1.13	0.94	1.50
	30 mm	1.24	1.37	1.47	1.57	1.65	1.7	1.72	1.79	1.83	1.87	2.08	1.68	1.54	1.61	1.37	1.17	0.92	1.53
	40 mm	1.23	1.37	1.47	1.57	1.65	1.7	1.72	1.78	1.84	1.87	2.13	1.74	1.58	1.57	1.36	1.17	0.92	1.55
	50 mm	1.23	1.37	1.47	1.57	1.65	1.7	1.72	1.78	1.82	1.86	2.14	1.8	1.58	1.61	1.42	1.17	0.92	1.56
	100 mm	1.23	1.37	1.47	1.56	1.65	1.7	1.73	1.79	1.83	1.87	2.13	1.86	1.69	1.66	1.42	1.22	0.92	1.59
Water roof	5 mm	1.05	1.05	1.04	1.03	1.03	1.03	1.02	1.03	1.03	1.02	1.02	1.01	1.02	1.01	1.01	1.01	1.01	1.03
	10 mm	1.08	1.09	1.08	1.07	1.07	1.07	1.06	1.07	1.05	1.06	1.04	1.02	1.02	1.08	1.01	1.01	1.02	1.05
	20 mm	1.08	1.11	1.11	1.12	1.14	1.13	1.12	1.12	1.12	1.11	1.06	1.09	1.07	1.1	1.02	1.01	1.04	1.08
	30 mm	1.09	1.11	1.13	1.14	1.16	1.16	1.16	1.16	1.15	1.15	1.08	1.13	1.08	1.13	1.08	1.02	1.08	1.11
	40 mm	1.09	1.12	1.13	1.15	1.18	1.18	1.17	1.18	1.17	1.17	1.13	1.14	1.11	1.17	1.08	1.07	1.12	1.14
	50 mm	1.09	1.12	1.14	1.16	1.18	1.19	1.19	1.19	1.18	1.19	1.14	1.17	1.14	1.2	1.08	1.07	inf	1.16
	100 mm	1.09	1.12	1.14	1.17	1.2	1.21	1.21	1.21	1.2	1.22	1.22	1.3	1.26	1.33	1.27	1.13	inf	1.24
Water square	5 mm	1.19	1.18	1.15	1.13	1.12	1.13	1.1	1.11	1.09	1.09	1.04	1.04	1.03	1.07	1.03	1.01	1.01	1.06
	10 mm	1.23	1.36	1.34	1.29	1.28	1.27	1.25	1.22	1.2	1.21	1.11	1.17	1.11	1.13	1.07	1.02	1.03	1.13
	20 mm	1.18	1.33	1.42	1.54	1.62	1.63	1.57	1.51	1.46	1.48	1.29	1.38	1.33	1.28	1.25	1.22	inf	1.31
	30 mm	1.13	1.24	1.34	1.4	1.52	1.6	1.63	1.7	1.73	1.73	1.63	1.6	1.46	1.37	1.47	1.4	inf	1.49
	40 mm	1.09	1.2	1.26	1.32	1.4	1.48	1.5	1.53	1.56	1.61	1.81	1.78	1.58	1.65	1.59	1.51	inf	1.63
	50 mm	1.06	1.14	1.2	1.25	1.33	1.37	1.41	1.44	1.44	1.48	1.78	1.86	1.75	1.81	1.69	1.57	inf	1.67
	100 mm	1	1.03	1.04	1.06	1.08	1.08	1.1	1.12	1.13	1.12	1.18	1.32	1.44	1.36	1.41	1.32	inf	1.31

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Results of the flow peak reduction factor and runoff volume reduction factor over the project area of two neighbourhoods

Flow peak factor for the whole area

	Residential Housing							Post-war garden city low-rise						
	Effective depth [mm]							Effective depth [mm]						
Measure	**5**	**10**	**20**	**30**	**40**	**50**	**100**	**5**	**10**	**20**	**30**	**40**	**50**	**100**
Urban wetland	1.06	1.15	1.38	1.72	2.12	3.23	3.23	1.06	1.14	1.37	1.71	2.11	3.26	3.26
Bioswale	1.45	1.82	2.5	2.89	3.23	3.51	3.6	1.63	2.42	3.25	3.47	3.47	3.48	3.5
Deep groundwater infiltration	1.85	3.34	10.04	34.4	34.4	34.4	34.4	1.82	3.39	12.04	40.61	40.61	40.61	40.61
Ditches	1.58	2.37	5.33	34.4	34.4	34.4	34.4	1.89	3.15	8.72	40.61	40.61	40.61	40.61
Intensive green roofs	1.19	1.33	1.43	1.54	1.6	1.72	1.89	1.14	1.23	1.31	1.38	1.42	1.5	1.61
Extensive green roofs	1.19	1.33	1.43	1.54	1.6	1.72	1.89	1.14	1.23	1.31	1.38	1.42	1.5	1.61
Drainage/Infiltration/Transport (DIT) drains	1.38	1.89	3.9	7.71	34.4	34.4	34.4	1.5	2.28	5.2	18.28	40.61	40.61	40.61
Infiltration fields and strips with surface storage	1.58	2.37	5.33	34.4	34.4	34.4	34.4	1.89	3.15	8.72	40.61	40.61	40.61	40.61
Infiltration trench	1.3	1.79	3.72	7.62	16.64	14.9	16.93	1.44	2.12	4.83	13.66	15.79	17.73	17.73
Infiltration shaft	1.3	1.77	3.64	8.02	34.4	34.4	34.4	1.43	2.11	4.8	15.64	40.61	40.61	40.61
Private green garden	6.82	12.24	34.4	34.4	34.4	34.4	34.4	6.76	15.73	40.61	40.61	40.61	40.61	40.61
Rain barrel	1.13	1.37	2.17	4.02	8.55	8.55	8.55	1.09	1.26	1.8	2.93	5.34	5.34	5.34
Rainwater storage below buildings	1.11	1.28	1.79	2.66	4.36	8.55	8.55	1.08	1.2	1.55	2.11	3.12	5.34	5.34
Retention soil filter	6.82	12.24	34.4	34.4	34.4	34.4	34.4	6.76	15.73	40.61	40.61	40.61	40.61	40.61
Infiltration boxes	1.18	1.43	1.71	1.87	2.16	2.42	3.76	1.28	1.74	3.17	5.05	8.54	17.38	40.61
Systems for rainwater harvesting	1.03	1.11	1.29	1.47	1.72	2.11	8.55	1.02	1.08	1.2	1.33	1.5	1.75	5.34
Water roof	1.08	1.15	1.3	1.32	1.37	1.42	1.64	1.06	1.11	1.21	1.23	1.26	1.3	1.45
Water square	1.24	1.7	3.81	10.51	34.4	34.4	34.4	1.27	1.75	4.31	17.43	40.61	40.61	40.61
Green roofs with drainage delay	1.76	1.85	2.7	4.76	5.8	7.98	7.98	1.53	1.59	2.14	3.35	3.92	5.07	5.07
Hollow roads	1.05	1.13	1.36	1.68	2.11	2.76	2.76	1.05	1.13	1.35	1.67	2.11	2.78	2.78
Underground storage	1.22	1.69	3.76	10.5	34.4	34.4	34.4	1.27	1.75	4.31	17.55	40.61	40.61	40.61
Use of groundwater (aquifer storage and recovery)	1.85	3.34	10.04	34.4	34.4	34.4	34.4	1.82	3.39	12.04	40.61	40.61	40.61	40.61
Rainwater detention pond (wet pond)	34.4	34.4	34.4	34.4	34.4	34.4	34.4	40.61	40.61	40.61	40.61	40.61	40.61	40.61
Bioretention cell	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.06	1.06	1.06	1.06	1.06	1.06	1.06
Gravel layers	1.31	1.8	3.75	8.27	34.4	34.4	34.4	1.44	2.12	4.83	14.75	40.61	40.61	40.61
Permeable pavement (storage)	1.61	2.4	5.41	14.99	34.4	34.4	34.4	1.62	2.87	7.8	40.61	40.61	40.61	40.61
Lowering part of terrace	1.06	1.13	1.36	1.68	2.06	2.76	2.76	1.05	1.13	1.34	1.67	2.06	2.78	2.78
Lowering part of garden	0.53	0.61	0.76	0.93	3.16	3.16	3.16	121.11	121.11	121.11	121.11	121.11	121.11	121.11
Rain garden	6.82	12.24	34.4	34.4	34.4	34.4	34.4	6.76	15.73	40.61	40.61	40.61	40.61	40.61

Runoff volume factor for the whole area

	Residential Housing							Post-war garden city low-rise						
	Effective depth [mm]							Effective depth [mm]						
Measure	**5**	**10**	**20**	**30**	**40**	**50**	**100**	**5**	**10**	**20**	**30**	**40**	**50**	**100**
Urban wetland	1.11	1.23	1.55	1.9	2.32	2.84	3.27	1.12	1.26	1.6	2	2.49	3.09	3.6
Bioswale	1.79	2.33	3.57	4.55	5.35	5.91	6.72	2.34	3.51	5.42	6.38	6.49	6.59	6.71
Deep groundwater infiltration	4.01	6.44	13.31	35.07	35.07	35.07	35.07	3.68	6.41	14.59	46.5	46.5	46.5	46.5
Ditches	3.06	4.54	8.68	17.15	26.09	35.07	35.07	3.86	6.09	12.67	31.87	46.5	46.5	46.5
Intensive green roofs	1.15	1.2	1.26	1.29	1.32	1.35	1.45	1.13	1.16	1.21	1.24	1.25	1.27	1.35
Extensive green roofs	1.15	1.2	1.26	1.29	1.32	1.35	1.45	1.13	1.16	1.21	1.24	1.25	1.27	1.35
Drainage/Infiltration/Transport (DIT) drains	2.08	2.97	5.2	8.53	14.57	19.38	35.07	2.61	3.97	8.09	16.05	26.38	46.5	46.5
Infiltration fields and strips with surface storage	3.06	4.54	8.68	17.15	26.09	35.07	35.07	3.86	6.09	12.67	31.87	46.5	46.5	46.5
Infiltration trench	1.88	2.74	5.35	9.67	15.2	18.77	20.85	2.3	3.56	7.45	14.04	17.92	23.57	23.57
Infiltration shaft	1.85	2.68	5.21	9.42	18.96	26.66	35.07	2.27	3.53	7.36	15.24	25.96	46.5	46.5
Private green garden	10.48	14.97	31.16	35.07	35.07	35.07	35.07	10.63	18.68	46.5	46.5	46.5	46.5	46.5
Rain barrel	1.24	1.6	2.68	4.22	6.24	8.07	8.7	1.2	1.48	2.26	3.3	4.56	5.64	5.98
Rainwater storage below buildings	1.2	1.46	2.21	3.22	4.62	6.67	8.7	1.16	1.37	1.93	2.63	3.55	4.82	5.98
Retention soil filter	10.48	14.97	31.16	35.07	35.07	35.07	35.07	10.63	18.68	46.5	46.5	46.5	46.5	46.5
Infiltration boxes	1.35	1.54	1.83	2.08	2.29	2.51	3.65	1.77	2.43	4.03	6.36	9.79	14.18	46.5
Systems for rainwater harvesting	1.06	1.14	1.32	1.57	1.9	2.39	6.99	1.05	1.11	1.26	1.45	1.71	2.06	5.01
Water roof	1.04	1.08	1.13	1.16	1.18	1.2	1.27	1.04	1.07	1.1	1.13	1.15	1.16	1.21
Water square	1.45	2.25	5.17	11.09	19.85	34.77	35.07	1.56	2.55	5.83	13.38	25.26	46.5	46.5
Green roofs with drainage delay	1.32	1.35	1.37	1.37	1.37	1.37	1.37	1.26	1.28	1.31	1.33	1.33	1.33	1.33
Hollow roads	1.02	1.04	1.05	1.05	1.05	1.06	1.06	1.03	1.04	1.06	1.07	1.08	1.08	1.08
Underground storage	1.44	2.24	5.14	11.05	19.83	34.81	35.07	1.58	2.58	5.86	13.42	25.45	46.5	46.5
Use of groundwater (aquifer storage and recovery)	4.01	6.44	13.31	35.07	35.07	35.07	35.07	3.68	6.41	14.59	46.5	46.5	46.5	46.5
Rainwater detention pond (wet pond)	35.07	35.07	35.07	35.07	35.07	35.07	35.07	46.5	46.5	46.5	46.5	46.5	46.5	46.5
Bioretention cell	1.02	1.02	1.02	1.02	1.02	1.02	1.02	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Gravel layers	1.88	2.75	5.36	9.93	19.25	28.14	35.07	2.3	3.57	7.47	15.47	26.19	46.5	46.5
Permeable pavement (storage)	3.3	5.05	9.48	21.15	34.36	35.07	35.07	3.5	5.83	11.7	28.95	46.5	46.5	46.5
Lowering part of terrace	1.02	1.03	1.05	1.05	1.05	1.05	1.05	1.02	1.04	1.06	1.07	1.08	1.08	1.08
Lowering part of garden	0.52	0.58	0.7	0.86	1.02	1.11	3.21	0	0	0	0	0	138.95	138.95
Rain garden	10.48	14.97	31.16	35.07	35.07	35.07	35.07	10.63	18.68	46.5	46.5	46.5	46.5	46.5

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Glossary

AST Adaptation Support Tool. iv, v, xiii, 1, 24, 25, 59, 133

GEV Generalized Extreme Value distribution. 133

GLO Generalized Logistic distribution. 133

KNMI Koninklijk Nederlands Meteorologisch Instituut. 133

LID Low Impact Development. 133

MUS Multiple Use Water Services. 133

SUDS Sustainable Urban Drainage Systems. 133

TUD Delft University of Technology. 133

UWBM Urban Water Balance Model. iv, xiii, 2, 4, 6, 8, 18, 24, 25, 56, 58, 59, 69, 133

WSUD Water Sensitive Urban Design. 133