EXPLORATION DYNAMIC BUFFERING

CAUMERBEEK

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SUMMARY

Limburg Water Board wants to optimize the existing buffers within the Caumerbeek system in Heerlen. Therefore, an exploration of the possibilities for dynamic buffering and expansion of buffer capacity (both managed by water board and municipalities) within the Caumerbeek system was carried out. Dynamically regulated buffers, as opposed to non-regulated buffers, can also be used for water retention in times of drought. By gaining more insight into the filling of the buffers, and specifically in relation to each other, the water board aims to be able to control the buffers more effectively from the control room during heavy precipitation.

When the capacity of a buffer is exceeded, it overflows. Buffer overflows are detrimental because a large volume of water is discharged uncontrollably at once. As a solution, the throughput of a buffer can be increased. Delaying the overflow moment is effective because there is more time to prepare for possible water nuisance. In addition, it reduces the likelihood of overflows from the buffer during smaller precipitation events.

For the purpose of this study, the catchment area of the Caumerbeek system was determined and information was requested from the Limburg Water Board and from the municipalities of Heerlen and Landgraaf. Thus, a complete picture of the total catchment area was obtained with insight into buffers, overflows and the systems connected to them, paved surface and unpaved surface. By schematizing precipitation as block precipitation on the basis of runoff surfaces, insight was gained into the functioning of the system, where the water comes from and to what extent specific buffers are overloaded.

Using a time-dependent throughput model developed for this study, the buffer fill and throughput were modeled. This model was set up in Excel, so no specific hydrology program is required to access and use it. Using block precipitation (50 mm in 2 hours and 70 mm in 24 hours), the hourly fill of each buffer (compartment) and the throughput in each watercourse were determined over a two-day period. In the model, the throughput can be adjusted for each buffer (compartment). It is therefore possible to determine for the different block precipitations what throughputs should be applied to optimally utilize each buffer (compartment).

Using this throughput model, these conclusions can be drawn:

- The Caumerbeek tributaries, namely the Palembergerbeek, Schroetebeek and Loopgraaf, are the most promising options for dynamic buffering. In the Schroetebeek and Loopgraaf, buffers do not seem to fill fully, which means that more water can actually be retained. In the Palembergerbeek, the watercourse has sufficient capacity to increase the throughput to the point where the buffers will not overflow.
- In the most upstream part of the Caumerbeek, there is also potential for dynamic buffering. Here, however, adjustments have to be made to the system. Consider for example:
    - Increasing buffer capacity in the municipal system.
    - Temporarily permitting water levels above the buffer or watercourse in some locations where flooding is not likely to occur.
    - Increasing the capacity of some watercourses.
- The biggest bottleneck is downstream of the De Dem buffer. Here the throughput may not exceed 3.2 m^3/s, otherwise flooding will occur. This means that the throughput of the buffer cannot simply be increased and that the possibilities for dynamic buffering in the downstream part of the Caumerbeek are the least promising. In any case, De Dem is already heavily loaded by, among other things, large amounts of water from the immediate vicinity.

1 INTRODUCTION

1.1 Background

Limburg Water Board wants the existing buffers within the Caumerbeek system in Heerlen to function more efficiently. During a period of extreme precipitation in the summer of 2021, some buffers overflowed, while other buffers were not fully filled. The water board therefore wishes to explore the possibilities of dynamic buffering and expansion of buffer capacity (both managed by the water board and municipalities) within the Caumerbeek system. In times of drought, dynamically regulated buffers can also be used more efficiently for retaining water than non-controlled buffers. By dynamic buffering is meant: rainwater buffers that are equipped with automatically operated sluices, are interconnected and, based on set parameters, automatically regulate the water levels in the water system or can be remotely controlled from, for example, the central control room.

1.2 Purpose

By gaining more insight into the filling of the buffers, and specifically in relation to each other, the water board aims to control the buffers more effectively from the control room during heavy precipitation. The specific goal of this exploration is:

- Gaining insight into the functioning of the buffers as part of the water system.
- Gaining insight into dynamic buffering as an option for making the stream system more robust.
- Gaining insight into which locations are an option for expanding buffer capacity (managed by water board as well as municipalities).
- Gaining insight into which buffers can be used to retain additional water to combat droughtInzicht krijgen in welke buffers mogelijkheden zijn voor het vasthouden van extra water, om droogte tegen te gaan

1.3 Procedure

Based on an AHN analysis in GIS, the catchment area of the Caumerbeek system was determined. In addition, information was requested from the Limburg Water Board and the municipalities of Heerlen and Landgraaf. In this way, as completely as possible, an overview of the total catchment area was obtained with insight into buffers, overflows and the connected systems and paved surfaces. The information obtained was also validated based on the findings and report of the field visit as part of the Limburg Water Board's ecological assessment.

The data collected were compiled into a map of the Caumerbeek system. This map incorporates information about all buffers and runoff surfaces (paved and unpaved). By schematizing precipitation as block precipitation, the map based on runoff surfaces can be used to gain insight into the functioning of the system, where the water comes from and to what extent specific buffers are loaded.

The map described above was used as the basis for a time-dependent throughput model, whose purpose it is to model buffer filling and throughput. This model was set up in Excel so it can be easily accessed and used. By again using block precipitations, the hourly fill of each buffer (compartment) and the throughput through each watercourse is determined over a two-day period. The throughput can be adjusted for each buffer (compartment), so for each different block precipitation it can be determined which throughput should be applied to optimally utilize each buffer (compartment). The results from this throughput model are used to draw conclusions about the gains to be achieved (in storage volume and flooding) and thus the feasibility of dynamic buffering.

The throughput model was used to calculate four scenarios, namely:

- Scenario 1: throughput equal to the 24-hour emptying of the buffers.
- Scenario 2: throughput equal to maximum actual discharge specified by the water board.
- Scenario 3: throughput equal to downstream watercourse capacity.
- Scenario 4: throughput such that buffers do not quite overflow

A variant of scenario 3 was also calculated. Incorporated in this variant are some measures to investigate the feasibility of making the Caumerbeek system more robust.

1.4 Results

Two products follow from this exploration, namely a map of the Caumerbeek system and a time-dependent throughput model in Excel. The map provides insight into the functioning of the Caumerbeek system. The aim of the time-dependent throughput model is to model the buffer filling and throughput. Based on this, conclusions can be drawn about the feasibility of dynamic buffering.

Using the throughput model, the following conclusions were drawn about the four scenarios:

- Scenario 1: 24-hour emptying is insufficient to use the buffers efficiently. They quickly fill up and then overflow. This means that downstream watercourses are still uncontrollably heavily stressed.
- Scenario 2: This scenario is most similar to the real situation. Buffers fill more efficiently but the throughput is still insufficient.
- Scenario 3: Although the throughput is equal to the capacity of the downstream watercourse, buffers still overflow to a limited extent. As a result, the watercourses are still quite heavily loaded.
- Scenario 4: Buffers no longer overflow but the large throughput puts heavy stress on the watercourses.

Because the Caumerbeek system is immediately overloaded during the block precipitation event of 50 mm in 2 hours, the buffer capacity is instantly exceeded and the buffers overflow. The runoff discharge cannot be passed through, making it impossible to use dynamic buffering to control this precipitation. The results of this 2-hour block precipitation are described in summary form, but only the block precipitation of 70 mm in 24 hours was actually used when analyzing the results and drawing conclusions. Although in total more water drains, this precipitation event is less intense. As a result, runoff discharge is more manageable and can be controlled using dynamic buffering.

Based on the throughput model results, the following conclusions were drawn:

- Scenario 3 (throughput equal to the capacity of the downstream watercourse) seems to yield the most desirable result of the four different scenarios.
- The tributaries of the Caumerbeek, namely Palembergerbeek, Schroetebeek and Loopgraaf, are the most promising options for dynamic buffering. In the Schroetebeek and Loopgraaf, buffers are not fully filled, allowing more water to be retained. In the Palembergerbeek, the watercourse has sufficient capacity to increase the throughput, thus preventing the buffers from overflowing.
- In the most upstream part of the Caumerbeek there are also possibilities for dynamic buffering. Here, however, adjustments have to be made to the system. Think of:
    - Increasing buffer capacity in the municipal system.
    - Temporarily allowing higher water levels at some locations where flooding is not likely to occur.
    - Increasing the capacity of some watercourses.
- The biggest bottleneck is downstream of the De Dem buffer. Here the throughput may not exceed 3.2 m^3/s because of the risk of flooding. This means that the throughput of

the buffer cannot simply be increased and that opportunities for dynamic buffering in the downstream part of the Caumerbeek are the least promising, partly because of the large volume of water that already has to be drained here.

- By adding additional storage in the upstream part of the Caumerbeek (using municipal buffers, for example) and applying dynamic buffering in the Caumerbeek tributaries, it is relatively easy to make the Caumerbeek system more robust.

1.5 Reading guide

Chapter 2 describes the Caumerbeek system and the buffers located in the Caumerbeek. Chapter 3 presents the data used and assumptions made for the purpose of the throughput model. Next, in Chapter 4, the functioning of the throughput model is outlined. The model results can be found in Chapter 5 and, based on these results, the conclusions in Chapter 6, with recommendations, opportunities and concerns.

2 SYSTEM DESCRIPTION

2.1 Introduction

Dit hoofdstuk beschrijft het Caumerbeeksysteem. De ligging van de beek, het stroomgebied en de verschillende buffers binnen het systeem zijn beschreven. Afsluitend zijn de bekende knelpunten in het systeem beschreven.

2.2 Geographical location and catchment area

The Caumerbeek originates in the south of Heerlen and then flows in a northwesterly direction, through Heerlen in the direction of Hoensbroek. At the site of RWZI Hoensbroek – near Hoensbroek Castle – the Caumerbeek flows into the Geleenbeek. The Caumerbeek flows largely through the built-up area of Heerlen. An important supply of water during precipitation is therefore the sewer systems and the paved area. In drier periods, this brook is mainly fed by groundwater.

Figure 1 shows the Caumerbeek system. The Caumerbeek has several tributary streams, of which the Palembergerbeek, Schroetebeek and Loopgraaf are important in this study because buffers are present in these tributaries.

Figure 1: The Caumerbeek and its outlet into the Geleenbeek

The ground level in the Caumerbeek catchment area varies roughly between NAP + 170 m and NAP + 70 m. The Caumerbeek catchment area was determined on the basis of a GIS analysis, which was then used to determine the unpaved runoff surfaces toward each individual buffer, see Figure 2.

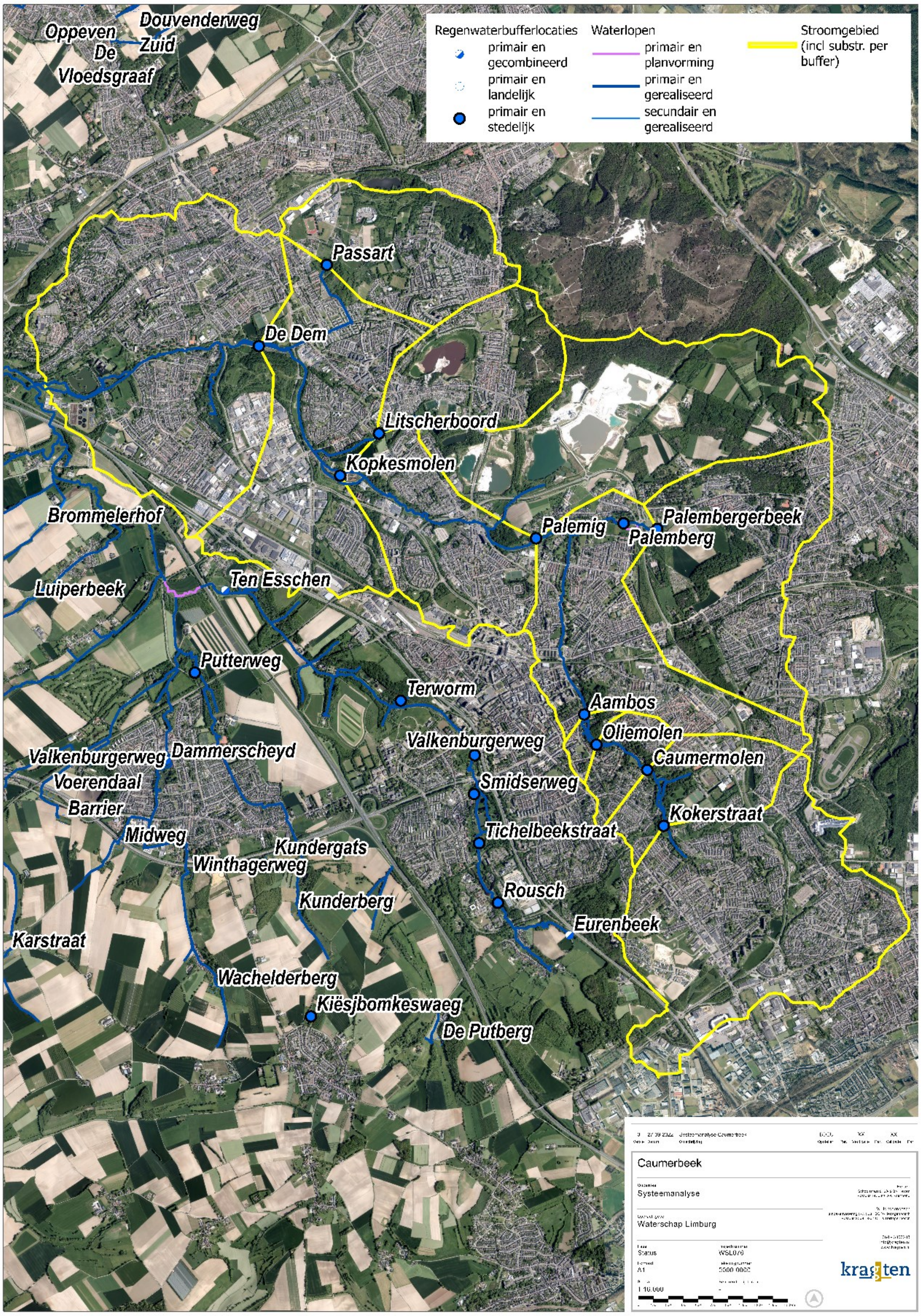

Figure 2. Caumerbeek catchment area, including buffers and associated sub-catchments

2.3 Buffers

The buffers of the Caumerbeek system that are important to this study (see Figure 2) are briefly described below. Broadly speaking, the buffers are listed in upstream to downstream order. See Appendix 1 for a map with detailed information on the buffers (this map is described further in Section 2.4).

2.3.1 Kokerstraat

The most upstream buffer in the Caumerbeek system is the Kokerstraat buffer. The Caumerbeek flows through the buffer.

2.3.2 Caumermolen

Downstream of the Kokerstraat buffer is the Caumermolen buffer. The Caumerbeek flows through the Caumermolen buffer. Between Kokerstraat and Caumermolen, the Caumerbeek consists of a spring-fed stream and a bypass that directs runoff from Kokerstraat to Caumermolen.

2.3.3 Oliemolen

Downstream of the Caumermolen buffer is the Oliemolen buffer. The Caumerbeek flows past the Oliemolen buffer, so the buffer is parallel to the stream. The buffer fills up from the stream via a orifice. The stream itself forms a mill stream along the Oliemolen, a water mill.

2.3.4 Aambos

Downstream of the Oliemolen buffer is the Aambos buffer. The Caumerbeek flows through the Aambos buffer. Aambos is intended to attenuate the discharge peak before the water flows into the culvert there. Aambos does not have the purpose of extensive and dynamic buffering of water.

2.3.5 Palembergerbeek

The Palembergerbeek buffer is located at the head of the Palembergerbeek and partly catches the (unpaved) runoff water coming from the municipality of Landgraaf. The Palembergerbeek buffer consists of two compartments through which water flows successively (in series).

2.3.6 Palemberg

Downstream of the Palembergerbeek buffer is the Palemberg buffer. This is a relatively new buffer, constructed because the capacity of the Palembergerbeek buffer was too limited and the downstream Palemig buffer cannot handle much extra water. The Palembergerbeek flows along the buffer, so the buffer is parallel to the stream. The buffer fills up from the stream with the help of a spillway.

2.3.7 Palemig

The Palembergerbeek flows into the Caumerbeek upstream of the Palemig buffer. As a result, the Palemig buffer is downstream of both the Aambos buffer and Palemberg buffer. The Palemig buffer consists of three compartments. The stream flows in series through the three buffer compartments. The Palemig buffer was constructed to slow down and smooth out the very high peak discharges coming from Aambos. The spillway and overflow of this buffer are designed to absorb these peaks as much as possible.

2.3.8 Köpkesmolen

The Köpkesmolen buffer consists of three compartments. The Caumerbeek stream flows past the buffer, so the buffer is parallel to the stream. The third compartment fills from the Caumerbeek via a spillway. The first compartment of the buffer is filled from the sewer system. When the first compartment is full, it overflows into the second compartment of the buffer. Then the second compartment can overflow into the third compartment of the buffer.

2.3.9 Litscherboord

The tributary stream Schroetebeek contains the Litscherboord buffer. The Schroetebeek flows through the buffer. The Litscherboord buffer collects rainwater from surrounding buildings (with a disconnected rainwater drainage).

2.3.10 Passart

The Passart buffer is located in the Loopgraaf tributary. The buffer is located at the head of the stream. Downstream of Passart, rainwater is discharged into the Loopgraaf from the nearby neighborhoods with a disconnected rainwater drainage).

2.3.11 De Dem

The Schroetebeek and Loopgraaf tributaries both flow into the Caumerbeek upstream of the De Dem buffer. The De Dem buffer lies downstream of Köpkesmolen, Litscherboord and Passart. The De Dem buffer consists of five compartments. The Caumerbeek flows along the buffer, so the buffer is parallel to the stream. One central compartment fills up from the stream via a spillway. This is compartment 5. Compartment 1 is filled by the sewer system. When full, it can overflow into compartment 2 and then into central compartment 5. Compartment 3 is also filled from the sewer system. Again, when full, it can overflow into compartment 4 and then the central compartment 5. Compartment 1 and 2 are located on the west side of compartment 5 and compartment 3 and 4 are located on the east side of compartment 5.

2.4 System

To get a sense of how the system functions, two maps of the system were drawn up. The maps can be found in Appendix 1. These maps indicate where the water comes from and which buffers are most heavily stressed. For this purpose, it was determined (in Excel) how much water drains toward the individual buffers, via surface runoff (land surface and sewer system) on the one hand and via throughput from any upstream buffers on the other hand.

Two area-wide block precipitation events were used, both with a return period of 25 years, namely:

- A shower with 50 mm of precipitation for 2 hours.
- A shower with 70 mm of precipitation for 24 hours.

These rain events are described further in Chapter 3.

Since two rain events were used, this has resulted into two maps. These two maps can be found in Appendix 1 and depict the following:

- The Caumerbeek system.
- The cumulative runoff volumes per sub-catchment.
- The cumulative stress on the buffers.

Chapter 3 describes the data used to create the maps.

2.5 Known bottlenecks

Downstream of the De Dem buffer the maximum allowable discharge is 3.2 m³/s. This has to do with the limited space for the stream, and the culverts under the Koumenweg and Burgemeester Slanghenstraat that can cause impoundment. The impounded water looks for another way further south, under the Koumenweg and causes flooding around Lotbroek. In addition, backwater from the Geleenbeek plays a role during large discharges.

By way of illustration, in the summer of 2021 the discharge at this location in the Geleenbeek was approximately 18 m^3/s. On top of that, the level of surrounding areas is lower than the level of the brook, so flooding is high when the brook overflows.

Molentak at the Oliemolen buffer may discharge a maximum of 0.1 m^3/s, because the mill in this branch is a bottleneck and floods quickly, which is what happened during the extreme discharges of 2021. Excess water must therefore be routed through the buffer.

In the watercourse just upstream of the Palemig buffer, the culvert under Meezenbroekerweg forms a bottleneck. Moreover, during the extreme discharges in the summer of 2021, compartment 1 of Palemig overflowed, making it more difficult for water to flow through the culvert, and homes on Palenbergstraat experienced flooding. Discharge can reach about 20 m^3/s at this location.

Downstream of the Palemig buffer, the culverts under Palemigerboord and Schelsberg form a bottleneck. The discharge at this location can reach approximately 7 m^3/s. Because the Palemig buffer overflows fairly quickly, the throughput capacity must be large (which is the case in the current situation). Pinching Palemig to avoid flooding here is therefore not an option.

Downstream of the Köpkesmolen buffer, the culvert under Rennemigstraat is a bottleneck. Homes on the Koningsbeemd may experience flooding here. The discharge at this location can amount to approximately 4 $m^3/sm^3/s$.

3 PRINCIPLES

3.1 Introduction

This chapter describes the starting points used to create the throughput model, which is discussed in Chapter 4. This throughput model was used to investigate the potential for dynamic buffering. The same principles were also used to prepare the maps in Appendix 1.

3.2 Precipitation events

As described in Chapter 2, two precipitation events were used, both having a return period of 25 years:

- A precipitation event with 50 mm of precipitation for 2 hours.
- A precipitation event with 70 mm of precipitation for 24 hours.

Both events are based on block precipitations covering the entire Caumerbeek system. This means that the same amount of precipitation falls over the entire catchment area. A block precipitation means that continuous precipitation falls with a single intensity for a given time.

3.3 Runoff over paved area

Within the Caumerbeek catchment area, sewer systems from two different municipalities are located. These sewer systems overflow into the Caumerbeek system. These are mainly sewer systems of the municipality of Heerlen. For a small part, the sewer system of the municipality of Landgraaf is connected to the Palembergerbeek, and industrial site De Beitel of the municipality of Kerkrade is connected to the most upstream point of the Caumerbeek.

Information was requested from the municipalities regarding the paved surfaces of the sewer systems, municipal rainwater storage facilities, rainwater retention basins and overflows to the Caumerbeek system. Based on this information, it was determined at which locations, and with what volumes, water enters the Caumerbeek system. For example, the rain water drainage at the De Beitel business park has been disconnected from the sewer system and rainwater is buffered. Only the first flush and limited outflow of the rainwater buffers is drained through the sewer system.

The necessary current data of the sewer systems are not always available. In order to construct a usable mathematical model, the assumptions below have been made. These assumptions supplement the available data, such as storage volumes (BBB, rainwater storage) and overflows.

- All precipitation falling on paved areas enters the sewer system (of course only for areas where the rainwater drainage is not disconnected from the sewer system).
- Excess precipitation enters the Caumerbeek system through overflows.
- The pump overcapacity is 0.7 mm/hour.
- The storage within the sewer system is 7 mm.

3.4 Runoff over unpaved area

For each sub-catchment (see Figure 2), GIS was used to determine how much unpaved area drains to the individual buffers. This is a simplification of reality. Precipitation falling on unpaved terrain can:

- Partly be retained by vegetation and ground level gradient.

- Partly infiltrate locally.
- Partly evaporate.
- Be delayed in its runoff.

Thus, relatively a large quantity of water does not reach the buffers or the stream. Therefore, a runoff coefficient of 0.1 was assumed. This runoff coefficient was determined in consultation with the water board's project hydrologist

3.5 Buffers

Information on the buffers was requested from the water board. Missing information was supplemented from public data sources or consulted via GIS. The information below was determined based on these two data sources:

- The location of each buffer or buffer compartment.
- The incorporation of the buffer into the stream system (does the stream run through the buffer or is the buffer parallel to the stream).
- The bottom height per buffer (compartment).
- The area per buffer (compartment).
- The maximum fill height per buffer (compartment).
- The volume per buffer (compartment).
- The emptying capacity of the individual buffers. Here it was assumed that each buffer should empty within 24 hours. The 24-hour emptying capacity was calculated based on the volume of the buffer.

3.6 Watercourses

The watercourses of the Caumerbeek system were simplified in the throughput model into individual watercourses that connect the different buffers, each with a maximum discharge capacity. The discharge capacities of the various watercourses were determined in consultation with the water board's project hydrologist. These capacities were used when testing whether the capacity of the watercourses is exceeded due to the throughput and overflow of the buffers. Table 1 lists the considered watercourses with the capacity attached. This capacity indicates the discharge that the watercourse can handle without the water overflowing the banks. The capacity says nothing about the actual discharge into the watercourse.

Table 1: Caumerbeeksystem watercourses

From	**To**	**Capacity**
Kokerstraat	Caumermolen	0,7 m^3/s
Caumermolen	Oliemolen	0,7 m^3/s
Oliemolen	Aambos	0,7 m^3/s
Aambos	Palemig	1 m^3/s
Palembergerbeek	Palemberg	1 m^3/s
Palemberg	Palemig	1 m^3/s
Palemig	Köpkesmolen	4 m^3/s
Köpkesmolen	Mouth of Schroetebeek	4 m^3/s
Schroetebeek	Mouth of Schroetebeek	1 m^3/s
Mouth of Schroetebeek	Mouth of Loopgraaf	4 m^3/s
Loopgraaf	Mouth of Loopgraaf	1 m^3/s
Mouth of Loopgraaf	De Dem	4 m^3/s
De Dem	Kasteel Hoensbroeklaan	3,2 m^3/s
Kasteel Hoensbroeklaan	Geleenbeek	6 m^3/s

Figure 3 shows the capacity of each watercourse in a schematized Caumerbeek system.

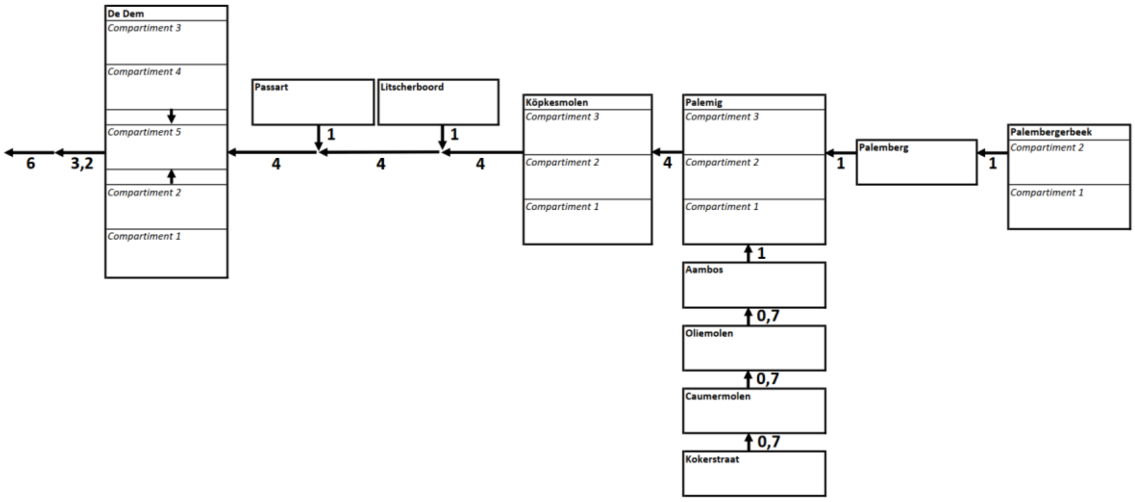

Figure 3: Schematized Caumerbeek system with water flow capacity in m³/s

4 MODEL DESCRIPTION

4.1 Introduction

This chapter describes how the requested data (which are outlined in Chapter 3) were used to create a time-dependent throughput model. Again the two previously described precipitation events, namely 50 mm in 2 hours and 70 mm in 24 hours, were used for this.

4.2 Time dependence of runoff

The runoff and the filling of the buffers was made time-dependent by working with time steps of one hour each. The rainwater runoff volumes were divided into a volume for each hour. The runoff in all watercourses and the filling of all buffers and buffer compartments was visualized hourly for 48 hours. The approach below was discussed with the project hydrologist of the Limburg Water Board.

The time dependence for the 2-hour precipitation and the 24-hour precipitation differs. This difference lies in the way runoff is included in the model. Below, the way this runoff is incorporated is described for both precipitation events.

The time dependence for the precipitation event of 50 mm in 2 hours is recorded as follows:

- Paved area: It is assumed that all rainwater that ends up on paved areas – and that cannot be stored or disposed of via the pumping overcapacity of the sewer system – is discharged through the sewer system toward the stream. Because the sewer system can respond quickly to the supply of water, the choice was made to have no delay in the runoff. Immediately in the first time step (of hour 1), the water comes to runoff toward the stream. As soon as the 2-hour precipitation event has passed, there is no further afterflow. The water thus flows toward the stream during the first 2 hours. The runoff volume is evenly distributed over the 2 hours. Every hour (50 mm – storage – pump overcapacity)/2 hours of water runs off.
- Unpaved area: For runoff from unpaved areas, the runoff volume is influenced by infiltration, local storage and evaporation. An additional effect is that it takes a while before the runoff water reaches the stream and that the water continues to flow for a while after the precipitation has stopped. Therefore, in addition to a runoff coefficient of 0.1, a delay was applied to the water discharge. The first water only enters the stream after 4 hours (so in hour 5). After the 2-hour runoff, the afterflow is still 6 hours, so the water runs off for 8 hours (so up to hour 12). The runoff volume is evenly distributed over these 8 hours, resulting in (0.1*50 mm)/8 hours of water runoff each hour.

The time dependence for the precipitation event of 70 mm in 24 hours is recorded as follows:

- Paved area: It is assumed that all rainwater that ends up on paved areas – and that cannot be stored or drained via the pumping overcapacity – is drained via the sewer system toward the stream. Because 7 mm of system storage is assumed and 0.7 mm is pumped per hour (the pump overcapacity of the sewer system), water enters the stream after three time steps, because (7+3*0.7)/(70/24) ≈ 3 hours. Once the 24-hour precipitation is over, there is no afterflow. This is because the sewer system can respond quickly to the supply of water. Thus, after 3 hours, the water flows off toward the stream in 21 hours. The runoff volume is evenly distributed over these 21 hours. Every hour (70 mm – storage – pumping overcapacity)/21 hours of water runs off.
- Unpaved area: For runoff from unpaved areas, the runoff volume is affected by infiltration, local storage and evaporation.

An additional effect is that it takes a while before runoff water enters the stream and continues to flow for a while after the precipitation has stopped. For runoff from unpaved areas, it was therefore decided that in addition to a runoff coefficient of 0.1, a delay occurs before the water enters the stream. It was also decided that an afterflow occurs. The first water only enters the stream after 4 hours. After the 24-hour runoff is over, the subsequent afterflow is another 6 hours, resulting in 30 hours of runoff. The runoff volume is evenly distributed over the 30 hours, resulting in (0.1*70 mm)/30 hours of water runoff each hour.

4.3 Buffers

In the throughput model, the filling of the buffers is depicted as a graph, in which the water level is plotted against time.

For some buffers, information from the water board on the actual maximum emptying capacity is available. This emptying capacity, in addition to the 24-hour emptying, is included in the throughput model as a frame of reference for each buffer (see Section 4.4). The water board has also provided data indicating which buffers are subject to immediate flooding in case of buffer overflow and which buffers are not. This information is indicated as a side note for each buffer in the throughput model.

4.4 Model

The model works as follows. The hourly runoff volumes are defined per watercourse. These hourly runoff volumes determine the discharge fluctuations in the watercourses. The fluctuation of discharge for each watercourse is shown in a graph. The discharge (in m³/hour) is plotted against time (in hours). As an example, Figure 4 shows the discharge of the Kokerstraat-Caumermolen watercourse during the 24-hour precipitation event. In the discharge fluctuation a distinction is made between the throughput of the upstream buffer (in this case the Kokerstraat buffer) and the total discharge (the throughput including the runoff surface toward the watercourse in question). In this example, the throughput is chosen in such a way that the buffers do not quite overflow, see Chapter 5.

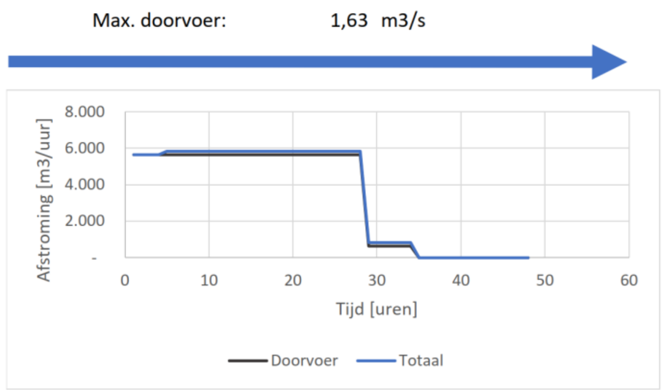

Figure 4: Kokerstraat-Caumermolen 24h

Depending on the resulting discharges, the buffers are filled. This filling is shown as a graph for each buffer, in which the water level (in m+NAP) is plotted against time (in hours). This buffer graph also shows the maximum filling height of the buffer. If the water level in the buffer rises above the maximum filling height, the buffer overflows.

As an example, the filling of the Caumermolen buffer for the 24-hour precipitation event is shown in Figure 5. Also in this example, the throughput is chosen in a way that the buffer does not quite overflow.

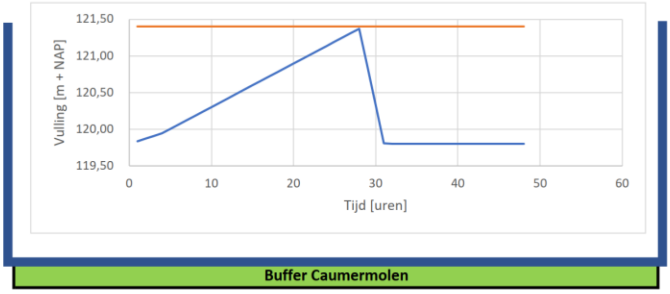

Figure 5: Filling Caumermolen buffer 24h

The following parameters can be adjusted in the model:

- The precipitation, being 50 mm in 2 hours or 70 mm in 24 hours.
- The maximum throughput of each buffer (compartment).
- If required, the buffer volume can also be adjusted (by adjusting the bottom height, the maximum fill height, the surface area, or directly the buffer volume).

The Excel file of the Caumerbeek map and throughput model is structured as follows:

- The input for the model is put under the tab ‘Blokken doorvoermodel’ (which means ‘Blocks throughput model’). Here, in the top left of the spreadsheet (cells B5 to B9), the event can be adjusted (70 mm in 24 hours or 50 mm in 2 hours) and overall preconditions such as pump overcapacity, system storage and discharge coefficient can be adjusted. If necessary, data for each drainage basin can also be adjusted in this tab.
- The map of the Caumerbeek system is under the tab ‘Kaart’ (which means ‘Map’). Nothing can be modified here, as data in this map is directly linked to the 'Blocks throughput model' tab.
- The throughput model is under the tab ‘Doorvoermodel’ (which means ‘Throughput model’). Figure 6 shows part of the throughput model (for the 24-hour event) to clarify the principle of this model. The left graph shows the fluctuation of the runoff discharge toward the Kokerstraat buffer. The middle graph shows the filling of the Kokerstraat buffer. It shows that the maximum filling (the red line) is not reached. The right graph shows the fluctuation of the discharge in the Caumerbeek downstream of the Kokerstraat buffer. This depends on the direction of the runoff surface flowing toward this part of the stream, but also on the throughput (and possible overflow) from the Kokerstraat buffer. In the blue cell, the maximum throughput of the Kokerstraat buffer can be adjusted (see red circle in Figure 6). Above, as a frame of reference, the 24-hour throughput and the maximum throughput capacity indicated by the water board are shown. In the green cells, the dimensions of the buffer can be adjusted if necessary to adjust the volume of the buffer. Below this graph are time series that define all parameters per time step. Nothing can be adjusted in these because they are directly linked to the values entered in the blue and green cells and the tab 'Blocks throughput model', or directly linked to each other. Here you can see per hour how the discharge is structured (rural runoff, urban runoff, throughput or overflow) and what the water level in the buffers is.

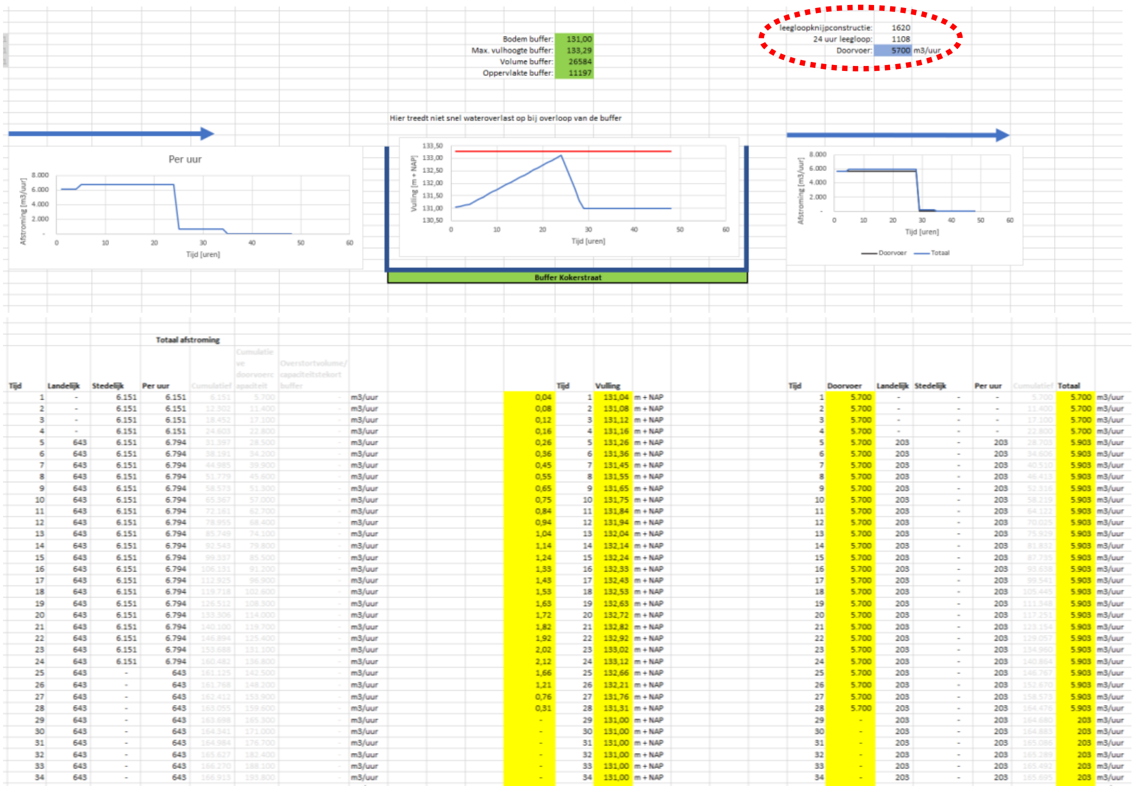

Figure 6: Principle throughput model

- The results of the model are summarized under the tab 'Kleurenschema doorvoermodel' (which means 'Color scheme throughput model'). Here you can find a schematization that summarizes the model results with the use of colors. A simple diagram shows the buffers and watercourses of the Caumerbeek system. Depending on the values entered into the throughput model, the diagram indicates for each buffer whether water exceeds the maximum fill height of the buffer and thus overflows or not by means of a color. If the buffer does not overflow, the buffer is colored green in the schematization. If the buffer overflows and, according to the water board, immediate flooding will occur, the buffer is colored red. If the buffer overflows and, according to the water board, no direct flooding will occur here, the buffer is colored yellow. This diagram also shows the throughput for each buffer and the time after which the buffer overflows (if a buffer does overflow). This diagram provides a clear picture of which buffers and watercourses pose a bottleneck. Furthermore, a colored circle per watercourse shows whether the discharge is below the watercourse capacity (green), above the watercourse capacity but there is no direct flooding (yellow) or above the watercourse capacity and there is immediate flooding (red). By iteratively changing the values for the various parameters in the throughput model, this color scheme can be used to check whether bottlenecks can be solved or mitigated.

4.5 Notes

A number of simplifications were made in the throughput model to keep the model as clear and usable as possible. The simplifications described below should be taken into account when interpreting the results.

- The buffers are schematized as square trays and have no slopes. A consequence of this is that the buffers are less deep than they are in reality, in order to arrive at the correct buffer volume. The filling of the buffers is therefore also somewhat different than in reality.

- The emptying of buffers is included in a simplified way:
  - Subsequent delivery of water volume from the buffer has been simplified. After the throughput capacity is reached, the maximum throughput capacity is as the throughput regardless of supply (this is independent of any overflow). This provides a reasonable approximation of buffer emptying but is usually a small underestimation.
  - The influence of the water level in the buffer on the throughput is not taken into account. This causes a slight overestimation of the outflow.
- The overflow of buffers is included in a simplified way: For buffer overflows (when the water level exceeds the maximum filling height), the model does not take into account the influence of the water level in the buffer on the overflow volume. This results in a large overestimation of overflow volumes. To include the overflow in the model in a plausible way (and to limit the overestimation), it was decided to set a maximum overflow per time step for each buffer. For each buffer this is assumed to be the same value as the watercourse capacity upstream of the buffer, see Section 3.6.
- For small throughputs in buffers, 48 time steps of 1 hour each may be insufficient to realistically depict buffer stress. This is due to the fact that 48 hours is insufficient time for the buffers to drain. As a result, buffers are stressed for longer than 48 hours, creating a discrepancy in the volume balance. Because water is continuously supplied to the buffer in the 24-hour block rain event, the buffer will not empty within 24 hours during a 24-hour emptying, and in most cases not in 48 hours either
- De buffers zijn geschematiseerd als vierkante bakjes en hebben geen taluds. Een gevolg hiervan is dat de buffers minder diep zijn dan in werkelijkheid, om op het juiste buffervolume uit te komen. De vulling van de buffers verloopt daarom ook wat anders dan in werkelijkheid.

Because of the caveats described above, the results are less realistic for small throughputs than for large throughputs and less realistic for large overflow volumes than for small overflow volumes. The throughput model serves as a tool to examine the impact on the utilization of buffer capacity by adjusting throughput, with the timing of overflows also being an important factor. Despite the many assumptions made, comparing different throughput scenarios gives a good insight into the functioning of the system. However, the model is not suitable for the exact investigation of buffered volumes, emptying, overflow from the buffers, or discharge fluctuations in the individual watercourses of the Caumerbeek. Therefore, further investigation about controlling the buffers is not possible using this model.

5 RESULTS

5.1 Introduction

The design of the throughput model means that the model is primarily suitable for examining the influence of throughput on the moment of overflow and on whether or not the capacity of buffers and watercourses is exceeded. The throughput model was used to 'simulate' four scenarios. For each scenario a different throughput was chosen and the efficiency of filling the buffers was examined. The four scenarios are:

1. The throughput is equal to the 24-hour emptying of the buffers.
2. The throughput is equal to the maximum actual emptying of the buffers as specified by the water board. This scenario most closely matches the actual regulation. However, because the maximum indicated emptying was chosen in the model, this emptying does not depend on level difference and the throughput is somewhat overestimated compared to reality.
3. The throughput is chosen so it is equal to the capacity of the downstream watercourse.
4. The throughput is chosen so the buffer does not quite overflow. This does not take into account the capacity of watercourses.

For each scenario, both a 24-hour precipitation event and a 2-hour precipitation event were 'simulated'. This yielded eight results. In addition, for the 24-hour precipitation event of scenario 3, a variant with measures was devised in which:

- 50 mm of additional water is stored in the Heerlerbaan/Hoogveld sewerage area (C01, C03 and C05).
- The buffers in the tributary streams are optimally set. Optimally set means that more water is put through at the Palembergerbeek buffer and less water at the Palemberg, Litscherboord and Passart buffers.

5.2 Results scenarios

Below, the results of the four different scenarios and the additional variant with measures are presented in diagrams, so the results of the different scenarios can be easily compared. In this diagram, the Caumerbeek system – consisting of watercourses, buffers and buffer compartments – is shown in simplified form. For each buffer (compartment), the throughput and the moment of overflowing are shown. The load of the watercourses, buffers and buffer compartments are visually represented by colors, which have the following meaning:

- Green area in buffer: The water level in the buffer remains below the maximum fill level.
- Yellow area in buffer: The water level in the buffer exceeds the maximum fill height and overflows, but there is no immediate risk of flooding at this location.
- Red area in buffer: The water level in the buffer exceeds the maximum fill height and overflows, and there is an immediate risk of flooding at this location.
- Green circle at watercourse: The discharge remains below the capacity of the watercourse.
- Yellow circle at watercourse: The discharge exceeds the capacity of the watercourse, but there is no immediate risk of flooding at this location.
- Red circle at watercourse: The discharge exceeds the capacity of the watercourse, and there is an immediate risk of flooding at this location.

5.2.1 Scenario 1: Throughput equal to 24-hour emptying of buffers

24-hour precipitation:

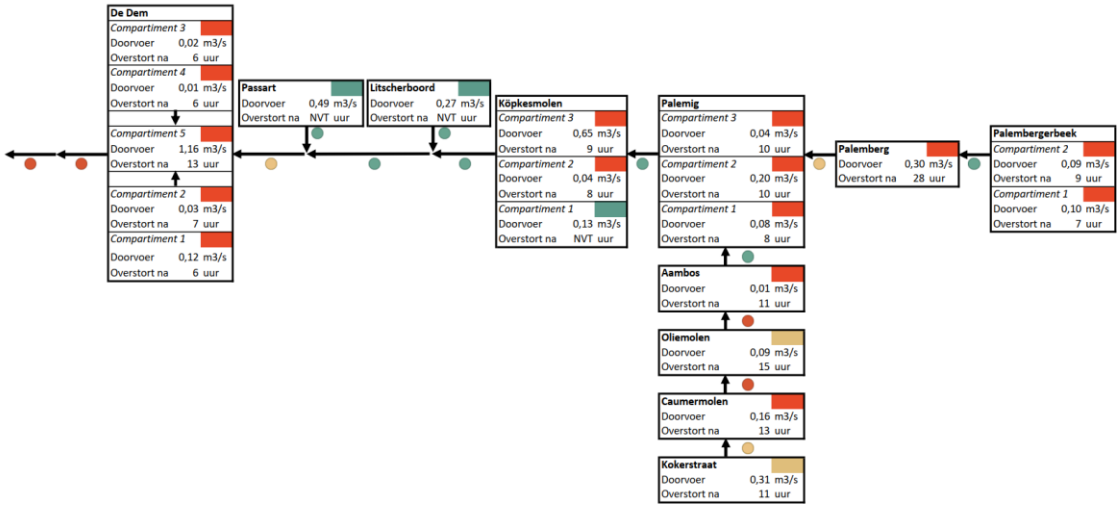

Figure 7: 24-hour precipitation, scenario 1

2-hour precipitation:

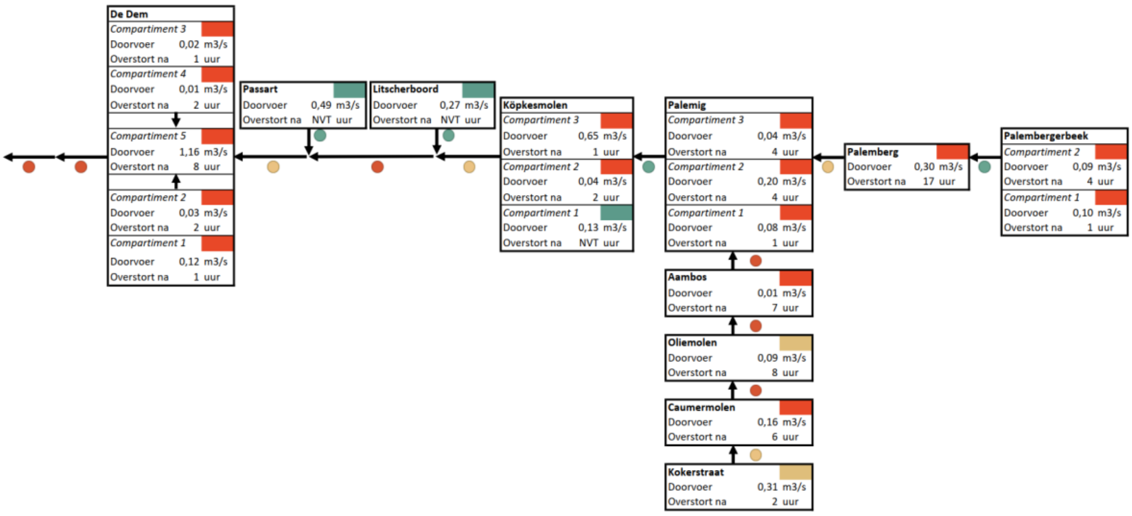

Figure 8: 2-hour precipitation, scenario 1

5.2.2 Scenario 2: Throughput equal to maximum actual emptying as specified by the water board

24-hour precipitation:

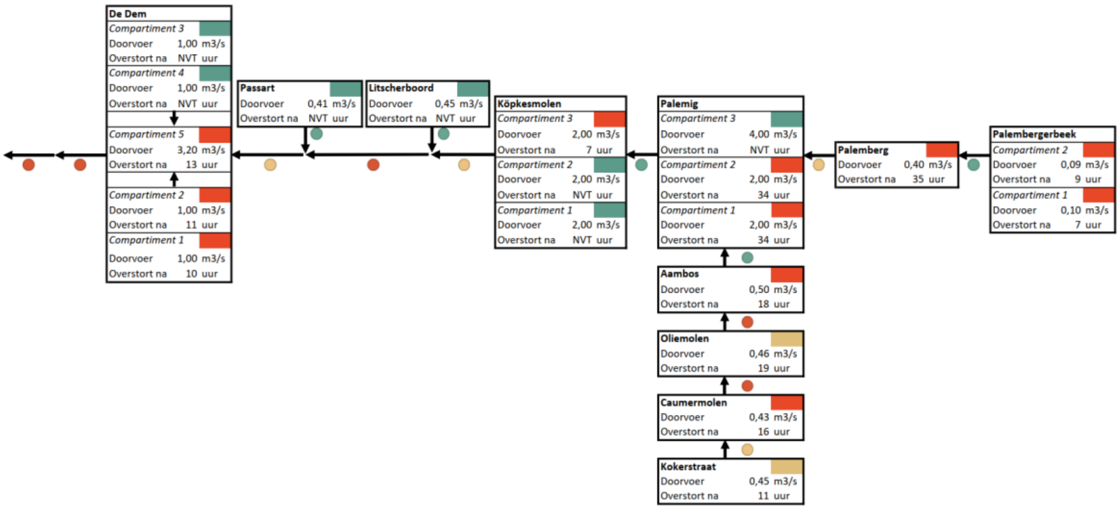

Figure 9: 24-hour precipitation, scenario 2

2-hour precipitation:

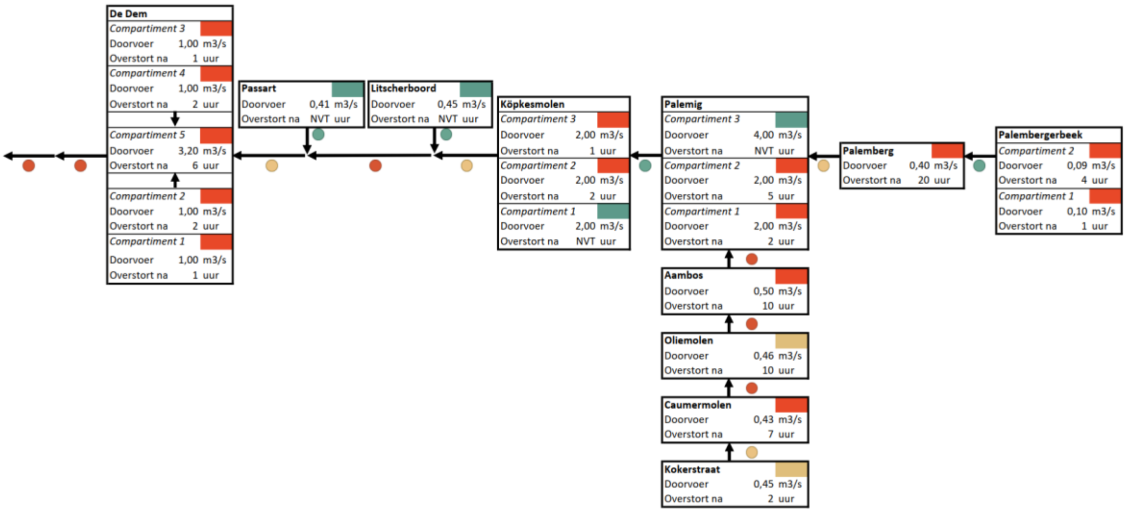

Figure 10: 2-hour precipitation, scenario 2

5.2.3 Scenario 3: Throughput equal to downstream capacity

<u>24-hour precipitation:</u>

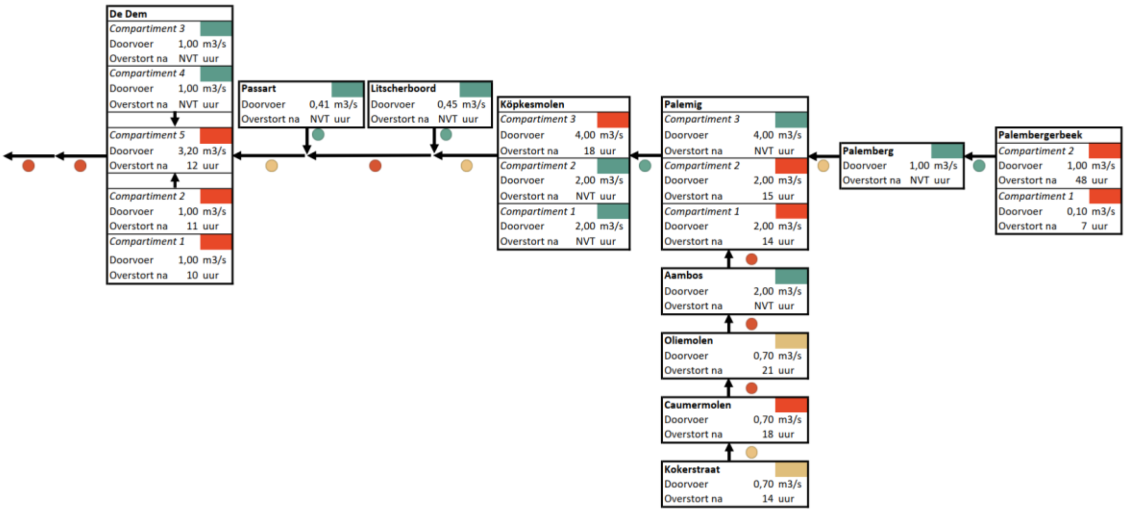

Figure 11: 24-hour precipitation, scenario 3

<u>2-hour precipitation:</u>

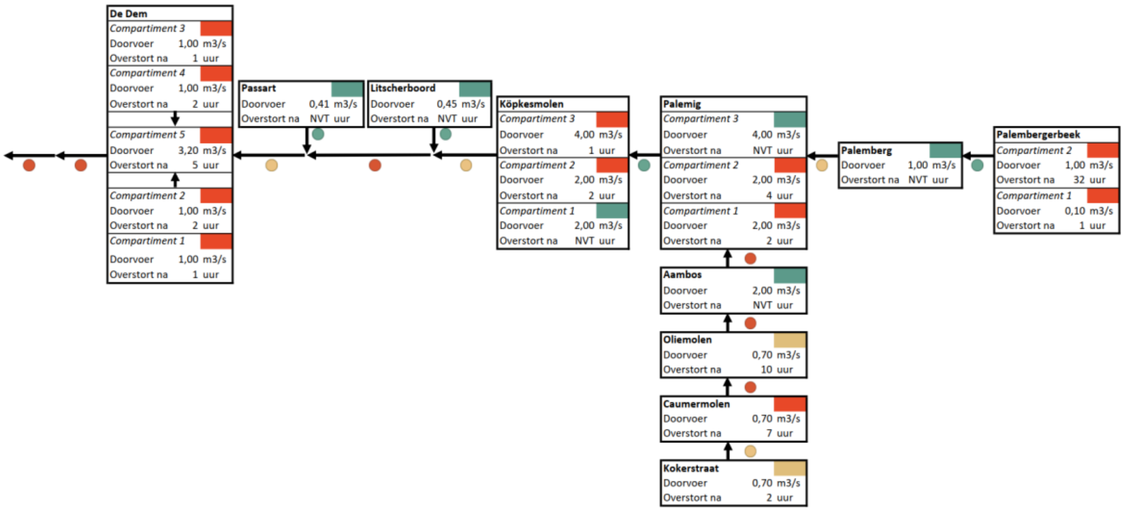

Figure 12: 2-hour precipitation, scenario 3

5.2.4 Scenario 4: Throughput such that buffers do not quite overflow

<u>24-hour precipitation:</u>

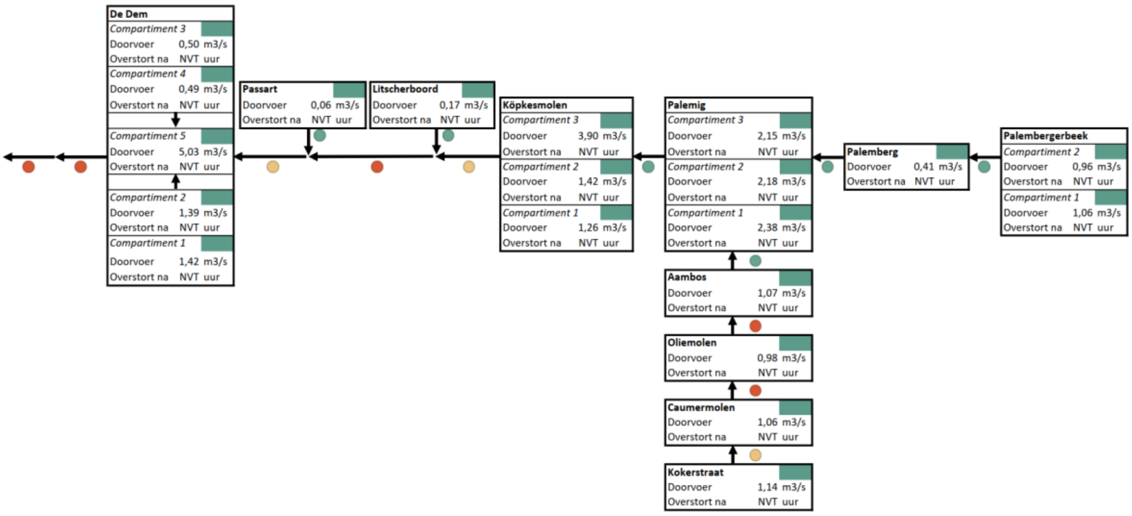

Figure 13: 24-hour precipitation, scenario 4

<u>2-hour precipitation:</u>

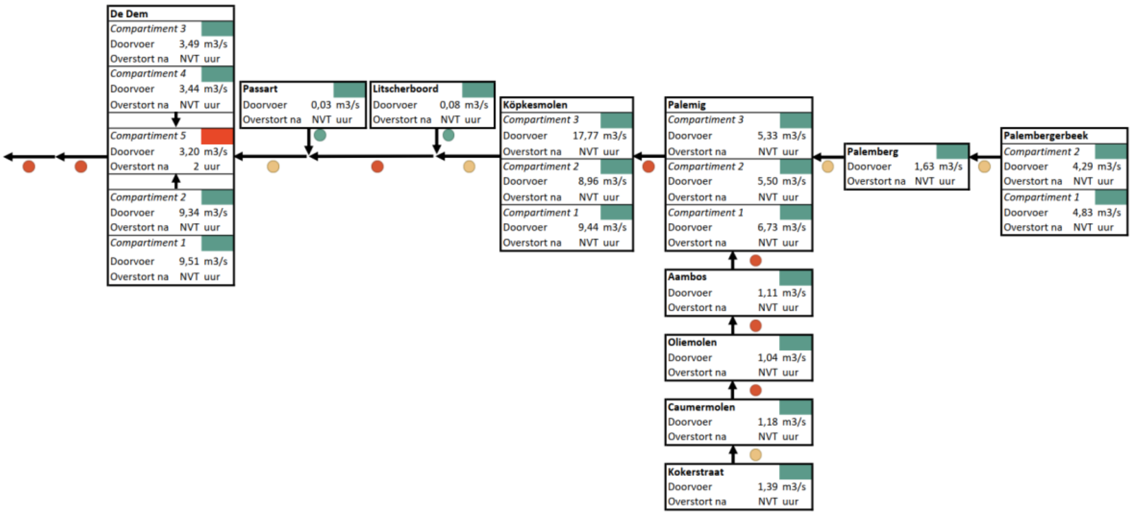

Figure 14: 2-hour precipitation, scenario 4

To further compare the results of the four different scenarios, the same diagrams are listed per block precipitation in Appendix 2.

5.2.5 Additional variant with measures (24-hour precipitation, scenario 3)

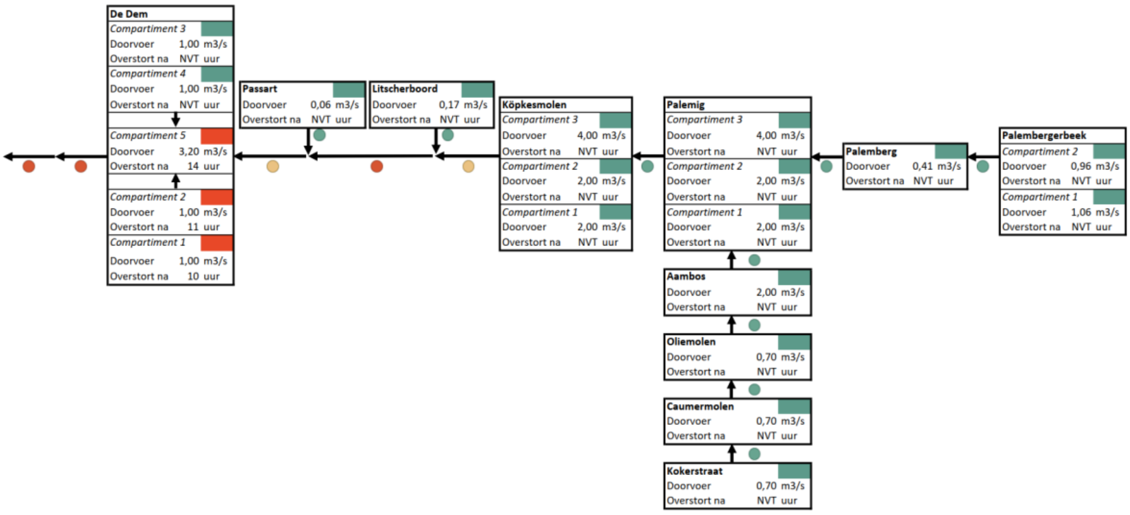

Figure 15: 24-hour precipitation, scenario 3 with measures

5.3 Calibration and validation

As described in Chapter 3, assumptions were made after consultation with the project hydrologist of the Limburg Water Board. The maximum overflow rate was then used to match the model results as far as possible with the information on discharges and bottlenecks provided by the water board. The model results were then also validated. The model results were validated using the known bottlenecks and overflow locations during extreme precipitation events such as the summer of 2021, see Section 2.5.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

It is worth noting that primarily with a 50 mm shower in 2 hours, the system is very heavily stressed in the first 2 hours and the buffers cannot handle this load. In 2 hours the system can get so heavily stressed that the buffers and watercourses cannot cope. In the case of such precipitation of 2 hours , no benefit can be gained from dynamic buffering. The conclusions about dynamic buffering described below relate therefore mainly to the 24-hour rain.

Based on the model results of the four scenarios, Figure 16 shows where opportunities lie. Herein, a distinction has been made between three types of areas, namely:

1. Framed in green: Opportunities for optimization.
2. Framed in yellow: Opportunities for optimization, provided preconditions are adjusted.
3. Framed in red: Optimization not obvious Rood omkaderd.

This distinction is explained later in this section.

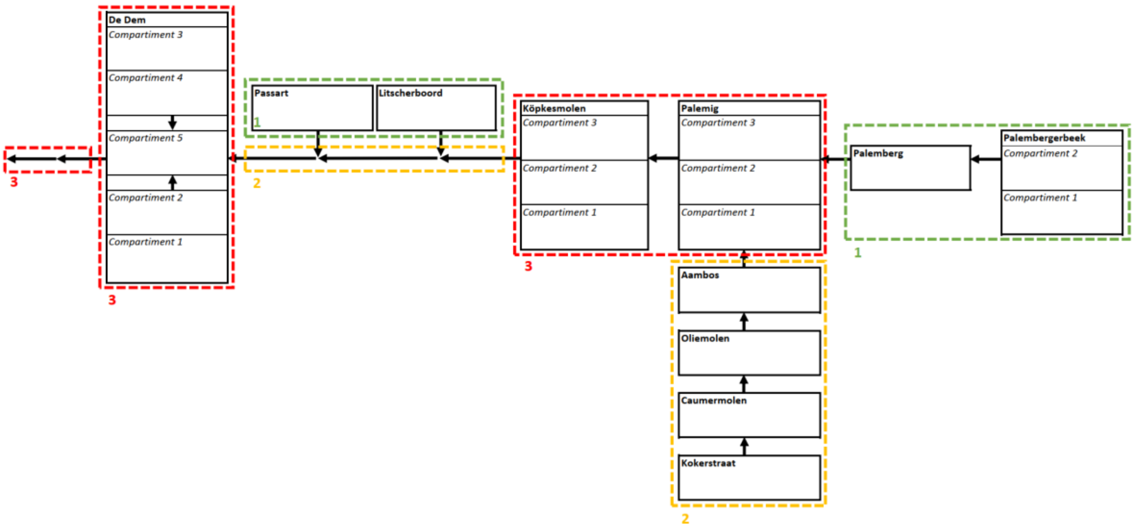

Figure 16: Promising areas

The standard 24-hour emptying (scenario 1) is insufficient to use buffers efficiently. The buffers quickly fill up and then overflow. This means that the downstream watercourses are still heavily loaded. Exceptions are the Litscherboord and Passart buffers. These buffers are located in the tributary streams Schroetebeek and Loopgraaf, respectively. Because the buffers do not fill completely, a smaller throughput than the 24-hour emptying is possible to limit unnecessary stress on the Caumerbeek. There are no buffers upstream of these two buffers and with the 24-hour emptying, these two buffers are not fully filled. These buffers also do not fill completely in scenarios 1, 2 and 3. When a very small throughput is chosen in scenario 4, they fill completely. In short, the Litscherboord and Passart buffers should be retained as much as possible. In Figure 16, the Litscherboord and Passart buffers are therefore framed in green.

At the site of the Palembergerbeek tributary stream, gains can also be made relatively easily. By increasing the throughput, the buffer capacity of these three buffers can be better utilized. In doing so, the discharge in the Palembergerbeek watercourses remains below the water passage capacity. In Figure 16 the Palembergerbeek and Palemberg buffers are therefore framed in green.

In the upstream part of the Caumerbeek system – from Kokerstraat to Aambos – watercourse capacity is a bottleneck. The throughput capacity of the watercourses in the upstream part of the Caumerbeek system cannot simply be increased without causing problems between Palemig and De Dem, as there is a bottleneck near the Koningsbeemd. Particular care must be especially taken to ensure that the extra water flow is well absorbed by De Dem. Downstream of De Dem the throughput may not exceed 3.2 m^3/s, because a lot of flooding can occur quickly here. This makes the watercourse capacity downstream of De Dem the main bottleneck of the system. Without adjusting the framework conditions in the system, little can be done here. Therefore, in Figure 16 the watercourses downstream of De Dem are framed in red.

Because the central compartment of De Dem itself (compartment 5) already has to capture a lot of water from the urban system (compartments 2 and 4) and from the immediate surrounding area, it cannot handle an extra large supply discharge from Köpkesmolen. Figure 13 shows this: although all buffers are optimally utilized, the watercourse downstream of De Dem cannot handle the additional flow of water. However, if the bottleneck near Koningsbeemd is addressed (for example, by placing a flood barrier at the site of the buildings on Koningsbeemd), creating additional storage between Köpkesmolen and De Dem is possible. Therefore, the watercourses connecting Köpkesmolen with De Dem are framed in yellow in Figure 16.

As indicated earlier, the watercourse capacity in the upstream part of the Caumerbeek system – from Kokerstraat to Aambos – appears to be insufficient. As also indicated earlier, the throughput capacity here cannot simply be increased because the throughput downstream of De Dem is very limited. However, there are some buffers and a watercourse here where no immediate flooding occurs when the capacity is exceeded. This concerns the Kokerstraat buffer, the Oliemolen buffer and the watercourse between the Kokerstraat buffer and Caumermolen buffer. It may therefore be interesting to investigate whether it is nevertheless possible to increase the throughput here and to absorb this in extra buffer volume by (temporarily) allowing more water into these buffers. In general, the upstream part of the Caumerbeek system can benefit from a larger buffer volume, so the extra throughput can be absorbed. Of course, the watercourses must then be dimensioned accordingly. It should be noted that the gain to be achieved here is limited in relation to the volumes to be processed further downstream in the Caumerbeek system. The bottleneck downstream of De Dem cannot be solved with this measure. In short, some gain can be achieved in the upstream part of the Caumerbeek system, but the framework conditions of the system have to be adapted to this end. The ecological aspects here must be taken into account as well, see Section 6.3. The buffers and watercourses from Kokerstraat to Aambos are framed in Yellow in Figure 16.

When a buffer is overloaded so that it overflows, the overflow moment of this buffer is important. The longer the overflow moment is postponed, the more time there is to prepare for possible flooding and the less likely the buffer will overflow during smaller precipitation events. Figure 7 through Figure 15 show that the buffer overflow moment can be delayed by several hours.

Limburg Water Board is interested in the effects of measures on scenario 3. This scenario is the most interesting because the watercourse capacity is used optimally. The buffers fill quite efficiently, without throughputs being so large that the capacity of the watercourses is greatly exceeded.

The conclusions described above show that increasing the storage in the upstream part of the Caumerbeek and more efficient water storage in buffers of the tributaries is effective. An additional variant incorporates this by creating 50 mm of additional storage in the Heerlerbaan/Hoogveld sewerage area (C01, C03 and C05). Moreover, the buffers in the tributary streams are optimally set. More water is put through to the Palembergerbeek and Palemberg buffers and less water is put through to the Litscherboord and Passart buffers.

By applying these measures, water nuisance in the upstream part of the Caumerbeek can be solved without adverse effects downstream. Downstream, water nuisance can be solved at Palemig (compartment 1 and 2) and at Köpkesmolen (compartment 3). Looking at the entire Caumerbeek system, throughputs are smaller and overflow moments are postponed to a limited extent throughout. In short, the Caumerbeek system becomes more robust as a result of these measures.

Dynamic buffering also has advantages with regard to monitoring from the central control room using remotely controlled sluices in the buffers. Remotely, it is possible to check the filling of the buffers and whether possible bottlenecks are occurring in the Caumerbeek system. An additional advantage is that the buffers can be drained more quickly to make room for the next precipitation. In the current situation with fixed settings, this is not possible. Another additional advantage is that water can be retained in times of drought.

6.2 Opportunities

On the basis of this study, it has become clear which buffers are better utilized by applying dynamic buffering (Palembergerbeek, Palemberg, Litscherboord and Passart).

If the water board is willing to make adjustments to the stream system, the buffers in the upstream part of the Caumerbeek could also be of interest with regards to dynamic buffering (Kokerstraat and Oliemolen). Adding extra buffer volume (in, for example, the Kokerstraat and Oliemolen buffers) and increasing the capacity of watercourses (between, for example, Kokerstraat and Caumermolen) can be included in the follow-up research into buffer regulation. This would make the configuration of the system even more efficient than just research buffer control. In addition, it is interesting to investigate whether it is possible, by means of dynamic buffering, to temporarily allow more water in here in case of high precipitation.

It is also possible to allow extra water into the watercourse between the Köpkesmolen buffer and the De Dem buffer. There is room for water storage at this location by allowing a level increase of roughly 0.5 m. However, the bottleneck near Koningsbeemd is located in this area, so in such a situation, the houses on Koningsbeemd will have to be protected by a flood barrier.

An important option is to increase buffer capacity within the urban system managed by the municipality of Heerlen. The most obvious system is Hoogveld/Heerlerbaan, which connects to the Kokerstraat buffer. Another possibility here is automated control of the municipal buffers already present, in order to better utilize the buffer capacity.

Additional buffering and more control opens the possibility of retaining (more) water in preparation for and in times of drought. This is independent of where exactly more buffering is done (Kokerstraat buffer, Caumermolen or in municipal management).

6.3 Considerations

6.3.1 Bottlenecks

As described in Section 2.5, there are some locations within the Caumerbeek system where flooding occurs on a regular basis. These include the culverts under the traffic intersection near Palemiggerboord and Schelsberg. However, solving this bottleneck is complex and therefore expensive. The watercourses downstream of De Dem are also very difficult to expand, since the culverts under Koumenweg and Burgemeester Slanghenstraat form a major bottleneck. The level in the watercourse is higher than the surrounding area and backflow from the Geleenbeek takes place during large discharges. Precisely because the watercourses downstream of De Dem are so difficult to expand, it is important that the throughput here does not exceed 3.2 m³/s. The research results show that De Dem is already (too) heavily loaded, which means that the throughput from upstream must remain limited. Solving the bottleneck below the traffic junction near Palemiggerboard and Schelsberg is therefore likely to have a negative effect on throughput downstream of De Dem.

6.3.2 Ecology

In terms of ecology, the (dynamic buffering) measures to be implemented must also take into account the following points:

- Buffers near roads or in urban areas with ‘dirt’ collection/pre-cleaning for twigs, leaves, seeds, sand/loam et cetera, which would otherwise rot in the stream and/or clog pumps or augers.
- Retention in stream valleys is undesirable from an ecological standpoint. Flow conditions for macrofauna that thrives in flows deteriorate, suspended particles cover hard substrates (essential for organisms in hillside streams).
- The natural flow regime should be disturbed as little as possible. The maximum discharges through the watercourses – especially at the level from Kokerstraat up to Aambos – must be kept to a minimum in view of the ecology, particularly the fauna, in the stream. A temporarily very high discharge can wash away too many elements from the stream valuable to ecology. However, when the flow surface of a watercourse is extended to increase its capacity, this can also mean that mostly the flow rate remains lower, which reduces the risk of ecological values being washed away. Follow-up research into the exact control of buffers and any capacity adjustments to buffers and watercourses should at least take this into account.
- Divert peak discharges as much as possible to larger robust streams downstream. This system is naturally more dynamic. These are the ‘less vulnerable to sewer overflows’ streams. In ‘T=5 highly vulnerable streams’, peak discharges are disastrous for characteristic species (drift, biotope loss, deep indentation).

From an ecology perspective, the following opportunities further exist:

- Realize buffers outside the water system, for example in dry valleys.
- Realize buffers in cascade succession so water is discharged more slowly, can be pre-treated, can infiltrate and peak discharges to the stream will be attenuated.
- An integrated approach: seek cooperation with farmers (as water managers) or municipalities.
- Take drought issues into consideration, further investigate infiltration options. Retaining water in buffers by using dynamic control to strongly constrain the throughput is desirable.
- Overdimensioning buffers: allowing room for retention and integrating the buffer into the landscape more easily with small elements.
- Increase sponge effect environment and apply inundation areas.
- The policy is not to discharge stormwater into springs and into the first section of the spring stream, see Geoweb under ‘Water System’ (‘spring run’ check registration).

6.4 Recommendations for follow-up research

The bottleneck downstream of De Dem (a maximum throughput of 3.2 m^3/s) limits the throughput of the buffers in Caumerbeek. It is therefore interesting to investigate which measures are required to increase the maximum throughput of 3.2 m^3/s.

It makes sense to investigate municipal storage near Hoogveld/Heerlerbaan in the municipality of Heerlen. Options include increasing the municipal buffer capacity on the one hand and, on the other hand, using the existing buffer capacity more efficiently by applying automated buffering in the municipality of Heerlen, near Hoogveld/Heerlerbaan.

It is interesting to investigate the possibility of storage in the watercourse between the Köpkesmolen and De Dem buffers. To this end, the protection of the buildings on Koningsbeemd, for example by means of a water barrier, must also be investigated. There is a bottleneck here in the current situation.

Any follow-up research into the control of the buffers considered most promising, must include monitoring in the buffers. Given the many assumptions made in the present study, it is advisable to have more knowledge of the actual filling and emptying of the buffers when investigating exact steering. In order to determine exact steering, a D-Hydro or Infoworks model is required, in which many more parameters must be determined. With sufficient measurement data, a good calibration of this model is possible and a good validation of the results is possible.

To investigate the exact control of the promising buffers, a more detailed (numerical) model is required that takes more account of the hydraulic functioning of the buffers and flow in the watercourses. This requires a D-Hydro or Infoworks model.

In the existing situation, the discharge limiters of the buffers in the Caumerbeek system are mostly coordinated, in order to make the best possible use of the capacity of the watercourses. When adjustments are made to the control of one or several buffers, it should be taken into account that adjustments may also have to be made to the pinch structures of other buffers in order to bring this coordination back into line. This should be included in the follow-up study.

For projects such as research into dynamic buffering, European grants may be available. The advice is to explore the possibilities for these grants. For example, the European LIFE grant may be worth looking into.

APPENDICES

B1 MAP CAUMERBEEK SYTEM

Map 1: 70 mm in 24 hours
Map 2: 50 mm in 2 hours

B2 RESULTS SCENARIO 1, 2, 3 EN 4