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## Modeling Retention and Evaluating Regulations on and Maintenance Needs of Bioretention Systems

Master's Thesis in the Master's Program Infrastructure and Environmental Engineering

LEIE KATZIN



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Cover: A bioretention cell by the building HSB Living Lab



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## ABSTRACT

This report focus on three aspects of stormwater retention; computer modeling in DHI MIKE Urban, Swedish legislation and maintenance of bioretention cells. The objective is to investigate if a specific type of bioretention cell located in Johanneberg, Gothenburg, can reduce the stormwater flows to the wastewater treatment plant when implemented on a large-scale district level. The aspects in focus are peak-flow and combined sewer overflow reduction. The focus lies also on evaluating the Swedish regulations on retentions systems and thereby illustrating the need for improvements to develop the use of sustainable bioretention systems in Sweden. Also, maintenance of Bio Retention Cells (BRCs) in the establishment period will be assessed in regard to type of activities and quantity.

The results from the specific rainfalls studied in this thesis, show that implementing BRCs that retain stormwater from 0.7 [ha] of the 12.7 [ha] catchment area have little effect on the retention of the water that discharge from the entire studied catchment area. Further on, to increase the development of sustainable stormwater management systems, the current legislation needs to extend beyond the limit of stormwater management in public areas. Results show that focus on making demands on property owners and to use larger parts of urban areas to retain stormwater is necessary. Results from the maintenance study show that regular watering and replanting of dead plants during the establishment period of the vegetation is necessary. The short study period in this thesis limits the result to the establishment period and cannot draw conclusion on any other maintenance activities further on in the life-span of the BRCs, which was an intention with this study.

Key words: modeling, low impact development, LID, bioretention, legislation, maintenance

Modellering av fördröjning och utvärdering av lagstiftning och underhållsbehov av regnträdgårdar

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## SAMMANFATTNING

Denna rapport fokuserar på tre aspekter av dagvattenfördröjning; modellering i programmet DHI MIKE Urban, svensk lagstiftning och underhåll av regnträdgårdar. Målet är att undersöka om den specifika typen av regnträdgård, belägen i Johanneberg, Göteborg, kan reducera dagvattenflödet till avloppsreningsverket om det implementeras på ett större område i staden. De aspekter som då är i fokus är reducering av flödestoppar och bräddning av avloppsvatten. Målet är också att utvärdera den svenska lagstiftning som reglerar dagvattenfördröjning och på så sätt illustrera behovet av att förbättra användningen av dagvattenfördröjning i Sverige. Utöver detta ska underhåll av regnträdgårdar under etableringsfasen utvärderas utifrån typ och mängd av åtgärder.

Resultaten från de specifika regnfall som studerats i denna rapport, visar att om regnträdgårdar implementeras så att det fördröjer dagvatten från 0.7 [ha] hårdgjord yta av ett specifikt upptagningsområde av storleken 12.7 [ha], så har det lite effekt på fördröjningen ut från hela det studerade upptagningsområdet. Angående svensk lagstiftning så behöver den utökas för att öka utvecklingen av hållbar dagvattenhantering på så sätt att den reglerar mer utöver allmänna ytor. Fokus bör ligga på att ställa krav på fastighetsägare och att använda större ytor av staden för att fördröja dagvatten. Resultat från underhållsstudien visar att regelbunden bevattning och utrensning av döda plantor behövs under etableringsfasen. Den korta tid som denna studie utfördes begränsar resultaten till etableringsfasen och slutsatser om behovet av underhållsåtgärder under en längre tidsperiod av regnträdgårdarna kan inte göras, vilket var intentionen av studien.

Nyckelord: modellering, lokalt omhändertagande av dagvatten, LOD, regnträdgård, lagstiftning, underhåll

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## **APPENDIX I – RESULTS FROM DETERMINING THE EFFECTIVE DISCHARGE COEFFICIENT OF THE TWO V-NOTCH WEIRS**

## **APPENDIX II – SETTING OF THE RUNOFF SIMULATIONS IN MIKE Urban**

## **APPENDIX III – SETTING OF THE NETWORK SIMULATIONS IN MIKE Urban**

## 1. List of abbreviations

ABVA	Allmänna Bestämmelser för brukandet av den allmänna VA-anläggningen
BRC(s)	Bioretention cell(s)
CS	Collection System
CSO(s)	Combined Sewer Overflow(s)
csv	Comma-separated values
DHI	Danish Hydraulic Institute
EU	European Union
EQS	Environmental Quality Standards
FD	Floods Directive
GPRS	General Packet Radio Service
LID	Low-Impact Development
MOUSE	MOdel for Urban SEwers
PBA	Planning and Building Act
PWSA	Public Water Services Act
RISE	Research Institutes of Sweden
RMQW	Regulation on the Management of the Quality of Water
SEC	Swedish Environmental Code
SUDS	Sustainable Urban Drainage System
SWMM5	Storm Water Management Model 5
UWWTD	Urban Waste Water Treatment Directive
WFD	Water Framework Directive
WSUD	Water Sensitive Urban Design
WWTP(s)	WasteWater Treatment Plants(s)

## 2. Introduction

### 2.1. Background

Particularly in areas with combined sewer systems, where wastewater and stormwater are transported in the same pipe, (Hey, Jönsson & Mattsson 2016: EPA, 2004; Weiss and Brombach, 2007; Schilperoort, 2004), there are problems associated with large amounts of water flowing into the system. One reason for these problems is the excessive inflow of stormwater into a system lacking adequate hydraulic capacity (Hey, Jönsson & Mattsson 2016: EPA, 2004; Schilperoort, 2004) or with malfunctioning pumps or pipe blockage (Hey, Jönsson & Mattsson 2016: Winder, 2003). This will likely result in combined sewer overflows (CSO) (Hey, Jönsson & Mattsson 2016: Field and Struzeski, 1972) that is the discharge of untreated wastewater from a combined sewer system (Hey, Jönsson & Mattsson 2016). There are ecological effects on the receiving environment due to these CSOs, the severeness of it depending on the quality of the discharge (Hey, Jönsson & Mattsson 2016: Winder, 2003).

Another issue associated with high flows in the sewer systems is insufficient wastewater treatment capacity. Calculations by Hey, Jönsson and Mattsson (2016) show that a “reduction in high flows will lower investment costs for [...] WWTPs” (Hey, Jönsson & Mattsson 2016, pp. 24) to reduce the bypass by extending the treatment plant (Hey, Jönsson & Mattsson 2016).

One way to reduce the high flows to the WWTP is to implement green infrastructure practices in the Urban area. These practices can reduce and retain the volume of stormwater discharged to the sewer system (Hey, Jönsson & Mattsson 2016: Dietz, 2007; Woodcock et al., 2013). Different terms for these types of green infrastructure are used around the world, such as “low-impact development (LID) technologies”, “water sensitive Urban design (WSUD)” and “sustainable Urban drainage systems (SUDS)” (Hey, Jönsson & Mattsson 2016: GDSDS, 2005).

A specific type of green infrastructure that reduce and retain the stormwater locally is bioretention cells (BRCs). The bioretention cell retain and treat stormwater from impervious Urban areas as the stormwater filter through the vegetation and filter media (Trowsdale & Simcock 2011). An example of a BRC is presented in figure 1.

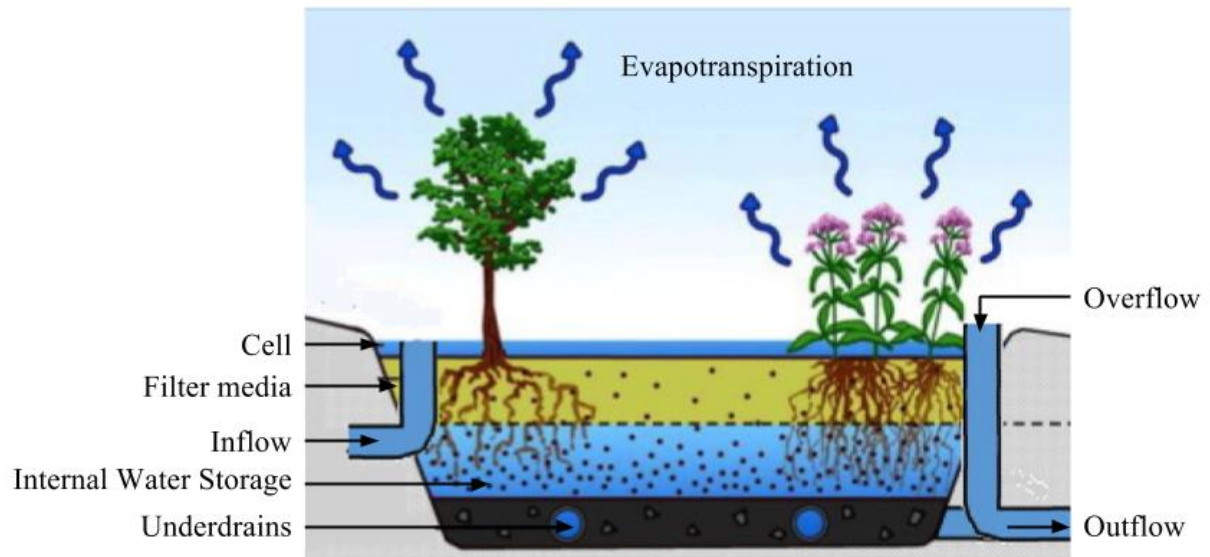


Figure 1. An example of a BRC design in profile, adapted from (Winston, Dorsey & Hunt 2016)

This type of BRC (figure 1) have been constructed in Gothenburg on the ground next to the property HSB Living Lab. The location of this property is illustrated in figure 2.



Figure 2. The location of HSB Living Lab in Gothenburg, Sweden

The stormwater from the roofs of the building HSB Living Lab is the inflow into two BRC located on the ground next to the building. The two BRCs can be seen in figure 3. Each BRC consists of a basin with a volume of  $8 \text{ m}^3$ , that will initially be constructed as plant beds. The basins are filled with two different materials, one in each basin. The first (BRC #1) is filled with “BaraMineraler” Rain Garden-substrate and the second (BRC #2) is filled with Luleå Technical University’s substrate for cold climates. The BRCs are each dimensioned to manage the stormwater from an 100 % impervious roof area of  $230 \text{ m}^2$ .



*Figure 3.* The two BRCs beside the building HSB living Lab in Gothenburg, that has the inflow to the system from the two roofs of the building, each with an area of  $230 \text{ m}^2$

The inflow to and overflow of the BRCs is presented in figure 4. The inflowing stormwater directly enters a distribution gutter that is located longitudinal in the middle of the surface of the filter media in the BRCs. The distributed stormwater reach the surface of the filter media and soaks down to the bottom of the basin where drainage pipes discharge the stormwater to a stormwater well, flowing further on into the municipal combined wastewater network. If the water level reach up to the edge of the basin it will overflow into a pipe that bypass the filter media.



Figure 4. One of the BRCs at HSB Living Lab. The inflow and overflow of the BRC are marked in the figure

## 2.2. Statement of purpose

The purpose of this project origin from the need to evaluate a sustainable stormwater system in local climatic conditions in Sweden and can lead to the development of new methods for retention of stormwater, new business opportunities surrounding this technology and to nationally and internationally spread new technical solutions.

## 2.3. Objective

The objective of this project is to investigate if this type of sustainable stormwater system, that provides additional value compared to underground stormwater retention, can reduce the stormwater flows to the wastewater treatment plant when implemented on a large-scale district level. The aspects in focus are peak-flow and combined sewer overflow (CSO) reduction.

Further on, the thesis focus on evaluating the Swedish regulations on retentions systems and thereby illustrating the need for improvements to develop the use of sustainable bioretention systems in Sweden. Also, maintenance of BRCs will be assessed in regard to type of activities and quantity.

## 2.4. Scope

This project focus on stormwater retention located close to estates, in the form of bioretention cells (BRCs). Computer modeling, maintenance guidelines and current Swedish legislation on innovative stormwater solutions are in focus.

## **2.5. Methodology**

The master's thesis consists of a literature study that will lead to deeper knowledge in measurements of stormwater flow, analysis of data and computer modeling (DHI MIKE Urban). The literature study will also include a study of current legislation regarding implementation of innovative stormwater solutions in Sweden and suggested principal maintenance activities for stormwater bioretention systems.

Data will be collected to evaluate the BRCs at HSB Living Lab and the data will be used in the computer modeling.

A photo journal of visual inspections at HSB Living Lab will be conducted. Together with the knowledge on maintenance activities for stormwater bioretention gathered in the literature study, the specific maintenance needs for the BRCs at HSB Living Lab will be evaluated.

### 3. Theory

#### 3.1. Computer modeling

The focus in this thesis regarding computer modeling is the program MIKE Urban, developed by Danish Hydraulic Institute (DHI).

##### 3.1.1. MIKE Urban

When using MIKE Urban and modeling a collection system (CS) either SWMM5 or MOUSE can be used (DHI 2016). In this chapter, the MOUSE applications on modeling BRCs will be described.

When running the simulations in MIKE Urban, the MIKE 1D engine can be used, which is a “reengineering and merger of the calculation capabilities of MIKE’s collection system and river simulation packages (MIKE URBAN / MOUSE and MIKE 11) into one engine.” (DHI 2012). The MIKE 1D engine can be used to run the MOUSE applications on modeling BRCs.

##### 3.1.1.1. MOUSE applications on modeling BRCs

A BRC, like a number of different green stormwater solutions, can be modelled in MIKE Urban in the form of a network point node type (number 5) named Soakaway, that can be connected to the pipe network. The configuration of the node is unlimited in regard to inlet pipe(s) with flow regulation, outlet pipe(s) with flow regulation, weirs(s) or orifice(s) (DHI 2016). Figure 5 is a schematic drawing of the Soakaway, with inflow ( $Q_{in}$ ), outflow ( $Q_{of}$ ) and water level ( $h$ ) in the BRC.

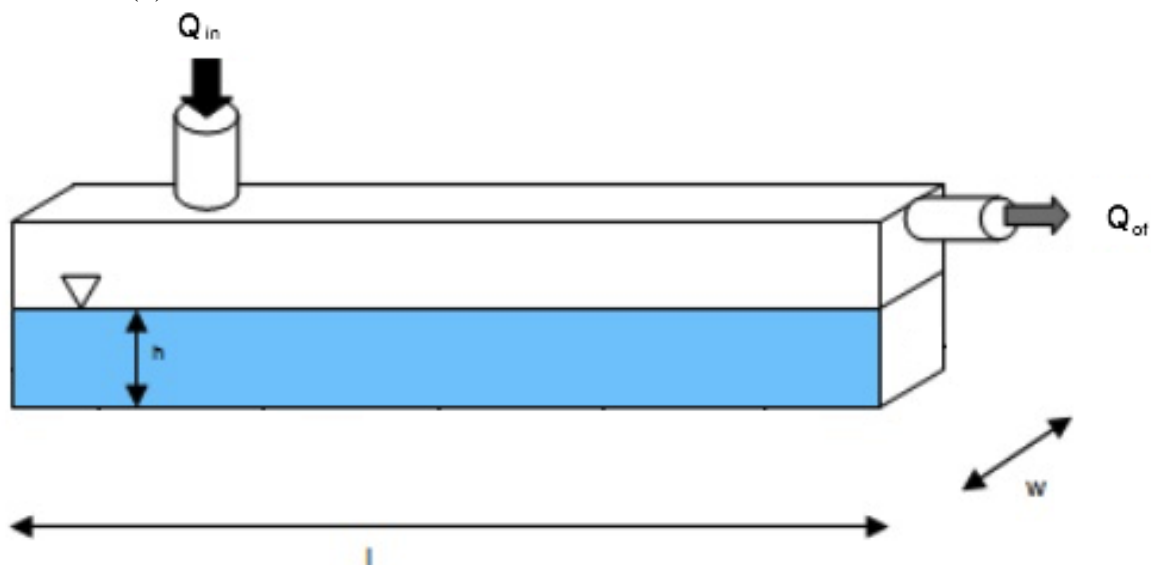


Figure 5. Schematic drawing of the Soakaway node, adapted from (DHI 2016)

The Soakaway node can be assigned the attributes invert level, ground level, basin geometry, CoverType (number 2) and headloss and can be provided with Direct Inflow (constant, time

series), Inflow from Rainfall Runoff (Runoff model A, B, C, Unit Hydrograph), saturated hydraulic conductivity [m/s] and porosity of the filling material [-] (DHI 2016).

MIKE Urban calculates the water level in the BRC based on inflow, outflow, porosity of the filling material and infiltration, where the option “No Infiltration” is selected if the Soakaway is to represent a stormwater solution where there is no infiltration out of the retention cell. The infiltration from the bottom of the Soakaway can be turned off by a flag and the infiltration from the sides can be turned off by setting the field-saturated hydraulic conductivity ( $K_{fs,side}$ ) to zero (DHI 2016).

A BRC can also be modeled in MIKE Urban with MOUSE using the LID Controls editor (figure 6) where each cell is defined by the properties of the layers and functional elements “Surface, Soil, Storage and Drain” (DHI 2016).

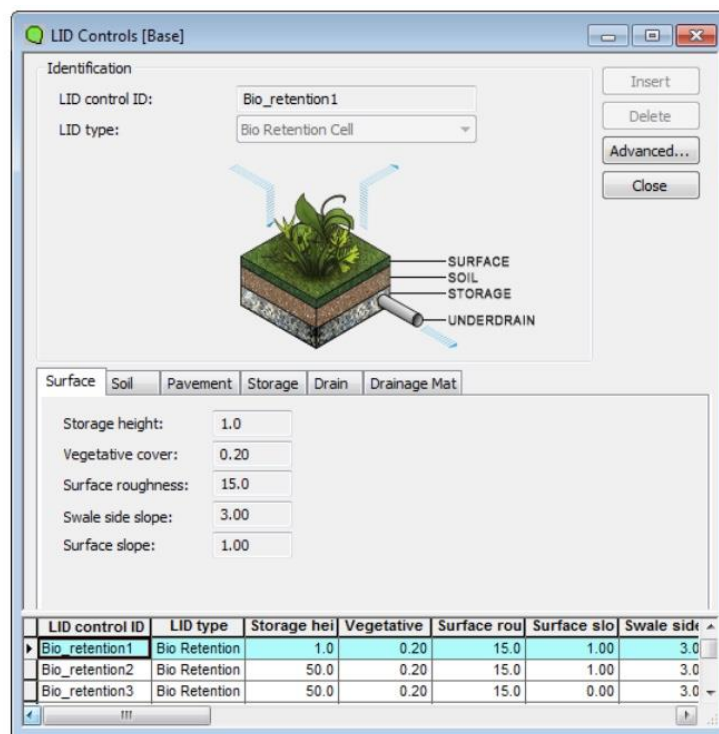


Figure 6. The LID Controls editor in MIKE Urban when modeling BRCs (DHI 2016)

The LID deployment editor enables to specify the area of the BRC and the impervious area from which stormwater is funneled into it (DHI 2016).

A result file can be generated for each BRC where the time series of fluxes and storages is presented and the outputs from the simulation can show reduced runoff hydrographs and the LID summary table (DHI 2016).

### 3.1.1.2. Rainfall-Runoff Modelling with MOUSE

The MOUSE engine enables the user to construct models with different levels of detail in regard to input data, with several tools and computational models (DHI 2016).

The runoff into a BRC, and further collected in the network, is generated on a catchment surface, that in MIKE Urban consists of a “catchment polygon” connected to the BRC. There are two classes of hydrological models for Urban catchments, continuous hydrological models and surface runoff model. In this chapter the later, and most common (DHI 2016), will be described.

The surface runoff model consists of the Time-Area Method, Kinematic Wave, Linear Reservoir and Unit Hydrograph Method and these models can only be used separately. How to choose a specific model for a catchment in MIKE Urban is shown in figure 7.

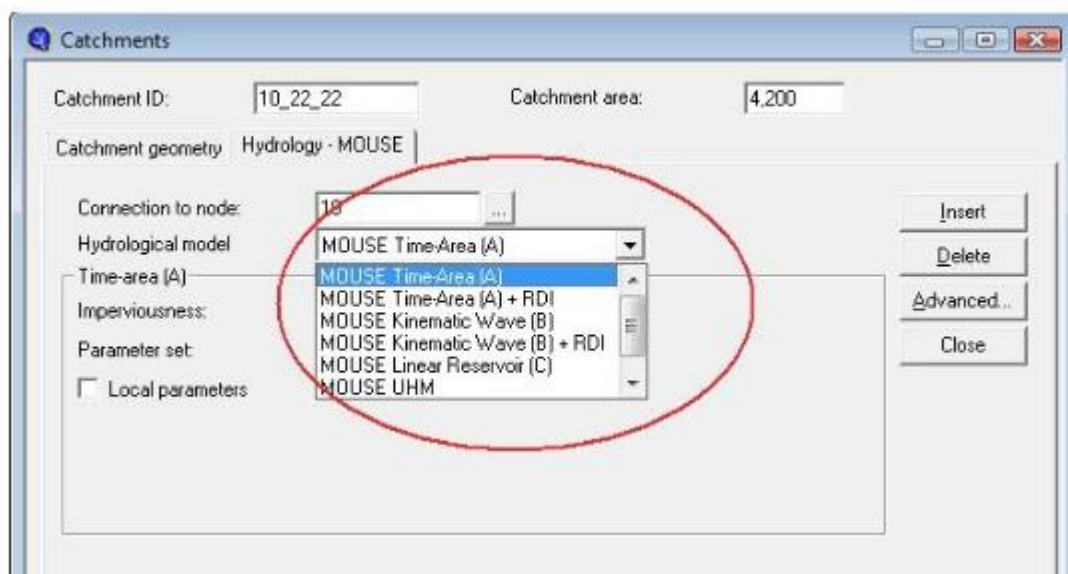


Figure 7. Choosing a hydrological model for a catchment in MIKE Urban

In the hydrological models the flow to the network starts and ends as a result of change in precipitation and only runoff on a surface is computed and is therefore suitable for Urban areas with relatively high density and for modeling single events, such as “design rainfall of certain recurrence interval” (DHI 2016).

### 3.1.2. Scaling of results from lot scales to larger scales

A BRC can be established and evaluated at a micro-scale, such as at a single lot scale, as many green stormwater solutions are, due to that most data regarding these solutions are from micro-scale monitoring (Ahiablame, Engel & Chaubey 2012).

To understand the interaction between and impact from implementing BRCs, scaling the results from lot scales to larger scales can be a way to avoid only short-term evaluation, high monitoring costs and to be able to incorporate specific processes, such as interflow, in watershed models (Ahiablame, Engel & Chaubey 2012).

This type of hydrological up-scaling consists of transferring information (Blöschl & Sivapalan 1995), from one scale to another (Blöschl & Sivapalan 1995: Gupta et al. 1986a)

across time-scales. This is associated with some problems, such as with the “spatial estimation of rainfall from rain gauge measurements” (Blöschl & Sivapalan 1995), that the effects on the large scale varies spatially and temporarily and that the performance of a BRC varies based on topography, soil and weather conditions (Ahiablame, Engel & Chaubey 2012).

### **3.2. Legislation**

Several EU directives and Swedish acts, codes and regulations include legislation regarding stormwater (National Board of Housing, Building and Planning 2015) and are relevant to address in this chapter. Different parts of the legislations formulate demands on stormwater management regarding different situations and a legal responsibility determined in one regulation cannot be annulled with a reference to another regulation (National Board of Housing, Building and Planning 2015).

Stormwater management is categorised under different definitions in the legislation, depending on aspects such as where it originates and how it is managed. When not directly mentioned as a concept in the legislation, stormwater management is still of importance in relation to the legislation due to the perspective of contamination of natural waters (Söderberg 2011).

Regulations regarding contamination of natural waters due to stormwater management are also relevant in regard of other aspects of sustainability, such as flooding (Söderberg 2011: Bergström; Widarsson 2007), strain on pipe networks and wastewater treatment plants and overflow of sewage to natural waters during heavy rains (Söderberg 2011: Bergström). These other aspects are not regulated in the same way as contamination, but have impacts on implementing more alternative solutions rather than traditional ones, due to that the later are not sufficient in covering all the mentioned aspects (Söderberg 2011).

The performance of BRCs is dependent on proper installation and maintenance and therefore regulating and researching these areas require further attention (Wardynski & Hunt 2012: Roy-Poirier et al. 2010)

#### **3.2.1. Planning and Building Act (Plan- och bygglagen)**

There is a clear connection between the Planning and Building Act (PBA) and stormwater management due to the municipalities responsibility for the strategic planning of land and water resources (Cettner et al. 2013; Söderberg 2011) and the use, development and preservation of the physical environment (National Board of Housing, Building and Planning 2015) regulated in the PBA. Stormwater management is suitable to regulate according to the PBA, when setting conditions or appendices for specific geographical areas in the comprehensive planning, due to the water's impact on land use and exploitation. The PBA gives the support to regulate the physical conditions, but does not regulate either quality or

quantity of stormwater management (National Board of Housing, Building and Planning 2015).

The municipalities dominating responsibility to manage that land and water is used appropriately from a public point of view, result in their key role in stormwater management, giving the opportunity to contribute with long-term and sustainable solutions (National Board of Housing, Building and Planning 2015; Söderberg, 2011). The municipality is responsible to arrange and maintain the necessary technical solutions that are needed to manage stormwater, such as retention or detention storage facilities and pumping stations (National Board of Housing, Building and Planning 2015).

The PBA provides the municipality with the opportunity, but not the obligation, to define how stormwater is managed, utilising both piped and non-piped solutions (Cettner et al. 2013; National Board of Housing, Building and Planning 2004). The stormwater management should add environmental and other values, when located in public areas, and the municipality should take special consideration to health, safety, flooding and erosion. Technical solutions can be implemented, however, extraordinary solutions should not be necessary to fulfill the requirements in the PBA, and foremost economic considerations should be made, including investment, operation and maintenance costs (National Board of Housing, Building and Planning 2015).

There is a connection between the PBA and The Swedish Environmental Code (SEC) which states that the SEC's environmental quality standards (EQS) should be complied and followed when taking decisions regarding both the municipality's comprehensive planning and legally binding development plans. However, it has been proved in practice that few plans are prevented by the EQS (Gipperth & Ekelund- Entson 2010).

### **3.2.2. Swedish Environmental Code (Miljöbalken)**

Stormwater is mainly categorised as sewage according to the definitions in the Swedish Environmental Code (SEC) (National Board of Housing, Building and Planning 2015; Söderberg 2011), including basically all stormwater that is diverted from an area in a legally binding development plan or a cemetery and all water that ends up in stormwater wells and pipes (Söderberg 2011).

According to the SEC, stormwater should be diverted and treated or disposed of in a way that cause no inconvenience to human health or the environment (National Board of Housing, Building and Planning 2015). There are also requirements on municipalities and other operators to have knowledge of the level of contamination in the stormwater and to act in accordance with the precautionary principle that in the legislation result in the right to make extensive demands on stormwater management (Söderberg 2011).

The precautionary principle contain the demands that preventive measures should be made to avoid spreading of contamination with discharge of stormwater to recipients or to divert the

contaminated discharge to less sensitive recipients. However, no stormwater is allowed to be discharged untreated if there is a risk to human health or the environment and specific drainage systems should be implemented to prevent this (Söderberg 2011).

These demands are not compatible with the current discharge of untreated stormwater to recipients. Without contamination measurements and in accordance with the SEC, the municipality and other authorities is responsible for seeing to that the regulations is complied with (Söderberg 2011).

### **3.2.3. Public Water Services Act (Lag om allmänna vattentjänster)**

The Public Water Services Act (PWSA) regulates the municipalities responsibility to arrange stormwater management areas and that the owner of a management facility, the municipality or municipal company, is responsible for the stormwater in its area if it includes a legally binding development area. The PWSA and the Planning and Building Act (PBA) applies in parallel (National Board of Housing, Building and Planning 2015).

According to the PWSA, stormwater should be managed if it constitutes a risk to human health or to the environment. If it constitutes a risk, a municipality or municipal company should construct and maintain a stormwater management facility and connect properties and public areas to the facility (National Board of Housing, Building and Planning 2015).

The PWSA aim to strengthen the requirements on the municipal stormwater management, however, the general phrasing of the legal text gives the municipality a great opportunity to determine by who, when and how the stormwater will be managed. This fact, in combination with the economical aspects leads to the tendency in many municipalities to give a low priority to implementing sustainable stormwater solutions which leads to a low increase of improving the management. Another aspect that deteriorates the possibilities to improve the management is that the municipality often have the oversight of its own activities (Söderberg 2011).

### **3.2.4. Regulation on the Management of the Quality of Water (Vattenförvaltningsförordningen)**

The base of the Regulation on the Management of the Quality of Water (RMQW) is the regulations in the EU Water Framework Directive (WFD). In some parts of the RMQW is also direct referenced to the WFD (Söderberg 2011).

In the RMQW the main principle is that the quality of natural waters, under no circumstances, should decrease which is a preventive measure for future deterioration of natural waters. Besides this, reparative and enhancing measurer should be made to improve the quality of the natural waters (Söderberg 2011).

A key aspect of the RMQW is the idea of cooperation between all concerned or interested in water management, in order to achieve the previously stated principle. This is regulated in the RMQW, stated that Sweden's water authorities should plan their work in a way that

encourage participation. They should also consult authorities, municipalities, organisations, other actors and individuals that are concerned, before they take decisions of great importance (Söderberg 2011).

### **3.2.5. The connection between Swedish legislation and EU directives**

In the stormwater sector, the most relevant international legislation is the EU Water Framework Directive (WFD) (Torgersen, Bjerkholt & Lindholm 2014) and the core of the WFD is that the implementation of solutions in the water sector should be made in collaborations (Söderberg 2011).

One of the main goal of the WFD is to deal with the contamination of natural waters. Even though stormwater is not mentioned specifically in the WFD it is relevant when connecting the aspect stormwater management to contamination of surface waters (Söderberg 2011).

Stormwater is the dominant source of contaminating surface- and groundwater, when not sufficiently treated stormwater is the effluent to lakes and streams. Successful stormwater management is therefore of great importance if the goal of good status on surface waters will be achieved, which is mentioned in several articles in the WFD (Söderberg 2011).

The WFD is incorporated in Swedish legislation mainly in the Swedish Environmental Code and the Regulation on the Management of the Quality of Water (Söderberg 2011) that are previously addressed in this chapter.

The EU Floods Directive should be coordinated with the Water Framework Directive and define flood risk management that by experience is shown to be the most effective approach to reduce the likelihood and/or the impact of floods (European Commission 2016a).

Flood risk management is defined as the elements prevention, protection, preparedness, emergency response and recovery and lessons learned. The elements relevant to stormwater management are first two, that include promoting appropriate land-use, reducing the likelihood of floods by taking both structural and non-structural measures and to reduce the impact of floods in a specific area (European Commission 2016a).

The EU Urban Waste Water Treatment Directive (UWWTD), in regard to stormwater management, address stormwater overflows from collecting systems. The goal is to limit the pollution of natural waters from the overflows and that national authorities take measures to prevent this type of pollution. The directive states that the measures should be taken in regard to unusual situations, such as heavy rain (European Commission 2016b).

### **3.3. Maintenance of stormwater bioretention cells**

Regular inspection and maintenance of stormwater bioretention cells (BRCs) is one issue to ensure proper functionality (Brown & Hunt 2012; Erickson et al. 2013; Hunt et al. 2015), keep the performance and efficiency at a level of the intended design (Erickson et al. 2013;

Hunt et al. 2015), extend the useable life of the BRCs (Erickson et al. 2013) and make sure that they are safe (Hunt et al. 2015). The maintenance needs of BRCs also have an aesthetic aspect and many of the maintenance tasks of that nature leads to improving other aspects (Hunt et al. 2015).

Lack of maintenance can lead to failure of the system (United States Environmental Protection Agency 2016) such as that the stormwater is directly bypassed when structures are blocked or broken (Blecken et al. 2017). The volume of stormwater that is bypassed can be reduced by restorative maintenance which can also lead to improved peak outflow mitigation, larger surface storage volumes and increased surface infiltration rates (Brown & Hunt 2012). These failures can lead to the need of restoration which is associated with high costs (United States Environmental Protection Agency 2016).

A challenge in this scientific field is to develop methods that determine if maintenance is needed, how frequently to inspect the BRC (United States Environmental Protection Agency 2016), what triggers there are for maintenance activities (Asleson et al. 2009; United States Environmental Protection Agency 2016) and how the BRC perform immediately after installation and over time (Asleson et al. 2009).

### **3.3.1. Visual inspection**

The BRCs must be assessed to determine its current level of performance in relation to its intended design, goals and desired level of performance prior to any maintenance activities are performed. Regularity, accuracy and within an acceptable level of uncertainty are key criteria of the assessment results and only when these criteria are fulfilled can wise decision be made regarding maintenance. The regularity criteria leads to that problems are identified and resolved as soon as possible which can minimize the frequency of non-routine and major maintenance actions (Erickson et al. 2013).

The type of decisions that assessment can support are if, when in future, what type of and at what level maintenance is needed. By determining or estimating if and when in future maintenance is needed, unnecessary maintenance activities are prevented resulting in more cost efficient BRCs (Erickson et al. 2013).

One useful assessment method is visual inspection which should include inspection of the:

- Filter media
- Inlet
- Outlet
- Overstructure
- Bypass structure
- Surrounding area
- Sediment forebays
- Vegetation

Inspection manuals state that this visual inspection should be conducted to ensure the effectiveness of the BRC with a frequency of once a month (Prince George's County 2009), every other month (Godecke 2017) or once a quarter (North Carolina Department of Environmental Quality 2017).

When the filter media is significantly clogged the BRC is not draining properly and excess stormwater will overflow or bypass the filter. A significantly clogged filter media can either contain a visible layer of fine material on the surface or be clogged in the entire depth of the media. Both cases leads to that a pool of standing water will remain on the media surface after the designed drain time, due to reduced permeability. The remaining pool of standing water can lead to the development of microorganism and the water will then be green from algae or biological activity. To detect the problem of a significantly clogged filter media, a visual inspection should occur when the design drain time has elapsed after a large runoff event looking for remaining water or a visible layer of fine material on the media surface (Erickson et al. 2013). Maintenance manuals state that this is within 24 or 48 hours after a storm greater than 25.4 mm (Prince George's County 2009; Wardynski & Hunt 2012). When the filter media contains macropores or large holes, ruts, or other openings the stormwater can pass the BRC without sufficient filtering. To detect this problem, a visual inspection of the filter media should be made to ensure the absence of these types of openings (Erickson et al. 2013).

Indicators of lack of maintenance is if no plants are present in the BRC, if wetland plants are present outside the forebay or if the BRC is overgrown with limited accessibility (Wardynski & Hunt 2012). Visual inspection of the vegetation can detect these indicators (Prince George's County 2009).

### **3.3.2. Testing**

The performance of the BRC is dependent on the soil medium and its condition (Le Coustumer et al. 2009). Testing the condition of the soil medium in the BRC can be used to schedule and select maintenance activities (Asleson et al. 2009; Erickson et al. 2013) and can consist of either feasibility testing or full-scale testing. Initial feasibility testing can reduce testing costs when determining if full-scale testing is necessary (Maryland Department of the Environment 2000).

When testing a BRC, two kinds of test can be conducted: capacity testing and synthetic runoff testing. These types of tests consists of measurements under conditions other than a natural runoff event (Erickson et al. 2013).

Inspection manuals state that some test of the BRC should be conducted periodically once a year (North Carolina Department of Environmental Quality 2017) or three times a year (spring, midsummer and late fall) (Erickson et al. 2013).

### 3.3.2.1. Capacity testing

Capacity testing uses a series of point measurements that are spatially distributed (Erickson et al. 2013) and the results from the tests can be used to identify areas in the BRC that need rehabilitation (Asleson et al. 2009) by estimating the depth of accumulated sediment or the surface saturated conductivity ( $K_s$ ) for specific locations in the BRC (Erickson et al. 2013).

The  $K_s$  is an estimation of the infiltration ability under saturated conditions (Asleson et al. 2009) and can be significantly affected by factors such as the root system of plants, where thin roots reduce (Le Coustumer et al. 2012; Archer et al. (2002)) and thick roots increase the conductivity (Le Coustumer et al. 2009; Le Coustumer et al. 2012; Archer et al. (2002)). The  $K_s$  can be used to assess the performance of the infiltration capacity over time, if the test is repeatedly, over a long period of time, conducted at the same locations in the BRC (Asleson et al. 2009) and also by comparing the measured values to the design specifications (Erickson et al. 2013). It can also be used to assess the spatial distribution the infiltration capacity (Asleson et al. 2009; Erickson et al. 2013) and predict the drain time of the BRC (Asleson et al. 2009).

### 3.3.2.2. Synthetic runoff testing

Synthetic runoff testing consists of applying a prescribed amount of synthetic stormwater to the BRC under controlled conditions and accounts for the increased infiltration around and near the stems of vegetation which capacity testing does not account for. This type of tests is limited to systems with a relatively small design discharge where an adequate water supply exists that can provide the total runoff volume and required discharge needed, with the possibility to continuously measure the inflow, outflow and elevation of the water surface in the BRC (Erickson et al. 2013).

The results of the tests can be used to assess the overall performance of the BRC, such as runoff volume reduction (Asleson et al. 2009; Erickson et al. 2013), the overall effective saturated hydraulic conductivity ( $K_s$ ) for the entire BRC, and to calibrate computer models of the watershed (Erickson et al. 2013).

The overall  $K_s$  may vary due to factors such as climatic season and soil conditions and for this purpose the testing should be performed at several different times throughout the year to obtain the seasonally or overall yearly overall  $K_s$  (Erickson et al. 2013).

Measurements of the BRCs total drain time can also be conducted simultaneously with the tests. The entire basin is then filled with synthetic stormwater and the change over time in water level is measured (Asleson et al. 2009; Erickson et al. 2013).

If the BRC is not performing as expected during synthetic runoff testing, more information is required to determine what type of maintenance activities are needed (Erickson et al. 2013).

### **3.3.3. Monitoring**

Monitoring consists of measuring the performance of the BRC during natural rainfall or snowmelt events and is a cost intensive method that should be considered if testing (capacity and/or synthetic runoff) is not sufficient (Erickson et al. 2013).

The method is to automatically measure (Asleson et al. 2009) and compare all inflow and outflow rates from the BRC and the results can be used to assess peak flow and runoff volume reduction or characterise watershed runoff coefficients. During the monitoring period, frequent visits to the site is required which results in frequent visual inspections. A monitoring project can therefore indirectly be used to schedule maintenance (Erickson et al. 2013).

Monitoring can result in minimal conclusive data and to get reliable results a significant amount of data is required due to the great amount and range of different variables that influence the performance of the BRC (Erickson et al. 2013).

### **3.3.4. Principal maintenance activities**

The principal maintenance activities for stormwater bioretention can be divided into the categories routine, non routine and major, where the first two categories should prevent or limit the need for the last category (Erickson et al. 2013).

#### **3.3.4.1. Routine maintenance activities**

The routine maintenance activities (table 1) are performed regularly and relatively frequent (Erickson et al. 2013) and include vegetation and ground cover upkeep and inspecting and cleaning the inlet, outlet, overstructure and sediment forebays (Blecken et al. 2017; Erickson et al. 2013) and preserving the infiltration capacity (Godecke 2017).

Vegetation upkeep consists of replanting and removal of weeds and dead plants (Blecken et al. 2017), watering, pruning, mulching, mowing and liming of the BRC (Hunt et al. 2015). These upkeep activities are important due to that the infiltration capacity is dependent on the vegetation's ability to limit clogging of the soil medium (Le Coustumer et al. 2012). This is especially important in the first one-two-year establishment period (Blecken et al. 2017) and also to complement with new plants if necessary (Godecke 2017). Inspection manuals state that if needed during this period, the plants should be watered at frequencies stated in table 1. After the establishment period watering should not be required, except during prolonged dry periods (North Carolina Department of Environmental Quality 2017) or drought (Hunt & Lord 2006).

Table 1. Vegetation Upkeep Tasks and Frequency Stated from Different References

Task	Frequency	Reference
Replanting and removal of weeds and dead plants	1 time / year	Hunt & Lord 2006
	2 times / year (spring and fall)	Minnesota Pollution Control Agency 2017
Weeding	1 time / 2 month	Minnesota Pollution Control Agency 2017
Watering	2 times / week first six weeks	North Carolina Department of Environmental Quality 2017
	Temporarily first 1 year	Minnesota Pollution Control Agency 2017
	1 time / 2 - 3 days first 1 - 2 month	Hunt & Lord 2006
	1 time / 2- 3 days during drought	Hunt et al. 2015
Pruning	1 - 2 times / year	Hunt & Lord 2006
	1 time / 3 year	Minnesota Pollution Control Agency 2017
Mulching	1 - 2 times / year	Hunt & Lord 2006
	1 time / 2 year (no heavy metal deposition)	North Carolina Department of Environmental Quality 2017
	1 / year (likely metal deposition)	North Carolina Department of Environmental Quality 2017
Mulch removal	1 time / 2 - 3 year	Hunt & Lord 2006
Mowing	2 - 12 times / year	Hunt & Lord 2006
Liming	1 time initially	Hunt et al. 2015
Spot-fertilized	1 time initially	Hunt & Lord 2006; Hunt et al. 2015

Inspecting and cleaning the inlet, outlet, overstructure and sediment forebays consists of removal of obstructing objects or litter that affect the flow (Blecken et al. 2017; Erickson et al. 2013; Godecke 2017). It is especially important to check the outlet that is prone to clogging and if the bypass structure have a grate (Hunt et al. 2015).

The cleaning maintenance activities and frequencies stated by different inspection manuals are presented in table 2.

*Table 2.* Cleaning as a Principal Routine Maintenance Activity and Frequency Stated from Different References

<b>Part of BRC</b>	<b>Frequency</b>	<b>Reference</b>
Inlet	12 times / year	Hunt & Lord 2006; Hunt et al. 2015
Outlet		
Overstructure		
Sediment forebays	A few times / year to 1 time / 3-5 years	Hunt et al. 2015
	2 times / year	Minnesota Pollution Control Agency 2017

#### 3.3.4.2. Non-routine and major maintenance activities

The non-routine and major maintenance include tree and sediment cleanout, structural repair, partial rehabilitation, rehabilitation and rebuilding, such as rototilling of the top 15 centimeters, removal of sediment layer, replacement of the top 15-20 centimeters of the filter media and removal and replacement of the entire bed. The last four maintenance activities are actions taken if the BRCs filtration rates are lower or higher than desired and should only be performed after any underlying causes are found and corrected (Erickson et al. 2013).

Preserving the infiltration rates of the filter media consists of maintaining the hydraulic conductivity of the system which can decrease mainly from clogging, leading to more frequent overflows, extended ponding time, reduced aesthetic value, public health problems and thereby not meeting the goals of the BRCs intended design (Le Coustumer et al. 2012).

Clogging consist of two types: surface and interstitial clogging (Le Coustumer et al. 2009), where the first is the most frequent type (Hunt et al. 2015). Both types are the result of mechanical, biological and chemical processes (Le Coustumer et al. 2012; Langergraber et al. 2003).

Surface clogging due to mechanical processes is the accumulation of suspended organic and inorganic solids (Langergraber et al. 2003) or sediment (Hunt et al. 2015; Brown & Hunt 2011), forming a “cake” (Le Coustumer et al. 2012) or “mat” (Langergraber et al. 2003) on top of the filter media. A biological process that cause surface clogging on BRCs in temperate climates is a biofilm (Hunt et al. 2015) that is the result of growing micro-organism and biomass decay, also referred to as surplus sludge production (Langergraber et al. 2003).

Interstitial clogging due to mechanical processes is the filling (Le Coustumer et al. 2009) or deposition of suspended solids (Langergraber et al. 2003) in the pores of the filter media. The infiltrated solids can also contribute to a biological process that cause interstitial clogging, when the organic part of the solid is mineralised by microorganisms. This process requires oxygen and if the clogging inhibits the oxygen supply the process decreases which leads to that the clogging increase exponentially (Langergraber et al. 2003).

Some other factors are stated to play a minor role related to clogging, such as “chemical precipitation and deposition in the pores (Platzer and Mauch, 1997), growth of plant-rhizomes and roots (Vymazal *et al.*, 1998), formation and accumulation of humic substances (Siegrist *et al.*, 1991) and generation of gas and compaction of the clogging layer (Pérez-Paricio and Carrera, 2001)”

To minimize the risk for clogging the need for pretreatment measures (Hunt et al. 2015; Wardynski & Hunt 2012), visual inspection, maintenance activities (Wardynski & Hunt 2012) and roots that are dense and uniform (Hunt et al. 2015) is emphasized. Pretreatment measures that are commonly used in temperate climates are “gravel verge (thin strip) with sod surrounding the perimeter, grass swale and forebays” (Hunt et al. 2015). Also, protecting the BRC from construction-generated sediment from the surrounding Urban area, minimize the risk for clogging by sediment (Hunt et al. 2015).

Principal maintenance activities conducted to reduce clogging and increase the hydraulic conductivity include removing the mulch and the top layer of the soil medium (Wardynski & Hunt 2012), removing the top 25-100 mm of the soil medium or removing the covering biofilm (Hunt et al. 2015).

The Non-routine and major maintenance tasks and frequency from inspection manuals are presented in table 3.

*Table 3.* Non-Routine and Major Maintenance Tasks and Frequency Stated from Different References

<b>Task</b>	<b>Frequency</b>	<b>Reference</b>
Removal of biofilm	1 time / 2 - 3 year	Hunt et al. 2015
Removal of mulch and top layer	1 time / 1 - 2 year	Wardynski & Hunt 2012

### 3.3.5. Specific to cold climates

There are some problems that are only relevant to BRCs in cold climates that can lead to considerably reduced or no functionality (Viklander & Bäckström 2008). The problems can originate from that precipitation falls as snow, accumulation of snowpack, low air temperature, low evapotranspiration (Bäckström & Viklander 2000), clogging of gutters and inlets, freezing in pipes, frost heaving (Maksimovic et al. 2000) ground frost, ice formation (Maksimovic et al. 2000), frozen soil, high snowmelt volumes (Khan et al. 2012) and inactive vegetation during the winter season (Viklander & Bäckström 2008). These problems may require altered design guidelines that consider local conditions (Khan et al. 2012).

The infiltration capacity is an important factor in regard to the performance of a BRC, both during the snowmelt and winter season (Muthanna, Viklander & Thorolfsson 2008). During late winter or early spring the accumulated snow melts (Bäckström & Viklander 2000) which could coincide with that the facility is clogged by ice (Bäckström & Viklander 2000: Lindwall and Hogland, 1981) and rain-on-snow events, leading to large runoff volumes that could be the design-type event for the BRC (Marsalek et al. 2003: Milina, 1998). Another influencing factor to the large runoff volumes during this period is the reduced infiltration capacity of surfaces that are permeable during the rest of the year, leading to a larger contributing area than usual (Bengtsson & Westerstrom 1992; Bäckström & Viklander 2000).

When the winter is approaching and the soil is starting to freeze, a BRC filter medium with a fine particle size and low hydraulic conductivity can lead to that remaining pore water freeze and form an almost impermeable layer. A solutions to avoid this problem is to use a coarser filter medium with a higher hydraulic conductivity (Godecke 2017).

Another solution to the problems that are only relevant to BRCs in cold climates is to use low temperature resistant plastic or aluminum in inlet structures, due to that metal grates or racks freeze earlier than these other materials (Maksimovic et al. 2000). There are also special structures to avoid periods of clogging from saturated snow in the inlet, developed in Iceland (Maksimovic et al. 2000: Skarphedinsson, 1993).

Maintenance activities for BRC in cold climates related to frost and snow accumulation and melting include planning actions to keep the system components free from ice and snow to enable operation at full capacity. One solution is steaming and mechanical devices that are specially designed to open up pipelines, inlets and gutters (Maksimovic et al. 2000).

Scheduling maintenance in cold climates can be planned with regard to the weather forecasts and where knowledge gained in the field will indicate which combinations of climatic factors that will lead to operational problems of the BRC. Local conditions, such as the pattern for freeze-thaw cycles, guide when emergency crews are to be sent to problem areas (Maksimovic et al. 2000).

## 4. Materials and methods

### 4.1. Determining the effective discharge coefficients of the v-notch weirs

To determine if the weirs are constructed according to the intended design, and fulfills the criteria that the effective discharge coefficient ( $\mu$ ) is within the span 0.6-0.8,  $\mu$  for each weir is going to be determined experimentally by following these steps:

1. Calculate or measure the angle ( $\alpha$ ) of the v-notch.
2. Calculate or measure the horizontal middle line of the v-notch.
3. Flush water at a constant flow ( $Q$ ) into the weir, keep the opening of the hose under the water level to avoid turbulence at the surface (figure 8).



Figure 8. Flushing of water at a constant flow into the weir, when determining experimentally the effective discharge coefficients of the v-notch weirs

4. Measure the height difference between the top of the weir and the unaffected water surface upstream the v-notch and use to calculate the height ( $h$ ) of the water surface over the v-notch.
5. Fill a vessel with the water that flows out of the weir and measure the time it takes with a stopwatch to get the flow ( $Q$ ) in liters per second.
6. Repeat and log for several different flows ( $Q_i$ ) and corresponding heights ( $h_i$ ).
7. Plot  $Q_i$  [l/s] on the x-axis and  $h_i$  [cm] on the y-axis.
8. Calculate the different effective discharge coefficients ( $\mu_i$ ) for corresponding flows ( $Q_i$ ) and heights ( $h_i$ ) using [1].

$$\mu = \frac{Q \times 15}{8 \times \tan \frac{\alpha}{2} \times h^{2.5} \times \sqrt{2 \times g}} \quad [1]$$

9. Calculate a mean value of the effective discharge coefficients ( $\mu_{\text{mean}}$ ).
10. If a specific interval of the effective discharge coefficient ( $a < \mu < b$ ) is desired, plot the theoretically calculated flows ( $Q$ ) and corresponding heights ( $h$ ) for  $\mu = a$  and  $\mu = b$  to see how the measured flows ( $Q_i$ ) and corresponding heights ( $h_i$ ) relate to the theoretical.

The result from determining the effective discharge coefficient ( $\mu$ ) of the two weirs, that were tested before installed in the stormwater wells at the site HSB Living Lab, can be seen in detail in appendix I.

Figure 9 and figure 40 in appendix I show, for the two weirs respectively, the measured flow ( $Q$ ) on the x-axis and the corresponding measured height ( $h$ ) of the water surface over the v-notch on the y-axis. Those values are labeled “Measurements”. To determine if the weir are in the intended span of  $\mu$  between 0.6 and 0.8 the theoretical values of  $Q$  and  $h$  for the two  $\mu$  are plotted in the figure and are labeled “ $\mu = 0.6 [-]$ ” and “ $\mu = 0.8 [-]$ ”. Furthermore, a trend line for the measured values are plotted.

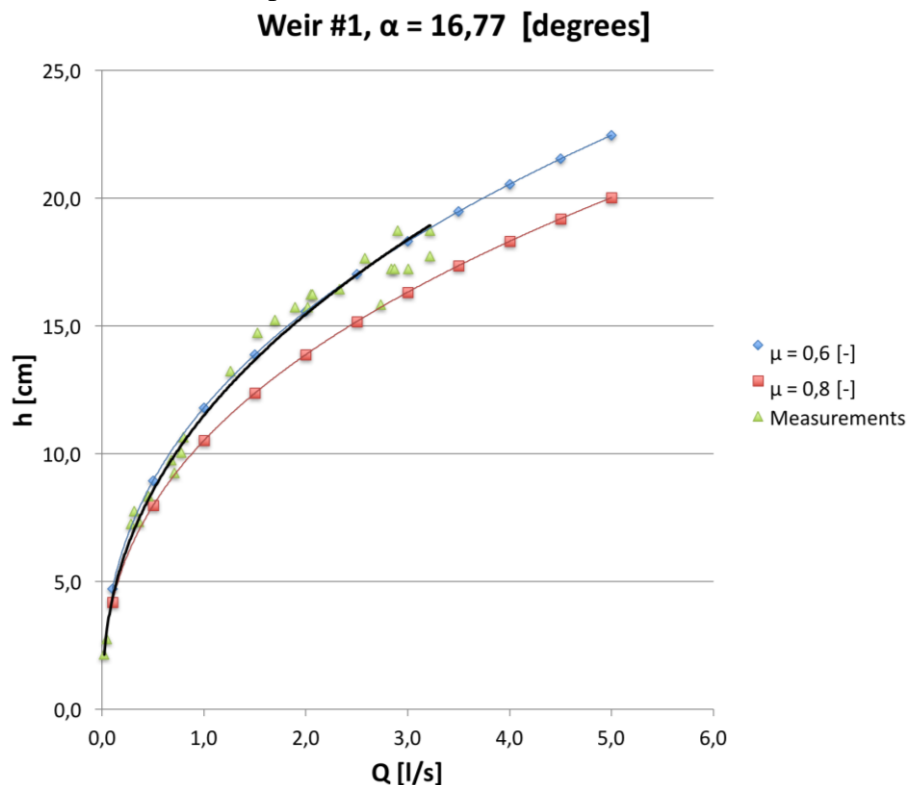


Figure 9. Graphs of flow ( $Q$ ) and height ( $h$ ) of the water surface over the v-notch for one of the two tested weirs.

The result of the measured values show that the trend lines in figure 9 and figure 40 are in the intended span which indicates that the weirs are correctly constructed and can give the desired flow measurements when installed in the stormwater wells at HSB Living Lab.

## 4.2. Data collection

### 4.2.1. Rain data

Data regarding precipitation can be collected online from REGNDATA (2017) or from Sweco Environment AB<sup>1</sup>. The approximate locations for the two rain gauges nearby HSB Living Lab, with data available from REGNDATA and the one with data available from Sweco are shown in figure 10.

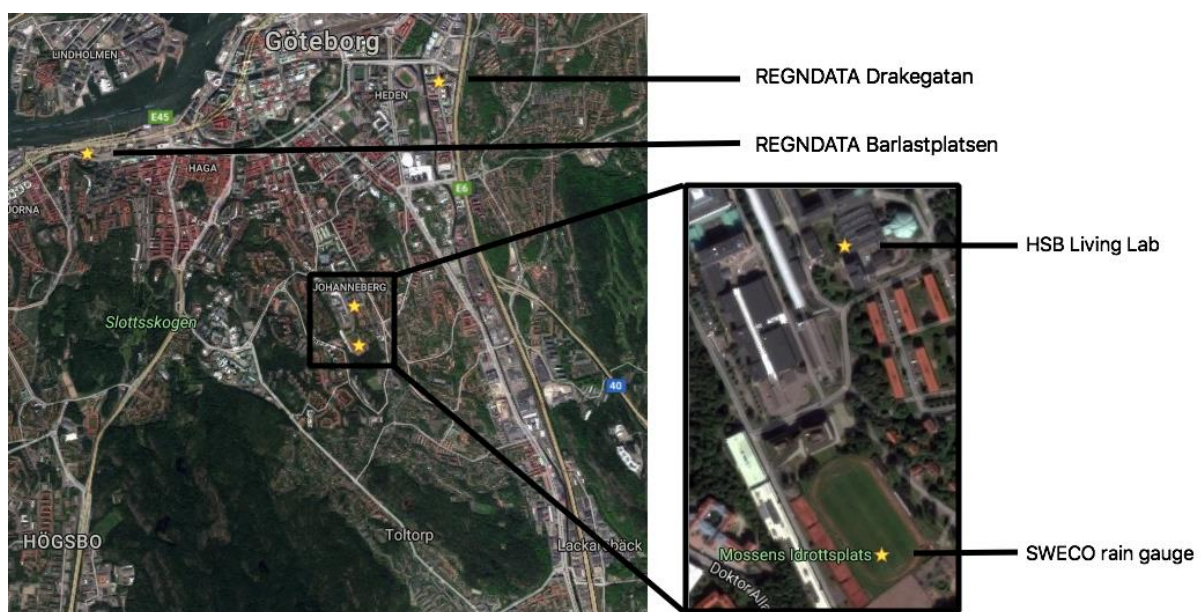


Figure 10. Map with markings of the locations of the rain gauges and HSB Living Lab

The online service REGNDATA is provided by DHI, where data from the rain gauges closest to HSB Living Lab are at Barlastplatsen and Drakegatan (figure 10).

To collect rain data from REGNDATA, use “Advanced search (Avancerad sökning)” and select a specific rain gauge (STATIONS ID) and a time period (DATUMTID) (figure 11).

<sup>1</sup>Lars Gillsjö Engineer at Sweco Environment AB, e-mail on the 26th of April 2017.

STATIONS ID	DATUMTID	REGNDATA
Barlastplatsen	2017-01-01 00:04:00	0.10
Barlastplatsen	2017-01-01 00:11:00	0.10
Barlastplatsen	2017-01-01 00:17:00	0.10
Barlastplatsen	2017-01-01 00:23:00	0.10
Barlastplatsen	2017-01-01 00:30:00	0.10
Barlastplatsen	2017-01-01 00:38:00	0.10
Barlastplatsen	2017-01-01 00:44:00	0.10
Barlastplatsen	2017-01-01 00:51:00	0.10
Barlastplatsen	2017-01-01 01:01:00	0.10

Figure 11. The layout of the online service REGNDATA, when using the advanced search to collect rain data from a specific rain gauge and time period

The selected rain data can be exported using the function “Export results (Exportera resultat)” and to use the data when modeling in this project, the CVS format is selected (figure 12).

Figure 12. The function Export results in the service REGNDATA, selecting the CVS format

The location of the Sweco rain gauge is illustrated in figure 10. The rain gauge is not heated and the data is sent four times per day by a sun panel powered General Packet Radio Service (GPRS), according to Gillsjö<sup>1</sup>. The department of Sustainable Waste and Water receive the rain data from Sweco once a month as a file in csv (comma-separated values) format.

<sup>1</sup>Lars Gillsjö Engineer at Sweco Environment AB, e-mail on the 26th of April 2017.

#### 4.2.2. Flow data from BRCs at HSB Living Lab

The stormwater flow out from the BRCs at HSB Living Lab are measured, each with an individual set of equipment, using a v-notch weir and a level transmitter (model TGL500) placed in the stormwater well connected to the outflow from the cell. Figure 13 shows the connection and where the weir with the level transmitter are placed.

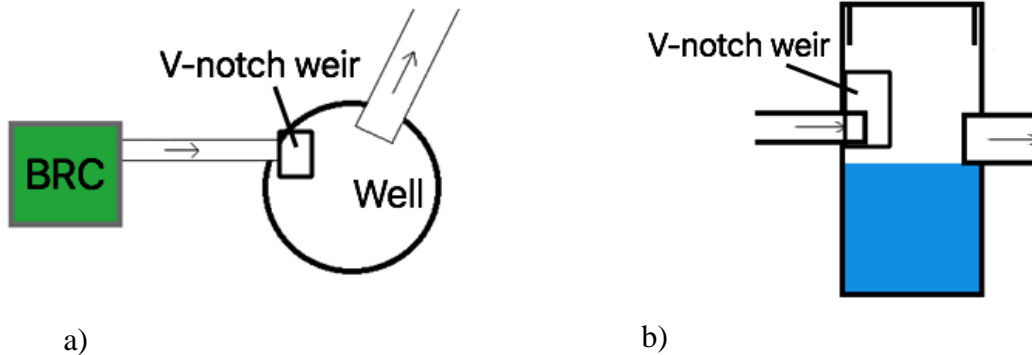


Figure 13. (a) General drawing and (b) profile drawing of the connection between the BRC and stormwater well where weir and level transmitter are installed

The weir and level transmitter can be seen installed in the well in figure 14. A specific height, of the water level in a specific weir, measured by the level transmitter, represents a water flow from the inlet of the weir and out over the v-notch which is the stormwater flow out of the BRC. What height that represent what flow depends on the design and construction of the weir and the two weirs installed at the site HSB Living Lab is designed and constructed by the department of Sustainable Waste and Water in the City of Gothenburg.



Figure 14. A v-notch weir and level transmitter installed in a stormwater well at HSB Living Lab

The data from the level transmitter is sent to a database (InfluxData) on a server belonging to the Research Institutes of Sweden (RISE). To access the data a tool named Grafana (figure 15) can be used to either look at or download the data.

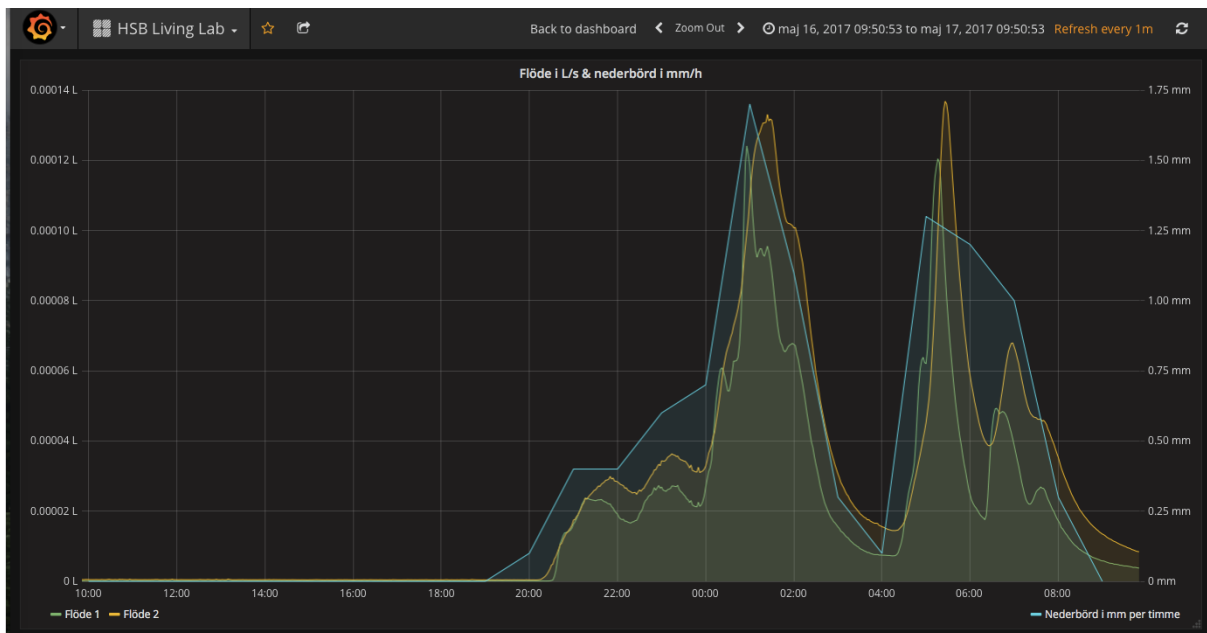


Figure 15. The flow data from the level transmitters in the stormwater wells at HSB Living Lab accessed in the tool Grafana

To download the data from the tool Grafana as a csv-file, follow the three steps in figure 16. The precipitation data available in the tool should not be used for scientific studies due to its low resolution regarding time steps. That precipitation data is not updated frequently enough to be compared to the flow measurements at HSB Living Lab.

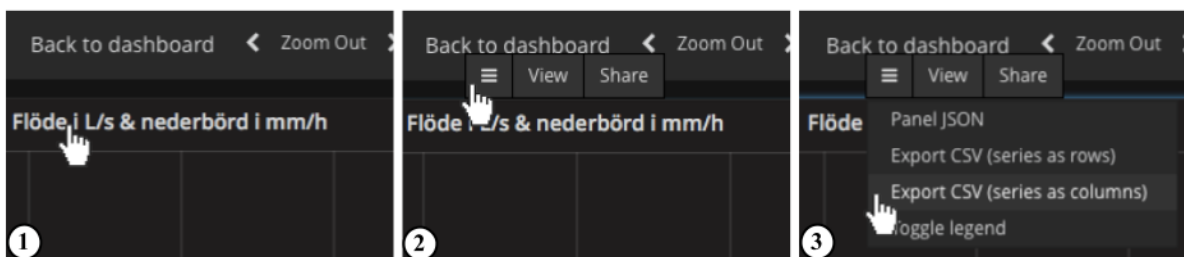


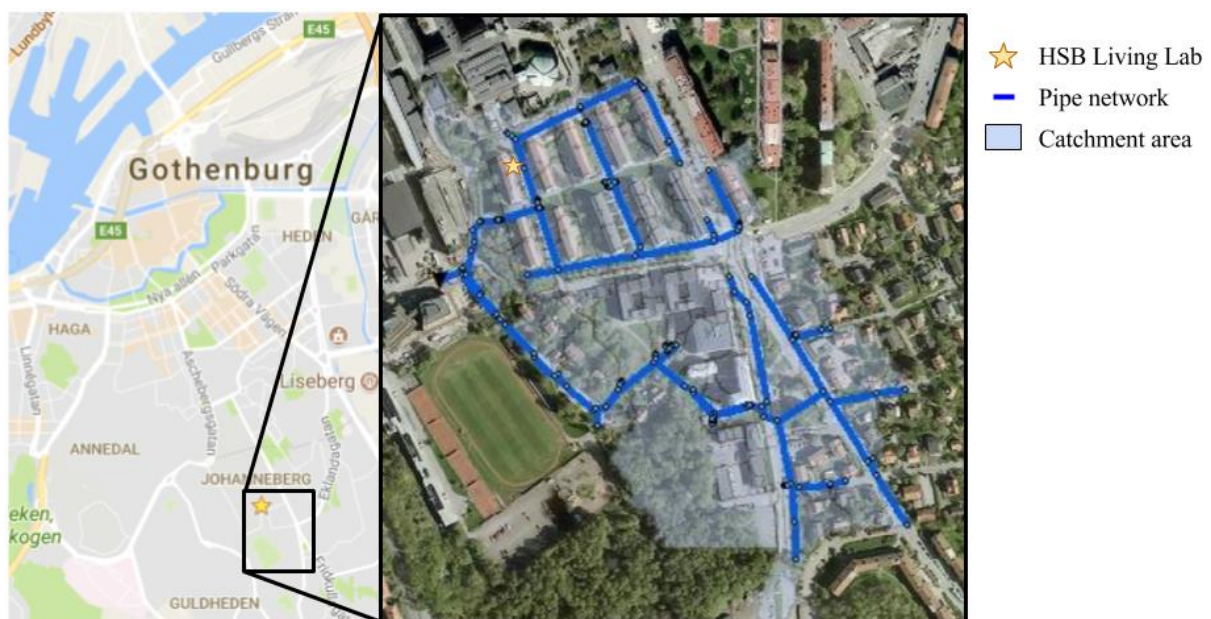
Figure 16. The procedure to download the flow data from the level transmitters in the stormwater wells at HSB Living Lab in the tool Grafana

### 4.3. Computer modeling in MIKE Urban

The collected data will be used to model the flow, up-scale and calibrate the model from a test site level to a district level. The modeling program that will be used is DHI MIKE Urban, where information on how the program can be used to fulfill the objective of the study will be gained from the user manual (DHI 2016).

The area used to model the flow from the two BRCs and to up-scale the model from a test site level to a district level is the surrounding area of HSB Living Lab (figure 17) in Gothenburg. The area is 12.7 hectare [ha].

The initial model is developed by the department of Sustainable Waste and Water in the City of Gothenburg and includes catchments, pipe network and orthophoto.

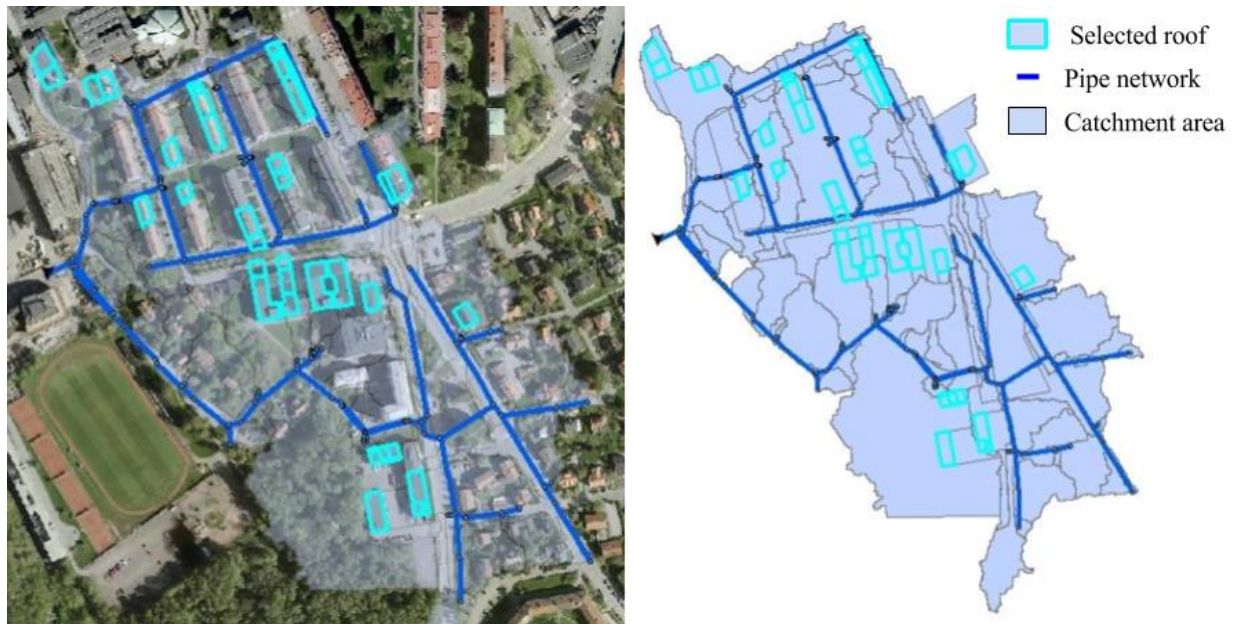


*Figure 17. The MIKE Urban-model of the surrounding area of HSB Living Lab and its location in Gothenburg. The model is developed by the department of Sustainable Waste and Water in the City of Gothenburg.*

Using the initial model, nodes, pipes and structures are added to simulate 21 bioretention systems similar to the existing system at HSB Living Lab. These additional systems are evenly spread out, where there are actual buildings, within the total catchment area.

19 roofs of buildings, present in the orthophoto and marked in figure 18, are selected to be connected respectively to 21 simulated BRCs. This is done to mimic the way that the two roofs at HSB Living Lab is connected to the two BRCs in from of that building. Any part of a roof area is part of a catchment area in the initial model developed by the department of Sustainable Waste and Water. Therefore, areas approximately in the location of the roofs are disjointed from the catchments so that the runoff from the roof areas can be diverted to run

through simulated BRCs. The 19 disjointed roof areas are given 100% imperviousness and have a combined area of 0.7 [ha].



*Figure 18.* The model area with and without orthophoto. The 19 roof areas, selected to be connected to 21 simulated BRCs, are marked in the model

Each of the 19 selected roofs are connected to one or two simulated BRCs. The method used to simulate a BRC in MIKE Urban is the Soakaway node and the connection is made so that the stormwater generated on a roof area in a runoff simulation is diverted to a catchment connection node. Thereafter, the flow is diverted through pipes to the Soakaway node and into a node in the existing combined pipe network. One of these previously described connections are presented in figure 19 (c). This same procedure is repeated for each of the 19 selected roofs in the model.

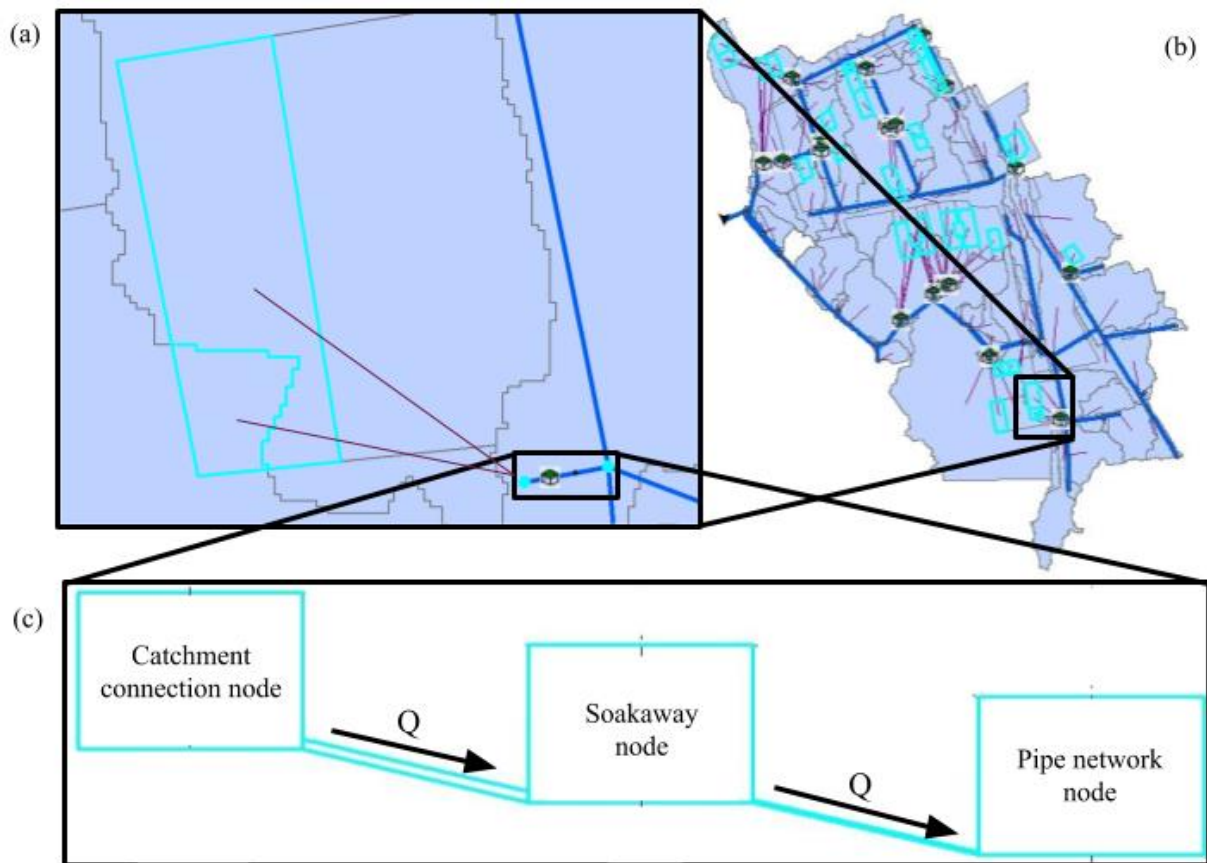


Figure 19. One created retention systems (a) out of 21 systems in the model area (b) and a profile of the retention system showing the three created nodes (c) used to simulate the type of system that is present at HSB Living Lab

When modeling BRCs in MOUSE using the node type Soakaway several different parameters can be changed. In this model, the parameters stated in table 4 are adjusted to correlate with the data of retention from the HSB Living Lab BRCs. Also, the size of the pipe out from the Soakaway node can be adjusted to calibrate the retention in the model

*Table 4.* Parameters of the Soakaway Node and Outflow Pipe Used to Make the Model Correlate with the Measurement Data from the BRCs at HSB Living Lab

<b>Parameter</b>	<b>Unit</b>	<b>Comment</b>
Range of volumes for basing geometry	[m <sup>3</sup> ]	Depending on size of connected roof area
Porosity of filling material	[-]	Depending on how many minutes of retention is wanted
Hydraulic conductivity of the walls of the node	[m/s]	Depending on how much loss of stormwater the system gives in form of leakage, evaporation and uptake from plants
Diameter of outflow pipe from the node	[m]	Depending on the retention. The diameter determines the placement of the graph along the x-axis

#### 4.3.1. Runoff simulation

The constructed model is tested with different rainfalls with different characteristics. The precipitation is added as time series collected from Sweco Environment AB and converted in MIKE Urban to a dfs0-format.

The two different rainfalls used in the runoff simulations are called “long and not intense” and “short and intense”. The total precipitation, duration and time occurrence in the day of the two rainfalls are presented in table 5.

*Table 5.* The Rainfalls Used in the Runoff Simulations

<b>Name</b>	<b>Total precipitation</b> [mm]	<b>Duration</b> [hours]	<b>Time</b> [hh:mm] - [hh:mm]
Long and not intense rainfall	13	11.5	19:50 - 07:20
Short and intense rainfall	8	3.5	04:30 - 08:00

An example of the two rainfalls, discharged from a 230 m<sup>2</sup> and 100% impervious area, used in a runoff simulation can be seen in figure 20. The plotted inflow of stormwater from a roof area is the discharge from the pipe between the catchment connection node and the Soakaway (figure 19). The simulation will be prolonged with 0 mm rain for two hours after the end of each rainfall to be able to see the retention from the BRCs in the following network simulation.

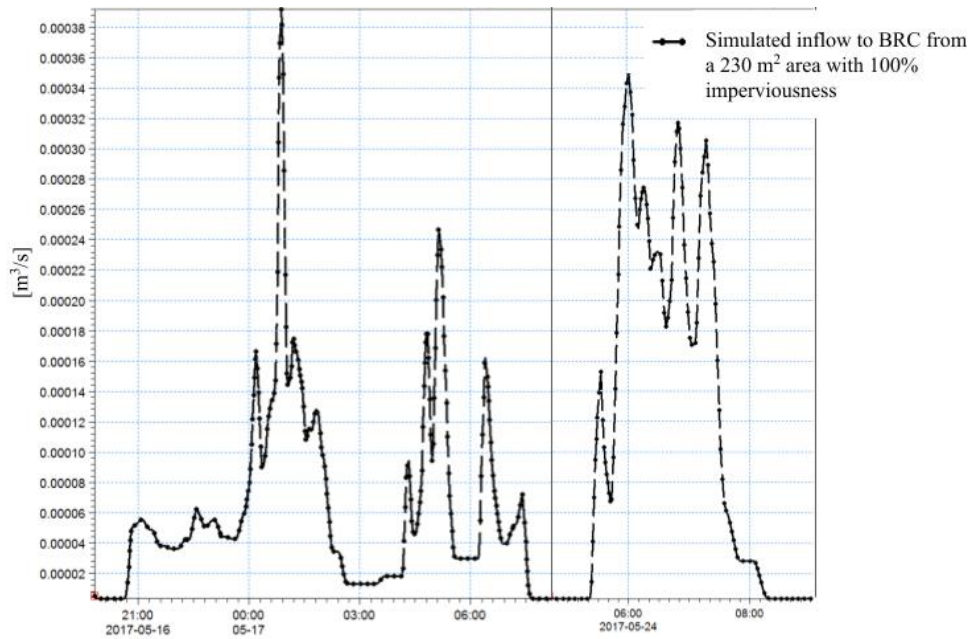


Figure 20. The two rainfalls, “long and not intense” (left) and “short and intense” (right) used in runoff simulations in the model. The flow in  $\text{m}^3/\text{s}$  (y-axis) is the discharge from a  $230 \text{ m}^2$  and 100% impervious area

The settings used during the runoff simulations in MIKE 1D are presented in appendix II.

#### 4.3.2. Network simulation

Each runoff simulation is used separately as input to a network simulation. The simulation is done on the combined sewer network and consists of stormwater as well as wastewater from the households located within the catchment area. The settings used during the network simulations in MIKE 1D are presented in appendix III.

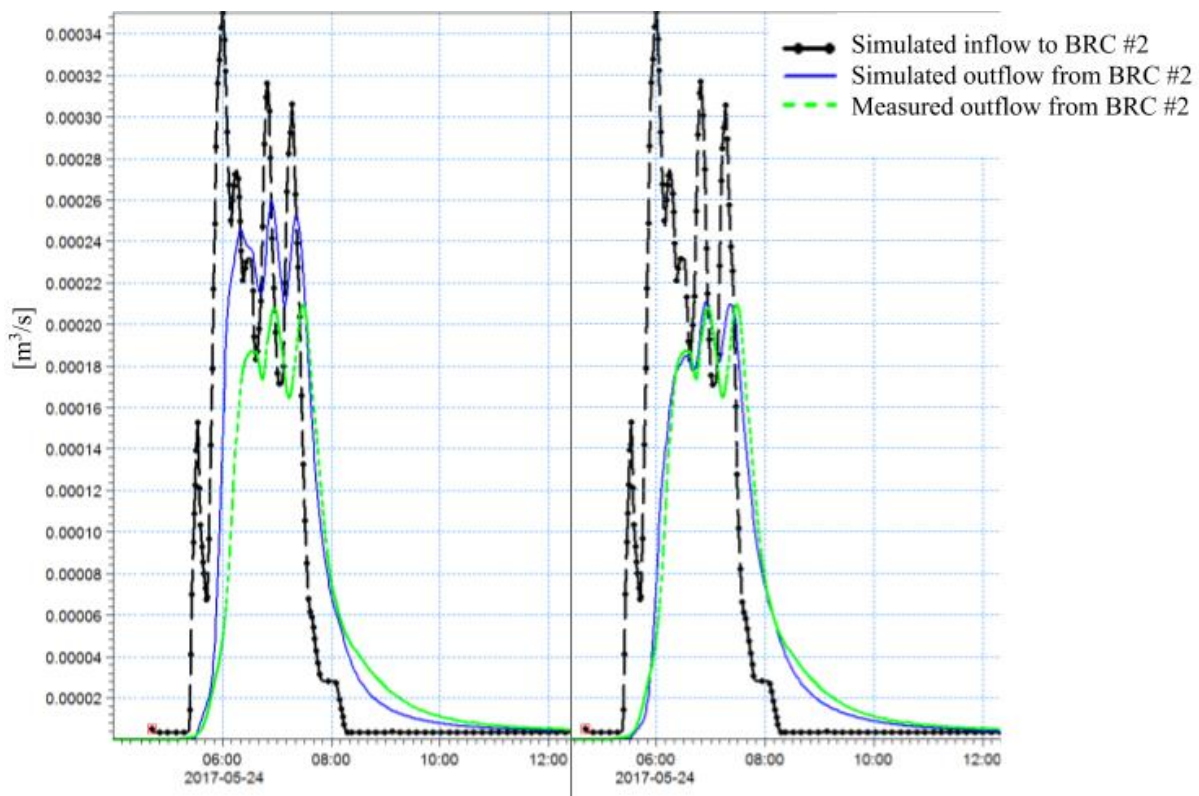
#### 4.3.3. Model calibration

The model is calibrated using the data from one of the BRCs at the site HSB Living Lab. The focus of the model calibration is to give the most retention in minutes, therefore it is selected to calibrate using the data from BRC #2. Two roof areas that are disjointed from the catchment so that the runoff from that area can be diverted through two Soakaway nodes are each of approximately  $230 \text{ m}^2$ . The values or range of values of the Soakaway node, as well as the size of the pipe after the Soakaway node, used to calibrate the model so that the simulated retention correlates to the measured retention is presented in table 6.

*Table 6.* Parameters of the Soakaway Nodes Used to Make the Model Correlate With the Measurement Data from the BRCs at HSB Living Lab

Parameter	Value	Unit
Range of volumes for basing geometry	40 - 120	[m <sup>3</sup> ]
Porosity of filling material	0.9	[-]
Infiltration method (Soakaway to ground) that represents volume loss in system	Infiltration	[-]
Hydraulic conductivity of the walls of the node	$7.5 \times 10^{-5}$	[m/s]
Diameter of outflow pipe from the node	0.05	[m]

The aim of the calibration is to make the graphs of the modeled outflow from the BRC and the measured outflow correlate. Examples of not sufficient and sufficient correlation are presented in figure 21.



*Figure 21.* Not sufficient (left graph) and sufficient (right graph) correlation in model between simulated and measured outflow from BRC #2. Also showing inflow to BRC

All other 21 Soakaway nodes in the model are adjusted to give the same retention time and stormwater volume decrease. The parameters are adjusted individually for the nodes, differing depending on the size of the connected roof area.

#### 4.3.4. Comparing with a model without retention

The developed model is adjusted to give no retention, to be able to compare the outflow from the whole area surrounding HSB Living Lab, with and without retention. The model is resaved and the Soakaway nodes are changed to manhole nodes and the pipe size after the manhole that was initially 0.05 m is set to 0.4 m. It can be seen in the graphs that there is no retention of the stormwater before compared to after the manhole node (previously Soakaway node). The same runoff simulations are the base for the network simulations as for the model with retention.

The discharge from the two points that will be compared between the model with and without retention are marked in figure 22. Point (a) is the location for the outflow of all water from the entire area and in point (b) the system has the possibility to overflow if the maximum capacity for the outflow is reached.

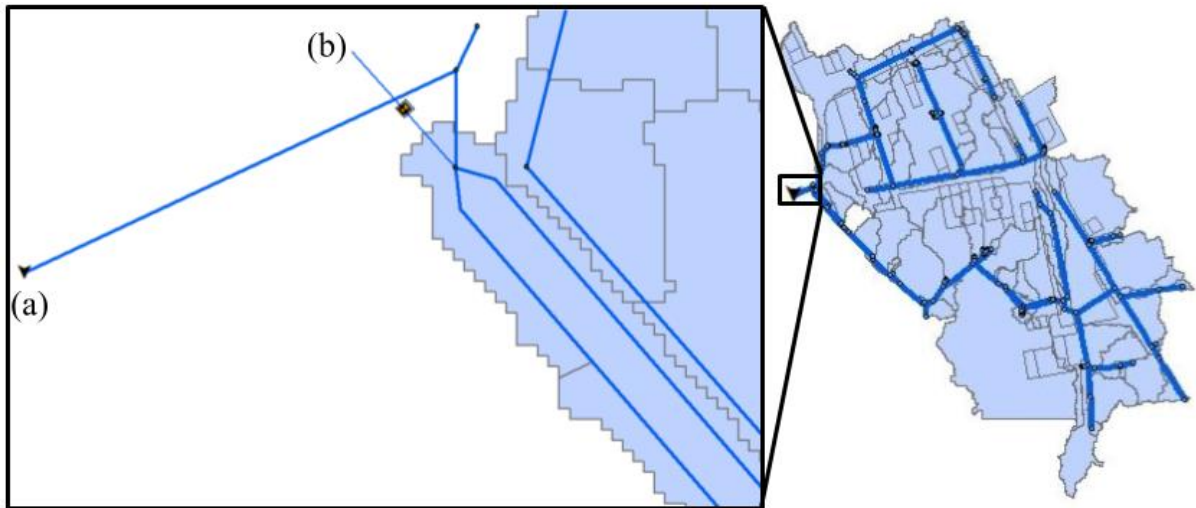
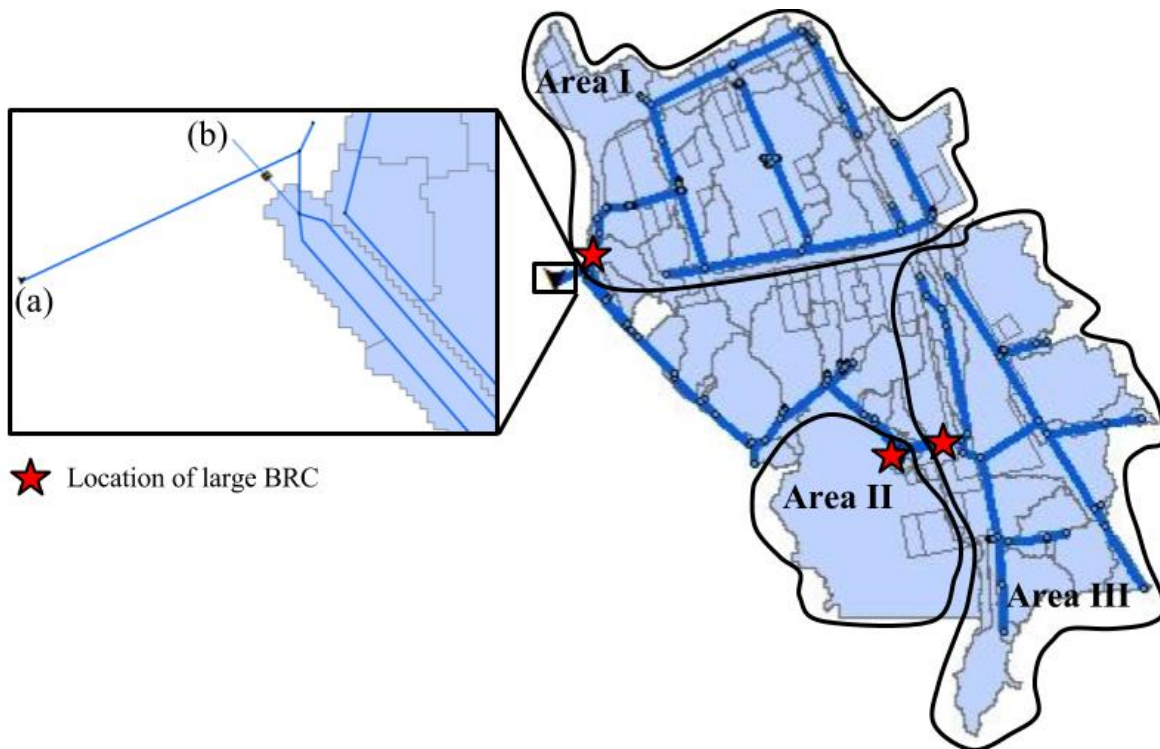


Figure 22. Showing the location of outflow (a) and overflow (b) in the model from the entire model area surrounding HSB Living Lab

#### 4.3.5 Retaining stormwater from larger areas in the model area

To get an idea of how much stormwater that needs to be retained from the model area to affect the outflow in point (a), three large BRCs, in the form of Basin nodes, retain the water from area I, II and III (figure 23). The specifics for each area are presented in table 7.



*Figure 23.* Model area with three areas where the stormwater is going to retained in larger BRCs in the form of Soakaway nodes in MIKE Urban. Showing the locations of the three large BRCs and the outflow (a) and overflow (b) in the model

The outflow from (a) with the three large BRCs can be compared with the outflow from (a) when the system has no retention cells active. The characteristics of the three Basin nodes are presented in table 7.

*Table 7.* Parameters of Area I, II and III and Corresponding Basin Nodes

Parameter	Area I	Area II	Area III	Unit
Total catchment area	4.3	1.8	3.6	[ha]
Average imperviousness of total catchment area	66	24	54	[%]
Volumes for basing geometry	200	100	200	[m <sup>3</sup> ]
Diameter of outflow pipe from Basin node	0.05	0.1	0.1	[m]

#### 4.4. Evaluating the literature study regarding legislation

To evaluate the part of the literature study regarding legislation on stormwater management in general and specifically BRCs, four topics are discussed with Lennart Lorick, a stormwater specialist at the department of Sustainable Waste and Water in the City of Gothenburg. These topics will be discussed with Lorick on a meeting and will be the base for the result in evaluating the legislation regarding stormwater management and BRCs as well as that part of the discussion.

#### 4.5. Assessing activities and quantity of maintenance

The method used to assess activities and quantity of maintenance is irregular frequent visits to the site, approximately once a week to once every other week. During these visits, the overstructure of the BRCs were photographed, the manholes were opened and the inlet and outlet were examined, every visit in the same manner. What to look for and where, was decided using the knowledge gained in the literature study regarding maintenance and table 8 presents the content of the visual inspection.

Table 8. Parts of the BRC Inspected Visually and What to Look for in Each Part

Part of BRC	Look for
Filter media	Remaining water when design drain time has elapsed after a large runoff event.
	Visible layer of fine material on the media surface.
	Macropores or large holes, ruts, or other openings.
Inlet	Obstructing objects or litter that affect the flow
Outlet	
Overstructure	
Distribution gutter	
Bypass structure	
Surrounding area	Vandalism or waste dumping
Vegetation	No plants present, dead plants, wetland plants present outside the forebay or system overgrown with limited accessibility
Weir	Sand or sediment

After eight visits to the site in two and a half months, the photographs taken were used to describe the development and change that the system had undertaken. The photographs are used in Chapter 5.3 to give a clear picture of the findings.

## 5. Result

### 5.1. Computer modeling

The results from the computer modeling in DHI MIKE Urban is divided into four parts, looking at two different rainfalls, comparing the two BRCs at HSB Living Lab and retention from three larger areas in the model area.

#### 5.1.1. Long and not intense rainfall

Results from the computer modeling in MIKE Urban show that the BRCs at HSB Living Lab retain the water from the roof of the building and slowly release it to the municipal pipe network. The retention, the measured and simulated outflow from the BRCs and the simulated inflow from the 230 m<sup>2</sup> roof, can be evaluated from figure 24. The first peak is retained according to table 9 in the two BRCs at HSB Living Lab.

*Table 9.* Peak flow retention in the two BRCs at HSB Living Lab during the “long and not intense” rainfall

	<b>Peak flow retention</b> [minutes]
<b>BRC #1</b>	5
<b>BRC #2</b>	30

When comparing the simulated stormwater volume flowing into and out from each BRC a decrease is calculated. The stormwater volume decrease approximately 33 % (BRC #1) and 14 % (BRC #2) during a “long and not intense” rainfall (table 10).

*Table 10.* Simulated volumes of inflow to and outflow from the Soakaway node during the “long and not intense” rainfall and calculated decrease in the system

	<b>Total inflow</b> [m <sup>3</sup> ]	<b>Total outflow</b> [m <sup>3</sup> ]	<b>Decrease</b> [%]
<b>BRC #1</b>	2.9	1.9	33
<b>BRC #2</b>	2.9	2.5	14

Regarding the drain times of the BRCs after the “long and not intense” rainfall, they can be evaluated from figure 24. The drain times are approximately 3 hours (BRC #1) and 4 hours (BRC #2).

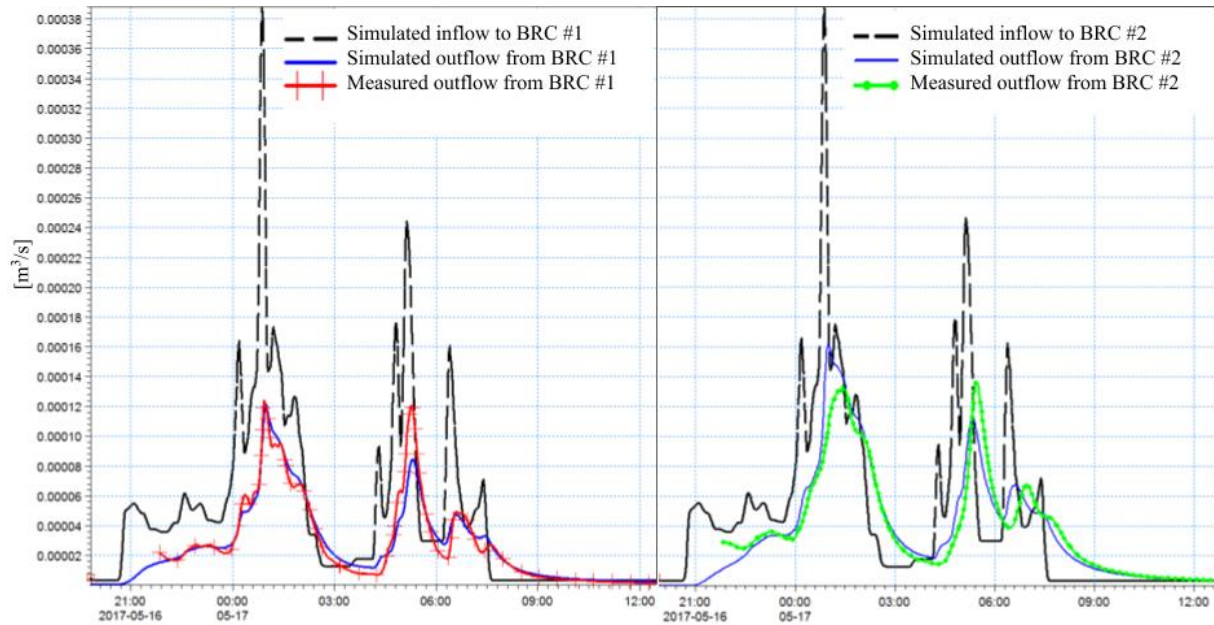


Figure 24. Results of a simulation with the “long and not intense” rainfall, showing simulated inflow from a 230 m<sup>2</sup> roof area, simulated and measured outflow from BRC #1 & BRC #2 at HSB Living Lab

The retention in the model area is the comparison of the discharge in point (a) from simulations with 21 BRCs compared to the same system without BRCs. The results from these two simulations of a “long and not intense” rainfall is presented in figure 25. The location for (a) in the area surrounding HSB Living Lab can be seen in figure 22. Figure 25 show no effect on the discharge in point (a) during a “long and not intense” rainfall when implementing 21 BRCs.

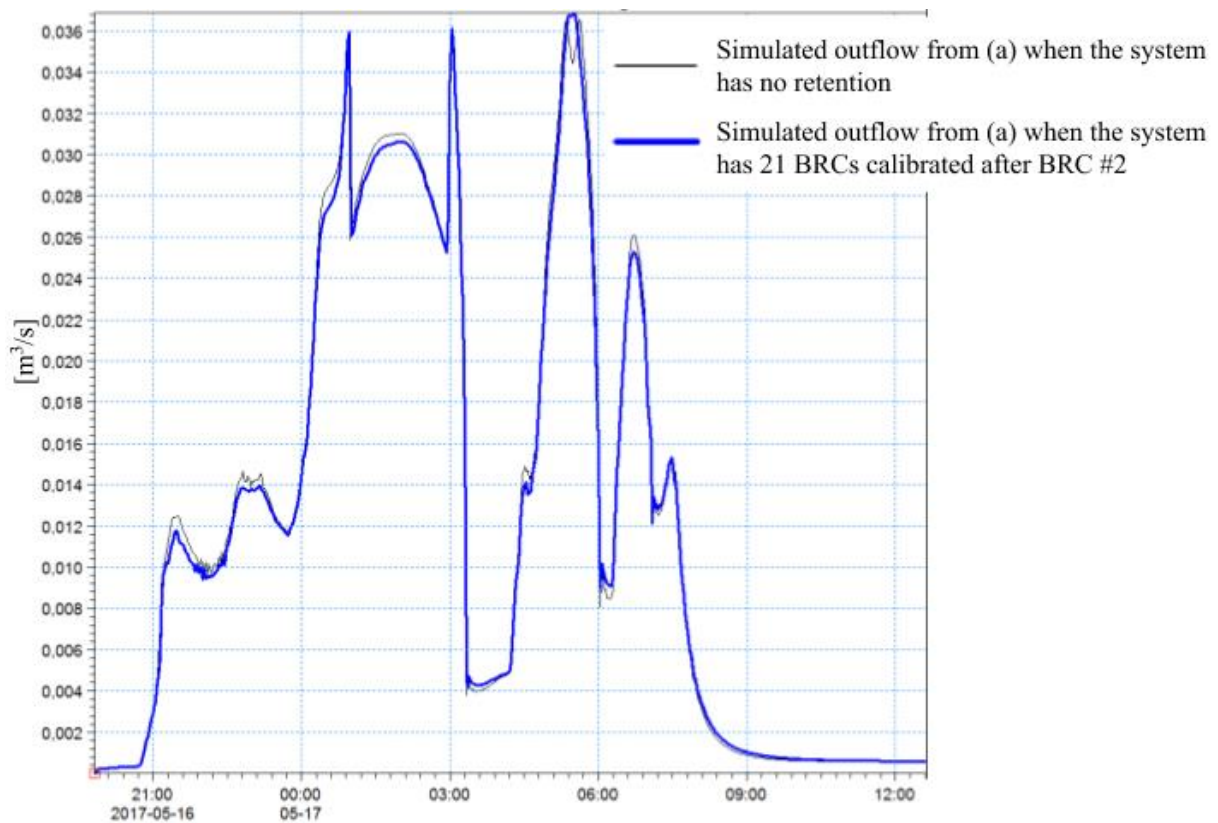


Figure 25. Results of a simulation with the “long and not intense” rainfall, showing the outflow from (a) (figure 22) of a system without retention and a system with 21 BRCs calibrated after BRC #2

Regarding the discharge in point (b), the “long and not intense” rainfall do not result in any overflow. The location for (b) in the area surrounding HSB Living Lab can be seen in figure 22.

### 5.1.2. Short and intense rainfall

Results from the computer modeling in MIKE Urban show that the BRCs at HSB Living Lab retain the water from the roof of the building and slowly release it to the municipal pipe network. The retention, the measured and simulated outflow from the BRCs and the simulated inflow from the 230 m<sup>2</sup> roof, can be evaluated from figure 26. The first peak is retained according to table 11 during the "short and intense" rainfall.

*Table 11.* Peak flow retention in the two BRCs at HSB Living Lab during the "short and intense" rainfall

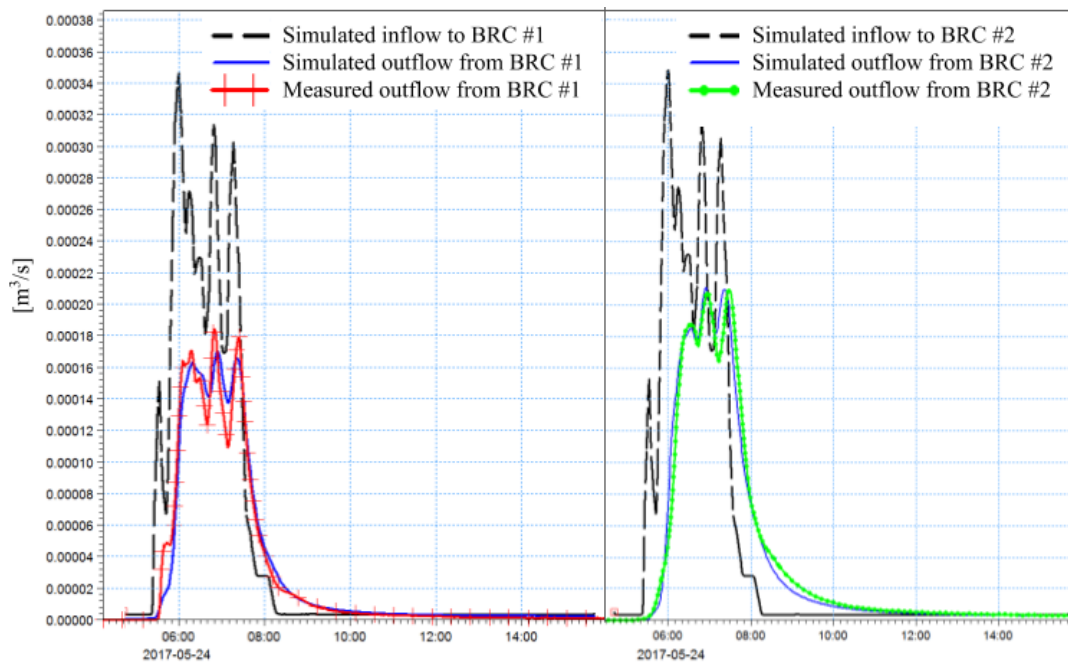
	<b>Peak flow retention</b> [minutes]
<b>BRC #1</b>	10
<b>BRC #2</b>	30

When comparing the simulated stormwater volume flowing into and out from each BRC a decrease is calculated. The stormwater volume decrease approximately 34 % (BRC #1) and 14 % (BRC #2) during a "short and intense" rainfall. The volumes of simulated inflow to and outflow from the Soakaway node is presented in table 12.

*Table 12.* Simulated volumes of inflow to and outflow from the Soakaway node during the "short and intense" rainfall and calculated volume decrease in the system

	<b>Total inflow</b> [m <sup>3</sup> ]	<b>Total outflow</b> [m <sup>3</sup> ]	<b>Decrease</b> [%]
<b>BRC #1</b>	1.837	1.21	34
<b>BRC #2</b>	1.842	1.586	14

Regarding the drain times of the BRCs after the "short and intense" rainfall, they can be evaluated from figure 26 and are approximately 3 (BRC #1) and 4 hours (BRC #2).



*Figure 26.* Results of a simulation with the “short and intense” rainfall showing simulated inflow from a 230 m<sup>2</sup> roof area, simulated and measured outflow from BRC #1 & BRC #2 at HSB Living Lab

The retention in the model area is the comparison of the discharge in point (a) from simulations with 21 BRCs compared to the same system without BRCs. The results from these two simulations of a “short and intense” rainfall is presented in figure 27. The location for (a) in the area surrounding HSB Living Lab can be seen in figure 22. Figure 27 show no effect on the discharge in point (a) during a “short and intense” rainfall when implementing 21 BRCs.

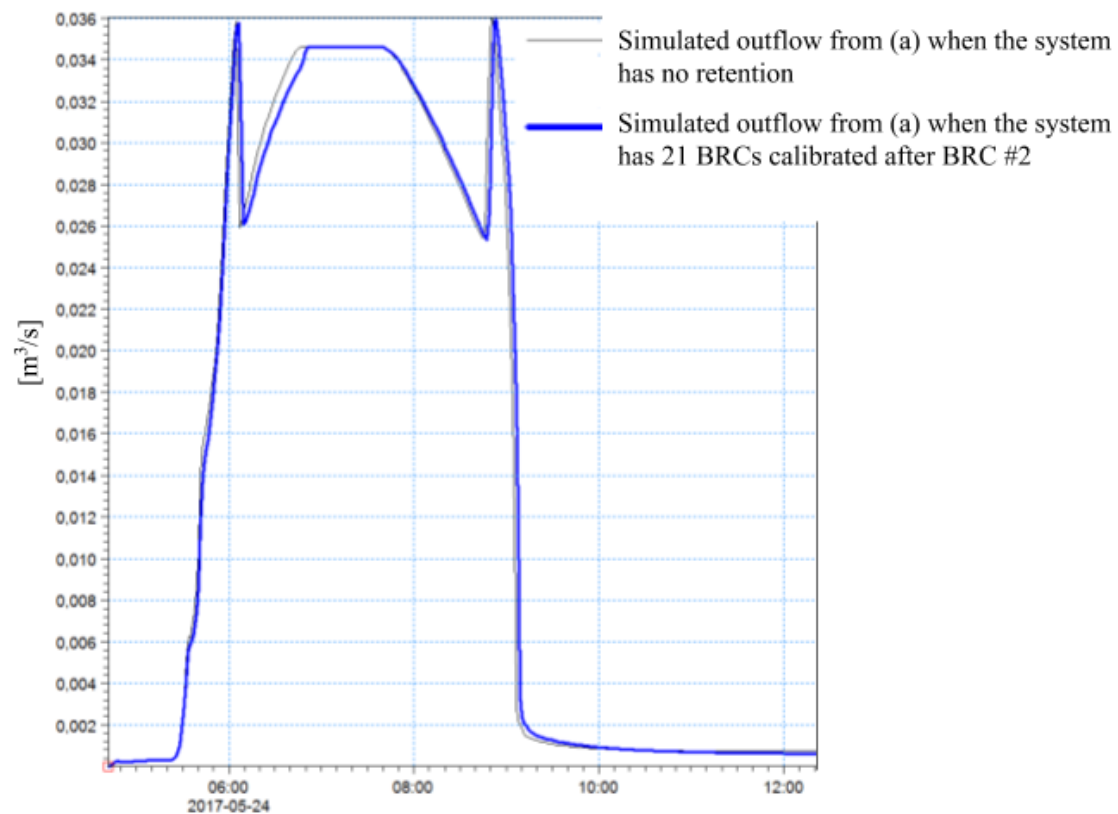


Figure 27. Results of a simulation with the “short and intense” rainfall, showing the outflow from (a) (figure 22) of a system without retention and a system with 21 BRCs calibrated after BRC #2

The "short and intense" rainfall result in overflow in point (b). To be clear this is not overflow of an individual BRC but overflow in the main pipe network close to point (a). The location for point (b) in the area surrounding HSB Living Lab can be seen in figure 22. The simulation show that the overflow volume for a system with 21 BRCs is 18.4 % less than in the same system but with no BRCs. The overflow in (b) for the two scenarios is presented in figure 28.

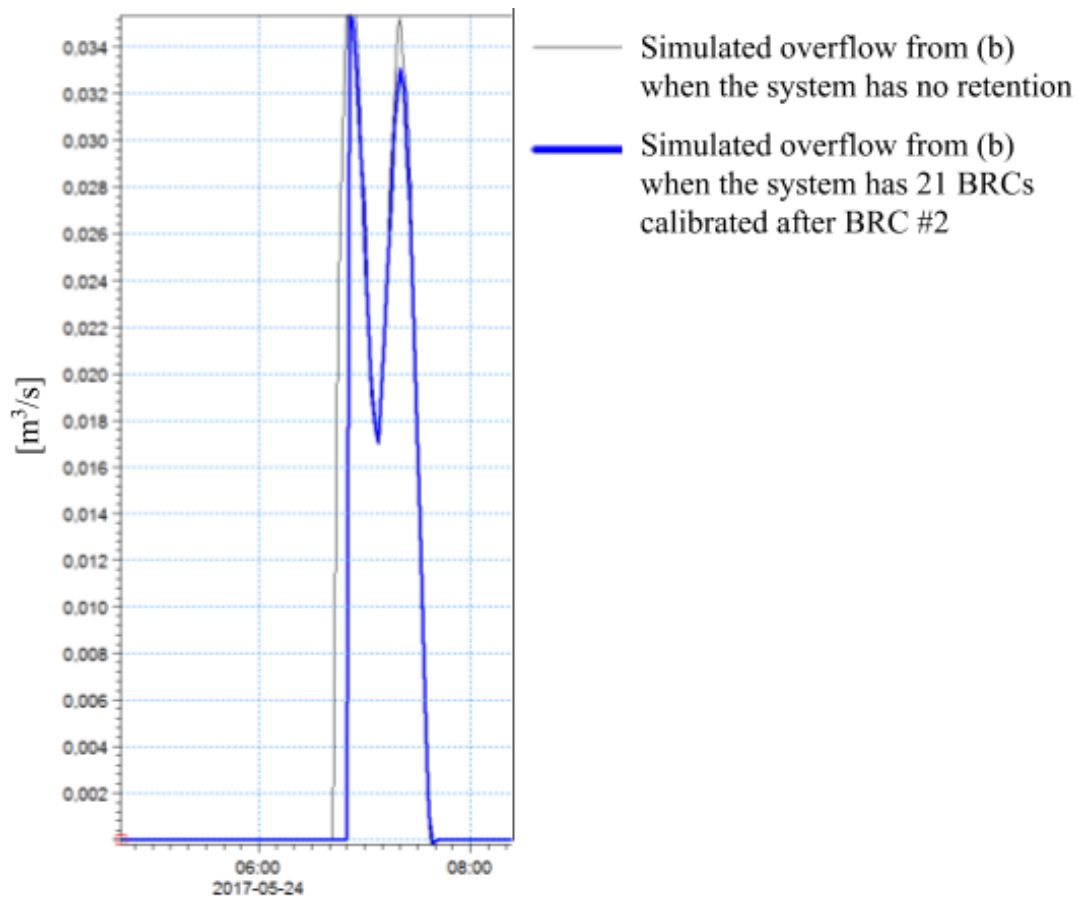


Figure 28. Results from simulations with "short and intense" rainfall, showing the overflow in (b) (figure 22) of the model without retention and the same system but with 21 BRCs calibrated after BRC #2

### 5.1.3. Differences between the two BRCs at HSB Living Lab

Looking at the measured outflow from the two BRCs at HSB Living Lab, it is clear that they are not functioning in the exact same way. In figure 29 the outflow from the BRCs are presented for two different rainfalls and the graphs show that the retention is greater in BRC #2 and that the volume loss of stormwater is greater in BRC #1. It is important to keep in mind that the inflow to the BRCs originate from two different but equally sized (230 m<sup>2</sup>) parts of the roof of the building HSB Living Lab.

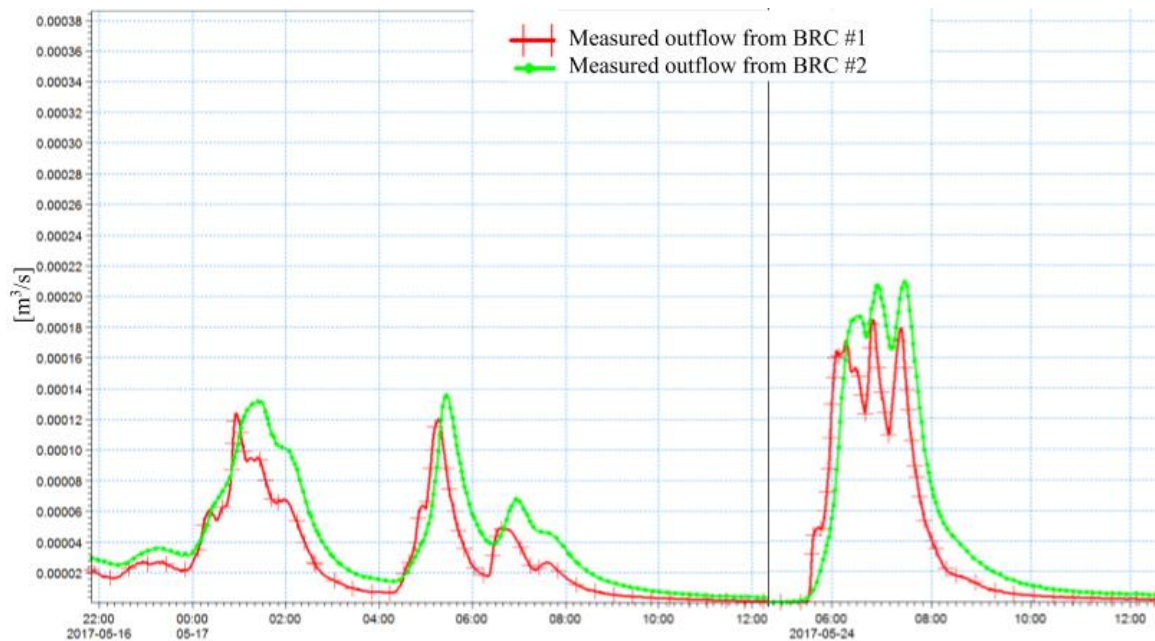


Figure 29. The measured outflow from BRC #1 and BRC #2 at HSB Living Lab, for two different rainfalls, the “long and not intense” (left) and the “short and intense” (right) rainfall

### 5.1.4 Retaining stormwater from larger areas in the model area

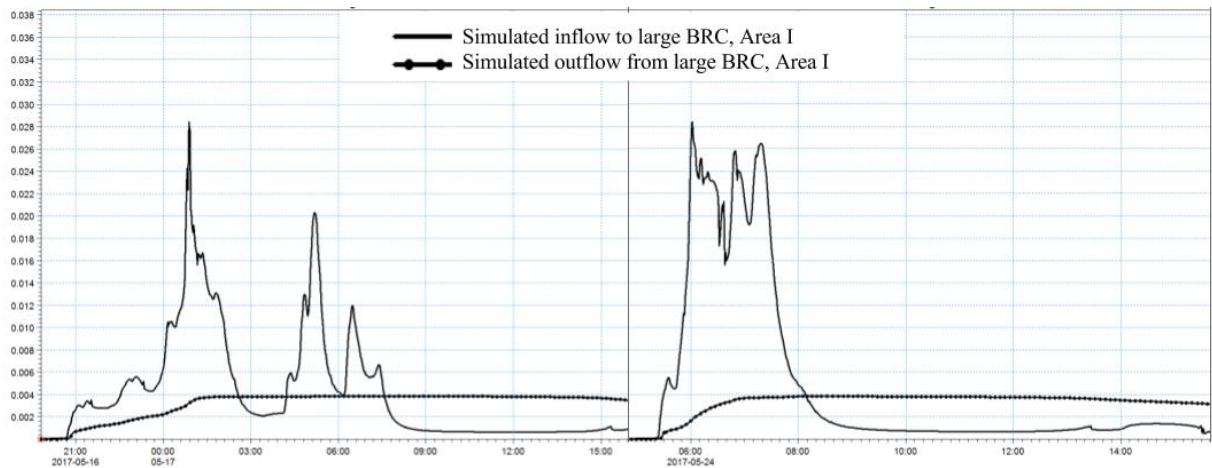
The three areas included in this part of the computer modeling is presented in figure 23. The outflow from each area and its connected retention basin as well as the outflow from point (a) in the system with and without retention is presented further on in this chapter. The location of (a) is marked in figure 22.

#### 5.1.4.1. Area I

This area is the largest one of Area I, II and III and also has the highest average imperviousness of the total catchment area of the three areas. Therefore the method used is to have the highest retention from this area which is achieved by having the smallest diameter possible on the outflow pipe from the Basin node that retain the water from Area I.

The result of the retention of the water from Area I is presented in figure 30. It shows the retention for two rainfalls, the “long and not intense” and the “short and intense” which is presented in more detail in Chapter 4.3.1.

The graphs in figure 30 show the inflow to and outflow from the Basin node that represents a BRC and the retention in the node for Area I is very high. The flow peaks are approximately retained entirely and can thereby give the highest impact on the retention in the entire system that is presented in Chapter 5.1.4.4.

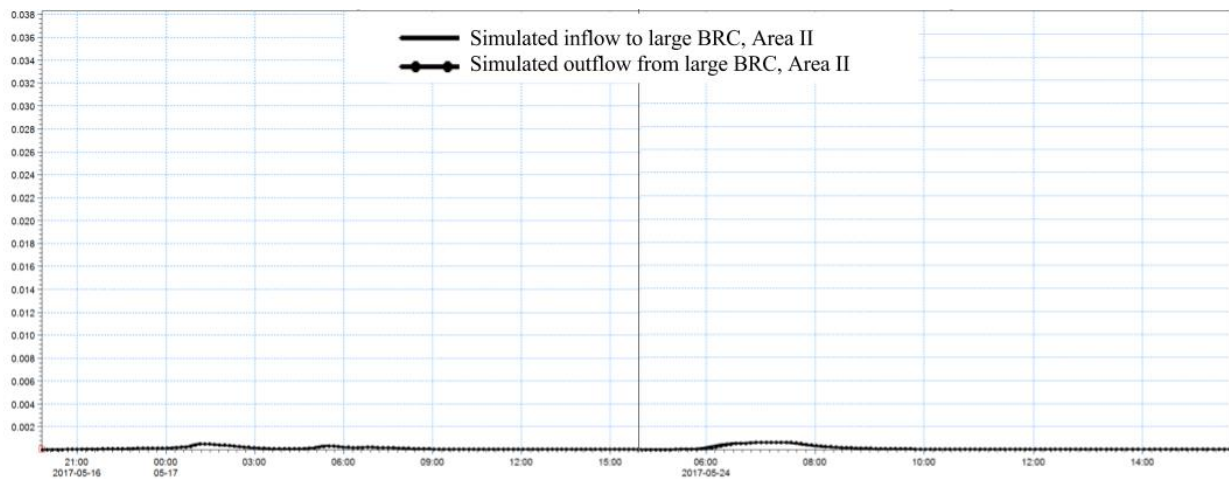


*Figure 30.* The simulated inflow to and outflow from the large BRC that retain water from Area I. The two rainfalls studied is the “long and not intense” (left) and “short and intense” (right)

#### 5.1.4.2. Area II

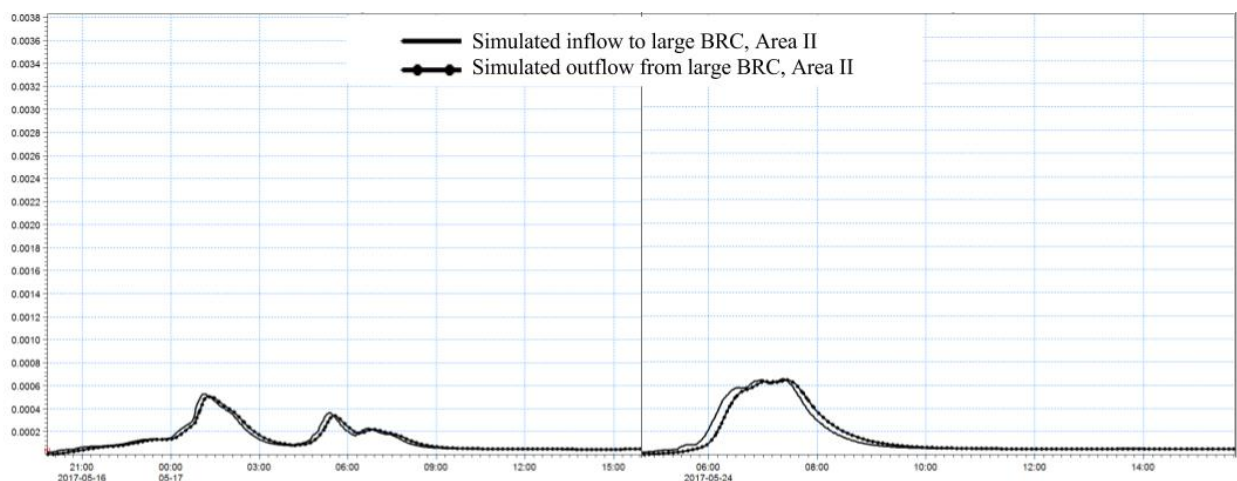
This area is the smallest one of Area I, II and III and also has the lowest average imperviousness of the total catchment area of the three areas.

The water generated in the catchment areas in Area II is insignificant compared to the water generated in Area I and the simulated inflow to and outflow from the large BRC that retain water from Area II (figure 31) is barely visible when using the same scale on the y-axis as in figure 30 and figure 33.



*Figure 31.* The simulated inflow to and outflow from the large BRC that retain water from Area II. The two rainfalls studied is the “long and not intense” (left) and “short and intense” (right). The graphs have the same scale on the y-axis as those in figure 30 and figure 33

To see the retention of the water from Area II the same graph as in figure 31 is plotted with another scale on the y-axis (figure 32). This figure show that the characteristics of the Basin node that retain the water from Area II barely have an impact on the retention.



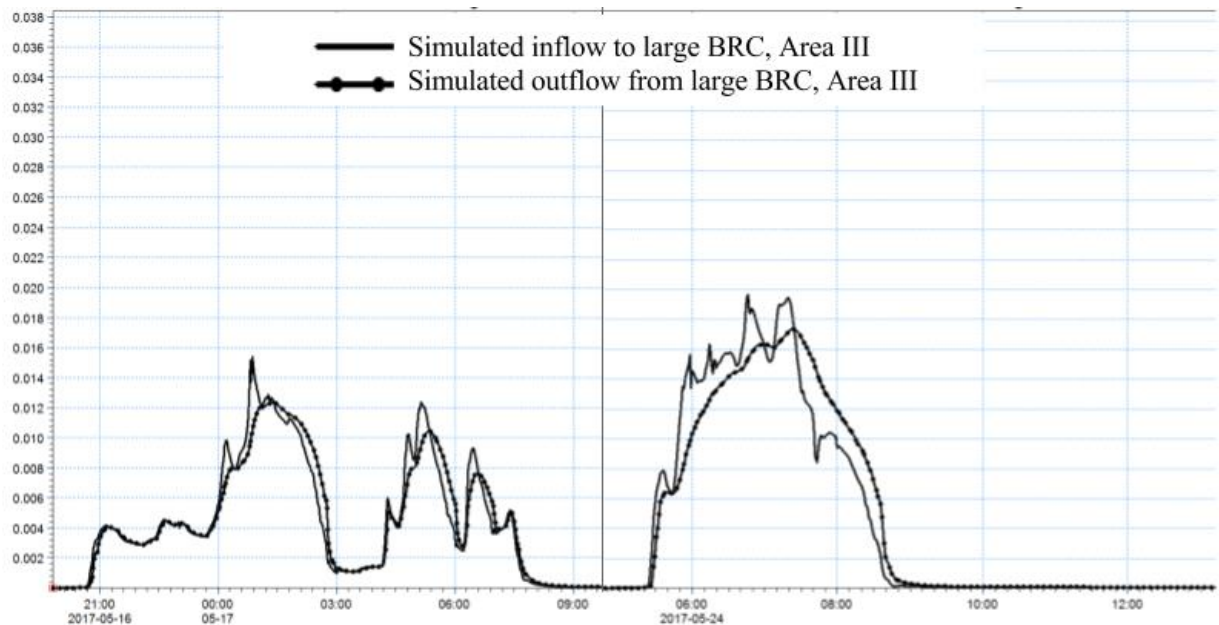
*Figure 32.* The simulated inflow to and outflow from the large BRC that retain water from Area I. The two rainfalls studied is the “long and not intense” (left) and “short and intense” (right). The graphs are plotted with another scale on the y-axis as figure 30 and figure 33

When comparing the flow of stormwater generated in Area I and Area II it is clear from figure 30 and figure 31 that Area II have an insignificant impact on the flow and retention in the entire system that is presented in Chapter 5.1.4.4.

#### 5.1.4.3. Area III

This area generates the second most water of Area I, II and III. The selected retention from this area is not the highest possible, however, it is located furthest away from point (a) and therefore have a lower impact than Area I on the flow and retention in the entire system that is presented in Chapter 5.1.4.4.

The simulated inflow to and outflow from the large BRC that retain water from Area III during two rainfalls are presented in figure 33.



*Figure 33.* The simulated inflow to and outflow from the large BRC that retain water from Area III. The two rainfalls studied are the “long and not intense” (left) and “short and intense” (right).

#### 5.1.4.4. Model area surrounding HSB Living Lab

The simulated outflow from the model area surrounding HSB Living Lab is the discharge in point (a) which location can be seen in figure 22.

The impact of the three BRCs in Area I, II and III on the discharge in (a) during two rainfalls is presented in figure 34. It shows a significant reduction in peak flow and retention of the stormwater that is desirable in regard to even out the flow to the WWTP. The largest impact on the retention in point (a) is the result of the retention of the stormwater generated in Area I.

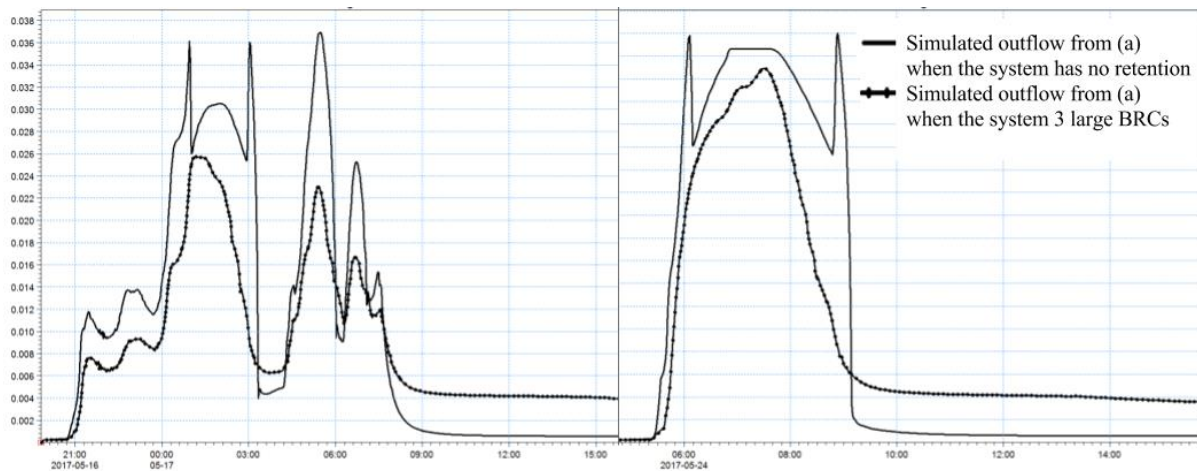


Figure 34. The simulated outflow from (a) in a system with no retention and the same system with three large BRCs connected to Area I, II and III. The two rainfalls studied is the “long and not intense” (left) and “short and intense” (right).

## 5.2. Evaluating the literature study regarding legislation on stormwater management

Presented in this chapter are the discussions, of four selected topics, with Lennart Lorick<sup>2</sup>, a stormwater specialist at the department of Sustainable Waste and Water in the City of Gothenburg.

### 5.2.1. Stormwater in regard to diversion, retention, quality and impacts on recipients

In the quest to build cities with green and blue elements, modern stormwater management has an important role to play regarding diversion, retention, quality and impacts on recipients as well as general climate and Urban management aspects. According to Lorick<sup>2</sup> the legislation that address this the most are PBA (Plan- och bygglagen), SEC (Miljöbalken) and PWSA (Lag om allmänna vattentjänster).

Lorick<sup>2</sup> points out that when discussing stormwater retention it is important to define where in the system the retention should occur, either locally or distributing the flow within the system due to hydraulic limitations downstream, possibly to also gain quality improvements or to divert a greater part of the total flow to a wastewater treatment plant.

Another important issue is the definition of “retention” and when the National Board of Housing, Building and Planning is reducing the concept to only address local infiltration it limits the definition too much, according to Lorick<sup>2</sup>. Local infiltration is not always possible and the definition of retention needs to include all measures that can reduce the speed of the runoff.

<sup>2</sup>Lennart Lorick Stormwater specialist at the Department of Sustainable Waste and Water in the City of Gothenburg, e-mail and meeting on the 9th of May 2017.

Lorick<sup>2</sup> states the need to use large parts of urban areas to retain stormwater due to the difficulty to manage the retention within the limited public areas that are available with the current legislation. This creates the need to make demands on property owners.

### **5.2.2. Ideal demands regarding stormwater retention**

To make the demand for stormwater retention effective, it is not enough to regulate the volume that needs to be retained but to state the maximum flow out from a property, diverted to the municipal pipe network. The more even flow the more beneficial regarding diversion, flooding and treatment. This is not facilitated by the PBA, SEC or PWSA and leads to a “roleplay” between different authorities, says Lorick<sup>2</sup>. Due to practical reasons it is also not possible to control this type of demands on maximum flow from every single property but it could be a possibility to make such a demand on several connected properties and industrial facilities. It is desirable to make this type of demands in the legally binding development plans regulated by the PBA and to complement the PWSA with specific demands of retention

Another alternative way to make demands is to put a price on the capacity in the connection node to the municipal pipe network, however, one problem with this is the relatively low price on stormwater management from the municipality, due to that the PWSA states only necessary taxes. Therefore it is a risk that all the property owners choose a high capacity in their connection node which makes taxation that affect behaviors a limited instrument for stormwater management, according to Lorick<sup>2</sup>.

### **5.2.3. How the department of Sustainable Waste and Water in the City of Gothenburg address the issue of stormwater retention**

The demands set by the Gothenburg municipality today is retention of 10 mm precipitation per m<sup>2</sup> impervious area when constructing new facilities and that has the advantage of being simple and understandable. Lorick<sup>2</sup> says that this type of demand additionally needs to be complemented with an aspect of time such as the time limit for releasing the retained volume of stormwater, however, that will make the demand to complicated and not manageable for the property owners.

### **5.2.4. Suggestions for how to further address stormwater retention in Swedish legislation**

A way to further address stormwater retention in Swedish legislation is to add a paragraph in the PWSA or implement it in the “Allmänna bestämmelser för brukandet av den allmänna VA-anläggningen” (ABVA). The risk when implementing it in the ABVA is that it will apply to all, and may not be compliant. Therefore to address the issue in the PWSA is a preferable option, according to Lorick<sup>2</sup>.

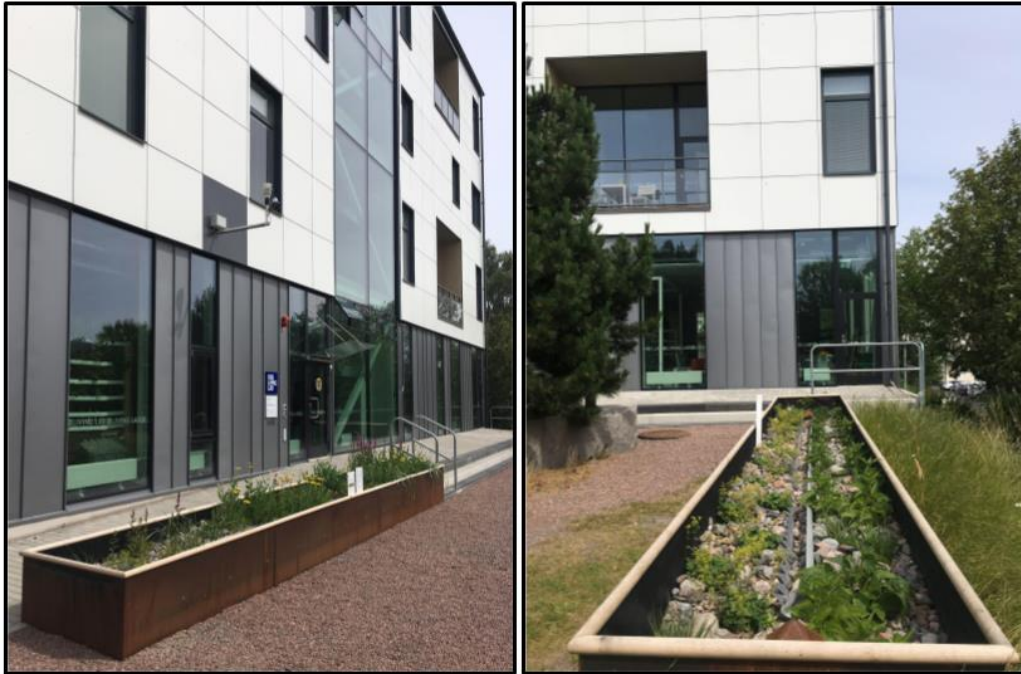
<sup>2</sup>Lennart Lorick Stormwater specialist at the Department of Sustainable Waste and Water in the City of Gothenburg, e-mail and meeting on the 9th of May 2017.

A way to maintain a functional level on the existing facilities for stormwater retention is to have mandatory inspections, possibly once every five years, says Lorick<sup>2</sup>. To rely on that a single system is functional and dimensioned to handle a desirable amount of stormwater, control is needed. This will result in a greater reliability on the whole system managing stormwater in the city.

<sup>2</sup>Lennart Lorick Stormwater specialist at the Department of Sustainable Waste and Water in the City of Gothenburg, e-mail and meeting on the 9th of May 2017.

### 5.3. Assessment of activities and quantity of maintenance

The assessment of activities and the quantity of maintenance required for the BRCs at HSB Living Lab (figure 35) is examined by visual inspection, testing, monitoring and performing principal maintenance activities. Each part of the assessment is described further on in this chapter.

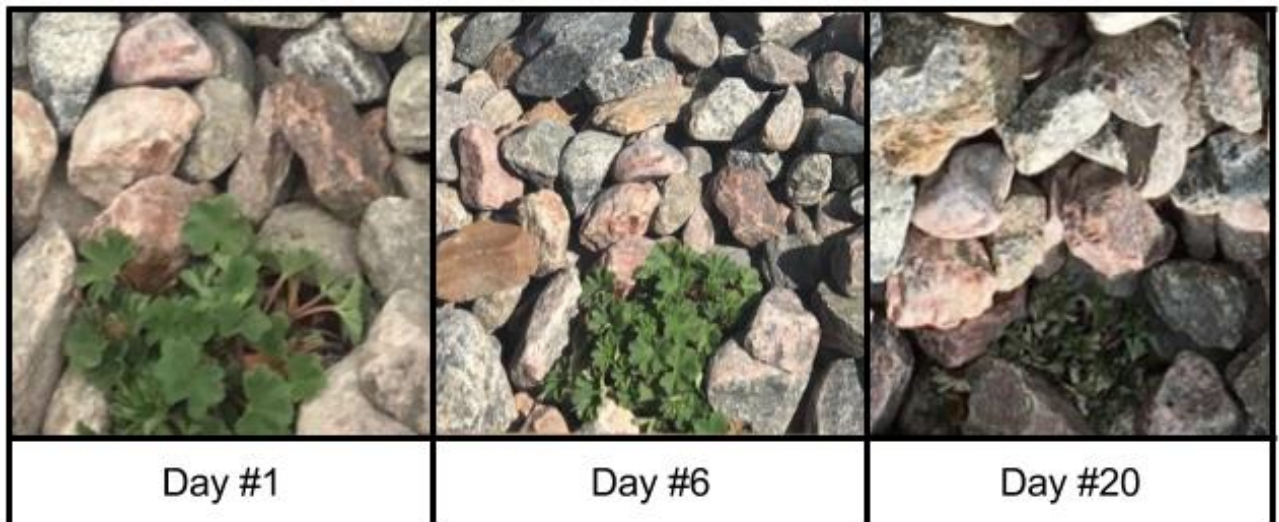


*Figure 35. The two BRCs at HSB Living Lab that is the object of the assessment of activities and quantity of maintenance*

#### 5.3.1. Visual inspection

Visual inspections have been conducted irregularly once per week to once every other week with assessment of the parts of the system listed in Chapter 3.3.1. The result of the visual inspection is in regard to the vegetation and distribution gutter, due to no observation of obstructing objects or litter that affect the flow, no changes in the filter media and no vandalism or waste dumping at the site.

Regarding the vegetation, dead plants are present in the BRC. An example of this can be seen in figure 36 where one plant is photographed on the day it was planted as well as six and 20 days thereafter.



*Figure 36.* One plant on the day of plating (day #1) and six and 20 days thereafter. The plant is dead 20 days after planting in BRC #1 at HSB Living Lab

The first time that plants can be confirmed dead is 20 days after planting. Before that it cannot certainly be said whether the plant is dead or just slow in becoming acclimatized to the new environment. The number of dead plant in each BRC, 20 to 42 days after the planting can be seen in table 13. On the 42nd day after planting, the dead plants were replaced with new ones in BRC #1 and the new plants were watered.

*Table 13.* Number of dead plant in each BRC, specific number of days after planting

Days after planting	Number of dead plants	
	BRC #1	BRC #2
20	4	0
34	7	0
42	7	0

Regarding the distribution gutter, sediment is accumulating there over time partially because after a rainfall the gutter is filled with remaining water (figure 37) that eventually evaporates.



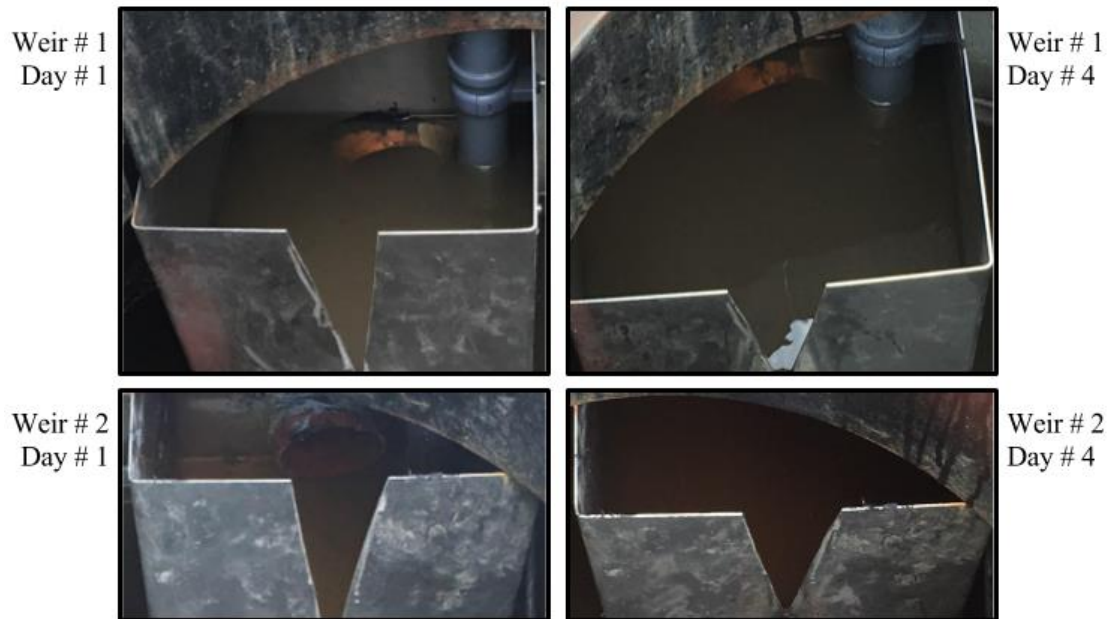
*Figure 37.* The distribution gutter in one of the BRCs at HSB Living Lab. Water is remaining in the gutter after a rainfall

Figure 38 shows a part of the gutter in BRC #1 from the day it was installed as well as 34 and 70 days thereafter. As can be seen in the picture taken 70 days after installation, the part of the gutter closest to the inlet has a substantial amount of accumulated sediment. The part of the gutter further away from the inlet do not have accumulated sediment and the gutters in both BRCs (#1 and #2) have similarly appearances of sedimentation.



*Figure 38.* The distribution gutter in BRC #1 at HSB Living Lab, from the day of installation (day #1) and 34 and 70 days thereafter

Regarding the weir in the stormwater wells where the outflow from the BRCs is measured, the water is sometimes filled with suspended sediment. Figure 39 shows the two weirs on two occasions, where the one occasion (weir #2, day #1) do not show sediment in the water.



*Figure 39.* The two weirs at HSB Living Lab, on day #1 and #4, showing sediment in the water in all pictures except the bottom left (weir #2, day #1)

### 5.3.2. Monitoring

In the project that this master's thesis is a part of, monitoring is conducted and will be for a longer period, approximately four years.

When the monitoring started, it showed that some part of the installation was leaking, which could be seen when the measured water level in the weir decreased below the level of the v-notch. The monitoring indicated that further investigations of faults in the system were needed. After the faults were corrected the monitoring could continue.

Further direct results from monitoring about the assessment of activities and the quantity of maintenance required cannot at this point be made due to that data from a longer time period is needed to assess problems such as clogging.

### 5.3.3. Principal maintenance activities

The principal maintenance activity conducted during the time of this project is vegetation upkeep (removal of dead plants and replanting) and was done 42 days after the initial planting of vegetation in the BRCs at HSB Living Lab. This vegetation upkeep was scheduled due to plants that did not survive the establishment period and could have been scheduled earlier. Around 30 days after the initial planting all the plant that did not survive the establishment period were dead and that could mark the appropriate time for the first routine maintenance activity.

Cleaning of the overstructure were conducted before the vegetation was planted in the BRCs. No obstructing objects or litter that affect the flow were present, however small pieces of litter, such as cigarette buds occurred frequently on the surface of the filter media, decreasing the positive appearance of the facility.

No other principal maintenance activities where required during the time of this thesis project.

## 6. Discussion

### 6.1. Computer modeling and data from the BRCs at HSB Living Lab

The theory referenced in the literature study indicated that several methods were possible to use when constructing a BRC in MIKE Urban using either the MOUSE or SWMM engine. In this project, it was only possible to use MOUSE, due to that the model received from the department of Sustainable Waste and Water in the City of Gothenburg is developed or run in MOUSE. Furthermore, the theory states that it is possible to simulate BRCs in two different ways, using either the LID Controls editor or the Soakaway node. In this project, it was unsuccessful to use the LID Controls editor method, due to the settings of MIKE Urban prohibiting it. Therefore, the method using Soakaway nodes were selected, limiting the simulations to the use of less parameters than the LID Controls editor method. This led to that the calibration of the Soakaway nodes to correlate with the measurements from the BRCs at HSB Living Lab could not be done very precisely. However, the calibration of each individual Soakaway node in the model do not seem to have an impact on the total outflow from the area surrounding HSB Living Lab and therefore not affect the results.

The results of the computer modeling fulfill the introductory statement of purpose by showing the effect of the BRCs when up-scaled in the larger area surrounding HSB Living Lab. Depending on what time in the day that the rainfall occurs, implementing 21 BRCs can reduce the overflow from the whole area. The parameter of time of occurrence of the rainfall affecting the overflow, is due to the varying flow of sewer water from the households in the area. In the morning hours more drinking water is used in the households, resulting in a higher flow of sewer water out from the properties. This theory is proven by running the same rainfall on other hours of the day, for example during lunch, when the drinking water consumption in the households are low, and then not resulting in any overflow out from the larger area.

The results from the simulations of retaining stormwater from larger areas in the model show that Area I contributes the most of the three areas to the total generated stormwater in the area surrounding HSB Living Lab. An explanation for this can be that it is the largest area with the most impervious surfaces of the three areas and that it is closest located to the outflow point (a). Therefore, it is preferable to implement the most measures to retain stormwater in that area if the purpose with the measures is to influence the outflow in point (a). If that is the goal, the result also indicates that no measures should be taken in Area II due to that the stormwater generated from that area are insignificant compared to the other areas. This can be explained by the relatively small catchment area with low impermeable surfaces.

The most unexpected result from the computer modeling is that the implementation of 21 BRCs in the area surrounding HSB Living Lab, do not retain the flow out from that area and only retain locally in each BRC. The 21 implemented BRCs in the model only retain 0.7 [ha] roof area out of a total 12.7 [ha] total catchment area. However, the quantity of roofs

connected in the area (19 roofs) are realistic, however, the ideal scenario is to connect 100 % of the roofs to BRCs, but that increase to 100 % is quite small and should not make a difference on the out flow from the larger area.

Another unexpected result is that the two BRCs retain the stormwater differently. The filter media and vegetation are different in the two BRCs, but the construction is intended to be the same. The differences can be described by, as mentioned, the differences in filter media and vegetation, but also by flaws in the construction, leakage out of the pipe system under the BRCs and differences in calibrations of the measurement equipment.

The rationale for the research is to use computer modeling to determine if it is economically feasible to implement several BRCs in the area. Results show that in regard of retention out of the larger area it is not feasible to construct 21 BRCs and connect them to 19 roofs with a total area of 0.7 [ha] out of 12.7 [ha] total catchment area. However, the BRCs have not been possible to test at its best potential since they are constructed to retain rainfalls with a return period up to 20 years. The only rainfalls during the testing periods of this thesis has been up to a return period of one year. Therefore, no measurement data is available to be compared to or used in the computer modeling.

## **6.2. Legislation**

There are many interesting questions regarding the current legislation in the stormwater management field, such as how well implemented the European Union's directives is in the Swedish legislation. Some very specific questions are difficult to answer without a background in legal education. Therefore should the method to interview a stormwater management specialist be complemented with comments from a lawyer working in this field, to gain knowledge on more specific questions that are not mentioned in the theory.

Without the qualification to interpret or draw conclusions from the text of the directives or laws the introductory statement of purpose is limited to cover only very wide issues, depending of the lack of references covering specific questions regarding Swedish stormwater management.

An opinion that is noticed in the discussion with employees at the department of Sustainable Waste and Water in the City of Gothenburg is that their hands are tied when setting the standards for stormwater retention. Instead, the approach is to lobby for the property owners to implement more stormwater retention, due to that they own, in total, the large areas that are not public.

A clear finding is that no-one have the final responsibility for managing the stormwater issue regarding retention and that no-one wants to take it. A conflict between different authorities or boards and their budgets occur and the problem is passed around. What authority should have the responsibility for stormwater retention and the management of its facilities?

A role model within this field, according to the stormwater specialist, is the Norwegian Three Step Strategy (Tretrinns Strategin). What could be implemented from that strategy into the Swedish legislation and guidelines?

It is also interesting to look at the extended responsibilities, given to the department of Sustainable Waste and Water in the City of Gothenburg, in regard to management of stormwater during heavy rainfall. The extended responsibilities, from the board of Sustainable Waste and Water, indicate their increasing awareness of the importance of this field which can lead to more investments and innovation regarding sustainable stormwater management.

### **6.3. Maintenance**

Many of the needs for maintenance activities stated in the literature requires longer periods of time to be evaluated and the only phase of the system's life time is the establishment period. Due to that very little of the problems stated in the literature occurred during these few month and mostly regarding the vegetation and litter before the planting.

The results showing that the establishment period for the vegetation is a crucial period for the survival of some plants were expected when looking at the literature study. The literature suggested regular watering during the establishment period and this should have been conducted to improve the chances of all plants surviving. With no employed personnel to maintain the vegetation or access to tap water, the watering were done irregularly, by different people and with no documentation. This makes it hard to state when the plants that died should have been watered, but in the end most plants survived. The reason for the plants dying could also be that those specific plants were grown up last year or that this type of plant was not suitable for this system.

The monitoring discovered problems when the system should be taken into use and the results of the monitoring in the establishment period can be used and compared with data collected in the future when the system has been in use for more and more time. This makes it possible to see changes in the running of the system.

The introductory statement of purpose to make a time plan for maintenance activities could only be done for the establishment period and is therefore not fulfilled during this short period of time, however, it is a start for the further studies of this system. Many important questions still needs to be answered, such as, how to detect when major maintenance activities needs to be conducted? This is important due to the high costs associated with these types of activities and that the system is not working as designed to when in need for major maintenance.

The expected result indicated by the literature referenced regarding the establishment period of the vegetation in the BRCs is that initial watering is needed. Regarding the method no literature on the methodology were referenced, and more effort should have been made to

gain knowledge on how to make this type of study on assessment of activities and quantity of maintenance. A more clearly thought through methodology is requested for further studies. Another desired element in this study, is the collaboration with the other people that visit the BRCs at HSB Living Lab. A summary on when the system has been watered and to what extent would have made it easier to assess the need for watering in the establishment period.

The results of plants dying in the establishment period could be explained by either the need for initial watering, those species of plants not suitable for this specific environment or that those specific plants were old plants supplied by the company responsible for planning and planting of the vegetation in BRC #1.

The sediment in the distribution gutter could be explained by activities on the roofs of HSB Living Lab and that water remained in the gutter after a rainfall and that the sediment therefore also remained. A suggestion is that small holes should be drilled in the bottom of the gutter so that the last remaining stormwater would flow out of the gutter after a rainfall. Additionally the sediment would also leave the gutter, however, the drilled holes should not be so large that the distribution gutter lose its initial function. A problem with the sediment is that large accumulations of particles either inside or under the gutter if there are drilled holes in the bottom could lead to clogging and with time leading to losing the initial function of the gutter and drilled holes and the need for maintenance activities. This type of problems are expected to occur in this type of facilities, if the stormwater entering the BRC originates from a surface exposed to large quantities of sediment, such as a parking lot or a roof with some sort of activity.

The remaining water in the weirs, were the flow measurements are made, contain suspended sediment. The inspections is random samples and it is hard to say if the water always is filled with suspended sediment. Nevertheless, the filter media in a BRCs is designed to clean the stormwater from small particles and contaminations, and by letting through sediment the BRCs are not living up to their intended design.

Before planting vegetation in the BRCs, the media surface were exposed to littering, such as cigarette butts, it was in a way treated as a waste bin. After the planting of vegetation, the littering decreased radically and it was treated more like a decoration of the public area leading to the result that the vegetation is needed in this type of system to reduce the quantity of littering. The vegetation do require maintenance, but also reduce the need for other types of maintenance activities and gives an extra dimension on the advantages of plants that were not expected before this study. The vegetation improve the design of the system in regard to decoration and appearance of the system.

The rationale to this research regarding is the need for standardised assessment of activities and quantity of maintenance for this type of facilities. The result show a need for personnel to maintain such systems and that it is not possible to construct stormwater management

systems and leave them unattended. Operation and maintenance are important parts and should be addressed from the beginning in the planning of BRCs.

Another requirement in Sweden is local studies of retention systems to assess them under local conditions. At the moment, the majority of studies of BRCs are done in the United States and a rationale to this research is to get data and results from the local conditions in Sweden.

Regarding evaluating the needed maintenance activities on the construction of the BRCs and make standard design recommendations it will not be possible due to the lack of construction drawings of the systems.

## **7. Conclusions**

### **7.1. Computer modeling**

When studying two specific rainfalls and up-scaling the results from the BRC #2 to retain stormwater from 0.7 [ha] of the 12.7 [ha] studied catchment area, there is little effect on the retention of the water from the entire studied catchment area. However, it is possible that other types of rainfall would have an effect on this retention. Simulations show that to achieve a positive retaining effect on the water flowing out from the entire model area, measures need to be prioritised to the north part of the model area (Area I).

Recommendations for future work are to investigate the local effect of BRCs on issues such as basement flooding. Another recommendation is to measure both the inflow and outflow to the BRC due to that a rain gauge located on a distance from the catchment area of the BRC cannot give accurate simulations of the inflow of stormwater to the BRC. Further on, heavier rainfalls, such as the design rainfalls for the BRCs at HSB Living lab that is a 20 year rainfall, is recommended to be studied in the computer model.

### **7.2. Legislation**

To increase the development of sustainable stormwater management systems, the current legislation needs to extend beyond the limit of stormwater management in public areas. Focus on making demands on property owners and to use larger parts of urban areas to retain stormwater is necessary.

A recommendation for future work is to discuss selected topics with personnel with legal education and that are working within the field of stormwater management, such as staff at the Swedish River Basin District Authorities.

### **7.3. Maintenance**

Regular watering and replanting of dead plants during the establishment period of the vegetation is necessary. The short study period in this thesis limits the result to the establishment period and cannot draw conclusion on any other maintenance activities further on in the life-span of the BRCs, which was an intention with this study.

A recommendation for future work is to investigate the function and construction of the distribution gutter from other BRCs to be able to manage the problem with remaining water in the gutter after a rainfall and the accumulated sediment in the gutter.

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## Appendix I – Results from determining the effective discharge coefficient of the two v-notch weirs

Table 14. Result from determining the effective discharge coefficient of v-notch weir #1

Q [l/s]	$\alpha$ [grader]	$\mu$ [-]	h [cm]
0,02	16,77	0,8	2,1
0,05		1,1	2,7
0,28		0,6	7,2
0,32		0,5	7,7
0,36		0,7	7,3
0,45		0,6	8,3
0,68		0,7	9,7
0,71		0,8	9,2
0,78		0,7	10,0
0,80		0,6	10,6
1,26		0,6	13,2
1,53		0,5	14,7
1,70		0,5	15,2
1,89		0,6	15,7
2,02		0,6	15,7
2,05		0,6	16,2
2,07		0,6	16,2
2,33		0,6	16,4
2,58		0,6	17,6
2,74		0,8	15,8
2,84		0,7	17,2
2,87		0,7	17,2
2,90		0,5	18,7
3,00		0,7	17,2
3,22		0,7	17,7
3,22		0,6	18,7

Table 15. Result from determining the effective discharge coefficient of v- notch weir #2

Q [l/s]	$\alpha$ [grader]	$\mu$ [-]	h [cm]
0,28	17,14	0,9	6,0
0,34		0,8	6,7
0,36		0,9	6,6
0,57		0,7	8,7
0,59		0,8	8,4
0,66		0,6	9,6
0,74		0,7	9,8
0,81		0,8	9,7
1,10		0,7	11,2
1,68		0,7	13,5
1,75		0,7	13,7
1,78		0,7	13,9
2,16		0,7	15,0
2,41		0,6	16,2
2,45		0,6	16,5
3,05		0,7	17,0

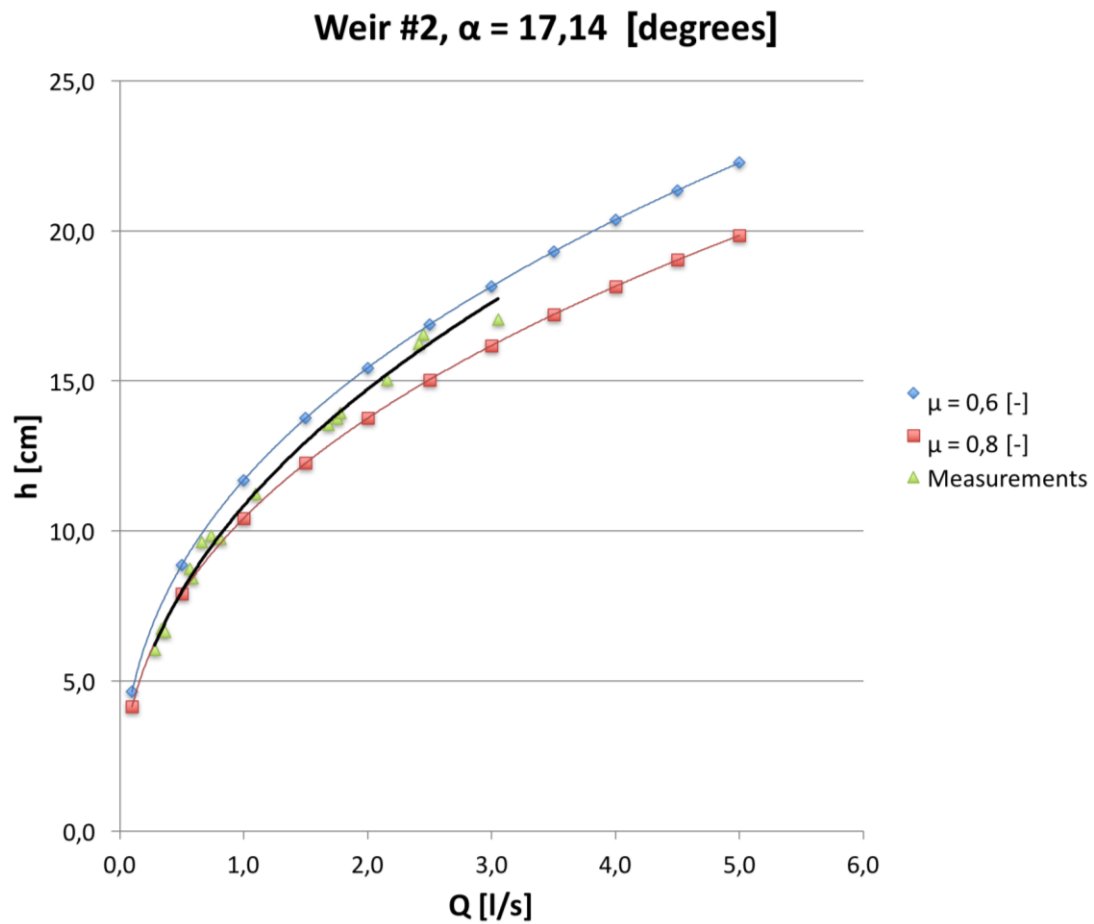


Figure 40. Graphs of flow ( $Q$ ) and height ( $h$ ) of the water surface over the v-notch for one of the two tested weirs (weir #2).

## APPENDIX II – Settings of the runoff simulations in MIKE Urban

General Runoff parameters Network parameters Network summary

Simulation: 16maj [Insert]

Scenario ID: Base [Copy]

Model type: T-A Curve (A) [Delete]

Simulation time step

Fixed time step: 60 [Advanced...]

Time step wet weather: 60 [Close]

Time step dry weather: 300

Time step FRC: 60

Time step SRC: 4,00

☐ Additional parameters

☐ Surface quality (SRQ)

☐ RDII hot start

Hot start file: [ ] [ ] [ ]

Results

☒ Overwrite

Simulation	Scenario	Include t	Description	Comput	Comput	Comput	MJL File	Content	Hot start	File	Overwrit	Overwrit
16maj	Base	False	<Null>	Network	2017-05-	2017-05-	<Null>	<Null>	<Null>	<Null>	True	True
24maj	Base	False	<Null>	Network	2017-05-	2017-05-	<Null>	<Null>	<Null>	<Null>	True	True

Figure 41. Settings of the runoff simulations in MIKE Urban used in the computer modeling

## APPENDIX III – Settings of the network simulations in MIKE Urban

General | Runoff parameters | **Network parameters** | Network summary

Simulation ID: 16maj Insert

Scenario ID: Base Copy

Delete

Advanced...

Close

Simulation mode

☒ Normal

☐ LTS

LTS job list

Generate Edit

Network load inputs

☒ Runoff

File: 16maj.res1d ...

☐ Catchment discharge

File: ...

Dynamic simulation

Model type: Dynamic Wave

Time step: Min. 10 Max. 60 Factor 1,30

Save every: Hour 0 Min. 1 Sec. 0

Hot start

☐ Hot start

File: ...

Hot start date/time: 2011-01-01 00:00:00

☐ AD Hot start

Processes

☐ RTC

☐ Additional parameters ...

Pollutants

☐ Transport (AD)

☐ Water quality ☐ ECO Lab

Integration: EULER

Sediments

☐ Transport (ST)

☐ Graded sediments

Results

☒ Standard ☐ User-specified

☒ Overwrite ☒ LTS statistics

Contents: ...

2D Results

Simulati	Scenari	Include t	Descript	Comput	Comput	Comput	Hot start	File	Overwrit	Overwrit	Model ty	Surface
16maj	Base	False	<Null>	Network	2017-05-	2017-05-	<Null>	<Null>	True	True	T-A Curv	False
24maj	Base	False	<Null>	Network	2017-05-	2017-05-	<Null>	<Null>	True	True	T-A Curv	False

Figure 42. Settings of the network simulations in MIKE Urban used in the computer modeling