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SUSTAINABLE DRAINAGE SYSTEMS ASSESSMENT AND OPTIMISATION – A CASE STUDY FOR LUSSEBÄCKEN CATCHMENT, HELSINGBORG

UTVÄRDERING OCH OPTIMERING AV HÅLLBARA DAGVATTENLÖSNINGAR – EN FALLSTUDIE I LUSSEBÄCKEN, HELSINGBORG




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Abstract

Increase of urbanisation and climate change are two factors that have been highlighted as they influence the hydrological cycle. Both result in increased in peak flow within urban watersheds, leading to downstream flood-ing and increased pollution. In order to address this, Sustainable Drainage Systems (SuDS) have been adopted to support peak flow reduction and increased baseflow. In the last decades, Helsingborg, in southern Sweden has witnessed several flooding events. With the aim to reduce flood vulnerability, this paper presents an as-sessment of multipurpose constructed structures used in the drainage systems in the Lussebäcken catchment in Helsingborg and proposes ideas for optimisation of some of these structures. Using the computer software MIKE URBAN with MOUSE engine, rainfall-runoff was simulated and flow in the network system was com-puted. Three scenarios have been simulated: before 2008 when no additional ponds were added; the current situation including newly constructed ponds and wetlands; and a proposed modification to improve the regula-tion. The events on the 15/09/1994 and the 05/07/2007 was used for the simulations, as they were selected as two extreme rainfall episodes. The results show a 22% and 33% peak flow reduction in the mainstream around the most critical area.

Keywords: Hydraulics; Hydrology; Stormwater; Runoff, Modelling; MIKE URBAN

Sammanfattning

Urbanisering och klimatförändring är två faktorer som har kommit i fokus eftersom de påverkar städers hydro-logi. Båda leder till ökade flöden och därmed risk för översvämning samt förorening genom bräddning. För att möta dessa problem används hållbara dagvattenlösningar. De senaste decennierna har Helsingborg drabbats av flera översvämningar. I den här studien undersöks multifunktionella dammar, våtmarker och tvåstegsdiken längs Lussebäcken med målet att minska översvämningsrisken. Idéer för hur man kan optimera existerande strukturer presenteras. Avrinningen i Lussebäcken simuleras med MIKE URBAN i tre olika scenarier: före 2008, som systemet såg ut vid senaste uppdatering av modellen, nuvarande situation, där ändringar efter 2008 lagts till i modellen, och ett framtida scenario med föreslagna förbättringar. Regnhändelserna 15/09/1994 och 05/07/2007 användes för simuleringar, eftersom de representerade två extrema nederbördepisoder. Resultatet visade att max-flödet kan minskas med 22 respektive 33 % i det mest känsliga området.

Introduction

Climate change, population increase and urbanisation has been recognized as critical challenges in stormwater management in Sweden (Lindh, 2013). Extreme rainfall resulting from climate change and increase of popula-tion, which has a considerable impact on urbanization, put many regions around the world to be more vulnera-ble to flooding by an increase of stormwater runoff (Huong et al., 2013). Because of this, different stormwater control measures have been taken, not the least in Sweden, to overcome the challenges (Zhang et al., 2018). Sustainable Drainage Systems (SuDS) is one of the approaches adopted for mitigating urban stormwater runoff, which has significant importance to attenuate flow, reduce runoff volume and minimise peak flow. Likewise, SuDS is a cost-effective and practical approach to prevent floods and control pollutants from surface water run-off. Several research studies conducted in different countries have described a numerous types of SuDS, design techniques and their performance, including ponds and wetlands, swales, retention basins, green roofs, trees, and permeable paving (Butler and Davies, 2011; Eckart et al., 2017; Mak et al., 2016; Woods-Ballard et al., 2007; Woods Ballard et al., 2015). These SuDS techniques have been implemented in many European countries and in the rest of the world. In Sweden, SuDS are used to control and mitigate stormwater runoff. A number of recent studies (Al-Rubaei et al., 2017; Persson, 2000; Sörensen et al., 2019) have discussed the capacity and capability of ponds and wetlands implemented in Sweden as stormwater control measures for improving runoff water quality, quantity and peak flow reduction. The results have revealed that the ponds and wetlands are good measures to reduce pollutant, but according to the authors, further studies should be carried out to find a long-term solution for optimising the flow (Al-Rubaei et al., 2017; Persson, 2000). Helsingborg is one of the mu-nicipalities that has constructed ponds, ditches and wetlands to increase the hydraulic retention time and flow detention in the upstream watercourse of Lussebäcken catchment and to decrease of peak flow and increase infil-tration. Even though these measures have been taken, the flow in the Lussebäcken River is still too high after intensive rainfall, resulting in flooding in the downstream areas.

The main objective of this study is to assess the possibilities to drain the constructed ponds and wetlands more slowly without major impact on upstream properties in the Lussebäcken catchment. The aim is to increase the baseflow and decrease the effect of heavy rainfall through the modelling of SuDS. More specifically, the aim is to reduce the maximum flow to 2 l/s/ha in the downstream part at Ramlösa ravine. To achieve the aim and objectives, the following research questions were answered; (1) How can the existing stormwater control measures be optimised in order to decrease the flow in a strategic manner and (2) where and how it is possible to regulate the flow?

Materials and Methods

Lussebäcken catchment in Helsingborg

This study was conducted in the Lussebäcken catchment, which is situated east and south-east of the Helsing-borg city. The catchment (20 km^2) begins at more rural part and extends into the urban neighbourhoods of the city, including several types of land covers (i.e. agriculture land, residential and industrial area). The upper part of the catchment mainly consists of farmland and an increasing industrial area at Ättekulla and Långeberga, that will contribute to an increase of impervious land and small urban areas of Påarp. Land use will in the future change by the conversion of rural land into industrial uses. Besides, the catchment is composed of 3 small streams, each one of the streams forms a branch that joins and forms the main Lussebäcken stream at the down-stream. The lower part of the catchment starts at Ramlösa, where the stream enters a culverted section (figure 1). It then goes through the Ramlösa Brunnspark in an open-air section at the end of where there are the second culvert starts. After this point, the creek runs mostly underground until the last part, close to the Rååån river, where it discharges its waters. The maximum elevation of the channel is 43 m. a. s. l. and the minimum alti-tude is just a few centimetres above sea level (Semadeni-Davies, et al., 2008).

The water is transported from an upstream high plain catchment with a good peak flow through the Ramlösa ravine and discharges in the Råå river, which is located near the sea. At the Downstream within the low-lying area is residential buildings, in-dustries and roads that are sensitive to flooding. The implemented stormwater control measures store runoff temporarily and attenuate flow to reduce peak runoff.

Data collection

Precipitation data (15-min resolution) were obtained from the Swedish Meteorological and Hydrologic Insti-tute's (SMHI) station Helsingborg A (1995–2018), which is located between Påarpsvägen and Österleden in the vicinity of the catchment. The data set was used to construct the hyetograph and to analyse peak flow in order to get insights about hydrological characteristics of the catchment (i.e. change of runoff). Also, water level data for Lussebäcken, provided by the Nordvästra Skånes Vatten och Avlopp (NSVA), was used to study seasonal river characteristic from July 2018 to February 2019. This data was also used to compare the simulation results. River flow measurements were used to analyse the variation of river flow. Field observation was carried out at different location of the Lussebächen catchment to gather information regarding the current situation of the study area by observing the different existing types of stormwater control measures (ponds, wetlands, two-stage ditches) and water level measurement points. The purpose was to assess the sustainable drainage system in order to find ways to reduce peak flow and increase base flow as well as to identify possible location for optimisa-tion. A digital elevation model of 2 m resolution, as well as vegetation cover data, were collected from Lantmäteriet (Swedish Surveying and Cadastral Agency) to analyse topography and the green cover of the area.

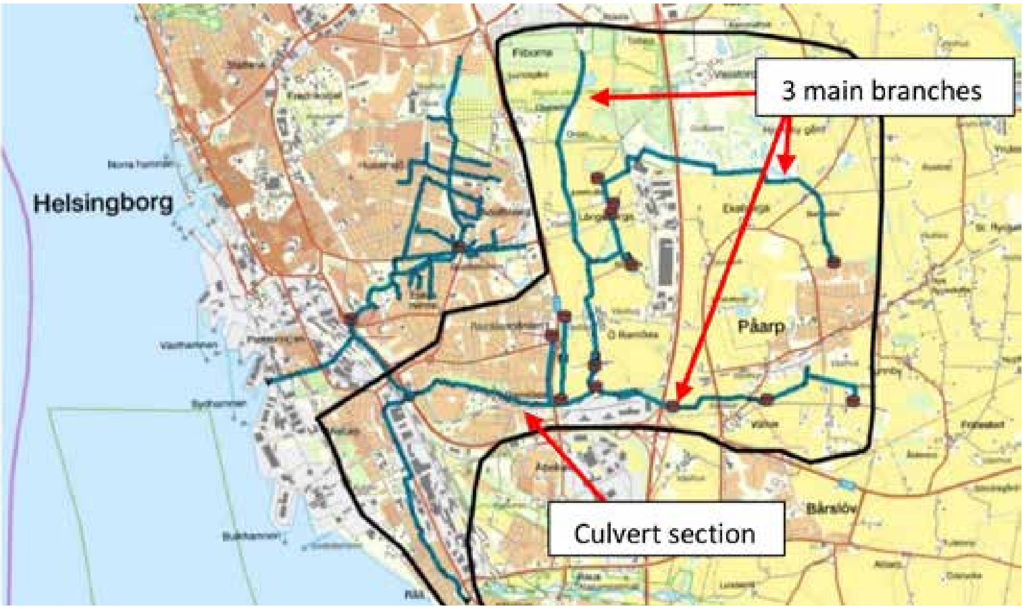

Figure 1. *Drainage system of Lussebäcken Catchment, including the three main branches and the culverted section downstream Ramlösa Ravine. Study area boundary (black line). The annual precipitation in Helsingborg is about 660 mm per year and the most extreme rainfall events typical-ly occur in July (monthly precipitation 66.1 mm) and the lowest precipitation occurs in February (25.2 mm). The weather has a profound effect on precipitation that accounts for the high inflow runoff in the Lussebäcken catchment.*

Table 1. *The highest accumulated rainfall depth for different periods (2, 6, 12 hours, 1 day and 5 days)*

Cumulative period	Time	Accumulated rainfall depth(mm)
2 h	2013-08-14 08:00	25.9
	2013-08-14 06:00	24.8
	2008-08-04 08:00	24.7
6 h	2013-08-14 06:00	55.7
	2007-07-05 12:00	37.4
	1999-08-09 12:00	31.7
12 h	2013-08-14 00:00	72.1
	2008-08-04 00:00	49.3
	2007-07-05 12:00	37.7
1 day	2008-08-04	79.7
	2013-08-14	75.4
	2007-07-05	54.4
	1994-09-15	75.8
5 days	1999-08-15	102
	2013-08-11	97.6
	2008-08-02	95.3

Rainfall data analysis and processing

The accumulated precipitation for different periods was determined to identify the extreme precipitation events for rainfall time series as shown in Table 1. The events on the 15/09/1994 and the 05/07/2007 was used for the simulations, as they were selected as two extreme rainfall events.

Modelling of sustainable drainage systems

The Lussebäcken catchment is modelled in MIKE URBAN, a 1-dimensional, hydraulic pipe flow model, to generate the incoming water flow in the pipe/drainage network, calculate water levels, flow discharges and ve-locities. In this study, the Time/Area Method was chosen to model the rainfall-runoff process, where the gener-ated runoff from connected sub-catchment areas for every time period are added to the hydrograph. While MIKE URBAN usually is used for pipe flow modelling, the model has earlier been chosen to model the Lussebäcken catchment, and in this study, the old model was verified and further developed. The ponds, wetlands and two-stage ditches in Lussebäcken catchment are included in the model. Some of these were however not included in the old model, as they were constructed later than the model. These recently constructed SuDS measures have been included and evaluated in this study. Also, new ideas for further development of the SuDS has been evalu-ated with the model.

Model verification

Model verification is essential to make sure that the modelled values have a similarity to the observed values. The modelled flow was compared with measured flow values from 23/01/2008 to 4/06/2008, provided by NSVA from Österleden and Välluv ponds (figure 2a&b). The model underestimates the discharge rate. The maximum error was noticed around 23/3/2008, with about 13.6 % lower discharge from the Välluv pond in comparison with the observed values (figure 2a) and about 32.6 % lower discharge from the Österleden pond (figure 2b). But, while the modelled values were lower than the observed values at the Österleden pond, it is noteworthy that the noisy data at the measurement point could contribute to the inaccuracy of the data. Even though there was a deviation of the modelled data, the reaction times after rainfall episodes fits well with the observations. The model from NSVA was used without any further modifications as scenario 1.

Model simulation with added construction ponds and wetlands

The development of the model was done by adding stormwater control structure such as ponds and wetlands that have been constructed in between 2008 and 2019 to the previously constructed model obtained from NSVA. These structures were built around three different locations, including Långeberga, Påarp, and Kö-pingegården (figure 3). At Långeberga, new ponds were excavated to manage the runoff water which flows into the mainstream. The purpose of those ponds and wetlands is to offset the reduction of pervious areas surround-ing the Långeberga industrial area by attenuating the additional discharge in a pond and the two ponds. The two ponds have a volume of 6,500 m^3 and 12,000 m^3 respectively.

The artificial pond (figure 4) in Påarp area (9,000 m^3) was built in the stream with a weir at

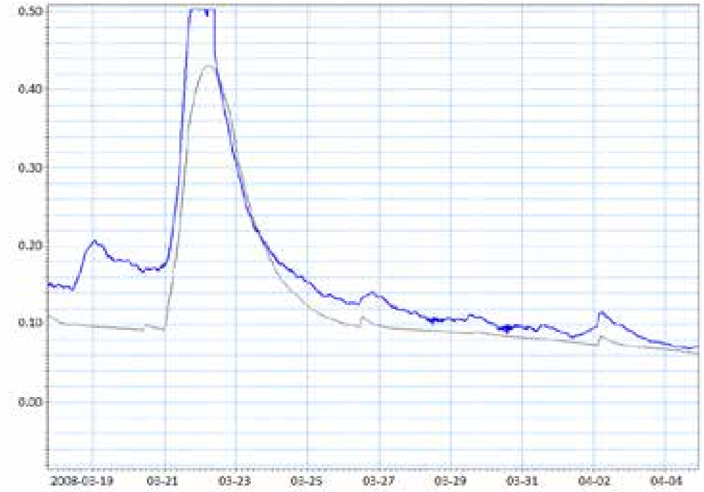

Figure 2a. *Discharge for 23-03-2008 at Välluv pond. The blue line corresponds to the observed values and the black line corresponds to the simulated values.*

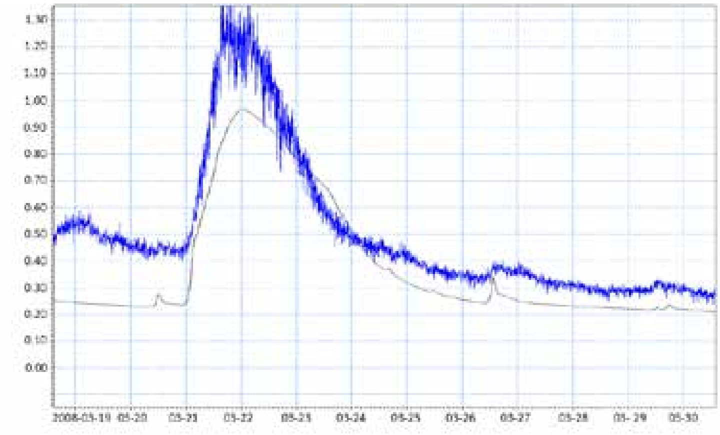

Figure 2b. *Discharge for 23/03/2008 at Österleden. The blue line corresponds to the observed values and the black line corresponds to the simulated values.*

Figure 3. *Illustration of the modelled ponds and wetlands in the three different areas, Långeberga, Påarp and Köpingegården. The darker, straight lines show the model and the lighter lines in the background show location of the watercourse according to the map. The brown cylinders represent ponds and wetlands, while the weirs are rep-resented by a black and yellow square symbol.*

the outlet to control the water flowing from the pond. The 30 cm height of that weir was measured from the bottom of a pond. In Köpingegården, the artificial wetland has been excavated with two different ponds of capacity of 1,390 m^3 for a one single pond. After adding those structures in the model, runoff was simulated with a design rainfall to determine the effects of them. In addition, some other, possible areas were modified in order to meet the project objective to optimize the existing constructed control structures to reduce the impacts of downstream flooding. At this stage, with the permission of the local authorities, the available location area which is possible to modify was identified. The Påarp pond was selected and modified with re-design of the weir to regulate the outflow and increase the residence time in a pond. Height of the weir (100 cm) from the bottom of the pond were cor-rected in the model and an orifice of 0.196 m^2 area which was placed in 20 cm above the bottom level were also added.

Results and discussion

During modelling of constructed stormwater control structures (i.e. ponds and wetlands), the three scenarios: 1) the old model without additional ponds and wetlands, 2) the developed model with additional ponds and wet-lands, and 3) the proposed optimization of the ponds, were simulated in MIKE URBAN for two extreme rainfall events (05/07/2007 and 15/09/1994). The goal of modelling with different scenarios and different rainfall episodes is to track down the impact of the most extreme rainfall fall event by comparing the existing storm-water conservation measures and after retrofitting new stormwater control structu-

Figure 4. *Photos of the artificial Påårp pond: storage area at the left and outlet of the pond with a control struc-ture at the right.*

res. By comparing the out-comes from the two first scenarios, modifications were suggested for optimisation. Hence, the third scenario was performed through adding a pond in Påarp. The height of the weir increased, and orifice added to keep water flowing even during the period of dry season.

After simulating all scenarios, three representative points have been selected in Lussebäcken to evaluate the change of discharge and water levels. Those points the Köpingegården, Långeberga and Påarp branches of Lussebäcken stream. The discharge at these three locations are presented for each scenario with two design rain-fall events. Figure 5a&b, 5c&d, and 5e&f represent the discharge for scenario 1, 2 and 3 respectively.

The output of the change of the peak flow of Köpingegården branch (i.e. at the outlet of Köpingegården pond) for each simulated scenario are shown in Table 2.

The assessment of the water level at the Köpingegården pond, in which the main branches of the stream in the catchment are merged, was deemed to be crucial for the study as this pond would be susceptible to the future flooding. The maximum water levels from scenario 1, 2 and 3 at Köpingegården pond were 26.3, 26.1, and 26.1 m

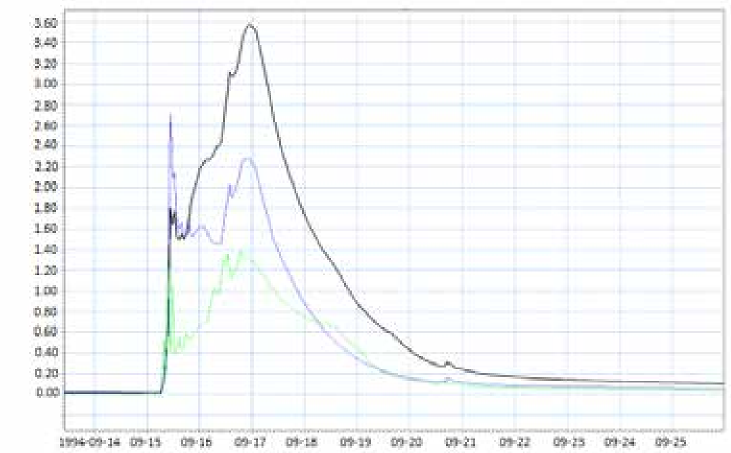

Figure 5a. *Simulated discharge for 15/09/1994 in the first scenario. The black line corresponds the outflow of the Köpingegården pond, the green line corresponds to the Långeberga incoming branch and the blue line corresponds to the discharge incoming from Påarp branch.*

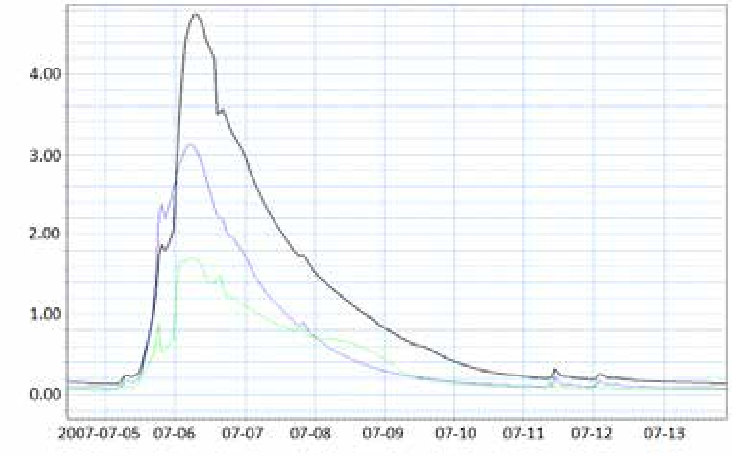

Figure 5b. *Simulated flows for 5/07/2007 in the first scenario. The black line corresponds the outflow of the Kö-pingegården pond, the green line corresponds to the Långeberga incoming branch and the blue line corresponds to the discharge incoming from Påarp branch.*

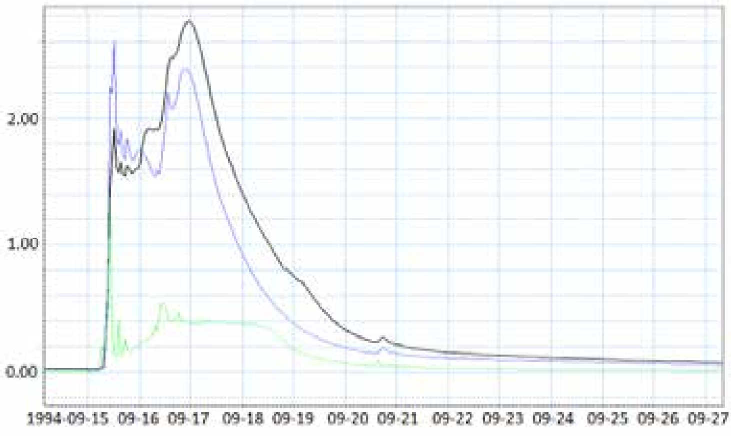

Figure 5c. *Simulated flows for 15/09/1994 in the second scenario. The black line corresponds the outflow of the Köpingegården pond, the green line corresponds to the Långeberga incoming branch and the blue line corresponds to the discharge incoming from Påarp branch.*

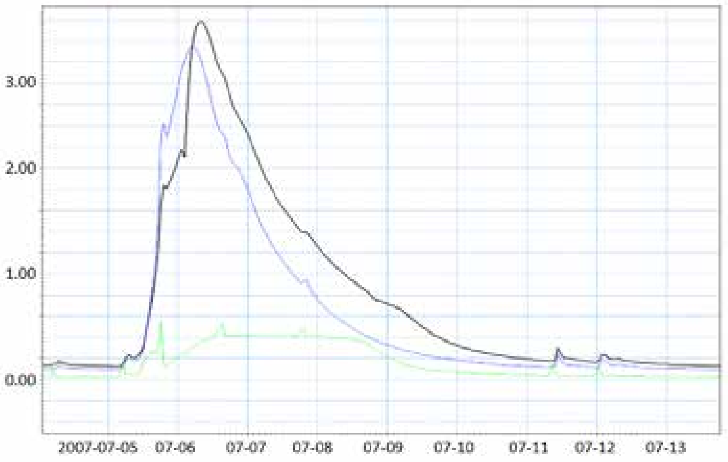

Figure 5d. *Simulated flows for 5/07/2007 in the second scenario. The black line corresponds the outflow of the Köpingegården pond, the green line corresponds to the Långeberga incoming branch and the blue line corresponds to the discharge incoming from Påarp branch.*

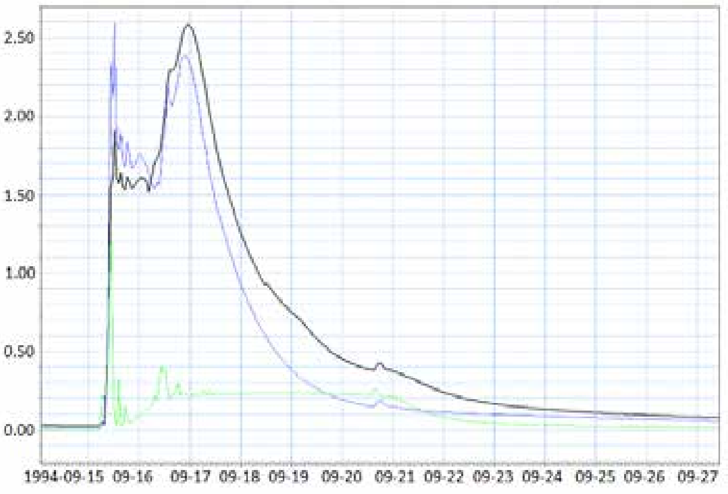

Figure 5e. *Simulated flows for 15/09/1994 in the third scenario. The black line corresponds the outflow of the Köpingegården pond, the green line corresponds to the Långeberga incoming branch and the blue line corresponds to the discharge incoming from Påarp branch.*

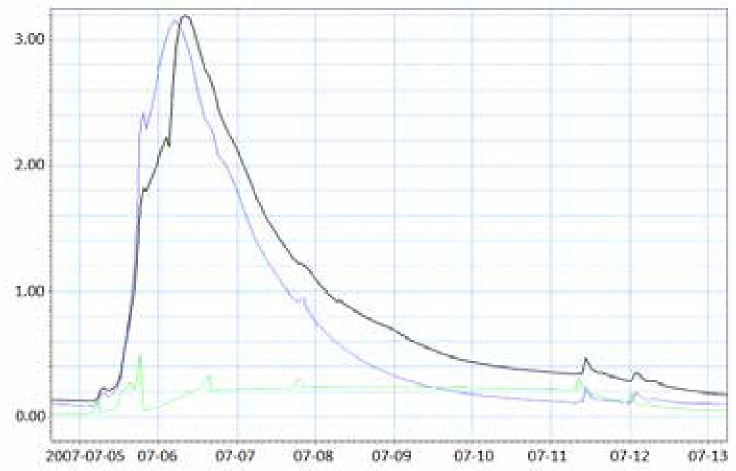

Figure 5f. *Simulated flows for 5/07/2007 in the third scenario. The black line corresponds the outflow of the Kö-pingegården pond, the green line corresponds to the Långeberga incoming branch and the blue line corresponds to the discharge incoming from Påarp branch.*

respectively for 2007 event. In this pond, the results of the first scenario indicate flooding. However, after adding and modifying the constructed stormwater control measures, no flooding occurred for 2007 event. Another critical point is the Ramlösa ravine at the downstream of the catchment. This section comprises a cul-vert where water passes through a pipe with the slope of about 13 cm/m that could consequently impact on the high-speed of the flow which contributes to cause flooding. Through adding storage capacity and source control in the upper catchment the water levels were reduced at the Ramlösa ravine.

By evaluating the three scenarios a considerable improvement of the peak flow reduction can be seen, between 4% and 6% reduction of peak flow was achieved (see difference between scenario 2 & 3 in Table 2), leading to lower water levels and a reduced risk of flooding. The main reduction of the flow is in the Påarp branch is due to the addition of the regulation pond between 2008 and 2019 (scenario 2). This has the biggest impact in the output flow of the pond into the stream. Additional improvements are produced with the modification of the output infrastructure of the Påarp pond (scenario 3), but not as pronounced as by adding storing capacity. It is also worth to mention that the absence of regulation in one of the Långeberga branch sections, which covers a big drainage area, produces a substantial impact in the downstream water levels. The water levels in the Kö-pingegården pond for extreme levels have been reduced below the overflow level provided by the NSVA. This improvement at Köpingegården would reduce the damage to the nearby fields of the area. Around a critical part of the catchment, in the Ramlösa ravine culvert where the highest slope of the network is located, there is a signifi-

Table 2. *Simulated peak flow at the Köpingegården branch (outflow of the pond). The change in peak flow is related to scenario 1.*

Scenarios	**Peak flow (m^3/s)**		**Peak flow (m^3/s)**	
	15/09/1994	Change	05/07/2007	Change
Scenario 1: **Simulation** without added ponds	3.56	-	4.76	-
Scenario 2: **Simulation** with added ponds	2.78	-22%	3.39	-29%
Scenario 3: **Simulation** with proposed modifications	2.57	-28%	3.19	-33%

cant reduction of the water depth. In scenario 1 with the rainfall episode of 05/07/2007, the water level reaches the top of the pipe according to the model. The addition of the regulation ponds in scenario 2 and scenario 3 minimizes the problem of the limited capacity of the culverted section that could lead to the excess of water running over the Ramlösa gardens and the historical buildings.

Conclusion

In this study, the performance of big scale sustainable drainage systems has been studied for the Lussebäcken catchment in the city of Helsingborg. The main aim of the project, regarding the improvement of the already existing ponds, has been accomplished by further improving their function as storm detention ponds. Based on the model results, between 4% and 6% reduction of peak flow for the simulated episodes has been achieved from the current situation. This result is considered as satisfying because the proposed modification for the increment of storing volume is relatively simple in terms of impact and its cost is lower than the cost related to building a new pond. The main improvements are produced when adding storing capacity to the network rather than regulating the existent ponds. Although both improvements should be considered as equally important to maximize the efficiency of sustainable drainage measures. The limitations of the places where it is possible to modify the structures without having an impact on the environment have been restrictive.

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