Sensitivity of urban stormwater systems to runoff from green/pervious areas in a changing climate

Sensibilité des systèmes de gestion des eaux pluviales urbaines aux apports des secteurs verts et perméables, dans un contexte de changement climatique

Karolina Berggren¹, Shahab Moghadas¹, Anna-Maria Gustafsson¹, Richard Ashley², Maria Viklander¹

1. Urban Water Research Group, Luleå University of Technology, Luleå, Sweden, karolina.berggren@ltu.se, shahab.moghadas@ltu.se, Anna-Maria.Gustafsson@ltu.se, Maria.Viklander@ltu.se

2. University of Sheffield, UK; University of Bradford, UK; UNESCO IHE Delft, Netherlands; and Luleå University of Technology, Sweden, r.ashley@sheffield.ac.uk

RÉSUMÉ

Les zones urbaines comprennent des secteurs/surfaces perméables et imperméables qui contribuent différemment au ruissellement de surface total en zone urbaine. Le ruissellement des secteurs imperméables est étudié de façon approfondie et régulière lors de l’évaluation de la capacité des systèmes d’assainissement, mais le potentiel de contribution (ou pas) des secteurs verts/perméables au ruissellement n’est pas intégralement compris. Les secteurs perméables en zone urbaine sont également considérés comme présentant un potentiel pour des mesures permettant d’adapter le système à un changement climatique à venir. Cet article étudie la contribution du secteur vert/perméable au ruissellement urbain et son impact sur les systèmes d’eaux pluviales urbains. Il se concentre sur les processus d’infiltration et d’évaporation liés aux évolutions de la pluviométrie, en utilisant une zone d’étude et une analyse de sensibilité par modèle, en modifiant successivement les paramètres physiques / du modèle à partir d’un scénario de base. Les résultats montrent que les évolutions de la capacité d’infiltration (ex. lorsque le sol est saturé ou non) ont un impact sur la zone urbaine et le système d’assainissement urbain, à la fois au niveau des volumes et des performances du système hydraulique. L’évapotranspiration (telle que décrite dans cette étude) n’est pas en elle-même un facteur significatif affectant la capacité du système d’assainissement urbain. Avec l’intérêt croissant pour la promotion et l’utilisation de secteurs verts/perméables dans l’environnement urbain, ces éléments pourraient être davantage étudiés, à la fois pour les zones construites et les secteurs naturels.

ABSTRACT

Urban areas consist of both impervious and pervious areas/surfaces which contribute in different ways to the total urban area surface runoff. The impervious area runoff has been extensively studied and routinely included when assessing the capacity of drainage systems, but the green/pervious areas’ potential to contribute (or not) to the runoff is not fully understood. The urban pervious areas are also seen as having potential for measures to adapt the system for a changing future climate. This paper reviews the green/pervious area contribution to urban runoff, and its impact on urban stormwater systems. It focuses on infiltration and evaporation processes related to changes in rainfall, using a study area and model sensitivity analysis successively changing model/physical parameters from a baseline scenario. The results show that changes in the infiltration capacity (e.g. when the soil is or is not saturated) will have an impact on the urban area and the urban drainage system, both in volume and on the hydraulic system performance. Evapotranspiration (as described in this study) is by itself not a significant factor affecting the urban drainage system capacity. With a growing interest in the promotion and use of green/pervious areas in the urban environment, these components should be studied further, both for constructed facilities and natural areas.

KEYWORDS

Climate change, Green/Pervious areas, Hydraulic capacity, Sensitivity analysis, Urban hydrology
1 INTRODUCTION

Urban areas comprise both impervious and pervious areas/surfaces which contribute in different ways to the total surface runoff. This runoff may have impacts on the urban area (e.g. flooding) due to limitations in the capacity of the urban drainage system. Impervious area runoff is the major contributor and has a characteristic of rapid runoff and high peak flows, whereas pervious areas have a slower runoff-pattern with a more attenuated peak. Therefore, when assessing the capacity of urban drainage systems much focus has previously been put on the impervious area runoff. When assessing impacts due to climate change on these systems, the 1D model approach (with focus on the pipe system dynamics) is the one mainly used in initial analyses. But with more extreme weather events, and the predictions that these will occur more frequently in the future (IPCC 2007), the dynamics of runoff above ground and flooding has become more important to take into account. For the use of urban hydraulic/hydrologic models, recommendations are currently a 1D/1D or 1D/2D model approach (e.g. Leandro et al. 2009). In these models the digitized terrain of the urban area is taken into account (1D/1D with a simplified flow route description, and 1D/2D with a more detailed surface terrain description). In these surface models the pervious areas have a more defined role, although the pervious/green area potential to contribute (or not) to the runoff is not always explicitly included. The urban pervious areas are, however, seen by many as offering opportunities for potential measures to improve the situation/adapt the system for the future (e.g. Digman et al. 2012).

Volume of water available for runoff, velocity of flow and magnitude of peak flow, will all increase with increasing amounts of imperviousness compared with an area with more green/pervious characteristics (e.g. Chow et al. 1988). Recent research on land-use changes, and thus the relative impervious vs pervious/green area contribution to runoff, has mostly been studied for large scale river catchments (e.g. Bronstert et al. 2002; Niehoff et al. 2002; Brath et al. 2006; Elfert and Bormann 2009; Deepak et al. 2010; Hamdi et al. 2010). Some of these studies also show the changes in runoff due to climate change (Bronstert et al. 2002; Hamdi et al. 2010). Gill et al. (2007) mapped urban morphology, to show the potential role of green area impact on urban runoff. The reduction of runoff volume and peak due to constructed infiltration facilities, BMPs/SuDS, and the process of retrofitting urban areas (e.g. Stovin et al. 2012), as well as how to include these facilities into runoff models (e.g. Soakaways, by Roldin et al. 2012a,b) is of much contemporary interest. Runoff from pervious areas (both natural and constructed facilities) is a complex process and much depends on the character of the soil and vegetation in combination with evapotranspiration potential. The infiltration processes are also related to the antecedent rainfall conditions, affecting the amount of water in the soil which may limit the infiltration rate and amount. Research in the urban hydrology field in the 1980ies revealed the importance of antecedent conditions in the urban area, affecting the runoff processes (Packman and Kidd 1980; Arnell 1982; Beaudoin et al. 1983; Marsalek and Watt 1983; Niemczynowicz 1984). Laboratory-scale simulations also showed the importance of antecedent conditions, as well as the connectivity, when comparing surfaces that were more or less impervious (Shuster et al. 2011).

Under climate change in the northern hemisphere, extreme rainfall events are likely to be more frequent. When considered in combination with the increasing use of pervious areas for adaptation urban area impact studies will need a more holistic view of the contributions from ALL urban surfaces. “Holistic” meaning here not only surface runoff patterns, but in relevant cases interactions with sea level and watercourses and also the water balance, including infiltration processes and evapotranspiration.

1.1 Objective

The objective of this paper is to study the green/pervious areas contribution to urban area runoff, and its’ impact on the urban stormwater system capacity. Focus will be on the infiltration and evaporation processes and the study use results from a small scale sensitivity analysis in the south of Sweden (Kalmar), changing one parameter at a time from a baseline scenario.

2 METHOD

2.1 Study area and model set up

The study area in Kalmar (SE of Sweden) has a population of about 3,000 and contributing catchment area of 2.23 km$^2$, of which 12 % is impervious (Figure 1). The urban drainage system is separate, and the stormwater model used for simulations of the area was a coupled hydraulic and surface runoff model (Mouse and MikeShe, by DHI 2008). This is a 1D/2D model set up, with a simple description of
the unsaturated zone (infiltration) and evapotranspiration processes included. The saturated zone with groundwater flow dynamics was, however, not included, and there was no infiltration allowed into pipes from groundwater. The MikeShe part of the model consists of 2.23 km², divided in 5m*5m grid cells. The model set up in Kalmar (MikeShe) has three possible equations to use for the infiltration in the unsaturated zone: Richards equation; Gravity flow; and 2 Layer Water balance (WB) flow (DHI 2008). In the Kalmar model set up the simplest 2 layer WB flow was used.

Groundwater level was set at 1m below ground and the soil defined as mostly Moraine (with a saturated hydraulic conductivity of $5 \times 10^{-6}$ m/s). Infiltration capacity was uniform (spatially) and set dry (field capacity) at the beginning of each rainfall event. Vegetation was set with a leaf area index of LAI 3, which is a mean value (LAI can vary from 0-7, depending on the growing season and vegetation type). Evapotranspiration is set at 3mm/day, which is a normal value for Kalmar in August (Eriksson 1981). This set up will be referred to as the “Baseline scenario” and is meant to represent normal conditions in the Kalmar area.

The Mouse model area consisted of 0.54 km² (mostly impervious areas) and the hydraulic model (1D) of 440 nodes (mostly gully pots and manholes) with three outlets (two in the north and one in the south of the system). The main outlet is in the north (about 70% of all the runoff). Time of concentration for the area at outlets is 50-60minutes, but considering flooding in all locations in the system (all nodes) most problems occur some 30min after rainfall starts. Measurements (rainfall and pipe flow) and associated calibration of the model were undertaken in 2004 according to standard procedures with iteration techniques (Håkan Strandner, DHI Water and Environment, personal communication, October 2010). The MikeShe part of the model was included as a supplement in 2008.

The two models interact at the gully pots (nodes in the Mouse model) where surface runoff and pervious area inputs (calculated in the MikeShe grid model) are passed on to the Mouse network model. Runoff from impervious surfaces (roads, buildings, paved areas) are estimated by the Mouse model (using a time-area approach) and input to the pipe network at the nodes. If water levels in the system exceed ground level (i.e. flooding) water from the Mouse model will be forced out from the nodes onto the surfaces (MikeShe) and can later re-enter the network at the same or another node.

Figure 1. The Mouse hydraulic model, network of pipes and nodes (to the left). ©Lantmäteriet Gävle. Medgivande I 2001/0084. Topography and larger catchment (to the right). (DHI 2008).
2.2 Sensitivity analysis

The study was a small-scale sensitivity analysis changing one parameter at a time from the Baseline scenario in the study area in Kalmar. The Baseline scenario represents normal conditions for the area, in the summer season. Parameters included in the study are: Precipitation (one higher scenario); Evapotranspiration (one lower and one higher scenario); and the Infiltration capacity using “Soil character” as an overall description (one lower and one higher scenario). Description of the scenarios, including parameters changed in each scenario are given in Table 1.

<table>
<thead>
<tr>
<th>Run</th>
<th>Scenario</th>
<th>P&lt;sub&gt;RP&lt;/sub&gt; [years]</th>
<th>P&lt;sub&gt;max&lt;/sub&gt; [mm/h]</th>
<th>ET [mm/d]</th>
<th>Soil character</th>
<th>K&lt;sub&gt;s&lt;/sub&gt; [m/s]</th>
<th>θ&lt;sub&gt;s&lt;/sub&gt; [-]</th>
<th>θ&lt;sub&gt;fc&lt;/sub&gt; [-]</th>
<th>θ&lt;sub&gt;w&lt;/sub&gt; [-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Baseline (BL)</td>
<td>10</td>
<td>69.6</td>
<td>3</td>
<td>“moraine”</td>
<td>5*10&lt;sup&gt;-6&lt;/sup&gt;</td>
<td>0.4</td>
<td>0.3</td>
<td>0.05</td>
</tr>
<tr>
<td>2</td>
<td>Pres High (PH)</td>
<td>10+20%</td>
<td>83.6</td>
<td>3</td>
<td>“moraine”</td>
<td>5*10&lt;sup&gt;-6&lt;/sup&gt;</td>
<td>0.4</td>
<td>0.3</td>
<td>0.05</td>
</tr>
<tr>
<td>3</td>
<td>Evapo Low (EL)</td>
<td>10</td>
<td>69.6</td>
<td>0</td>
<td>“moraine”</td>
<td>5*10&lt;sup&gt;-6&lt;/sup&gt;</td>
<td>0.4</td>
<td>0.3</td>
<td>0.05</td>
</tr>
<tr>
<td>4</td>
<td>Evapo High (EH)</td>
<td>10</td>
<td>69.6</td>
<td>6</td>
<td>“moraine”</td>
<td>5*10&lt;sup&gt;-6&lt;/sup&gt;</td>
<td>0.4</td>
<td>0.3</td>
<td>0.05</td>
</tr>
<tr>
<td>5</td>
<td>Infiltr High (IH)</td>
<td>10</td>
<td>69.6</td>
<td>3</td>
<td>“sand”</td>
<td>5*10&lt;sup&gt;-4&lt;/sup&gt;</td>
<td>0.4</td>
<td>0.1</td>
<td>0.02</td>
</tr>
<tr>
<td>6</td>
<td>Infiltr Low (IL)</td>
<td>10</td>
<td>69.6</td>
<td>3</td>
<td>“bedrock”</td>
<td>1*10&lt;sup&gt;-10&lt;/sup&gt;</td>
<td>0.3</td>
<td>0.1</td>
<td>0.05</td>
</tr>
</tbody>
</table>

P<sub>RP</sub> – Rainfall return period, P<sub>max</sub> – Rainfall Max intensity, ET – Evapotranspiration, θ<sub>s</sub> – water content at saturation, θ<sub>fc</sub> – water content at field capacity, θ<sub>w</sub> – water content at wilting point, K<sub>s</sub> – Saturated hydraulic conductivity

2.2.1 Rainfall

Rainfall of a Chicago design storm (CDS, by Kiefer and Chu 1957) type with a skewness factor of 0.37 (Figure 2) was used in this study, as it is the design rainfall used mostly in Sweden. The temporal resolution was 5min, and the duration 60min. The simulations where, however, run for three extra hours after the rain ceased to include the slower processes (runoff from green/pervious areas, infiltration, evapotranspiration). In the Baseline scenario (normal conditions) rainfall of a 10 year return period was used, so as to address the current design standards of urban drainage systems (SWWA 2004). This rainfall had a maximum intensity 69.6mm/h, using rainfall statistics for Kalmar presented in national guidelines (SWWA 2004).

Figure 2. The CDS rainfall profile, with duration of 60min, skewness 0.37 and return period 10 years.

The rainfall parameter is included in this study to have a “climate change” reference to compare response with changes in the other parameters. Addressing changes in rainfall intensity is the most common way of taking climate change into account when performing impact assessment of urban drainage systems (e.g. Berggren et al. 2012). In current guidelines for Sweden the recommendation to take climate change into account in practice is to add a factor to design rainfall; in the Kalmar case about 20% (SWWA 2011). The new rainfall of 20% added to the original 10 year return period rainfall has a maximum intensity of 83.6 mm/h (scenario 2: PH in Table 1).

2.2.2 Evapotranspiration

Evapotranspiration and (soil) infiltration processes are interconnected, as the evapotranspiration depends on the availability of water in the soil (soil moisture) which is related to the soil characteristics and the infiltration process. The potential evapotranspiration is the maximum evapotranspiration that
can occur if there is no limitation in the availability of water to evaporate. Evapotranspiration for the Baseline scenario was set at 3mm/day, which is a normal value for Kalmar in August (Eriksson 1981). For the scenarios, evapotranspiration was changed to a minimum of 0mm/day (scenario 3: EL) and to a maximum of 6mm/day (scenario 4: EH). The minimum evapotranspiration scenario represents an autumn condition with lower temperatures. For current conditions, evapotranspiration is normally at a minimum in July (4.1mm/d) based on calculations for the period 1961-1978 (Eriksson 1981), but with climate change and increasing future temperature, it is likely that this parameter can be even greater in the future.

2.2.3 Infiltration

For green and pervious areas in the urban area, the infiltration processes influence how much of the precipitation will become surface runoff (and further on enter the sewer systems), and how much of the water will infiltrate into groundwater. The infiltration capacity is dependent on the soil moisture, and the soil characteristics (ability to “keep” the water). The soil character is described as Moraine in the Baseline scenario, having a saturated hydraulic conductivity ($K_s$) of $5 \times 10^{-6}$ m/s. For the two studied scenarios the saturated hydraulic conductivity was set as “Sand” with $5 \times 10^{-4}$ m/s (scenario 5: IH, corresponding to sandy soil, where most of the water infiltrates) and to “Bedrock” with $1 \times 10^{-10}$ m/s (scenario 6: IL, corresponding to bedrock-like characteristics with little to no infiltration normally). The soil is also described by parameters for water content at saturation ($\theta_s$), at field capacity ($\theta_{fc}$) and at wilting point ($\theta_w$). Water content is the available amount of water that the soil can store at different conditions. Water content at field capacity is the maximum amount of water stored in the soil when only gravity is affecting the soil. Wilting point is the point when water is no longer available for plant uptake.

2.3 Evaluation criteria

The results from the model simulations were evaluated with the overall water balance (both in MikeShe and in Mouse), and system performance parameters: water levels in nodes; peak flow at the outlet; and pipe flow ratio.

2.3.1 Water balance

The two models were run integrated but still separated, thus the water balance results have been obtained both from the MikeShe model for the whole catchment (2.23 km$^2$) and details for the stormwater system from the Mouse model (connected areas 0.54 km$^2$). Information was obtained about the main processes of input precipitation amount, infiltration, evapotranspiration, the change in overland surface water (flooding/ponding) and the amount of runoff entering the stormwater system from Mouse impervious areas and the extra water from MikeShe to Mouse, as well as the system outlet water volumes.

2.3.2 Water level in nodes

The water levels in nodes were evaluated using both the number of flooded nodes (related to different threshold levels) and the actual water levels in every node (as suggested by Berggren et al. 2012). The numbers of nodes were counted when maximum water level exceeded each of three threshold levels (ground level, GL, and critical levels, CL, at -0.5m and -1.0m below ground). The three thresholds help to indicate the safety margin in the system. The max water levels in each node are compared in pairs between the scenarios using mean and standard deviation of differences, and a t-test at 95% significance level. The test $t_0$ value in this case is $t_{0.025, 439}=1.960$ (Montgomery 2001). The maximum water levels in all nodes were also presented graphically to view differences related to ground level.

2.3.3 Peak flow

The peak flow has long been a common evaluation criterion (e.g. Packman and Kidd 1980), for evaluation of the capacity of an urban drainage system, but care needs to be taken if the system is surcharged. Then the values may be representative only for the outlet or for a few points in the system. In this paper the peak flow is presented for the main outlet of the Mouse system.

2.3.4 Pipe flow ratio

As a complement to this, the pipe flow ratio ($Q/Q_{full}$) was also evaluated. A value of higher or equal to 1 means that the pipe was surcharged, thus evaluating this parameter also gives an indication of the system capacity. The maximum pipe flow ratio in the system and the number of pipes in the system with values equal to or exceeding 1 were determined.
3 RESULTS AND DISCUSSION

Water balance for the model simulations for both the total catchment (MikeShe- part of the model, total of 2.23 km²) and the volumes diverted in the stormwater model and their direct connected impervious surfaces (Mouse- part of the model, total of 0.54 km²) are shown in Table 2.

Precipitation input is different only for the scenario 2 (PH) naturally, and Infiltration is also higher. The scenario 6 (IL) shows zero infiltration as expected. The ponding of water on the surface compared with the Baseline scenario (BL) was higher for scenario 2 (PH) and much higher for scenario 6 (IL), and also the volume water from MikeShe to the Mouse stormwater system is higher or much higher for these scenarios. For the study of impacts on urban drainage systems due to increased or decreased runoff from green/pervious areas, the column “MikeShe to Mouse” in Table 2 is very important. During flooding in the stormwater system (Mouse model) water will be forced out from the nodes onto the urban surfaces (in the MikeShe model) and can then infiltrate, or later re-enter the network at the same or another node. This will affect the water balance, especially the total amount water from MikeShe to Mouse. In most scenarios this term is positive, but for the scenario 5 (IH) the high infiltration rates makes water infiltrate before re-entering the system, thus the contribution from Mike to Mouse is negative. The high ponding volume in combination with higher Mouse end volume for scenario 6 (IL), implies that the simulation was too short to take all the slow runoff processes into account. More than 3 extra hours is needed. It is, however, unlikely that these slow running volumes will affect the peak flow and maximum hydraulic impacts in the stormwater system, which is often more dependent on the faster runoff component. The time delay in runoff from green/pervious runoff is regarded as common knowledge in urban hydrology (e.g. Chow et al. 1988). A test run with longer simulation time showed the same peak flow values and maximum water levels, but with an increase of the evapotranspiration component. For all scenarios except scenario 6 (IL) the infiltration is very high for the green/pervious areas in the MikeShe model, and the runoff volume from the green/pervious areas to the stormwater system is much less than the infiltration part.

<table>
<thead>
<tr>
<th>Run</th>
<th>Precip. [m³]</th>
<th>Inflitr. [m³]</th>
<th>Evapotr. [m³]</th>
<th>Ponding [m³]</th>
<th>MikeShe to Mouse [m³]</th>
<th>Input: runoff [m³]</th>
<th>Input: infiltr [m³]</th>
<th>End volume [m³]</th>
<th>Output [m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: BL</td>
<td>37 500</td>
<td>34 656</td>
<td>1 081</td>
<td>764</td>
<td>957</td>
<td>4 761</td>
<td>17</td>
<td>23</td>
<td>5 708</td>
</tr>
<tr>
<td>2: PH</td>
<td>44 992</td>
<td>40 323</td>
<td>1 081</td>
<td>1 336</td>
<td>1 761</td>
<td>5 733</td>
<td>30</td>
<td>23</td>
<td>7 481</td>
</tr>
<tr>
<td>3: EL</td>
<td>37 500</td>
<td>34 885</td>
<td>0</td>
<td>853</td>
<td>978</td>
<td>4 761</td>
<td>17</td>
<td>23</td>
<td>5 729</td>
</tr>
<tr>
<td>4: EH</td>
<td>37 500</td>
<td>34 411</td>
<td>2 152</td>
<td>665</td>
<td>935</td>
<td>4 761</td>
<td>17</td>
<td>23</td>
<td>5 687</td>
</tr>
<tr>
<td>5: IH</td>
<td>37 500</td>
<td>37 082</td>
<td>1 074</td>
<td>4</td>
<td>-58</td>
<td>4 761</td>
<td>0</td>
<td>22</td>
<td>4 696</td>
</tr>
<tr>
<td>6: IL</td>
<td>37 500</td>
<td>2</td>
<td>1 082</td>
<td>22 041</td>
<td>10 949</td>
<td>4 761</td>
<td>102</td>
<td>347</td>
<td>15 378</td>
</tr>
</tbody>
</table>

System performance, described in terms of maximum water levels in nodes, as well as peak flow and pipe flow ratio values is shown in Table 3, as output from the Mouse-part of the coupled model. The Baseline scenario represents a normal situation in the Kalmar area, and with rainfall corresponding to 10 years return period, the system capacity was exceeded for a small number of nodes (22 of a total 440), and 115 of the pipes were surcharged in this scenario.

The climate change impact described as increased rainfall intensity (with 20% increase, scenario 2: PH) have a clear impact on the hydraulic performance of the system as expected, although for this case the low infiltration scenario (6: IL) has a greater influence. This is probably an effect of the large amount of green/pervious areas in the catchment and when the infiltration is low the volume of runoff entering the stormwater system is heavily increased (Table 2) and thus the system performance also affected. The time dependency is however also clear, the extra volume water entering the system from scenario 6 (IL) is much higher than for scenario 2 (PH) and still the hydraulic impacts in terms of number of affected nodes and surcharged pipes compared to the rainfall scenario (2: PH) is not that much higher. Peak flow at the outlet show impact on the system, but the dynamics of the whole system were better shown by the maximum water levels or the pipe flow ratio. The low infiltration scenario (6: IL) and the rainfall scenario (2: PH) make the most impact on the stormwater system, and the increased infiltration (5: IH) makes less impact compared to the Baseline scenario. The evaporation scenarios (3: EL and 4: EH) make no hydraulic impact on the stormwater system.
Table 3. Maximum water levels in nodes, peak flow and pipe flow ratio, from the Mouse model results.

<table>
<thead>
<tr>
<th>Run</th>
<th>Water levels (WL) in nodes:</th>
<th>Peak flow:</th>
<th>Pipe flow ratio:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nodes WL ≥ GL</td>
<td>Nodes WL ≥ -0.5m</td>
<td>Nodes WL ≥ -1.0m</td>
</tr>
<tr>
<td>1: BL</td>
<td>22</td>
<td>80</td>
<td>147</td>
</tr>
<tr>
<td>2: PH</td>
<td>40</td>
<td>137</td>
<td>212</td>
</tr>
<tr>
<td>3: EL</td>
<td>22</td>
<td>80</td>
<td>147</td>
</tr>
<tr>
<td>4: EH</td>
<td>22</td>
<td>80</td>
<td>146</td>
</tr>
<tr>
<td>5: IH</td>
<td>15</td>
<td>72</td>
<td>127</td>
</tr>
<tr>
<td>6: IL</td>
<td>57</td>
<td>168</td>
<td>261</td>
</tr>
</tbody>
</table>

WL – Water levels relative the Ground, GL - Ground level

In Table 4 the maximum water levels in the nodes are shown compared with the baseline scenario (1: BL). The levels are higher for scenario 6 (IL) and for scenario 2 (PH), lower for scenario 5 (IH) and similar to the baseline (1: BL) for scenarios 3 (EL) and 4 (EH). In Figure 3, the maximum water levels in all nodes are shown graphically in boxplots relative the ground level, and as shown there is a clear difference between the baseline scenario (1: BL) compared to scenario 2 (PH) and scenario 6 (IL) which are higher. The overall capacity of the stormwater system was not significantly affected by the changes in evapotranspiration (scenarios 3, 4). The impact on the urban drainage system from a high infiltration scenario (5: IH) indicate the potential of the green/pervious areas to improve the urban drainage situation.

Table 4. Water levels in nodes, mean values, standard deviation, confidence interval and t-value for statistical evaluation. All scenarios compared with the Baseline scenario (nr1: BL).

<table>
<thead>
<tr>
<th>Run vs BL(1)</th>
<th>MV [m]</th>
<th>σ [m]</th>
<th>CI</th>
<th>T-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2: PH</td>
<td>0.354</td>
<td>0.329</td>
<td>0.322</td>
<td>0.385</td>
<td>22.53</td>
</tr>
<tr>
<td>3: EL</td>
<td>-8*10&lt;sup&gt;-4&lt;/sup&gt;</td>
<td>0.008</td>
<td>-1*10&lt;sup&gt;-5&lt;/sup&gt;</td>
<td>0.002</td>
<td>1.94</td>
</tr>
<tr>
<td>4: EH</td>
<td>0.002</td>
<td>0.010</td>
<td>0.004</td>
<td>0.001</td>
<td>-4.78</td>
</tr>
<tr>
<td>5: IH</td>
<td>-0.127</td>
<td>0.141</td>
<td>-0.140</td>
<td>-0.114</td>
<td>-18.87</td>
</tr>
<tr>
<td>6: IL</td>
<td>0.504</td>
<td>0.592</td>
<td>0.448</td>
<td>0.560</td>
<td>17.87</td>
</tr>
</tbody>
</table>

MV – Mean Value period, σ – Standard deviation, CI – Confidence interval

Figure 3. Maximum water levels in nodes in relation to the ground level (marked at 0m).
The impact of climate change as described as increased rainfall intensity in the precipitation scenario (2: PH) are expected to be predominant in regard to the system performance, but from this study it is also apparent that there is a risk related to the contribution of runoff from green/pervious areas to the system (when the infiltration capacity is decreased, scenario 6: IL). A decrease in infiltration capacity that occurs due to changes in the soil characteristics is unlikely and more likely due to antecedent precipitation conditions – when the soil is totally saturated and the infiltration is much reduced. Another example of situations alike are frozen ground in the autumn, and in springtime during snowmelt. A test run with higher groundwater table (at the ground level, reflecting a totally saturated soil) was also performed with similar results as with the scenario 6 (IL). In Sweden future climate scenarios predict a wetter situation, especially during winter and autumn which can cause reduced capacity for any green/pervious areas to attenuate more intense rainfall events. A combination of higher intensity rainfalls at the same time as saturated soil conditions will further worsen the situation.

The study described in this paper illustrates that natural green/pervious areas in towns and cities may also have a significant impact on the urban area as a total and also the hydraulic performance of the stormwater system. These surfaces respond to rainfall in most cases much more slowly compared with impervious areas, but are at the same time more difficult to control as they are not usually constructed facilities with a specific and defined connection to the urban piped system, unless they are specifically designed areas of green infrastructure. At times of wet antecedent conditions and heavy precipitation, these areas may contribute significantly to the total runoff volumes and, if at the same time the urban drainage system is overloaded, water from the green/pervious areas also needs to be routed around and through the urban area in the same way as runoff from impervious areas. Thus, the green/pervious area contribution needs to be given more explicit consideration as it has both a character of limiting the consequences of extreme rainfall events, but, once the attenuation capacity is exceeded, it will start instead to add to the consequences (e.g. London Borough of Croydon et al. 2011).

4 CONCLUSIONS
In this paper the runoff contribution of green/pervious areas and its' impact on the urban stormwater system capacity have been investigated using a small scale sensitivity analysis, changing parameters individually. The Infiltration and Evapotranspiration were used to represent characteristics of the green/pervious areas, and the results compared when precipitation increases more than the design standard requirements (10 year return period). This has shown that, for the Kalmar catchment:

- Infiltration processes are more important for the runoff contribution to the urban drainage system than evapotranspiration when considered separately. These processes are, however, very much related.
- The changes in infiltration capacity give large impacts on the total water balance and ponding, and may have a great impact on the system performance as well. In some cases more pronounced impacts than from changes in rainfall intensities.
- Changes in evapotranspiration cause a small relative impact on the total volume and water balance, but the difference is insignificant for the capacity of the stormwater system.
- There is a need to further study the potential of the green/pervious areas in future research, also as these areas are being used more frequently in the adaptation of urban areas to climate change.

5 ACKNOWLEDGEMENTS
Thanks to Kalmar Vatten AB, for permission to use the urban drainage model.
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