Revista Română de Inginerie Civilă, Volumul 13 (2022), Numărul 2

Modelling Sustainable Urban Drainage Systems

Modelarea sistemelor de drenaj urban durabil

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DOI: 10.37789/rjce.2022.13.2.1

Abstract - In the recent years natural phenomena such as flood have cost billions of euros and numerous losses of human life. In this context, accurate modelling of storm runoff from urban catchments is very important, but it is difficult to achieve because of the complexity of modelling green areas. Depending on the local practice, the available software, the data availability, the possibility of data processing, computation time, and even the experience of the modeller, storm runoff from urban catchments can be analysed using different modelling approaches. Choosing the modelling approach, the rainfall loads to the model and the model parameters are very important steps that must be made with caution, and there is thus a need to establish more precise guidelines to help modellers in choosing the most suitable modelling approach. The overall objective of the research project is to investigate the possibilities of managing the storm water to cope with climate change in a sustainable way. The storm water can be used as a resource, as an element in urban recreational activities. This initiative is supported by the key principles of sustainability: water recycling, minimizing pollutants in storm water and urban environmental protection against flood events.

Index Terms - 1D modelling, Climate Change, Sustainability, SUDS

Introduction

Over the next decades, extreme weather events are expected to become even more frequent due to climate changes (Arnbjerg-Nielsen, Leonardsen, & Madsen, 2015). The extent and nature of expected changes varies across the globe. In the past 30 years, changes in rain patterns have been observed in Denmark in terms of extreme precipitation. These changes are mainly visible in the frequency of extreme events, but there is also a tendency for an effect on their magnitude (Arnbjerg-Nielsen, 2012). There are different approaches to adapt cities to these extreme events. One approach is the conventional adaptation where the sewer system is enlarged, but this is not always possible due to very big implementation costs. Another approach is adapting the urban landscape for stormwater management, which is often called Low Impact Development (LID) or Sustainable Urban Drainage Systems (SUDS) and involves elements of Green Infrastructure (GI) (Fletcher et al., 2014). There are several possibilities to ‘reconstruct’ the cities considering the space needed for stormwater. This will allow the cities to redirect the stormwater to areas that are designed and suitable for flooding, inside or outside the cities, during extreme rain events. This approach has become increasingly popular in Denmark over the past few years (The City of Copenhagen, 2015).

Materials and methods

The presented research is applied to the area of Trekroner Øst (Figure 1), located in Roskilde municipality, at 28km west of Copenhagen where the storm water system was designed based on the principals of sustainability. The research presented here focuses on the complexity of modelling stormwater movements in urban catchments during extreme events with an emphasis on the consideration of green areas and SUDS’s. The flood modelling approach is developed and tested using the MIKE 2016 software package (DHI, 2016). Storm runoff from urban catchments is modelled by considering green areas using Horton’s equation (eq. 1) where infiltration is an exponentially decaying process with large infiltration capacity in the beginning of the event.

$$I_H(t) = I_{Imin} + (I_{Imax} - I_{Imin}) \cdot e^{-k_a \cdot t} \qquad (1)$$

where:

$I_{H(t)}$ Horton infiltration (m/s);

I_{Imin} initial (maximum) infiltration capacity (m/s);

I_{Imax} final (minimum) infiltration capacity (m/s);

K_a empirical constant (time factor) (s^{-1});

t time since the rainfall starts (s).

The storm runoff from green areas is included in the runoff model as a runoff that loads the drainage system. In Denmark the adopted modelling approach is to consider both paved and green urban areas through an initial loss in the runoff model a fact that may generate unrealistically loading of the sewer system if the runoff from this type of areas becomes a significant part of the total runoff model (extreme events).

The Trekroner Øst catchment is divided into 40% flat impermeable areas and 60% permeable areas with an average infiltration capacity. Impermeable areas such as roofs, roads and parking areas are reduced by the initial losses divided into: $5x10^{-5}$m initial losses in wetlands and $6x10^{-4}$m initial losses stored. The runoff from Impermeable areas is also reduced by initial losses: $5x10^{-5}$m initial losses in wetlands and $4x10^{-2}$m initial losses stored. The soil type is clayey and based on the infiltration parameters in the literature, the maximum infiltration capacity has been established $5x10^{-5}$m/s and will be reduced during the rain event to $1x10^{-6}$m/s. Non-perishable surfaces are divided into steep surfaces (roofs) and flat surfaces (parking lots) while the permeable areas are divided into permissible areas where the infiltration capacity is high, medium and small. In this study for ease of calculation the assumption is that all non-perishable surfaces in the model are flat and all permeable areas have an average infiltration capacity. This method allows to consider infiltrations for permeable areas where infiltrations decrease exponentially. A high infiltration capacity at the beginning of the precipitation event is also considered. For this conceptual model, the properties of the soil are represented by the input parameters.

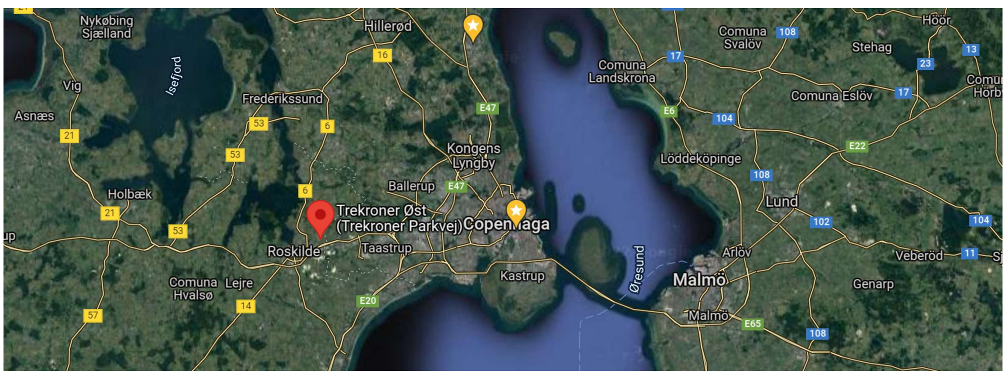

Figure 1: Trekroner Øst area

Mathematical modelling

The research study will be concentrated only on the possibilities of modelling the storm water system where the urban landscape is used for the storm water management. The software that will be used for this research study is the MIKE suite by DHI (Danish Hydraulic Institute). MIKE URBAN will be used to describe the collection of storm water and water flow to the sewer system. The model will describe the drainage system structure, reservoirs, swales, open channels, etc. In MIKE URBAN the hydrological units are represented by catchments, where the storm water and the infiltration are generated based on different sets of parameters for each unit. It will be used a one-dimensional model to get a better understanding of the connection between the surcharged drainage network and overland urban flooding, to give a clear overview of the locations of flooding. The mathematical model will be used to simulate the hydrology and the hydraulics of the implemented Sustainable Urban Drainage Systems.

When the area was constructed the space for the storm water was considered, the storm water drainage became an urban component, allowing the area to be prepared for redirecting the storm water to areas outside the project area largely on the surface. To simulate this in the analysis both hydrological and hydraulic models used in this research were validated and calibrated based on in situ measurements. A rainfall-runoff model which consists of a hydrological model and a hydraulic model was created to forecast the future situations in the newly constructed drainage system. The model will be calibrated based on in situ measurements. Quantitative data such as rainfall, flow and water levels were recorded to perform a calibration of the model.

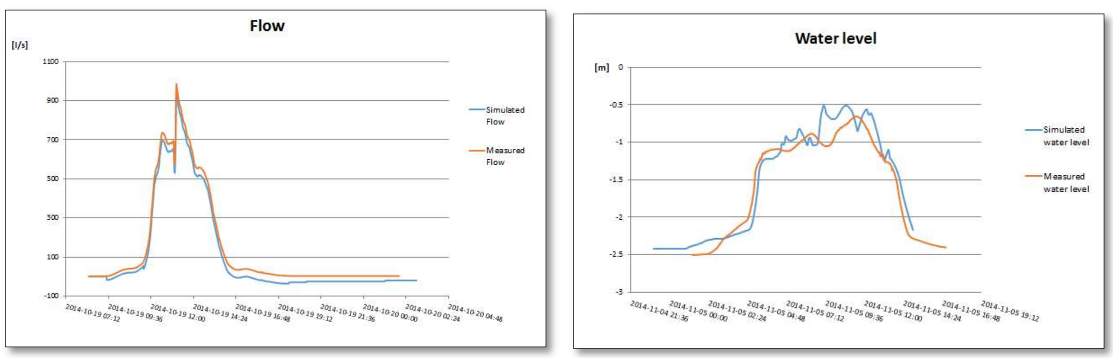

Figure 3: Calibration showing flow results / water level results

After the calibration, the mathematical model was able to recreate a similar flow/ water level model as the measured flow / water level shows. The requirement of the calibration was that the error in volume may be up to 10% and the error in peak flow may be up to 10%.

After the calibration and validation, the mathematical model was used to analyse the capability of the Sustainable Urban Drainage Systems to retain and transport different rain events. Several types of Sustainable Urban Drainage Systems have been implemented in the area: swales, bio retention areas, grassed or paved open channels, etc., presented in Figure 2:

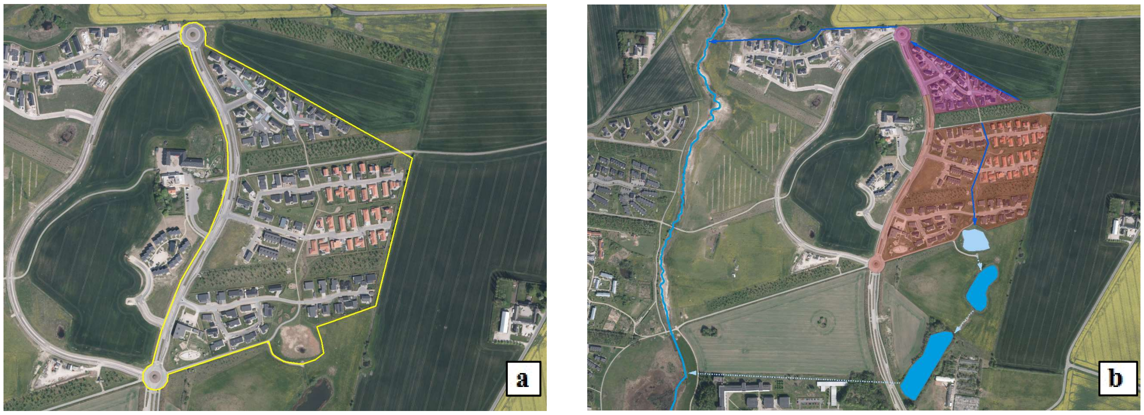

Figure 2: The Trekroner Øst catchment (a) and storm water management (b)

After the validation, the model was used to analyse rain events measured in the stations close to the project area: 5855 (ROSKILDE NAVERVÆNGET PE3) and 5840 (ROSKILDE NYMARKEN OB8). A long time simulation (LTS) based on 20 years historical rain events was performed in order to validate the model and the Sustainable Urban Drainage Systems contribution.

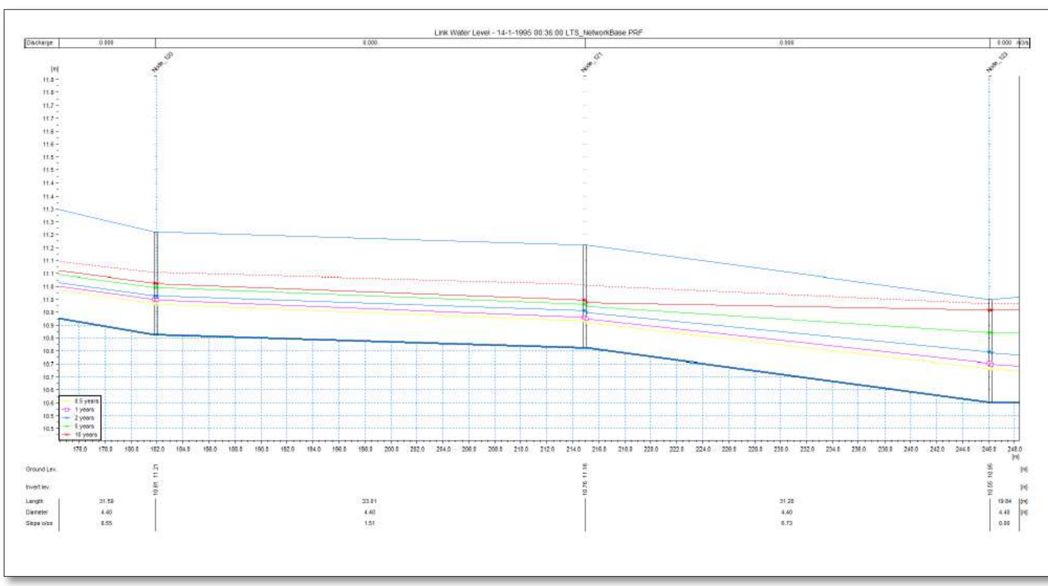

Figure 3: The water level results for a part of the Trekroner Øst sewer system

The mathematical model was also used for flood computations. There was defined four scenarios that represent different predictions of future rain events, considering the predicted increase in precipitations, in order to evaluate the drainage system's capacity and future function. The proposed events are the 5-year event, the 10-year event, the 20-year event and the 50-year event. For the calculation of statistical rain with a a 10-year event, the latest version of the Skrift 30 guide was used. In this version are presented the average annual precipitation (the number of extreme events) and the average daily extreme precipitation (magnitude of events) according to the regional climate model (1989-2010). In the statistical calculation, the research area is identified on the basis of the coordinates x (east) - y (north) where the ETRS 1989 UTM ZONE 32N coordinate system is used. Once the area is identified, average annual rainfall and average daily rainfall are automatically identified from the database.

Results and discussion

Based on the expected significant increase in the frequency and intensity of precipitation, the research presented in this article address the hydraulic and hydrological modelling of urban basins. The calibration of the mathematical model was carried out exclusively taking into account the hydrological parameters that directly influence the amount of rainwater discharged into the sewer system. The target of this calibration was that the volume and maximum errors recorded to be up to 10%, and the correlation coefficient (R) to be between 0.8 - 1. All events were calibrated separately, and the analysis performed on the runoff parameters resulted in values that matched in more than 50% with the recorded events. In order to determine the water flows transported by the sewer system, the hydrological reduction factor, the concentration time and the initial losses as recommended in the literature were taken into account, thus making it possible that after calibration, the model would be able to convey a transported flow rate and a depth of water in the channel similar to the measured data. Climate change has a significant impact on the urban environment, so it was important to develop a mathematical model that would be able to reproduce present situations in terms of precipitation. After the mathematical model of the sewer system was calibrated, it was used to analyse the consequences of increasing the intensity of precipitation due to climate change. The results showed that the permeable areas the rains cannot infiltrate completely on extreme events and that the Sustainable Urban Drainage Systems are helping the sewer system to cope the extreme events rainwater volumes.

Acknowledgement

We are grateful to Henrik Sønderup (Head of Department, Climate Adaptation and Landscape Architecture, Rambøll Denmark) for providing the input data and all the software used in this research.

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