

Tools for measuring climate change impacts on urban drainage systems

Les outils de mesure des effets du changement climatique sur les systèmes d'assainissement pluvial urbain

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RESUME

Le changement climatique, par exemple des événements pluvieux plus intenses, aura un effet sur les systèmes d'assainissement pluvial urbain et causera des problèmes dans les grands centres municipaux. Il y a un besoin de mieux comprendre et évaluer les effets et les conséquences ; donc une stratégie et les outils possibles sont suggérés dans cet article. Les outils recommandés sont les Simulations d'assainissement Pluvial Urbain, un Rapport de Sécurité, et un Système d'Information Géographique (SIG). Puisque les effets des changements climatiques sur les systèmes d'assainissement pluvial urbain concernent plusieurs domaines, l'évaluation devra être effectuée en coopération avec, par exemple des experts en assainissement pluvial urbain, en changement climatique, des praticiens, des politiciens, etc.

ABSTRACT

Climate change, e.g. more intense rainfall events, will affect urban drainage systems, and cause problems in cities. There is a need to understand and assess these impacts and consequences better; therefore, a strategy and possible tools are suggested in this paper. The recommended tools are Urban Drainage Simulations, Risk Analysis, and Geographic Information Systems (GIS). Since the impacts of climate change on urban drainage concerns several different disciplines, the assessment should be performed in cooperation with, e.g. urban drainage experts, climate change experts, practitioners, politicians, etc.

KEYWORDS

Climate Change; GIS ; Risk analysis ; Urban Drainage; Vulnerability

1 INTRODUCTION

The global mean temperature has increased during the last hundred years according to IPCC (2001), consequently changing the hydrological cycle. In recent years we have seen weather considered by many as “extreme weather events”, but what will be the consequences if these events occur more often in the future? Technologies for urban drainage have been developed over a long period of time, though design criteria have been relatively constant throughout the major urbanisation era. As a consequence, changes in climatic conditions, such as increasing rain intensities and changing snowmelt patterns, and more extreme weather events, such as thunderstorms, will most likely create problems in cities. The issue of climate change and urban drainage has previously been emphasised in studies concerning integrated urban drainage planning (e.g. Semadeni-Davies et al., 2006; 2004; Ashley et al., 2005; Waters et al., 2003) and on climate change and urban water considering flooding and risks (e.g. Evans et al., 2004). A study from the UK has shown, for example, that the potential effects of climate change on urban property flooding are likely to be significant (Ashley et al., 2005).

According to an investigation by the Swedish Meteorological and Hydrological Institute (SMHI) in 2004/2005, very few Swedish sectors had strategies for adaptation to climate change, and among those measures already taken, the majority were adaptations to the existing climate and not the future (Rummukainen et al., 2005). Some things have happened since then, e.g. the establishment of a national group of experts in drinking water supply and leadership during crisis (VAKA, started in 2005) and a vulnerability investigation was set up by the Swedish government, which recently presented part time results regarding the vulnerability of society due to climate change (SOU, 2006).

Still, there is a need for more knowledge to successfully adapt society. For the area of urban drainage, there is also a need for better and updated tools and strategies to assess the impacts and to feasibly adapt the system. For this reason, the aim of the study is to investigate the possible impacts concerning urban drainage systems and future climate change, and in more detail, to find and recommend a strategy and tools that can be used for this purpose.

2 METHOD

This work has been carried out as a literature study together with simulations using an urban drainage model (Mike Urban/MOUSE by DHI), as well as discussions with representatives from different disciplines, e.g. Water and Wastewater engineers, in order to develop a useful strategy for climate change impact studies in urban areas.

3 RESULTS

The strategy to investigate the climate change impact on urban drainage has for this research project been designed as shown in Figure 1, where the boxes marked with bolder lines are the main focus for this particular study and the other boxes represent the overall approach. SMHI has provided precipitation data from the regional atmospheric climate model (RCA3, developed at the Rosby Centre, SMHI (Kjellström et al., 2005)), originating from the global circulation model ECHAM4 and future scenarios SRES A2 and B2 (defined by UN IPCC in Nakicenovic et al. (2000)), which are intermediate (not extremely high or low). These results have been used for local climate projections for the municipality of Kalmar, southern Sweden, and further transferred from areal to point rainfall via the Delta Change method, previously used in the urban environment by, e.g., Semadeni-Davies et al. (2006), and later improved and adjusted for this particular study by Olsson et al. (2006). The point rainfall data

have the form and pattern as tipping-bucket rainfall data, and were used as input to the urban drainage simulations carried out with Mike Urban (MOUSE) by DHI. The urban drainage simulations combined with risk analysis methodology and Geographic Information Systems (GIS) will improve the impact assessment for the urban drainage system. These impacts will undoubtedly have consequences for the city as a whole. When a municipality gains knowledge of weak and sensitive areas in the system and the city this way, it may be easier to choose and prioritize between adaptation strategies.

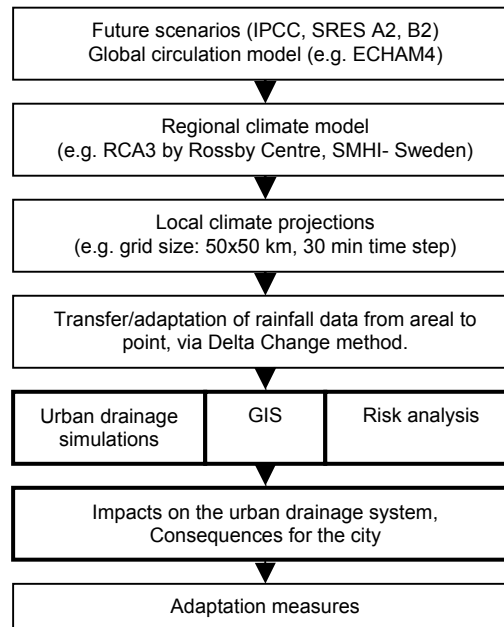


Figure 1. The overall strategy for this research project, which aims at investigate climate change impacts on urban drainage systems and the consequences for the city, where the boxes marked with bolder lines are the main focus of this article.

3.1 Urban Drainage simulations

Several different types of urban drainage simulation tools are available, e.g. Mike Urban (MOUSE), SWMM, Infoworks etc. Many researchers have used these tools to describe the impacts of both climate change and urbanisation (e.g. Semadeni-Davies et al., 2006; Ashley et al., 2005; Waters et al., 2003) and can give information about future conditions, provided that it is used appropriately and the model is calibrated for the specific system. The model can, for example, provide information about water levels in nodes and links, frequency of floods indicating weak spots in the system and city, and consequently pinpoint where more resources are needed. Water level durations in nodes can also be compared in the model for future conditions, indicating how the duration of floods may increase, and connected with a model for surface runoff to give more precise information on where problems will occur. Different scenarios for future changes in city characteristics, e.g. increase of impervious areas, help to analyse the impacts of city change on urban drainage. Water level output results from model runs can be inserted into a GIS and compared with more data sources, such as infrastructure, economic and environmental values.

Calculating the economic cost for specific areas produces a vulnerability map showing reasons for improvement of the sewer system or building of rerouting possibilities to areas with less economic/environmental value.

Lindsdal, a suburb of Kalmar, was used as a reference area in a pilot study. According to results from SWECLIM (Swedish Regional Climate Modelling Programme), precipitation in Sweden during the winter will possibly increase by as much as 30 to 50% in the future. Summer precipitation in southern Sweden is likely to decrease in amount, but become more intense, whereas northern Sweden can expect an increase in both intensity and amount (Bernes, 2003).

Details about the Lindsdal area: 410 nodes, population 3,000, size of the contributing catchment areas 54 ha and amount impervious area 20 ha. To decrease the data volume for the long simulation time, 120 nodes were selected as representative for the system. The urban drainage model (separated, only stormwater) has run with four different rainfall series, representing today's climate (TC), near future climate (FC1: 2011-2040), intermediate future climate (FC2: 2041-2070), and distant future climate, (FC3 : 2071-2100). The original tipping-bucket rainfall series (Hernebring, 2006) for TC has been transformed by the Delta Change method described in Olsson et al. (2006). Figure 2 shows how the number of flooded nodes (water level exceeds ground level) in the system will increase in the future.

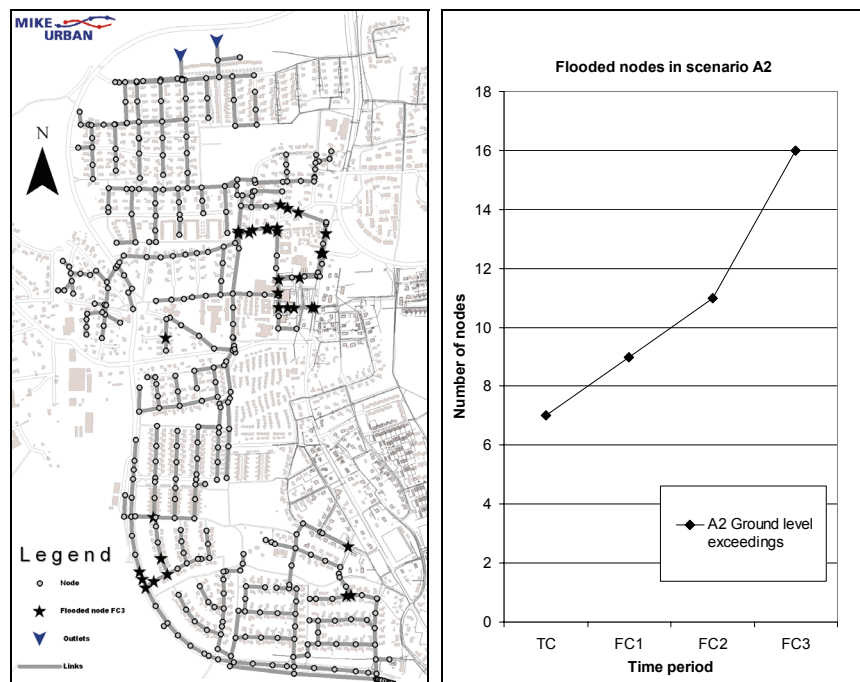


Figure 2a. Lindsdal area; flooded nodes in time period FC3. Figure 2b, Number of nodes where ground level was exceeded in the different time periods.

3.2 Risk Analysis

A definition is needed whenever speaking about risks, as the word has been used in the literature to mean either probability of danger or the hazard itself (SCOPE, 1980). Christensen et al. (2003) summarised the most important risk definitions (including material from, e.g. EU, UN/OECD, US-EPA and ISO guidelines) and the actions taken to assess risk. Risks can easily be presented by answering three questions: 1) *What can happen?* 2) *How likely is it to happen?* 3) *If it happens, what are the consequences?* (e.g. Ljungquist, 2005), which may also be presented as a cause-effect relationship (Christensen et al., 2003). Hauger et al. (2003) suggest that the concept of vulnerability should be used with the concept of hazard in an urban drainage risk assessment approach. Hazard assessment can be, e.g. frequency of extreme weather events; vulnerability assessment is more site specific and can be, e.g. the amount of damage to a specific house due to flooding.

There are several methods for risk analysis, and what to use depending on, e.g. the detail requirements, the objectives of the study, and the available resources. At the beginning of a project, it is recommended to start with a rough methodology to gain an overview. Both qualitative and quantitative methods are included in most risk analysis. A weakness in using deterministic or probabilistic methods, where the deterministic approach is based on consequences (worst-case scenario etc) and can be easy to conduct and communicate, is that problems can arise if there is no probability check, such as too many resources can be laid on events that are very unlikely to occur, etc. The probabilistic approach is based on risk, and uses both probability and consequences, but its drawback is the resource demand and the uncertainty connected to probability estimation (Davidsson, 2003).

Future precipitation in Sweden will increase in intensity and in amount (especially in the north) (Bernes, 2003), which inevitably will impact urban drainage systems and cities. Table 1 summarises examples of possible impacts in different parts of an urban drainage system due to high intensity rain events (as a cause-effect relation, where the risk source is the intense rainfall). However, this is not a complete summary and should only indicate the possible impacts in different parts of the system. There is also of course a need to make this table more detailed for the specific place of study, since the local conditions are very important and should preferably be performed in cooperation with both climate and urban drainage experts and those working more practically with the system, e.g. in a municipality. Local conditions can be highlighted for a large amount of people, which could be a good way to start working with any type of question requiring development and improvements of the organisation, infrastructure, etc. These types of studies may also gain a better understanding if used as a complement to other tools in a GIS.

Combined system	<ul style="list-style-type: none"> ▪ If the sewer system has too low a capacity, the water level in the system can <i>cause basements to be flooded</i> ▪ Increased amount of <i>combined sewer overflow (CSO)</i>, which can cause environmental problems concerning the receiving waters and also jeopardize the drinking water sources ▪ If the ground water level rises because of a higher amount of precipitation, more ground water will <i>infiltrate into the pipes</i>, and thus decrease the capacity of the system
WWTP (combined system)	<ul style="list-style-type: none"> ▪ At a wastewater treatment plant, during times of high flows, <i>dosages of chemicals</i> for the processes can become unnecessarily high ▪ Increased amount of urban <i>polluted runoff</i> can reach to the treatment plant, which will cause more pollutants, e.g. heavy metals, in the sludge.

Pump stations	<ul style="list-style-type: none"> ▪ Pump stations can easily become flooded as they often are located in low-lying areas. There is then a risk of getting <i>pipe surcharge</i> in the system if water is damming up backwards in the system ▪ Increased amount of <i>pump station sewer overflow</i>, which can cause environmental problems concerning the receiving waters and also jeopardize the drinking water sources
Separate system (only storm water)	<ul style="list-style-type: none"> ▪ If the system has too low a capacity, the water level in the system can cause <i>surfaces in a city to be flooded</i> ▪ If the ground water level rises because of a higher amount of precipitation, more ground water will <i>infiltrate into the pipes</i>, and thus decrease the capacity of the system ▪ Heavy precipitation over urban areas can cause a <i>rapid runoff and wash of urban surfaces</i> and thus higher concentrations of pollutants, e.g. heavy metals to BMPs or receiving waters
Storm water pond	<ul style="list-style-type: none"> ▪ At storm water ponds, the amount of <i>sediment losses</i> during heavy rain may increase if the pond is insufficiently dimensioned, and there are no by-pass facilities. Thus polluted sediments may reach the receiving waters.
Infiltration basin	<ul style="list-style-type: none"> ▪ The <i>infiltration capacity may decrease</i> if the ground water level rises, and cause, for example, <i>surface flooding</i>

Table 1. Examples of impacts in urban drainage systems during high intensity rainfall events.

4 DISCUSSION

4.1 Economic valuation

To serve as a useful and practical decision-making tool, most methods need to have an economic valuation included. Placing an economic value on an infrastructure might be realistic, but how will health aspects, nuisance from basement floods, closed roads, longer travel time, etc. be valued? An economic evaluation is, however, necessary to choose whether it is worth protecting a possible event from occurring. When different input is used in a GIS the vulnerability and possible damage on real estate and other areas can be assessed depending on the data from drainage models, infrastructure, real estate, demographic data, soil layers, future city plans, political economy, social factors, repair costs for different damages and areas, etc. The economic cost for affected areas can be identified, e.g. via a Cost-Benefit approach. A cost analysis can be made by a so-called raster- or vector analysis, depending on the available data, and show where it is most efficient to adapt the urban drainage system to maximise the future benefit, where this benefit is seen as a value of something not being flooded. This will support policy and decision-making of how to manage the urban drainage system in a time of climate change.

4.2 Cooperation

Risk and vulnerability analysis always needs to be done in cooperation with the parties concerned, since most problems involve several different disciplines. One big challenge in the urban drainage system is the close multiple interactions that exist, both within the system and related to city infrastructure. Dialogue with experts and politicians should also take place to make the most of the results and precautions should be taken, especially since climate change is a very uncertain area to base decisions upon.

4.3 Uncertainty

Climate change modelling is generally considered as very uncertain, and it is not possible to give an exact probability of future change. There are several uncertainty levels, e.g. data/parameter uncertainty, model/structure uncertainty, variability, and outcome uncertainty (e.g. Christensen et al., 2003). However, the scenarios used

give a range in which the results can vary. It is common to use this as a measure to consider future trends. How useful it is can only be shown by the future itself. Urban drainage simulations represent one type of model uncertainty in this study and the results should always be interpreted with some caution. This model is, however, previously calibrated for this specific area, and may serve well especially for present and near future climate runs if assuming that no urban development activities will occur in that time. Uncertainty of the variability and the outcome of the project may be reduced if a dialogue and common sense are used.

4.4 Other aspects

As always, there are many other factors affecting the performance of the urban drainage system, e.g. impacts from the surrounding areas, water courses, sea level, etc., and the amount of impervious areas, which may increase with increasing population and new developments (e.g. Semadeni-Davies, 2006). There is also an aspect concerning the life expectancy of pipes and facilities (e.g. BMPs, WWTP etc), where pipes may be one hundred years or older and still be in operation (previously discussed by, e.g. Waters et al., 2003). In addition, the system will be more sensitive to extreme weather events and climate change factors if the capacity is decreased, e.g. if the pipe system is perforated and filled by roots, extra sand and sediment in the pipe system (e.g. originated from anti-skid measures), pipes are damaged and deteriorates, and other more temporary events, e.g. ice-blockages at the inlets. Through GIS analysis the results from combining factors are shown and each aspect can be valued, considered and analysed, thus increasing the knowledge and making it easier to suggest adaptation strategies for the urban drainage system to minimise the vulnerability of affected areas. When adapting to the future climate, it is also wise to keep updated in the field and adapt the urban drainage system step by step to gain knowledge with time and to invest available resources in the right places.

Plans for future research within this project are to compare different municipalities (different climate characteristics, and climate change) in Sweden, to consider the influence of sea, watercourses and ground water on urban areas, and to use risk analysis methodology and GIS to get a more holistic approach to climate change impacts assessment.

5 CONCLUSIONS

The strategy used to increase the understanding should be used in combination with different tools available (urban drainage simulations, risk analysis, GIS, etc.) and in cooperation with parties concerned, (urban drainage experts, climate change experts, practitioners, politicians, etc.), since most problems concern several different disciplines and a multifunctional understanding.

6 ACKNOWLEDGEMENT

This work was financially supported by FORMAS (Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning) which is gratefully acknowledged.

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