Indicators for urban drainage system -assessment of climate change impacts

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ABSTRACT

Changes of the climatic conditions will affect urban drainage systems, as they are closely related to the weather phenomenon and are built as to cope with the weather occurring. The aim of this paper is to investigate indicators that can be used to describe and compare impacts and adaptation measures in existing urban drainage systems. Problems in the system due to climate change can be summarised as problems with flooding of surfaces and basements, increased amount of combined sewer overflows (CSO), increase of the inflow to waste water treatment plants (WWTP) and increase in pollutants spreading from urban areas to the environment. The impacts needs to be described with indicators taking into account the system behaviour both before, during and after an event (e.g. urban flooding) has occurred, and can be divided into (A) description of the system performance, (B) capacity exceeding in the system, and (C) description of consequences as a result of capacity exceeding. The consequences can be divided into sustainable aspects as: technical, economical, socio-cultural, environmental, and health. The research is performed within a project which will also include model simulations of urban drainage systems in four Swedish municipalities as to assess impacts and evaluate the use of indicators.

KEYWORDS

Climate change; impacts; indicators; urban drainage systems;

INTRODUCTION

Changes in the climatic conditions (IPCC, 2007) will affect infrastructure in cities and the vulnerability of the society increases also as urbanisation continues and population grows. Urban drainage systems are closely related to weather phenomenon, and when these events might change as a consequence of global warming, the risk of problem in the system or related to the system increases. In order to cope with future climate change, it is necessary to consider both mitigation actions and adaptation (Stern Report, 2006) and also about how to identify risks and vulnerability in our societies. For urban drainage systems, the adaptation actions are most evident, but these actions should however be taken with the mitigation issues in mind. The adaptation actions should be able to cope with changes for a long period of time, since the life-length of pipes can be up to 100 years, or more. In such a long time, there are many things that can change. The solutions or measures for adaptation should therefore be robust and able to cope with a variety of future changes.

Climate impacts on urban drainage systems has been studied previously, (e.g. Waters *et al.*, 2003; Ashley *et al.*, 2005; Semadeni-Davies *et al.*, 2005; Denault *et al.*, 2006), and can be summarised as problems with flooding of surfaces and basements, increased amount of combined sewer overflows (CSO), increase of the inflow to waste water treatment plants (WWTP) and increase in pollutants spreading from urban areas to the environment. These impacts are described often in a traditional way, where system performance is assessed and interpreted regarding consequences for the system and the city. Rainfall intensity and amount is the problem which has had the most attention so far, due to the often rapid runoff situation in urban environment. When addressing impacts of a changing climate, there is always the question how to describe these impacts and risks in a good way. Are there indicators which make it possible or easier to describe and compare impacts in different parts of an existing system? And can these parameters or indicators which are used for the impact assessment also be of use for the evaluation and prioritising between adaptation actions, and between different areas of the city? Is it also possible to find out how sensitive an urban drainage system is, before any consequences are registered? And if there is impacts, and damage (e.g. surface flooding, basement flooding etc) can these be described and evaluated from sustainability point of view (technical, environmental, socio-cultural, health and economy)? When changes are to be planned for an urban drainage system, these aspects are important to involve. Palme (2007) describes how indicators can be used in order to assess the sustainability of urban water systems, which are valuable information but in general too coarse to be used for the purpose of climate change impact assessment. There is a need of more detailed and specified indicators for this purpose.

The aim of this paper is to investigate possible indicators which can be of use when describing and comparing impacts of climate change on urban drainage systems. The paper is a part of a project where four municipalities in Sweden are involved, and case studies in these municipalities will further on support the evaluation and assessment of indicators, and also their capacity to describe the effect of different adaptation measures.

METHODS

The project consists of two parts, literature study of the indicators and a first classification of their character, and the model simulation part with case studies and tests of the indicators. The second part is not finished at the time of writing but preliminary results from this part will be presented at the time of the conference.

The first part of this paper is literature review, of both urban drainage impacts due to climate change, and of indicators, starting with sustainable development criteria. Then a classification of the indicators found in literature, and indicators suggested in this paper, according to their purpose, what they describe, and their character.

In a continuation, the suggested indicators are to be tested in case studies in four municipalities in Sweden, within a newly started project. From each municipality, two catchment areas are to be modelled, and with help from these model simulations evaluation of the indicator is to be performed in collaboration with representatives from each municipality.

In figure 1, the framework of the project is described. Input for the simulations of urban drainage models are climate parameters (rainfall intensity, changes in temperature, sea levels, etc). Changes in the urban environment (urbanisation, changes of impervious areas, runoff characters) are to be held constant at first, and later on changed according to thoughts about development in the municipalities. Model simulations are to be performed and the results are to be evaluated with help from indicators. Adaptation measures are also to be suggested and tested for their impact on the system and how they react on climate changes.

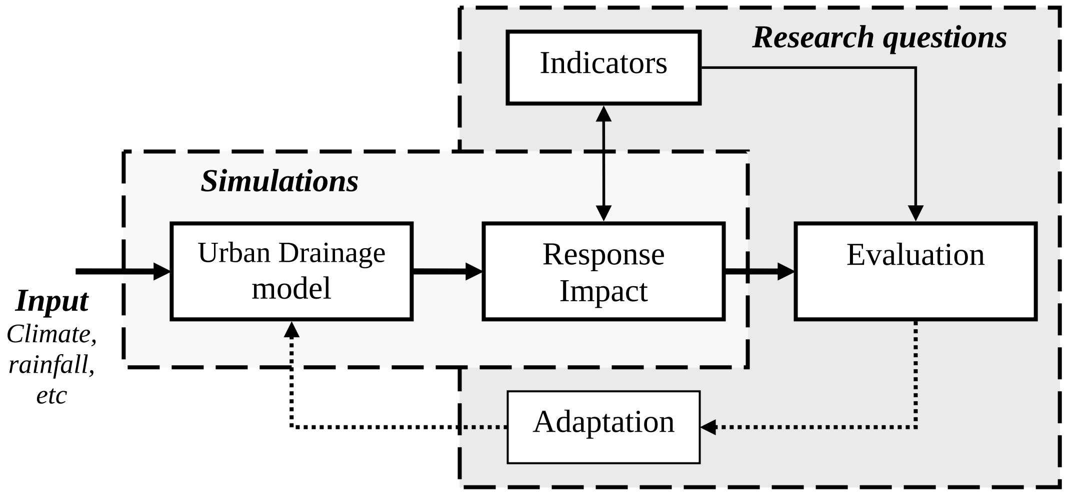

Figure 1. Framework for the project, model simulations and research environment with evaluation with help from indicators. Adaptation measures changes the urban drainage models and thus the results of the simulations.

RESULTS AND DISCUSSION

Urban drainage impacts due to climate change

There are some specific problems connected to this area, and the main issues are:

- The existing urban drainage system is designed to cope with the weather conditions for a specific area. The age of the system can vary and, in some parts, it can be very old, e.g. in many old city centres. This means that the existing urban drainage systems have been designed for the past climate conditions, but maybe not for the situation occurring today or for the future.
- Increase of population also affect the number of events causing damages, more people will be affected and are vulnerable to natural phenomena, such as heavy rainfall events, storms, flooding etc. Urbanization is also a major issue as the urban drainage system might have been constructed for a city whose impervious surface areas were fewer and smaller than those in today's cities or will be in tomorrow's cities. This will affect urban runoff.

- Several global climate models are available, and there are also different scenarios that affect the model results; together, these contribute to the many choices when choosing the input data for a research project. There are also large uncertainties involved in this field. Due to the spatial and temporal resolution of global climate model data, there is a problem connected with the use of rainfall for simulations or calculations of urban hydrology (urban runoff). Therefore, some dissaggregation or adaptation techniques of data are needed.

The assessment of climate impacts on urban drainage systems can be performed from different points of view. Berggren *et al.* (2007) suggested Urban Drainage Model Simulations, Geographical Information Systems (GIS) and Risk Analysis, as tools for the assessment of impacts. From earlier literature, the most common approach is urban drainage model simulations (e.g. Niemczynowicz, 1989; Waters *et al.*, 2003; Ashley *et al.*, 2005; Semadeni-Davies *et al.*, 2005; Denault *et al.*, 2006). GIS has also become more common, for example used as a complement to other tools in describing the impacts on a geographical scale.

Considering climate change, the most urgent problem for many cities is the intensification of the hydrological cycle with, for example, more intense rainfall and extreme weather events occurring. These events may cause e.g. flooding of surfaces and basements, combined sewer overflow, and also decreased flow capacity in the system due to increased amount of infiltration into pipes.

The different ways to handle climate model information for the use in urban drainage contexts can be described as *static, semi static* and *dynamic* (Berggren, 2007), according to the way information from climate models are used, from a fixed percentage of changes, a dynamic dissagregation, or something in between where climate model information is used but not directly in an urban model (e.g. delta change method, Olsson *et al*., 2006).

The typical problems in an urban drainage system can be intensified due to climate change, and more intense rainfall events. Urbanisation (more impervious surfaces in a city) has great impact on urban runoff and gives e.g. more rapid runoff and higher amounts of water in the systems (Waters *et al.*, 2003; Semadeni-Davies *et al.*, 2005; Denault *et al.*, 2006). Ashley *et al.* (2005) suggested that potential effects of climate change on urban property flooding are likely to be significant in the future. Infiltration into pipe systems increases as the precipitation increases in amount and in intensity (Niemczynowicz, 1989; Semadeni-Davies, 2004; Semadeni-Davies *et al.*, 2005), which will affect the inflow to the wastewater treatment plant, and facilities for treatment of storm water (BMPs), and can also decrease the capacity of the system, which makes it more probable to have flooding and combined sewer overflow during rainfall events. The impact on the system due to exfiltration and damage (also sediments) to pipes, and how this may change in the future, has not been found in the literature.

Regarding the impacts on receiving waters, Niemczynowicz (1989) showed potential environmental impacts due to an increased amount of pollutant released to receiving waters (suspended solids (SS), biological oxygen demand (BOD7), phosphorus, copper, zinc, and lead). Semadeni-Davies *et al.* (2005) showed that the total load of nitrogen released to receiving waters via overflow (CSOs) would increase in the future. And also Denault *et al.* (2006) found that the environmental impacts of climate change and urbanisation (increase of the impervious areas in the city) indicate a great vulnerability for the natural ecosystems of the receiving waters.

Climate change parameters

Since 1988, the UN's Intergovernmental Panel on Climate Change (IPCC) has worked to assess changes in the climate and gather the latest findings of researchers from all over the world in order to put together assessments of observed and expected changes in the climate. The first assessment report was published in 1990, and the latest during this year (2007), which is also the fourth assessment report (IPCC, 2007). The last twelve years (1992-2005) contained eleven of the warmest years since 1850, and the global mean temperature increased by 0,7 °C (±0,2°) during that time (IPCC, 2007). IPCC considers it very likely that the warming will continue in the 21st century, which will have an impact on, for example, precipitation patterns, snow cover, sea levels, and extreme weather events. For the northern hemisphere the warming is likely to continue in the 21st century, and is likely to be above the global mean. The changes in precipitation amount differ from area to area; in general, dry areas will become drier (e.g. Mediterranean) and wet areas wetter (e.g. north Europe). Intensity is likely to increase due to intensified hydrological cycle. Increases in the number of heat waves, heavy precipitation events, and total area affected by drought have been observed. Changes in storms (frequency, intensity etc) and small-scale severe weather phenomena have not been easy to estimate, due to e.g. the close relation to natural variations, and insufficient studies and measurements, but extreme weather events seems to become more often occurring in the future. (IPCC, 2007). These events will have impact on urban drainage systems.

Indicators

Palme (2007) presented indicators of use for the assessment of sustainability for urban water systems, from a whole systems approach. Usually, sustainability criteria are divided into different parts, reflecting the holistic view of the concept. Palme summarizes these as to hold either three, four or five dimensions, but also that the sustainability approach can be divided according to type of environmental-technical system. Hellström *et al.* (2000) describes criteria for sustainable urban water management as: Health and hygiene, social-cultural, environmental, economical, functional and technical. These criteria and indicators suggested in connection to this, are sometimes to coarse to be used when addressing impacts due to climate change on urban drainage systems, due to the need of rapid response on hydraulic behaviour. The indicators reflecting sustainability are however a good starting point, as the systems both should fulfil the sustainability criteria as well as to meet new climatic conditions in a good way.

Some of the functions of indicators is described in the document from UN (2007) on sustainable development indicators:

Indicators perform many functions. They can lead to better decisions and more effective actions by simplifying, clarifying and making aggregated information available to policy makers. They can help incorporate physical and social science knowledge into decision-making, and they can help measure and calibrate progress toward sustainable development goals. They can provide an early warning to prevent economic, social and environmental setbacks. They are also useful tools to communicate ideas, thoughts and values.

Some of these functions are also qualities wanted in indicators describing climate change impacts on urban drainage systems. Although, the indicators presented in this paper are of a different type in general and used on a more daily basis for example as decision support.

Classification
The classification follows the principle of: (A) description of the system performance, (B) capacity exceeding, and (C) description of consequences as a result of capacity exceeding. These can also be divided into how they are related to events occurring in the system, before any event has happen, during an event and after an event has occurred (Table 1). Events in these cases are e.g. heavy rainfall events that may cause flooding, snow melting in combination with rainfall, and more extreme weather events affecting the urban drainage system.

Table 1. Classes for indicators, based on when they are occurring, their character and how they are describing the events occurring in the urban drainage system.

	Before	While	After
System performance	A	-	-
Capacity exceeding	-	B	-
Consequences	-	-	C

Before an event has affected the systems and caused something to happen, it is important to evaluate the system performance, so that the daily function can be assessed. During an event, for example heavy rainfall occurring, the system will react on this and the capacity of the system needs to be evaluated. If the capacity (e.g. flow capacity) is exceeded then there will be consequences in the system and in the city (e.g. flooding of surfaces, flooding of basements, CSOs, etc) and these consequences can be divided or organised regarding their character after the event has occurred. The consequences can also be divided into subgroups according to the type: technical, economical, socio-cultural, environmental, and health, and also according to the persons and organizations affected. Examples of consequences:

Technical: Damage to pipes, facilities, pump stations, infrastructure, land (erosion and landslides), and property, which affects e.g. the system capacity, other parts of the technical infrastructure in the urban environment and inhabitants in the city.
Environmental: Spread of pollutants, nutrients, and hazardous substances in the water, soil, and/or air, affecting the ecosystems and species especially in the receiving waters.
Economical: cost of damage, cost of treatment of a polluted environment, and secondary costs, e.g. if people are hindered from doing their job due to infrastructure failure (roads, railways, internet, etc).
Socio-cultural: In the city/municipality/country, some areas might be more affected by damage and pollution than others, and if these are areas where poor people settle, then a class or social distinction will develop in the society.
Health: people become sick or are injured or killed by the damage and the polluted environment, and also in connection to drinking water quality.

In the literature found regarding impacts of climate change on urban drainage systems (e.g. Semadeni-Davies *et al.*, 2005; Ashley *et al.*, 2005; Waters *et al.*, 2003; Niemczynowicz, 1989), different indicators or parameters have been used to describe what is happening in the system. The indicators found in the literature together with some other examples of indicators has been summarized and divided into classes (Table 2), following the principle presented previously as A, B, C (Table 1).

In the list presented in Table 2, some indicators are missing. For example, pollutants and nutrients that affect the environment are not represented, nor is geographical distribution of a flood, which is important when describing consequences. There are also other characters that are important for an indicator describing climate impacts on urban drainage systems. They should for example:

- Easily describe hydraulic performance in the system (A, B)
- Give indications about how close to a consequence the system is, i.e. safety margin. (B)
- Make it possible to compare different catchment areas according to their sensitivity for climate change (B, C)
- Make it possible to compare different adaptation actions for the same catchment area, in order to decide what is best to do for this part of the system (B,C)
- Give indications about how adaptable, flexible and robust a system is (-)

Table 2. Examples of indicators used in literature in order to describe impacts of climate change on urban drainage systems, classified in group A, B or C. A: System performance, B: Capacity exceeding, and C: Consequences.

Type of system	Indicator	Unit	Ref.*	Classification
Combined system	CSO volume	[m3]	1, 2	B
	CSO frequency	[-]	-	B
	Pumping station overflow volume	[m3]	2	A
	Inflow to sewer system,	[m3]	1	A
	Inflow to WWTP	[m3]	2	A (B)
	Number of properties affected	[-]	3	C
	Economic loss due to damage	[EUR]	3	C
Separated system	Total flow volume	[m3]	2	A
	Total runoff volume	[m3]	4	A
	Time to peak discharge	[t]	4	B (A)
	Volume of peak discharge	[m3]	4	B (A)
	Number of pipes surcharged	[-]	4	B
	Frequency of flood	[m3]	-	B
	Duration of flood	[m3]	-	B
	Pipe flow ratio	[-]	-	B

*References, 1: Niemczynowicz (1989), 2: Semadeni-Davies *et al.* (2005), 3: Ashley *et al.* (2005), 4: Waters *et al.* (2003). CSO= combined sewer overflow, WWTP= Wastewater treatment plant

There is more work needed in order to find possible indicators, and they also need to be evaluated in case studies, regarding their sensitivity and to determine how well they describe impacts.

Case studies

In the Swedish project ("climate change and urban drainage") four municipalities (two from the south of Sweden and two from the north) are involved, and within this project study areas or catchment areas has been chosen as to represent problems occurring in the urban drainage system today, and what they will be in the future with a changing climate. These case studies are also to be used as to test the usability of the indicators suggested. Evaluation will also be performed of the indicators, what they are describing, and what the possibilities are to use them as decision support when addressing adaptation in the areas. The municipalities are Trelleborg (south of Sweden, at the coast), Borås (south of Sweden, inland), Sundsvall (north of Sweden, coast), and Skellefteå (north of Sweden, coast). The amounts of people living in these municipalities are 41 000, 100 000, 95 000 and 72 000 persons respectively.

CONCLUSIONS

There is a need of indicators that firmly and easily describes the impacts of climate change on urban drainage system. In this paper the classes A, B and C are suggested as tools for better understanding of indicators that can be used: (A) description of the system performance, (B) capacity exceeding in the system, and (C) description of consequences as a result of capacity exceeding. These can also be divided into how they are related to events occurring in the system, before any event (e.g. flooding) has occurred, during an event and after. The consequences can be divided into sustainable aspects as: technical, economical, socio-cultural, environmental, and health.

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