

Climate change management in drainage systems – A “Climate Cookbook” for adapting to climate changes

Gestion des changements climatiques dans les
systèmes d'assainissement – Un livre de recettes pour
l'adaptation au changement climatique

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RÉSUMÉ

En raison des graves inondations que le monde a connues au cours des dix dernières années, il est évident que des outils hydrauliques sont nécessaires pour adapter le monde au changement climatique et établir une base solide pour les décisions politiques. Ce document couvre les sujets suivants: 1) La description des méthodes d'adaptation au changement climatique dans les zones urbaines par rapport au cycle complet de l'eau, 2) La proposition des moyens de communication avec les pouvoirs politiques, 3) La description des problèmes interdisciplinaires pouvant émerger dans le processus, 4) La description de moyens pour prioriser les efforts d'adaptation des villes au changement climatique et 5) La proposition de méthodes et outils hydrauliques utilisables dans le processus d'adaptation. Ce document décrit des stratégies modernes de gestion pour adapter les systèmes d'assainissement urbain au changement climatique, telles que présentées dans DANVA, 2007. Enfin, le projet démontre l'usage de ces lignes directrices appliquées au bassin versant de Greve, au Danemark.

ABSTRACT

Due to the serious flooding the world has experienced during the last ten years, it is obvious that hydraulic tools are necessary to adapt the world to climate changes and establish a solid basis for political decisions. This paper is focused on: 1) Describing methods for adapting to climate changes in urban areas with respect to the total water cycle, 2) Suggesting ways of communication with the political system, 3) Describing interdisciplinary issues, 4) Describing how to prioritize the efforts when adapting to climate changes in a city and 5) Proposing methods and hydraulic tools which can be used in the adapting process. The paper outlines updated management strategies for the adaptation of urban drainage systems to climate change as presented in DANVA, 2007. Finally the project demonstrates the use of these guidelines in the catchment of Greve, in Denmark.

KEYWORDS

Prioritizing adaptation to climate changes in urban areas, total water cycle, flood modelling, emergency plans, guidelines on “climate proofing” a city.

1 INTRODUCTION

It is in the interest of the society to protect the population and infrastructure from the damage, cost and public health risk associated with overload of sewage and drainage systems. The climate scenarios estimated by IPCC (IPCC, 2007) indicate that the precipitation in Denmark will change significantly. It is important that the sewage and drainage systems are prepared to handle the expected increase in precipitation. The upgrade and management of the systems should be implemented in the most cost-effective way with respect to environmental legislation and national standards in Denmark. To ensure a high level of service in all municipalities in Denmark an overview of how to analyze the effects of climate change a set of guidelines (DANVA, 2007) was published by The Danish Water and Wastewater Association (DANVA) in 2007. The guidelines have amongst the Danish municipalities got the nickname "The Climate Cookbook", as it "gives recipes" for consistent analyses on the impacts of climate change.

This paper presents an updated version of "Guidelines on how to manage the effect of climate change on the sewage system". Since the first version of the "Climate Cookbook", new software tools have been developed partly based on new experiences of implementing the guidelines.

Further, in the summer of 2007 many cities in Denmark were subject to severe flooding and this showed an immediate need to begin the work with securing and preparing Danish cities to meet the challenges of climate change. A new section in the guidelines includes descriptions and illustrations of a methodology used to prioritize implementation of strategies needed to reduce flooding. In 2007, after the first publication of the guidelines, prolonged extreme rains have resulted in flooding of low-lying areas. The capacity of the sewage systems, drainage channels and streams were exceeded and it showed a need for the traditional hydraulic pipe flow modelling to be extended to include integrated modelling of the water cycle. The methodology for integrated modelling consists of a combined model of surface water, groundwater and the sewage system. In addition to the change in rainfall the groundwater levels may also change due to climate change, and how integrated modelling should be implemented in resilient flood management will be discussed together with the integrated modelling results.

In this paper key learning points for future implementation of integrated urban drainage management will be discussed. In addition to the technical modelling aspects, the collaboration and accountability of all levels of government and individuals in a bottom-up process of shared planning and decision-making will be discussed. One case study demonstrating the guidelines in a catchment in Greve, Denmark are included.

2 METHODS

The updated "Climate Cookbook" describes adaptation methods in order to help the municipalities to:

1. Take into account the latest available knowledge about the effects of climate change from IPCC, e.g. changes in precipitation, groundwater and rise in sea level.
2. Identify flood risk areas and make flood risk maps.
3. Prioritize implementation of efforts to reduce flooding and upgrade of drainage systems, e.g. emergency plans.
4. Implement climate change management (guidelines on legislation, communication, cross disciplinary collaboration, etc.)

The "Climate Cookbook" is aiming to be continuously brought up to date with the latest climate change prognosis and measures for adaptation to a changing climate. Hence, it provides the Danish municipalities with state-of-the-art information so they can prepare for tomorrow's climate in the most cost-efficient way.

Below is a short description of the methods used to adapt storm water systems to climate change (the methods are described in detail in the updated "Climate Cookbook"):

- GIS calculation of potential ponding, calculating the maximum potential flood without taking into account the actual rain and the system hydraulics (e.g. Djordjevic, 1999). This method is simple and quick, and only digital terrain data is needed, but the results are rather complicated to analyze. Large-scale catchments can be calculated with this method.
- 1D surface model applying rainwater to a 1D integrated surface but disregarding the collection

system (e.g. Jensen et al, 2010). Quick method and the level of input data are restrained to digital terrain data, impervious areas and rainfall. Large-scale catchments can be calculated with this method. Important input information regarding the collection system is neglected and less accuracy in the results must be expected compared to the following methods.

- 1D-1D coupled model applying the rainwater and the collection system (e.g. Jensen et al, 2010 forthcoming). Quick method, but high level of input data is necessary. Suitable for calculating large-scale catchments and online simulations. The accuracy of the results is close to the level of using a 2D surface model, but the actual flow on the surface is unknown.
- 1D-2D model applying a 2D dynamic surface model to a 1D collection model (e.g. Mike Flood, DHI 2009, Wallingford Software, 2009). Present the most accurate combined model type for flood simulation, but also time-consuming in respect to simulation time and restricted to calculation on small catchments or using large grid size. Suitable for detailed modelling.
- 1D-2D-Groundwater model applying a groundwater model to the 1D-2D model (e.g. Domingo et al, 2009). The most accurate combined model type for flood simulation influenced by groundwater. Time-consuming in respect to simulation time and restricted to calculation on small catchments or using large grid size.

In the following key learning points from the adaption methods described in the “Climate Cookbook” will be presented and discussed.

3 RESULTS AND DISCUSSION

3.1 Knowledge about climate change

The expected global climate change will result in changes in the Danish climate and changing sea levels for Danish waters. Generally it is expected that the temperature will rise, there will be more precipitation, evaporation will increase and sea level will rise. It is also expected that there will be more rain events with high intensity and stronger wind. Forecasts for temperature, precipitation and evaporation ratio varies over Denmark. Projections of the climatic conditions in Denmark are calculated by the Danish Meteorological Institute (DMI), using global climate models as boundary condition. DMI works with a resolution of approx. 12.5 km x 12.5 km in a network covering Denmark.

Officially three climate scenarios (A2, B2, EU2C) calculated by the Climate Center at DMI are used in Denmark. These three scenarios are calculated based on IPCC reports from 2001 (IPCC, 2001). In Denmark these three scenarios are equal, i.e. there is not one of the scenarios that are considered to be more likely than the others and it is up to the Danish municipalities to choose which climate scenario, they will use.

From DMI's modelling of the change in precipitation from 1960-1990 to 2070-2100 it is estimated, that the maximum precipitation is likely to increase 20-50% (1 hr) during this period (Grum et al., 2005). Model calculations have provided hourly values of precipitation for areas of approx. 12.5 x 12.5 km. Variation from area to area is quite large. Some areas in Denmark have increases of up to 100% while others do not have any increase. There has been no explanation for these differences. They are evidently not terrain dependent or province specific. They appear to be random. It is therefore chosen so far to recommend the same factor range for the entire country, namely 1.2-1.5.

Intervals for expected sea level rise, groundwater changes and water levels in freshwater areas are presented in the “Climate Cookbook”. These guidelines are important so all municipalities in Denmark use the same set of values.

3.2 Identify flood risk areas

When adapting to climate change it is important to use the correct hydraulic tools at the right stage in the process otherwise resources may be used incorrectly: e.g. if the design of the storm water system is unknown there is no point in setting up a detailed hydraulic model based on a lot of assumptions and insufficient knowledge; the result will be too uncertain. On the other hand, important (i.e. expensive) decisions cannot be made on too little system knowledge.

In the beginning of an adaptation process, GIS analysis can be used to a large extent to prioritize how and where to make better models and to become familiar with how the urban drainage system works. The GIS analysis is able to tell where flooding is most likely to occur and where safe areas are located. In prioritized areas further analysis using rough hydraulic models can be used to evaluate the

physics of possible floods and thereby to decide whether more complex models should be used, e.g. is there a need for hydraulic modelling of the recipient (the stream, lake or sea)? Or is there a need for modelling the groundwater zone to calculate the flow to the streams from the groundwater zone?

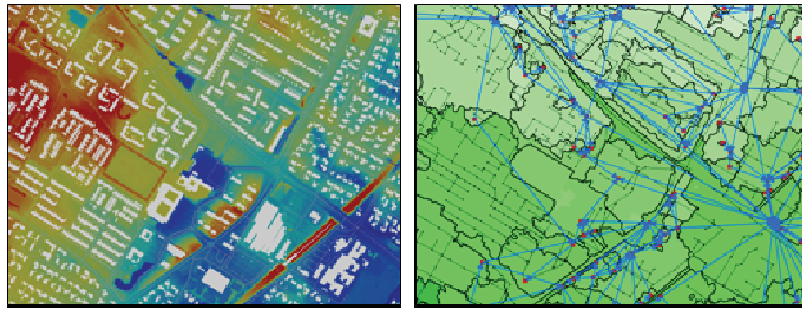


Figure 1: From pure terrain data manipulated in GIS to advanced hydraulic computer modelling.

The method using the terrain model at one of the levels can be called "technical track" (see Figure 2). When you want to use terrain models for analysis of climate change, it is very important to make clear what the analysis must be used for:

- Is it for the very first presentations for politicians who must decide on the administration to proceed with assessments of risk of flooding?
- Is it for deciding the level of service for the drainage system?
- Or on whether to implement climate adaptation and which solutions to choose?

Looking at the method from GIS model to sophisticated computer model as a speedometer or "climate meter" from left to right (see Figure 2), one can see the corresponding "decision meter" from the decision "we must investigate climate adaptation" to "we must adapt to climate change" or "the city is climate adapted and we will monitor the city". The application can be called the "political track". The "political track" follows the "technical track", because the policy-making processes require varying degrees of technical knowledge.

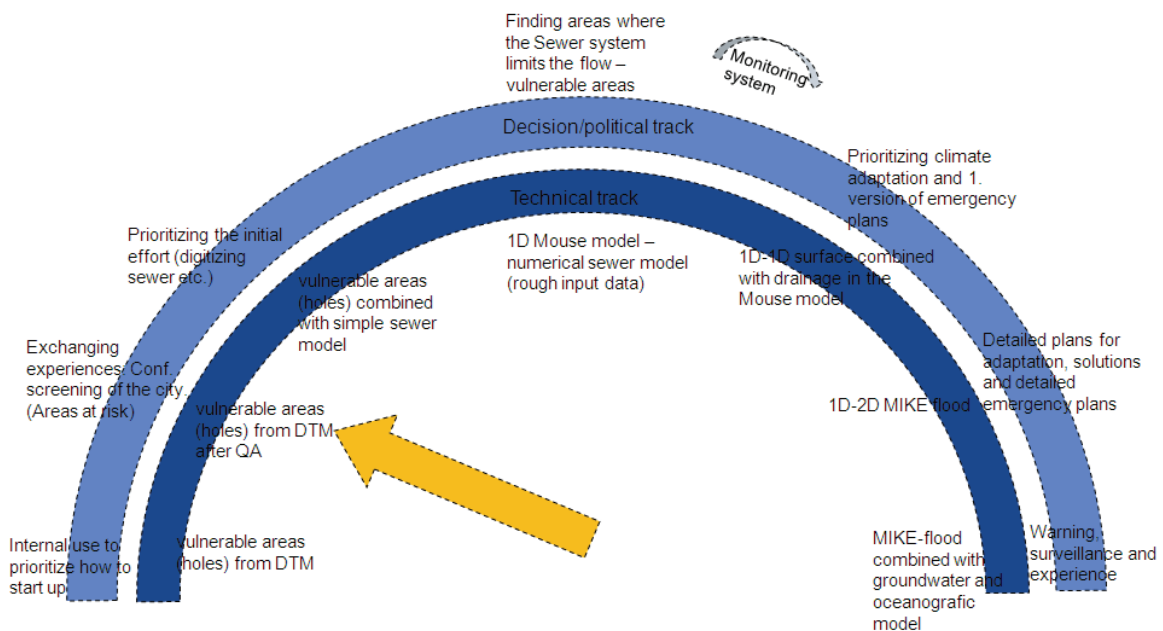


Figure 2: Illustration of how to use model tools - "Climate or decision meter".

When climate adaptation is to be implemented in the administration, terrain models can be combined with hydraulic assessments and used for very different things: the city planner will have an idea of which areas to reserve for rainwater, they can be used to assess whether there can be given planning permission, they can be used by environmental planner/river authorities to assess where to create wet

lands and the landscape architect to assess how various natural elements should be located. Here the different disciplines use different technical knowledge and follow the “climate meter” for the “technical track”. There can be added a “multidisciplinary track”, where the potential use of different disciplines in technical management can be placed.

The cost for achieving the various levels of knowledge on the “climate meter” ranging from relatively cheap to relatively expensive, from left to right: one can develop a relatively simple GIS model, but the work needed to establish an advanced hydraulic model which includes the entire water cycle is much more complicated and time consuming.

Similarly, many other aspects of climate adaptation fit into the “climate meter” to support decisions on where to start and where to end: e.g. who will use different methods: the State, the Regions, municipalities or utilities.

3.3 Prioritizing adaptation to climate changes

The guidelines on recommendations (called service levels) for flooding in Denmark are the following:

- In combined systems maximum return period of water reaching critical level is 10 year
- In separate systems maximum return period of water reaching critical level is 5 year

These are minimum requirements, and the municipalities may decide to implement additional and/or more stringent requirements. It is the actual situation in the catchment which is decisive, meaning the experienced flooding and it is pointed out that renovation of the drainage systems must take into account the expected future changes in climate, so the system throughout the life expectancy meets the required functional requirements.

To check whether service levels for the sewage system are met, calculations (equivalent to rainfall described in section 3.1) can be carried out. This will illustrate the drainage system response to changes in climate with return periods of 10, 25, 50 and 100 years. The analysis will show for which parts of the drainage system the functional demand is exceeded and an indication of how often it happens. This information can be included in plans for maintenance, renovation and used to prioritize the adaptation process.

Since detailed calculations have to be completed before the large investments are made, it is not possible to obtain an instant adaption for the complete urban city. Consequently it is necessary to prioritize adaptation for the urban areas. The hierarchy of city areas can be based on experiences of earlier floods and the terrain model of the municipality from the principle: the areas that have been most effected by floods should be the first to adapt to climate changes; secondly, areas with the highest amount of low-lying buildings can be identified using the terrain model.

Prioritizing the order of investigations can be based solely on the GIS analysis, whereas making decisions about expensive investments needs more detailed technical studies using more or less advanced hydraulic tools/models - depending on the decision to be made and the complexity of the area.

Prioritizing climate change adaptation can be added to the “climate meter” as another track that reflects the priorities can be implemented at various technical levels. E.g. it will be possible to prioritize where to start pipe registration if it is not available, based on a relatively simple GIS model, possible combined with an estimated hydraulic model.

3.4 Implementing climate change management

One of the most challenging issues of managing a sewer system is to explain to the public that flooding must be accepted to a certain extent. Figure 3 illustrates how to explain the choices to the decision-making politicians: How much flooding is acceptable? On the horizontal axis is shown the amount of precipitation (the farther to the right the greater rainfall) and on the vertical axis is the probability of flooding.

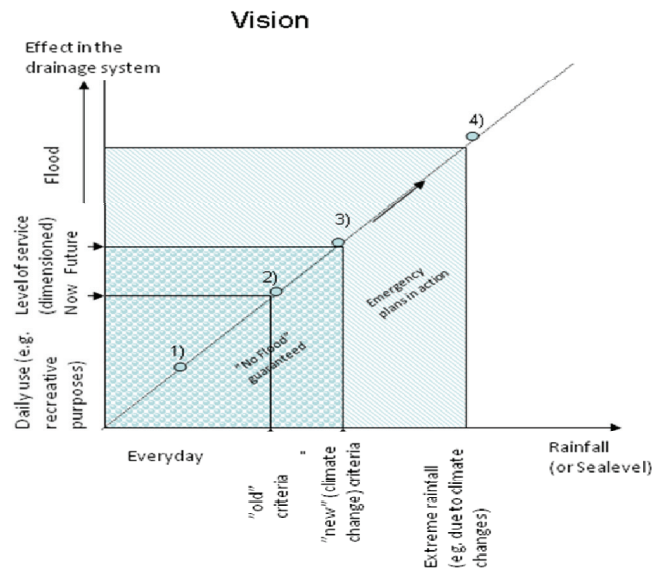


Figure 3: Illustration of design criteria (service level) of drainage and sewer systems.

Point 1) represents a normal rainfall and in this situation flooding should never occur. In this situation the facilities - lakes, canals, streams, etc. should be a natural part of the city and appear to be as recreational elements as possible.

Point 2) illustrates the limits on the guarantee against flooding with the old criteria in Denmark. This is equivalent to a rainfall with intensity of 8-9 mm over 10 minutes (return period of 2 years). In this situation the drainage systems will be under pressure, but there will not necessary be flooding.

In recent years heavy rainfall, has created a need to revise the criteria for an acceptable flood event and drainage systems need to be able to handle more rain. It is shown by point 3) which illustrates the new Danish functional practice from 2005. This is a guaranteed minimum service levels for all new installations. With rainfall greater than this flooding is accepted. This can be interpreted as a raise of the level of service. When going from 3) to 4) contingency plans need to be applied to reduce the damage from floods.

Point 4) specifies the conditions of the extreme rainfall, as seen in recent years in many municipalities in Denmark. In these situations (4) there are no guarantees against flooding. Contingency plans might reduce flooding, but it is likely that there is flooding. To ensure the city against such rainfall it would be necessary to move the guaranteed minimum service levels to 4) with significant investments as a consequence. It is a political issue, where you will place the guaranteed minimum level of service when upgrading the drainage system and what the inhabitants will tolerate or pay to secure the city against a given incident.

As it is today in Denmark, nobody is responsible for flooding in the cases where precipitation is above point 2) and there is no legislation guaranteeing the citizens against these extreme rain events.

Preparedness plans should be in place for rain events above point 4). They involve a wide range of actions protecting values and persons against damage caused by water. The contingency plans should of course include important phone numbers and other important administrative information, but in the "Climate Cookbook", it was only the hydraulic aspects of preparedness that was discussed. Preparedness can be divided into *before*, *during* and *after*. Before the event the situation must be investigated and a contingency plan shall be in place. During the event action must be taken and the plan must be followed. After the event experience will be evaluated and possibly incorporated into new plans. Figure 4 illustrates the possible components of flood preparedness.

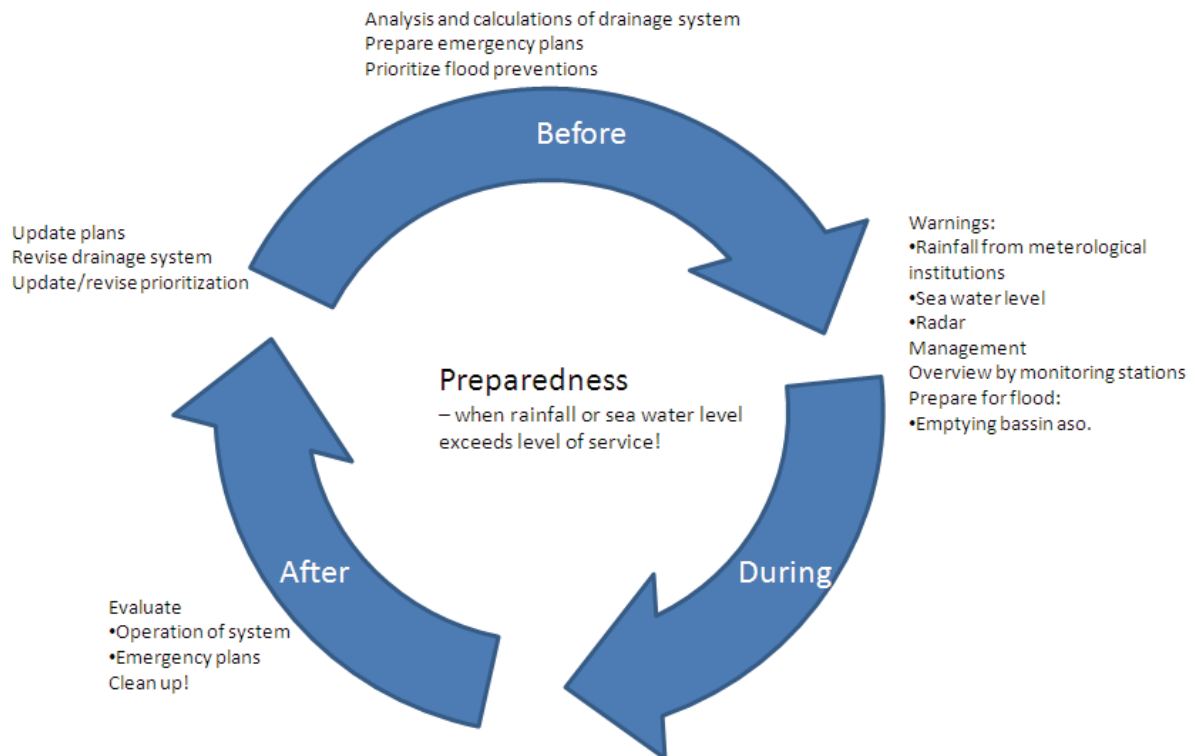


Figure 4 Illustration of a contingency plan.

3.5 Case study

The method in the “Climate Cookbook” was used in Greve, Denmark to enable politicians to decide whether to adapt to climate change or not and to what extent. “The Climate Cookbook” approach was applied to the most vulnerable area in the municipality and the cost was calculated.

In Greve Municipality it is politically decided that the entire drainage system in the city shall be upgraded to a maximum flooding frequency of once every 10 year. Based on experiences from the flooding in 2002 and 2007 (see Figure 5) and a vulnerability map prepared using a GIS model the municipality is divided into 42 urban areas and the climate adaptation is prioritised over the next 12-15 years.



Figure 5: Flooding, Greve 2002 – before adaptation to climate changes

Prioritization is carried out by the motto: those areas which have been hit the hardest will be adapted

first. An approach which is politically accepted. The hydraulic models will be developed and improved through measurement campaigns and experiences. If these models show that there is reason to prioritize differently than is done here, reprioritization will be made and presented to the political system. Economic issues may similarly prove it necessary to reprioritize, e.g. if a relatively simple and inexpensive measures will have significant positive impact on climate adaptation.

For the prioritization is used:

- Lessons from the floods in July 2007, which is reported directly from citizens or landowners.
- The digitization of storm water system.
- The digital terrain model for Greve Municipality which is used to calculate the depth of surface depressions.
- GIS themes of buildings in the municipality and the theme of business and public buildings.

Figure 6 shows the prioritizing Greve. If only a few previous flooding experiences exist in a city, terrain models or/and hydraulic modelling can be used to prioritize which areas to work on first. In Greve a model of the total storm water system (including streams) has been developed. To simulate flow on the terrain the digital terrain model has been used to locate “basins” in the city areas. This model, called “the strategic hydraulic model of Greve” has been used to quality assure the prioritization.



Figure 6: The prioritized city areas of Greve, Denmark.

Detailed emergency plans are in the process of being prepared for all areas to minimize the material damage and health risk in case of extreme rainfall. An example is shown in Figure 7.



Figure 7: Extreme rainfall. Left: without activating an emergency plan. Right: Activating an emergency plan.

4 CONCLUSION

This paper gives an overview of the work with upgrading the “Climate Cookbook” in Denmark and a status on the knowledge on climate change in Denmark today - in relation to drainage systems. The climate scenarios that exist today, suggest that rainfall over Denmark and water levels in the Danish waters are expected to change significantly. Danish drainage systems may have difficulties in complying with today's functional requirements, under the effect of future climate change if nothing is done. It is therefore important that the drainage systems are prepared to handle the anticipated increase in rainfall so that there is a sound and safe management of rain and sewage in accordance with Danish guidelines, while the financial investment is optimized.

Data requirements for climate analysis of drainage systems is, in addition to the data used today: climate projected rainfall and water levels in recipients, if the recipient has an impact on the capacity of the drainage system.

The paper describes methods for consistency analysis for design and analysis of functional requirements, taking into account possible future climate conditions and extreme rain events. The paper describes the problem identification and methods used to quantify the excess of functional requirements and determine the potential damage from floods. The methods presented in the paper are applied to a catchment in Greve, Denmark.

The methods described in this report are generic and can also be used when the existing climate scenarios will be updated with new estimates of precipitation and sea level rise.

A challenge in management and prioritization of climate change is the estimation of damage to society because of flooding. The principles behind the estimation of damage from flooding need to be discussed along with methods to reduce damage. There are still some issues, including pricing of damage before it can be more than just a count of the individual types of damage.

Forecast of extreme rain and warnings of floods in cities is an unexplored area in Denmark. Forecast of floods are systematically used abroad in combination with contingency plans. It is recommended to evaluate the efficacy of warning in combination with contingency plans to establish knowledge of Danish conditions at this point. Forecasts may be able to reduce the cost of adjusting the drainage systems to climate change, and can be used for optimization of existing systems in combination with or instead of constructing of new drainage systems.

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