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A regional and nonstationary model for partial duration series of extreme rainfall

Regional extreme value models for estimation of extreme rainfall intensities are widely applied, but their underlying assumption of stationarity is challenged. Many recent studies show that the rainfall extremes worldwide exhibit a nonstationary behavior. This paper presents a spatiotemporal model of extreme rainfall. The framework is built on a partial duration series approach with a nonstationary, regional threshold value. The model is based on generalized linear regression solved by generalized estimation equations. It allows a spatial correlation between the stations in the network and accounts furthermore for variable observation periods at each station and in each year. Marginal regional and temporal regression models solved by generalized least squares are used to validate and discuss the results of the full spatiotemporal model. The model is applied on data from a large Danish rain gauge network for four durations ranging from 10 min to 24 h. The observation period differs between stations, and the number of stations with more than 10 years of observations has increased over the years. A spatiotemporal model for the threshold is suggested, applying the mean annual precipitation and time as the explanatory variables in the regional and temporal domain, respectively. Further analysis of partial duration series with nonstationary and regional thresholds shows that the mean exceedances also exhibit a significant variation in space and time for some rainfall durations, while the shape parameter is found to be constant.
Assessing the importance of spatio-temporal RCM resolution when estimating sub-daily extreme precipitation under current and future climate conditions

The increase in extreme precipitation is likely to be one of the most significant impacts of climate change in cities due to increased pluvial flood risk. Hence, reliable information on changes in sub-daily extreme precipitation is needed for robust adaptation strategies. This study explores extreme precipitation over Denmark generated by the regional climate model (RCM) HIRHAM-ECEARTH at different spatial resolutions (8, 12, 25 and 50km), three RCM from the RiskChange project at 8km resolution and three RCMs from ENSEMBLES at 25km resolution at temporal aggregations from 1 to 48h. The performance of the RCM simulations in current climate as well as projected changes for 2081-2100 is evaluated for non-central moments of order 1-3 and for the 2- and 10-year events. The comparison of the RCM simulations and observations shows that the higher spatial resolution simulations (8 and 12km) are more consistent across all temporal aggregations in the representation of high-order moments and extreme precipitation. The biases in the spatial pattern of extreme precipitation change across temporal and spatial resolution. The hourly extreme value distributions of the HIRHAM-ECEARTH simulations are more skewed than the observational dataset, which leads to an overestimation by the higher spatial resolution simulations. Nevertheless, in general, under current conditions RCM simulations at high spatial resolution represent extreme events and high-order moments better. The changes projected by the RCM simulations
depend on the global climate model (GCM)-RCM combination, spatial resolution and temporal aggregation. The simulations disagree on the magnitude and spatial pattern of the changes. However, there is an agreement on higher changes for lower temporal aggregation and higher spatial resolution. Overall, the results from this study show the influence of the spatial resolution on the precipitation outputs from RCMs. The biases of the RCM simulations increase, and the projected changes decrease for decreasing spatial resolution of the simulations. This points towards the need for high spatial and temporal resolution RCMs to obtain reliable information on changes in sub-daily extreme precipitation.

**General information**
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Assessment of Urban Pluvial Flood Risk and Efficiency of Adaptation Options Through Simulations – A New Generation of Urban Planning Tools

We present a new framework for flexible testing of flood risk adaptation strategies in a variety of urban development and climate scenarios. This framework couples the 1D-2D hydrodynamic simulation package MIKE FLOOD with the agent-based urban development model DAnCE4Water and provides the possibility to systematically test various flood risk adaptation measures ranging from large infrastructure changes over decentralised water management to urban planning policies. We have tested the framework in a case study in Melbourne, Australia considering 9 scenarios for urban development and climate and 32 potential combinations of flood adaptation measures. We found that the performance of adaptation measures strongly depended on the considered climate and urban development scenario and the other implementation measures implemented, suggesting that adaptive strategies are preferable over one-off investments. Urban planning policies proved to be an efficient means for the reduction of flood risk, while implementing property buyback and pipe increases in a guideline-oriented manner was too costly. Random variations in location and time point of urban development could have significant impact on flood risk and would in some cases outweigh the benefits of less efficient adaptation strategies. The results of our setup can serve as an input for robust decision making frameworks and thus support the identification of flood risk adaptation measures that are economically efficient and robust to variations of climate and urban layout.

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Environmental impacts of stormwater management and pollutant discharges

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Environmental impacts of stormwater management and pollutant discharges

Stormwater management systems are necessary to protect people and assets from flooding and pollution, especially in densely built, sealed urban areas. The possible solutions range from underground pipes and basins, where rain water is often handled together with wastewater, to local and multi-functional solutions, e.g. rain beds or retention lakes. Ideally, these solutions are not only economically, but also environmentally sustainable. Risk assessments are sometimes carried out, e.g. to determine the effect of discharges during extreme events, but they lack a holistic perspective: While pollutants in runoff are one possible source of (local) environmental impacts, the stormwater management system itself is a source of emissions. Raw material extraction, construction, operation, renewal, and disposal all cause environmental impacts at a more regional or even global scale. These impacts can be quantified using life cycle assessment, which on the other hand usually neglects the impacts from local emissions, even though these may potentially be significant. By integrating local emissions into the assessment, we are able to quantify the total environmental impacts of stormwater management solutions.

We have tested the approach using a sub-catchment of Copenhagen. The existing stormwater management system has to be adapted to climatic changes to maintain existing flood safety levels. The environmental impacts from both local and global emissions over a period of 100 years have been quantified using life cycle assessment. The inventory for the assessment is based on an extensive literature research, planning documents and expert interviews.

Here, we focus on the ecotoxicity impacts: The impact over the whole life cycle of the system, excluding local emissions, is 14 mio comparative toxic units (CTUe). This ecotoxicity impact is mainly caused by the emission of metals. Metals are, however, also important pollutants in stormwater runoff. In Copenhagen, the emission of stormwater pollutants from runoff are found to cause additional impacts of 19 mio CTUe when discharged directly to freshwater. If the water first infiltrates through soil, the impacts are significantly lower (10 mio CTUe). The stormwater system itself is passive, and mainly causes impacts during construction, while runoff goes through the system constantly over 100 years, which explains the large difference in impacts. The results are characterized by a high uncertainty, which is caused by large ranges in measured concentrations in literature (up to 5 orders of magnitude). Limiting these uncertainties is the subject of ongoing research. Our results highlight the importance of including local emission of toxic compounds in stormwater management systems. Often, an increase in global emission, e.g. through the construction of treatment facilities, will lead to reduced local impacts, and vice versa. By taking into account both local and global impacts, stormwater management systems can be optimized holistically to minimize environmental impacts and create more sustainable stormwater management systems.

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**Flood damage assessment – Literature review and recommended procedure**

The assessment of flood risk is an essential tool in evaluating the potential consequences of a flood. The analysis of the risk can be applied as part of the flood plain management, but can also be used in a cost-benefit analysis, when comparing different adaption strategies. This analysis is therefore important when assessing flood disaster mitigation options and economical optimizations of possible measures. A common definition is that the flood risk is found with the use of a flood hazard assessment and a flood vulnerability assessment (Apel, Merz and Thieken, 2008).

The flood hazard is the quantification of amount, extent, and location of flooding expected to occur with a given return period. This means that the spatial distribution of the calculated inundation depth as a function of the return period can be used to describe the flood hazard. The vulnerability is the susceptibility of the area subjected to the flooding. A way to express the vulnerability is through a damage cost assessment.

**Formulating and testing a method for perturbing precipitation time series to reflect anticipated climatic changes**

Urban water infrastructure has very long planning horizons, and planning is thus very dependent on reliable estimates of the impacts of climate change. Many urban water systems are designed using time series with a high temporal resolution. To assess the impact of climate change on these systems, similarly high-resolution precipitation time series for future climate are necessary. Climate models cannot at their current resolutions provide these time series at the relevant scales. Known methods for stochastic downscaling of climate change to urban hydrological scales have known shortcomings in constructing realistic climate-changed precipitation time series at the sub-hourly scale. In the present study we present a deterministic methodology to perturb historical precipitation time series at the minute scale to reflect non-linear expectations to climate change. The methodology shows good skill in meeting the expectations to climate change in extremes at the event scale when evaluated at different timescales from the minute to the daily scale. The methodology also shows good skill with respect to representing expected changes of seasonal precipitation. The methodology is very robust against the actual magnitude of the expected changes as well as the direction of the changes (increase or decrease), even for situations where the extremes are increasing for seasons that in general should have a decreasing trend in precipitation. The methodology can provide planners with valuable time series representing future climate that can be used as input to urban hydrological models and give better estimates of climate change impacts on these systems.
This paper presents a novel modeling analysis of a 40-year-long dataset to examine the impact of urbanization, with widespread stormwater infiltration, on groundwater levels and the water balance of a watershed. A dataset on the hydrologic impact of urbanization with extensive stormwater infiltration is not widely available, and is important because many municipalities are considering infiltration as an alternative to traditional stormwater systems. This study analyzes groundwater level observations from an urban catchment located in Perth, Western Australia. The groundwater observation data cover approximately a 40-year-long period where land use changes (particularly due to urbanization) occurred; moreover, the monitored area contains both undeveloped and urbanized areas where stormwater infiltration is common practice via soakwells (shallow vertical infiltration wells). The data is analyzed using a distributed and dynamic...
hydrological model to simulate the groundwater response. The model explicitly couples a soakwell model with a groundwater model so that the performance of the soakwells is reduced by the increase of groundwater levels. The groundwater observation data is used to setup, calibrate and validate a coupled MIKE SHE-MIKE URBAN groundwater model and the model is used to quantify the extent of groundwater rise as a result of the urbanization process. The modeled urbanization processes included the irrigation of new established private and public gardens, the reduction of evapotranspiration due to a decrease in green areas, and the development of artificial stormwater infiltration. The study demonstrates that urbanization with stormwater infiltration affects the whole catchment water balance, increasing recharge and decreasing evapotranspiration. These changes lead to a rise in the groundwater table and an increase in the probability of groundwater seepage above terrain.

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Regional frequency analysis of short duration rainfall extremes using gridded daily rainfall data as co-variate

A regional partial duration series (PDS) model is applied for estimation of intensity duration frequency relationships of extreme rainfalls in Denmark. The model uses generalised least squares regression to relate the PDS parameters to gridded rainfall statistics from a dense network of rain gauges with daily measurements. The Poisson rate is positively correlated to the mean annual precipitation for all durations considered (1 min to 48 hours). The mean intensity can be assumed constant over Denmark for durations up to 1 hour. For durations larger than 1 hour the mean intensity is significantly correlated to the mean extreme daily precipitation. A Generalised Pareto distribution with a regional constant shape parameter is adopted. Compared to previous regional studies in Denmark a general increase in extreme rainfall intensity for durations up to 1 hour is found, whereas for larger durations both increases and decreases are seen. A subsample analysis is conducted to evaluate the impacts of non-stationarities in the rainfall data. The regional model includes the nonstationarities as an additional source of uncertainty together with sampling uncertainty and uncertainty caused by spatial variability.
Weather radar rainfall data in urban hydrology

Application of weather radar data in urban hydrological applications has evolved significantly during the past decade as an alternative to traditional rainfall observations with rain gauges. Advances in radar hardware, data processing, numerical models, and emerging fields within urban hydrology necessitate an updated review of the state of the art in such radar rainfall data and applications. Three key areas with significant advances over the past decade have been identified: (1) temporal and spatial resolution of rainfall data required for different types of hydrological applications, (2) rainfall estimation, radar data adjustment and data quality, and (3) nowcasting of radar rainfall and real-time applications. Based on these three fields of research, the paper provides recommendations based on an updated overview of shortcomings, gains, and novel developments in relation to urban hydrological applications. The paper also reviews how the focus in urban hydrology research has shifted over the last decade to fields such as climate change impacts, resilience of urban areas to hydrological extremes, and online prediction/warning systems. It is discussed how radar rainfall data can add value to the aforementioned emerging fields in current and future applications, but also to the analysis of integrated water systems.

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Accounting for multiple functions in environmental life cycle assessment of storm water management solutions

The wide range of approaches to handle storm water runoff have varying effects on the environment. Local stormwater control measures for retention and treatment are increasingly used components in urban climate adaptation plans. Often, these solutions modify the multiple functions of urban environments by adding green and blue elements, and they change the water balance compared to traditional, underground approaches. Additionally, different implementation and maintenance processes are required. All of these transformations affect the environmental impacts of urban storm water management (SWM) systems, which can be quantified using Life Cycle Assessment (LCA). This study aims to define the multiple functions provided by a SWM system at sub-catchment scale, and to assess the environmental impacts arising from fulfilling these functions. The approach is tested using the Nørrebro catchment in Copenhagen, Denmark, where extensive implementation of green infrastructure is planned to mitigate the adverse effects of climate change. This « green » scenario is compared to a traditional « grey » solution, utilizing pipes and basins. The environmental impacts, which are dominated by material production in both scenarios, are significantly lower for the « green » solution (35% down to 8% of the "grey" impacts). The allocation of impacts shows that the various functions of the SWM systems cause different impacts.

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Relations
A new tool for quantifying the hydrological effects of LID retrofit designs – the power of simplicity

We developed a new tool to address the needs of utility companies in the early planning and design phase of LID for retrofitting in existing urban areas, where a high degree of collaboration among stakeholders with different professional backgrounds is needed. The tool uses simplified methods to assist the user in quickly assessing two key overall performance indicators of a LID plan: 1. Return period for overflow, and 2. Impact on the annual water budget of the catchment. The tool currently allows combining three types of stormwater control measures (SCMs) commonly used in LID: permeable paving, bioretention units and local detention ponds. We present a case study to illustrate the usefulness of the tool in the context of climate change adaptation in Copenhagen and discuss further development plans including more SCMs, better user interface and assessing the uncertainties introduced by the simplifications in the tool.

An interdisciplinary approach to identify adaptation strategies that enhance flood resilience and urban liveability

This paper provides guidance on how to identify and design the most suitable climate adaptation strategies for enhancing the liveability and flood resilience of urban catchments. It presents findings from a case study of Elwood, a coastal Melbourne suburb regularly affected by flooding. The research integrates social science, architecture and environmental engineering to co-develop technical, design and policy solutions that respond to the local community’s vision for the future and are robust under a range of future climate, population and urban development scenarios. The paper shows that ensuring a city’s flood resilience involves a range of measures to retreat from, adapt to and defend against flooding; this necessarily requires an integrated approach and interdisciplinary expertise to develop adaptation pathways that are grounded in community aspirations and priorities, inspired by novel design solutions and informed by modelling of performance, robustness and economic viability.

Applying the “WSUD potential”-tool in the framework of the Copenhagen Climate Adaptation and Cloudburst Management Plans

Water Sensitive Urban Design (WSUD) is still in the “Opportunity”-phase of its stabilization process in Copenhagen, Denmark, indicating that there are controversies surrounding its proper use and the regulatory framework is not completely adapted to the new technology. In 2015 private land owners in Denmark could get up to 100% of the construction costs of climate adaptation measures funded by the utility companies, which resulted in a race to apply for this co-funding plan. In this study we briefly review the climate adaptation framework in Copenhagen, and then discuss
how well different scenarios of WSUD in a case study area interact with this framework. The impacts of the different scenarios are assessed using the "WSUD-potential" tool, which builds upon the Three Points Approach. The results indicate that there is a schism between the city’s Cloudburst Management Plan on one side and its Climate Adaptation Plan and general service goal on the other side, which may result in over-sizing of the collective stormwater management system.

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**Assessment of Coastal and Urban Flooding Hazards Applying Extreme value Analysis and Multivariate Statistical techniques A Case study in Elwood, Australia**

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Developing Fast and Reliable Flood Models
State-of-the-art flood modelling in urban areas are based on distributed physically based models. However, their usage is impeded by high computational demands and numerical instabilities, which make calculations both difficult and time consuming. To address these challenges we develop and test a cheaper-to-run surrogate model, which aims to emulate the response of an original model. The surrogate model is set up by lumping the original model into compartments. These are confined areas in which the volume is modelled by surrogates. We develop two types of surrogates: (i) The drainage system is modelled by response surface surrogates, which are empirical data driven models. These are trained using the volume-discharge relations by piecewise linear functions. (ii) The surface flooding is modelled by lower-fidelity physically based surrogates, which are based on surface depressions and flow paths. A surrogate model is set up for a case study area in Aarhus, Denmark, to replace a MIKE FLOOD model. The drainage surrogates are able to reproduce the MIKE URBAN results for a set of rain inputs. The coupled drainage-surface surrogate model lacks details in the surface description which reduces its overall accuracy. The model shows no instability, hence larger time steps can be applied, which reduces the computational time by more than a factor 1400. In conclusion, surrogate models show great potential for usage in urban water modelling.

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems
Authors: Thrysøe, C. (Intern), Toke, J. (Intern), Borup, M. (Intern), H. Ravn, N. (Ekstern), Ambjerg-Nielsen, K. (Intern)
Number of pages: 4
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Host publication information
Title of host publication: Proceedings of 9th International Conference on Planning and Technologies for Sustainable Urban Water Management
Main Research Area: Technical/natural sciences
Conference: 9th International Conference on Planning and Technologies for Sustainable Urban Water Management (NOVATECH), Lyon, France, 28/06/2016 - 28/06/2016
Emulation, Flood, Hydraulic modelling, Surrogate, Urban drainage
Electronic versions:
Thrysoe_NOVATECH_2016.pdf
Source: PublicationPreSubmission
Source-ID: 125379730
Publication: Research - peer-review › Article in proceedings – Annual report year: 2016

Downscaling future precipitation extremes to urban hydrology scales using a spatio-temporal Neyman–Scott weather generator

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems, Danish Meteorological Institute
Authors: Sørup, H. J. D. (Intern), Christensen, O. B. (Ekstern), Ambjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern)
Pages: 1387-1403
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Main Research Area: Technical/natural sciences

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Web of Science (2016): Indexed yes
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Scopus rating (2015): SJR 2.225 SNIP 1.497 CiteScore 3.74
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Scopus rating (2014): SJR 2.144 SNIP 1.635 CiteScore 3.71
Drivers of flood damage on event level

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems
Number of pages: 1
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Main Research Area: Technical/natural sciences
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Drivers of flood damage on event level

Flood risk is dynamic and influenced by many processes related to hazard, exposure and vulnerability. Flood damage increased significantly over the past decades, however, resulting overall economic loss per event is an aggregated indicator and it is difficult to attribute causes to this increasing trend. Much has been learned about damaging processes during floods at the micro-scale, e.g. building level. However, little is known about the main factors determining the amount of flood damage on event level. Thus, we analyse and compare paired flood events, i.e. consecutive, similar damaging floods that occurred in the same area. In analogy to ‘Paired catchment studies’ - a well-established method in hydrology to understand how changes in land use affect streamflow – we will investigate how and why resulting flood damage in a region differed between the first and second consecutive flood events. One example are the 2002 and 2013 floods in the Elbe and Danube catchments in Germany. The 2002 flood caused the highest economic damage (EUR 11600 million) due to a natural hazard event in Germany. Damage was so high due to extreme flood hazard triggered by extreme precipitation and a high number of resulting dyke breaches. Additionally, exposure hotspots like the city of Dresden at the Elbe river as well as some smaller municipalities at the river Mulde (e.g. Grimma, Eilenburg, Bitterfeld, Dessau) were severely impacted. However, affected parties and authorities learned from the extreme flood in 2002, and many governmental flood risk programs and initiatives were launched. Considerable improvements since 2002 occurred on many levels that deal with flood risk reduction and disaster response, in particular in 1) increased flood prevention by improved spatial planning, 2) an increased number of property-level mitigation measures, 3) more effective early warning and improved coordination of disaster response and 4) a more targeted maintenance of flood defence systems and their deliberate relocation. Thus, despite higher hydrological severity damage due to the 2013 flood was significantly lower than in 2002. In our international comparative paired event study we investigate under which circumstances similar or contrasting processes occurred and hope to identify common key processes which determine flood damage on event level.
Effect of climate change on stormwater runoff characteristics and treatment efficiencies of stormwater retention ponds; a case study from Denmark using TSS and Cu as indicator pollutants. SpringerPlus, 5:1984, 1-12.

This study investigated the potential effect of climate changes on stormwater pollution runoff characteristics and the treatment efficiency of a stormwater retention pond in a 95 ha catchment in Denmark. An integrated dynamic stormwater runoff quality and treatment model was used to simulate two scenarios: one representing the current climate and another representing a future climate scenario with increased intensity of extreme rainfall events and longer dry weather periods. 100-year long high-resolution rainfall time series downscaled from regional climate model projections were used as input. The collected data showed that total suspended solids (TSS) and total copper (Cu) concentrations in stormwater runoff were related to flow, rainfall intensity and antecedent dry period. Extreme peak intensities resulted in high particulate concentrations and high loads but did not affect dissolved Cu concentrations. The future climate simulations showed an increased frequency of higher flows and increased total concentrations discharged from the catchment. The effect on the outlet from the pond was an increase in the total concentrations (TSS and Cu), whereas no major effect was observed on dissolved Cu concentrations. Similar results are expected for other particle bound pollutants including metals and slowly biodegradable organic substances such as PAH. Acute toxicity impacts to downstream surface waters seem to be only slightly affected. A minor increase in yearly loads of sediments and particle-bound pollutants is expected, mainly caused by large events disrupting the settling process. This may be important to consider for the many stormwater retention ponds existing in Denmark and across the world.

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems, Environmental Chemistry
Authors: Sharma, A. K. (Intern), Vezzaro, L. (Intern), Birch, H. (Intern), Ambjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern)
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BFI (2016): BFI-level 1
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Web of Science (2016): Indexed yes
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Scopus rating (2015): SJR 0.433 SNIP 0.562 CiteScore 1.02
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Scopus rating (2014): SJR 0.313 SNIP 0.551 CiteScore 0.83
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Electronic versions:
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Source-ID: 127229162
Publication: Research - peer-review › Journal article – Annual report year: 2016

Efficiency of stormwater control measures for combined sewer retrofitting under varying rain conditions: Quantifying the Three Points Approach (3PA)
We present a method to assess and communicate the efficiency of stormwater control measures for retrofitting existing urban areas. The tool extends the Three Points Approach to quantitatively distinguish three rainfall domains: (A) rainwater resource utilisation, (B) urban stormwater drainage pipe design, and (C) pluvial flood mitigation. Methods for calculating
efficiencies are defined recognizing that rainfall is both a valuable resource and a potential problem. Efficiencies are quantified in relation to rainfall volume, supplied potable water volume and volume of wastewater treated. A case study from Denmark is used to illustrate how the efficiency varies between the rainfall domains. The method provides a means for communicating some important quantitative aspects of stormwater control measures among engineers, planners and decision makers working with management of water resources, stormwater drainage and flood risks.

**General information**

State: Published

Organisations: Department of Environmental Engineering, Urban Water Systems

Authors: Sørup, H. J. D. (Intern), Lerer, S. M. (Intern), Arnbjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern), Rygaard, M. (Intern)

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Main Research Area: Technical/natural sciences

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- Scopus rating (2016): SJR 1.656 SNIP 1.605 CiteScore 3.9
- Web of Science (2016): Indexed Yes
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- Scopus rating (2015): SJR 1.647 SNIP 1.514 CiteScore 3.83
- BFI (2014): BFI-level 2
- Scopus rating (2014): SJR 1.826 SNIP 1.848 CiteScore 4.02
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- Scopus rating (2013): SJR 1.695 SNIP 1.999 CiteScore 4.08
- ISI indexed (2013): ISI indexed yes
- BFI (2012): BFI-level 2
- Scopus rating (2012): SJR 1.499 SNIP 1.652 CiteScore 3.35
- ISI indexed (2012): ISI indexed yes
- BFI (2011): BFI-level 2
- Scopus rating (2011): SJR 1.299 SNIP 1.689 CiteScore 3.06
- ISI indexed (2011): ISI indexed yes
- BFI (2010): BFI-level 2
- Scopus rating (2010): SJR 1.271 SNIP 1.338
- BFI (2009): BFI-level 2
- Scopus rating (2009): SJR 1.155 SNIP 1.56
- BFI (2008): BFI-level 2
- Scopus rating (2008): SJR 0.991 SNIP 1.094
- Scopus rating (2007): SJR 0.936 SNIP 1.565
- Web of Science (2007): Indexed yes
- Scopus rating (2006): SJR 0.694 SNIP 1.421
- Scopus rating (2005): SJR 0.607 SNIP 1.166
- Web of Science (2005): Indexed yes
- Scopus rating (2004): SJR 0.598 SNIP 1.227
- Scopus rating (2003): SJR 0.39 SNIP 0.701
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- Scopus rating (2001): SJR 0.327 SNIP 0.301
- Web of Science (2001): Indexed yes
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- Scopus rating (1999): SJR 0.197 SNIP 0.273

Original language: English

Stormwater control measures, Stormwater management, Three point approach
Environmental impacts of flood control measures in climate change adaptation strategies

Because of climatic changes, large investments are needed to keep flood risk at an acceptable level in urban areas. Increasing dimensions of underground sewer systems and retention basins are increasingly supplemented with multi-functional approaches, aimed at managing water locally and/or route it on the surface without harming assets. When evaluating different adaptation approaches, a cost assessment is typically carried out, while environmental impacts usually are not considered. To close this gap, a Life Cycle Assessment (LCA) based method is developed, which allows to quantify environmental impacts of different storm water management strategies. It is tested with two different adaptation strategies for the Nørrebro catchment in Copenhagen, Denmark: A Cloudburst Management Plan (CMP), which uses a multi-functional approach and combines green infrastructure with subsurface pipes, and a Subsurface scenario (SSA), which uses only pipes and underground retention basins. To ensure comparability, flood safety levels for different rain events are defined, which have to be met in both scenarios. The environmental impacts are calculated for eight different categories, including climate change, resource depletion, eutrophication and acidification. The case study shows significantly lower impacts for the multi-functional, green infrastructure CMP, compared to the SSA. Among the installations, those measures which are installed to ensure no water on the surface during rain events with a return period of 10 years and handling small events with a return period of up to 0.2 years cause by far the largest share of the total environmental impacts in both scenarios (up to 96% for the CMP, and up to 84% for the SSA. In contrast, measures aimed at handling extreme events with a return period of up to 100 years only contribute up to 4% of the environmental impacts for the CMP and less than 1% for the SSA. Our method helps explain how the handling of everyday events and extreme rain events affect the environmental sustainability of climate change adaptation and it enables cities to consider the environmental sustainability of climate change adaptation solutions in the planning process.
Environmental impacts of flood control measures in climate change adaptation strategies

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Environmental life cycle assessment of urban storm water management

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems
Authors: Brudler, S. (Intern), Arnbjerg-Nielsen, K. (Intern), Rygaard, M. (Intern)
Pages: 10-10
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DWF_Environmental_life_cycle_assessment_of_urban_storm_water_management.pdf
Source: PublicationPreSubmission
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Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2016

Explanatory analysis of the relationship between atmospheric circulation and occurrence of flood generating events in a coastal city

The aim of this study is to enhance the understanding of the occurrence of flood generating events in urban areas by analyzing the relationship between large-scale atmospheric circulation and extreme precipitation events, extreme sea water level events and their simultaneous occurrence, respectively. To describe the atmospheric circulation we used the Lamb circulation type (LCT) classification and re-grouped it into Lamb circulation classes (LCC). The daily LCCs/LCTs were connected with rare precipitation and water level events in Aarhus, a Danish coastal city. Westerly and cyclonic LCCs (W, C, SW, and NW) showed a significantly high occurrence of extreme precipitation. Similarly, for extreme water level events westerly LCCs (W and SW) showed a significantly high occurrence. Significantly low occurrence of extreme precipitation and water level events was obtained in easterly LCCs (NE, E, and SE). For concurrent events significantly high occurrence was obtained in LCC W. We assessed the change in LCC occurrence frequency in the future based on two regional climate models (RCMs). The projections indicate that the westerly directions in LCCs are expected to increase in the future. Consequently, simultaneous occurrence of extreme water level and precipitation events is expected to increase in the future as a result of change in LCC frequencies. The RCM projections for LCC frequencies are uncertain because the representation of current LCCs is poor; a large number of days cannot be classified and the frequencies of the days that can be classified differ from the observed time series. This article is protected by copyright. All rights reserved.

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering, Department of Hydrodynamics and Water Resources, Water Resources Engineering, Department of Environmental Science and Engineering, DHI
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Main Research Area: Technical/natural sciences

Publication information
Journal: Hydrological Processes
Volume: 30
Issue number: 16
ISSN (Print): 0885-6087
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
Flood risk assessment as an integral part of urban planning

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems
Authors: Löwe, R. (Intern), Urich, C. (Ekstern), Sto Domingo, N. (Ekstern), Mark, O. (Ekstern), Deletic, A. (Ekstern), Arnbjerg-Nielsen, K. (Intern)
Number of pages: 1
Publication date: 2016
Håndtering af regnvand i byer – herunder LAR

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems
Authors: Arnbjerg-Nielsen, K. (Intern)
Pages: 3-3
Publication date: 2016

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Title of host publication: Håndtering af regnvand i byen - herunder LAR : Vand & Jord
Volume: 4
Publisher: Nepper & Stagehøj
Editor: Øgaard Dahl, S.
Series: Vand
ISSN: 0908-7761
Main Research Area: Technical/natural sciences
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High-resolution rainfall time series for future climate

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems, Department of Applied Mathematics and Computer Science, Statistics and Data Analysis
Authors: Sørup, H. J. D. (Intern), Georgiadis, S. (Intern), Gregersen, I. B. (Intern), Arnbjerg-Nielsen, K. (Intern)
Pages: 42-42
Publication date: 2016

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Place of publication: Bergen, Norway
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Conference: 4th Nordic Conference on Climate Change Adaptation, Bergen, Norway, 29/08/2016 - 29/08/2016
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Hurra! Hurra?!

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems
Authors: Arnbjerg-Nielsen, K. (Intern)
Impacts of urban development and climate change in exposing cities to pluvial flooding

Urban areas are characterized by very high concentrations of people and economic activities and are thus particularly vulnerable to flooding during extreme precipitation. Urban development and climate change are among the key drivers of changes in the exposure of cities to the occurrence and impacts of pluvial flooding. Cities are often dominated by large areas of impervious surfaces, that is, man-made sealed surfaces which water cannot penetrate, and increases in these – for example, as a consequence of urban development – can cause elevated run-off volumes and flood levels during precipitation. Climate change is expected to affect the intensity and frequency of extreme precipitation, with increases projected for many regions, including most parts of Europe.

General information
State: Published
Organisations: Department of Management Engineering, Systems Analysis, Department of Environmental Engineering, Urban Water Systems, Department of Applied Mathematics and Computer Science, Dynamical Systems
Authors: Kaspersen, P. S. (Intern), Drews, M. (Intern), Arnbjerg-Nielsen, K. (Intern), Madsen, H. (Intern)
Number of pages: 48
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Source-ID: 127822491
Joint optimization of regional water-power systems

Energy and water resources systems are tightly coupled; energy is needed to deliver water and water is needed to extract or produce energy. Growing pressure on these resources has raised concerns about their long-term management and highlights the need to develop integrated solutions. A method for joint optimization of water and electric power systems was developed in order to identify methodologies to assess the broader interactions between water and energy systems. The proposed method is to include water users and power producers into an economic optimization problem that minimizes the cost of power production and maximizes the benefits of water allocation, subject to constraints from the power and hydrological systems. The method was tested on the Iberian Peninsula using simplified models of the seven major river basins and the power market. The optimization problem was successfully solved using stochastic dual dynamic programming. The results showed that current water allocation to hydropower producers in basins with high irrigation productivity, and to irrigation users in basins with high hydropower productivity was sub-optimal. Optimal allocation was achieved by managing reservoirs in very distinct ways, according to the local inflow, storage capacity, hydropower productivity, and irrigation demand and productivity. This highlights the importance of appropriately representing the water users' spatial distribution and marginal benefits and costs when allocating water resources optimally. The method can handle further spatial disaggregation and can be extended to include other aspects of the water-energy nexus.

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems, Water Resources Engineering, SINTEF, DHI Høra
Authors: Cardenal, S. J. P. (Intern), Mo, B. (Ekstern), Gjelsvik, A. (Ekstern), Riegels, N. D. (Ekstern), Ambjerg-Nielsen, K. (Intern), Bauer-Gottwein, P. (Intern)
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Main Research Area: Technical/natural sciences

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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.303 SNIP 2.093 CiteScore 4.31
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.948 SNIP 1.964 CiteScore 3.66
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.448 SNIP 1.786 CiteScore 3.03
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.574 SNIP 1.769 CiteScore 2.81
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.611 SNIP 1.734 CiteScore 2.84
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.707 SNIP 1.479
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.862 SNIP 1.652
Expected increases in pluvial flooding, due to climatic changes, require large investments in the retrofitting of cities to keep damage at an acceptable level. Many cities have investigated the possibility of implementing stormwater management (SWM) systems which are multi-functional and consist of different elements interacting to achieve desired safety levels. Typically, an economic assessment is carried out in the planning phase, while environmental sustainability is given little or no attention. In this paper, life cycle assessment is used to quantify environmental impacts of climate change adaptation strategies. The approach is tested using a climate change adaptation strategy for a catchment in Copenhagen, Denmark. A stormwater management system, using green infrastructure and local retention measures in combination with planned routing of stormwater on the surfaces to manage runoff, is compared to a traditional, sub-surface approach. Flood safety levels based on the Three Points Approach are defined as the functional unit to ensure comparability between systems. The adaptation plan has significantly lower impacts (3-18 person equivalents/year) than the traditional alternative (14-103 person equivalents/year) in all analysed impact categories. The impacts of handling smaller events with a return period of up to 0.2 years and extreme events with a return period of up to 100 years are lower in both alternatives. The uncertainty analysis shows the advantages of conducting an environmental assessment in the early stages of the planning process, when the design can still be optimised, but it also highlights the importance of detailed and site-specific data.
Modelling the impact of Water Sensitive Urban Design technologies on the urban water cycle

Alternative stormwater management approaches for urban developments, also called Water Sensitive Urban Design (WSUD), are increasingly being adopted with the aims of providing flood control, flow management, water quality improvements and opportunities to harvest stormwater for non-potable uses. WSUD structures (WSUDs) are typically small, decentralized systems for managing stormwater runoff near the source. These systems interact with the urban hydrological cycle, modifying the evapotranspiration, runoff and groundwater recharge fluxes. It is challenging to quantify these hydrological changes because of the cost and complexity of modelling multiple WSUD systems in larger scale urban catchments. For this reason, new modelling tools are needed. These tools must be simple enough to be computationally efficient, while still describing the observed hydrological responses of urban catchments. The models must be able to simulate both the response of single WSUDs and many coupled WSUDs in an urban catchment.

This thesis aims to develop new models of two WSUD technologies: green roofs and infiltration trenches/soakaways. In particular the thesis has the following objectives:

1. To identify and develop new models of green roofs and infiltration devices relevant for urban drainage applications, and integrate them into urban hydrological models.
2. To quantify the long term hydrological performance of green roofs and infiltration devices using a statistical analysis of WSUD performance.
3. To model the interaction of infiltration based WSUDs with groundwater.
4. To assess a new combination of different WSUD techniques for improved stormwater management.
5. To model the impact of a widespread implementation of multiple soakaway systems at the catchment scale.
6. To test the models by simulating observed data describing the performance of single WSUD units, and the performance of multiple systems at a catchment scale.

To address these aims, new models of green roofs and soakaways are developed and tested using observations from several urban catchments. The models are used to quantify the hydrological performance of single devices relevant for urban drainage applications. Moreover, the coupling of soakaway and detention storages is also modeled to analyze the benefits of combining different local stormwater management systems. These models are then integrated into urban drainage network models and groundwater models in order to analyze the
impact of stormwater infiltration and local detention on drainage networks and groundwater flows. Results show that soakaways/infiltration trenches and green roofs significantly reduce annual stormwater runoff. Annual runoff from green roofs is 43-68% of the incoming rainfall and 0-62% for soakaways. Peak flow and volume reductions during single events are also quantified as a function of the return period. Using a part of a soakaway as detention storage significantly improves its ability to reduce single event peak runoff without significant changes to its annual performance. Peak flow and annual runoff reductions are quantified for different soakaway and detention volume combinations. These systems also avoid problems of sewer network surcharge in a small catchment during a 10 year return period event. The thesis quantifies the hydrological performance of infiltration devices interacting with groundwater. A threshold distance between infiltration devices and groundwater is estimated in order to classify whether infiltration devices are affected by groundwater or not. The threshold distance is determined as function of the soil hydraulic conductivity and the storage volume of the infiltration device. For instance, it is shown that in clay soils, infiltration trenches must be more than 11-12m above the water table if they are to be fully effective. Widespread stormwater infiltration leads to increased groundwater recharge and the risk of groundwater flooding in areas with shallow groundwater. The increased occurrence of groundwater seepage above terrain is quantified in a case study by a catchment hydrological model that is calibrated to observations. Moreover, the performance of existing stormwater infiltration systems is affected by landuse changes in other parts of their catchment. These changes were quantified for the case study by a model and observations over a 20 year period. It was shown that urbanization with widespread stormwater infiltration increased the risk of groundwater flooding. WSUDs are useful technologies for controlling urban stormwater runoff and the models presented in this thesis can help by simulating their hydrological impact. Careful engineering design is required to ensure that optimal results are achieved and to avoid unexpected outcomes such as increased groundwater flooding.

General information
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Organisations: Department of Environmental Engineering, Urban Water Systems, Water Resources Engineering
Authors: Locatelli, L. (Intern), Binning, P. J. (Intern), Mark, O. (Ekstern), Mikkelsen, P. S. (Intern), Arnbjerg-Nielsen, K. (Intern)
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Modificering af regnserier så de reflekterer et ændret klima

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Organisations: Department of Environmental Engineering, Urban Water Systems, Rambøll Danmark A/S
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Modificering af regnserier så de reflekterer et ændret klima

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Perturbing high-resolution precipitation time series to represent future climates

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- Organisations: Department of Environmental Engineering, Urban Water Systems
- Authors: Sørup, H. J. D. (Intern), Arnbjerg-Nielsen, K. (Intern)
- Number of pages: 1
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- Web of Science (2013): Indexed yes
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- BFI (2009): BFI-level 1
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  - EGU2016_5842.pdf
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Probabilistic modelling of sea surges in coastal urban areas

General information
- State: Published
- Organisations: Department of Applied Mathematics and Computer Science, Statistics and Data Analysis, Department of Environmental Engineering, Urban Water Systems
- Authors: Georgiadis, S. (Intern), Sørup, H. J. D. (Intern), Arnbjerg-Nielsen, K. (Intern), Nielsen, B. F. (Intern)
- Number of pages: 1
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Sustainable flood risk management – What is sustainable?
Sustainable flood risk management has to be achieved since flood protection is a fundamental societal service that we must deliver. Based on the discourse within the fields of risk management and sustainable urban water management, we discuss the necessity of assessing the sustainability of flood risk management, and propose an evaluation framework for doing so. We argue that it is necessary to include quantitative sustainability measures in flood risk management in order to exclude unsustainable solutions. Furthermore, we use the concept of absolute sustainability to discuss the prospects of maintaining current service levels without compromising future generation’s entitlement of services. Discussions on the sustainability of different overall flood risk schemes must take place. Fundamental changes in the approaches will require fundamental changes in the mind-sets of practitioners as well as lawmakers, politicians and the general public, which inevitably will take some time. Right now, the importance lies in setting an agenda where sustainability is important and needs to be quantified and assessed when managing flood risk.

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems, Department of Civil Engineering, Section for Structural Engineering, Department of Applied Mathematics and Computer Science, Statistics and Data Analysis, Department of Management Engineering, Quantitative Sustainability Assessment
Authors: Sørup, H. J. D. (Intern), Brudler, S. (Intern), Lerer, S. M. (Intern), Miraglia, S. (Intern), Georgiadis, S. (Intern), Dong, Y. (Intern), Arnbjerg-Nielsen, K. (Intern)
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Systematic testing of flood adaptation options in urban areas through simulations

General information
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Organisations: Department of Environmental Engineering, Urban Water Systems
Authors: Löwe, R. (Intern), Urich, C. (Ekstern), St. Domingo, N. D. (Ekstern), Mark, O. (Ekstern), Deletic, A. (Ekstern), Arnbjerg-Nielsen, K. (Intern)
Number of pages: 1
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Urban drainage research and planning. Quo vadis?

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State: Published
Organisations: Department of Environmental Engineering, Urban Water Systems
Authors: Arnbjerg-Nielsen, K. (Intern), Langeveld, J. (Ekstern), Marsalek, J. (Ekstern)
Pages: 133-135
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Publisher: IWA Publishing Company
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Edition: 2
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What does it take to practice sustainable flood risk management?

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Authors: Sørup, H. J. D. (Intern), Brudler, S. (Intern), Lerer, S. M. (Intern), Miraglia, S. (Intern), Georgiadis, S. (Intern), Arnbjerg-Nielsen, K. (Intern)
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Main Research Area: Technical/natural sciences
Links: http://www.sustain.dtu.dk/

Bibliographical note

Water Sensitive Urban Design (WSUD) poses new challenges for decision makers compared with traditional stormwater management, e.g., because WSUD offers a larger selection of measures and because many measures are multifunctional. These challenges have motivated the development of many decision support tools. This review shows that the tools differ in terms of the types of questions they can assist in answering. We identified three main groups: "How Much"-tools, "Where"-tools and "Which"-tools. The "How Much"-tools can further be grouped into tools quantifying hydraulic impacts, hydrologic impacts, water quality impacts, non-flow-related impacts and economic impacts. Additionally, the tools differ in terms of how many aspects of water they address, from those focused only on bio-physical aspects to those attempting to find the best WSUD based on multiple criteria. Finally, we suggest that variability among the tools can partly be explained by variability in local context including conditions such as type of existing stormwater systems, groundwater conditions and legislative frameworks.

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Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Lerer, S. M. (Intern), Ambjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern)
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Main Research Area: Technical/natural sciences

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Scopus rating (2015): SJR 0.522 SNIP 1.043 CiteScore 1.96
Web of Science (2015): Indexed yes
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Scopus rating (2014): SJR 0.466 SNIP 0.862 CiteScore 1.45
Web of Science (2014): Indexed yes
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Source: PublicationPreSubmission
Source-ID: 107881252
Publication: Research - peer-review › Journal article – Annual report year: 2015
A new tool for quantifying the impacts of water sensitive urban design – the power of simplicity

We present a prototype for a new software tool which enables quantification of impacts of water sensitive urban design (WSUD) plans in a simplifying manner. The tool is designed to fill a gap between the needs of utility companies for assessing WSUD performance and available urban drainage simulation tools. Emphasis is put on reducing complexity in order to help drainage engineers communicate their priorities to other stakeholders. The tool outputs include two key indicators: The first is the amount of runoff held back in stormwater control measures on event basis, presented graphically against three distinct decision domains. The second is the percentage of runoff managed locally on an annual basis, presented graphically as a water budget. The tool concept was tested on several smaller case studies in Denmark, and we plan to have it ready for full-scale testing ultimo 2015.

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Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Lerer, S. M. (Intern), Sørup, H. J. D. (Intern), Arnbjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern)
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Water sensitive urban design, Low impact development, Sustainable urban drainage systems, Planning, Communication
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An Integrated Modelling Framework to Assess Flood Risk under Urban Development and Changing Climate

Flood risk in cities is strongly affected by the development of the city itself. Many studies focus on changes in the flood hazard as a result of, for example, changed degrees of sealing in the catchment or climatic changes. However, urban developments in flood prone areas can affect the exposure to the hazard and thus have large impacts on flood risk. Different urban socio-economic development scenarios, rainfall inputs and options for the mitigation of flood risk, quickly lead to a large number of scenarios that need to be considered in the planning of the development of a city. This calls for automated analyses that allow the planner to quickly identify if, when and how infrastructure should be modified. Such analysis, which accounts for the two-way interactions between city development and flood risk, is possible only to a limited extent in existing tools. We have developed a software framework that combines a model for the socio-economic development of cities (DANCE4WATER) with an urban flood model. The urban flood model is a 1D-2D spatially distributed hydrologic and hydraulic model that, for a given urban layout, simulates flow in the sewer system and the surface flow in the catchment (MIKE FLOOD). The socio-economic model computes urban layouts that are transferred to the hydraulic model in the form of changes of impervious area and potential flow paths on the surface. Estimates of flood prone areas, as well as the expected annual damage due to flooding, are returned to the socio-economic model as an input for further refinement of the scenarios for the urban development. Our results in an Australian case study suggest that urban development is a major driver for flood risk and vice versa that flood risk can be significantly reduced if it is accounted for in the development of the cities. In particular, flood risk in a scenario with strong urban growth and almost a doubling of the amount of sealed area in the catchment was found to remain almost unchanged, if flood hazards where used as a constraint on the urban development, i.e. as an input to the socio-economic model. Further developments will focus on improving the socio-economic model, on the evaluation of flood damages as well as the required complexity of the hydraulic model.

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Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Löwe, R. (Intern), Urich, C. (Ekstern), Sto Domingo, N. (Ekstern), Mark, O. (Ekstern), Arnbjerg-Nielsen, K. (Intern)
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An Integrated Modelling Framework to Assess Flood Risk under Urban Development and Changing Climate

Flood risk in cities is strongly affected by the development of the city itself. Many studies focus on changes in the flood hazard as a result of, for example, changed degrees of sealing in the catchment or climatic changes. However, urban developments in flood prone areas can affect the exposure to the hazard and thus have large impacts on flood risk. Different urban socio-economic development scenarios, rainfall inputs and options for the mitigation of flood risk, quickly lead to a large number of scenarios that need to be considered in the planning of the development of a city. This calls for automated analyses that allow the planner to quickly identify if, when and how infrastructure should be modified. Such analysis, which accounts for the two-way interactions between city development and flood risk, is possible only to a limited extent in existing tools. We have developed a software framework that combines a model for the socio-economic development of cities (DANCE4WATER) with an urban flood model. The urban flood model is a 1D-2D spatially distributed hydrologic and hydraulic model that, for a given urban layout, simulates flow in the sewer system and the surface flow in the catchment (MIKE FLOOD). The socio-economic model computes urban layouts that are transferred to the hydraulic model in the form of changes of impervious area and potential flow paths on the surface. Estimates of flood prone areas, as well as the expected annual damage due to flooding, are returned to the socio-economic model as an input for further refinement of the scenarios for the urban development. Our results in an Australian case study suggest that urban development is a major driver for flood risk and vice versa that flood risk can be significantly reduced if it is accounted for in the development of the cities. In particular, flood risk in a scenario with strong urban growth and almost a doubling of the amount of sealed area in the catchment was found to remain almost unchanged, if flood hazards where used as a constraint on the urban development, i.e. as an input to the socio-economic model. Further developments will focus on improving the socio-economic model, on the evaluation of flood damages as well as the required complexity of the hydraulic model.

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Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Löwe, R. (Intern), Urich, C. (Ekstern), Sto Domingo, N. (Ekstern), Mark, O. (Ekstern), Ambjerg-Nielsen, K. (Intern)
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An urban flood risk assessment method using the Bayesian Network approach

Flooding is one of the most damaging natural hazards to human societies. Recent decades have shown that flooding constitutes major threats worldwide, and due to anticipated climate change the occurrence of damaging flood events is expected to increase. Urban areas are especially vulnerable to flooding, because these areas comprise large amounts of valuable assets. Flooding in urban areas can grow into significant disruptions and national threats unless appropriate flood risk management (FRM) plans are developed and timely adaptation options are implemented. FRM is a well-established process that aims to keep flood risk at, or reduce flood risk to, an acceptable level in flood prone areas. According to IPCC’s Summary for policy-makers (2014), risk management is an iterative process that is divided into 3 phases, which in this thesis are adapted to fit FRM terminology. Hence, FRM includes flood risk scoping, flood risk assessment (FRA), and adaptation implementation and involves an ongoing process of assessment, reassessment, and response. This thesis mainly focuses on the FRA phase of FRM. FRA includes hazard analysis and impact assessment (combined called a risk analysis), adaptation identification and adaptation assessment. The main task of FRA is to combine these assessments in a robust and systematic manner to provide valuable information to decision-makers by identifying suitable adaptation options and developing feasible adaptation strategies. In this study, a FRA method using the Bayesian Network (BN) approach is developed, and the method is exemplified in an urban catchment. BNs have become an increasingly popular method for describing complex systems and aiding decision-making under uncertainty. In environmental management, BNs have mainly been utilized in ecological assessments and water resources management studies, whereas climate risk studies have not yet fully adapted the BN method. A BN is a graphical model that utilizes causal relationships to describe the overall system where risk occurs. A BN can be further extended into a Bayesian Influence diagram (ID) by including decision and utility nodes, which are beneficial in decision-
making problems. This thesis aims at addressing four specific challenges identified in FRA and showing how these challenges may be addressed using an ID. Firstly, this thesis presents how an ID can be utilized to describe the temporal dimension of flood risk in a coherent and systematic manner. Herein, risk is assessed in so called time slices, where each time slice represents one specific year. For each time slice, separate hazard analyses are conducted to assess the occurrence probability of hazards in that specific year. Time slices are connected with each other by connecting the adaptation nodes in the time slices. Secondly, this thesis recognizes the need for including a spatial dimension in FRA. An urban catchment is rarely homogenous, and there are areas that have a higher risk than others. From a decision-making point of view, a spatial risk profile may provide valuable insight in where risk is higher than acceptable and where additional adaptation measures are needed to keep risk at an acceptable level. In an ID, the urban catchment can be divided into subregions, and risk is described for each sub-region separately. Thirdly, the objective is to improve FRA by including multiple hazards caused by concurrent events. Concurrent events refer to two or more flood hazards that occur simultaneously. In such circumstances the hazards may interact, and total damage from such a concurrent event may be larger than for the hazards separately. Currently, FRA is mainly based on single hazard events, but with expected climate change impacts there may be a need to include several hazards into FRA to assure that risk is described correctly for identification of important adaptation. This thesis shows that IDs may serve as a good approach for inclusion of multiple hazards in FRAs. Lastly, the inclusion of multiple hazards in FRA may be challenging, among others because concurrent events are rare. However, with climate change, the annual variation of hazards may change, and concurrent events may become more frequent. Large-scale atmospheric circulation influences local and regional climate and is considered an important factor when aiming at improving our understanding of local weather conditions and the occurrence of extreme events. Hence, this thesis presents a study that explores the relationship between flood generating hazards and large-scale atmospheric circulation. This thesis concludes that IDs can serve as a good approach for describing the complex system in which flood risk occurs. The final product is a spatiotemporal FRA approach that can include the impacts from multiple hazards.

**Comparing Methods of Calculating Expected Annual Damage in Urban Pluvial Flood Risk Assessments**

Estimating the expected annual damage (EAD) due to flooding in an urban area is of great interest for urban water managers and other stakeholders. It is a strong indicator for a given area showing how vulnerable it is to flood risk and how much can be gained by implementing e.g., climate change adaptation measures. This study identifies and compares three different methods for estimating the EAD based on unit costs of flooding of urban assets. One of these methods was used in previous studies and calculates the EAD based on a few extreme events by assuming a log-linear relationship between cost of an event and the corresponding return period. This method is compared to methods that are either more complicated or require more calculations. The choice of method by which the EAD is calculated appears to be of minor importance. At all three case study areas it seems more important that there is a shift in the damage costs as a function of the return period. The shift occurs approximately at the 10 year return period and can perhaps be related to the design criteria for sewer systems. Further, it was tested if the EAD estimation could be simplified by assuming a single unit cost per flooded area. The results indicate that within each catchment this may be a feasible approach. However the unit costs varies substantially between different case study areas. Hence it is not feasible to develop unit costs that can be used to calculate EAD, most likely because the urban landscape is too heterogeneous.
Comparison of different statistical downscaling methods to estimate changes in hourly extreme precipitation using RCM projections from ENSEMBLES

Changes in extreme precipitation are expected to be one of the most important impacts of climate change in cities. Urban floods are mainly caused by short duration extreme events. Hence, robust information on changes in extreme precipitation at high-temporal resolution is required for the design of climate change adaptation measures. However, the quantification of these changes is challenging and subject to numerous uncertainties. This study assesses the changes and uncertainties in extreme precipitation at hourly scale over Denmark. It explores three statistical downscaling approaches: a delta change method for extreme events, a weather generator combined with a disaggregation method and a climate analogue method. All three methods rely on different assumptions and use different outputs from the regional climate models (RCMs). The results of the three methods point towards an increase in extreme precipitation but the magnitude of the change varies depending on the RCM used and the spatial location. In general, a similar mean change is obtained for the three methods. This adds confidence in the results as each method uses different information from the RCMs. The results of this study highlight the need of using a range of statistical downscaling methods as well as RCMs to assess changes in extreme precipitation. © 2014 Royal Meteorological Society.

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering, Water Resources Engineering, DHI Hørsholm
Authors: Sunyer Pinya, M. A. (Intern), Gregersen, I. B. (Intern), Rosbjerg, D. (Intern), Madsen, H. (Intern), Luchner, J. (Ekstern), Ambjerg-Nielsen, K. (Intern)
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Main Research Area: Technical/natural sciences
Coupling Modelling of Urban Development and Flood Risk – An Attempt for a Combined Software Framework

We have developed a setup that couples the urban development model DANCE4WATER with the 1D-2D hydraulic model MIKE FLOOD. The setup makes it possible to assess the impact of urban development and infrastructural change scenarios on flood risk in an automated manner. In addition, it permits us to use the results of the hydraulic simulation to condition DANCE4WATER and to account for flood risk in the simulated urban development. In an Australian case study,
we demonstrate that future flood risk can be significantly reduced while maintaining the overall speed of urban development.

**Determining the extent of groundwater interference on the performance of infiltration trenches**

Infiltration trenches are widely used in stormwater management, but their capacity decreases when installed in areas with shallow groundwater where infiltration is limited by groundwater drainage. Here the hydrological performance of single infiltration trenches in areas with shallow water tables is quantified in terms of their capability to reduce peak flow, peak volume and annual stormwater runoff volume. To simulate the long term hydrological performance of infiltration trenches two different models are employed. The models continuously simulate infiltration rates from infiltration trenches using a 19-year rainfall time series from Copenhagen as input. The annual and single event stormwater runoff reduction from infiltration trenches was determined for 9 different scenarios that covered different soil conditions and infiltration trench dimensions. Monte Carlo simulations were used in order to quantify the impact of parameter variability for each scenario. Statistical analysis of the continuous long term model simulations was used to quantify the hydrological performance of infiltration trenches. Results show that infiltration trenches are affected by groundwater when there is an unsaturated depth of less than 1.5-3. m in sandy loam, 6.5-8. m in silt loam and 11-12. m in silty clay loam. A correction factor that can be applied for infiltration trench design when there is a shallow groundwater table is presented. The analyses showed that below a certain value of unsaturated depth the dissipation capacity of the mound/groundwater becomes the dominant process determining the infiltration capacity from infiltration trenches. In these cases it is essential to consider the local groundwater conditions in the infiltration trench design process.
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Scopus rating (2011): SJR 1.753 SNIP 1.858 CiteScore 3.16
ISI indexed (2011): ISI indexed yes
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Scopus rating (2010): SJR 1.784 SNIP 1.714
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Scopus rating (2009): SJR 2.018 SNIP 1.835
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.922 SNIP 1.758
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.851 SNIP 1.936
Web of Science (2007): Indexed yes
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Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.602 SNIP 1.887
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Scopus rating (2003): SJR 1.444 SNIP 1.788
Web of Science (2003): Indexed yes
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Et samfund i forandring

General information
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Evaluating adaptation options for urban flooding based on new high-end emission scenario regional climate model simulations

Climate change adaptation studies on urban flooding are often based on a model chain approach from climate forcing scenarios to analysis of adaptation measures. Previous analyses of climate change impacts in Copenhagen, Denmark, were supplemented by 2 high-end scenario simulations. These include a regional climate model projection forced to a global temperature increase of 6 degrees C in 2100 as well as a projection based on a high radiative forcing scenario (RCP8.5). With these scenarios, projected impacts of extreme precipitation increase significantly. For extreme sea surges, the impacts do not seem to change substantially compared to currently applied projections. The flood risk (in terms of expected annual damage, EAD) from sea surge is likely to increase by more than 2 orders of magnitude in 2100 compared to the present cost. The risk from pluvial flooding in 2000 is likely to increase by almost 4 and 8 times the current EAD for the RCP8.5 and 6 degrees C scenario, respectively. For both hazards, business-as-usual is not a possible scenario, since even in the absence of policy-driven changes, significant autonomous adaptation is likely to occur. Copenhagen has developed an adaptation plan to pluvial flooding that makes the urban areas more robust and reduces the risk of flooding under the current climate to a very low level. The reduction in flood risk for the A1B scenario is substantial (corresponding to 0.2-0.3 times the current EAD in 2100), and even in the high-end scenarios, the risk is significantly reduced (corresponding to 0.6-1.0 and 1.2-2.1 times the current EAD for the RCP8.5 and 6 degrees C scenario, respectively).

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Scopus rating (2015): SJR 1.107 SNIP 0.909 CiteScore 2.14
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
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Exploring Elwood's flood challenges: A Collaborative Approach for a Complex Problem

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Organisations: Department of Environmental Engineering, Urban Water Engineering, Monash University, Cooperative Research Centre for Water Sensitive Cities
Authors: Rogers, B. C. (Ekstern), Bertram, N. (Ekstern), Gunn, A. (Ekstern), Löwe, R. (Intern), Murphy, C. (Ekstern), Pasman, R. (Ekstern), Radhakrishnan, M. (Ekstern), Urich, C. (Ekstern), Arnbjerg-Nielsen, K. (Intern)
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Flood risk assessment as an integral part of urban planning

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Flood risk assessment as an integral part of urban planning

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Hvad betyder klimaændringer for Danmark?

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Henriksen, H. J. (Ekstern), Hansen, J. M. (Ekstern), Hinsby, K. (Ekstern), Jensen, J. B. (Ekstern), Skjoldborg Hansen, A. (Ekstern), Arnbjerg-Nielsen, K. (Intern)
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Identifying added value in high-resolution climate simulations over Scandinavia

High-resolution data are needed in order to assess potential impacts of extreme events on infrastructure in the mid-latitudes. Dynamical downscaling offers one way to obtain this information. However, prior to implementation in any impacts assessment scheme, model output must be validated and determined fit-for-purpose. This study presents the results from two 8-km resolution perfect boundary experiments over Scandinavia. Two different regional climate models were initialised and driven with ERA interim reanalysis from 1990 to 2010. Reference data come from both gridded products and point-based station observations. In addition to the canonical variables of daily precipitation and temperature, winds were also investigated. The models exhibit systematic cold and wet biases on seasonal time scales (−1 K and +50–100%, respectively). However, frequency-based skill scores for daily precipitation and temperature are high, indicating that the distributions of these variables are generally well captured. Wind speeds over the North and Norwegian Seas were simulated more realistically in the models than in the ERA interim reanalysis. However, most importantly, for impacts assessments, the models should be capable of capturing the timing, intensity and location of short-duration extreme events, in particular precipitation. In this respect, both models outperform the reanalysis over the city of Copenhagen, where recent pluvial floods led to costly damages to infrastructure.
Identifying climate analogues for precipitation extremes for Denmark based on RCM simulations from the ENSEMBLES database

Climate analogues, also denoted Space-For-Time, may be used to identify regions where the present climatic conditions resemble conditions of a past or future state of another location or region based on robust climate variable statistics in combination with projections of how these statistics change over time. The study focuses on assessing climate analogues for Denmark based on current climate data set (E-OBS) observations as well as the ENSEMBLES database of future climates with the aim of projecting future precipitation extremes. The local present precipitation extremes are assessed by means of intensity-duration-frequency curves for urban drainage design for the relevant locations being France, the Netherlands, Belgium, Germany, the United Kingdom, and Denmark. Based on this approach projected increases of extreme precipitation by 2100 of 9 and 21% are expected for 2 and 10 year return periods, respectively. The results should be interpreted with caution as the best region to represent future conditions for Denmark is the coastal areas of Northern France, for which only little information is available with respect to present precipitation extremes.

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering, DHI Denmark
Authors: Arnbjerg-Nielsen, K. (Intern), Funder, S. G. (Ekstern), Madsen, H. (Ekstern)
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Scopus rating (2014): SJR 0.587 SNIP 0.685 CiteScore 1.14
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.568 SNIP 0.7 CiteScore 1.3
ISI indexed (2013): ISI indexed yes
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ISI indexed (2012): ISI indexed yes
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BFI (2011): BFI-level 1
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ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.522 SNIP 0.602
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.589 SNIP 0.686
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.579 SNIP 0.697
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.749 SNIP 0.781
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.693 SNIP 0.796
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.763 SNIP 0.85
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.877 SNIP 0.904
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.882 SNIP 0.902
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.903 SNIP 0.888
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 0.759 SNIP 0.967
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Influence of urban land cover changes and climate change for the exposure of European cities to flooding during extreme precipitation

General information
State: Published
Organisations: Department of Management Engineering, Systems Analysis, DTU Climate Centre, Energy Systems Analysis, Department of Environmental Engineering, Urban Water Engineering, Technical University of Denmark
Authors: Kaspersen, P. S. (Intern), Høegh Ravn, N. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Madsen, H. (Ekstern), Drews, M. (Intern)
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Influence of urban land cover changes and climate change for the exposure of European cities to flooding during high-intensity precipitation

In this paper we present a methodology suitable for investigating the relative and combined influence of urban land cover changes and climate change for the exposure of cities to pluvial flooding. A combined hydrological-hydrodynamic modelling and remote sensing approach enables the quantification of the flood risk relative to changes in imperviousness and climate change. The methodology is evaluated for the Danish city of Odense, but is easily applicable for the majority of cities within Europe, as it relies on open source data for the European continent. Results from Odense show that urban development during the past 30 years caused an increase in flood exposure that is comparable to what is expected in the RCP4.5 (+2°C) climate scenario.

Influence of urban land cover changes and climate change for the exposure of European cities to flooding during extreme precipitation

In this paper we present a methodology suitable for investigating the relative and combined influence of urban land cover changes and climate change for the exposure of cities to pluvial flooding. A combined hydrological-hydrodynamic modelling and remote sensing approach enables the quantification of the flood risk relative to changes in imperviousness and climate change. The methodology is evaluated for the Danish city of Odense, but is easily applicable for the majority of cities within Europe, as it relies on open source data for the European continent. Results from Odense show that urban development during the past 30 years caused an increase in flood exposure that is comparable to what is expected in the RCP4.5 (+2°C) climate scenario.

General information
State: Published
Organisations: Department of Management Engineering, Systems Analysis, DTU Climate Centre, Energy Systems Analysis, Department of Environmental Engineering, Urban Water Engineering, LNH Water
Authors: Kaspersen, P. S. (Intern), Høegh Ravn, N. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Madsen, H. (Ekstern), Drews, M. (Intern)
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Influence of urban land cover changes and climate change for the exposure of European cities to flooding during extreme precipitation

Influence of urban land cover changes and climate change for the exposure of European cities to flooding during extreme precipitation

General information
Influence of urban land cover changes and climate change for the exposure of European cities to flooding during high-intensity precipitation

The extent and location of impervious surfaces within urban areas due to past and present city development strongly affects the amount and velocity of run-off during high-intensity rainfall and consequently influences the exposure of cities towards flooding. The frequency and intensity of extreme rainfall are expected to increase in many places due to climate change and thus further exacerbate the risk of pluvial flooding. This paper presents a combined hydrological-hydrodynamic modelling and remote sensing approach suitable for examining the susceptibility of European cities to pluvial flooding owing to recent changes in urban land cover, under present and future climatic conditions. Estimated changes in impervious urban surfaces based on Landsat satellite imagery covering the period 1984–2014 are combined with regionally downscaled estimates of current and expected future rainfall extremes to enable 2-D overland flow simulations and flood hazard assessments. The methodology is evaluated for the Danish city of Odense. Results suggest that the past 30 years of urban development alone has increased the city’s exposure to pluvial flooding by 6% for 10-year rainfall up to 26% for 100-year rainfall. Corresponding estimates for RCP4.5 and RCP8.5 climate change scenarios (2071–2100) are in the order of 40 and 100 %, indicating that land cover changes within cities can play a central role for the cities’ exposure to flooding and conversely also for their adaptation to a changed climate.
LAR-potentiale: a new planning tool to support sustainable stormwater management

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Lerer, S. M. (Intern), Sørup, H. J. D. (Intern), Arnbjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern)
Number of pages: 1
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Life Cycle Assessment of Cloudburst Management Plans in Adaptation to Climate Change

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Brudler, S. (Intern), Arnbjerg-Nielsen, K. (Intern), Rygaard, M. (Intern)
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Poster presentation
Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2015
Long term variations of extreme rainfall in Denmark and southern Sweden
A high number of studies have detected changes in the observed heavy rainfall in Northern and Central Europe, all adding to the debate on anthropogenic climate change and its potential impact on rainfall extremes. However, it is equally relevant to understand natural variations on which the anthropogenic changes are imposed. This study identifies multi-decadal variations in daily rainfall extremes from Denmark and southern Sweden, with a recurrence level relevant for flood hazard analysis. Based on smoothed series it is concluded that the frequency of the extreme events shows both a general increase from 1874 to present and an oscillation with a cycle of 25-40 years. The magnitude of the extreme events also oscillates, but with a cycle of 15-30 years and a smaller amplitude. Regional analysis of a larger Danish dataset with a shorter observations period found a countrywide low period in 1970-1979. It is furthermore concluded that the oscillation signal along the west coast of Denmark is dominated by the changeable coastal weather of this region. The eastern part of Denmark shows a more consistent signal, which partly can be explained by an index derived from sea level pressure differences between Gibraltar and Haparanda. The identification of a cyclic pattern in the extreme rainfall is highly relevant for our understanding of the non-stationarities in flood hazard. © 2014 Springer-Verlag Berlin Heidelberg.

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering, Water Resources Engineering, DHI Denmark
Authors: Gregersen, I. B. (Intern), Madsen, H. (Ekstern), Rosbjerg, D. (Intern), Arnbjerg-Nielsen, K. (Intern)
Pages: 3155-3169
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BFI (2016): BFI-level 2
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BFI (2015): BFI-level 2
Scopus rating (2015): SJR 3.48 SNIP 1.302 CiteScore 3.86
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 3.501 SNIP 1.421 CiteScore 4.07
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 3.585 SNIP 1.59 CiteScore 4.35
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 3.265 SNIP 1.558 CiteScore 3.76
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 3.009 SNIP 1.537 CiteScore 3.74
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 3.248 SNIP 1.514
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 3.9 SNIP 1.616
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 3.962 SNIP 1.635
Scopus rating (2007): SJR 3.646 SNIP 1.471
Web of Science (2007): Indexed yes
Modelling the impact of retention–detention units on sewer surcharge and peak and annual runoff reduction

Stormwater management using water sensitive urban design is expected to be part of future drainage systems. This paper aims to model the combination of local retention units, such as soakaways, with subsurface detention units. Soakaways are employed to reduce (by storage and infiltration) peak and volume stormwater runoff; however, large retention volumes are required for a significant peak reduction. Peak runoff can therefore be handled by combining detention units with soakaways. This paper models the impact of retrofitting retention-detention units for an existing urbanized catchment in Denmark. The impact of retrofitting a retention-detention unit of 3.3 m(3)/100 m(2) (volume/impervious area) was simulated for a small catchment in Copenhagen using MIKE URBAN. The retention-detention unit was shown to prevent flooding from the sewer for a 10-year rainfall event. Statistical analysis of continuous simulations covering 22 years showed that annual stormwater runoff was reduced by 68-87%, and that the retention volume was on average 53% full at the beginning of rain events. The effect of different retention-detention volume combinations was simulated, and results showed that allocating 20-40% of a soakaway volume to detention would significantly increase peak runoff reduction with a small reduction in the annual runoff.

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering, Water Resources Engineering, Orbicon, DHI Denmark
Authors: Locatelli, L. (Intern), Gabriel, S. (Ekstern), Mark, O. (Ekstern), Mikkelsen, P. S. (Intern), Arnbjerg-Nielsen, K. (Intern), Taylor, H. (Ekstern), Bockhorn, B. (Ekstern), Larsen, H. (Ekstern), Kjølby, M. J. (Ekstern), Steensen Blicher, A. (Ekstern), Binning, P. J. (Intern)
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Main Research Area: Technical/natural sciences

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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.466 SNIP 0.599 CiteScore 1.19
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BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.587 SNIP 0.685 CiteScore 1.14
Hydroeconomic models have been used to determine policies for efficient allocation of scarce water resources. Hydropower benefits are typically represented through exogenous electricity prices, but these do not consider the effect that the power market can have on the hydropower release policy and vice versa. To improve the representation of hydropower benefits in hydroeconomic models, an application of stochastic dynamic programming, known as the water value method, was used to maximize irrigation benefits while minimizing the costs of power generation within a power market. The method yields optimal operation rules that maximize current and expected future benefits as a function of reservoir level, week of the year, and inflow state. The method was tested on the Iberian Peninsula and performed better than traditional approaches that use exogenous prices: resulting operation rules were more realistic and sensitive to hydrological variability. Internally calculated hydropower prices provided better results than exogenous hydropower prices.
and can therefore improve the representation of hydropower benefits in hydroeconomic models. (C) 2014 American Society of Civil Engineers.

General information
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Organisations: Department of Environmental Engineering, Urban Water Engineering, Water Resources Engineering
Authors: Pereira-Cardenal, S. J. (Ekstern), Mo, B. (Ekstern), Riegels, N. (Ekstern), Ambjerg-Nielsen, K. (Intern), Bauer-Gottwein, P. (Intern)
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Web of Science (2014): Indexed Yes
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Scopus rating (2013): SJR 1.298 SNIP 2.119 CiteScore 2.25
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Scopus rating (2012): SJR 1.019 SNIP 1.5 CiteScore 1.8
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.775 SNIP 1.378 CiteScore 1.65
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.655 SNIP 1.43
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.149 SNIP 2.002
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 1.133 SNIP 1.582
Scopus rating (2007): SJR 1.635 SNIP 1.786
Scopus rating (2006): SJR 1.182 SNIP 2.088
Scopus rating (2005): SJR 0.783 SNIP 1.36
Scopus rating (2004): SJR 0.931 SNIP 1.313
Scopus rating (2003): SJR 0.816 SNIP 1.412
Scopus rating (2002): SJR 0.75 SNIP 1.3
Scopus rating (2001): SJR 0.68 SNIP 1.286
Scopus rating (2000): SJR 0.648 SNIP 1.17
Scopus rating (1999): SJR 1.031 SNIP 1.522
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Past, present and future variations of extreme rainfall in Denmark

A well-functioning drainage system is of utmost importance to ensure safe and liveable cities. The cost of urban flooding is high and in worst case fatal. Denmark has a long tradition for providing guidelines for urban drainage design, including recommendations on design rainfall. A regional model for estimation of urban design intensities has been applied since 1999. The main motivation is that the uncertainty of the estimated design intensities can be reduced by including regional information. The model has been updated several times, but its basic assumptions are now challenged by several indications of non-stationary extreme rainfall behaviour, in Denmark as well as worldwide.

To provide recommendations on future design intensities it is necessary to explore and understand patterns of temporal variation in urban design rainfall and identify potential drivers behind past, present and future changes. In addition, there is a need for an extreme value model that can include both regional and temporal explanatory variables, evaluate their significance and on this basis estimate the design rainfall. Both topics are addressed in this thesis. The analysed data material includes 137 years of observed daily rainfall, and 34 years of high-resolution observations from a regional tipping-bucket network. To evaluate future design intensities climate model simulations from the ENSEMBLES project is applied, in combination with two high-end simulations. The number of extreme rainfall events and the mean intensity of sub-daily extreme rainfall have increased over the last 34 years. Analysis of the long daily rainfall series show that the number of extreme rainfall events, smoothed by a 10-year moving average, fluctuates between periods of relative high and periods of relatively low number of extremes. The increase observed over the last 34 years fits well into this pattern. Sea level pressure differences over the North Atlantic are found to be a potential driver of this multi-decadal variability. Specific constellations of high and low pressure zones favour a high number of extreme rainfall events in Denmark, and these form more frequently in some decades. In relation to the increase in mean intensity of sub-daily extreme rainfall, sea surface temperature of the Danish waters is a strong candidate among the potential drivers. The correlation between the two is not studied in detail in this thesis. In relation to projections of future rainfall extremes anthropogenic climate change plays an important role. At higher temperatures the air can hold more water and therefore release more rainfall. Climate change can also affect the variability of the extreme rainfall indirectly by a modification or intensification of the large scale drivers.

Climate models are the most important tool for assessing the magnitude of the change, but their output should be critically assessed especially in regard to extreme rainfall. The thesis shows that the spatial correlation structure of observed hourly extreme rainfall is not reproduced well by the two climate models assessed. The thesis also presents a framework in which regional and temporal variability of extreme rainfall statistics can be modelled simultaneously. The framework is an extension of the regional model presently used for estimation of urban design intensities. It applies a threshold value for extreme rainfall that varies in both time and space. This eliminates the issue of having a nonuniform distribution of extremes events over the observation period. Furthermore, the model is capable of taking the spatial correlation structure of the rainfall extremes into account. The model can compare the relative importance of the temporal and regional variation. For several of the analysed rainfall durations regional variation is identified, but temporal variability explains a larger percentage of the total variability. The presented model only includes ‘time’ as a temporal variable. It can be modified to contain physical explanatory variable, like the two large scale drivers discussed above, when their present and future influence is confirmed. The analysed climate model simulations show that over the next 100 years the most likely increase of a 2-year event with a rainfall duration of 1 hour is 20%. This almost corresponds to the change observed over the last 34 years, which emphasises the importance of understanding the large scale drivers behind. It is very important to quantify and communicate the uncertainty of the design rainfall both in relation to the natural variability, the expected impacts of climate change and their interplay. A large part of the uncertainty is inherent and cannot be reduced. On top of this come the many unknown features in the climate system. The irrational behaviour of mankind contributes to the uncertainty, as it both affects the greenhouse gas emissions, and the requirements to cities of the future. Simple case studies based on different decision making frameworks show that the uncertainty of the future is not a hindrance for adaptation.
Quantification the Effects of Water Sensitive Urban Design in a Simplifying Manner

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Lerer, S. M. (Intern), Sørup, H. J. D. (Intern), Arnbjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern)
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Quantitative potential for stormwater control measures

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Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Sørup, H. J. D. (Intern), Lerer, S. M. (Intern), Arnbjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern)
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Sub-daily extreme precipitation under current and future climate conditions from high resolution RCMs

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Organisations: Department of Environmental Engineering, Urban Water Systems, DHI Harsholm, Arup
Authors: Luchner, J. (Ekstern), Sunyer, M. A. (Ekstern), Madsen, H. (Ekstern), Onof, C. (Ekstern), Arnbjerg-Nielsen, K. (Intern)
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Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2016
Sustainable Urban Drainage Systems: Using rainwater as a resource to create resilient and liveable cities

The white paper presents the various possibilities of using rainwater as a resource as opposed to considering it as something that simply needs to be hidden in sewers. The aim of using rainwater as a resource is partly to reduce the risk of flooding by optimising the rainwater management and partly to contribute to creating more green and liveable cities.

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Using the three points approach to see beyond extremes for urban hydrology

General information
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Publication date: 2015
A Bayesian Approach for Uncertainty Quantification of Extreme Precipitation Projections Including Climate Model Interdependency and Nonstationary Bias

Climate change impact studies are subject to numerous uncertainties and assumptions. One of the main sources of uncertainty arises from the interpretation of climate model projections. Probabilistic procedures based on multimodel ensembles have been suggested in the literature to quantify this source of uncertainty. However, the interpretation of multimodel ensembles remains challenging. Several assumptions are often required in the uncertainty quantification of climate model projections. For example, most methods often assume that the climate models are independent and/or that changes in climate model biases are negligible. This study develops a Bayesian framework that accounts for model dependencies and changes in model biases and compares it to estimates calculated based on a frequentist approach. The Bayesian framework is used to investigate the effects of the two assumptions on the uncertainty quantification of extreme precipitation projections over Denmark. An ensemble of regional climate models from the Ensemble-Based Predictions of Climate Changes and their Impacts (ENSEMBLES) project is used for this purpose. The results confirm that the climate models cannot be considered independent and show that the bias depends on the value of precipitation. This has an influence on the results of the uncertainty quantification. Both the mean and spread of the change in extreme precipitation depends on both assumptions. If the models are assumed independent and the bias constant, the results will be overconfident and may be treated as more precise than they really are. This study highlights the importance of investigating the underlying assumptions in climate change impact studies, as these may have serious consequences for the design of climate change adaptation strategies.
A decision-making framework for flood risk management based on a Bayesian Influence Diagram

We develop a Bayesian Influence Diagram (ID) approach for risk-based decision-making in flood management. We show that it is a flexible decision-making tool to assess flood risk in a non-stationary environment and with an ability to test different adaptation measures in order to agree on the best combination of adaptation measures and the best time to invest in flood adaptation. IDs use Bayesian statistics which apply prior probabilities to produce posterior probabilities and, hence, use Bayesian probabilistic thinking to describe relationships between variables in a system. Hence, we allow for assessing the risk of something we ‘believe’ may occur in the future. An ID has two layers: 1) a graphical description of the system built up by system variables, adaptation measures, costs/benefits of these measures and the dependencies of all these, which is an effective means to communicate the system configuration, and 2) conditional probability tables (CPTs) in which the domain of all possible states taken by the variable is listed combined with conditional probabilities of any state of that variable. When the ID is compiled, i.e. posterior probabilities are calculated; the network can be updated each time new values of variables are observed, assuring that the risk assessment is constantly based on best available knowledge for each variable. Input data to IDs can come from multiple sources, and since each variable is described with a probability density function (pdf) this method provides an effective means to describe uncertainty in the system. Hence, an ID contributes with several advantages in risk assessment and decision-making. We present an ID approach for risk-based decision-making in which we improve conventional flood risk assessments by including several types of hazards into the assessment. By doing so, we explicitly consider the risk from concurrent events. Further, we add large scale weather patterns to the risk assessment as an additional variable to describe the occurrence of extremes. This allows
using projected changes in large scale circulations from climate models to estimate pdfs of extreme events in a future climate. Our method provides means to assess non-stationarity of flood risk by including several time steps in the risk assessment (Ström et al., 2013). Hence, our approach effectively communicates to decisionmakers how risk changes over time and the uncertainty related to these changes. We combine a flexible impact assessment method with our ID that can assess the overall risk in a given area as well as within subareas. This impact assessment provides for a transparent and robust assessment of both instant and long-term benefits for different adaptation measures and combinations of these. Adaptation options can be tested at different points in time (in different time slices) which allows for finding the optimal time to invest. The usefulness of our decision-making framework was exemplified through case studies in Aarhus and Copenhagen. Risk-based decision-making is difficult, and considering the partly unknown processes related to anthropogenic climate change we need to model a very complex system. In our study we showed that IDs are a noteworthy alternative as decision-making method in flood risk management and is a useful method when several hazards and their simultaneous occurrence need to be assessed. The approach provided several benefits such as a transparent explanation of the system at risk, clear description of the uncertainty in the system and the changes over time, and flexible means to assess the best combination of adaptation measures.

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Ændringer og variationer i ekstremregn fra 1874 til 2100

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A framework for testing the ability of models to project climate change and its impacts
Models used for climate change impact projections are typically not tested for simulation beyond current climate conditions. Since we have no data truly reflecting future conditions, a key challenge in this respect is to rigorously test models using proxies of future conditions. This paper presents a validation framework and guiding principles applicable across earth science disciplines for testing the capability of models to project future climate change and its impacts. Model test schemes comprising split-sample tests, differential split-sample tests and proxy site tests are discussed in relation to their application for projections by use of single models, ensemble modelling and space-time-substitution and in relation to use of different data from historical time series, paleo data and controlled experiments. We recommend that differential-
split sample tests should be performed with best available proxy data in order to build further confidence in model projections.

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**Organisations:** Department of Environmental Engineering, Urban Water Engineering, Department of Management Engineering, Systems Analysis, DTU Climate Centre, Energy Systems Analysis, Geological Survey of Denmark and Greenland, DHI Denmark, Irstea, Aarhus University, University of Waikato, Swedish Meteorological and Hydrological Institute, Katholieke Universiteit, Danish Meteorological Institute


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A model validation framework for climate change projection and impact assessment

Models used for projection of climate change and its impacts are usually not validated for simulation of future climate conditions. This is a serious deficiency that introduces an unknown level of uncertainty in the projections. A framework and guiding principles are presented for testing models using proxies of future conditions. In general, a model that has been setup for solving a specific problem at a particular site should be tested in order to document its predictive capability and credibility. In a climate change context such tests, often referred to as model validations tests, are particularly challenging since the model is used for an unknown future with a climate that is significantly different from current conditions. Most model studies reported on projections of climate change and its impacts have not included formal model validation tests that address this issue. A model validation framework and guiding principles for testing the capabilities of models for projection of climate change and its impacts have been proposed by Refsgaard et al. (2014). This framework is based on the hierarchical test scheme for model validation developed by Klemes (1986), which distinguishes between model predictions performed under stationary (split-sample tests) or non-stationary conditions (differential split-sample test), and if the model is applied at the site where it was calibrated or at a different site (proxy site tests). This model validation scheme has been assessed in relation to use of different methods for projection of climate change (single and ensemble model projections and space-time-substitution) and use of different data sources as proxy for future climate conditions (long historical records comprising non-stationarity, paleo data, and controlled experiments). The basic guiding principles state that: (i) before a model is used for climate change projections and impact assessments it must demonstrate its predictive capabilities using data that reflects the expected future climate, (ii) the validation test must be carried out using data that have not been used for model calibration, and (iii) the validation test must provide evidence on the expected accuracy of the model projections and impact assessments. The most commonly used validation test, the split-sample test, is not sufficient in a climate change context. The differential split-sample test should be applied by using adequate proxy data, reflecting future conditions. This test can be used with both single and ensemble model projections as well as with space-time-substitutions. It is generally expected to be more powerful when applied to a model ensemble than to a single model. Since space-time-substitutions include identification of locations with current climate similar to the expected future climate at the site in consideration, any test with this projection methodology involves elements of proxy site tests. For testing models under non-stationary conditions in a climate change context it is recommended to apply a differential split-sample test using best available proxy data that reflect the expected future conditions at the site being considered. Such proxy data may be obtained from long historical records comprising nonstationarity, paleo data, or controlled experiments. The test can be applied with different projection methods, including single and ensemble model projections and space-time-substitutions.

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Analyse af IPCC delrapport 2: Effekter, klimatilpasning og sårbarhed - med særligt fokus på Danmark

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An influence diagram for urban flood risk assessment through pluvial flood hazards under non-stationary conditions
Urban flooding introduces significant risk to society. Non-stationarity leads to increased uncertainty and this is challenging to include in actual decision-making. The primary objective of this study was to develop a risk assessment and decision support framework for pluvial urban flood risk under non-stationary conditions using an influence diagram (ID) which is a Bayesian network (BN) extended with decision and utility nodes. Non-stationarity is considered to be the influence of climate change where extreme precipitation patterns change over time. The overall risk is quantified in monetary terms expressed as expected annual damage. The network is dynamic in as much as it assesses risk at different points in time. The framework provides means for decision-makers to assess how different decisions on flood adaptation affect the risk now and in the future. The result from the ID was extended with a cost-benefit analysis defining the net benefits for the investment plans. We tested our framework in a case study where the risk for flooding was assessed on a railway track in Risskov, Aarhus. Drainage system improvements are planned for the area. Our study illustrates with the use of an ID how risk for flooding increases over time, and the benefits of implementing flood adaptation measures.

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Assessing climate change impacts on the Iberian power system using a coupled water-power model

Climate change is expected to have a negative impact on the power system of the Iberian Peninsula; changes in river runoff are expected to reduce hydropower generation, while higher temperatures are expected to increase summer electricity demand, when water resources are already limited. However, these impacts have not yet been evaluated at the peninsular level. We coupled a hydrological model with a power market model to study three impacts of climate change on the current Iberian power system: changes in hydropower production caused by changes in precipitation and temperature, changes in temporal patterns of electricity demand caused by temperature changes, and changes in irrigation water use caused by temperature and precipitation changes. A stochastic dynamic programming approach was used to develop operating rules for the integrated system given hydrological uncertainty. We found that changes in precipitation will reduce runoff, decrease hydropower production (with accompanying increases in thermal generation), and increase irrigation water use, while higher temperatures will shift power demand from winter to summer months. The combined impact of these effects will generally make it more challenging to balance agricultural, power, and environmental objectives in the operation of Iberian reservoirs, though some impacts could be mitigated by better alignment between temporal patterns of irrigation and power demands.

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Climatic changes of extreme precipitation in Denmark from 1874 to 2100

During the past 30 years rather dramatic changes in extreme precipitation have been observed in Denmark. These changes are mainly in the frequency of extreme events, but there is also a tendency towards more severe events. Both are considered effects of anthropogenic climate change. The increase in precipitation extremes has led to inundations in most of the larger cities during the last 10 years. The flood in Copenhagen in 2011 implied the second highest damage costs measured in Denmark during the last 100 years. To establish cities that are resilient to pluvial floods robust projections of the frequency and intensity of extreme precipitation events in a changing climate are needed. Additionally, it is equally important to understand the natural variation on which the anthropogenic changes are imposed. This study presents the results of a coordinated effort to estimate the changes and uncertainties in Danish design rainfall. Trends and oscillations are identified in five daily precipitation records from 1874 to present, 83 records from high-resolution rain-gauges from 1979 to present and 18 state-of-the-art climate model simulations. It is shown that the frequency of extreme events in the past has oscillated with a cycle of 25-35 years, a behavior that can in part be explained by sea level pressure differences over the Atlantic. Projections based on the historical observations suggest that precipitation extremes in the Eastern part of Denmark should have been ascending in the last two decades. However, the increase has continued longer than expected and with larger amplitude in the most recent years. This indicates a likely influence from anthropogenic greenhouse gas emissions. With the complex combination of general increase and natural variation several additional years of observation are needed before this hypothesis can be evaluated by statistical means. Extensive analysis of 18 different regional climate model (RCM) simulations shows that anthropogenic activity will very likely contribute to a significant increase in extreme precipitation amount and occurrence in Denmark. It is argued that climate models are incapable of simulating extreme precipitation at the temporal scales relevant for evaluation of the urban pluvial inundation risk. Hence statistical downscaling methods have been applied. Furthermore, the effect of the emission scenario, the spatial resolution of the RCM and the interdependency between RCMS are discussed. Accounting for the uncertainty introduced by these factors a 10-year event is expected to increase by 30% over a projection period of 100 years. This is less than the variation within one natural oscillation cycle, indicating that it is crucial to understand and account for the future multi-decadal variations of extreme precipitation.
Climatic changes of extreme precipitation in Denmark from 1874 to 2100

This study presents the results of a coordinated effort to estimate past, present and future changes and uncertainties in Danish design rainfall for urban drainage systems. The performed analyses cover long historical precipitation records, observations from a high-resolution rain-gauge network, an ensemble of climate model simulations, and two high-end climate scenarios. During the past 30 years rather dramatic changes in extreme precipitation have been observed in Denmark. These changes are mainly in the frequency of extreme events, but there is also a tendency towards more severe events. Both are considered effects of anthropogenic climate change. The increase in precipitation extremes has led to inundations in most of the larger cities during the last 10 years. To establish cities that are resilient to pluvial floods, robust projections of the frequency and intensity of extreme precipitation events in a changing climate are needed. Additionally, it is equally important to understand the natural variation onto which the anthropogenic changes are imposed. Trend analysis of observations from the high-resolution rain-gauge network currently applied for estimation of design intensities shows that the frequency of extreme events has increased by approximately 2% per year during the last three decades. Additional analyses of five long daily precipitation series show that the frequency of extreme events in the past has oscillated with a cycle of 25-35 years, a behavior that can in part be explained by sea level pressure differences over the Atlantic. On this basis the precipitation extremes in the Eastern part of Denmark are projected to be ascending in the last two decades. However, the increase has continued longer than expected and with larger amplitude in the most recent years. This indicates a likely influence from anthropogenic greenhouse gas emissions. With the complex combination of general increase and natural variation several additional years of observation are needed before this hypothesis can be evaluated by statistical means. Extensive analysis of 17 different regional climate model (RCM) simulations shows that anthropogenic activity very likely will contribute to a significant increase in extreme precipitation amount and occurrence in Denmark. It is argued that climate models are incapable of simulating extreme precipitation at the temporal scales relevant for evaluation of the urban pluvial inundation risk. Hence different statistical downscaling methods have been applied. Furthermore, the effect of the emission scenario, the spatial resolution of the RCM and the interdependency between RCMs are discussed. Taking this information into account a 2-year event is expected to increase by 20% over a projection period of 100 years. This approximates the variation within one natural oscillation cycle, indicating that it is crucial to understand and account for the future multi-decadal variations of extreme precipitation. The study estimates the expected magnitude of variation in design rainfall for urban drainage design due to anthropogenic climatic changes and natural variation. The analyses show that the most recent increase in design intensities is not attributed to anthropogenic climate change alone, but also heavily influenced by the natural variation of extreme rainfall. Together with a robust sign of increase in the design intensities, derived from an ensemble of climate models combined with different statistical downscaling methods, this gives confidence to the climate models’ ability to project future change of extreme rainfall over Denmark. The potential interaction between the natural variability and changes driven by the anthropogenic forcing is still to be better understood. However, the generated knowledge can assist the design of robust adaptation measures for changes in pluvial flood risk.
Evaluating climate change adaptation options for urban flooding in Copenhagen based on new high-end emission scenario simulations

Climate change adaptation studies on urban flooding are often based on a model chain approach from climate forcing scenarios to analysis of adaptation measures. Previous analyses of impacts in Denmark using ensemble projections of the A1B scenario are supplemented by two high-end scenario simulations. These include a regional climate model projection forced to a global temperature increase of 6 degrees as well as a projection based on the RCP8.5 scenario. With these scenarios projected impacts of extreme precipitation increase significantly. For extreme sea surges the impacts do not seem to change substantially. The impacts are assessed using Copenhagen as a case study. For both types of extremes large adaptation measures are essential in the global six degree scenario; dikes must be constructed to mitigate sea surge risk and a variety of measures to store or convey storm water must be implemented as well as new paradigms for city planning to mitigate the impact of change in extreme precipitation risk. For both hazards business-as-usual are not possible scenarios, because large autonomous adaptation will occur in lack of suitable policy-driven changes.

Copenhagen has developed an adaptation plan to pluvial flooding that makes the urban areas more robust and reduces the risk of flooding in current climate to a very low level. The economic benefit in the A1B scenario is substantial, and even in the 6 degree scenario the frequency of flooding is not much higher than national recommendations today. The expected annual damage in the six degree scenario will be higher than today because the size and frequency of extreme events will increase.

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Organisations: Department of Environmental Engineering, Urban Water Engineering, Copenhagen Municipality
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Extreme precipitation in a future climate-assessing climate factors at sub-daily scales from regional climate model projections

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Extreme precipitation in a future climate-assessing climate factors at sub-daily scales from regional climate model projections
Flood Resilience in Water Sensitive Cities: how do we reduce flood risk and why should we do it?

Floods and climate: emerging perspectives for flood risk assessment and management

Flood estimation and flood management have traditionally been the domain of hydrologists, water resources engineers and statisticians, and disciplinary approaches abound. Dominant views have been shaped; one example is the catchment perspective: floods are formed and influenced by the interaction of local, catchment-specific characteristics, such as meteorology, topography and geology. These traditional views have been beneficial, but they have a narrow framing. In this paper we contrast traditional views with broader perspectives that are emerging from an improved understanding of the climatic context of floods. We come to the following conclusions: (1) extending the traditional system boundaries (local catchment, recent decades, hydrological/hydraulic processes) opens up exciting possibilities for better understanding and improved tools for flood risk assessment and management. (2) Statistical approaches in flood estimation need to be complemented by the search for the causal mechanisms and dominant processes in the atmosphere, catchment and river system that leave their fingerprints on flood characteristics. (3) Natural climate variability leads to time-varying flood characteristics, and this variation may be partially quantifiable and predictable, with the perspective of dynamic, climate-informed flood risk management. (4) Efforts are needed to fully account for factors that contribute to changes in all three risk components (hazard, exposure, vulnerability) and to better understand the interactions between society and floods. (5) Given the global scale and societal importance, we call for the organization of an international multidisciplinary collaboration and data-sharing initiative to further understand the links between climate and flooding and to advance flood research.
Identifying added value in two high-resolution climate simulations over Scandinavia

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Implications of long-term oscillations in rainfall extremes on urban drainage design practices

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Organisations: Department of Environmental Engineering, Urban Water Engineering, KU Leuven
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Implications of long-term oscillations in rainfall extremes on urban drainage design practices

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Authors: Gregersen, I. B. (Intern), Madsen, H. (Ekstern), Willems, P. (Ekstern), Arnbjerg-Nielsen, K. (Intern)
The frequent flooding of European cities within the last decade has motivated a vast number of studies, among others addressing the non-stationary behaviour of hydrological extremes driven by anthropogenic climate change. However, when considering future extremes it also becomes relevant to search for and understand natural variations on which the anthropogenic changes are imposed. This study identifies multi-decadal variations in six 137-years-long diurnal rainfall extremes.
series from Denmark and southern Sweden, focusing on extremes with a reoccurrence level relevant for Danish drainage design. By means of a Peak over Threshold model series of the annual number of events ($\lambda$) and the mean annual magnitude of events ($\mu$) are generated and analysed separately. A moving window with a length of ten years is used to highlight the multi-decadal variations and a perturbation factor is calculated for each time step, comparing the given subseries with the full series. A general increase is found for $\lambda$, together with an oscillation pattern with a period of 25-40 years. Oscillations also are identified for $\mu$ but with a period of 15-30 years. Furthermore, regional differences and similarities are analysed, together with a possible link to different climatic drivers, like sea level pressure and sea surface temperature. Regarding Danish drainage design, the found oscillations have implied a substantial variation in the design intensities over time and are partly responsible for the most recent increase observed from 1979 to 2012. This illustrates the importance of understanding and accounting for the natural variation of extremes. The applied methodology can easily be transferred to other hydrological variables.

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**Modelling of green roof hydrological performance for urban drainage applications**

Green roofs are being widely implemented for stormwater management and their impact on the urban hydrological cycle can be evaluated by incorporating them into urban drainage models. This paper presents a model of green roof long term and single event hydrological performance. The model includes surface and subsurface storage components representing the overall retention capacity of the green roof which is continuously re-established by evapotranspiration. The runoff from the model is described through a non-linear reservoir approach. The model was calibrated and validated using measurement data from 3 different extensive sedum roofs in Denmark. These data consist of high-resolution measurements of runoff, precipitation and atmospheric variables in the period 2010–2012. The hydrological response of green roofs was quantified based on statistical analysis of the results of a 22-year (1989–2010) continuous simulation with Danish climate data. The results show that during single events, the 10 min runoff intensities were reduced by 10–36% for 5–10 years return period and 40–78% for 0.1–1 year return period; the runoff volumes were reduced by 2–5% for 5–10 years return period and 18–28% for 0.1–1 year return period. Annual runoff volumes were estimated to be 43–68% of the total precipitation. The peak time delay was found to greatly vary from 0 to more than 40 min depending on the type of event, and a general decrease in the time delay was observed for increasing rainfall intensities. Furthermore, the model was used to evaluate the variation of the average annual runoff from green roofs as a function of the total available storage and vegetation type. The results show that even a few millimeters of storage can reduce the mean annual runoff by up to 20% when compared to a traditional roof and that the mean annual runoff is not linearly related to the storage. Green roofs have therefore the potential to be important parts of future urban stormwater management plans.

**General information**

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Modelling of spatio-temporal precipitation relevant for urban hydrology with focus on scales, extremes and climate change

Time series of precipitation are necessary for assessment of urban hydrological systems. In a changed climate this is challenging as climate model output is not directly comparable to observations at the scales relevant for urban hydrology.
The focus of this PhD thesis is downscaling of precipitation to spatio-temporal scales used in urban hydrology. It investigates several observational data products and identifies relevant scales where climate change and precipitation can be assessed for urban use. Precipitation is modelled at different scales using different stochastic techniques. A weather generator is used to produce an artificial spatio-temporal precipitation product that can be used both directly in large scale urban hydrological modelling and for derivation of extreme precipitation statistics relevant for urban hydrology. It is discussed why precipitation time series from a changed climate are nec-essary for assessment of urban hydrological systems under climate change. For this, a quantification of the tool "Three Points Approach" is introduced along with a municipal water balance approach. This is done to highlight why it is important to assess the performance of urban water structures for all possible weather and not only for extreme precipitation where problems are expected.

Observational data is investigated at different spatio-temporal scales and re-event scales for assessment of climate change for urban application are identified. Four different observational data sets of precipitation are compared and used to rank climate models with respect to performance metrics. The four different observational data sets themselves are compared at daily temporal scale with respect to climate indices for mean and extreme precipitation. Data density seems to be a crucial parameter for good representation of extreme precipitation and gridding lowers the peak levels of the extremes. Measurements from a tipping bucket rain gauge are investigated and modelled at the temporal scale of minutes using Markov chain models. The noise at this temporal scale is considerable and the model framework is not considered feasible for spatial application and inclusion of climate change.

Correlated point measurements are compared to regional climate model output and the spatial correlation structure of extreme precipitation at the event level is assessed for both. Clearly, regional climate models have too long de-correlation lengths for sub-daily extreme precipitation besides having too low intensities. Especially the wrong spatial correlation structure is disturbing from an urban hydrological point of view as short-term extremes will cover too much ground if derived directly from bias corrected regional climate model output.

A weather generator is introduced to statistically downscale precipitation to urban scales. The weather generator is fitted using data from a dense network of tipping bucket rain gauges. The weather generator is operated at hourly time step and generates output on a 2 km grid. The output from the weather generator performs very well when compared to observations both with respect to absolute intensities and spatial correlation of precipitation extremes at event level. Furthermore, the weather generator is able to produce an output with a realistic seasonal behaviour with most of the hourly extremes happening in summer and most of the daily extremes in fall. This behaviour is in good accordance with reality where short term extremes originate in convective precipitation cells that occur when it is very warm and longer term extremes originate in frontal systems that dominate the fall and winter seasons.

The weather generator is perturbed with climate change signals derived from six different regional climate model runs. The regional climate model runs represent several emission scenarios, RCMs, GCMs and spatial model resolution and result in six very different perturbation schemes. Even so, the resulting precipitation outputs have comparable extremes for comparable emission scenarios and the estimated change in extremes is in accordance with other studies for the area. The study furthermore shows that there is no simple scaling between moderate emission scenarios and high-end emission scenarios as the sub daily extremes seem to grow faster in magnitude than the daily and multi daily ones for the high-end scenarios.

This study shows that spatio-temporal data products representing realistic precipitation in a changed climate can be produced at scales relevant for urban hydrology using stochastic weather generators. Good observational data for present conditions are however required as the correlation structures between different time series are important. If more sophisticated models are to be implemented at finer spatio-temporal scales models including physical behaviour describing precipitation movement and link it to synoptic scale weather are required. Alternatively, very high resolution regional climate models or simplifications thereof could be used for generation of data products at the desired scales.

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**Modelling the Impact of Implementing Water Sensitive Urban Design on at a catchment scale**

Stormwater management using Water Sensitive Urban Design (WSUD) is expected to be part of future drainage systems. This project aimed to develop a set of hydraulic models of the Harrestrup Å catchment (close to Copenhagen) in order to demonstrate the importance of modeling WSUDs at different scales, ranging from models of an individual soakaway up to models of a large urban catchment. The models were developed in Mike Urban with a new integrated soakaway model. A
small-scale individual soakaway model was used to determine appropriate initial conditions for soakaway models. This model was applied to a 22 year rain time series and statistical analysis performed. Results show that soakaways, depending on the design criteria, are on average 20-60% full at the beginning of rain events; outflow intensities from soakaways are reduced depending on the soakaway design return period, and the annual infiltration is > 80% of the annual precipitation even for small soakaway volumes. A local scale (<10ha) model examined the benefit of employing soakaways and detention basins for reducing flooding. A baseline scenario was set up and the areas which must be disconnected in order to avoid flooding identified. Different WSUD solutions such as soakaways and basins ("skybrudsfaskiner") were applied to these areas, with the WSUDs being dimensioned using simple estimation methods. Results showed that soakaways would require big volumes if events > 0.5 year return period are to be handled. However, smaller temporary detention volumes can reduce peak flows. The catchment scale model was then used to determine the potential impact of different percentages of impervious area disconnection (30, 50 and 70%) on catchment flooding and Combined Sewer Overflows (CSO). Results show that 30% disconnection would considerably reduce CSOs, whereas 70% disconnection is required to significantly reduce flooding. This study showed that WSUDs can significantly reduce flooding and runoff volumes discharged into the sewer system. However, large storage volumes are required to reduce flooding for design events. It was shown that combined soakaway-basin solutions require much less volume for peak reduction compared to ordinary soakaways and they are more robust towards peak reductions. An improved method for choosing initial conditions for soakaway models was proposed. This study presented an approach for designing WSUDs at the catchment scale and demonstrated the importance of employing both individual soakaway and catchment scale simulations. Flooding was shown to be generated by either excess inflow from upstream parts of the catchment or by reduction of downstream drainage capacity. From a hydraulic point of view WSUDs are shown to have the potential for flood and runoff volume reductions.

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Uncertainties in extreme precipitation under climate change conditions

The latest report from the Intergovernmental Panel on Climate Change (IPCC) states that it is unequivocal that climate change is occurring. One of the largest impacts of climate change is anticipated to be an increase in the severity of extreme events, such as extreme precipitation. Floods caused by extreme precipitation pose a threat to human life and cause high economic losses for society. Thus, strategies to adapt to changes in extreme precipitation are currently being developed and established worldwide. Information on the expected changes in extreme precipitation is required for the development of adaptation strategies, but these changes are subject to uncertainties.

The focus of this PhD thesis is the quantification of uncertainties in changes in extreme precipitation. It addresses two of the main sources of uncertainty in climate change impact studies: regional climate models (RCMs) and statistical downscaling methods (SDMs). RCMs provide information on climate change at the regional scale. SDMs are used to bias-correct and downscale the outputs of the RCMs to the local scale of interest in adaptation strategies.

In the first part of the study, a multi-model ensemble of RCMs from the European ENSEMBLES project was used to quantify the uncertainty in RCM projections over Denmark. Three aspects of the RCMs relevant for the uncertainty quantification were first identified and investigated. These are: the interdependency of the RCMs; the performance in current climate; and the change in the performance of the RCMs from current to future climate. The interdependency of the RCMs was estimated using two different methods. These led to slightly different results but to the same conclusion; that the RCMs cannot be considered independent.

The performance of the RCMs under current climate conditions was assessed using a range of precipitation indices, metrics, and observational data sets. It was found that these factors have a large influence on the performance estimated for the RCMs. This highlights the fact that it is not possible to identify a single best or worst RCM.

The possible change in the performance of the RCMs under future climate conditions was explored using the relation between the bias of the RCMs and the observed precipitation intensity. For all the RCMs, the magnitude of the bias depends on the precipitation intensity. Hence, changes in bias can be expected to occur with changes in extreme precipitation. These findings were taken into account in the development of a Bayesian approach, which quantifies the statistical uncertainty in the change in extreme precipitation. In general, extreme precipitation intensity is expected to increase by the end of the century, but this change is associated with large uncertainties, especially in summer. With a probability of 95%, extreme precipitation is estimated to increase in winter, but in summer the values range from a decrease of 40% to an increase of 40%. A set of tests were carried out to assess the influence of accounting for the interdependency and change in bias of the RCMs in the quantification of uncertainty. The results highlight the importance of taking these two aspects into account. If they are not accounted for there is a risk of underestimating the uncertainty and reaching overconfident results.

The second part of the study addressed the uncertainty arising from SDMs for two applications: river flooding in eleven European catchments; and urban flooding in Denmark. A range of SDMs were applied at daily and hourly resolution to the RCMs in the ensemble. The results for Denmark from both applications showed that in general the SDMs agree on an expected increase in extreme precipitation intensity. The uncertainty was explored by analysing the differences in the results of the SDMs and by comparing them with the differences within the RCM outputs. It was found that even though the variability within the SDMs is smaller than within the RCMs, it is not negligible. For example, in the river flooding application it represents approximately 30% of the total variance.

This study contributes to the understanding of the uncertainties in climate change impact studies arising from RCMs and SDMs. The Bayesian approach suggested is a step forward towards a more comprehensive quantification of the uncertainties in a multi-model ensemble of RCMs. This approach could potentially be extended to include the uncertainty arising from other sources, such as SDMs. Further research is suggested in this direction. The findings of this study point out that there are large uncertainties in changes in extreme precipitation under climate change conditions. These uncertainties should not be seen as a reason for postponing action on climate adaptation. We have enough knowledge to carry on with the development of adaptation strategies, but their robustness must be ensured by including information on the uncertainties in climate change impact studies.
Uncertainty assessment of urban pluvial flood risk in a context of climate change adaptation decision making

There has been a significant increase in climatic extremes in many regions. In Central and Northern Europe, this has led to more frequent and more severe floods. Along with improved flood modelling technologies this has enabled development of economic assessment of climate change adaptation to increasing urban flood risk. Assessment of adaptation strategies often requires a comprehensive risk-based economic analysis of current risk, drivers of change of risk over time, and measures to reduce the risk. However, such studies are often associated with large uncertainties. The uncertainties arise from basic assumptions in the economic analysis and the hydrological model, but also from the projection of future societies to local climate change impacts and suitable adaptation options. This presents a challenge to decision makers when trying to identify robust measures. We present an integrated uncertainty analysis, which can assess and quantify the overall uncertainty in relation to climate change adaptation to urban flash floods. The analysis is based on an uncertainty cascade that by means of Monte Carlo simulations of flood risk assessments incorporates climate change impacts as a key driver of risk changes over time. The overall uncertainty is then attributed to six bulk processes: climate change impact, urban rainfall-runoff processes, stage-depth functions, unit cost of repair, cost of adaptation measures, and discount rate. We apply the approach on an urban hydrological catchment in Odense, Denmark, and find that the uncertainty on the climate change impact appears to have the least influence on the net present value of the studied adaptation measures. This does not imply that the climate change impact is not important, but that the uncertainties are not dominating when deciding on action or in-action. We then consider the uncertainty related to choosing between adaptation options given that a decision of action has been taken. In this case the major part of the uncertainty on the estimated net present values is identical for all adaptation options and will therefore not affect a comparison between adaptation measures. This makes the chose among the options easier. Furthermore, the explicit attribution of uncertainty also enables a reduction of the overall uncertainty by identifying the processes which contributes the most. This knowledge can then be used to further reduce the uncertainty related to decision making, as a substantial part of the remaining uncertainty is epistemic.
Validation of two high-resolution climate simulations over Scandinavia

Before running climate projections with numerical models it is important to validate their performance under present climate conditions. Within the RiskChange project two high-resolution regional climate models were run as a perfect boundary experiment over Scandinavia. The simulations are validated with respect to timing, location and intensity of extreme events. The main objective of the RiskChange project (www.riskchange.dhigroup.com) is to establish a consistent scientifically-based framework for risk-based design using state-of-the-art knowledge of future changes in climate extreme statistics. Very high resolution is required in impact models that are employed to address particular societal needs and risks in terms of adaptation to future climate challenges, (e.g. future storm surge protection of coastlines and low-level lands or drainage systems in urban areas). The purpose of this study is to analyse the properties of high-resolution climate simulations over Scandinavia by testing a hypothesis that dynamic simulations are better at retaining the properties of precipitation, notably precipitation extremes than coarser simulations. When compared to statistical methods the dynamical downscaling has the advantage of retaining the full set of atmospheric variables as well as a physically more realistic description of e.g. complex terrain (e.g. mountain ranges and coastlines) and when the representation and behaviour of extremes are important to be captured in a realistic manner. Here, we present a set of two high-resolution dynamical downscaling simulations on an 8 km grid. Before performing climate simulations under future emission scenarios, it is crucial to validate the model performance under present-day climate conditions to identify systematic biases within the models (Jacob et al., 2007) and to evaluate to what degree the models simulate observed weather. This is done by performing a so-called perfect boundary experiment by dynamically downscaling ERA interim data. The atmospheric models WRF and HIRHAM5 were used as regional climate models (RCMs) in this study. Both models were initialized and driven at their lateral boundaries with ERA-interim data. The simulation period covers 1989-2010 with the first year considered spin-up and discarded. As observational reference we have used both gridded data (EOBS, Haylock et al., 2008) as well as station observations. Various methods are employed to examine the performance of the RCMs behaviour on a seasonal to sub-daily time scale. Both models exhibit a wet bias of 50-100 % (1-3 mm) in seasonal precipitation. This bias is most pronounced during winter. The lower-resolution reanalysis data underestimates wet-day precipitation in all four season by 13-36 % over the selected cities Bergen, Oslo and Copenhagen. The RCM simulations show a reduction of this underestimation and even indicate a sign change in some seasons/locations. A spatio-temporal evaluation of downscaled precipitation extremes shows that both RCM downscalings are much closer to the observational behaviour. The analysis of higher-order statistical models indicates that short duration extreme precipitation during summer is better simulated within both models.
Adaption to Extreme Rainfall with Open Urban Drainage System: An Integrated Hydrological Cost-Benefit Analysis

This paper presents a cross-disciplinary framework for assessment of climate change adaptation to increased precipitation extremes considering pluvial flood risk as well as additional environmental services provided by some of the adaptation options. The ability of adaptation alternatives to cope with extreme rainfalls is evaluated using a quantitative flood risk approach based on urban inundation modeling and socio-economic analysis of corresponding costs and benefits. A hedonic valuation model is applied to capture the local economic gains or losses from more water bodies in green areas. The framework was applied to the northern part of the city of Aarhus, Denmark. We investigated four adaptation strategies that encompassed laissez-faire, larger sewer pipes, local infiltration units, and open drainage system in the urban green structure. We found that when taking into account environmental amenity effects, an integration of open drainage basins in urban recreational areas is likely the best adaptation strategy, followed by pipe enlargement and local infiltration strategies. All three were improvements compared to the fourth strategy of no measures taken.

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A framework for joint management of regional water-energy systems

Water and energy systems are closely linked. Energy is needed in most stages of water usage, while water is needed to extract and process energy resources and generate electric power. However, policy goals associated with providing adequate water and energy supplies are often in opposition, causing conflicts over these two resources. This problem will be aggravated by population growth, rising living standards and climate change, highlighting the importance of developing integrated assessment and solutions. In this context, this study focused on the interaction between water and electric energy (or power) systems, with the goal of identifying a method that could be used to assess the broader spatio-temporal interactions between water and energy systems.

The proposed method is to include water users and power producers into a joint optimization problem that minimizes the cost of power production and maximizes the benefits of water allocation. This approach turns the multiobjective problem of water and power system management into a single objective one: net costs minimization. The economic value of water is calculated as a function of the state of the system, and this value is used to determine optimal allocations for each time step of the planning horizon. The physical linkages between the two systems are described as constraints in the optimization problem, and the problem is solved using stochastic dynamic programming or stochastic dual dynamic programming.

The method was implemented on the Iberian Peninsula to assess some of the interactions between the water and power system. The impact of climate change on the current Iberian power system was assessed. It was found that expected precipitation reductions will reduce runoff, decrease hydropower production, and increase irrigation water demand; whereas expected temperature increases will modify seasonal power demand patterns.

The proposed approach was also used to determine hydropower benefits in a coupled water-power system, and the results compared with traditional methods that represent hydropower benefits through exogenous prices. It was found that representing hydropower benefits through a constant price can be inadequate because it does not reflect the seasonality in power demand and water inflows, which affect the availability, and therefore value, of hydropower. Monthly prices were able to represent seasonality but resulted in unrealistic operation rules, such as emptying the reservoir during the month with the highest price, which can only be avoided through the inclusion of additional constraints. In contrast, including a simple representation of the power market into a hydro-economic model resulted in more realistic reservoir operation policies that adapted to changing inflow conditions. The effects of spatial aggregation on the analysis of water-power systems were evaluated by comparing results from an aggregated and a partially disaggregated model. The aggregated model, where all reservoirs were represented as a single equivalent energy reservoir, provided valuable insights into the management of water and power systems, but only at the Peninsula scale. The disaggregated model revealed that optimal allocations were achieved by managing water resources differently in each river basin according to local inflow, storage capacity, hydropower productivity, and irrigation demand and productivity. This highlights the importance of considering spatial differences in this type of analysis. The method was successfully used to assess linkages between the water and the power systems of the Iberian Peninsula. The framework is flexible and can potentially be used to model more aspects of the water-energy nexus, for instance: the energy requirements of the transport sector and the impact of biofuels on agriculture; the impact of reduced river discharge on cooling of thermal power plants; or the impact of carbon capture and storage on water resources. The increasing pressure of population growth, rising living standards, and climate change on water, energy, land, and climate systems will increase the need for integrated methods and models to assess the linkages between these systems. The methodological framework proposed here is a step forward in the development of these integrated tools.
**An influence diagram for urban flood risk assessment through pluvial flood hazards under non-stationary conditions**

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**A simple rainfall-runoff model for the single and long term hydrological performance of green roofs**

Green roofs are being widely implemented for storm water control and runoff reduction. There is need for incorporating green roofs into urban drainage models in order to evaluate their impact. These models must have low computational costs and fine time resolution. This paper aims to develop a model of green roof hydrological performance. A simple conceptual model for the long term and single event hydrological performance of green roofs, shows to be capable of reproducing observed runoff measurements. The model has surface and subsurface storage components representing the overall retention capacity of the green roof. The runoff from the system is described by the non-linear reservoir method and the storage capacity of the green roof is continuously re-established by evapotranspiration. Runoff data from a green roof in Denmark are collected and used for parameter calibration.

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A spatial and nonstationary model for the frequency of extreme rainfall events

Changes in the properties of extreme rainfall events have been observed worldwide. In relation to the discussion of ongoing climatic changes, it is of high importance to attribute these changes to known sources of climate variability. Focusing on spatial and temporal changes in the frequency of extreme rainfall events, a statistical model is tested for this purpose. The model is built on the theory of generalized linear models and uses Poisson regression solved by generalized estimation equations. Spatial and temporal explanatory variables can be included simultaneously, and their relative importance can be assessed. Additionally, the model allows for a spatial correlation between the measurements. Data from a Danish rain gauge network are used as a case study for model evaluation. Focusing on 10 min and 24 h rainfall extremes, it was found that regional variation in the mean annual precipitation could explain a significant part of the spatial variability. Still, this variable was found to be of minor influence in comparison to explanatory variables in the temporal domain. The identified significant temporal variables comprise the East Atlantic pattern, the average summer precipitation, and the average summer temperature. The two latter showed a high relative importance. The established link will be beneficial when predicting future occurrences of precipitation extremes. © 2013. American Geophysical Union. All Rights Reserved.
Assessing damage cost estimation of urban pluvial flood risk as a mean of improving climate change adaptations investments

Estimating the expected annual damage (EAD) due to flooding in an urban area is of great interest for urban water managers and other stakeholders. It is a strong indicator for a given area showing how it will be affected by climate change and how much can be gained by implementing adaptation measures. This study investigates three different methods for estimating the EAD based on a loglinear relation between the damage costs and the return periods, one of which has been used in previous studies.

The results show with the increased amount of data points there appears to be a shift in the log-linear relation which could be contributed by the Danish design standards for drainage systems. Three different methods for estimating the EAD were tested and the choice of method is less important than accounting for the log-linear shift. This then also means that the statistical approximation of the EAD used in previous studies appears to be valid and is a good assumption. The EAD estimation can be simplified by having a single unit cost per flooded area which is multiplied with the extent of the flood. It does however depend on the lower threshold chosen in the estimation of the flood extent.

Assessing future climatic changes of rainfall extremes at small spatio-temporal scales

Climate change is expected to influence the occurrence and magnitude of rainfall extremes and hence the flood risks in cities. Major impacts of an increased pluvial flood risk are expected to occur at hourly and sub-hourly resolutions. This
makes convective storms the dominant rainfall type in relation to urban flooding. The present study focuses on high-resolution regional climate model (RCM) skill in simulating sub-daily rainfall extremes. Temporal and spatial characteristics of output from three different RCM simulations with 25 km resolution are compared to point rainfall extremes estimated from observed data. The applied RCM data sets represent two different models and two different types of forcing. Temporal changes in observed extreme point rainfall are partly reproduced by the RCM RACMO when forced by ERA40 re-analysis data. Two ECHAM forced simulations show similar increases in the occurrence of rainfall extremes of over a 150-year period, but significantly different changes in the magnitudes. The physical processes behind convective rainfall extremes generate a distinctive spatial inter-site correlation structure for extreme events. All analysed RCM rainfall extremes, however, show a clear deviation from this correlation structure for sub-daily rainfalls, partly because RCM output represents areal rainfall intensities and partly due to well-known inadequacies in the convective parameterization of RCMs. The results highlight the problem urban designers are facing when using RCM output. The paper takes the first step towards a methodology by which RCM performance and other downscaling methods can be assessed in relation to the simulation of short-duration rainfall extremes.

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Authors: Gregersen, I. B. (Intern), Sørup, H. J. D. (Intern), Madsen, H. (Ekstern), Rosbjerg, D. (Intern), Mikkelsen, P. S. (Intern), Arnbjerg-Nielsen, K. (Intern)
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Authors: Arnbjerg-Nielsen, K. (Intern)
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Climate change adaptation to increased urban flood risk: comparing the socio-economic efficiency of water sensitive urban design practices with upgrading traditional infrastructure

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Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Arnbjerg-Nielsen, K. (Intern)
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Climate Change Impacts on Rainfall Extremes and Urban Drainage: a State-of-the-Art Review
Under the umbrella of the IWA/IAHR Joint Committee on Urban Drainage, the International Working Group on Urban Rainfall (IGUR) has reviewed existing methodologies for the analysis of long-term historical and future trends in urban
rainfall extremes and their effects on urban drainage systems, due to anthropogenic climate change. Current practices have several limitations and pitfalls, which are important to be considered by trend or climate change impact modellers and users of trend or impact results. The review (Willems et al., 2012) considers the following aspects: analysis of long-term historical trends due to anthropogenic climate change, analysis of long-term future trends due to anthropogenic climate change, and implications for urban drainage infrastructure design and management. A summary is provided in this paper.

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Organisations: Department of Environmental Engineering, Urban Water Engineering, University of Leuven, Swedish Meteorological and Hydrological Institute, University of South Australia, UNESCO-IHE Institute for Water Education, DHI Denmark, McGill University
Authors: Willems, P. (Ekstern), Olsson, J. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Beecham, S. (Ekstern), Pathirana, A. (Ekstern), Gregersen, I. B. (Intern), Madsen, H. (Ekstern), Nguyen, V. (Ekstern)
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Climate Change Impacts on Rainfall Extremes and Urban Drainage: a State-of-the-Art Review
Under the umbrella of the IWA/AHHR Joint Committee on Urban Drainage, the International Working Group on Urban Rainfall (IGUR) has reviewed existing methodologies for the analysis of long-term historical and future trends in urban rainfall extremes and their effects on urban drainage systems, due to anthropogenic climate change. Current practices have several limitations and pitfalls, which are important to be considered by trend or climate change impact modellers and users of trend/impact results. The review considers the following aspects: Analysis of long-term historical trends due to anthropogenic climate change: influence of data limitation, instrumental or environmental changes, interannual variations and longer term climate oscillations on trend testing results. Analysis of long-term future trends due to anthropogenic climate change: by complementing empirical historical data with the results from physically-based climate models, dynamic downscaling to the urban scale by means of Limited Area Models (LAMs) including explicitly small-scale cloud processes; validation of RCM/GCM results for local conditions accounting for natural variability, limited length of the available time series, difference in spatial scales, and influence of climate oscillations; statistical downscaling methods combined with bias correction; uncertainties associated with the climate forcing scenarios, the climate models, the initial states and the statistical downscaling step; uncertainties in the impact models (e.g. runoff peak flows, flood or surcharge frequencies, and CSO frequencies and volumes), including the impacts of more extreme conditions than considered during impact model calibration and validation. Implications for urban drainage infrastructure design and management: upgrading of the urban drainage system as part of a program of routine and scheduled replacement and renewal of aging infrastructure; how to account for the uncertainties; flexible and sustainable solutions; adaptive approach that provides inherent flexibility and reversibility and avoids closing off options; importance of active learning.

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Organisations: Department of Environmental Engineering, Urban Water Engineering, University of Leuven, Swedish Meteorological and Hydrological Institute, University of South Australia, UNESCO-IHE Institute for Water Education, DHI Denmark, McGill University
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Publication information
Climatic changes of extreme precipitation in Denmark from 1872 to 2100

During the past 30 years rather dramatic changes in extreme precipitation has been observed in Denmark. The changes have mainly been observed in the frequency of extreme events, but also a tendency towards more severe events is occurring. The increase in precipitation extremes have led to inundations in most of the larger cities during the last 10 years; the flood in Copenhagen in 2011 implied the second highest damage costs measured in Denmark during the last 100 years. Hence much effort is directed at explaining the observed increase and to predict future occurrence rates and sizes of precipitation extremes. The objective is to establish cities that are resilient to pluvial floods by means of a gradual upgrading of the drainage capacity in combination with a structured risk management approach.

Using the regional climate model (RCM) data repositories from PRUDENCE and ENSEMBLES, estimates of climate change impacts from anthropogenic effects can be established based on projections of daily precipitation. These estimates have then been further downscaled to enable urban pluvial inundation calculations using different statistical downscaling and extreme value analysis techniques. From the results it is clear that the impact from anthropogenic activity is very likely to be a significant increase in extreme precipitation amount and occurrence. The increase will be larger for higher return periods and shorter durations. However, the uncertainty of the increase is very high, and the RCM outputs are to some extent correlated which leads to over-confidence in the results obtained by using these repositories. Studies of data from a high-resolution network show that some of the observed changes during the recent decades can be partly explained by changes in atmospheric teleconnections. These results are important for the extrapolation to future events. Currently efforts are dedicated to constructing similar models based on outputs from climate models, but the models are complicated due to the fact that the correlation structure of high-resolution precipitation in the climate models deviates from the structure we observe in historical networks of rain gauges. The results from the analysis will be combined with an analysis of non-stationary behavior in a network of gauges measuring daily precipitation from 1872 to present.

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Correlations between rainfall data and insurance damage data related to sewer flooding for the case of Aarhus, Denmark

Sewer flooding due to extreme rainfall may result in considerable damage. Damage data to quantify costs of cleaning, drying, and replacing materials and goods are rare in literature. In this study, insurance claim data related to property damages are analysed for the municipality of Aarhus, Denmark. The aim of this paper was to study the extent to which
rainfall data can be used to explain variations in insurance claim data. In particular, the paper addresses the issue of time-lag between claim date and time of the damaging rainfall event, which may, if not taken into account, lead to underestimations of correlations between rainfall and damage variables. Rainfall data from two rain gauges were used to extract rainfall characteristics. From cross correlations between time series of rainfall and claim data, it can be concluded that rainfall events induce claims mostly on the same day, but also on the three days after. A linear model that takes into account rainfall data from previous days slightly improves correlations between rainfall and damage variables compared to a simple linear model. Best correlation coefficients were found between maximum hourly rainfall intensity and daily number of claims (0.47-0.57) and daily total damage (0.43-0.53).

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Economic assessment of climate change adaptation options incorporating Bayesian networks: An integrated framework

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Effects of climate model interdependency and common biases on the uncertainty quantification of extreme rainfall projections

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Organisations: Department of Environmental Engineering, Urban Water Engineering, Water Resources Engineering, DHI Denmark
Authors: Sunyer Pinya, M. A. (Intern), Madsen, H. (Ekstern), Rosbjerg, D. (Intern), Arnbjerg-Nielsen, K. (Intern)
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Publisher: The Danish Water Research and Innovation Platform
Editors: Jensen, B. K., Levysohn, N.
Main Research Area: Technical/natural sciences
Effects of climate model interdependency and common biases on the uncertainty quantification of extreme rainfall projections

Changes in rainfall extremes under climate change conditions are subject to numerous uncertainties. One of the most important uncertainties arises from the inherent uncertainty in climate models. In recent years, many efforts have been made in creating large multi-model ensembles of both Regional Climate Models (RCMs) and General Circulation Models (GCMs). These multi-model ensembles provide the information needed to estimate probabilistic climate change projections. Several probabilistic methods have been suggested. One common assumption in most of these methods is that the climate models are independent. The effects of this assumption on the uncertainty quantification of extreme rainfall projections are addressed in this study. First, the interdependency of the 95% quantile of wet days in the ENSEMBLES RCMs is estimated. For this statistic and the region studied, the RCMs cannot be assumed independent. Then, a Bayesian approach that accounts for the interdependency of the climate models is developed in order to quantify the uncertainty. The results of the Bayesian approach show that the uncertainty is narrower when the models are considered independent. These results highlight the importance of accounting for the climate model interdependency when estimating the uncertainty of climate change projections.
Impacts of climate change on rainfall extremes and urban drainage systems: A review

A review is made of current methods for assessing future changes in urban rainfall extremes and their effects on urban drainage systems, due to anthropogenic-induced climate change. The review concludes that in spite of significant advances there are still many limitations in our understanding of how to describe precipitation patterns in a changing climate in order to design and operate urban drainage infrastructure. Climate change may well be the driver that ensures that changes in urban drainage paradigms are identified and suitable solutions implemented. Design and optimization of urban drainage infrastructure considering climate change impacts and co-optimizing these with other objectives will become ever more important to keep our cities habitable into the future. © IWA Publishing 2013.

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering, University of Leuven, Swedish Meteorological and Hydrological Institute, University of South Australia, UNESCO-IHE Institute for Water Education, DHI Denmark, McGill University
Authors: Arnbjerg-Nielsen, K. (Intern), Willems, P. (Ekstern), Olsson, J. (Ekstern), Beecham, S. (Ekstern), Pathirana, A. (Ekstern), Gregersen, I. B. (Intern), Madsen, H. (Ekstern), Nguyen, V. (Ekstern)
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Kalibrering af en regngenerator til brug for nedskalering af klimastudier

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Authors: Sørup, H. J. D. (Intern), Bøsning Christensen, O. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern)
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Long term oscillations in rainfall extremes

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Organisations: Department of Environmental Engineering, Urban Water Engineering, Water Resources Engineering, Technical University of Denmark
Authors: Gregersen, I. B. (Intern), Madsen, H. (Ekstern), Rosbjerg, D. (Intern), Arnbjerg-Nielsen, K. (Intern)
Number of pages: 1
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Main Research Area: Technical/natural sciences
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On the importance of observational data properties when assessing regional climate model performance of extreme precipitation

In recent years, there has been an increase in the number of climate studies addressing changes in extreme precipitation. A common step in these studies involves the assessment of the climate model performance. This is often measured by comparing climate model output with observational data. In the majority of such studies the characteristics and uncertainties of the observational data are neglected.

This study addresses the influence of using different observational datasets to assess the climate model performance. Four different datasets covering Denmark using different gauge systems and comprising both networks of point measurements and gridded datasets are considered. Additionally, the influence of using different performance indices and metrics is addressed. A set of indices ranging from mean to extreme precipitation properties is calculated for all the datasets. For each of the observational datasets, the RCMs are ranked according to their performance using two different metrics. These are based on the error in representing the indices and the spatial correlation.

In comparison to the mean, extreme precipitation indices are highly dependent on the spatial resolution of the observations. The spatial correlation also shows differences between the observational datasets. These differences have a clear impact on the ranking of the climate models, which is highly dependent on the observational dataset, the index and the metric used. The results highlight the need to be aware of the properties of observational data chosen in order to avoid overconfident and misleading conclusions with respect to climate model performance.

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Authors: Sunyer Pinya, M. A. (Intern), Sørup, H. J. D. (Intern), Christensen, O. B. (Ekstern), Madsen, H. (Ekstern), Rosbjerg, D. (Intern), Mikkelsen, P. S. (Intern), Arnbjerg-Nielsen, K. (Intern)
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Perturbing a Stochastic Weather Generator with Different Climate Change Signals to Assess Extreme Precipitation under Influence of Climate Change at Urban Scales

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Number of pages: 2
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Event: Abstract from AGU Fall Meeting 2013, San Francisco, United States.
Quantitative potentials for rainwater handling using the "Three Points Approach" (3PA)

Rainwater in cities is both a resource for e.g. recreational and amenity purposes and a potential problem due to e.g. pluvial flooding. This study provides a new tool to communicate the potentials for alternative rainwater handling taking into account the properties of rainfall making it both a problem and a resource. The quantitative potentials of alternative rainwater handling are calculated in relation to the total precipitation volume, the total supplied potable water volume and the total volume of wastewater treated. Two different cases are investigated: one where rainwater is infiltrated and one where it is harvested and used for toilet flushing. The potential is calculated for the two largest municipalities of Denmark: Copenhagen and Aarhus. The Three Points Approach is used to distinguish between different rain domains, and to subdivide the quantitative potentials accordingly. This analysis shows that designing alternative rainwater handling systems for larger return periods than 5 to 10 years result in a very marginal increase in rainwater volume handled by these systems compared to systems designed for less severe events.

Regional interdependency of precipitation indices across Denmark in two ensembles of high-resolution RCMs

Outputs from climate models are the primary data source in climate change impact studies. However, their interpretation is not straightforward. In recent years, several methods have been developed in order to quantify the uncertainty in climate projections. One of the common assumptions in almost all these methods is that the climate models are independent. This study addresses the validity of this assumption for two ensembles of regional climate models (RCMs) from the Ensemble-Based Predictions of Climate Changes and their Impacts (ENSEMBLES) project based on the land cells covering Denmark. Daily precipitation indices from an ensemble of RCMs driven by the 40-yrECMWFRe-Analysis (ERA-40) and an ensemble of the same RCMs driven by different general circulation models (GCMs) are analyzed. Two different methods are used to estimate the amount of independent information in the ensembles. These are based on different statistical properties of a measure of climate model error. Additionally, a hierarchical cluster analysis is carried out. Regardless of the method used, the effective number of RCMs is smaller than the total number of RCMs. The estimated effective number of RCMs varies depending on the method and precipitation index considered. The results also show that the main cause of interdependency in the ensemble is the use of the same RCMdriven by different GCMs. This study shows that the precipitation outputs from the RCMs in the ENSEMBLES project cannot be considered independent. If the interdependency between RCMs is not taken into account, the uncertainty in the RCMsimulations of current regional climatemay be underestimated. This will in turn lead to an underestimation of the uncertainty in future precipitation projections. © 2013 American Meteorological Society.
Simple værktøjer til helhedsorienteret vurdering af alternative teknologier til regnvandshåndtering

General information

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Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Sørup, H. J. D. (Intern), Arnbjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern), Rygaard, M. (Intern), Lerer, S. M. (Intern)
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Steps towards Quantitative Assessment of the Effects of Water Sensitive Urban Design

For 150 years combined sewerage systems have been serving the task of efficiently draining Danish and other Nordic cities. Over the years, society’s expectations and needs have changed, and planners have upgraded and extended the systems. Current challenges include climate change, growth and densification of cities, and demands for sustainability and multifunctionality. One of the solutions suggested is decentralized source control management, also known as Water Sensitive Urban Design (WSUD). However, previous research has shown that WSUD must be seen in a wider context than the mere retrofitting of sewage systems, since it adds value to a city in many other ways. Thus successful planning of WSUD must bring together drainage engineers with city planners and architects. Our project aims to develop a decision support tool to assist in the interdisciplinary planning process of transition towards WSUD in existing urban areas. The tool will facilitate a quantification of the effects of implementing WSUD on a city district level.

This project considers an effect of implementing WSUD to be any measurable impact on the physical and social environment. The tool will include simple methods for assessing effects such as reduction in combined sewer overflow, increase in groundwater recharge, reduction in use of potable water, and increase in local recreational and property value. The tool will assess these effects for a number of different WSUD techniques, including green roofs, rainwater harvesting, swales, soakaways, rain gardens and retention ponds. Thus the tool will help answer questions such as what is the expected reduction in potable water consumption if rainwater harvesting is implemented in a given neighborhood. The global constraints, such as restrictions on usage of nonpotable water, and local constraints, such as the available area for collection of rainwater, will be taken into account in order to produce a realistic assessment. The assessments will be presented in an overview matrix to make the tool user friendly. The matrix results can further be summarized by using the optional weighting matrix according to stakeholder preferences.

Results presented will include findings from a review of the scientific literature and interviews with key stakeholders. These show that a large diversity of decision support tools for WSUD exist and are being used. However, decisions remain difficult because the tools use different framings and contextual information is difficult to include in their assessments. We will present results from applying our suggested approach on two case studies, one urban area in Århus and one in Copenhagen. Methods to select the optimal solution will be described, and the difficulties of composing decision criteria discussed. The best solution is also shown to be site specific, with local geographical constraints playing an important role in the outcome. An evaluation of the uncertainty in the predictions will be discussed, set in perspective against the general uncertainties in this type of planning. Finally we will present plans for implementing the tool in a software package to be made publicly available.

The results of this project are important because Danish cities are investing large amounts of resources in urban infrastructure renewal. For example, the Danish government agreed with the Danish municipalities to spend 2.5 billion DKK in 2013 on improving stormwater management to mitigate impacts of climate change. The municipalities are eagerly waiting for tools like the one developed in this project so that they can effectively prioritize their spending.
The role of uncertainty in climate change adaptation strategies — A Danish water management example

We propose a generic framework to characterize climate change adaptation uncertainty according to three dimensions: level, source and nature. Our framework is different, and in this respect more comprehensive, than the present UN Intergovernmental Panel on Climate Change (IPCC) approach and could be used to address concerns that the IPCC approach is oversimplified. We have studied the role of uncertainty in climate change adaptation planning using examples from four Danish water related sectors. The dominating sources of uncertainty differ greatly among issues; most uncertainties on impacts are epistemic (reducible) by nature but uncertainties on adaptation measures are complex, with ambiguity often being added to impact uncertainties. Strategies to deal with uncertainty in climate change adaptation should reflect the nature of the uncertainty sources and how they interact with risk level and decision making: (i) epistemic uncertainties can be reduced by gaining more knowledge; (ii) uncertainties related to ambiguity can be reduced by dialogue and knowledge sharing between the different stakeholders; and (iii) aleatory uncertainty is, by its nature, non-reducible. The uncertainty cascade includes many sources and their propagation through technical and socio-economic models may add substantially to prediction uncertainties, but they may also cancel each other. Thus, even large uncertainties may have small consequences for decision making, because multiple sources of information provide sufficient knowledge to justify action in climate change adaptation.

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Authors: Refsgaard, J. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Drews, M. (Intern), Halsnæs, K. (Intern), Jeppesen, E. (Ekstern), Madsen, H. (Ekstern), Markandya, A. (Ekstern), Olesen, J. (Ekstern), Porter, J. R. (Ekstern), Christensen, J. (Ekstern)
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Scopus rating (2015): SJR 0.846 SNIP 1.078 CiteScore 2.2
BFI (2014): BFI-level 1
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Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.943 SNIP 1.244 CiteScore 2.27
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
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Scopus rating (2012): SJR 0.763 SNIP 0.992 CiteScore 1.78
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Scopus rating (2011): SJR 0.772 SNIP 0.861 CiteScore 1.63
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.73 SNIP 0.856
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.92 SNIP 0.906
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.589 SNIP 0.805
Scopus rating (2007): SJR 0.523 SNIP 1.02
Towards Adaptive Urban Water Management: Up-Scaling Local Projects

Increasingly, the need for adaptive urban water management approaches is advertised, but the transition towards such approaches in the urban water sector seems to be slow. The purpose of this paper is to provide an in-depth study of how an innovative approach has been adopted in practice by looking into how contextual knowledge from a local project has been up-scaled to more generic knowledge. Specifically, the paper outlines how two planners from a Danish municipality succeeded in developing a more innovative sewage plan on the basis of a local project with implementation of local handling of rainwater. This insight into the processes of learning aggregation of water practices points towards the important role that the dedicated work performed by local facilitators and intermediaries play in relation to a transition towards more adaptive urban water management.

Un diagramme d'influence pour l'évaluation des risques d'inondations urbaines au travers des dangers de rejet pluvial dans des conditions non-stationnaires

Urban flooding introduces significant risk to society. Decision-makers need to agree on how to adapt urban areas to flooding. Non-stationarity leads to increased uncertainty and this is shown to be difficult to include into actual decision-making. Transparent methods are needed to facilitate the decision-making process. The primary objective of this study was to develop a risk assessment and decision support framework for pluvial urban flood risk under non-stationary conditions using an Influence diagram (ID) which is a Bayesian network (BN) extended with decision and utility nodes. Non-stationarity is considered to be the influence of climate change where extreme precipitation patterns change over time. The overall risk is quantified in monetary terms expressed as expected annual damage (EAD). The network is dynamic inasmuch as it assesses risk at different points in time to evaluate the non-stationarity in the urban system. The framework provides means for decision-makers to assess how different decisions on flood adaptation affect the risk now and in the future. For the development of the BN we used the HUGIN software. The result from the ID was extended with a cost-benefit analysis defining the net benefits for the investment plans. We tested our framework in a case study where...
the risk for flooding was assessed on a railway track in Risskov (Aarhus). Drainage system improvements are planned for the area and our case study presents how the developed ID illustrates the increase in risk over time and the decrease in risk due to the planned improvement.

**General information**

*State:* Published  
*Organisations:* Department of Environmental Engineering, Urban Water Engineering, Det Norske Veritas  
*Authors:* Åström, H. L. A. (Intern), Friis Hansen, P. (Ekstern), Garré, L. (Ekstern), Arnbjerg-Nielsen, K. (Intern)  
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*Bayesian network, Climate change, Flood risk assessment, Influence diagram*  
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*Source-ID:* u::9339  
*Publication:* Research - peer-review › Paper – Annual report year: 2013

**Using a weather generator to downscale spatio-temporal precipitation at urban scale**

In recent years, urban flooding has occurred in Denmark due to very local extreme precipitation events with very short lifetime. Several of these floods have been among the most severe ever experienced. The current study demonstrates the applicability of the Spatio-Temporal Neyman-Scott Rectangular Pulses weather generator at urban scale and how it can be used for downscaling by perturbation with a changed climate. The weather generator is calibrated against a dense network of high resolution tipping bucket rain gauges in and around Copenhagen. The model is validated by its ability to reproduce realistic extreme statistics. The model satisfactorily reproduces extreme statistics down to the one-hour scale and further produces realistic spatial correlation patterns at the rain event level. This is also the case for the extreme events. Furthermore, the weather generator is able to reproduce the observed spatio-temporal differences at very fine scale for all measured parameters. For downscaling, perturbation with a climate change signal, precipitation from four different regional climate model simulations has been analysed. The analysed models are two runs from the ENSEMBLES (RACMO/ECHAM and HIRHAM/ECHAM, A1B scenario and 25 km spatial scale) and two models run just for southern Scandinavia (both HIRHAM/EC-EARTH, rcp 4.5 and rcp 8.5 scenarios and 8 km spatial scale). All datasets are at one-hour time resolution. All models result in marked different perturbation schemes for the weather generator. The downscaled time series are analysed similarly to the validation procedure and change factors for the extremes are derived as a function of return period. Despite different perturbation schemes both A1B scenario models and the rcp 4.5 scenario model result in very similar downscaled precipitation time series and extreme statistics. Hence, the weather generator seems to be very robust to how a climate change signal is transferred to a perturbation scheme.

**General information**

*State:* Published  
*Organisations:* Department of Environmental Engineering, Danish Meteorological Institute  
*Authors:* Sørup, H. J. D. (Intern), Christensen, O. B. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern)  
*Number of pages:* 1  
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*Main Research Area:* Technical/natural sciences  
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*Source:* dtu  
*Source-ID:* u::8794  
*Publication:* Research - peer-review › Conference abstract for conference – Annual report year: 2013

**Using satellite imagery to assess the influence of recent urban development on the impacts of extreme rainfall**

**General information**

*State:* Published  
*Organisations:* Department of Management Engineering, Systems Analysis, DTU Climate Centre, Department of Environmental Engineering, Urban Water Engineering, DHI Denmark  
*Authors:* Kaspersen, P. S. (Intern), Drews, M. (Intern), Arnbjerg-Nielsen, K. (Intern), Madsen, H. (Ekstern)  
*Number of pages:* 2  
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*Electronic versions:*
Using satellite imagery to assess the influence of urban development on the impacts of extreme rainfall

We investigate the applicability of medium resolution Landsat satellite imagery for mapping temporal changes in urban land cover for direct use in urban flood models. The overarching aim is to provide accurate and cost- and resource-efficient quantification of temporal changes in risk towards the impacts of pluvial flooding. Initial results show that satellite imagery may have considerable potential in this respect.

Verification of flood damage modelling using insurance data

This paper presents the results of an analysis using insurance data for damage description and risk model verification, based on data from a Danish case. The results show that simple, local statistics of rainfall are not able to describe the variation in individual cost per claim, but are, however, feasible for modelling the overall cost per day. The study also shows that in combining the insurance and regional data it is possible to establish clear relationships between occurrences of claims and hazard maps. In particular, the results indicate that with improvements to data collection and analysis, improved prediction of damage costs will be possible, for example based also on socioeconomic variables. Furthermore, the paper concludes that more collaboration between scientific research and insurance agencies is needed to improve inundation modelling and economic assessments for urban drainage designs.
Climate change impact assessment of extreme precipitation on urban flash floods – case study, Aarhus, Denmark

Climate change is expected to cause more intense extreme rainfall events, which will have a severe impact on the risk of flash floods in urban areas. An assessment study was performed for the city of Aarhus, Denmark, analysing different methods of statistical downscaling of climate model projections for estimation of changes in extreme rainfall characteristics. Climate model projections from 20 regional climate models (RCM) from the ENSEMBLES data archive were used in the analysis. Two different estimation methods were applied, using, respectively, a direct estimation of the changes in the extreme value statistics of the RCM data, and application of a stochastic weather generator fitted to the changes in rainfall characteristics from the RCM data. The results show a large variability in the projected changes in extreme precipitation between the different RCMs and the two estimation methods considered. Urban flooding in Aarhus was simulated with a model that dynamically couples a hydraulic model of the drainage system and a 2D overland flow model.
model. Scenarios representing current and future climate including uncertainties in the climate projections were analysed using synthetic design storms derived from the estimated intensity-duration-frequency curves.

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Organisations: Department of Environmental Engineering, Urban Water Engineering, Water Resources Engineering, DHI Denmark
Authors: Madsen, H. (Ekstern), Sunyer Pinya, M. A. (Intern), Rosbjerg, D. (Intern), Arnbjerg-Nielsen, K. (Intern), St. Domingo, N. D. (Ekstern)
Number of pages: 1
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**Climate change impact assessment on urban rainfall extremes and urban drainage: Methods and shortcomings**

Cities are becoming increasingly vulnerable to flooding because of rapid urbanization, installation of complex infrastructure, and changes in the precipitation patterns caused by anthropogenic climate change. The present paper provides a critical review of the current state-of-the-art methods for assessing the impacts of climate change on precipitation at the urban catchment scale. Downscaling of results from global circulation models or regional climate models to urban catchment scales are needed because these models are not able to describe accurately the rainfall process at suitable high temporal and spatial resolution for urban drainage studies. The downscaled rainfall results are however highly uncertain, depending on the models and downscaling methods considered. This uncertainty becomes more challenging for rainfall extremes since the properties of these extremes do not automatically reflect those of average precipitation. In this paper, following an overview of some recent advances in the development of innovative methods for assessing the impacts of climate change on urban rainfall extremes as well as on urban hydrology and hydraulics, several existing difficulties and remaining challenges in dealing with this assessment are discussed and further research needs are described.

**General information**

State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering, Katholieke Universiteit, Swedish Meteorological and Hydrological Institute, Sweden, McGill University
Authors: Willems, P. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Olsson, J. (Ekstern), Nguyen, V. (Ekstern)
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ISI indexed (2012): ISI indexed yes
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Climate change-induced impacts on urban flood risk influenced by concurrent hazards

In coastal regions, several hazards may lead to floods, and if they occur concurrently, the damage will be higher than for the hazards individually. The paper outlines an approach for carrying out a risk analysis with several hazards and applies it on a case study in Greater Copenhagen where two hazards, rainfall and sea surge, are both important. The core in the methodology is the application of copula functions as an extension of one-dimensional risk analysis and projections of future climatic changes. The results for Greater Copenhagen indicate that the dependence between the hazards is weak and that climate change most likely will not increase the correlation. The overall change in flood return periods over a forecast horizon of 110 years are estimated to decrease by one to three orders of magnitude.

General information
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Organisations: Department of Environmental Engineering, Urban Water Engineering, Technical University of Denmark
Authors: Pedersen, A. N. (Ekstern), Mikkelsen, P. S. (Intern), Arnbjerg-Nielsen, K. (Intern)
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Comparing Regional Climate Model output to observational data sets for extreme rainfall

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Organisations: Department of Environmental Engineering, Urban Water Engineering, Water Resources Engineering, DHI Denmark

Authors: Sunyer Pinya, M. A. (Intern), Sørup, H. J. D. (Intern), Madsen, H. (Ekstern), Rosbjerg, D. (Intern), Arnbjerg-Nielsen, K. (Intern)

Number of pages: 1

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**Coupled water-energy modelling to assess climate change impacts on the Iberian Power System**

Water resources systems and power systems are strongly linked; water is needed for most power generation technologies, and electricity is required in every stage of water usage. In the Iberian Peninsula, climate change is expected to have a negative impact on the power system: changes in runoff are expected to reduce hydropower generation and cooling water availability for thermal power generation; and higher temperatures are expected to increase (decrease) summer (winter) electricity demand, when water resources are already constrained. We use coupled hydrological and power system models to study the effects of climate change on the current Iberian power system. The Iberian power system is a competitive power market where power price is determined by power supply and demand, and which can be simulated by a market equilibrium model considering the power demand function and the installed capacities and marginal costs of the power producers. Two effects of climate change on the power system were studied: changes in the hydropower production caused by changes in precipitation and temperature, and changes in the electricity demand over the year caused by temperature changes. A rainfall-runoff model was established to estimate the impact of precipitation and temperature changes on reservoir inflows. The model was calibrated using observed precipitation, temperature and river discharge time series. Potential evapotranspiration was estimated from temperature data, and snow accumulation/melt was modelled using a temperature index method. The delta change approach was used to generate...
synthetic precipitation and temperature data based on observations (1961-1990) and three regional climate models (2036-2065, CLM, RACMO and REMO). Because modelling generation on 1000+ hydropower plants is intractable, the capacities, inflows and minimum releases of all reservoirs were converted to energy and power units, and then aggregated into an equivalent energy reservoir. Irrigation water demands were also converted to power units and added to the minimum releases of upstream reservoirs and to power sinks of downstream ones. The water value method, an adaptation of stochastic dynamic programming, was used to estimate the marginal costs of hydropower as a function of the time of the year, the energy storage and the inflow state. The power system was simulated with estimated power demand, and the installed capacities and marginal costs of every generation technology, providing estimates of electricity prices and power production per technology under different climate scenarios. The simulation results indicate that hydropower production is likely to decrease as a consequence of reduced inflows, causing higher electricity prices. Temperature changes will shift a portion of the electricity demand from winter to summer months, resulting in increased electricity prices. The reduction of water availability caused by climate change will increase the competition between irrigation and power production, leading to a sharper trade-off between electricity prices and agricultural benefits.

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State: Published
Organisations: Department of Environmental Engineering, Water Resources Engineering, Urban Water Engineering, DHI Denmark
Authors: Pereira Cardenal, S. J. (Intern), Madsen, H. (Ekstern), Riegels, N. (Ekstern), Jensen, R. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Bauer-Gottwein, P. (Intern)
Number of pages: 1
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PereiraCardenal-ClimateChangeImpactsIberianPowerSystem.pdf
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Decision strategies for handling the uncertainty of future extreme rainfall under the influence of climate change
Several extraordinary rainfall events have occurred in Denmark within the last few years. For each event, problems in urban areas occurred as the capacity of the existing drainage systems were exceeded. Adaptation to climate change is necessary but also very challenging as urban drainage systems are characterized by long technical lifetimes and high, unrecoverable construction costs. One of the most important barriers for the initiation and implementation of the adaptation strategies is therefore the uncertainty when predicting the magnitude of the extreme rainfall in the future. This challenge is explored through the application and discussion of three different theoretical decision support strategies: the precautionary principle, the minimax strategy and Bayesian decision support. The reviewed decision support strategies all proved valuable for addressing the identified uncertainties, at best applied together as they all yield information that improved decision making and thus enabled more robust decisions.

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Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Gregersen, I. B. (Intern), Arnbjerg-Nielsen, K. (Intern)
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Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.466 SNIP 0.599 CiteScore 1.19
Descriptive and predictive evaluation of high resolution Markov chain precipitation models

A time series of tipping bucket recordings of very high temporal and volumetric resolution precipitation is modelled using Markov chain models. Both first and second-order Markov models as well as seasonal and diurnal models are investigated and evaluated using likelihood based techniques. The first-order Markov model seems to capture most of the properties of precipitation, but inclusion of seasonal and diurnal variation improves the model. Including a second-order Markov Chain component does improve the descriptive capabilities of the model, but is very expensive in its parameter use. Continuous
modelling of the Markov process proved attractive because of a marked decrease in the number of parameters. Inclusion of seasonality into the continuous Markov chain model proved difficult. Monte Carlo simulations with the models show that it is very difficult for all the model formulations to reproduce the time series on event level. Extreme events with short (10 min), medium (60 min) and long (12 h) durations were investigated because of their importance in urban hydrology. Both the descriptive likelihood based statistics and the predictive Monte Carlo simulation based statistics are valuable and necessary tools when evaluating model fit and performance. Copyright © 2012 John Wiley & Sons, Ltd.
Climate change is likely to influence the water cycle by changing the precipitation patterns, in some cases leading to increased occurrences of precipitation extremes. Urban landscapes are vulnerable to such changes due to the concentrated population and socio-economic values in cities. Feasible adaptation requires better flood risk quantification and assessment of appropriate adaptation actions in term of costs and benefits. This paper presents an economic assessment of three prevailing climate adaptation options for urban drainage design in a Danish case study, Odense. A risk-based evaluation framework is used to give detailed insights of the physical and economic feasibilities of each option. Estimation of marginal benefits of adaptation options are carried out through a step-by-step cost-benefit analysis. The results are aimed at providing important information for decision making on how best to adapt to urban pluvial flooding due to climate impacts in cities.

**General information**

State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering, Department of Management Engineering, Systems Analysis, DTU Climate Centre
Authors: Zhou, Q. (Intern), Halsnæs, K. (Intern), Arnbjerg-Nielsen, K. (Intern)
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Scopus rating (2015): SJR 0.466 SNIP 0.599 CiteScore 1.19
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BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.587 SNIP 0.685 CiteScore 1.14
Web of Science (2014): Indexed yes
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ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.601 SNIP 0.669 CiteScore 1.13
ISI indexed (2012): ISI indexed yes
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Scopus rating (2011): SJR 0.591 SNIP 0.626 CiteScore 1.25
Effects of climate model interdependency on the uncertainty quantification of extreme rainfall projections

The inherent uncertainty in climate models is one of the most important uncertainties in climate change impact studies. In recent years, several uncertainty quantification methods based on multi-model ensembles have been suggested. Most of these methods assume that the climate models are independent. This study investigates the validity of this assumption and its effects on the estimated probabilistic projections of the changes in the 95% quantile of wet days. The methodology is divided in two main parts. First, the interdependency of the ENSEMBLES RCMs is estimated using the methodology developed by Pennell and Reichler (2011). The results show that the projections from the ENSEMBLES RCMs cannot be assumed independent. This result is then used to estimate the uncertainty in climate model projections. A Bayesian approach has been developed using the procedure suggested by Tebaldi et al. (2005) in order to quantify the uncertainty.

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Authors: Sunyer Pinya, M. A. (Intern), Madsen, H. (Ekstern), Rosbjerg, D. (Intern), Arnbjerg-Nielsen, K. (Intern)
Number of pages: 5
Publication date: 2012
Evaluation of high resolution spatio-temporal precipitation extremes from a stochastic weather generator

Spatio-temporal rainfall is modelled for the North-Eastern part of Zealand (Denmark) using the Spatio-Temporal Neyman-Scott Rectangular Pulses model as implemented in the RainSim software. Hourly precipitation series for fitting the model are obtained from a dense network of tipping bucket rain gauges in the model area. The spatio-temporal performance of the model with respect to precipitation extremes is evaluated in the points of a 2x2 km regular grid covering the full model area. The model satisfactorily reproduces the extreme behaviour of the observed precipitation with respect to event intensity levels and unconditional spatial correlation when evaluated using an event based ranking approach at point scale and an advanced spatio-temporal coupling of extreme events. Prospectively the model can be used as a tool to evaluate the impact of climate change without relying on precipitation output from climate model modelled precipitation directly, but merely on the climate change signal derived from climate models.

Extreme and mean rainfall differences in observational data used as reference in climate studies

Extreme and mean rainfall differences in observational data used as reference in climate studies
Framework for economic pluvial flood risk assessment considering climate change effects and adaptation benefits

Climate change is likely to affect the water cycle by influencing the precipitation patterns. It is important to integrate the anticipated changes into the design of urban drainage in response to the increased risk level in cities. This paper presents a pluvial flood risk assessment framework to identify and assess adaptation options in the urban context. An integrated approach is adopted by incorporating climate change impact assessment, flood inundation modeling, economic tool, and risk assessment, hereby developing a step-by-step process for cost-benefit assessment of climate change adaptation measures. A Danish case study indicates that the introduced framework presented in the paper can be considered as an important decision support tool that can supplement and further develop existing decision practices in relation to urban drainage.
Impacts of Climate Change on Rainfall Extremes and Urban Drainage Systems

Impacts of Climate Change on Rainfall Extremes and Urban Drainage Systems provides a state-of-the-art overview of existing methodologies and relevant results related to the assessment of the climate change impacts on urban rainfall extremes as well as on urban hydrology and hydraulics. This overview focuses mainly on several difficulties and limitations regarding the current methods and discusses various issues and challenges facing the research community in dealing with the climate change impact assessment and adaptation for urban drainage infrastructure design and management.

General information
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Organisations: Department of Environmental Engineering, Urban Water Engineering, University of Leuven, Swedish Meteorological and Hydrological Institute, University of South Australia, UNESCO-IHE Institute for Water Education, DHI Denmark, McGill University
Authors: Willems, P. (Ekstern), Olsson, J. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Beecham, S. (Ekstern), Pathirana, A. (Ekstern), Gregersen, I. B. (Intern), Madsen, H. (Ekstern), Nguyen, V. V. (Ekstern)
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Organisations: Urban Water Engineering, Department of Environmental Engineering, Københavns Energi A/S
Authors: Arnbjerg-Nielsen, K. (Intern), Juel-Berg, K. (Ekstern), Johansen, N. B. (Ekstern)
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Electronic versions:
Samlet_rapport_82.pdf
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Limitations and pitfalls of climate change impact analysis on urban rainfall extremes

Under the umbrella of the IWA/AHHR Joint Committee on Urban Drainage, the International Working Group on Urban Rainfall (IGUR) has reviewed existing methodologies for the analysis of long-term historical and future trends in urban rainfall extremes and their effects on urban drainage systems, due to anthropogenic climate change. Current practices have several limitations and pitfalls, which are important to be considered by trend or climate change impact modellers and users of trend/impact results. Climate change may well be the driver that ensures that changes in urban drainage paradigms are identified and suitable solutions implemented. Design and optimization of urban drainage infrastructure considering climate change impacts and co-optimizing with other objectives will become ever more important to keep our cities liveable into the future.

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Organisations: Department of Environmental Engineering, Urban Water Engineering, University of Leuven, Swedish Meteorological and Hydrological Institute, University of South Australia, UNESCO-IHE Institute for Water Education, DHI Denmark, McGill University
Quantification of climate change effects on extreme precipitation used for high resolution hydrologic design

Design of urban drainage structures should include the climatic changes anticipated over the technical lifetime of the system. In Northern Europe climate changes implies increasing occurrences of extreme rainfall. Three approaches to quantify the impact of climate changes on extreme rainfall are studied, all based on output from historical rain series of the present climate and output from Regional Climate Models. Two models are applied, one being based on an extreme value model, the Partial Duration Series Approach, and the other based on a stochastic rainfall generator model. Finally an approach is based on identification of areas, where the present climate resembles the anticipated future climate for the region in question. The results indicate that design intensities in Denmark are likely to be increased by 10–50% within the next 100 years. The increase in design intensities depend on the duration and the return period in question.
Risikostyring i vandforsyningen

Drinking water in Denmark is distributed with only few or no hygienic barriers between catchment and consumer, and it is therefore essential to monitor the drinking water quality. Traditionally, drinking water monitoring has been performed as a control of the delivered water quality rather than as a risk management, allowing to react timely on quality changes to prevent distribution of a deteriorated water quality. ‘From risk monitoring to risk management – risk assessment in water supply’ is a 3-year (2011-2013) innovation project under the strategic partnership ‘Water in Urban Areas’ (www.vandibyer.dk) carried out by the knowledge institutions DTU Environment, DHI, the water utilities Copenhagen Energy, Aarhus Water, VCS Denmark and the public authorities Odense municipality and the Danish Nature Agency. The purpose of the project is to develop and implement risk management as a part of the climate adaptation measures in the water supply. The risk management will be based on the development of a new and improved monitoring strategy from catchment to consumer - taking into consideration the possibilities and limitations of analytical methods and sensors - and
the development and implementation of advanced quantitative risk analysis and management systems. The project work includes: a) Identification of focus areas based on experiences gathered from contamination cases in the involved water supplies; b) Identification of additional demand for management systems for monitoring based on experiences from the processes of implementing Water Safety Plans; c) Development of a new monitoring strategy; d) Development of quantitative risk assessment in water supply; e) Development of strategies for implementing extra hygienic barriers e.g. UV; f) Development of new software to cover identified demands for monitoring and management; g) Implementing and evaluating developed tools in demonstration projects, hereby ensuring further dissemination. The first part of the project has been a knowledge gathering based on the water utilities experiences from implementation of Water Safety Plans and from contamination cases. The knowledge gathering will be used to define monitoring strategies for the three scenarios a) the normal situation; b) a contamination situation; c) source tracking situation.

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Uncertainty assessment of climate change adaptation using an economic pluvial flood risk framework
Introduction. Adaptation is necessary to cope with the increasing flood risk in cities due to climate change in many regions of the world. Decision marking of adaptation strategies often requires a comprehensive risk-based economic analysis to indicate the net benefits of proposed options. Priority should be given to measures that are beneficial irrespective of uncertainties in the assessment (no-regret measures). One challenging question is how to assess the associated uncertainties of costs and benefits in the evaluation procedure, since the assessment is complicated by inherent uncertainties of various input variables.

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Uncertainty assessment of climate change adaptation options in urban flash floods
Introduction. Adaptation is necessary to cope with the increasing flood risk in cities due to climate change in many regions of the world. Decision marking of adaptation strategies often requires a comprehensive risk-based economic analysis to indicate the net benefits of proposed options. Priority should be given to measures that are beneficial irrespective of uncertainties in the assessment (no-regret measures). One challenging question is how to assess the associated uncertainties of costs and benefits in the evaluation procedure, since the assessment is complicated by inherent uncertainties of various input variables.
Urban drainage design and climate change adaptation decision making

Since the middle of the 19th century urban drainage has been a vital infrastructure in cities. Traditionally, urban drainage has been used as a convenient cleaning mechanism for public hygiene and an efficient conveyance facility to tackle floods for life and assets protection. From the early 20th century, the design objectives of urban drainage systems also include elements such as environmental protection and amenity values. Among the objectives, flood protection has received much attention in recent years as a result of increasing flood hazards and risks due to climate change impacts. Although mitigation steps have been taken in attempts to reduce global warming, adaptation is highly advocated to supplement mitigation to cope with the unavoidable adverse impacts of flooding on vulnerable assets. The emphasis of this PhD thesis is flood protection in the context of pluvial flooding by investigating new principles and approaches for assessment of urban drainage adaptation measures under climate change impacts. The thesis describes a new framework for design and analysis of urban drainage that accurately assesses hazards and vulnerabilities of urban areas and quantifies the present and future risks based on projections of climate change and city development. Furthermore, this framework can be utilized to identify cost-effective measures that can reduce the overall flood risk to an acceptable level considering both costs and benefits of adaptation. The framework is mainly based on a utilitarian approach that studies urban drainage adaptation solutions from a socio-economic point of view. The methodologies involve the state-of-the-art flood inundation modelling, risk assessment tools, socio-economic analysis tools, city planning, and uncertainty analysis. The thesis has explored several limitations of the current design practice of urban drainage. To further supplement and develop the common practice, a systemic and integrated framework is proposed by incorporating three research areas: (i) risk-based economic approaches for assessment of climate adaptation design, (ii) uncertainty analysis of climate adaptation assessment and (iii) reframing the assessment approaches by incorporating additional benefits and costs of adaptation alternatives. To strategically provide a functional performance of urban drainage systems, a risk-based economic approach is developed to take into account the impacts of all probable floods in terms of their probabilities and consequences (e.g. extents of floods, costing of damage). It is found that this approach contributes to a better understanding of the contributions of different return periods/flood events to the overall risk under both current and future climatic conditions and therefore can be used as guidance for further adaptation actions (e.g. formulation of an appropriate service level). Furthermore, the risk-based economic approach enables an assessment and comparison of the expected benefits (due to saved flood damage) and corresponding costs of different adaptation measures. This gives more detailed insights into the pros and cons of different adaptation options, thus helping to optimize the efficiency and performance of urban drainage adaptation design. The thesis investigates impacts of uncertainties associated with not only the hydrological conditions (e.g. design intensities, climate change impacts), but also the present and future vulnerability conditions (e.g. impacts on assets). This enables a complete assessment of effects of various uncertainties in the climate change assessment process. Furthermore, in the study, two types of uncertainties are distinguished: 1) the overall uncertainty of
Based on assessments of the two types of uncertainties, it is found that although climate change adaptation assessment is often associated with large uncertainties, it is still possible to identify robust adaptation options based on calculated marginal uncertainties. This is because that the uncertainties related to costing of floods and magnitude of climate impacts will be levelled out when comparing adaptation alternatives. In addition, a sensitivity analysis is also incorporated in the framework to assess the relative contribution of inherent uncertainties in the assessment. This allows an identification of critical/important uncertainties that matter for decision making and also provides a guide for further efforts to improve decision making in relation to climate change adaptation.

Traditionally, assessment of climate change adaptation is based on conventional engineering solutions, meaning that only response impacts in the context of hydrological extremes are considered while the added intangible values (e.g. recreational amenities due to a nice blue-green neighbourhood) of adaptation options are often ignored or underestimated. In order to facilitate the development and implementation of water sensitive urban design concepts climate change adaptation tools must take into account the additional benefits of using these concepts. This thesis develops a reframed design framework to account for such intangible goods/values of adaptation options. This serves as a valuable basis for evaluating the benefits of provision of positive environmental values and the preservation of water resources. It is found that neglecting intangible values in climate adaptation assessment can easily bias the decision making; the reframed approach hence provide an important tool for assessment of additional benefits and costs of such innovative solutions. The thesis points towards an integrated framework for urban drainage adaptation design considering climate change effects and adaptation benefits and costs. The case studies show how the proposed framework can be utilized to manage the anticipated climate change risks in a cost-effective way under different circumstances. The introduced framework provides an important supplement or replacement of current design practices under influence of climate change.
Variations of extreme rainfall in space and time

In the ongoing climate change discussion, methods for identification of variability governed by climate change are important tools. The magnitude of variables that can describe this variability should be compared with magnitudes of variables describing variability in a stationary setting. This study focuses on variations of extreme rainfall events, observed at 70 different locations in Denmark over a period of 31 years. The aim is to identify and compare variables, both spatially and temporally, which can explain different parts of the variability in this data set. Assuming that the number of extremes at each location is generated by a point process, we develop a spatio-temporal model based on Poisson regression. The starting point of the analysis is two marginal models formulated for number of events 1) averaged over all years of observations 2) averaged over all measurement sites. The first resembles a classical regional extreme value model, which includes the spatial correlation between the observations and a weighing based on the number of active observation days at each site. The latter resembles a Generalized Least Squares regression, with a weighing based on the number of active measurement sites each year. To explain the observed variability we consider the mean annual precipitation at a given location as a spatial regression variable. As temporal variables we consider both local variables, like the average Danish summer temperature in a given year, and large-scale variables like the variety of well-known teleconnections in the Northern Hemisphere. The analyses are performed for rainfall of 10 min and 24 hour duration, to represent different rainfall characteristics relevant to urban hydrology. We find that the mean annual precipitation explains a significant amount of the spatial variation, whereas annual variations are related to changes in the average Danish summer precipitation, the average Danish summer temperature and the East Atlantic pattern. The spatio-temporal Poisson regression model was found to be a helpful tool when comparing the internal importance of these variables. Still there are challenges when we explicitly model the number of extreme events at a given year, at a given location. It was found that the goodness of the model highly depends on assumptions in the generalized linear model, notably the link function between the continuous regression model and the observed count process and that the count process follows a Poisson distribution.

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Verification of flood damage modelling using insurance data
This paper presents the results of an analysis using insurance data for damage description and risk model verification, based on data from a Danish case. The results show that simple, local statistics of rainfall are not able to describe the variation in individual cost per claim, but are, however, feasible for modelling the overall cost per day. The study also shows that combining the insurance and regional data it is possible to establish clear relationships between occurrences of claims and hazard maps. In particular, the results indicate that with improvements on data collection and analysis,
improved prediction of damage information will be possible, e.g. based on also socioeconomic variables. Furthermore, the paper concludes that more collaboration between scientific research and insurance agencies is necessary to improve inundation modelling and economic assessments for urban drainage designs.

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**Organisations:** Department of Environmental Engineering, Urban Water Engineering, University of Copenhagen
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**Water in Urban Areas in a Climate Change Perspective: Challenges and Research Needs**
Climatic changes will influence the water cycle substantially. This will have an immediate impact on the performance of urban water infrastructure. A case study from Roskilde shows that assuming an increase in design intensities of 40% over a 100 year horizon will lead to increased cost of individual very extreme events (e.g. more than 100 years) of approximately 70% and a 900% increase in the expected annual losses due to floods. Other case studies in Denmark show smaller impacts, but still very significant increased annual costs compared to the present state. This calls for systematic planning of adaptation to the anticipated climatic changes and research to identify optimal strategies. In other areas of the world droughts and/or water resource availability in general will also become increasingly important. As such the water cycle in urban areas will be controlled more extensively in the future as part of engineering design. However, climatic changes are only one of a suite of time varying drivers of urban design. Other key drivers include technological and modelling capabilities, city planning, environmental considerations, increasing urbanization, and changes in social behaviour. There is a need to forecast all the changes that can be foreseen within the technical lifetime of city infrastructure, notably the water system and the impacts on other aspects of urban liveability. Based on the projects in Partnership Water in Urban Areas (www.vandibyer.dk) these drivers will be discussed and research needs identified. The partnership uses 6 pillars to map the challenges associated with the drivers, see Figure 1. The partnership has so far identified 11 innovation projects that address specific challenges. The projects aim at closing knowledge gaps and disseminate current state-of-the-art solutions to provide better liveability in urban areas by considering urban water management in a broader context. The mapping also show that further research is needed to address the challenges in a sustainable way.

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**Authors:** Arnbjerg-Nielsen, K. (Intern)
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**A risk-based evaluation tool for feasible urban drainage design under influence of climate change**

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**Organisations:** Department of Environmental Engineering, Urban Water Engineering
**Authors:** Zhou, Q. (Intern), Arnbjerg-Nielsen, K. (Intern)
**Publication date:** 2011
Climate Change Impacts on Flood risk in Urban Areas due to Combined Effects of Extreme Precipitation and Sea Surges

Climate change will impact the hydrological cycle greatly and lead to increases in flood hazards due to both pluvial and fluvial floods as well as sea surges in many regions. The impacts of the individual effects are analysed for a catchment in Greater Copenhagen. Based on both the present and anticipated future hazards the two most important hazards are found to be flash floods induced by precipitation and sea surges, respectively. The present and future extreme properties of these two variables are modelled by means of partial duration series with parameters that contains annual variations. By means of Monte Carlo simulation the combined present and future hazards are modelled by means of copula functions. The simulation results show that the observed correlation between the two variables can be assumed to be due to the underlying annual variation of the extremes of precipitation and sea surges. Presently the most important hazard is due to extreme precipitation. However, due to climate change impacts the future most important hazard is due to sea surges. The increase in probability of floods is substantial over a 70 year horizon and actions must be taken to decrease either the hazards or the impacts.

Decision strategies for handling the uncertainty of future extreme rainfall under influence of climate change

Several extraordinary rainfall events have occurred in Denmark within the last few years. For each event problems in urban areas occurred as the capacity of the existing drainage systems were exceeded. Adaptation to climate change is necessary but also very challenging as urban drainage systems are characterized by long technical lifetimes and high, unrecoverable construction costs. The most important barrier for the initiation and implementation of the adaptation strategies is therefore the uncertainty when predicting the magnitude of the extreme rainfall in the future. This challenge is explored through the application and discussion of three different theoretical decision support strategies: The precautionary principle, the minimax strategy and Bayesian decision support. The reviewed decision support strategies all proved valuable for addressing the identified uncertainties, at best applied together as they all yield information that improve decision making and thus enables more robust decisions.
Economic assessment of climate adaptation options for urban drainage design in Odense, Denmark

Climate change is likely to influence the water cycle by changing the precipitation patterns. An increase in potential flood damage in the urban context is anticipated due to the concentrated population and socio-economic values in cities. Feasible adaptation requires a higher performance on flood risk quantification and assessment of appropriated adaptation actions in terms of costs and benefits. This paper represents an economic assessment of three prevailing climate adaptation options for urban drainage design in a Danish case study, Odense. A risk-based evaluation framework is used to give detailed insights of the physical and economic feasibilities of each option. Estimations of marginal benefits of adaptation options are carried out through a step-by-step cost benefit analysis. The results are aimed to provide important information to decision making on how best to adapt for urban pluvial flooding due to climate impacts in cities.

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Organisations: Department of Environmental Engineering, DTU Climate Centre, Systems Analysis Division, Risø National Laboratory for Sustainable Energy, Urban Water Engineering
Authors: Zhou, Q. (Intern), Halsnæs, K. (Intern), Arnbjerg-Nielsen, K. (Intern)
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Effect of climate change on stormwater characteristics and treatment efficiencies of stormwater retention ponds

The aim of this study was to investigate the potential effect of climate changes on stormwater characteristics and treatment efficiency of retention ponds. This was performed by using an integrated model for two scenarios representing the current situations and a climate change scenario with increased intensity of extreme events. The study was conducted in a catchment in Albertslund, Denmark. The collected data showed a clear relation between stormwater quality parameters and rainfall intensity and antecedent dry period. Extreme events resulted in high particulate concentrations and high loads. The dissolved concentrations showed no strong relationship to rainfall intensity. The simulations with the integrated model showed that the climate change increase of rainfall intensity led to an increase in the concentrations discharged from the catchment. The higher flows caused a decrease in the pond removal performance with an overall increase in the particulate concentrations discharged to the environment. The changes in the two scenarios affected only the particulate phase, so no major impact on toxicity due to stormwater discharge is expected due to climate change. Further research is needed to address the seasonal fluctuations and provide a better analysis of the potential impacts due to climate change.

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**Estimation of climate factors for future extreme rainfall: Comparing observations and RCM simulations**

The application of climate factors has become more common in urban drainage design. The climate factor accounts for the expected increase in the magnitude of the extreme rainfall events during the technical lifetime of the drainage system. The present practice in Denmark is the application of climate factors of 1.2, 1.3 and 1.4 for 2-, 10- and 100-year events, respectively. These estimates are based on a comparison between the 'control' and 'scenario' period simulated by the regional climate model, HIRHAM4. The present paper presents new estimates of the climate factors on the basis of two new sources of data, focusing on a rainfall duration of 60 minutes. Temporal development of observed extreme rainfall is described by a parametric model and subsequently extrapolated, resulting in estimates of climate factors between 2.3 and 2.5. A recent transient model simulation by the regional climate model RACMO is divided into five time slices whereby their independent extreme rainfall characteristics.

**Integration of Hydropower in a Competitive power market model for water-energy scenario analysis**

Hydrological systems and power systems are strongly linked: water is needed for most electricity generation technologies, and electricity is required for all stages of water usage. Growing water and energy demands, and potential climate changes suggest this relationship will become more important for the management of both water and energy resources, and should be assessed. We propose a coupled water-energy modeling approach in which a hydrological model imposes the water constraints on the power system model; hydropower generation is bid to the power market based on the hydrological state of the system; and the demands from one system to the other are computed by both models jointly. For this purpose, we develop a bidding strategy for a price-taker hydropower generator based on reservoir volumes and expected electricity prices. The results from the methodology are comparable to those from a dynamic program. The hydropower bidding strategy showed reasonable performance when tested in a simplified model of a competitive power market.

**Markov chain modeling of precipitation time series: Modeling waiting times between tipping bucket rain gauge tips**

A very fine temporal and volumetric resolution precipitation time series is modeled using Markov models. Both 1st and 2nd order Markov models as well as seasonal and diurnal models are investigated and evaluated using likelihood based techniques. The 2nd order Markov model is found to be insignificant. The 1st order Markov model seems to be the most important, followed by the seasonal and diurnal ones. The final model is a continuous state-space 1st order Markov.
process with seasonal variation. Inclusion of seasonality in the continuous Markov chain model proved difficult, and with respect to likelihood it actually makes the model fit decrease.

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**Nøgletal for miljøfarlige stoffer i spildevand fra renseanlæg - på baggrund af data fra det nationale overvågningsprogram for punktkilder 1998-2009**

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**Past, present, and future design of urban drainage systems with focus on Danish experiences**
Climate change will influence the water cycle substantially, and extreme precipitation will become more frequent in many regions in the years to come. How should this fact be incorporated into design of urban drainage systems, if at all? And how important is climate change compared to other changes over time? Based on an analysis of the underlying key drivers of changes that are expected to affect urban drainage systems the current problems and their predicted development over time are presented. One key issue is management of risk and uncertainties and therefore a framework for design and analysis of urban structures in light of present and future uncertainties is presented.

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Uncertainty assessment of climate change adaptation options in urban flash floods

Adaptation is necessary to cope with the increasing flood risk in cities due to anthropogenic climate change in many regions of the world. The choice of adaptation strategies can and should be based on a comprehensive risk-based economic analysis to indicate the net benefits of proposed options. However, the analysis is complicated by irreducible uncertainties about present and future hydrologic conditions as well as the present and future vulnerability of the area in question. Further, modelling of the actual hazards given the hydrologic conditions also entails substantial uncertainty. The work presented is based on a flood risk framework that is in accordance with the EU flood directive, but adapted and extended to incorporate anticipated future changes due to city development and hydrologic extremes. The framework is used to study the importance of inherent uncertainties in order to find robust adaptation options. The case study is a small urban catchment where no significant city development is anticipated. Therefore the main focus is on estimation of impact of uncertainties related to present and future hydrological conditions, impacts on assets, and costing of the damages. The uncertainties are calculated using Monte Carlo simulations and thus the resulting uncertainties are described by probability density functions. Two different adaptation options are studied to reduce the increase in risk of flooding, namely increasing the pipe capacity and the use of local infiltration measures to hold water back from flood prone areas. The two options represent classical engineering solutions and water sensitive urban design, respectively. These options are compared to a business-as-usual scenario, where no adaptation is foreseen in the area. The results indicate that infiltration is less cost-effective regardless of the uncertainties from climate change impacts and/or damage estimation procedure when considering the ability to reduce the risk of flooding. The description of the correlation structure between the key inputs proved to be important in order to obtain a correct description of the resulting uncertainties. The study shows that uncertainties associated with climate adaptation benefits are large, but still it is possible to choose no-regret adaptation options. The introduced procedure provides an important tool for achieving an explicit and thorough uncertainty analysis of the risk-based economic evaluation.

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Use Of Risk Analysis Frameworks in Urban Flood Assessments

In the period 1960 – 1990 rapid urban development took place all over Europe, and notably in Denmark urban sprawl occurred around many cities. Favorable economic conditions ensured that the urbanization continued, although at a lower rate, until recently. However, from 1990 to present a increase in extreme precipitation has been observed, corresponding to an increase of design levels of at least 30 %. Analysis of climate change model output has given clear evidence, that further increases in extreme precipitation must be expected in the future due to anthropogenic emissions of greenhouse gasses. The design guidelines for urban sewer drainage capacity allow surcharge approximately 1 in 2 years. Studies in the 1980ies indicated that that is close to the optimum in socio-economic calculations. Recent developments in simulation software using detailed digital elevation models have confirmed these results. However, they have also highlighted a shortcoming of the design practice that jeopardized the entire design process: the floods occur the same places every time, meaning that the losses are not equally distributed. Other key players in society are now starting to react upon this knowledge, primarily insurance companies and mortgage providers, but also politicians and media are highly interested.

Presently two very different approaches are being followed in both research and practice. One is the introduction of risk analysis and risk management tools to provide professionals and politicians with better decision support tools. Some of the developments are risk frameworks that encompass economic and/or ethic evaluation of climate change adaptation options and improved risk management. This line of development is based on a societal-based evaluation of maximizing the outcome for society and accepting losses that are outweighed by benefits to society as a whole. Another, very different approach is to apply more stakeholder driven approaches, much in the line of Integrated Water Resources Management. The key difference is that it is recognized that the costs and benefits of both existing and planned urban drainage solutions are shared between very different stakeholders and that current practices are leading to personal bankruptcy by those bearing the highest costs. Therefore solutions must be developed that are understandable and can be communicated between different stakeholders and be acceptable also to the ones who bears the costs.

Denmark has supported research in both approaches by supporting a wide strategic partnership with many stakeholders covering all aspects of urban design, planning and utilization as well as two research projects on developing tools for risk assessments and decision support with time-varying loads and preferences. Time will show which of these approaches will be most predominantly used in the future. The presentation will outline the two research projects and the pros and cons of each approach as well as the preliminary findings of each of them. Both are being carried out in real-life applications combining researchers, practitioners, and NGOs.
Design practice for urban drainage including climate change impacts

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Design practice for urban drainage incorporating climate change impacts

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Publisher: BALTEX
Main Research Area: Technical/natural sciences
Conference: The 6th Study Conference on BALTEX, Międzyzdroje, Island of Wolin, Poland, 14 to 18 June 2010, 01/01/2010
Source: orbit
Source-ID: 268699
Fremtidige klimatilpasningsteknologier

General information
State: Published
Organisations: Department of Environmental Engineering, Department of Environmental Science and Engineering
Publication date: 2010

Publication information
Place of publication: København
Publisher: Energistyrelsen
ISBN (Print): 978-87-7844-867-5
Original language: Danish
Main Research Area: Technical/natural sciences
Links:

Relations
Projects:
Fremtidige klimatilpasningsteknologier
Source: orbit
Source-ID: 265067
Publication: Research › Report – Annual report year: 2010

Hvordan tilpasser vi os til et ændret klima?

General information
State: Published
Organisations: Department of Environmental Engineering
Authors: Arnbjerg-Nielsen, K. (Intern)
Publication date: 2010
Main Research Area: Technical/natural sciences

Publication information
Journal: Vand og Jord
ISSN (Print): 0908-7761
Ratings:
ISI indexed (2013): ISI indexed no
ISI indexed (2012): ISI indexed no
ISI indexed (2011): ISI indexed no
Original language: Danish
Source: orbit
Source-ID: 272824
Publication: Research - peer-review › Journal article – Annual report year: 2010

Parametric analysis of regional trends in observed extreme rainfall in Denmark

General information
State: Published
Organisations: Department of Environmental Engineering
Authors: Gregersen, I. B. (Intern), Ambjerg-Nielsen, K. (Intern), Madsen, H. (Ekstern)
Publication date: 2010

Host publication information
Title of host publication: International Workshop Advances in Statistical Hydrology, May 23-25, 2010 Taormina, Italy
Volume: Conference Proceeding
Place of publication: Catania, Italy
Publisher: University of Catania, Department of Civil and Environmental Engineering
Main Research Area: Technical/natural sciences
Conference: International Workshop Advances in Statistical Hydrology, May 23-25, 1010 Taormina, Italy, 01/01/2010
Design of urban drainage structures incorporating climate change impacts in a risk framework

**General information**
State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern)
Publication date: 2009

**Host publication information**
Title of host publication: Ozwater
Place of publication: Leonards, NSW, Australia
Publisher: Australian Water Association
Main Research Area: Technical/natural sciences
Conference: Ozwater, Melbourne, Australia, 01/01/2009
Source: orbit
Source-ID: 240461
Publication: Research - peer-review › Article in proceedings – Annual report year: 2009

Dimensionering af afløbssystemer ved hjælp af både regnserier og dimensioneringsregn

**General information**
State: Published
Organisations: Department of Environmental Engineering
Authors: Gregersen, I. (Ekstern), Arnbjerg-Nielsen, K. (Intern)
Publication date: 2009
Main Research Area: Technical/natural sciences
Links:
Source: orbit
Source-ID: 257589
Publication: Research › Poster – Annual report year: 2009

Feasible adaptation strategies for increased risk of flooding in cities due to climate change

**General information**
State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Feischer, H. (Ekstern)
Pages: 273-281
Publication date: 2009
Main Research Area: Technical/natural sciences

**Publication information**
Journal: Water Science and Technology
Volume: 60
Issue number: 2
ISSN (Print): 0273-1223
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.3 SJR 0.394 SNIP 0.621
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.466 SNIP 0.599 CiteScore 1.19
Web of Science (2015): Indexed yes
Infrastructure and climate change

General information
State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering, Section for Geotechnics and Geology, Department of Civil Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Hededal, O. (Intern), Henze, M. (Intern)

Original language: English
DOIs: 10.2166/wst.2009.298
Source: orbit
Source-ID: 257150
Publication: Research - peer-review > Journal article – Annual report year: 2009
Host publication information
Title of host publication: DTU Climate Change Technologies: Recommendations on accelerated development and deployment of climate change technologies
Volume: 4.1.C
Place of publication: Kgs. Lyngby
Publisher: Technical University of Denmark (DTU)
Edition: 1
ISBN (Print): 978-87-990378-2-7
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 251888
Publication: Research › Book chapter – Annual report year: 2009

Infrastruktur og klimaændringer: Workshop afholdt som led i workshopserien DTU Climate Change Technologies 1. september

General information
State: Published
Organisations: Department of Environmental Engineering, Department of Civil Engineering
Authors: Arnbjerg-Nielsen, K. (ed.) (Intern), Henze, M. (Intern), Hededal, O. (Intern)
Number of pages: 12
Publication date: 2009

Publication information
Place of publication: Kgs. Lyngby
Original language: Danish
Main Research Area: Technical/natural sciences
Links:
http://www.dtu.dk/upload/subsites/klima/workshop%20praesentationer/workshopinfrastrukturafrapportering.pdf
Source: orbit
Source-ID: 252646
Publication: Research › Report – Annual report year: 2009

Quantification of anticipated future changes in high resolution design rainfall for urban areas

General information
State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering
Authors: Onof, C. (Ekstern), Arnbjerg-Nielsen, K. (Intern)
Pages: 350-363
Publication date: 2009
Main Research Area: Technical/natural sciences

Publication information
Journal: Atmospheric Research
Volume: 92
Issue number: 3
ISSN (Print): 0169-8095
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.568 SNIP 1.657 CiteScore 3.93
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.65 SNIP 1.678 CiteScore 3.36
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.415 SNIP 1.699 CiteScore 3.06
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.139 SNIP 1.537 CiteScore 2.48
Update of regional intensity-duration-frequency curves in Denmark: Tendency towards increased storm intensities

The regional model for estimation of extreme rainfall characteristics in Denmark has been updated with data from the augmented rain database 1 January 1997-1 August 2005, corresponding to almost twice the amount of data used in the previous study (1 January 1979-1 January 1997). In general, the analysis shows that the regional statistical extreme value model introduced in the previous analysis is satisfactory. In accordance with the previous study a significant regional variability of extreme rainfall characteristics is observed, which can partly be explained by the mean annual precipitation patterns and a sub-regional division of the country in a western and eastern part. Comparison with the previous regional analysis shows a general increase in extreme rainfall characteristics. For the durations (30 min-3 h) and return periods (similar to 10 years) typical for most urban drainage designs the increase in intensity is in the order of 10%. The analysis reveals that the changes are not statistically significant compared with the uncertainties of the regional estimation model, but the increases in design intensities are large and have significant consequences to the costs of engineering designs.

General information
State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering
Authors: Madsen, H. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Mikkelsen, P. S. (Intern)
Pages: 343-349
Publication date: 2009
Conference: International Workshop on Precipitation in Urban Areas, St Moritz, SWITZERLAND, 01/01/2006
Main Research Area: Technical/natural sciences

Publication information
Journal: Atmospheric Research
Volume: 92
Issue number: 3
Increased intensity, Extreme precipitation, Regional analysis, IDF curves

DOI:
10.1016/j.atmosres.2009.01.013

Source: orbit
Source-ID: 243648

Publication: Research - peer-review › Conference article – Annual report year: 2009

Vandbremsen skal slås fra: Kronik

General information
State: Published
Organisations: Department of Environmental Engineering
Authors: Mark, O. (Ekstern), Arnbjerg-Nielsen, K. (Intern)
Pages: 18
Publication date: 2009
Main Research Area: Technical/natural sciences
Forventede ændringer i ekstremregn som følge af klimaændringer

Identifying economically and technically feasible adaptation strategies for mitigation of flood risks in cities. Two case studies from Denmark

Klimadebatten kører - hvordan håndterer vi stigende risiko for oversvømmelser?
Modernizing sewers and wastewater systems with new technologies: The Danish action plan for promotion of eco-efficient technologies - Danish lessons

After continuous problems and challenges with dead fish and oxygen depletion in the waters, Denmark initiated an action plan for Danish waters to reduce pollution in the late 1980s. The action plan puts focus on stricter criteria for wastewater treatment plants. Over the years, the plan has been revised three times to ensure continuity in the work. As a result, Danish waters are significantly cleaner today. Since 1987 the pollution caused by wastewater has been reduced by 80 - 90 % - depending on the type of pollutant. Upgrading the wastewater treatment system with a number of new and innovative Danish technologies is one of the main contributions to this success. However, education of staff, improved legislation and good cooperation between several stakeholders played an important role as well.

Quantification of climate change impacts on extreme precipitation used for design of sewer systems

Spildevandskomiteens vejrradarudvalg
Stricter regulatory goals improve Danish waste water systems: The Danish action plan for promotion of eco-efficient technologies - Danish lessons

Risk assessment of Giardia duodenalis and Cryptosporidium parvum in Danish drinking water

Quantitative risk assessment for human infection by the protozoans Giardia and Cryptosporidium related to different water uses in Denmark: Paper 73
Bearbejdning af målinger af regnbetingede udledninger af Npo og miljøfremmede stoffer fra fællessystemer i forbindelse med NOVA 2003

General information
State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering, PH-Consult Aps.
Authors: Arnbjerg-Nielsen, K. (Intern), Hvitved-Jacobsen, T. (Ekstern), Ledin, A. (Intern), Auffarth, K. P. S. (Intern), Mikkelsen, P. S. (Intern), Baun, A. (Intern), Kjølholt, J. (Ekstern)
Publication date: 2002

Publication information
Place of publication: København
Publisher: Miljøstyrelsen
Original language: English
Series: Miljøprojekt
Number: 701
Main Research Area: Technical/natural sciences
Links:
http://www.mst.dk/udgiv/Publikationer/2002/87-7972-159-1/pdf/87-7972-160-5.PDF
Source: orbit
Source-ID: 43292
Publication: Research › Report – Annual report year: 2002

Hvor meget forurener afløbssystemer i regnvejr?

General information
State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Hvitved-Jacobsen, T. (Ekstern), Ledin, A. (Intern), Auffarth, K. P. S. (Intern), Mikkelsen, P. S. (Intern), Baun, A. (Intern), Kjølholt, J. (Ekstern)
Pages: 39-42
Publication date: 2002
Main Research Area: Technical/natural sciences

Publication information
Journal: Ny Viden fra Miljøstyrelsen
Issue number: 4
Original language: Danish
Source: orbit
Source-ID: 43293
Publication: Communication › Journal article – Annual report year: 2002

Biologiske effekter af toksiske stoffer i regnbetingede udløb

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Kjølholt, J. (Ekstern), Baun, A. (Intern), Arnbjerg-Nielsen, K. (Intern)
Publication date: 2001
Ragnvand fra veje kan påvirke vandlevende organismer

General information
State: Published
Organisations: Department of Environmental Engineering, Urban Water Engineering
Authors: Kjølholt, J. (Ekstern), Baun, A. (Intern), Arnbjerg-Nielsen, K. (Intern)
Pages: 59-62
Publication date: 2001
Main Research Area: Technical/natural sciences

Publication information
Journal: Ny Viden fra Miljøstyrelsen
Issue number: 4
Original language: Danish
Links:
http://www.mst.dk/udgiv/NyViden/2001_4/07011214.htm
Source-ID: 43713
Publication: Communication › Journal article – Annual report year: 2001

Artificial neural networks and grey-box modelling: A comparison

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Loke, E. (Intern), Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern)
Publication date: 1999

Host publication information
Title of host publication: eds. Joliffe, I.B. & Ball, J.E.
Place of publication: Sydney
Publisher: The Institution of Engineers Australia
Main Research Area: Technical/natural sciences
Conference: 8th International Conference on Urban Storm Drainage, Sydney, Australia, 30/08/1999 - 30/08/1999
Source-ID: 172942
Publication: Research - peer-review › Article in proceedings – Annual report year: 1999

Generering af kunstige regnserier

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Arnbjerg-Nielsen, K. (Intern)
Publication date: 1999

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Integer Valued Autoregressive Models for Tipping Bucket Rainfall Measurements

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Department of Environmental Science and Engineering
Authors: Thyregod, P. (Intern), Carstensen, N. J. (Intern), Madsen, H. (Intern), Arnbjerg-Nielsen, K. (Intern)
Pages: 395-411
Publication date: 1999
Main Research Area: Technical/natural sciences

Publication information
Journal: Environmetrics
Volume: 10
Original language: English
Source: orbit
Source-ID: 172579
Publication: Research - peer-review › Journal article – Annual report year: 1999

On the selection of historical rainfall series for simulation of urban drainage

General information
State: Published
Organisations: Department of Environmental Science and Engineering, Department of Hydrodynamics and Water Resources
Authors: Mikkelsen, P. S. (Intern), Madsen, H. (Intern), Arnbjerg-Nielsen, K. (Intern), Rosbjerg, D. (Intern), Harremoës, P. (Intern)
Pages: 982-989
Publication date: 1999
Main Research Area: Technical/natural sciences

Host publication information
Title of host publication: Proceedings of the 8th International Conference on Urban Storm Drainage, August 30 - September 3
Volume: 2
Place of publication: Sydney
Publisher: The Institution of Engineers Australia
Source: orbit
Source-ID: 172946
Publication: Research - peer-review › Article in proceedings – Annual report year: 1999

Opdatering af tilstande i afløbssystemer ved brug af on-line målinger

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Arnbjerg-Nielsen, K. (Intern)
Publication date: 1999
Main Research Area: Technical/natural sciences

Publication information
Original language: Danish
Source: orbit
Source-ID: 173018
Publication: Research - peer-review › Report – Annual report year: 1999

Regional variation af ekstremregn i Danmark

General information
Urban pollution runoff modelling from combined sewer overflows

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Johansen, N. (Ekstern), Schlütter, F. (Ekstern), Kaasgaard, M. (Ekstern), Rauch, W. (Intern), Mikkelsen, P. (Intern)
Publication date: 1999

Host publication information
Title of host publication: Urban pollution runoff modelling from combined sewer overflows
Place of publication: Sydney
Publisher: The Institution of Engineers Australia
Main Research Area: Technical/natural sciences
Conference: 8th International Conference on Urban Storm Drainage, Sydney, Australia, 30/08/1999 - 30/08/1999
Source: orbit
Source-ID: 172923
Publication: Research - peer-review › Article in proceedings – Annual report year: 1999

A rationale for using local and regional point rainfall data for design and analysis of urban storm drainage systems

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Publication date: 1998

Publication information
Journal: Water Science and Technology
Volume: 37
Issue number: 11
ISSN (Print): 0273-1223
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.3 SJR 0.394 SNIP 0.621
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.466 SNIP 0.599 CiteScore 1.19
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.587 SNIP 0.685 CiteScore 1.14
Web of Science (2014): Indexed yes
Calibration of tipping bucket rain gauges

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Overgaard, S. (Ekstern), El-Shaarawi, A. (Ekstern), Arnbjerg-Nielsen, K. (Intern)
Pages: 139-145
Publication date: 1998
Main Research Area: Technical/natural sciences

Publication information
Journal: Water Science and Technology
Volume: 37
Issue number: 11
ISSN (Print): 0273-1223
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.3 SJR 0.394 SNIP 0.621
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.466 SNIP 0.599 CiteScore 1.19
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.587 SNIP 0.685 CiteScore 1.14
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.568 SNIP 0.7 CiteScore 1.3
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.601 SNIP 0.669 CiteScore 1.13
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.591 SNIP 0.626 CiteScore 1.25
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.522 SNIP 0.602
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.589 SNIP 0.686
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.579 SNIP 0.697
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.749 SNIP 0.781
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.693 SNIP 0.796
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.763 SNIP 0.85
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.877 SNIP 0.904
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.882 SNIP 0.902
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.903 SNIP 0.888
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 0.759 SNIP 0.967
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 0.76 SNIP 0.885
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 0.889 SNIP 0.936
Original language: English
Source: orbit
Findes der en dimensioneringspraksis for afløbssystemer?

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Jakobsen, C. (Ekstern), Harremoës, P. (Intern)
Pages: 15-18
Publication date: 1998
Main Research Area: Technical/natural sciences

Publication information
Journal: Stads- og Havneingeniøren
Volume: 89
Issue number: 9
Original language: Danish
Source: orbit
Source-ID: 171508
Publication: Research › Journal article – Annual report year: 1998

Formulating and testing a rain series generator based on tipping bucket gauges

General information
State: Published
Organisations: Department of Environmental Science and Engineering, Department of Informatics and Mathematical Modeling
Authors: Arnbjerg-Nielsen, K. (Intern), Madsen, H. (Intern), Harremoës, P. (Intern)
Pages: 47-55
Publication date: 1998
Main Research Area: Technical/natural sciences

Publication information
Journal: Water Science and Technology
Volume: 37
Issue number: 11
ISSN (Print): 0273-1223
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.3 SJR 0.394 SNIP 0.621
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.466 SNIP 0.599 CiteScore 1.19
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.587 SNIP 0.685 CiteScore 1.14
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.568 SNIP 0.7 CiteScore 1.3
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.601 SNIP 0.669 CiteScore 1.13
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Historical rainfall series: crucial and doubtful model input

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Einfalt, T. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Fankhauser, R. (Ekstern)
Pages: 69-75
Publication date: 1998

Host publication information
Title of host publication: UDM '98, 4th International Conference on Developments in Urban Drainage Modelling, 21-24 September, Pre-Prints
Volume: 1
Place of publication: London, UK
Publisher: IAWQ, IAHR, UNESCO
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 171492
Publication: Research - peer-review › Article in proceedings – Annual report year: 1998
Modelling the embedded rainfall process using tipping bucket data

A new method for modelling the dynamics of rain measurement processes is suggested. The method takes the discrete nature and autocorrelation of measurements from the tipping bucket rain gauge into consideration. The considered model is a state space model with a Poisson marginal distribution. In the model there is only one parameter, a thinning parameter. The model is tested on 39 rain events. The estimated value for the various rain events is reflecting a subjective classification of rain events into frontal and convective rain. Finally, it is demonstrated how the model can be used for simulation and prediction.
Use of Historical Rainfall Series for Hydrological Modelling. Selected Proceedings of the Third International Workshop on Rainfall in Urban Areas, Pontresina, Switzerland, December 4-7

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Arnbjerg-Nielsen, K. (ed.) (Intern)
Publication date: 1998

Publication information
Place of publication: London, GB
Publisher: Pergamon Press
Original language: English
Main Research Area: Technical/natural sciences
Source-ID: 171438
Publication: Book – Annual report year: 1998

Use of historical rainfall series for hydrological modelling - workshop summary

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Einfalt, T. (Ekstern), Arnbjerg-Nielsen, K. (Intern), Fankhauser, R. (Ekstern), Rauch, W. (Intern), Nguyen, V. (Ekstern), Despotovic, J. (Ekstern)
Pages: 1-6
Publication date: 1998
Main Research Area: Technical/natural sciences

Publication information
Journal: Water Science and Technology
Volume: 37
Issue number: 11
ISSN (Print): 0273-1223
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.3 SJR 0.394 SNIP 0.621
A rationalistic approach to using local and regional rainfall data for design and analysis of urban storm drainage systems

General information
State: Published
Consequences for established design practice from geographical variation of historical rainfall data

The Danish measuring network for high-resolution rainfall data was initiated in 1979 and consists of approximately 50 tipping bucket rain gauges separated by one to 300 km, covering an area of 43,000 square kilometres. T-year design events and the associated sampling error variances were estimated at each site using the bootstrap method and the partial duration series method and a methodology was developed for quantifying the inter-site correlation structure due to spatial coverage of rain storms. The data reveals a dramatic geographical(regional) variation that may be divided into true regional variation and variation due to (correlated) sampling errors. Further analyses indicate that the observed variation can be explained only partially by correlation with regional climatological variables and that a significant residual variation remains, especially for large return periods. The new perceptions question the value of local rain data for design and call for an increased use of statistical concepts in engineering design practice. (C) 1997 IAWQ. Published by Elsevier Science Ltd.

General information

State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Mikkelsen, P. (Intern), Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern)
Number of pages: 7
Pages: 1 - 6
Publication date: 1997
Main Research Area: Technical/natural sciences

Publication information
Journal: Water Science and Technology
Volume: 36
Issue number: 8-9
ISSN (Print): 0273-1223
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 1.3 SJR 0.394 SNIP 0.621
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.466 SNIP 0.599 CiteScore 1.19
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.587 SNIP 0.685 CiteScore 1.14
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.568 SNIP 0.7 CiteScore 1.3
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.601 SNIP 0.669 CiteScore 1.13
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.591 SNIP 0.626 CiteScore 1.25
ISI indexed (2011): ISI indexed yes
urban drainage, rainfall data, regional variation, statistics, stochastic models, design practice

DoIs:
10.1016/S0273-1223(97)00626-4

Source: orbit
Source-ID: 169670
Publication: Research - peer-review › Journal article – Annual report year: 1997

Forbedring af projekteringsgrundlaget for afløbssystemer ved brug af kunstige regnserier

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Harremøes, P. (Intern)
Pages: 13
Publication date: 1997
Main Research Area: Technical/natural sciences

Publication information
Journal: EDB-anvendelse i Vandmiljøteknikken
Volume: 10
Issue number: 1
Original language: Danish
Source: orbit
Source-ID: 169703
Publication: Research › Journal article – Annual report year: 1997

Integer valued autoregressive models for rainfall measurement processes

General information
State: Published
Modelling the Embedded Rainfall Process using Tipping Bucket Data

Statistical analysis of urban hydrology with special emphasis on rainfall modelling

Use of historical rainfall series for hydrological modelling. 3rd International Workshop on Rainfall in Urban Areas, Pontresina, Switzerland, December 4-7. Preprints of papers
Assessment of uncertainties in state-of-the-art urban storm drainage

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern)
Publication date: 1996

Host publication information
Title of host publication: Proceedings
Volume: 3
Place of publication: Hannover, Germany
Publisher: SuG-Verlagsgesellschaft
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 169514
Publication: Research - peer-review › Article in proceedings – Annual report year: 1996

Interpretation of regional variation of extreme values of point precipitation in Denmark

General information
State: Published
Organisations: Department of Environmental Science and Engineering, Department of Informatics and Mathematical Modeling
Authors: Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern), Spliid, H. (Intern)
Pages: 99-111
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Journal: Atmospheric Research
Volume: 42
Issue number: 1-4
ISSN (Print): 0169-8095
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.568 SNIP 1.657 CiteScore 3.93
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.65 SNIP 1.678 CiteScore 3.36
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.415 SNIP 1.699 CiteScore 3.06
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.139 SNIP 1.537 CiteScore 2.48
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.341 SNIP 1.355 CiteScore 2.3
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.116 SNIP 1.144 CiteScore 2.17
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
Modelling of tipping bucket gauges: single rain events and rain series

General information
State: Published
Organisations: Department of Environmental Science and Engineering, Department of Informatics and Mathematical Modeling
Authors: Arnbjerg-Nielsen, K. (Intern), Spliid, H. (Intern), Harremoës, P. (Intern)
Pages: 115-120
Publication date: 1996

Host publication information
Title of host publication: Proceedings
Volume: 1
Place of publication: Hannover, Germany
Publisher: SuG-Verlagsgesellschaft
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 169515
Publication: Research - peer-review › Article in proceedings – Annual report year: 1996

Mulighed for generering af lokale kunstige regnserier

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern)
Pages: 9 - 13
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Journal: EDB-anvendelse i Vandmiljøteknikken
Volume: 9
Issue number: 2
Original language: Danish
Source: orbit
Prediction of hydrological reduction factor and initial loss in urban surface runoff from small ungauged catchments

An advanced runoff model is compared to a simple one employing only a runoff coefficient and a regression parameter allowing for initial loss. The present study shows that the more detailed description of the runoff processes cannot be justified due to the uncertainty from using only one gauge in a catchment for the description of the rain input. A significant variation of the two parameters from one catchment to another has been found and the uncertainty of the two variables are evaluated. The uncertainty of the hydrological reduction factor and the initial loss should be taken into account in the evaluation of the yearly discharges. In the case of extreme events, the uncertainty of the predicted runoff of the single event should also be taken into account.

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern)
Pages: 137-147
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Journal: Atmospheric Research
Volume: 42
Issue number: 1-4
ISSN (Print): 0169-8095
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.568 SNIP 1.657 CiteScore 3.93
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.65 SNIP 1.678 CiteScore 3.36
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.415 SNIP 1.699 CiteScore 3.06
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.139 SNIP 1.537 CiteScore 2.48
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.341 SNIP 1.355 CiteScore 2.3
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.116 SNIP 1.144 CiteScore 2.17
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.958 SNIP 0.959
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.991 SNIP 1.212
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.779 SNIP 0.973
Scopus rating (2007): SJR 1.097 SNIP 1.112
Scopus rating (2006): SJR 0.822 SNIP 0.813
Scopus rating (2005): SJR 0.943 SNIP 1.003
Web of Science (2005): Indexed yes
The importance of inherent uncertainties in state-of-the-art urban storm drainage modelling for ungauged small catchments

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern)
Pages: 305 - 319
Publication date: 1996
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Hydrology
Volume: 179
ISSN (Print): 0022-1694
Ratings:
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.89 SJR 1.745 SNIP 1.759
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 1.708 SNIP 1.771 CiteScore 3.54
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 1.679 SNIP 2.005 CiteScore 3.45
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 1.71 SNIP 1.997 CiteScore 3.36
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.924 SNIP 2.016 CiteScore 3.38
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.753 SNIP 1.858 CiteScore 3.16
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.784 SNIP 1.714
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 2.018 SNIP 1.835
Databehandling og stokastisk modelling af regn og regnafstrømning i byer - Rapport til Den kommunale Momsfond herunder rapportering af projektet: "Bearbejdning af ti års regndata til projektering af afløbsystemer"

General information
State: Published
Organisations: Department of Environmental Science and Engineering, Department of Informatics and Mathematical Modeling
Authors: Harremoës, P. (Intern), Carstensen, N. J. (Intern), Mikkelsen, P. S. (Intern), Arnbjerg-Nielsen, K. (Intern), Jacobsen, J. L. (Intern)
Number of pages: 26
Publication date: 1995

Publication information
Place of publication: Kgs. Lyngby
Publisher: Danmarks Tekniske Universitet (DTU)
Original language: Danish
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 318527
Publication: Research › Report – Annual report year: 1995

Modeling of Tipping Bucket Rain Gauges: Single Rain Events, Rain Series and Geographical Variation

General information
State: Published
Organisations: Department of Environmental Engineering, Department of Informatics and Mathematical Modeling
Authors: Arnbjerg-Nielsen, K. (Intern), El-Shaarawi, A. (Ekstern), Spliid, H. (Intern), Harremoës, P. (Intern)
Number of pages: 2
Publication date: 1995
Event: Abstract from 6th International Conference on Environmentrics, Kuala Lumpur, Malaysia.
Main Research Area: Technical/natural sciences
Publication: Research - peer-review › Conference abstract for conference – Annual report year: 1995

Modelling of Rain Data - Single Rain Events
Modelling of Regional-Scale Spatial Variation of Historical Rainfall Data

General Information
State: Published
Organisations: Department of Environmental Science and Engineering, Department of Hydrodynamics and Water Resources
Authors: Mikkelsen, P. S. (Intern), Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern), Madsen, H. (Intern), Rosbjerg, D. (Intern)
Number of pages: 5
Publication date: 1995
Main Research Area: Technical/natural sciences

Bibliographical note
This contribution was presented as a poster at the conference.
Publication: Research - peer-review › Paper – Annual report year: 1995

Mulighed for generering af lokale kunstige regnserier

General Information
State: Published
Organisations: Department of Environmental Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern)
Number of pages: 19
Publication date: 1995
Main Research Area: Technical/natural sciences
Publication: Research › Paper – Annual report year: 1995

Properties of Extreme Rainfall Based on Measurements from Tipping Bucket Gauges

General Information
State: Published
Organisations: Department of Environmental Science and Engineering, Department of Informatics and Mathematical Modeling, Mathematical Statistics, National Water Research Institute
Authors: Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern), El-Shaarawi, A. H. (Ekstern), Spliid, H. (Intern)
Publication date: 1995
Event: Poster session presented at Fifth International Conference on Precipitation, Elounda, Crete Greece.
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 318682
Publication: Research - peer-review › Poster – Annual report year: 1995

Usikkerhedsfaktorer ved afløbstekniske beregninger

General Information
State: Published
Organisations: Department of Environmental Engineering
Non-Parametric Statistics on Extreme Rainfall

General information
State: Published
Organisations: Department of Environmental Science and Engineering, Department of Informatics and Mathematical Modeling, Mathematical Statistics
Authors: Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern), Spliid, H. (Intern)
Pages: 267-278
Publication date: 1994
Main Research Area: Technical/natural sciences

Publication information
Journal: Nordic Hydrology
Volume: 25
ISSN (Print): 0029-1277
Ratings:
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.666 SNIP 0.69 CiteScore 1.66
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.026 SNIP 0.811 CiteScore 1.57
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.94 SNIP 1.053 CiteScore 1.78
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.196 SNIP 1.101 CiteScore 1.91
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.707 SNIP 0.818 CiteScore 1.18
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.517 SNIP 0.786 CiteScore 1
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.873 SNIP 0.816
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.606 SNIP 0.549
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.777 SNIP 0.885
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.625 SNIP 0.736
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.766 SNIP 1.027
Scopus rating (2005): SJR 0.526 SNIP 0.67
Usikkerhedsvurdering af urban afstrømning: 2. analyse af eksisterende opland

General information
State: Published
Organisations: Department of Environmental Science and Engineering, Technical University of Denmark
Authors: Arnbjerg-Nielsen, K. (Intern), Schultz, N. (Ekstern), Thrane, S. (Ekstern), Harremoës, P. (Intern)
Pages: 26-30
Publication date: 1994
Main Research Area: Technical/natural sciences

Publication information
Journal: Stads- og havneingeniøren
Volume: 12
Original language: Danish
Source: orbit
Source-ID: 317602
Publication: Research - peer-review › Journal article – Annual report year: 1994

Usikkerhedsvurdering af urban afstrømning fra små oplande

General information
State: Published
Organisations: Department of Environmental Science and Engineering
Authors: Arnbjerg-Nielsen, K. (Intern), Harremoës, P. (Intern)
Pages: 48-52
Publication date: 1994
Main Research Area: Technical/natural sciences

Publication information
Journal: Stads- og havneingeniøren
Volume: 11
ISSN (Print): 0038-8947
Original language: Danish
Source: orbit
Source-ID: 317602
Publication: Research - peer-review › Journal article – Annual report year: 1994

Ekstremregn og urban afstrømning

General information
State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering
Authors: Arnbjerg-Nielsen, K. (Intern)
Number of pages: 52
Publication date: 1993

Publication information
Place of publication: Denmark
Publisher: Danmarks Tekniske Højskole
Original language: Danish
Statistical Tools Applied on Urban Storm Drainage

General information
State: Published
Organisations: Urban Water Engineering, Department of Environmental Engineering
Authors: Arnbjerg-Nielsen, K. (Intern)
Publication date: 1993

Host publication information
Title of host publication: Proceedings of Fourth European Postgraduate Workshop on Urban Runoff: Sewer Systems, Treatment plants and Receiving Waters
Place of publication: Denmark
Publisher: Aalborg University
Main Research Area: Technical/natural sciences
Conference: Fourth European Postgraduate Workshop on Urban Runoff: Sewer Systems, Treatment plants and Receiving Waters, Aalborg, Denmark, 01/01/1993
Source: orbit
Source-ID: 314638
Publication: Research - peer-review › Article in proceedings – Annual report year: 1993

Projects:

Balancing Costs and Benefits of New Urban Water Management Objectives for Both Real Time Applications and Urban Planning
Department of Environmental Engineering
Period: 01/06/2017 → 31/05/2020
Number of participants: 4
Phd Student: Skrydstrup, Julie (Intern)
Supervisor:
Gregersen, Ida Bülow (Intern)
Löwe, Roland (Intern)
Main Supervisor:
Arnbjerg-Nielsen, Karsten (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Balancing costs and benefits of new urban water management objectives for both real time applications and urban planning
Department of Environmental Engineering
Period: 01/10/2016 → 30/12/2016
Number of participants: 4
Phd Student: Nielsen, Marie Rosenlund (Intern)
Supervisor:
Gregersen, Ida Rosenlund (Intern)
Löwe, Roland (Intern)
Main Supervisor:
Arnbjerg-Nielsen, Karsten (Intern)

Financing sources
Source: Internal funding (public)
Digital tools for landscape architects: A case study of digital tools used for analyzing and screening climate adaptation challenges in the early design phase

Danish Title: Undersøgelse af digitale værktøjer hos arkitekter og teknologin i den tidlige designfase

DTU Environment/European Regional Development Fund.

Department of Civil Engineering
Section for Building Design

Department of Environmental Engineering

Urban Water Systems
Period: 01/09/2016 → 31/12/2016
Number of participants: 3
Project participant:
Ambjørn-Nielsen, Karsten (Intern)
Mikkelsen, Peter Steen (Intern)

Project Manager, academic:
Jensen, Lotte Bjerregaard (Intern)

Surrogate modeling of inundation for both real time control and planning applications

Department of Environmental Engineering
Period: 01/09/2015 → 30/05/2019
Number of participants: 3
Phd Student:
Thrysøe, Cecilie (Intern)
Supervisor:
Borup, Morten (Intern)
Main Supervisor:
Ambjørn-Nielsen, Karsten (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

Life-cycle assessment of climate adaption technologies for stormwater management

Department of Environmental Engineering
Period: 15/08/2015 → 07/02/2019
Number of participants: 5
Phd Student:
Brudler, Sarah (Intern)
Supervisor:
Ambjørn-Nielsen, Karsten (Intern)
Hauschild, Michael Zwicky (Intern)
Lauesen, Linne Marie (Ekstern)
Main Supervisor:
Rygaard, Martin (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Industrial PhD
Project: PhD
Definition of a generic decision making framework and design of an Open Decision Support Platform

The research activity is addressing the definition of the overall decision theoretical and methodical framework to structure and facilitate decision processes when different decision alternatives are available and when the available information are subject to uncertainty and/or are incomplete, thus providing a robust tool to rank those alternatives in accordance with their consequences on sustainability, benefits and risks. Moreover, the framework shall facilitate the introduction of new information, changes in preferences and models and expert opinions with associated uncertainties. Based on the developed theoretical framework integrating quantitative assessment of risk and sustainability, the architecture of an Open Platform for the storage of information and models, the organisation of an analysis of models as well as the presentation of results of decision analyses shall be developed.

The research activity is part of the joint GDSI project aiming at supporting decision makers from industry and public authorities.

Department of Civil Engineering
Section for Structural Engineering
Department of Management Engineering
Quantitative Sustainability Assessment
Department of Applied Mathematics and Computer Science
Statistics and Data Analysis
Department of Environmental Engineering
Urban Water Engineering
Period: 01/04/2015 → 31/03/2018
Number of participants: 5
Risk Analysis, sustainability, Decision making, decision support tool, LCA, climate change, Uncertainty Quantification, Reliability Engineering
Project participant:
Miraglia, Simona (Intern)
Supervisor:
Nielsen, Bo Friis (Intern)
Arnbjerg-Nielsen, Karsten (Intern)
Main Supervisor:
Thöns, Sebastian (Intern)
Faber, Michael Havbro (Intern)

Quantitative spatio-temporal flood risk modelling in an urban context

Department of Environmental Engineering
Period: 01/09/2013 → 30/09/2014
Number of participants: 3
Phd Student:
Sto. Domingo, Niña Donna Farpale (Intern)
Supervisor:
Helwigh, Ole Mark (Ekstern)
Main Supervisor:
Arnbjerg-Nielsen, Karsten (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Eksternt finansieret virksomhed
Project: PhD

City Development, Urban Systems and the Impacts of Climate Extremes

Department of Management Engineering
Period: 15/12/2012 → 19/01/2017
Number of participants: 7
Phd Student:
Kaspersen, Per Skougaard (Intern)
**Supervisor:**
Arnbjerg-Nielsen, Karsten (Intern)
Madsen, Henrik (Intern)

**Main Supervisor:**
Drews, Martin (Intern)

**Examiner:**
Münster, Marie (Intern)
Kreibich, Heidi (Ekstern)
Sandholt, Inge (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Institut/centerfinansieret
Project: PhD

**Kvantitativt potentiale for regnvandshåndtering**

Department of Environmental Engineering
Period: 01/11/2012 → 10/12/2018
Number of participants: 3
Phd Student:
Lerer, Sara Maria (Intern)

**Supervisor:**
Arnbjerg-Nielsen, Karsten (Intern)

**Main Supervisor:**
Mikkelsen, Peter Steen (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

**Modeling the impact of soakaways on urban water flooding**

Department of Environmental Engineering
Period: 01/02/2012 → 29/02/2016
Number of participants: 8
Phd Student:
Locatelli, Luca (Intern)

**Supervisor:**
Ambjerg-Nielsen, Karsten (Intern)
Helwigh, Ole Mark (Ekstern)
Mikkelsen, Peter Steen (Intern)

**Main Supervisor:**
Binning, Philip John (Intern)

**Examiner:**
Bauer-Gottwein, Peter (Intern)
Stovin, Virginia (Ekstern)
Trolldborg, Lars (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

**Innovativ klimatilpasning med borgerne**

Department of Management Engineering
Period: 01/01/2012 → 31/07/2012
Number of participants: 4
Phd Student:
Risk Management of Climate Extremes in an Urban Environment

Department of Environmental Engineering
Number of participants: 8
Phd Student:
Åström, Helena Lisa Alexandra (Intern)
Supervisor:
Friis-Hansen, Peter (Intern)
Madsen, Henrik (Intern)
Rosbjerg, Dan (Intern)
Main Supervisor:
Arnbjerg-Nielsen, Karsten (Intern)
Examiner:
Mikkelsen, Peter Steen (Intern)
Henriksen, Hans Jørgen (Ekstern)
Merz, Bruno (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Bayesian methods for uncertainty analysis of extremes based on multi-model techniques

Department of Environmental Engineering
Period: 01/04/2011 → 27/08/2014
Number of participants: 6
Phd Student:
Sunyer Pinya, Maria Antonia (Intern)
Supervisor:
Rosbjerg, Dan (Intern)
Main Supervisor:
Arnbjerg-Nielsen, Karsten (Intern)
Examiner:
Binning, Philip John (Intern)
Kilsby, Chris (Ekstern)
Refsgaard, Jens Christian (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Risk based design in a changing climate

The main objective of the RiskChange project is to establish a consistent scientifically-based framework for risk-based design of critical infrastructure that includes state-of-the-art knowledge of projected changes in climate extremes.
Department of Environmental Engineering
Period: 03/01/2011 → 31/12/2014
Number of participants: 2
Acronym: RiskChange
Project ID: 30809
Project participant:
Rosbjerg, Dan (Intern)
Ambjerg-Nielsen, Karsten (Intern)

Financing sources
Source: Forskningsrådene - Andre
Name of research programme: Ukendt
Amount: 2,616,480.00 Danish Kroner

Risk-based design in a changing climate
The main objective of the RiskChange project is to establish a consistent scientifically-based framework for risk-based design of critical infrastructure that includes state-of-the-art knowledge of projected changes in climate extremes.

Department of Management Engineering
Systems Analysis
DTU Climate Centre
Energy Systems Analysis
Department of Environmental Engineering
Urban Water Engineering
Period: 01/01/2011 → 31/12/2014
Number of participants: 5
climate change adaptation, climate risk, extreme events, infrastructure
Acronym: RiskChange
Project participant:
Gregg, Jay Sterling (Intern)
Halsnæs, Kirsten (Intern)
Kaspersen, Per Skougaard (Intern)
Åström, Helena Lisa Alexandra (Intern)
Ambjerg-Nielsen, Karsten (Intern)

From surveillance to risk management – Risk management in the water supply
The goal of the project is to develop and implement risk management as part of the climate change adaptation strategy in the water supply.

Department of Environmental Engineering
Department of Systems Biology
Urban Water Engineering
Period: 01/01/2011 → 31/12/2013
Number of participants: 6
Acronym: RiskStyr-VF
Project ID: 30850
Project participant:
Corfitzen, Charlotte B. (Intern)
Ambjerg-Nielsen, Karsten (Intern)
Larsen, Sille Lyster (Intern)
Rygaard, Martin (Intern)
Christensen, Sarah Christine Boesgaard (Intern)
Project Manager, organisational:
Albrechtsen, Hans-Jørgen (Intern)
Financing sources
Source: Forskningsrådene - Andre
Name of research programme: Ukendt
Amount: 1,150,000.00 Danish Kroner

Relations
Publications:
Erfaringsopsamling af vandforsyningers læring i relation til Dokumenteret Drikkevandssikkerhed, monitoring ogforureningssituationer

Reducing uncertainty in future extreme precipitation
Department of Environmental Engineering
Period: 15/12/2010 → 19/12/2014
Number of participants: 7
Phd Student:
Sørup, Hjalte Jomo Danielsen (Intern)
Supervisor:
Arnbjerg-Nielsen, Karsten (Intern)
Christensen, Ole B (Ekstern)
Main Supervisor:
Mikkelsen, Peter Steen (Intern)
Examiner:
Binning, Philip John (Intern)
Jonas, Olsson (Ekstern)
Thorndahl, Søren (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Innovation network for environmental Technology (Innovationsnetværk på miljøteknologi)
Innovationsnetværket for Miljøteknologi skal være det oplagte forum for netværkets medlemmer og cleantech-branchen, når den tager initiativ til at igangsætte teknologi- og udviklingsprojekter der kræver supplerende, tværgående kompetencer og nye samarbejdspartnere, uanset om medlemmernes forretningsområde og kernekompetencer primært er på luft-, vand-, jord- eller affaldsområdet.

Department of Environmental Engineering
Period: 01/07/2010 → 01/07/2014
Number of participants: 7
Acronym: 1113
Project ID: 30856
Project participant:
Baun, Anders (Intern)
Albrechtsen, Hans-Jørgen (Intern)
Henze, Mogens (Intern)
Bjerg, Poul Løgstrup (Intern)
Astrup, Thomas Fruegaard (Intern)
Arnbjerg-Nielsen, Karsten (Intern)
Project Manager, organisational:
Andersen, Henrik Rasmus (Intern)

Financing sources
Source: Forskningsrådene - Andre
Name of research programme: Ukendt
Amount: 180,000.00 Danish Kroner
Project
Reducing uncertainty in future extreme precipitation (RUFEP)
Current estimates of extreme precipitation impacts from climate change range from a 20-60% increase over the next decade, but are based on climate model simulations at larger spatial and temporal scales than what is relevant for typical urban drainage systems. Thus this PhD fellowship will focus on reducing the uncertainty in future projections of extreme precipitation and quantifying the spatial and temporal scaling properties of extreme precipitation characteristics from observations and climate model simulations. This calls for a strategic collaborative research collaboration mobilizing both urban water and climatology expertise, which are among the key competencies at DTU Environment and the Danish Meteorological Institute.

Water in Urban Areas - partnership for climate change adaptation and innovation
The partnership addresses the challenge of adaptation of cities to a changing climate and aims at develop, document and disseminate sustainable technologies and water management methods.
Future climate change technologies
An assessment of emerging and future climate change technologies is needed that focus on national needs and possibilities for export of Danish technologies and services.

Department of Environmental Engineering

Urban Water Engineering
Period: 01/12/2009 → 01/07/2010
Number of participants: 8
Acronym: 1073
Project ID: 30746
Project participant:
Eriksson, Eva (Intern)
Albrechtsen, Hans-Jørgen (Intern)
Henze, Mogens (Intern)
Binning, Philip John (Intern)
Andersen, Henrik Rasmus (Intern)
Rygaard, Martin (Intern)
Sharma, Anitha Kumari (Intern)
Project Manager, organisational:
Arnbjerg-Nielsen, Karsten (Intern)

Financing sources
Source: Indtægtsdækket virksomhed UK 90
Name of research programme: Ukendt
Amount: 430,000.00 Danish Kroner

Relations
Publications:
Fremtidige klimatilpasningsteknologier

Renere teknologi til håndtering og rensning af separat regnvand
Projektet har til formål at skabe grundlag for en kvalificeret anvendelse og udbredelse af renseteknologi for separatkloakeret regnvand. Dette sker ved at opsamle, systematisere, dokumentere og formidle viden om renere teknologier til håndtering og rensning af separat regnvand.

Department of Environmental Engineering
Period: 01/11/2009 → 31/10/2011
Number of participants: 1
Acronym: 965
Project Manager, organisational:
Arnbjerg-Nielsen, Karsten (Intern)

Financing sources
Source: Unknown
Name of research programme: Ukendt
Amount: 0.00 Danish Kroner

Centre for regional change in the Earth system
To improve climate change predictions and its impacts, there is an urgent need for better quantification of how human activities, interacting with natural processes affect climate and vice versa. CRES will establish a common Danish multidisciplinary climate research platform to target Danish and wider regional needs.

Department of Environmental Engineering
Period: 01/10/2009 → 01/10/2014
Number of participants: 1
Acronym: CRES
Project ID: 30742
Project Manager, organisational:
Arnbjerg-Nielsen, Karsten (Intern)

Financing sources
Source: Forskningsrådene - Andre
Name of research programme: Ukendt
Amount: 2,272,000.00 Danish Kroner

A simulation-optimization approach for coupled water-energy systems
Department of Environmental Engineering
Period: 15/09/2009 → 30/09/2013
Number of participants: 7
Phd Student:
Cardenal, Silvio Javier Pereira (Intern)
Supervisor:
Arnbjerg-Nielsen, Karsten (Intern)
Madsen, Henrik (Intern)
Main Supervisor:
Bauer-Gottwein, Peter (Intern)
Examiner:
Mikkelsen, Peter Steen (Intern)
Fosso, Olav Bjarte (Ekstern)
Pulido-Velázquez, Manuel A. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD

Urban Runoff Design under influence of Climate Change
Department of Environmental Engineering
Period: 01/05/2009 → 21/11/2012
Number of participants: 8
Phd Student:
Zhou, Qianqian (Intern)
Supervisor:
Halsnæs, Kirsten (Intern)
Mikkelsen, Peter Steen (Intern)
Nielsen, Susanne Balslev (Intern)
Main Supervisor:
Arnbjerg-Nielsen, Karsten (Intern)
Examiner:
Bauer-Gottwein, Peter (Intern)
Krebs, Peter (Ekstern)
Merz, Bruno (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Evaluation tools targeted at Water and Water Supply Technologies
Deterioration of water quality and reduced availability of water caused by anthropogenic and climate pressures require prompt actions by water managers in order to maximize the economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Technologies for e.g. waste water treatment, water saving and reduction of non-point source pollution are being developed to mitigate the deterioration of the water resources and ecosystems. Efficient selection and implementation of these technologies requires advanced tools. The aim of this research proposal is to extend, improve, adopt and test a suite of management tools targeted at evaluation of water
related environmental technologies. The development of tools will consider the specific technological, hydrological and socioeconomic context of the implementation and at the same time ensure a consistent comparison of the efficiency of different technologies. The ET-WATER framework will enable use of systematic and analytical approaches in identifying appropriate and efficient water related environmental technologies required e.g. in order to fulfil goals of the Water Framework Directive or needs related to climate change adaptation, by integrating economic and hydrological tools addressing uncertainties and probabilities. Expected results include flexible water management tools based on state-of-the-art technical, hydrologic and economic knowledge aiming at identifying cost-efficient measures and implementation modalities facilitating the water and environmental management and decision-making process., The water and environmental managers at national, regional and local level and the water management industry will benefit from this development through knowledge transfer using the rich Danish experiences. The export potential of water management tools and advisory services from Denmark will increase.

Department of Environmental Engineering
Period: 01/01/2009 → 01/01/2012
Number of participants: 1
Acronym: ET-WATER
Project Manager, organisational:
Ambjerg-Nielsen, Karsten (Intern)

Financing sources
Source: Unknown
Name of research programme: Ukendt
Amount: 0.00 Danish Kroner
Project

Uncertainty and adaptive estimation in storm- and wastewater system modelling
Department of Environmental Engineering
Period: 01/01/2009 → 02/07/2014
Number of participants: 7
Phd Student:
Borup, Morten (Intern)
Supervisor:
Grun, Morten (Intern)
Madsen, Henrik (Intern)
Main Supervisor:
Mikkelsen, Peter Steen (Intern)
Examiner:
Ambjerg-Nielsen, Karsten (Intern)
Savic, Dragan A. (Ekstern)
Weerts, Albrecht (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

National climate change adaptation webportal, input on Water
Levering af input til klimatilpasningsportalen om emnet Vand på vegne af Miljøministeriet, By- og Landskabsstyrelsen
Department of Environmental Engineering
Period: 27/10/2008 → 14/11/2008
Number of participants: 5
Acronym: Vandportal
Project ID: 30638
Project participant:
Arvin, Erik (Intern)
Albrechtsen, Hans-Jørgen (Intern)
Henze, Mogens (Intern)
Binning, Philip John (Intern)
Project Manager, organisational:
Ambjerg-Nielsen, Karsten (Intern)
Financing sources
Source: Indtægtsdækket virksomhed UK 90
Name of research programme: Ukendt
Amount: 40,000.00 Danish Kroner
Project

Collaboration with "Spildevandskomiteen": Skrift 29
Preparation of Skrift 29 based upon Spildevandskomiteens recommendations
Department of Environmental Engineering
Period: 01/07/2008 → 31/12/2008
Number of participants: 1
Acronym: Skrift29
Project ID: 30627
Project Manager, organisational:
Ambjerg-Nielsen, Karsten (Intern)

Financing sources
Source: Sam.arb.aftaler, Private danske - Andre virksomheder
Name of research programme: Ukendt
Amount: 50,000.00 Danish Kroner
Project

Integrated modelling of sustainable urban stormwater systems
Department of Environmental Engineering
Period: 01/04/2008 → 17/10/2012
Number of participants: 7
Phd Student:
Roldin, Maria Kerstin (Intern)
Supervisor:
Helwigh, Ole Mark (Ekstern)
Mikkelsen, Peter Steen (Intern)
Main Supervisor:
Binning, Philip John (Intern)
Examiner:
Ambjerg-Nielsen, Karsten (Intern)
Lerner, David (Ekstern)
Svensson, Gilbert (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU, Samfinansiering
Project: PhD

19K: Innovation in the municipal technical administration and public utilities - in interplay with private companies, knowledge institutions and trade networks
A systematic focus on improved solutions is a precondition for innovation in the public sector, which is not driven by market forces like the private sector. This is in particular the case for municipal technical administrations and public utilities responsible for large and resource consuming infrastructures, which experience increasing expectations and performance demands but typically lack possibilities for developing and assessing innovative solutions. Accepting that learning is the strongest incentive for innovation in the public sector, the project aims to initiate a cross-municipal staff-driven innovation process, which is expected to result in new solutions and products as well as identification of factors that may contribute to strengthening the public innovation culture. Employing experienced researchers and consultants to facilitate the process and product developers from leading companies to bridge to the market, focus is on the Danish water supply and urban sewerage infrastructures, which due to climate change, urban growth and increasing demands to water quality are under constant pressure and where conventional solutions – even with major resource injections – cannot match the challenges. The process is anchored at the management level and communicated via trade associations.

Department of Environmental Engineering
Period: 01/01/2008 → 31/12/2009
Number of participants: 2
Acronym: 19K
Optimal Allocation of Water and Land Resources at the Catchment Scale

Department of Environmental Engineering
Period: 01/08/2007 → 20/04/2011
Number of participants: 7
Phd Student:
Riegels, Niels (Intern)
Supervisor:
Jensen, Roar A. (Ekstern)
Møller, Flemming (Ekstern)
Main Supervisor:
Bauer-Gottwein, Peter (Intern)
Examiner:
Ambjerg-Nielsen, Karsten (Intern)
Cai, Ximing (Ekstern)
Termansen, Mette (Ekstern)

Geographical variation of extreme point rainfall
In 1979 the institute initiated a nationwide rain gauge system suitable for monitoring short, intense rain events. The system consists of approximately 50 measuring stations separated by one to 300 km, and covering a total of 43,000 square kilometres. At the present time the longest records include 16 years of data. Statistical analysis of the new data reveals a remarkable geographical variation which can be explained only partially by correlation with regional climatological variables that describe differences in physiography and microclimate. In addition to sampling errors originating from use of limited samples for estimation at individual sites, there is a significant statistical residual that cannot be explained by a regional model. Consequently, the engineering application of rainfall data for design and analysis are being revised. The project aims at establishing guidelines for use of rain data in modelling of urban drainage systems.

Department of Environmental Science and Engineering

Geographical variation of extreme point rainfall
In 1979 the institute initiated a nationwide rain gauge system suitable for monitoring short, intense rain events. The system consists of approximately 50 measuring stations separated by one to 300 km, and covering a total of 43,000 square kilometres. At the present time the longest records include 16 years of data. Statistical analysis of the new data reveals a remarkable geographical variation which can be explained only partially by correlation with regional climatological variables that describe differences in physiography and microclimate. In addition to sampling errors originating from use of limited samples for estimation at individual sites, there is a significant statistical residual that cannot be explained by a regional model. Consequently, the engineering application of rainfall data for design and analysis are being revised. The project aims at establishing guidelines for use of rain data in modelling of urban drainage systems.

Department of Environmental Science and Engineering

Geographical variation of extreme point rainfall
In 1979 the institute initiated a nationwide rain gauge system suitable for monitoring short, intense rain events. The system consists of approximately 50 measuring stations separated by one to 300 km, and covering a total of 43,000 square kilometres. At the present time the longest records include 16 years of data. Statistical analysis of the new data reveals a remarkable geographical variation which can be explained only partially by correlation with regional climatological variables that describe differences in physiography and microclimate. In addition to sampling errors originating from use of limited samples for estimation at individual sites, there is a significant statistical residual that cannot be explained by a regional model. Consequently, the engineering application of rainfall data for design and analysis are being revised. The project aims at establishing guidelines for use of rain data in modelling of urban drainage systems.

Department of Environmental Science and Engineering

Geographical variation of extreme point rainfall
In 1979 the institute initiated a nationwide rain gauge system suitable for monitoring short, intense rain events. The system consists of approximately 50 measuring stations separated by one to 300 km, and covering a total of 43,000 square kilometres. At the present time the longest records include 16 years of data. Statistical analysis of the new data reveals a remarkable geographical variation which can be explained only partially by correlation with regional climatological variables that describe differences in physiography and microclimate. In addition to sampling errors originating from use of limited samples for estimation at individual sites, there is a significant statistical residual that cannot be explained by a regional model. Consequently, the engineering application of rainfall data for design and analysis are being revised. The project aims at establishing guidelines for use of rain data in modelling of urban drainage systems.

Department of Environmental Science and Engineering
Geographical variation of extreme point rainfall

In 1979 the institute initiated a nationwide rain gauge system suitable for monitoring short, intense rain events. The system consists of approximately 70 measuring stations separated by one to 300 km, and covering a total of 43,000 square kilometres. At the present time the longest records include 16 years of data. Statistical analysis of the new data reveals a remarkable geographical variation which can be explained only partially by correlation with regional climatological variables that describe differences in physiography and microclimate. In addition to sampling errors originating from use of limited samples for estimation at individual sites, there is a significant statistical residual that cannot be explained by a regional model. Consequently, the engineering application of rainfall data for design and analysis are being revised. Part of the conclusions have recently been published in a new guide from the Danish Water Pollution Control Committee.

Department of Environmental Engineering

Department of Hydrodynamics and Water Resources

Danish Meteorological Institute
Period: 01/08/1996 → 30/06/1999
Number of participants: 3
Acronym: 33
Project participant:
Rosbjerg, Dan (Intern)
Arnbjerg-Nielsen, Karsten (Intern)
Project Manager, organisational:
Harremoës, Poul (Intern)

Stochastic modelling of high-resolution rainfall time series

Two approaches to generate artificial high-resolution rain series for use as input to simulation of urban drainage systems have been tested, both based on waiting times between consecutive tips of tipping bucket gauges calibrated to sample rain in a 0.2 mm depth resolution. ARIMA-models give a reasonable description of data but they have found limited practical use due to difficulties with identification, estimation and simulation of individual extreme rain events. Markov chain models including a state variable representing accumulated rain depth are able to extract the statistical properties of the data series and may be used to generate artificial rain series that resemble the original data structure. The perspective is to couple a stochastic time series model with a regional model for extreme point rainfall in order to make inference about extreme rainfall at ungauged locations.

Department of Environmental Science and Engineering

Department of Informatics and Mathematical Modeling
Period: 01/08/1996 → 30/06/1999
Number of participants: 4
Project participant:
Arnbjerg-Nielsen, Karsten (Intern)
Mikkelsen, Peter Steen (Intern)
Spliid, Henrik (Intern)
Project Manager, organisational:
Harremoës, Poul (Intern)

Financing sources
Source: Unknown
Name of research programme: Ukendt
Amount: 150,000.00 Danish Kroner

Statistisk analyse af nedbør og dens betydning for afløbssystemer

Department of Environmental Engineering
Period: 01/02/1993 → 17/03/1997
Number of participants: 3
Phd Student:
Arnbjerg-Nielsen, Karsten (Intern)
Supervisor:
Rosbjerg, Dan (Intern)
Main Supervisor:
Harremoës, Poul (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-Su Stipendium, Eksperiment
Project: PhD