Identifying fit-for-purpose lumped surrogate models for large urban drainage systems using GLUE

Distributed physically based models (DPMs) have become the standard tool for urban drainage modelling. However, high computational demands limit these in applications where fast or multiple simulations are needed. This paper presents simple fit-for-purpose cheaper-to-run surrogate models (SMs) for pipe network simulations which are validated against a DPM. The SMs are set up by lumping the DPM network into compartments in which the volume of water is governed by mass balances. Outgoing discharges to downstream compartment(s) and surcharging are computed from unambiguous volume-discharge curves. The SMs are applied on a 45 km² catchment, Elster Creek in Melbourne, Australia. The number of simulated states and simulation times are reduced by approximately 3 and 6 orders of magnitude, respectively. Different SM complexities are examined. The simplest SM using steady state training data performed well with NSE of 0.98 for volume in the most upstream compartment. When emulating the aggregated surcharge from that compartment, the SM captured all surcharge events correctly. NSE improved from 0.35 to 0.84 when subdividing the compartment into 17 subcompartments. Uncertainty of SM parameters was examined using the Generalized Likelihood Uncertainty Estimation (GLUE) methodology. Two different sampling methods were applied. Limits of acceptability for real-time control, warning and planning, resulted in many accepted models upstream and few to none in downstream backwater-prone areas. All applications showed SM uncertainty bands within expected uncertainty bands for DPM, supporting the use of a simpler conceptual model in fit-for-purpose modelling in urban water systems when computational demands of DPMs are prohibitive.
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Valve status identification by temperature modelling in water distribution networks

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Evaluating catchment response to artificial rainfall from four weather generators for present and future climate
The technical lifetime of urban water infrastructure has a duration where climate change has to be considered when alterations to the system are planned. Also, models for urban water management are reaching a very high complexity level with e.g. decentralized stormwater control measures being included. These systems have to be evaluated under as close-to-real conditions as possible. Long Term Statistics (LTS) modelling with observational data is the most close-to-real solution for present climate conditions, but for future climate conditions artificial rainfall time series from weather generators (WGs) have to be used. In this study we run LTS simulations with four different WG products for both present and future conditions on two different catchments. For present conditions all WG products result in realistic catchment responses when it comes to the number of full flowing pipes and the number and volume of combined sewer overflows. For future conditions, the differences in the WGs representation of the expectations to climate change is evident. Nonetheless, all future results indicate that the catchments will have to handle more events that utilize the full capacity of the drainage systems. Generally WG products are relevant to use in planning of future changes to sewer systems.

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Importance of Subdivision Resolution of Surrogate models for Emulating Catchment Response and Surchage

State-of-the-art urban drainage modelling applies high-fidelity physically based distributed models. However, high computational demands of such models limit the usage. In this study a conceptual surrogate model is set up to emulate the output of a Mike URBAN model. The surrogate model is a volume-based model, which models discharges from a user-defined compartment to downstream compartment(s) as well as to the surface. Training data is created by extracting steady state volume-discharge points from Mike URBAN and applying a piecewise linear interpolation between the points. Two surrogate models are set up for the Elster Creek catchment in Melbourne, Australia. The first consists of one compartment and the second subdivides this into 17 smaller compartments. Results show that both surrogate models perform very well in emulating the compartment volume and discharge from Mike URBAN. The surcharge is more difficult to model as its behaviour is more dynamic and hence most different from the steady state training data. Increasing compartment resolution shows an overall improvement of all results - especially in capturing surcharge behaviour. The results show that even surcharging urban drainage systems can be modelled sufficiently accurate for many purposes with the proposed surrogate models.

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Investigation of the usefulness of weather generator data as input to long-term simulations in urban hydrology

Is your data correct? Validating and improving data collected in smart water networks

Model predictive control of urban drainage systems: A review and perspective towards smart real-time water management
understanding and further development within the field, and eventually lead to more operational implementations.

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Robust model for estimating pump characteristics and sewer flows from pumping station data

Flow data represent crucial input for reliable diagnostics of sewer functions and identification of potential problems such as unwanted inflow and infiltration. Flow estimates from pumping stations which are integral part of many of the middle sized and larger separate sewer systems might help in this regard. A robust model and an associated optimization procedure is proposed for estimating inflow to a pumping station using only registered water levels in the pump sump and power consumption. The model is suitable for identification of pump capacity and volume thresholds for switching the pump on and off. These are parameters which are required for flow estimation during periods with high inflows or during periods with flow conditions triggering pump switching on and off at frequencies close to the temporal resolution of monitored data. The model, however, requires further development to provide reliable inflows during time steps within which the pump switches on or off.

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Technical Note on the Dynamic Changes in Kalman Gain when Updating Hydrodynamic Urban Drainage Models

To prevent online models diverging from reality they need to be updated to current conditions using observations and data assimilation techniques. A way of doing this for distributed hydrodynamic urban drainage models is to use the Ensemble Kalman Filter (EnKF), but this requires running an ensemble of models online, which is computationally demanding. This can be circumvented by calculating the Kalman gain, which is the governing matrix of the updating, offline if the gain is approximately constant in time. Here, we show in a synthetic experiment that the Kalman gain can vary by several orders of magnitude in a non-uniform and time-dynamic manner during surcharge conditions caused by backwater when
updating a hydrodynamic model of a simple sewer system with the EnKF. This implies that constant gain updating is not suitable for distributed hydrodynamic urban drainage models and that the full EnKF is in fact required.

Urban tunnel systems for conveyance and storage of storm- and wastewater: features, classification, and modelling

Tunnels have been integrated in many urban drainage systems to assist in preventing combined sewer overflows and flooding. Despite a wide range of designs, these structures share a common defining feature: conveying and storing large quantities of water. Urban tunnel systems can then be classified based on the type of water conveyed (wastewater, stormwater, or combined). The analysis of a representative sample of case studies shows how tunnels have been adapted to different economic, demographic, and climatic contexts. Across different designs, the management of existing urban tunnels can be optimized with intelligent monitoring and control strategies. These require models capable of providing real-time system-wide state estimates and reliable forecasts.
Using the Ensemble Kalman Filter to update a fast surrogate model for flow forecasting

Many cities face issues with rain induced flooding and combined sewer overflows, which can be addressed by using hydrodynamic models. These models are often simplified in a real-time setting to make them faster, and their performance can be improved by using data assimilation. In this study we use the Ensemble Kalman Filter to update a simplified model of a small area of Copenhagen, Denmark. The model is evaluated using perfect rain data for one summer month in 2016, and flow forecasts are used to quantify the performance of the update. We found that the 1-60 minutes forecast can be improved by updating the model. Having a small noise on the rain gives slightly worse results on a short forecast horizon and slightly better forecasts on a longer horizon. The forecast performance is also dependent on which model parts are updated.

Advancing from underground to above-ground model predictive control in urban drainage

A fast surrogate model tailor-made for real time control

A surrogate model of a detailed hydraulic urban drainage model is created for supplying inflow forecasts to an MPC model for 31 separate locations. The original model is subdivided into 66 relationships extracted from the original model. The surrogate model is 9000 times faster than the original model, with just a minor deviation from the original model results.
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.
Dynamic gauge adjustment of high-resolution X-band radar data for convective rain storms: Model-based evaluation against measured combined sewer overflow

Numerous studies have shown that radar rainfall estimates need to be adjusted against rain gauge measurements in order to be useful for hydrological modelling. In the current study we investigate if adjustment can improve radar rainfall estimates to the point where they can be used for modelling overflows from urban drainage systems, and we furthermore investigate the importance of the aggregation period of the adjustment scheme. This is done by continuously adjusting X-band radar data based on the previous 5–30 min of rain data recorded by multiple rain gauges and propagating the rainfall estimates through a hydraulic urban drainage model. The model is built entirely from physical data, without any calibration, to avoid bias towards any specific type of rainfall estimate. The performance is assessed by comparing measured and modelled water levels at a weir downstream of a highly impermeable, well defined, 64 ha urban catchment, for nine overflow generating rain events. The dynamically adjusted radar data perform best when the aggregation period is as small as 10–20 min, in which case it performs much better than static adjusted radar data and data from rain gauges situated 2–3 km away.

Evaluation of Maximum a Posteriori Estimation as Data Assimilation Method for Forecasting Infiltration-Inflow Affected Urban Runoff with Radar Rainfall Input

High quality on-line flow forecasts are useful for real-time operation of urban drainage systems and wastewater treatment plants. This requires computationally efficient models, which are continuously updated with observed data to provide good...
initial conditions for the forecasts. This paper presents a way of updating conceptual rainfall-runoff models using Maximum a Posteriori estimation to determine the most likely parameter constellation at the current point in time. This is done by combining information from prior parameter distributions and the model goodness of fit over a predefined period of time that precedes the forecast. The method is illustrated for an urban catchment, where flow forecasts of 0–4 h are generated by applying a lumped linear reservoir model with three cascading reservoirs. Radar rainfall observations are used as input to the model. The effects of different prior standard deviations and lengths of the auto-calibration period on the resulting flow forecast performance are evaluated. We were able to demonstrate that, if properly tuned, the method leads to a significant increase in forecasting performance compared to a model without continuous auto-calibration. Delayed responses and erratic behaviour in the parameter variations are, however, observed and the choice of prior distributions and length of auto-calibration period is not straightforward.

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Identification and Application of Surrogate Models for Urban Drainage Modelling

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Målerdata kan gemme på gratis informationer for forsyningerne: Et case studie fra Halsnæs Forsyning baseret på højoplöste måledata
A partial ensemble Kalman filtering approach to enable use of range limited observations

The ensemble Kalman filter (EnKF) relies on the assumption that an observed quantity can be regarded as a stochastic variable that is Gaussian distributed with mean and variance that equals the measurement and the measurement noise, respectively. When a gauge has a minimum and/or maximum detection limit and the observed quantity is outside this range, the signal from the gauge can, however, not be related to the observed quantity in this way. The current study proposes a method for utilizing this kind of out-of-range observations with the EnKF by explicitly treating the out-of-range observations. By doing this it is possible to update the ensemble members that are within the observable range of the gauge towards the observation limit and thereby reduce the ensemble spread. The method is tested using both a linear and a non-linear simple forcing-driven model in perfect model experiments where the same model and noise descriptions are used for the truth simulation and for the EnKF. The results show that the positive impact of the method in case of range-limited observations can exceed that of increasing the ensemble size from 10 to 100 and that the method makes it possible to improve model forecasts using observations that would otherwise have been non-informative.
Flow Forecasting using Deterministic Updating of Water Levels in Distributed Hydrodynamic Urban Drainage Models

There is a growing requirement to generate more precise model simulations and forecasts of flows in urban drainage systems in both offline and online situations. Data assimilation tools are hence needed to make it possible to include system measurements in distributed, physically-based urban drainage models and reduce a number of unavoidable discrepancies between the model and reality. The latter can be achieved partly by inserting measured water levels from the sewer system into the model. This article describes how deterministic updating of model states in this manner affects a simulation, and then evaluates and documents the performance of this particular updating procedure for flow forecasting. A hypothetical case study and synthetic observations are used to illustrate how the Update method works and affects downstream nodes. A real case study in a 544 ha urban catchment furthermore shows that it is possible to improve the 20-min forecast of water levels in an updated node and the three-hour forecast of flow through a downstream node, compared to simulations without updating. Deterministic water level updating produces better forecasts when implemented in large networks with slow flow dynamics and with measurements from upstream basins that contribute significantly to the flow at the forecast location.
Real Time Updating in Distributed Urban Rainfall Runoff Modelling

When it rains on urban areas the rainfall runoff is transported out of the city via the drainage system. Frequently, the drainage system cannot handle all the rain water, which results in problems like flooding or overflows into natural water bodies. To reduce these problems the systems are equipped with basins and automated structures that allow for a large degree of control of the systems, but in order to do this optimally it is required to know what is happening throughout the system. For this task models are needed, due to the large scale and complex nature of the systems. The physically based, distributed urban drainage models (DUDMs) are the most detailed models available of the urban drainage system. They contain a virtual replica of the main parts of the hydraulic system and can therefore potentially be used to estimate the hydraulic conditions anywhere in the system.

In order to produce useful estimates of the conditions in the system the models are highly dependent on the rainfall data used as model forcing. The rainfall estimates from raingauges as well as weather radar are, however, very uncertain for the spatial and temporal scale required for urban runoff simulations. This is especially so for the convective events of the summer. Therefore a method was developed for adjusting radar rainfall estimates using raingauge measurements in areas with an existing dense network of raingauges. The result was much improved rainfall estimates, which proved good enough to allow quantitative overflow modelling.

As with raingauge data the acquisition of online radar data is an economic expense and therefore it is necessary to be able to prioritise whether to invest in one or the other. In a theoretical study the impact of choosing one type of rainfall data over the other for models that are being updated from system measurements was studied. The results showed that the fact alone that it takes time for rainfall data to travel the distance between gauges and catchments has such a big negative effect on the forecast skill of updated models, that it can justify the choice of even very uncertain radar data over raingauge data.

Rainfall estimates will never be perfect and nor will the models. Therefore model estimates will continue to be uncertain. The uncertainty within the models can be reduced by means of data assimilation (DA) that correct the models based on comparisons between model estimates and system observations. The only current existing operational DA method for DUDMs is the Mouse Update tool, which works by correcting the water levels locally in the model at the observed sites. In a case study this simple DA tool proved to have some ability to improve downstream flow forecasts when it was used to update the water level in multiple upstream basins. This method is, however, not capable of utilising the spatial correlations in the errors to correct larger parts of the models. To accommodate this a method was developed for correcting the slow changing inflows to urban drainage systems that relate to infiltrating water. The method works by estimating a linearised version of the model response, which is used to control the correction by the DA scheme in such a way that model stability is ensured without dampening the correction more than necessary. A case study showed that this method can significantly improve a DUDMs forecast ability when a large part of the runoff from a catchment comes from infiltrating water. The proposed method is computationally efficient since it does not require additional model simulations. The method is, however, limited to adjusting the inflow to the hydrodynamic model and is not capable of updating the water levels in pipes and basins explicitly.

The statistical data assimilation method the Ensemble Kalman Filter (EnKF) was investigated as a tool to update all the state variables in a DUDM. The method was tested in synthetic experiments as well as in a real data case study. The results confirmed that the method is indeed suitable for DUDMs and that it can be used to utilise upstream as well as downstream water level and flow observations to improve model estimates and forecasts. Due to upper and lower sensor limits many sensors in urban drainage systems (and elsewhere) do not measure the quantity they are observing continuously. A new method was developed for utilising this kind of range-limited observations better when using the EnKF. The method works by counteracting the ensemble in spreading into to observable range when the lack of observations indicate that the quantity is outside this range. Synthetic experiments using a linear reservoir cascade model showed that the method can significantly improve model forecasts when observations frequently are outside the observable range. An experiment with a simplified DUDM showed that the method is suitable for assimilating range-limited water level observations from an overflow structure. This thesis contributes some important stepping stones towards the online usage of physically based, distributed urban drainage models for both estimation and forecasting purposes.

Provided that a good model exists for an urban area with weather radar data coverage, the principles are now outlined for synthesising most of the data from the system into an online model.

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Biotransformation kinetics and sorption of cocaine and its metabolites and the factors influencing their estimation in wastewater

The quantitative analysis of human urinary metabolites as biomarkers in wastewater streams has been used to estimate the rates of illicit drug use in the wider community. The primary underlying assumption in such studies is that a sample of wastewater is equivalent to a cumulative sample of urine. Drug metabolism in humans is predominantly enzymatically mediated, but these processes are not exclusive to the human body, and are found to occur in the environment and the sewer network. Understanding what happens to drugs and their urinary metabolites in the sewer system between the point of excretion and sampling is particularly important since it is possible that in-sewer transformation may influence final biomarker concentration. The present study uses batch experiments to measure and assess the biotransformation processes of cocaine and its two major human metabolites, benzoylecgonine and ecgonine methyl ester. The activated sludge modelling framework for xenobiotic organic micro-pollutants (ASM-X) is used for model structure identification and calibration. Biotransformation was observed to follow pseudo first-order kinetics. The biodegradation kinetics of cocaine, benzoylecgonine and ecgonine methyl ester is not significantly affected by the availability of dissolved oxygen. Results obtained in this study show that omitting in-pipe biotransformation affects the accuracy of back-calculated cocaine use estimates. This varies markedly depending on the in-sewer hydraulic retention time, total biomass concentration and the relative concentration of each metabolite. However, back-calculated cocaine use estimates derived from wastewater concentrations of benzoylecgonine and ecgonine methyl ester do show very close agreement if ex-vivo biotransformation of these compounds is considered.
Comparing the impact of time displaced and biased precipitation estimates for online updated urban runoff models

When an online runoff model is updated from system measurements, the requirements of the precipitation input change. Using rain gauge data as precipitation input there will be a displacement between the time when the rain hits the gauge and the time where the rain hits the actual catchment, due to the time it takes for the rain cell to travel from the rain gauge to the catchment. Since this time displacement is not present for system measurements the data assimilation scheme might already have updated the model to include the impact from the particular rain cell when the rain data is forced upon the model, which therefore will end up including the same rain twice in the model run. This paper compares forecast accuracy of updated models when using time displaced rain input to that of rain input with constant biases. This is done using a simple time-area model and historic rain series that are either displaced in time or affected with a bias. The results show that for a 10 minute forecast, time displacements of 5 and 10 minutes compare to biases of 60 and 100%, respectively, independent of the catchments time of concentration. © IWA Publishing 2013.

Comparison of short-term rainfall forecasts for model-based flow prediction in urban drainage systems

Forecast-based flow prediction in drainage systems can be used to implement real-time control of drainage systems. This study compares two different types of rainfall forecast - a radar rainfall extrapolation-based nowcast model and a numerical weather prediction model. The models are applied as input to an urban runoff model predicting the inlet flow to a waste water treatment plant. The modelled flows are auto-calibrated against real-time flow observations in order to certify the best possible forecast. Results show that it is possible to forecast flows with a lead time of 24 h. The best performance of the system is found using the radar nowcast for the short lead times and the weather model for larger lead times.
Comparison of short term rainfall forecasts for model based flow prediction in urban drainage systems

Forecast based flow prediction in drainage systems can be used to implement real time control of drainage systems. This study compares two different types of rainfall forecasts – a radar rainfall extrapolation based nowcast model and a numerical weather prediction model. The models are applied as input to an urban runoff model predicting the inlet flow to a waste water treatment plant. The modelled flows are auto-calibrated against real time flow observations in order to certify the best possible forecast. Results show that it is possible to forecast flows with a lead time of 24 hours. The best performance of the system is found using the radar nowcast for the short leadtimes and weather model for larger lead times.

Impact of time displaced precipitation estimates for on-line updated models

When an online runoff model is updated from system measurements the requirements to the precipitation estimates change. Using rain gauge data as precipitation input there will be a displacement between the time where the rain intensity hits the gauge and the time where the rain hits the actual catchment, due to the time it takes for the rain cell to travel from the rain gauge to the catchment. Since this time displacement is not present for system measurements the data assimilation scheme might already have updated the model to include the impact from the particular rain cell when the rain data is forced upon the model, which therefore will end up including the same rain twice in the model run. This paper compares forecast accuracy of updated models when using time displaced rain input to that of rain input with constant biases. This is done using a simple time-area model and historic rain series that are either displaced in time or affected with a bias. The results show that for a 10 minute forecast, time displacements of 5 and 10 minutes compare to biases of 60% and 100%, respectively, independent of the catchments time of concentration.
Flow Forecasting in Urban Drainage Systems using Deterministic Updating of Water Levels in Distributed Hydraulic Models

There is a growing need for generating more precise model simulations of urban drainage systems, both in off-line and on-line situations. In order to generate these improved model simulations data assimilation tools are needed that make it possible to include system measurements in the models to eliminate some of the unavoidable discrepancies between model and reality. The latter can partly be achieved by using the commercial tool MOUSE UPDATE, which is capable of inserting measured water levels from the system into the distributed, physically based MOUSE model. This study evaluates and documents the performance of the updating procedure for flow forecasting. Measured water levels in combination with rain gauge input are used as basis for the evaluation. When compared to simulations without updating, the results show that it is possible to obtain an improvement in the 20 minute forecast of the water level in an updated node and in the 3 hour forecast of flow through a downstream node. Our results indicate that updating produces better forecasts when implemented in a network with slow flow dynamics and with measurements from basins that are located upstream and contribute significantly to the flow at the forecast location.

Real time adjustment of slow changing flow components in distributed urban runoff models

In many urban runoff systems infiltrating water contributes with a substantial part of the total inflow and therefore most urban runoff modelling packages include hydrological models for simulating the infiltrating inflow. This paper presents a method for deterministic updating of the hydrological model states governing the infiltrating inflow based on downstream flow measurements. The fact that the infiltration processes follows a relative large time scale is used to estimate the part of the model residuals, at a gauged downstream location, that can be attributed to infiltration processes. This information is then used to update the states of the hydrological model. The method is demonstrated on the 20 km² Danish urban catchment of Ballerup, which has substantial amount of infiltration inflow after succeeding rain events, for a very rainy period of 17 days in August 2010. The results show big improvements for regular simulations as well as up to 10 hour forecasts. The updating method reduces the impact of non-representative precipitation estimates as well as model structural errors and leads to better overall modelling results.
Performance of MOUSE UPDATE for level and flow forecasting in urban drainage systems

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Pedersen, A. N., PhD Student, Department of Environmental Engineering
Mikkelsen, P. S., Main Supervisor
Borup, M., Supervisor
Dahl, A., Supervisor
Christiansen, L. E., Supervisor
01/02/2019 → 31/01/2022
Project: PhD

**Intelligent integration of deep urban tunnel systems in energy systems**
Bjerregård, M. B., PhD Student, Department of Mathematics
Christiansen, L. E., Main Supervisor
Borup, M., Supervisor
Niyato, D., Supervisor
Technical University of Denmark
01/12/2017 → 30/11/2020
Award relations: Intelligent integration of deep urban tunnel systems in energy systems
Project: PhD

**Hydraulic Modelling and data assimilation for deep urban tunnel systems**
Palmitessa, R., PhD Student, Department of Environmental Engineering
Mikkelsen, P. S., Main Supervisor
Borup, M., Supervisor
Law, A. W. K., Supervisor
Technical University of Denmark
01/12/2017 → 30/11/2020
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**FUPARU: Fuldautomatisk decentral rensning af partikler i regnbetingede udledninger**
Nielsen, K., Project Participant, Department of Environmental Engineering, Urban Water Systems
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Vezzaro, L., Project Participant, Department of Environmental Engineering, Urban Water Systems
Borup, M., Project Participant, Department of Environmental Engineering, Urban Water Systems
Chhetri, R. K., Project Participant, Department of Environmental Engineering, Water Technologies
01/11/2016 → 31/10/2018
Collaborators: HydroSystems, Danish Technological Institute
Project: Research

**Optimized water distribution using high-resolution data sources and novel data analysis methods**
Kirstein, J. K., PhD Student, Department of Environmental Engineering
Rygaard, M., Main Supervisor
Borup, M., Supervisor
Hagh, K., Supervisor
Samfinansieret - Andet
01/09/2016 → 14/11/2019
Award relations: Optimized water distribution using high-resolution data sources and novel data analysis methods
**Optimized real-time management of interacting water systems for a smarter city**

Lund, N. S. V., PhD Student, Department of Environmental Engineering  
Mikkelsen, P. S., Main Supervisor  
Borup, M., Supervisor  
Helwigh, O. M., Supervisor  
Madsen, H., Supervisor  
Bauer-Gottwein, P., Examiner  
Gennari, M. G. C., Examiner  
Savic, D. A., Examiner  
Samfinansierede - Virksomhed  
01/07/2016 → 28/08/2019  
Award relations: Optimized real-time management of interacting water systems for a smarter city  
Project: PhD

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

Thrysøe, C., PhD Student, Department of Environmental Engineering  
Ambjerg-Nielsen, K., Main Supervisor  
Borup, M., Supervisor  
Technical University of Denmark  
01/09/2015 → 19/02/2020  
Award relations: Surrogate modeling of inundation for both real time control and planning applications  
Project: PhD

**Uncertainty and adaptive estimation in storm- and wastewater system modelling**

Borup, M., PhD Student, Department of Environmental Engineering  
Mikkelsen, P. S., Main Supervisor  
Grum, M., Supervisor  
Madsen, H., Supervisor  
Ambjerg-Nielsen, K., Examiner  
Savic, D. A., Examiner  
Weerts, A., Examiner  
Technical University of Denmark  
01/01/2009 → 02/07/2014  
Award relations: Uncertainty and adaptive estimation in storm- and wastewater system modelling  
Project: PhD

**Addressing China's water challenges with hydroeconomic optimization**

Martinsen, G., PhD Student, Department of Environmental Engineering  
Bauer-Gottwein, P., Main Supervisor  
Borup, M., Examiner  
Madsen, H., Examiner  
Harou, J. J., Examiner  
Samfinansieret - Andet  
01/11/2015 → 03/03/2019  
Award relations: Addressing China's water challenges with hydroeconomic optimization  
Project: PhD

**Activities:**

**Valve status identification by temperature modelling in water distribution networks**

Period: 31 Jan 2019  
Jonas Kjeld Kirstein (Guest lecturer)  
Martin Rygaard (Other)  
Morten Borup (Other)  
Klavs Høgh (Other)  
Department of Environmental Engineering
Urban Water Systems
Degree of recognition: National
Documents:
JKIR_DWF_temperature_modelling2

Related event

13th Annual Water Research Conference: Danish Water Forum
31/01/2019 → 31/01/2019
Copenhagen, Denmark
Activity: Talks and presentations › Conference presentations

Integration af energi- og vandsektoren - potentialer og udfordringer
Period: 19 Sep 2018
Morten Borup (Invited speaker)
Department of Environmental Engineering
Urban Water Systems
Degree of recognition: National

Related external organisation

Danish Intelligent Energy Alliance
Denmark
Activity: Talks and presentations › Conference presentations

MIKE POWERED BY DHI SEMINAR 2016
Period: 10 Mar 2016
Morten Borup (Invited speaker)
Department of Environmental Engineering
Urban Water Systems

Related event

MIKE POWERED BY DHI SEMINAR 2016
10/03/2016 → …
Hørsholm, Denmark
Activity: Talks and presentations › Guest lectures, external teaching and course activities at other universities

Theoretical aspects of ensemble data assimilation for the Earth system
Period: 5 Apr 2015 → 10 Apr 2015
Morten Borup (Invited speaker)
Department of Environmental Engineering
Urban Water Engineering

Description
5 days of presentations and discussions regarding ensemble data assimilation.

Les Houches workshop: "Theoretical aspects of ensemble data assimilation for the Earth system".

Related event

Theoretical aspects of ensemble data assimilation for the Earth system
05/04/2015 → 10/04/2015
Les Houches, France
Activity: Talks and presentations › Conference presentations

International Workshop On Urban Pluvial Flood Modelling
Period: 6 Oct 2014
Morten Borup (Participant)
Department of Environmental Engineering
Urban Water Engineering

Related event

International Workshop On Urban Pluvial Flood Modelling
06/10/2014 → …
Exeter, United Kingdom
Keywords: Flood modelling, Pluvial flooding
Activity: Attending an event › Participating in or organising workshops, courses, seminars etc.

Press clippings:

Interview for "P4 Morgen Bornholm"
Morten Borup
15/03/2019

Description
Interview about the NOAH project
Department of Environmental Engineering, Urban Water Systems

Media contribution (1)

dr radio
15/03/2019
Denmark, Radio
Morten Borup
Press/Media: Press / Media

Article about NOAH
Morten Borup
14/03/2019
Department of Environmental Engineering, Urban Water Systems

Media coverage (1)

Interview about NOAH
14/03/2019
Ingeniøren (National), Denmark, Web
Ingeniøren WaterTech
1 pages
Interview about NOAH
Morten Borup
Press/Media: Press / Media