Informal uncertainty analysis (GLUE) of continuous flow simulation in a hybrid sewer system with infiltration inflow - Consistency of containment ratios in calibration and validation?

Monitoring of flows in sewer systems is increasingly applied to calibrate urban drainage models used for long-term simulation. However, most often models are calibrated without considering the uncertainties. The generalized likelihood uncertainty estimation (GLUE) methodology is here applied to assess parameter and flow simulation uncertainty using a simplified lumped sewer model that accounts for three separate flow contributions: wastewater, fast runoff from paved areas, and slow infiltrating water from permeable areas. Recently GLUE methodology has been criticised for generating prediction limits without statistical coherence and consistency and for the subjectivity in the choice of a threshold value to distinguish “behavioural” from “non-behavioural” parameter sets. In this paper we examine how well the GLUE methodology performs when the behavioural parameter sets deduced from a calibration period are applied to generate prediction bounds in validation periods. By retaining an increasing number of parameter sets we aim at obtaining consistency between the GLUE generated 90% prediction limits and the actual containment ratio (CR) in calibration. Due to the large uncertainties related to spatio-temporal rain variability during heavy convective rain events, flow measurement errors, possible model deficiencies as well as epistemic uncertainties, it was not possible to obtain an overall CR of more than 80%. However, the GLUE generated prediction limits still proved rather consistent, since the overall CRs obtained in validation periods for all proportions of retained parameter sets evaluated. When focusing on wet and dry weather periods separately, some inconsistencies were however found between calibration and validation and we address here some of the reasons why we should not expect the coverage of the prediction limits to be identical in calibration and validation periods in real-world applications. The large uncertainties result in wide posterior parameter limits, that cannot be used for interpretation of, for example, the relative size of paved area vs. the size of infiltrating area. We should therefore try to learn from the significant discrepancies between model and observations from this study, possibly by using some form of non-stationary error correction procedure, but it seems crucial to obtain more representative rain inputs and more accurate flow observations to reduce parameter and model simulation uncertainty. © Author(s) 2013.
A convex programming framework for optimal and bounded suboptimal well field management

This paper presents a groundwater management model, considering the interaction between a confined aquifer and an unlooped Water Distribution Network (WDN), conveying the groundwater into the Water Works distribution mains. The pumps are controlled by regulating the characteristic curves. The objective of the management is to minimize the total cost of pump operations over a multistep time horizon, while fulfilling a set of time-varying management constraints. Optimization in groundwater management and pressurized WDNs have been widely investigated in the literature. Problem formulations are often convex, hence global optimality can be attained by a wealth of algorithms. Among these, the Interior Point methods are extensively employed for practical applications, as they are capable of efficiently solving large-scale...
problems. Despite this, management models explicitly embedding both systems without simplifications are rare, and they usually involve heuristic techniques. The main limitation with heuristics is that neither optimality nor suboptimality bounds can be guaranteed. This paper extends the proof of convexity to mixed management models, enabling the use of Interior Point techniques to compute globally optimal management solutions. If convexity is not achieved, it is shown how suboptimal solutions can be computed, and how to bind their deviation from the optimality. Experimental results obtained by testing the methodology in a well field located nearby Copenhagen (DK), show that management solutions can consistently perform within the 99.9% of the true optimum. Furthermore it is shown how not considering the Water Distribution Network in optimization is likely to result in unfeasible management solutions.

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Evaluation of probabilistic flow predictions in sewer systems using grey box models and a skill score criterion

In this paper we show how the grey box methodology can be applied to find models that can describe the flow prediction uncertainty in a sewer system where rain data are used as input, and flow measurements are used for calibration and updating model states. Grey box models are composed of a drift term and a diffusion term, respectively accounting for the deterministic and stochastic part of the models. Furthermore, a distinction is made between the process noise and the observation noise. We compare five different model candidates’ predictive performances that solely differ with respect to the diffusion term description up to a 4 h prediction horizon by adopting the prediction performance measures; reliability, sharpness and skill score to pinpoint the preferred model. The prediction performance of a model is reliable if the observed coverage of the prediction intervals corresponds to the nominal coverage of the prediction intervals, i.e. the bias between these coverages should ideally be zero. The sharpness is a measure of the distance between the lower and upper prediction limits, and skill score criterion makes it possible to pinpoint the preferred model by taking into account both reliability and sharpness. In this paper, we illustrate the power of the introduced grey box methodology and the probabilistic performance measures in an urban drainage context.

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Analysis and treatment of the Søndersø time series: Grey Box Well Field Modelling

This report deals with grey box modelling applied to the Well Field Optimisation project. The subject is the real case study of Søndersø, located north-west of Copenhagen, DK. This report contains a comprehensive description on how the dataset of measurements taken at Søndersø have been treated and analysed. The purpose of such analysis is twofold. Firstly is to identify a suitable architecture for the grey-box model. Secondly to design a procedure to select values from the dataset that will be used for the calibration of the parameters of the grey-box model. Section 1 describes the Søndersø well field, and provides an overview of the dataset. Section 2 describes the numeric treatments that have been applied to the dataset; the result is summarized in Section 3. Section 4 illustrates the analysis performed on the treated dataset. In this section, the fundamental mechanisms of the well field system are detected and decomposed (subsections 4.1 - 4.3). Based on the results of such analysis, a simple modelling exercise is performed showing that linear models can be
effectively employed to simulate a well field (subsection 4.4). Section 5 describes a sampling approach, designed to calibrate the parameters of the grey-box model with a representative database which is also reasonably reduced in size. Summary and conclusions are in Section 6.

Grey Box Modelling of Flow in Sewer Systems with State Dependent Diffusion

Generating flow forecasts with uncertainty limits from rain gauge inputs in sewer systems require simple models with identifiable parameters that can adequately describe the stochastic phenomena of the system. In this paper, a simple grey-box model is proposed that is attractive for both forecasting and control purposes. The grey-box model is based on stochastic differential equations and a key feature is the separation of the total noise into process and measurement noise. The grey-box approach is properly introduced and hypothesis regarding the noise terms are formulated. Three different hypotheses for the diffusion term are investigated and compared: one that assumes additive diffusion; one that assumes state proportional diffusion; and one that assumes state exponentiated diffusion. To implement the state dependent diffusion terms Itô's formula and the Lamperti transform are applied. It is shown that an additive diffusion noise term description leads to a violation of the physical constraints of the system, whereas a state dependent diffusion noise avoids this problem and should be favoured. It is also shown that a logarithmic transformation of the flow measurements secures positive lower flow prediction limits, because the observation noise is proportionally scaled with the modelled output. Finally it is concluded that a state proportional diffusion term best and adequately describes the one-step flow prediction uncertainty, and a proper description of the system noise is important for ascertaining the physical parameters in question.
Grey Box Modelling of Hydrological Systems: With Focus on Uncertainties

The main topic of the thesis is grey box modelling of hydrologic systems, as well as formulation and assessment of their embedded uncertainties. Grey box model is a combination of a white box model, a physically-based model that is traditionally formulated using deterministic ordinary differential equations, and a black box model, which relates to models that are obtained statistically from input-output relations. Grey box model consists of a system description, defined by a finite set of stochastic differential equations, and an observation equation. Together, system and observation equations represent a stochastic state space model. In the grey box model the total noise is divided into a measurement noise and a process noise. The process noise is due to model approximations, undiscovered input and uncertainties in the input series. Estimates of the process noise can be used to highlight the lack of fit in state space formulation, and further support decisions for a model expansion. By using stochastic differential equations to formulate the dynamics of the hydrological system, either the complexity of the model can be increased by including the necessary hydrological processes in the model, or formulation of process noise can be considered so that it meets the physical limits of the hydrological system and give an adequate description of the embedded uncertainty in model structure. The thesis consists of two parts: a summary report and a part which contains six scientific papers. The summary report is divided into three distinct parts that introduce the main concepts and methods used in the following papers. The first part contains the basic concepts in hydrology and related hydrological models. The second part explains the grey box model by presenting stochastic differential equations and show how the equations can be linked to the available measurements. Moreover, impulse response function models are introduced as an alternative to stochastic differential equation based models, but by
exploiting known hydrological models as the impulse response function in this model makes this model framework partly physically-based. For estimating the parameters in the grey box models maximum likelihood method is used. The third important part of the summary report is predictions, and with focus on uncertainty of prediction intervals the corresponding performance measures have to include the intervals. The thesis illustrates three performance measures for this performance evaluations: reliability, sharpness and resolution. For decision making, a performance criterion is preferred that quantifies all of these measures in a single number, and for that the quantile skill score criterion is discussed in this thesis. The second part of the thesis, which contains the papers, is divided into two different subjects. First are four papers, which consider the grey box model approach to a well field with several operating pumps. The model foundation is the governing equation for groundwater flow, which can be simplified and represented a state space form that resembles the methods used in numerical methods for well field modelling. The objective in the first two papers is to demonstrate how a simple grey box model is formulated and, subsequently, extended in terms of parameter estimation using statistical methods. The simple models in these papers consider only part of the well field, but data analysis reveals that the wells in the well field are highly correlated. In the third paper, all wells pumping from the same aquifer are included in the state space formulation of the model, but instead, but instead of extending the physical description of the system, the uncertainty is formulated to handle the spatio-temporal variation in the output. The uncertainty in the model are then evaluated by using the quantile skill score criterion. In the fourth paper, the well field is formulated by considering the impulse response function models to describe water level variation in the wells, as a function of available pumping rates in the well field. The paper illustrates, through a case study, how the model can be used to define and solve the well field management problem. The second half of part II consists of two papers where the stochastic differential equation based model is used for sewer runoff from a drainage system. A simple model is used to describe a complex rainfall-runoff process in a catchment, but the stochastic part of the system is formulated to include the increasing uncertainty when rainwater flows through the system, as well as describe the lower limit of the uncertainty when the flow approaches zero. The first paper demonstrates in detail the grey box model and all related transformations required to obtain a feasible model for the sewer runoff. In the last paper this model is used to predict the runoff, and the performances of the prediction intervals are evaluated by the quantile skill score criterion.
Optimal combined wind power forecasts using exogenous variables: PSO2004/FU5766 Improved wind power prediction