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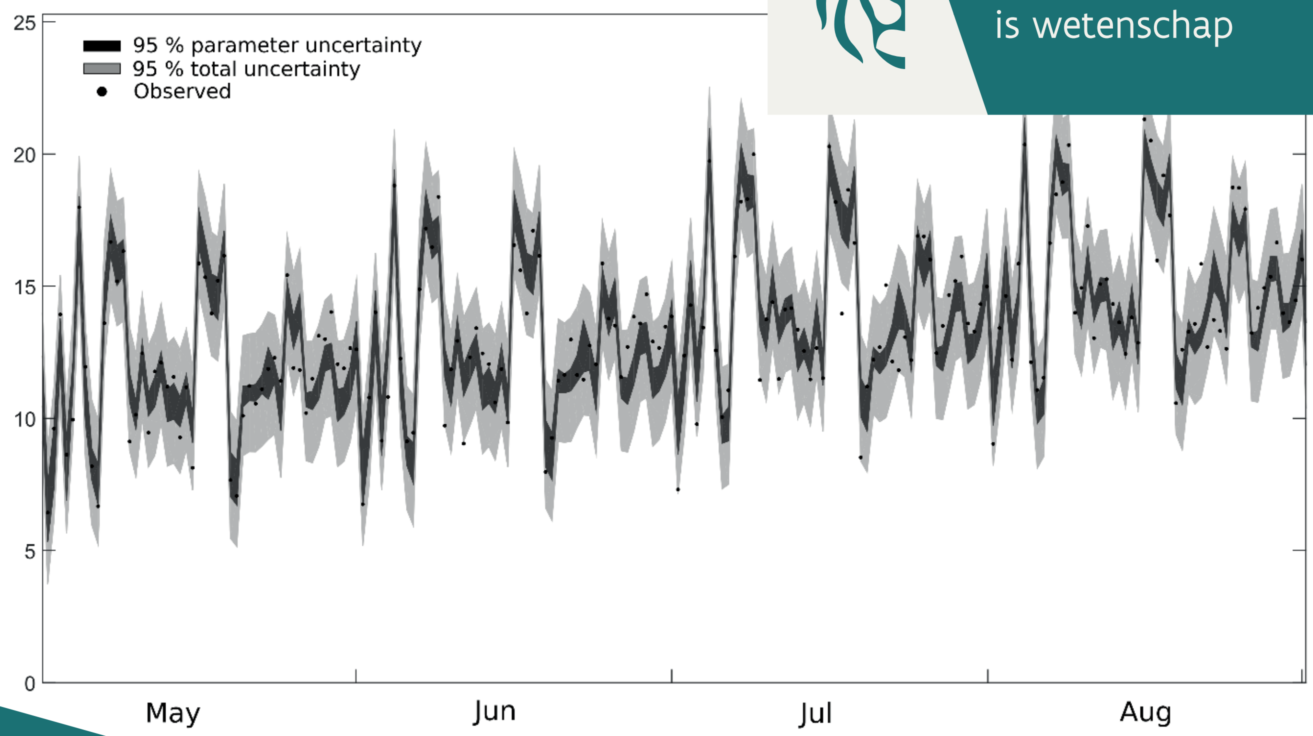

14_063_1
WL rapporten

Onzekerheden op hydrologische modellen

Eindrapport

DEPARTEMENT
MOBILITEIT & OPENBARE WERKEN

waterbouwkundiglaboratorium.be

Onzekerheden op hydrologische modellen

Eindrapport

Nossent, J.; Bauwens, W.; Mostaert, F.

Waterbouwkundig Laboratorium
Vlaanderen is wetenschap

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Abstract

Dit rapport geeft een overzicht van het onderzoek dat werd uitgevoerd in het kader van project 14_063 (JNT persoonlijk onderzoek "Uncertainty in hydrological modelling") in samenwerking met de dienst Hydrologie en Waterbouwkunde van de Vrije Universiteit Brussel en enkele andere partners rond het thema onzekerheidsanalyse (en daarbij aansluitend gevoeligheidsanalyse, optimalisatie en statistische analyse) van (hydrologische) modellen.

Naast de wetenschappelijke output, worden in dit rapport ook de lopende samenwerkingen en de cross-correlatie met WL-projecten beschreven.

Inhoudstafel

Lijst van de figuren

1 Inleiding

Om de kennis en expertise van het Waterbouwkundig Laboratorium voortdurend actueel te houden en te verbeteren is wetenschappelijk onderzoek uitgevoerd door de werknemers een belangrijke hefboom. In het kader van project 14_063 (JNT persoonlijk onderzoek "Uncertainty in hydrological modelling") werd daarom in samenwerking met de dienst Hydrologie en Waterbouwkunde van de Vrije Universiteit Brussel onderzoek gedaan rond het thema onzekerheidsanalyse (en daarbij aansluitend gevoeligheidsanalyse, optimalisatie en statistische analyse) van (hydrologische) modellen.

Het initiële voorstel van dit project omvatte twee specifieke onderzoekslijnen die binnen dit thema passen (“Regionalisatie van parameters van een hydrologisch model” en “Belangrijkheid van input voor de output van hydrologische modellen”), maar in de loop van het project werd de scope verbreed. Er werd de voorbije maanden en jaren dan ook meer ingezet op samenwerkingen met doctorandi en post-docs om onze expertise te verbeteren en te delen.

In het tweede deel van dit rapport zal een overzicht gegeven worden van de concrete wetenschappelijke output die gegenereerd werd op basis van het werk binnen dit project (posters en mondelinge presentaties worden alleen vermeld wanneer ze effectief door mezelf gepresenteerd werden), terwijl een derde deel nieuwe en nog lopende samenwerkingen en onderzoekslijnen zal belichten. Een korte bespreking van de evolutie op vlak van de twee initiële onderzoekslijnen zal eveneens aan bod komen in dit deel. Tot slot volgt er in deel vier een kort overzicht van andere projecten van het WL waarbinnen de resultaten en opgedane kennis van dit onderzoek reeds toegepast konden worden.

Naast de onderzoeksresultaten en expertise, leverde het werk in het kader van dit project ook uitstraling op voor het Waterbouwkundig Laboratorium. Zo kreeg ik in 2015 de “Outstanding Reviewer Award” voor het journal “Environmental Modelling and Software” (Figuur 1). Daarnaast werd ik in 2016 gevraagd als extern jurylid voor het doctoraat van Stijn Van Hoey (“Development and application of framework for model structure evaluation in environmental modelling”, promotoren: Prof. Ingmar Nopens & Prof. Piet Seuntjens, UGent). Later dit jaar zal ik ook deel uitmaken van de doctoraatsjury’s van Befekadu Woldegiorgis en Syed Md. Touhidul Mustafa (VUB).

Figuur 1 – De aankondiging voor de “Outstanding reviewers 2015” in Environmental Modelling and Software

Environmental Modelling & Software 83 (2016) iii

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

Top 10 reviewers for environmental modelling and software in 2015

The journal aims to continue to strengthen its position at the frontier of environmental modelling, software and decision support, where its niche is to showcase innovations in the frameworks and methods for the model-based integration required to make progress on the resolution of environmental policy and management issues, as well as promote developments in generic methods and software that apply across a range of environmental sectors. An indication of EMS' success is in achieving an Impact factor of 4.420 for 2015 (5-year: 4.359). This progress would not be possible without our dedicated reviewers. We are very grateful to every one of the more than a thousand reviewers who devoted their time, expertise and efforts to the journal in 2015. Their support is crucial to ensure the very high quality and scientific value of our publications, and serves to advance the journal's aim of improving our capacity to represent, understand, predict or manage the behaviour of environmental systems at all practical scales, and to communicate those improvements to a wide scientific and professional audience.

Every year, the Editors select ten outstanding reviewers who have provided exceptional contributions to the journal. These ‘Outstanding Reviewer Award’ recipients are shortlisted by the Editors based on the rigor, constructiveness and timeliness of their reviews in addition to the number of reviews performed. Our Award for “Reviewer of the Year” is shared this time between Baihua Fu and Jan Kwakkel.

The 10 awardees for 2015 and their institutions are:

Mohammad Abouali, Michigan State University, USA
K W Chau, Hong Kong Polytechnic University
Matteo Convertino, University of Minnesota Twin Cities, USA
Baihua Fu, Australian National University, Australia
Carlos Granell, Universitat Jaume I of Castellón, Spain
Jan Kwakkel, Delft University of Technology, The Netherlands
Jesús Mateo-Lázaro, University of Zaragoza, Spain
Jiri Nossent, Flanders Hydraulics Research, Belgium
Ombretta Paladino, Università di Genova, Italy
Jai Vaze, CSIRO, Australia

In addition to these we would also like to give an “Honourable Mention” to the following previous awardees who have continued to provide outstanding service to the journal:

David Cecil, Gabriele Freni, Jon Goodall, Joseph Guillaume, Jon Herman, Jeffery Horsburgh, Derek Karssenberg, Joseph Kasprzyk, Rob Knapen and Daniel Wallach.

The Editors congratulate these awardees and thank them for their sustained efforts and contributions. We will be presenting the awards for the Top 10 reviewers for the last two years at the upcoming 8th iEMSs Biennial meeting in Toulouse, France in July 2016.

Honorary Editor-in-Chief
Anthony J. Jakeman

Editor-in-Chief
Daniel Ames

Editors
Ioannis N. Athanasiadis, Stefan Reis,
Andrea E. Rizzoli, Alexey A. Voinov

De inhoud van dit rapport wordt als “vertrouwelijk” gecatalogeerd, aangezien een deel van het onderzoek dat aan bod komt nog lopend is en pas publiek bekend kan worden wanneer het reeds gepubliceerd is. Alle reeds gepubliceerde wetenschappelijke output is beschikbaar in de bibliotheek van het WL.

2 Wetenschappelijke output

2.1 Persoonlijk onderzoek

In het kader van de 2de initiële onderzoekslijn ("Belangrijkheid van input voor de output van hydrologische modellen") werden reeds enkele conference papers gepubliceerd (met bijhorende presentatie of poster).

De methodologie werd een eerste keer gepresenteerd en afgetoetst met experten in het veld in het kader van de "7th International Congress on Environmental Modelling and Software" in 2014 (iEMSs2014) in San Diego aan de hand van een conference paper (Figuur 2) en een mondelinge presentatie (Figuur 3):

> Nossent, J., Bauwens, W., Pereira, F., Verwaest, T. and Mostaert, F. (2014) Are the driving forces of hydrological models really driving the model output? In: Ames, D.P., Quinn, N.W.T., Rizzoli, A.E. (Eds.), Proceedings of the 7th International Congress on Environmental Modelling and Software, June 15-19, San Diego, California, USA. ISBN: 978-88-9035-744-2
> http://www.iemss.org/sites/iemss2014/proceedings.php

Een jaar later werden op de European Geosciences Union General Assembly (EGU2015) de eerste resultaten getoond aan de hand van een abstract (Figuur 4) en poster (Figuur 5):

> Nossent, J., Pereira, F. and Bauwens, W. (2015) Assessing the importance of rainfall uncertainty on hydrological models with different spatial and temporal scale. Geophysical Research Abstracts, Vol. 17, Vienna, Austria

Meer recent (2017) warden bijkomende resultaten gepresenteerd op European Geosciences Union General Assembly (EGU2017) aan de hand van een abstract (Figuur 6) en poster (Figuur 7):

> Nossent, J., Pereira, F. and Bauwens, W. (2017) Rainfall or parameter uncertainty? The power of sensitivity analysis on grouped factors. Geophysical Research Abstracts, Vol. 19, Vienna, Austria

De huidige toestand van dit onderzoek wordt verder besproken in sectie 3.1.

Figuur 2 – De eerste pagina van de conference paper (Nossent et al., 2014) voor iEMSs2014

International Environmental Modelling and Software Society (iEMSs)
7th Intl.Congress on Env. Modelling and Software, San Diego, CA, USA,
Daniel.P. Ames, Nigel W.T. Quinn and Andrea E. Rizzoli (Eds.)
http://www.iemss.org/society/index.php/iemss-2014-proceedings

Are the driving forces of hydrological models really driving the model output?

Jiri Nossent[1,2], Willy Bauwens[2], Fernando Pereira[1], Toon Verwaest[1] and Frank Mostaert[1]
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jiri.nossent@mow.vlaanderen.be

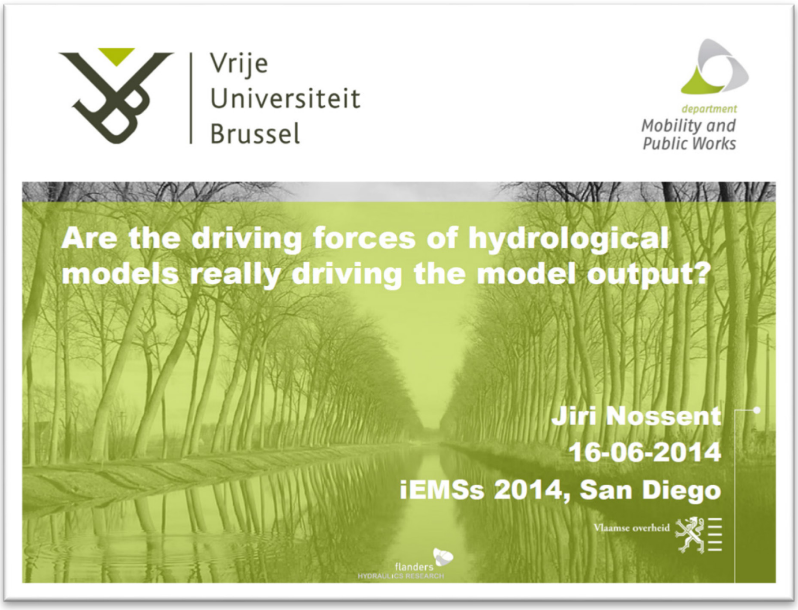
Abstract: Rainfall is very often considered as the driving force of hydrological models. If the rainfall changes, the model output (i.e. flow) is also expected to change. In principal, as long as the values of the model parameters are fixed, rainfall will indeed determine the model output. Yet, uncertainties on the input, the model(parameters) and the output lead to variations of the actual values and can disrupt this rigid hypothesis. Hence, the question could be raised if it would be possible to maintain exactly the same initial model output when the model input changes, by varying the model parameter values? Or, in other words, how important is the rainfall/input and the related uncertainty for the model output with respect to the model parameter importance?
We assess the significance of the input uncertainty on the model output and compare it to the importance of the model parameters by applying a Sobol' sensitivity analysis for 3 different hydrological models, considering 4 scenario's for the parameters included in the analysis. Within these sensitivity analyses, the input uncertainty is handled in a probabilistic way by applying so called rainfall multipliers on hydrological independent storm events and treating them as regular model parameters.
This paper presents the main expected results of these sensitivity analyses. The results increase the awareness for research prioritization in view of the improvement of hydrological modelling. Besides, this study highlights the close relationship between uncertainty analysis and sensitivity analysis, and provides new opportunities to use sensitivity analysis for uncertainty importance assessment.

***Keywords**:* Uncertainty analysis; Sensitivity analysis; Hydrological modelling; Input uncertainty; Rainfall multipliers

1 INTRODUCTION

Hydrological models are typically used to study and represent (a part of) the hydrological cycle. Based on a number of inputs, model states and boundary conditions, we try to compute e.g. the amount of flow in the river. As researchers and policy makers often rely on the outcome of hydrological models to formulate their conclusions and decisions, the simulation results need to be as accurate as possible or, at least, need to provide a level of reliability of the results. This accuracy or reliability highly depends on the level of uncertainty on the different inputs (Vrugt et al., 2008).
Like for the hydrological cycle, precipitation is one of the key inputs for hydrological models. Above and beyond, rainfall is very often even considered to be the main driving force of hydrological models. If the rainfall changes, the model output is also expected to change. Yet, the available rainfall records are very often point measurements at a discrete time step (hourly, daily, monthly,…) and therefore contain uncertainty due to a latent lack of spatial and temporal variability, or even due to possible measurement errors. Hence, the actual precipitation can differ from the measured values used in the model (McMillan et al., 2011). Nevertheless, modellers always have the intention to mimic the observed output, whatever the variation of the rainfall might be, and he/she might achieve this objective by adapting the model parameter values (Beven, 2000).

Figuur 3 – De titelpagina van de mondelinge presentatie op iEMSs2014



Figuur 4 – Het abstract (Nossent et al., 2015) voor EGU2015

Geophysical Research Abstracts
Vol. 17, EGU2015-13271, 2015
EGU General Assembly 2015

Assessing the importance of rainfall uncertainty on hydrological models with different spatial and temporal scale

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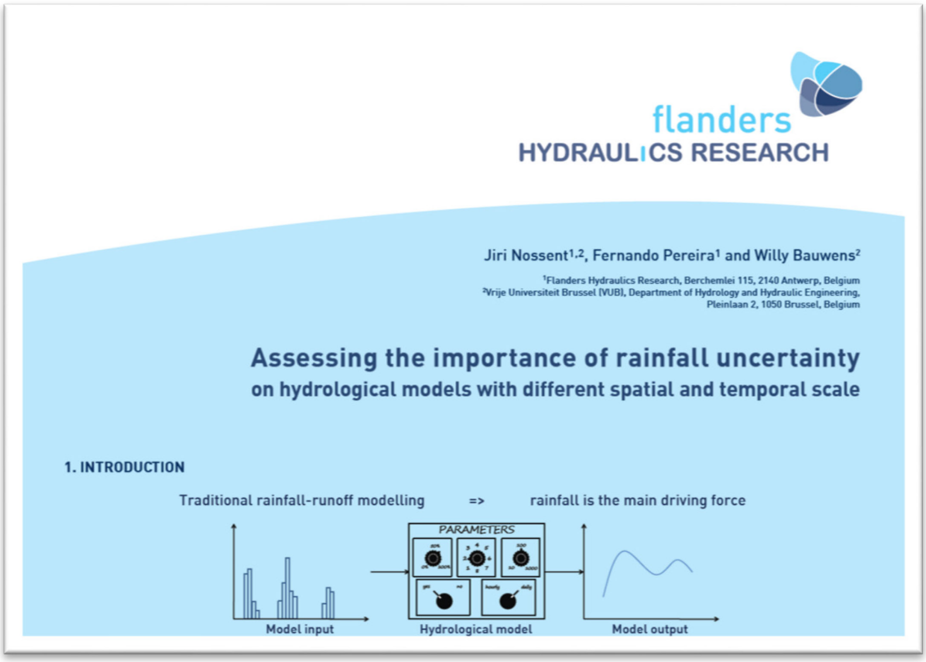
Precipitation is one of the key inputs for hydrological models. As long as the values of the hydrological model parameters are fixed, a variation of the rainfall input is expected to induce a change in the model output. Given the increased awareness of uncertainty on rainfall records, it becomes more important to understand the impact of this input - output dynamic. Yet, modellers often still have the intention to mimic the observed flow, whatever the deviation of the employed records from the actual rainfall might be, by recklessly adapting the model parameter values. But is it actually possible to vary the model parameter values in such a way that a certain (observed) model output can be generated based on inaccurate rainfall inputs? Thus, how important is the rainfall uncertainty for the model output with respect to the model parameter importance?

To address this question, we apply the Sobol' sensitivity analysis method to assess and compare the importance of the rainfall uncertainty and the model parameters on the output of the hydrological model. In order to be able to treat the regular model parameters and input uncertainty in the same way, and to allow a comparison of their influence, a possible approach is to represent the rainfall uncertainty by a parameter. To tackle the latter issue, we apply so called rainfall multipliers on hydrological independent storm events, as a probabilistic parameter representation of the possible rainfall variation.

As available rainfall records are very often point measurements at a discrete time step (hourly, daily, monthly,. . .), they contain uncertainty due to a latent lack of spatial and temporal variability. The influence of the latter variability can also be different for hydrological models with different spatial and temporal scale. Therefore, we perform the sensitivity analyses on a semi-distributed model (SWAT) and a lumped model (NAM). The assessment and comparison of the importance of the rainfall uncertainty and the model parameters is achieved by considering different scenarios for the included parameters and the state of the models.

Figuur 5 – Het eerste deel van de poster op EGU2015



Figuur 6 – Het abstract (Nossent et al., 2017) voor EGU2017

Geophysical Research Abstracts
Vol. 19, EGU2017-12797, 2017
EGU General Assembly 2017

Rainfall or parameter uncertainty? The power of sensitivity analysis on grouped factors

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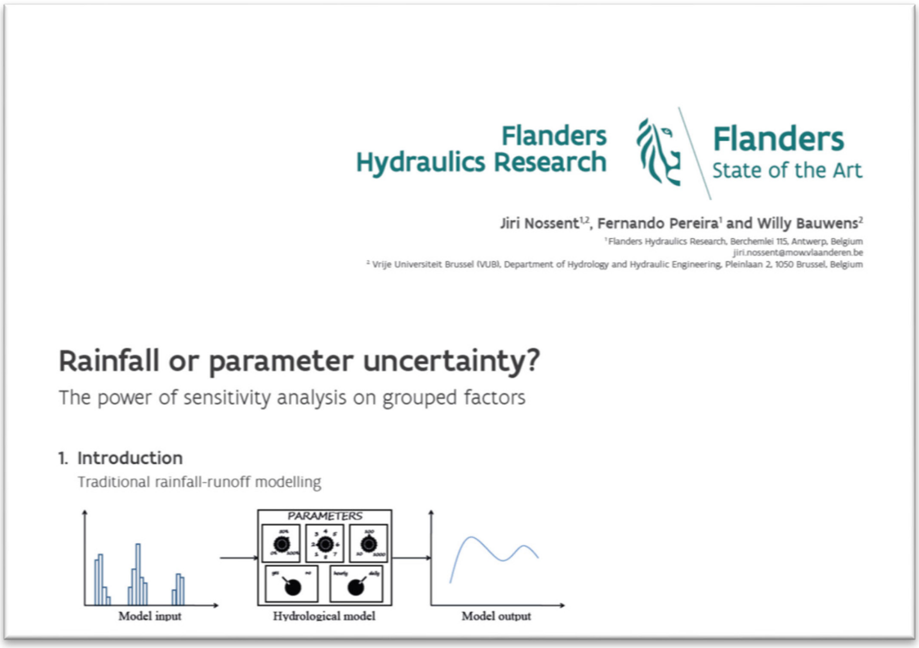
Hydrological models are typically used to study and represent (a part of) the hydrological cycle. In general, the output of these models mostly depends on their input rainfall and parameter values. Both model parameters and input precipitation however, are characterized by uncertainties and, therefore, lead to uncertainty on the model output. Sensitivity analysis (SA) allows to assess and compare the importance of the different factors for this output uncertainty. Hereto, the rainfall uncertainty can be incorporated in the SA by representing it as a probabilistic multiplier. Such multiplier can be defined for the entire time series, or several of these factors can be determined for every recorded rainfall pulse or for hydrological independent storm events. As a consequence, the number of parameters included in the SA related to the rainfall uncertainty can be (much) lower or (much) higher than the number of model parameters. Although such analyses can yield interesting results, it remains challenging to determine which type of uncertainty will affect the model output most due to the different weight both types will have within the SA.

In this study, we apply the variance based Sobol' sensitivity analysis method to two different hydrological simulators (NAM and HyMod) for four diverse watersheds. Besides the different number of model parameters (NAM: 11 parameters; HyMod: 5 parameters), the setup of our sensitivity and uncertainty analysis-combination is also varied by defining a variety of scenarios including diverse numbers of rainfall multipliers. To overcome the issue of the different number of factors and, thus, the different weights of the two types of uncertainty, we build on one of the advantageous properties of the Sobol' SA, i.e. treating grouped parameters as a single parameter. The latter results in a setup with a single factor for each uncertainty type and allows for a straightforward comparison of their importance. In general, the results show a clear influence of the weights in the different SA scenarios. However, working with grouped factors resolves this issue and leads to clear importance results.

Figuur 7 – Het eerste deel van de poster op EGU2017



2.2 Samenwerking met dr. Jef Dams (VUB, Vito)

In 2015 resulteerde een samenwerking met Jef Dams (VUB, Vito) rond het inschatten van de invloed van onzekerheden van klimaatscenario's en model structuren op de totale modelonzekerheid tot een A1-publicatie in "Journal of Hydrology" (Figuur 8):

> Dams, J., Nossent, J., Senbeta, T.B., Willems, P. and Batelaan, O. (2015) Multi-model approach to assess the impact of climate change on runoff. Journal of Hydrology 529 (3) 1601-1616. doi: 10.1016/j.jhydrol.2015.08.023

Mogelijk wordt deze samenwerking in de toekomst verder gezet in het kader van een vervolgpaper rond model-selectie en ensembles, maar voorlopig staat dit "on-hold".

Figuur 8 – De eerste pagina van (Dams et al., 2015) in Journal of Hydrology

Journal of Hydrology 529 (2015) 1601–1616

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Multi-model approach to assess the impact of climate change on runoff

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Hydrological uncertainty
Extremes
Model errors

SUMMARY

The assessment of climate change impacts on hydrology is subject to uncertainties related to the climate change scenarios, stochastic uncertainties of the hydrological model and structural uncertainties of the hydrological model. This paper focuses on the contribution of structural uncertainty of hydrological models to the overall uncertainty of the climate change impact assessment. To quantify the structural uncertainty of hydrological models, four physically based hydrological models (SWAT, PRMS and a semi- and fully distributed version of the WetSpa model) are set up for a catchment in Belgium. Each model is calibrated using four different objective functions. Three climate change scenarios with a high, mean and low hydrological impact are statistically perturbed from a large ensemble of climate change scenarios and are used to force the hydrological models. This methodology allows assessing and comparing the uncertainty introduced by the climate change scenarios with the uncertainty introduced by the hydrological model structure.

Results show that the hydrological model structure introduces a large uncertainty on both the average monthly discharge and the extreme peak and low flow predictions under the climate change scenarios. For the low impact climate change scenario, the uncertainty range of the mean monthly runoff is comparable to the range of these runoff values in the reference period. However, for the mean and high impact scenarios, this range is significantly larger. The uncertainty introduced by the climate change scenarios is larger than the uncertainty due to the hydrological model structure for the low and mean hydrological impact scenarios, but the reverse is true for the high impact climate change scenario. The mean and high impact scenarios project increasing peak discharges, while the low impact scenario projects increasing peak discharges only for peak events with return periods larger than 1.6 years. All models suggest for all scenarios a decrease of the lowest flows, except for the SWAT model with the mean hydrological impact climate change scenario.

The results of this study indicate that besides the uncertainty introduced by the climate change scenarios also the hydrological model structure uncertainty should be taken into account in the assessment of climate change impacts on hydrology. To make it more straightforward and transparent to include model structural uncertainty in hydrological impact studies, there is a need for hydrological modelling tools that allow flexible structures and methods to validate model structures in their ability to assess impacts under unobserved future climatic conditions.

1. Introduction

Assessing the impact of climate change on the hydrological cycle is currently one of the major challenges in hydrological research (IPCC, 2013; Peel and Blöschl, 2011). Given the large uncertainty of climate predictions, due to unknown future greenhouse gas emissions, simplifications in General Circulation Models (IPCC, 2013) and downscaling methods (Stoll et al., 2011), it has become common practice to apply an ensemble of climate change scenarios. The range in the hydrological predictions following from such an ensemble of climate change scenarios is often considered as the uncertainty range of the hydrological impact (e.g. Minville

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http://dx.doi.org/10.1016/j.jhydrol.2015.08.023

2.3 Samenwerking met Farkhondeh Khorashadi Zadeh (VUB)

Farkhondeh Khorashadi Zadeh is een doctoraatstudent aan de vakgroep HYDR van de VUB die ook deels werkt voor project 00_131 “Ontwikkeling van conceptuele modellen”. Sinds 2014 wordt er samengewerkt rond sensitiviteitsanalyse van hydrologische modellen, wat in 2015 resulteerde in 3 bijdrages op conferenties:

- Een abstract (Figuur 9) op de European Geosciences Union General Assembly (EGU2015):

  Zadeh, F.K., Sarrazin, F., Nossent, J., Pianosi, F., van Griensven, A., Wagener, T. and Bauwens, W. (2015) Global sensitivity analysis of a SWAT model: comparison of the variance-based and moment-independent approaches. Geophysical Research Abstracts, Vol. 17, Vienna, Austria

- Een conference paper (Figuur 10) op de SWAT Conferentie (SWAT2015):

  Zadeh, F.K., Nossent, J., van Griensven, A. and Bauwens, W. (2015) Two-step global sensitivity analysis of a SWAT model: joint utilization of simple screening methods and advance quantitative methods. Proceedings of the 2015 international SWAT conference, 24-26 June 2015, Pula, Italy

- Een conference paper (Figuur 11) op de International Association for Hydro-Environment Engineering and Research (IAHR) Conferentie (IAHR2015):

  Zadeh, F.K., Sarrazin, F., Nossent, J., Pianosi, F., van Griensven, A., Wagener, T. and Bauwens, W. (2015) Comparison of the PAWN and Sobol’ sensitivity analysis methods for a highly-parameterized hydrological model using SWAT. E-proceedings of the 36th IAHR World Congress, 28 June – 3 July 2015, The Hague, the Netherlands

Begin dit jaar verscheen dan ook een A1-publicatie met de resultaten van dit onderzoek in “Environmental Modelling and Software” (Figuur 12):

> Zadeh, F.K., Nossent, J., Sarrazin, F., Pianosi, F., van Griensven, A., Wagener, T. and Bauwens, W. (2017) Comparison of variance-based and moment-independent global sensitivity analysis approaches by application to the SWAT model. Environmental Modelling & Software, 91, 210-220. doi: 10.1016/j.envsoft.2017.02.001

Een van de aspecten uit deze paper werd ook nog eens bijkomend toegelicht op de European Geosciences Union General Assembly van 2017 (EGU2017) aan de hand van een abstract (Figuur 13) en mondelinge presentatie (Figuur 14):

> Zadeh, F.K., Nossent, J., van Griensven, A. and Bauwens, W. (2017) Parameter screening: the use of a dummy parameter to identify non-influential parameters in a global sensitivity analysis. Geophysical Research Abstracts, Vol. 19, Vienna, Austria

Het verdere verloop en de huidige stand van zaken van deze samenwerking wordt besproken in sectie 3.2.

Figuur 9 – Het abstract (Zadeh et al., 2015a) voor EGU2015

Geophysical Research Abstracts
Vol. 17, EGU2015-997, 2015
EGU General Assembly 2015

Global sensitivity analysis of a SWAT model: comparison of the variance-based and moment-independent approaches

Farkhondeh Khorashadi Zadeh (1), Fanny Sarrazin (2), Jiri Nossent (1,3), Francesca Pianosi (2), Ann van Griensven (1,4), Thorsten Wagener (2,5), and Willy Bauwens (1)

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Uncertainty in parameters is a well-known reason of model output uncertainty which, undermines model reliability and restricts model application. A large number of parameters, in addition to the lack of data, limits calibration efficiency and also leads to higher parameter uncertainty. Global Sensitivity Analysis (GSA) is a set of mathematical techniques that provides quantitative information about the contribution of different sources of uncertainties (e.g. model parameters) to the model output uncertainty. Therefore, identifying influential and non-influential parameters using GSA can improve model calibration efficiency and consequently reduce model uncertainty.
In this paper, moment-independent density-based GSA methods that consider the entire model output distribution – i.e. Probability Density Function (PDF) or Cumulative Distribution Function (CDF) - are compared with the widely-used variance-based method and their differences are discussed. Moreover, the effect of model output definition on parameter ranking results is investigated using Nash-Sutcliffe Efficiency (NSE) and model bias as example outputs. To this end, 26 flow parameters of a SWAT model of the River Zenne (Belgium) are analysed. In order to assess the robustness of the sensitivity indices, bootstrapping is applied and 95% confidence intervals are estimated. The results show that, although the variance-based method is easy to implement and interpret, it provides wider confidence intervals, especially for non-influential parameters, compared to the density-based methods. Therefore, density-based methods may be a useful complement to variance-based methods for identifying non-influential parameters.

Figuur 10 – De eerste pagina van de conference paper (Zadeh et al., 2015b) voor SWAT2015

Session C4: Sensitivity Calibration and Uncertainty

A two-step global sensitivity analysis of a SWAT model, using simple screening methods and advanced quantitative methods

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Abstract

SWAT (Soil and Water Assessment Tool) is a physically-based, semi-distributed hydrological simulator, which has been widely used to support alternative watershed management practices in large river basins all over the world. A SWAT model includes a large number of parameters, requiring a model optimization process -i.e. calibration- for their estimation. However, searching for the optimal value of all the parameters is often not feasible. Therefore, a parameter sensitivity analysis can be essential to identify a subset of the most sensitive parameters prior to calibration. Moreover, the sensitivity analysis can support the identification of model processes, parameter values and parameter interaction effects.

This paper presents a two-step approach for a global sensitivity analysis (GSA) of a SWAT model. First, relatively simple screening methods, including the Latin-Hypercube- One-factor-At-a-Time (LH-OAT) algorithm and the regression-based method of SWAT-CUP (SWAT Calibration Uncertainty Procedures), are applied to screen out the influential parameters with a limited number of model evaluations. Next, the identified important parameters are further analyzed to fully characterize the effect of the parameters on the model output, using computational demanding quantitative GSA methods, including the density-based PAWN and the variance-based Sobol' methods. Using this approach, it is possible to optimally benefit from a joint utilization of the techniques. In fact, the non-influential parameters are identified by the screening methods with low cost, while extra information about the sensitive parameters and a more reliable parameter ranking are obtained using the quantitative methods. To illustrate the two-step GSA approach, 26 water quantity related parameters of a SWAT model of the River Zenne (Belgium) are selected to be analysed and ranked.

Keywords

Global sensitivity analysis, SWAT model, Two-step approach, Screening methods, Quantitative methods

Figuur 11 – De eerste pagina van de conference paper (Zadeh et al., 2015c) voor IAHR2015

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Comparison of the PAWN and Sobol' sensitivity analysis methods for a highly-parameterized hydrological model using SWAT

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ABSTRACT

The high number of parameters is a major problem for complex environmental models as it restricts their application. Therefore, sensitivity analysis (SA) methods, that aim to identify the influential and the non-influential parameters of a model, can be essential for an efficient calibration of these models. The SA indeed allows for a reduction of the number of parameters involved in a calibration procedure, by applying factor fixing (FF) and factor prioritization (FP). In this paper, a density-based Global Sensitivity Analysis (GSA) method -PAWN- is applied to the Soil and Water Assessment Tool (SWAT), a highly-parameterized hydrological simulator. The objective of this study is to compare the newly developed PAWN method with the Sobol' method, which is a well-established and widely used variance-based SA method. The PAWN method considers the entire model output distribution to describe the output uncertainty while the Sobol' method implicitly assumes that the variance is a sufficient indicator for this purpose. To this end, 26 water quantity related parameters of a SWAT model of the River Zenne (Belgium) are selected to be ranked, using both the PAWN and the Sobol' methods. In addition, the two SA methods are evaluated and compared in terms of convergence, the related evolution of the parameter ranking results and required computation cost.

Keywords: Global sensitivity analysis, Moment-independent method, Variance-based method, SWAT model

1. INTRODUCTION

Due to an improved knowledge of the physical processes and an increased computational power, environmental modeling tools, such as hydrological simulators, have become more complex over the past decades. In addition, the application of these models has increased considerably, especially for an integrated modeling approach (Nossent et al., 2011; Shrestha et al., 2013). However, such complex simulators often contain many parameters and most of these parameters cannot be measured directly. Therefore, a model optimization process -i.e. calibration- is needed to estimate the parameters values. In order to obtain an efficient optimization and avoid over-parameterization, a sensitivity analysis (SA) is essential to identify the influential and the non-influential parameters of a model. The SA indeed allows for a reduction of the number of parameters incorporated in the calibration. This may be achieved by factor fixing (FF), where non-influential parameters are set to a fixed value and excluded from the calibration process, or by factor prioritization (FP), where more attention is put to the parameters that have the highest influence on the model output (Saltelli et al., 2008).

Many different methods have been developed for SA (Sobol', 1990; van Griensven et al., 2006; Borgonovo, 2007). The readers are referred to Saltelli et al. (2000) for a detailed description of SA techniques. Based on the way the parameters are treated, SA methods are classified into two main branches, the local methods and the global methods (Saltelli et al., 2000). Local techniques evaluate the sensitivity at one point in the parameter hyperspace while global methods allow to take into consideration the entire parameter range (van Griensven et al., 2006). In the presence of parameter uncertainty, when it is difficult to assign a certain value to the parameters, a global sensitivity analysis (GSA) is recommended (Saltelli et al., 2002b). A GSA permits to assess and quantify the relative contribution of different sources of uncertainty to the model output uncertainty using sensitivity indices (Saltelli, 2002b).

A well-established and widely applied GSA approach is the variance-based method of Sobol' (Sobol' 1990; Saltelli, 2002b; Pappenberger et al., 2008; Nossent et al., 2011). Generally, variance-based methods seek to measure the output sensitivity to an uncertain input using the contribution of that input to the total output variance. A well-known merit of

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Figuur 12 – De eerste pagina van (Zadeh et al., 2017) in Environmental Modelleing and Software

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Comparison of variance-based and moment-independent global sensitivity analysis approaches by application to the SWAT model

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ABSTRACT

Global Sensitivity Analysis (GSA) is an essential technique to support the calibration of environmental models by identifying the influential parameters (screening) and ranking them.

In this paper, the widely-used variance-based method (Sobol') and the recently proposed moment-independent PAWN method for GSA are applied to the Soil and Water Assessment Tool (SWAT), and compared in terms of ranking and screening results of 26 SWAT parameters. In order to set a threshold for parameter screening, we propose the use of a "dummy parameter", which has no influence on the model output. The sensitivity index of the dummy parameter is calculated from sampled data, without changing the model equations. We find that Sobol' and PAWN identify the same 12 influential parameters but rank them differently, and discuss how this result may be related to the limitations of the Sobol' method when the output distribution is asymmetric.

1. Introduction

Due to advancements in the understanding of natural processes and their interactions, and due to the advancements in software engineering and the increased computational power, environmental modeling tools have become more complex over the past decades (e.g. Arnold et al., 1998; Rossman, 2009; DHI, 2009). In general, such complex simulators contain many parameters, most of which cannot be measured directly and can only be inferred by calibration to observed system responses (Yapo et al., 1998; Vrugt et al., 2002). Consequently, parameter estimation has become a major issue, which may limit the applicability of complex simulators (van Griensven et al., 2006). A manual calibration of a model with a large number of parameters is very tedious and time consuming (Vrugt et al., 2003). On the other hand, the efficiency of automatic calibration algorithms is reduced when the number of parameters is large (Duan et al., 1992). In fact, it is not feasible to include all the model parameters in the calibration process (Bekele and Nicklow, 2007; Nossent et al., 2011). In order to support the choice of which model parameters should be the focus of calibration, and which ones could be instead excluded from calibration (and set to 'default' values), Global Sensitivity Analysis (GSA) is becoming popular in environmental modeling practices (e.g. Muleta and Nicklow, 2005; van Werkhoven et al., 2009; Norton, 2015; Pianosi et al., 2016a, b). GSA indeed allows for the identification of the parameters that have the largest influence on a set of model performance metrics (so called 'factor prioritization') and the identification of non-influential parameters ('factor fixing') (Saltelli et al., 2008; Nossent et al., 2011). Other uses of GSA include the understanding and the interpretation of the model behavior, the prioritization of efforts for uncertainty reduction and the model simplification (Nossent et al., 2011; Pianosi et al., 2016a, b).

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) is a particular example of a relatively complex environmental simulator, which has been widely applied all over the world for watershed management purposes (e.g. Gassman et al., 2010; van Griensven et al., 2012; Bressiani et al., 2015). In SWAT, different watershed processes, including surface runoff, groundwater flow, plant growth, and pesticide and nutrient conversion and transport, are controlled by a large number of parameters (more than 100).

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Figuur 13 – Het abstract (Zadeh et al., 2017) voor EGU2017

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Parameter screening: the use of a dummy parameter to identify non-influential parameters in a global sensitivity analysis

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Parameter estimation is a major concern in hydrological modeling, which may limit the use of complex simulators with a large number of parameters. To support the selection of parameters to include in or exclude from the calibration process, Global Sensitivity Analysis (GSA) is widely applied in modeling practices. Based on the results of GSA, the influential and the non-influential parameters are identified (i.e. parameters screening). Nevertheless, the choice of the screening threshold below which parameters are considered non-influential is a critical issue, which has recently received more attention in GSA literature.
In theory, the sensitivity index of a non-influential parameter has a value of zero. However, since numerical approximations, rather than analytical solutions, are utilized in GSA methods to calculate the sensitivity indices, small but non-zero indices may be obtained for the indices of non-influential parameters. In order to assess the threshold that identifies non-influential parameters in GSA methods, we propose to calculate the sensitivity index of a "dummy parameter". This dummy parameter has no influence on the model output, but will have a non-zero sensitivity index, representing the error due to the numerical approximation. Hence, the parameters whose indices are above the sensitivity index of the dummy parameter can be classified as influential, whereas the parameters whose indices are below this index are within the range of the numerical error and should be considered as non-influential.
To demonstrated the effectiveness of the proposed "dummy parameter approach", 26 parameters of a Soil and Water Assessment Tool (SWAT) model are selected to be analyzed and screened, using the variance-based Sobol' and moment-independent PAWN methods. The sensitivity index of the dummy parameter is calculated from sampled data, without changing the model equations. Moreover, the calculation does not even require additional model evaluations for the Sobol' method. A formal statistical test validates these parameter screening results. Based on the dummy parameter screening, 11 model parameters are identified as influential. Therefore, it can be denoted that the "dummy parameter approach" can facilitate the parameter screening process and provide guidance for GSA users to define a screening-threshold, with only limited additional resources.

Key words: Parameter screening, Global sensitivity analysis, Dummy parameter, Variance-based method, Moment-independent method

Figuur 14 – De titelpagina van de mondelinge presentatie op EGU2017

2.4 Samenwerking met dr. Tanja de Boer-Euser (TU Delft) en Laurène Bouaziz (Deltares, TU Delft)

Naar aanleiding van het “2nd symposium on the hydrological modelling of the Meuse” werd een studie opgestart onder leiding van Tanja de Boer-Euser (TU Delft) en Laurène Bouaziz (Deltares, TU Delft), waarbij de hydrologische simulatoren die door verschillende instanties gebruikt worden met elkaar vergeleken werden voor enkele subbekkens van de Maas. Het doel hiervan was om het gedrag van verschillende processen binnen verschillende simulatoren te evalueren en meer inzicht te krijgen op model structuur onzekerheden. De eerste resultaten van deze studie werden gepresenteerd op de European Geosciences Union General Assembly van 2016 (EGU2016) aan de hand van een abstract (Figuur 15):

> Bouaziz, L., de Boer-Euser, T., Brauer, C., Drogue, G., Fenicia, F., Grelier, B., de Niel, J., Nossent, J., Pereira, F., Savenije, H., Thirel, G. and Willems, P. (2016) Looking beyond general metrics for model evaluation: lessons from an international model intercomparison study. Geophysical Research Abstracts, Vol. 18, Vienna, Austria

In 2017 resulteerde deze samenwerking ook in een A1-publicatie in “Hydrology and Earth System Sciences” (Figuur 16):

> de Boer-Euser, T., Bouaziz, L., de Niel, J., Brauer, C., Dewals, B., Drogue, G., Fenicia, F., Grelier, B., Nossent, J., Pereira, F., Savenije, H., Thirel, G. and Willems, P. (2017) Looking beyond general metrics for model comparison – lessons from an international model intercomparison study. Hydrology and Earth System Sciences, 21, 423-440. doi:10.5194/hess-21-423-2017

Binnenkort vindt de 4de editie van het “symposium on the hydrological modelling of the Meuse” plaats en komt er mogelijk een vervolg op deze studie. Voorlopig staat deze samenwerking echter “on-hold”.

Figuur 15 – Het abstract (Bouaziz et al., 2016) voor EGU2016

Geophysical Research Abstracts
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EGU General Assembly 2016

Looking beyond general metrics for model evaluation - lessons from an international model intercomparison study

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International collaboration between institutes and universities is a promising way to reach consensus on hydrological model development. Education, experience and expert knowledge of the hydrological community have resulted in the development of a great variety of model concepts, calibration methods and analysis techniques. Although comparison studies are very valuable for international cooperation, they do often not lead to very clear new insights regarding the relevance of the modelled processes. We hypothesise that this is partly caused by model complexity and the used comparison methods, which focus on a good overall performance instead of focusing on specific events. We propose an approach that focuses on the evaluation of specific events. Eight international research groups calibrated their model for the Ourthe catchment in Belgium (1607 km2) and carried out a validation in time for the Ourthe (i.e. on two different periods, one of them on a blind mode for the modellers) and a validation in space for nested and neighbouring catchments of the Meuse in a completely blind mode. For each model, the same protocol was followed and an ensemble of best performing parameter sets was selected. Signatures were first used to assess model performances in the different catchments during validation. Comparison of the models was then followed by evaluation of selected events, which include: low flows, high flows and the transition from low to high flows. While the models show rather similar performances based on general metrics (i.e. Nash-Sutcliffe Efficiency), clear differences can be observed for specific events. While most models are able to simulate high flows well, large differences are observed during low flows and in the ability to capture the first peaks after drier months. The transferability of model parameters to neighbouring and nested catchments is assessed as an additional measure in the model evaluation. This suggested approach helps to select, among competing model alternatives, the most suitable model for a specific purpose.

Figuur 16 – De eerste pagina van (de Boer-Euser et al., 2017) in Hydrology and Earth System Sciences

Hydrol. Earth Syst. Sci., 21, 423–440, 2017
www.hydrol-earth-syst-sci.net/21/423/2017/
doi:10.5194/hess-21-423-2017

Hydrology and Earth System Sciences
Open Access

Looking beyond general metrics for model comparison – lessons from an international model intercomparison study

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Abstract. International collaboration between research institutes and universities is a promising way to reach consensus on hydrological model development. Although model comparison studies are very valuable for international cooperation, they do often not lead to very clear new insights regarding the relevance of the modelled processes. We hypothesise that this is partly caused by model complexity and the comparison methods used, which focus too much on a good overall performance instead of focusing on a variety of specific events. In this study, we use an approach that focuses on the evaluation of specific events and characteristics. Eight international research groups calibrated their hourly model on the Ourthe catchment in Belgium and carried out a validation in time for the Ourthe catchment and a validation in space for nested and neighbouring catchments. The same protocol was followed for each model and an ensemble of best-performing parameter sets was selected. Although the models showed similar performances based on general metrics (i.e. the Nash–Sutcliffe efficiency), clear differences could be observed for specific events. We analysed the hydrographs of these specific events and conducted three types of statistical analyses on the entire time series: cumulative discharges, empirical extreme value distribution of the peak flows and flow duration curves for low flows. The results illustrate the relevance of including a very quick flow reservoir preceding the root zone storage to model peaks during low flows and including a slow reservoir in parallel with the fast reservoir to model the recession for the studied catchments. This intercomparison enhanced the understanding of the hydrological functioning of the catchment, in particular for low flows, and enabled to identify present knowledge gaps for other parts of the hydrograph. Above all, it helped to evaluate each model against a set of alternative models.

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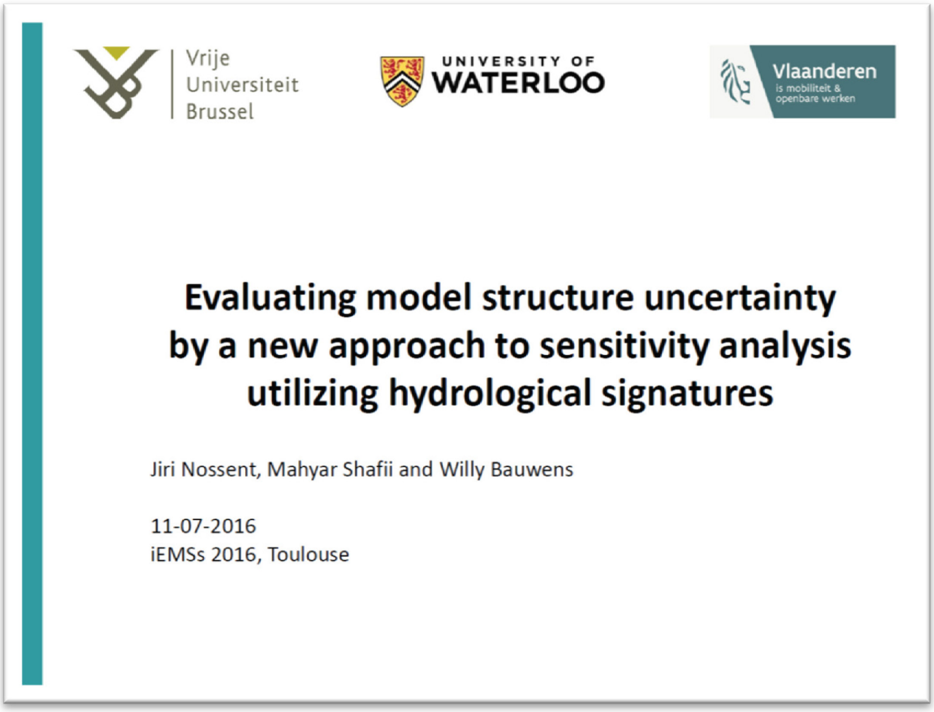
2.5 Samenwerking met dr. Mahyar Shafii (University of Waterloo)

Een samenwerking uit het verleden met dr. Mahyar Shafii (University of Waterloo, toen nog VUB) werd de voorbije jaren nieuw leven in geblazen. De focus van deze samenwerking ligt bij het begrijpen en verminderen van model structuur onzekerheid op basis van zogenaamde "signatures". Deze laatste zijn een soort van objectieffuncties die het hydrologisch gedrag beschrijven, maar niet samenvatten in een scalaire score. Dit onderzoek leverde reeds een abstract (Figuur 18) en presentatie (Figuur 17) op de "8th International Congress on Environmental Modelling and Software" in 2016 (iEMSs2016) in Toulouse:

> Nossent, J., Shafii, M., and Bauwens, W. (2016) Evaluating model structure uncertainty by a new approach to sensitivity analysis utilizing hydrological signatures. In: Sauvage, S., Sánchez-Pérez, J-M., Rizzoli, A.E. (Eds.), Proceedings of the 8th International Congress on Environmental Modelling and Software, June 10-14, Toulouse, France

Het doel is om dit onderzoek verder uit te bouwen en te werken aan een of meerdere A1-publicaties, maar door de drukke agenda van beide partijen staat dit momenteel "on-hold".

Figuur 17 – De titelpagina van de mondelinge presentatie op iEMSs2016



Figuur 18 – Het abstract (Nossent et al., 2016) voor iEMSs2016

International Environmental Modelling and Software Society (iEMSs)
8th International Congress on Environmental Modelling and Software
Toulouse, France, Sabine Sauvage, José-Miguel Sánchez-Pérez, Andrea Rizzoli (Eds.)
http://www.iemss.org/society/index.php/iemss-2016-proceedings

Evaluating model structure uncertainty by a new approach to sensitivity analysis utilizing hydrological signatures

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Abstract: Model structure uncertainty is one of the most significant sources of uncertainty in traditional hydrological modelling and, above all, challenging to quantify. Structurally flexible models have recently become very popular in hydrology as they tend to allow a reduction of this uncertainty due to their flexibility in the mathematical representation of the hydrological response of a catchment. Reducing structural uncertainty within the flexible framework requires identifying (using top-down or bottom-up approaches) the most suitable (hydrologically consistent) model structure for a given watershed. To assess the models' hydrological consistency, diagnostic model evaluation techniques are employed to test their capability of reproducing the watershed's behavior, quantified utilizing hydrological signatures (e.g. flow duration curves). Among other evaluation approaches to balance model complexity is sensitivity analysis, which is traditionally conducted with respect to one or multiple summary statistics quantifying the goodness-of-fit between the time series of model simulations and observations.

In this study, we develop a novel sensitivity analysis approach based on Sobol' SA, utilizing multiple hydrological signatures that are useful to constrain model outcomes. Our hypothesis is that the extra information provided by signatures would facilitate a more comprehensive evaluation of the model parameterization compared to the traditional sensitivity analysis using time series-focused aggregate summary statistics. In addition, the systematic application of the sensitivity analysis to groups of parameters which are linked to certain model structures could assist in the identification of the most suitable and consistent structure. To test these hypotheses, the proposed signature-based sensitivity analysis, as well as the traditional approach are applied to a range of model structures developed within a computationally efficient and flexible hydrological modelling framework called RAVEN. The main objective of the numerical experiments in this study is to demonstrate the applicability of the proposed sensitivity analysis approach in view of the model structure selection and, thus, the model structure uncertainty reduction.

Keywords: Model structure uncertainty; Flexible hydrological modelling; Hydrological signatures; Sensitivity analysis

2.6 Samenwerking met dr. Christian Anibas (VUB)

In het kader van een studie van dr. Christian Anibas (VUB) rond oppervlaktewater-grondwater-interactie, werd mijn expertise in statistiek aangewend voor het analyseren van verschillende experimenten en bijhorende modelresultaten. Naast een A1-publicatie die binnenkort gepubliceerd zal worden (zie sectie 3.3), leidde deze samenwerking dit jaar ook tot een abstract (Figuur 19) op de European Geosciences Union General Assembly (EGU2017):

> Anibas, C., Tolche, A., Ghysels, G., Schneidewind, U., Nossent, J., Touhidul Mustafa, S.M., Huysmans, M, and Batelaan, O. (2017) Investigating temporal and spatial patterns of groundwater-surface water interaction on a river reach by applying transient thermal modelling. Geophysical Research Abstracts, Vol. 19, Vienna, Austria

Figuur 19 – Het abstract (Anibas et al., 2017) voor EGU2017

Geophysical Research Abstracts
Vol. 19, EGU2017-6783, 2017
EGU General Assembly 2017

Investigating temporal and spatial patterns of groundwater-surface water interaction on a river reach by applying transient thermal modelling

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The quantification of groundwater-surface water interaction is an important challenge for hydrologists and ecologists. Within the last decade, many new analytical and numerical estimation methods have been developed, including heat tracer techniques. In a number of publications, their sources of errors were investigated, and future directions for the research in groundwater-surface water exchange were discussed. To improve our respective knowledge of the Belgian lowland Aa River we reinvestigate temperature data which was gathered in the river bed and used for the quantification of the 1D vertical groundwater-surface water exchange. By assuming a thermal steady state of the river bed temperature distribution, Anibas et al. (2011) were unable to use the full potential of the entire large data set. The analysis tool STRIVE is modified to use the river water temperature time series as the upper model boundary. This transient thermal set up overcomes many of the limitations of the steady state assumption and allows for the analysis of vertical 1D exchange fluxes in space and time. Results of about 380 transient simulations covering a period of more than 1.5 years show high absolute changes in exchange fluxes in the upstream part of the river. However, in the downstream part, the relative changes in fluxes are larger. The 26 spatially distributed thermal profiles along the river reach are interpolated using kriging based on variograms calculated from the temperature dataset. Results indicate gaining conditions for most locations and most of the time. Few places in the downstream part show losing conditions in late winter and early spring. While in autumn and winter the mean exchange fluxes can be -90 mmd^{-1}, in spring to early summer fluxes are only -42 mmd^{-1}. The river bed near the banks shows elevated fluxes compared to the center of the river. Probably driven by regional groundwater flow, the river bed near the left and right bank shows fluxes respectively a factor 3 and 2 higher than at the center of the river. The transient model allows for the calculation of model quality (like the RMSE) and can be used for data sets collected at any time during the year. The flux results represent integrations over the simulated period (i.e. weeks or month); short time changes in groundwater-surface water interaction cannot be estimated. With the adapted STRIVE model, future research can focus on the role of heterogeneity of the riverbed and better integration of riverbed parameters like hydraulic and thermal conductivities.

2.7 Samenwerking met Pieter Meert (KUL)

Pieter Meert werkt als doctoraatstudent aan de KUL en is een van de medewerkers van project 00_131 “Ontwikkeling van conceptuele modellen”. Een van de deelopdrachten van dit project is het inschatten van de onzekerheden voor het deel waterkwantiteit. Gezien mijn expertise in dit veld werd er bij het onderzoek voor dit topic dan ook samengewerkt. Dit resulteerde in een abstract (Figuur 20) op de European Geosciences Union General Assembly (EGU2017):

> Meert, P., Nossent, J., Pereira, F. and Willems, P. (2017) Decomposing river model output uncertainty in its contributing sources: a Belgian case study. Geophysical Research Abstracts, Vol. 19, Vienna, Austria

Verder zal er in het kader van deze samenwerking binnenkort ook een A1-publicatie verschijnen (zie 3.4).

Figuur 20 – Het abstract (Meert et al., 2017) voor EGU2017

Geophysical Research Abstracts
Vol. 19, EGU2017-12860, 2017
EGU General Assembly 2017

Decomposing river model output uncertainty in its contributing sources: a Belgian case study

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The use of hydrologic and hydrodynamic models in flood forecasting systems is inevitably connected with the existence of errors and uncertainties. These uncertainties are often significant and should be recognized in any modelling application. Assessing the degree of uncertainty, its impact on model results and a decomposition in its major contributing sources is therefore critically important. This delivers decision makers additional information on model accuracy, on the relative importance of individual uncertainty sources and, hence, also on efficient approaches to reduce the total model output uncertainty.

In this paper, we demonstrate a data-based approach for uncertainty quantification and decomposition of river model outputs on a case study of the Belgian river Dender. Model input and model parameter uncertainties are assessed by comparing model results for uncertain inputs and parameters with historical observations or are based on expert elicitation. These uncertainties are subsequently propagated through the model, based on a Latin Hypercube Sampling procedure, to quantify the impact at locations of interest. The total model output uncertainty is separated in bias and variance components of all quantifiable error sources and a rest term uncertainty component that lumps the remaining unquantifiable and secondary error sources.

Performing a detailed uncertainty analysis within a tolerable timeframe is virtually impossible with a detailed full hydrodynamic river model. Instead, a grey-box model, based on a concatenation of reservoir elements, is used. This grey-box model succeeds in accurately reproducing the detailed model results, with an important reduction of computational burden.

The uncertainty decomposition results show that the relative importance of each uncertainty source is far from constant. The bias and variance contributions were found to vary over the range of modelled water levels and discharges, but they also differ spatially and for each model output type (water levels vs. discharges). The results of this uncertainty analysis and decomposition provide the modeler valuable insights on the system under study.

2.8 Samenwerking met Syed Md. Touhidul Mustafa (VUB)

In het kader van zijn onderzoek naar droogte door overmatig gebruik van grondwater, was Syed Md. Touhidul Mustafa (doctoraatstudent aan de vakgroep HYDR van de VUB) op zoek naar een methode om onzekerheidsanalyse toe te passen op de resultaten van zijn grondwatermodel. Het is dan ook op dit vlak dat ik mijn inbreng heb bij zijn onderzoek. Dit jaar verscheen reeds een abstract (Figuur 21) op de European Geosciences Union General Assembly (EGU2017):

> Touhidul Mustafa, S.M., Nossent, J., Ghysels, G. and Huysmans, M. (2017) Estimation and impact assessment of input and parameter uncertainty in predicting groundwater flow with a fully distributed model. Geophysical Research Abstracts, Vol. 19, Vienna, Austria

Deze samenwerking loopt momenteel ook nog verder (zie sectie 3.5), met onder andere het afwerken van een A1-publicatie.

Figuur 21 – Het abstract (Mustafa et al., 2017) voor EGU2017

Geophysical Research Abstracts
Vol. 19, EGU2017-8658, 2017
EGU General Assembly 2017

Estimation and impact assessment of input and parameter uncertainty in predicting groundwater flow with a fully distributed model

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Transient numerical groundwater flow models have been used to understand and forecast groundwater flow systems under anthropogenic and climatic effects, but the reliability of the predictions is strongly influenced by different sources of uncertainty. Hence, researchers in hydrological sciences are developing and applying methods for uncertainty quantification. Nevertheless, spatially distributed flow models pose significant challenges for parameter and spatially distributed input estimation and uncertainty quantification. In this study, we present a general and flexible approach for input and parameter estimation and uncertainty analysis of groundwater models. The proposed approach combines a fully distributed groundwater flow model (MODFLOW) with the DiffeRential Evolution Adaptive Metropolis (DREAM) algorithm. To avoid over-parameterization, the uncertainty of the spatially distributed model input has been represented by multipliers. The posterior distributions of these multipliers and the regular model parameters were estimated using DREAM. The proposed methodology has been applied in an overexploited aquifer in Bangladesh where groundwater pumping and recharge data are highly uncertain. The results confirm that input uncertainty does have a considerable effect on the model predictions and parameter distributions. Additionally, our approach also provides a new way to optimize the spatially distributed recharge and pumping data along with the parameter values under uncertain input conditions. It can be concluded from our approach that considering model input uncertainty along with parameter uncertainty is important for obtaining realistic model predictions and a correct estimation of the uncertainty bounds.

2.9 Samenwerking met Celray James Chawanda (VUB)

Gedurende het academiejaar 2015-2016 werkte Celray James Chawanda aan een MSc-thesis rond "Baseflow Separation Tools" (op het WL gekend als tools voor het "splitsen in deelstromen"). Gezien de sterke link met de gebruikelijke "algemene methodologie" voor het optimaliseren van hydrologische modellen op het WL, begeleidde ik deze thesis. Sinds eind 2016 is Celray James Chawanda doctoraatstudent aan de vakgroep HYDR van de VUB en is het de bedoeling om de resultaten van de thesis te valoriseren. Dit leidde dit jaar tot een abstract (Figuur 22) en bijhorende poster (Figuur 23) op de European Geosciences Union General Assembly (EGU2017):

> Chawanda, C.J., Nossent, J. and Bauwens, W. (2017) Baseflow Seperation Tools; What do they really do? Geophysical Research Abstracts, Vol. 19, Vienna, Austria

De huidige stand van zaken in deze samenwerking wordt verder beschreven in sectie 3.6.

Figuur 22 – Het abstract (Chawanda et al., 2017) voor EGU2017

Geophysical Research Abstracts
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EGU General Assembly 2017
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Baseflow Separation Tools; What do they really do?

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Baseflow separation plays a major role in calculation of runoff coefficients and in the component-wise calibration of hydrologic models. The tools which are used in separating baseflow are based on various assumptions which may not be fully met across various catchments. When used in the cases where the hypotheses behind their operation are not fully met, what will the tools do? This study investigated the performance of selected baseflow separation tools if some of the assumptions on which they were based are not met. Different natures of catchments were represented by models created in a flexible modelling platform, SUPERFLEX. Flow time series for the base flow component, the quick flow component and the total discharge were generated from the models at daily and hourly time step. Three baseflow separation tools, namely; the BFI tool, the SWAT baseflow separation tool and WETSPRO, were used to filter baseflow from the total discharge time series and the filtered baseflow was compared to the original baseflow from the model. The results show that the assumption of exponential recession holds true across a wide range of catchment structures. Thus, WETSPRO provides better estimates of baseflow in a wider range of catchments. It was also shown that the assumptions behind the SWAT baseflow separation tool, and hence performance, heavily depend on the time step of the discharge time series. The BFI was found to mostly overestimate the baseflow during wet periods when used in most catchments although modifying the block size improved its performance.

Keywords: SUPERFLEX, SWAT, WETSPRO, BFI.

Figuur 23 – Het eerste deel van de poster van Celray James Chawanda op EGU2017

VRIJE UNIVERSITEIT BRUSSEL

Baseflow separation tools: what do they really do?

Celray James CHAWANDA[1], Jiri NOSSENT[2,1] and Willy BAUWENS[1]
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[2]Flanders Hydraulics Research, Antwerp, Belgium

3 Lopend onderzoek

3.1 Persoonlijk onderzoek

3.1.1 Initiële onderzoekslijn 1

Het onderzoek in het kader van de “Regionalisatie van parameters van een hydrologisch model” loopt momenteel nog steeds verder. Naast het werk dat reeds verricht werd met bekkens uit de MOPEX-dataset uit de VS, is gelijklopend met WL project 14_080 (“Update en inventarisatie van de hydrologische modellen”) al een grote hoeveelheid informatie verzameld over Vlaamse hydrologische bekkens.

De huidige stand van zaken van dit onderzoek wordt momenteel samengevat in een memo (Figuur 24) die voor het einde van dit project afgewerkt zal worden. Deze zal ook voorgelegd worden aan de partner in dit onderzoek, prof. Jasper A. Vrugt (University of California).

Het doel is om ook in de toekomst nog verder te werken aan dit onderzoek en een aantal A1-publicaties te schrijven, bv.

> Nossent, J., Vrugt, J.A. and Bauwens, W. (201?) Enhanced parameter regionalization from improved treatment of modeling uncertainty. Water Resources Research

Figuur 24 – Het eerste deel van de memo rond onderzoekslijn 1

Memo

//

Titel: Preliminary work and results on regionalization

Datum: 30/08/2017

Auteurs: Nossent, Jiri

Ref.: WL2017M14_063_1

//

Preliminary work and results on regionalization

Cooperation Jasper Vrugt, University of California, Irvine (UCI)

In January 2013, a short visit at the research group of Prof. Jasper Vrugt at UCI, initiated an informal research collaboration between the Department of Civil and Environmental Engineering at UCI and the Department of Hydrology & Hydraulic Engineering at VUB, in the field of uncertainty analysis. The specific research question that we are trying to solve can be formulated as follows:

Is it possible to improve the regionalization of hydrological model parameters over different catchments, by taking into account the full model error structure?

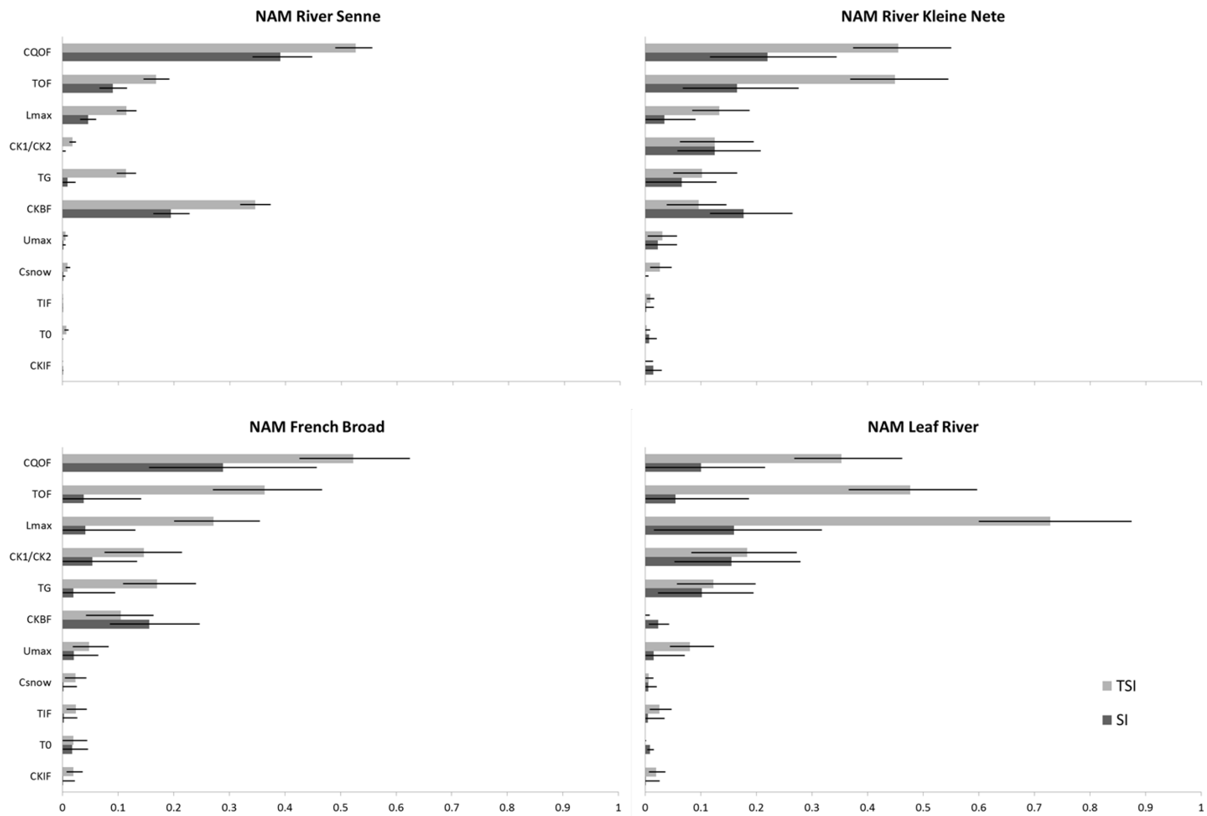
This work has been re-initiated at Flanders Hydraulics Research in view research project 14_063. This memo provides an overview of the work that has been done so far and the preliminary results obtained. In a first section, the employed dataset and the data analysis procedure will be presented. In a second section, the methodology and the preliminary regionalization results will be discussed. The third section discusses the additional data that has been collected for Flanders so far and finally, an outlook for future work will be given.

3.1.2 Initiële onderzoekslijn 2

Het eigenlijke onderzoek rond “Belangrijkheid van input voor de output van hydrologische modellen” is grotendeels afgewerkt. Nieuwe ideeën rond dit topic zijn in de toekomst zeker nog mogelijk, maar momenteel wordt deze onderzoekslijn afgerond. Dit wordt geconcretiseerd door het schrijven van een A1-publicatie (Figuur 25) die voor het einde van dit project zal ingediend worden:

> Nossent, J., Pereira, F. and Bauwens, W. (2017) Are the driving forces of hydrological models really driving the model output? Assessing the importance of rainfall uncertainty on hydrological models. Environmental Modelling & Software

Figuur 25 – Figuur uit de A1-publicatie over onderzoekslijn 2



3.1.3 Algemeen

Door de keuze die gemaakt werd om voor het onderzoek in het kader van project 14_063 samenwerkingen aan te gaan (rond de geformuleerde thema’s), zijn de initiële onderzoekslijnen nog niet volledig afgewerkt. Zeker voor wat betreft onderzoekslijn 1 was er bij volledige focus op dit onderwerp meer vooruitgang mogelijk geweest. Daarentegen is de vooruitgang voor onderzoekslijn 2 bevredigend, gezien het eigenlijke onderzoek hiervan afegrond is en zal gevaloriseerd worden met een A1-publicatie.

3.2 Samenwerking met Farkhondeh Khorashadi Zadeh (VUB)

Farkhondeh Khorashadi Zadeh werkt momenteel aan twee bijkomende onderzoekslijnen rond gevoeligheids en onzekerheidsanalyse waarbij ik haar adviseer. Uiteindelijk is het doel hiervan om nog twee A1-publicaties hierover te schrijven.

Verder werken we samen rond het optimaliseren van de convergentie van de Sobol' sensitiviteits analyse in combinatie met het gebruik van een dummy parameter. Dit onderzoek combineert twee aspecten waarrond we eerder al werkten:

Nossent, J. and Bauwens, W. (2012) Optimising the convergence of a Sobol' sensitivity analysis for an environmental model: application of an appropriate estimate for the square of the expectation value and the total variance; International Environmental Modelling and Software Society (iEMSs), 2012 International Congress on Environmental Modelling and Software, Managing Resources of a Limited Planet: Pathways and Visions under Uncertainty, Sixth Biennial Meeting, Leipzig, Germany, 1 - 5 July 2012. Eds.: R. Seppelt, A.A. Voinov, S. Lange, D. Bankamp.
http://www.iemss.org/society/index.php/iemss-2012-proceedings ISBN: 978-88-9035-742-8

Zadeh, F.K., Nossent, J., van Griensven, A. and Bauwens, W. (2017) Parameter screening: the use of a dummy parameter to identify non-influential parameters in a global sensitivity analysis. Geophysical Research Abstracts, Vol. 19, Vienna, Austria

Het gebruik van de dummy parameter verklaart deels de resultaten die bekomen werden rond de optimalisatie van de convergentie van de Sobol' sensitiviteits analyse. De gecombineerde analyse zal beschreven worden in een nieuwe A1-publicatie:

Nossent, J., Zadeh, F.K., van Griensven, A. and Bauwens, W. (2017) Optimizing the computations and convergence of a Sobol' sensitivity analysis for an environmental model. Environmental Modelling & Software

3.3 Samenwerking met dr. Christian Anibas (VUB)

De onderzoekssamenwerking met dr. Christian Anibas wordt momenteel afgerond met de publicatie van een A1-paper. Deze werd eerder dit jaar ingediend en kreeg een minor-revision, waarna een geupdate versie werd ingestuurd. Momenteel wachten we op de aanvaarding van de publicatie:

Anibas, C., Tolche, A., Ghysels, G., Nossent, J., Schneidewind, U., Huysmans, M, and Batelaan, O. (2017) Delineation of spatio-temporal patterns of groundwater-surface water interaction along a river reach with transient thermal modelling. Hydrogeology Journal

3.4 Samenwerking met Pieter Meert (KUL)

De onderzoekssamenwerking met Pieter Meert wordt momenteel afgerond met de publicatie van een A1-paper. Deze werd eerder dit jaar ingediend en kreeg al twee maal een major-revision. De tweede revisie werd ook reeds ingediend en momenteel wachten we op de aanvaarding van de publicatie:

> Meert, P., Nossent, J., Pereira, F. and Willems, P. (2017) Data-based approach of uncertainty analysis and decomposition for complex river systems. Journal of Hydrology

3.5 Samenwerking met Syed Md. Touhidul Mustafa (VUB)

Het eerste deel van de onderzoekssamenwerking met Syed Md. Touhidul Mustafa rond onzekerheidsanalyse van een gedistribueerd grondwatermodel wordt momenteel geconcretiseerd door het schrijven van een A1-publicatie:

> Touhidul Mustafa, S.M., Nossent, J., Ghysels, G. and Huysmans, M. (2017) Estimation and impact assessment of input and parameter uncertainty in predicting groundwater flow with a fully distributed model. Water Resources Research

Deze zal waarschijnlijk begin septermber 2017 ingediend worden bij het prestigieuse journal “Water Resources Research”.

Daarnaast wordt ook reeds werk gemaakt van een nieuw onderwerp waarbij met “Bayesian averaging” de bijdrage van verschillende bronnen van onzekerheid bepaald zal worden. Een derde thema waarrond gewerkt wordt is het inschatten van de invloed van klimaatswijzigingen en de onzekerheid op de verschillende scenario’s. Beide onderwerpen moeten uitendelijk tot een A1-publicatie leiden.

3.6 Samenwerking met Celray James Chawanda (VUB)

Momenteel werkt Celray James Chawanda aan een A1-publicatie die de belangrijkste resultaten van zijn MSc thesis bundelt:

> Chawanda, C.J., Nossent, J. and Bauwens, W. (2017) Baseflow Seperation Tools; What do they really do? Journal of Hydrology

Mogelijk worden in de toekomst de resultaten nog verder uitgebreidt.

3.7 Andere samenwerkingen

Ondertussen zijn er ook enkele andere samenwerkingen die in de toekomst vorm kunnen krijgen. Het gaat hier om samenwerkingen met doctorandi van de vakgroep HYDR aan de VUB rond gevoeligheidsanalyse, optimalisatie van modellen en onzekerheidsanalyse. Concreet gaat het om onderzoek in samenwerking met Imeshi Weerasinghe, Sarah Mutua en Ting Tang.

4 Cross-correlatie met WL-projecten

Naast de onderzoekssamenwerkingen die geïnitieerd werden op basis van WL-projecten (Pieter Meert ihkv project 00_131, Celray James Chawanda ihkv project 15_119), was de kennis en expertise die opgedaan is in het kader van dit persoonlijk onderzoek ook al nuttig voor verschillende andere WL-projecten:

- 00_131: de kennis van gevoeligheids- en onzekerheidsanalyse
- 00_162: de kennis over klimaatswijzigingen en hydrologisch modelleren
- 14_080: de kennis rond optimalisatie en onzekerheidsanalyse van hydrologische modellen
- 16_048: de kennis van statistische analyses
- 14_109: de kennis rond optimalisatie en onzekerheidsanalyse van hydrologische modellen
- 14_094: de kennis van statistische analyses en onzekerheidsanalyse

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