17th International Conference on Environmental Science and Technology

Athens, Greece, 1 to 4 September 2021

Uncertainty aspects of 2D flood modelling in a benchmark case study

BELLOS V.[1*] and TSIHRINTZIS V.A[1]

1 Laboratory of Reclamation Works and Water Resources Management, School of Rural and Surveying Engineering, National Technical University of Athens, 9 Iroon Polytechniou str., 15780, Zografou

*corresponding author: e-mail: vmpellos@mail.ntua.gr

Abstract In this study, we investigate the contribution of several uncertainty drivers towards the total uncertainty of a 2D flood model, in a benchmark case study under steady flow conditions. The simulator used for the analysis is the in-house FLOW-R2D software, whilst the benchmark case study consists of a compound trapezoidal channel, which represents the main channel and the floodplains. Unlike the conventional taxonomy of the uncertainty sources (input data, parametric and structural), we define five drivers: a) the forcing driver which consists of the inflow to the computational domain; b) the geometric driver which depends on the topography of the case study; c) the physical driver which incorporates all the parameters required to describe a physical process (such as friction); d) the computational driver which includes the parameters needed for computational reasons (e.g. space step); e) the structural driver which is metric for the weakness of the numerical model to capture an idealized analytical solution or observed data, due to the abstraction from reality. For the quantification of each driver contribution, we present the Uncertainty Index, which is based on the stochastic Monte Carlo technique.

Keywords: flood modelling, uncertainty, Monte Carlo

1. Introduction

Typically, uncertainty sources of numerical models are classified in three groups: a) input data; b) parametric; c) structural. However, there is no clear distinction between all these sources for hydrodynamic models used for flood modelling.

For example, the friction coefficients: if they are drawn from hydraulic handbooks they are considered as input data, but if their grey-box nature is taken into account and they are calibrated, their uncertainty can be considered as parametric.

One more indicative example is the space step used in the simulations. It could be categorized as input data, since the bathymetry of the surface elevation is entered by the user. On the other hand, it could also be categorized as a parameter, from the point of view of a modeler. Finally, its uncertainty could be characterized as structural uncertainty, since the numerical errors added to the results derived by the numerical solution depend on the space step size, and hence, to the grid size selected for the simulation.

Therefore, we propose a modified taxonomy, defining five drivers of uncertainty: a) forcing driver; b) geometric driver; c) physical driver; d) computational driver; and e) structural driver.

The forcing driver consists of the inflow to the computational domain, namely the constant discharge for steady flows or the parameters related to the flood hydrograph for unsteady flows. The geometric driver is the topography of the computational domain. The physical driver consists of the required parameters by the simulator in order to describe a physical process, such as friction or infiltration. The computational driver consists of the parameters required by the simulator for computational reasons, such as the space or time step. Finally, the structural driver are the residuals between observed data or analytical solutions (if they exist) and the corresponding numerical results, due to the fact that a numerical model is an abstract from reality.

2. Material and methods

2.1. Benchmark case study

In order to perform our analysis, we create a synthetic computational domain with a size of 1000 x 2000 m, which has the form depicted in Figure 1. One of the advantages of this topography is the analogy between this benchmark and a real-world case study, namely the main channel and the floodplains. Besides, in this benchmark we can derive an analytical solution for the water depths, based on Manning equation. Therefore, the structural driver can be estimated.

2.1. FLOW-R2D software

FLOW-R2D software (Tsakiris and Bellos, 2014) is a numerical solver of the full form of 2D Shallow Water Equations, based on Finite Difference Method and McCormack numerical scheme. It has been used in several case studies, including urban environments and pluvial flooding (Bellos et al., 2020a).

3. Uncertainty analysis

3.1. Total uncertainty

For the quantification of uncertainty, Monte Carlo methodology is used (Dimitriadis et al., 2016; Tscheikner-Gratl et al., 2019). Due to the computational burden, a preliminary Morris-based sensitivity analysis is performed in order to select the most influential components, in respect with the metric selected, namely the water depths along the main channel and the floodplains (Table 1).

Table 1. Components used for the total uncertainty quantification

Component	Range	Units	Driver
Discharge	100-900	m^3/s	Forcing
Main channel slope	0.2-2	%	Geometric
Main channel width	100-300	m	Geometric
Bank height	0.5-1.5	m	Geometric
Manning friction coefficient in the main channel	0.02-0.1	$s/m^{1/3}$	Physical
Manning friction coefficient in the floodplains	0.05-0.2	$s/m^{1/3}$	Physical
Upstream boundary condition parameter	0.3-0.7	-	Computational

The rest of the components which have minor impact on the selected metrics are: a) space step (5-25 m); b) floodplains slope (0.5-2 %); c) diffusion factor used for numerical stability (0.90-0.92).

For the total uncertainty quantification, 2000 simulations were implemented drawing values from the ranges of Table 1. The sampling is performed assuming uniform distribution (Latin Hypercube Sampling). For the rest 3 components, we selected the average values in between the above ranges. The uncertainty bands of the water depth profiles for both main channel and floodplains are depicted at Figure 2. Figure 2 also shows the empirical distribution of the water depths and the fitting performed using the Weibull distribution, in indicative positions.

3.1. Uncertainty drivers

For the uncertainty quantification of each driver, 500 simulations were implemented for each driver, drawing values from the pre-specified ranges. For each set of runs, the rest of the variables are taken equal to the average of their range. For the computational driver, space step is also included in the analysis.

For the structural driver, the dataset derived for defining the total uncertainty is used. The statistical analysis is performed with the residuals $|h_{model} - h_{analytical}|$, where h_{model} is the water depth derived by the model and $h_{analytical}$ is the water depth calculated using Manning's equation.

The Uncertainty Index (UI) for each driver or a group of components can be calculated as the ratio of the variance of the driver divided by the variance of the total uncertainty.

$$UI = \frac{\mathrm{var}(driver)}{\mathrm{var}(total)} \tag{1}$$

The *UI* for each driver, across the main channel and the floodplains, for both empirical and Weibull distributions are depicted in Figures 4 and 5.

3. Discussion and concluding remarks

The findings can be summarized in the following points:

- A skewness is observed in the empirical distribution for both main channel and floodplain water depth. Therefore, a fitting distribution such as Weibull seems to be a proper choice and it is according to the bibliography (Bellos et al. 2020b).
- For the main channel, the most crucial drivers are the geometric and the forcing drivers, following the physical driver. Computational and structural drivers seem to have negligible impact, except the areas near the upstream and downstream boundaries.
- For the floodplains, the picture is the same, except from the structural driver, which has more impact than the corresponding impact observed in the main channel.
- Since the geometric parameters cover a wide range of topographies and taking into account that for a specific area the terrain model uncertainties are much smaller, forcing driver seems to be the more crucial factor, regarding the uncertainty observed to the water depths.
- The physical driver is also important, since these parameters are also characterized by uncertainties, especially in the case there are no observed data, and therefore, they cannot be calibrated.
- The structural driver seems to have impact in floodplains. A further investigation is required in order to identify if is solver's issue or is a global conclusion.

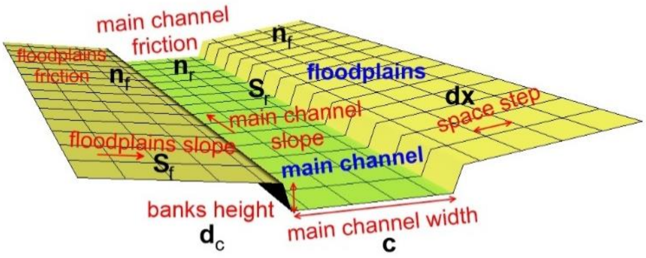

Figure 1. Benchmark case study

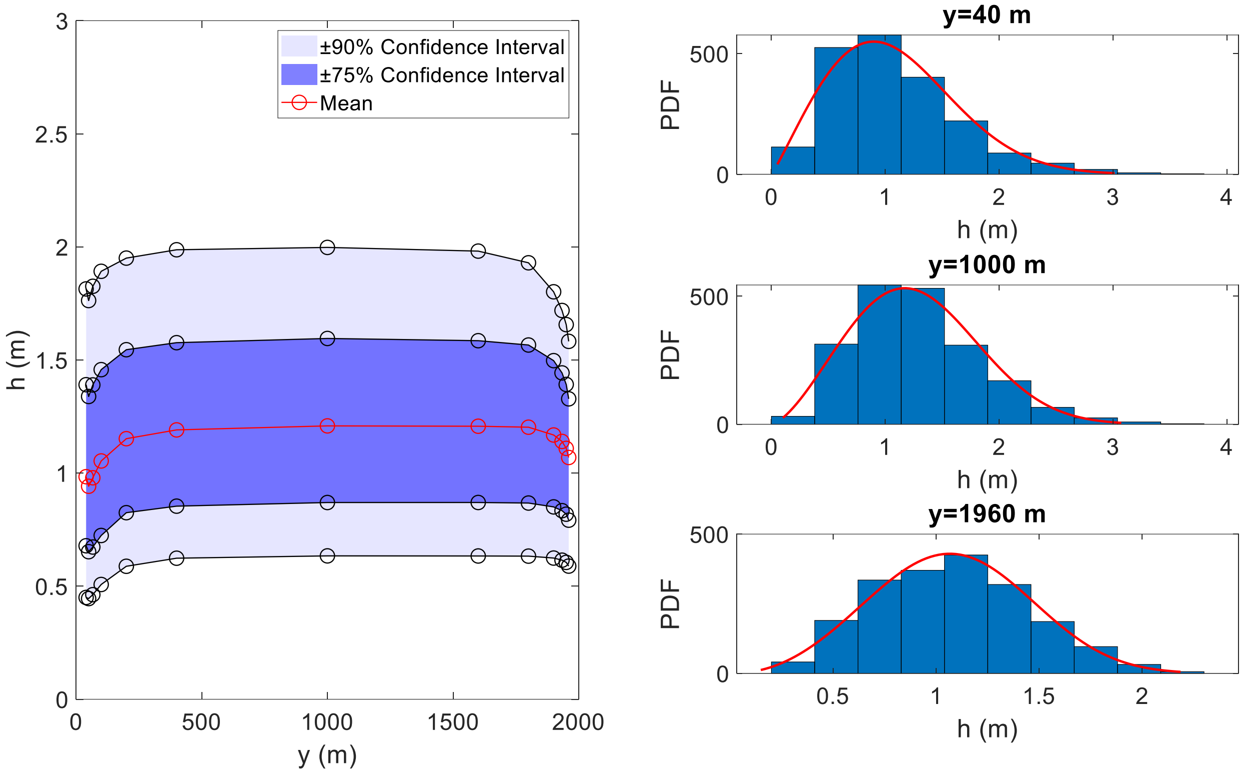

Figure 2. Uncertainty band for several confidence intervals of water depths along the main channel (left); empirical and Weibull distributions of water depths in three indicative positions along the main channel (right)

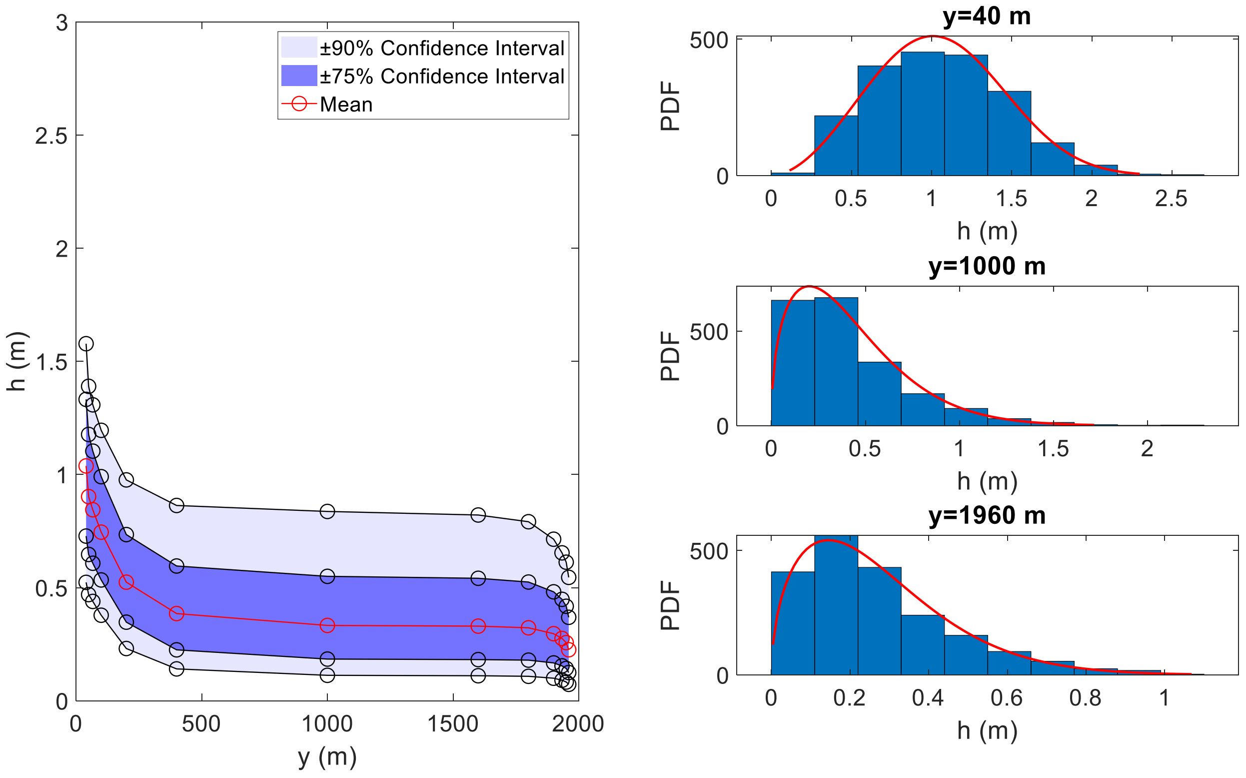

Figure 3. Uncertainty band for several confidence intervals of water depths along the floodplains (left); empirical and Weibull distributions of water depths in three indicative positions along the main channel (right)

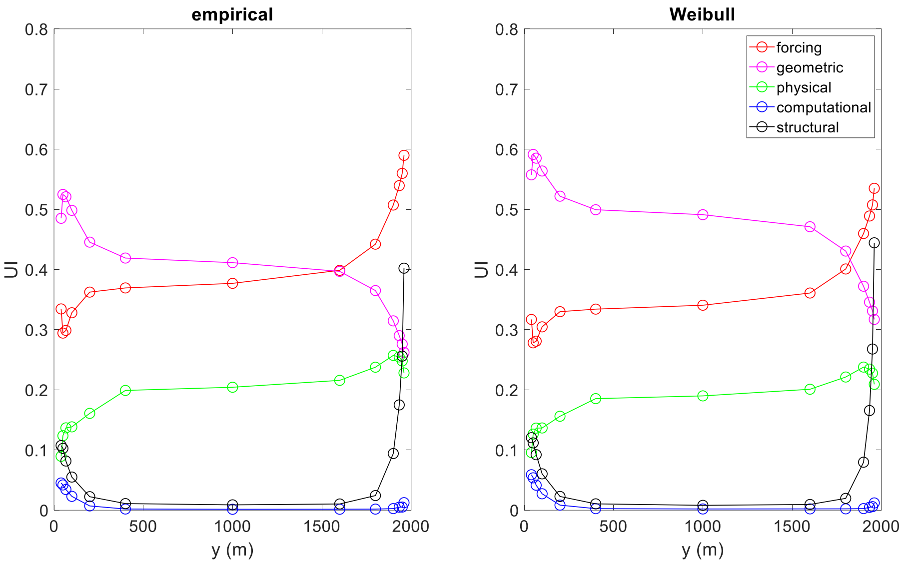

Figure 4. Uncertainty Index derived by empirical (left) and Weibull distributions (right) along the main channel

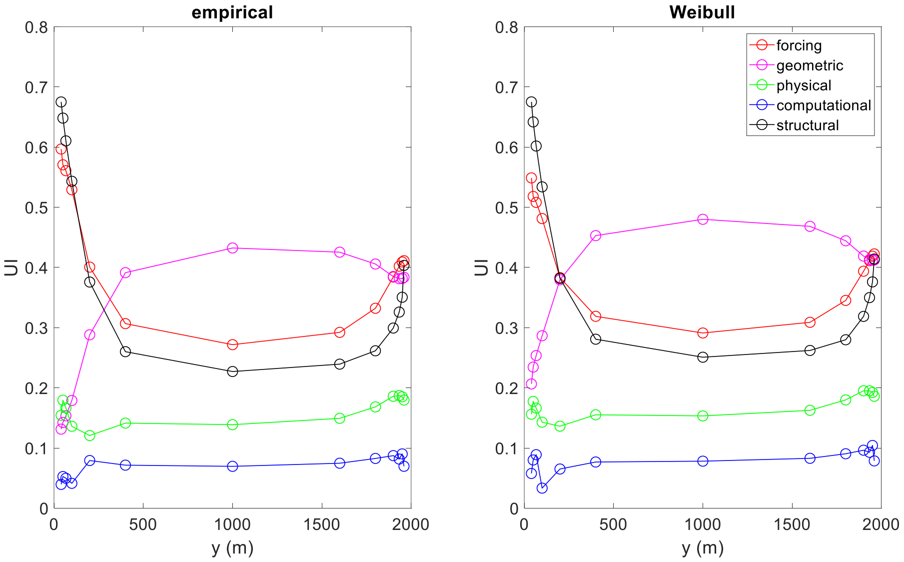

Figure 5. Uncertainty Index derived by empirical (left) and Weibull distributions (right) along the floodplains

Acknowledgments

This postdoctoral research is co-financed by Greece and the European Union (European Social Fund - ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project “Reinforcement of Postdoctoral Researchers − 2nd Cycle” (MIS-5033021), implemented by the State Scholarships Foundation (IKY).

References

Bellos, V., Papageorgaki, I., Kourtis, I., Vangelis, H., Kalogiros, I., Tsakiris, G. (2020a), Reconstruction of a flash flood event using a 2D hydrodynamic model under spatial and temporal variability of storm, *Natural Hazards*, **101(3)**, 711-726.

Bellos, V., Tsakiris, V.K., Kopsiaftis, G., Tsakiris, G. (2020b), Propagating dam breach parametric uncertainty in a river reach using the HEC-RAS software, *Hydrology*, **7(4)**, 72.

Dimitriadis, P., Tegos, A., Oikonomou, A., Pagana, V., Koukouvinos, A., Mamassis, N., Koutsoyiannis, D., Efstratiadis, A. (2016), Comparative evaluation of 1D and quasi-2D hydraulic models based on benchmark and real-world applications for uncertainty assessment in flood mapping, *Journal of Hydrology*, **534**, 478-492.

Tsakiris, G. and Bellos, V. (2014), A numerical model for two-dimensional flood routing in complex terrains, *Water Resources Management*, **28(5)**, 1277-1291.

Tscheikner-Gratl, F., Bellos, V., Schellart, A., Moreno-Rodenas, A., Muthusamy, M. Langeveld, J., Clemens, F., Benedetti, L., Rico-Ramirez, M.A., Carvalho, R.F., Breuer, L., Shucksmithc, J., Heuvelink, G., Tait, S. (2019), Recent insights on uncertainties present in integrated catchment water quality modelling, *Water Research*, **150(1)**, 368-379.