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Uncertainty in the calibration of effective roughness parameters in HEC-RAS using inundation and downstream level observations

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Abstract

An uncertainty analysis of the unsteady flow component (UNET) of the one-dimensional model HEC-RAS within the generalised likelihood uncertainty estimation (GLUE) is presented. For this, the model performance of runs with different sets of Manning roughness coefficients, chosen from a range between 0.001 and 0.9, are compared to inundation data and an outflow hydrograph. The influence of variation in the weighting coefficient of the numerical scheme is also investigated. For the latter, the empirical results show no advantage of using values below 1 and suggest the use of a fully implicit scheme (weighting parameter equals 1). The results of varying the reach scale roughnesses shows that many parameter sets can perform equally well (problem of equifinality) even with extreme values. However, this depends on the model region and boundary conditions. The necessity to distinguish between effective parameters and real physical parameters is emphasised. The study demonstrates that this analysis can be used to produce dynamic probability maps of flooding during an event and can be linked to a stopping criterion for GLUE.

Keywords: GLUE; HEC-RAS; Uncertainty; Flood; Roughness; Inundation

1. Introduction

One-dimensional (1D) flow routing approaches such as Mike 11, ISIS or HEC, based on the St. Venant/Shallow Water Equations or variations, still form the majority of traditional numerical hydraulic models used in practical river engineering. The widespread usage in practice might be explained not only by the fact that 1D models are (in comparison to higher dimensional models) simpler to use and require a minimal amount of input data and computer power, but also because the basic concepts and programs have already been around for several decades (Stoker, 1957; US Army Corps of Hydraulic Engineers, 2001).

However, these models have been criticised not only because of the expectation that representation of flood-plain flow as a two-dimensional (2D) flow interacting with the channel flow will give more accurate predictions of flood wave propagation (Anderson et al., 1996; Aronica et al., 1998; Bates et al., 1992; Bates et al., 1998;

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Nomenclature

θ	Weighting factor
Θ	Parameter set
$\mu_{obs/com}$	Observed and computed membership value of the cells
$\Delta\mu$	Absolute difference between observed and computed membership value of each cell
Δt	Time step
Δx	Space step
c	Speed of floodwave
D	Kuiper statistic distance
F	Coefficient of efficiency (inundation)
$L_o(\Theta)$	Prior likelihood weight of parameter set Θ
$L_y(\Theta\|z)$	Calculated likelihood weight of the parameter sets (with the set of new observations z)
$L_p(\Theta\|z)$	Posterior likelihood weight
n_{Sobs}	Number of flooded cells observed
$N_{1,2}$	Number of data points in the first and second distribution
R^2	Coefficient of efficiency (outflow)
$S_{obs/comp}$	Set of observed and computed flooded cells/pixels, respectively
S_N	Cumulative probability distribution
t	Time
V_k	Constant sum of the negative and positive Kuiper statistic D

Subscripts

c	Channel
f	Floodplain

Cunge, 1975; Dutta et al., 2000; Ervine and MacLeod, 1999; Gee et al., 1990; Hromadka et al., 1985), but also for the usage of the Manning equation (which can be also a criticism for higher dimensional models). This flow equation is computed:

(1) with an exponent of the wetted perimeter which Manning set to 2/3 despite the fact that his (and later) analysis of existing data showed that the value can vary (in his case between 0.6175 and 0.8395) (Laushey, 1989; Manning, 1891);
(2) is dimensionally inhomogeneous (Chow, 1959; Dooge, 1992; Manning, 1895);
(3) furthermore, was developed to represent uniform flow and not non-uniform conditions (see criticism of Laushey, 1989).

All model packages focus on the calibration of the roughness parameter which, together with the geometry, is considered to have the most important impact on predicting inundation extent and flow characteristics (Aronica et al., 1998; Bates et al., 1996; Hankin and Beven, 1998; Hardy et al., 1999; Rameshwaran and Willetts, 1999; Romanowicz et al., 1996).

Whether the model is more sensitive to either or both of the roughness and geometry uncertainty is in part a result of the dimensionality of the model structure, which represents geometry in different ways (Lane et al., 1999). Every model geometry is an approximation of the real geometry, with all its downstream variations, and therefore will have an implicit effect on the values of the effective roughness parameters. This also means that it should be possible to compensate to a certain degree for geometrical uncertainty, by varying the effective roughness values (Aronica et al., 1998; Marks and Bates, 2000). The extent to which this is possible varies with model dimensionality and discretisation.

Therefore, the focus of this study is an evaluation of the uncertainty of the roughness coefficients which is also driven by the fact that many modellers see the main problem in practical applications as a problem of choosing the 'correct' roughness (Barr and Das, 1986; Bathurst, 2002; Boss International, 2001; Dingman and Sharma, 1997; Graf, 1979; Rameshwaran and Willetts, 1999; Rice et al., 1998; Tinkler, 1997). Some studies (Trieste and Jarrett, 1987) have demonstrated discrepancies between calibrated effective model values and roughnesses which have been estimated based only on the nature of the channel and flood plain surfaces, despite many sources of guidance about how to choose a value, such as photographs (Arcement and Schneider, 1989; Chow et al., 1988), tables (Chadwick and Morfett, 1999; Chow, 1959; Chow et al., 1988; King, 1918), composite formulae (Barkau, 1997; Bathurst, 1994; Dingman and Sharma, 1997; Knight et al., 1989; Li and Zhang, 2001;