Demystifying hydrological monsters: can flexibility in model structure help explain monster catchments?

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Rainfall-runoff hydrological models are commonly used to investigate and simulate catchment behaviour and predict discharges. The simulation of observed discharge is never perfect and in some cases a model is not able to simulate catchment behaviour appropriately. This can be referred to as a hydrological monster (Andréassian et al., 2010). To find out to what extent hydrological monsters can be related to structural errors, this study compares a fixed modelling approach to a flexible one.

The GR4H model is an empirically developed structure that has proven to perform well on various types of catchments (Le Moine, 2008; Le Moine et al., 2007; Perrin et al., 2003). Identifying the role of the model structure in case of poor performance is difficult for this model because of its fixed and empirical nature. The SUPERFLEX approach on the other hand, is designed to allow for flexibility in the model structure which enables the comparison of different model structures (Fenicia et al., 2011; Kavetski and Fenicia, 2011). This study tries to explain the reasons for hydrological monsters and the role of model structure herein.

Ten year hourly discharge time series on 237 French catchments are used to calibrate and validate thirteen model structures. Besides GR4H, twelve alternative structures in SUPERFLEX are used. All models are calibrated and validated twice using a split sample test, where the ten year time series is split in two periods. Calibration took place on the first and second period while validation was done on the second and first period respectively. Inconsistency between calibrated parameter sets or between best model structures (for SUPERFLEX) on the two test periods is considered as failure of the modelling approach.

Model structure

This study found that relatively simple model structures with some key components can lead to relatively good simulations of observed discharge. Important findings are:

- The use of a power function to describe reservoir outflow increases model performance over all catchments significantly,
- Independently calibrated parallel reservoirs increase model performance in permeable catchments with dominant base flow,
- A lag-function between reservoirs leads to no significant improvement in model performance in any catchment, and
- The most complex structures used in this study do not outperform the relative simple structures on average but do perform better on catchments that are simulated poorly by the simpler structures.

Monster catchments

For 69 of the 237 catchments the fixed and flexible modelling approach gave poor or inconsistent results. In these monster catchments three groups can be distinguished: catchments with climatic differences between calibration and validation period, catchments with flashy flow and catchments with small scale disturbances.

Catchments with climatic differences between calibration and validation period

Wet years in the first period and dry years in the second period lead to differences in flow that are too large to be simulated by most models. Especially in permeable, groundwater dominated catchments flow differences between the periods is large and even leads to a pattern of increasing base flow in the wet years and decreasing base flow in the dry years. Models with independent parallel flow paths are in some cases able to simulated these inter-annual patterns, but calibration conditions often remain too different from the validation period for correct simulation.

Catchments with flashy flow

Long periods of low flow interrupted by very steep and high peak flows are simulated poorly by all model structures. These catchments, mainly situated near the Mediterranean sea, are impermeable or small. Poor model simulation is linked to the influence of catchment saturation on the response to individual rainfall events and poor gauging of convective rainfall events. Some very simple single reservoir models are able to give reasonable results.

Catchments with small scale disturbances

Disturbances in observed flow, either caused by measurement errors or actual (downstream) influences on the stream water level, hinder good simulation. In some catchments observed flow is very small leading to relatively large influences of downstream disturbances, i.e. vegetation or fallen logs. Also downstream locks or dams can influence larger streams, especially during recession or low flow. The used models are not equipped to mimic these disturbances while general behaviour can be quite good. The reasons for poor performance can be linked to a response of the calibration or over-sensitivity of the evaluation criteria (especially for low flow) to the disturbances.

Conclusion

Generally, flexibility in model structure helps to rehabilitate some hydrological monsters but adding complexity is no guarantee for better results. Large differences between the performance of different model structures on different catchments indicate that selecting the best structure for each catchment separately will yield the best results.

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