Conceptual modelling to predict unobserved system states
The case of groundwater flooding in the UK Chalk

Andreas Hartmann[1,2], Andrew Ireson[3]

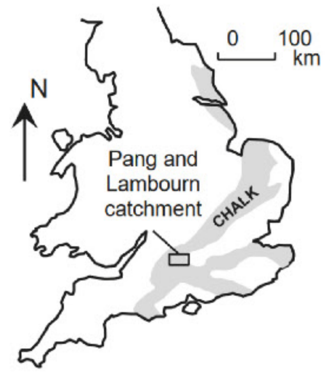
MOTIVATION

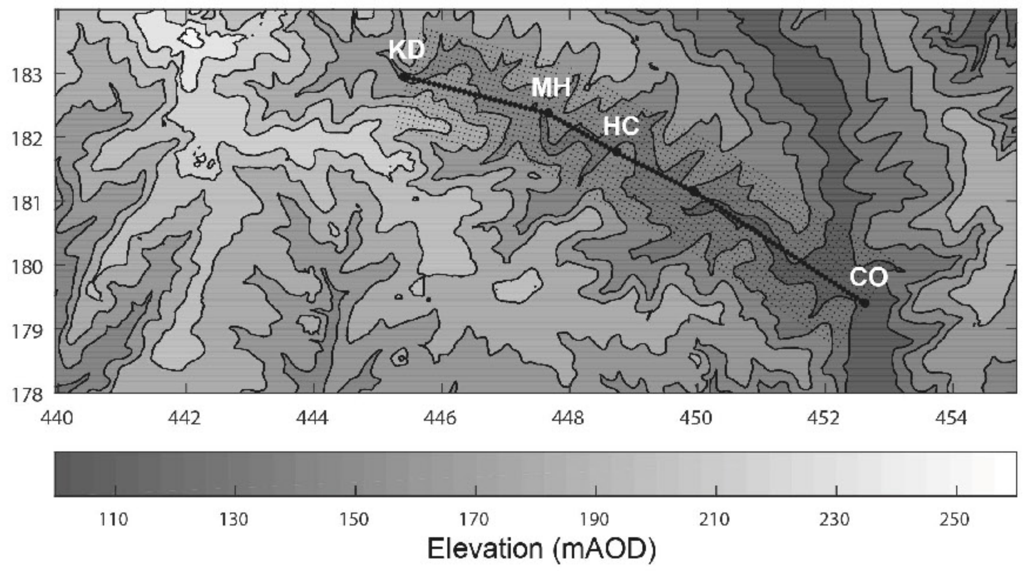
Chalk aquifers represent an important source of drinking water in the UK. Due to its fractured-porous structure, Chalk aquifers are characterized by highly dynamic groundwater fluctuations that enhance the risk of groundwater flooding. The risk of groundwater flooding can be assessed by physically-based groundwater models. But for reliable results, a-priori information about the distribution of hydraulic conductivities and porosities is necessary, which is often not available. For that reason, conceptual simulation models are often used to predict groundwater behaviour. They commonly require calibration by historic groundwater observations. Consequently, their prediction performance is often seen to reduce significantly, when it comes to system states that did not occur within the calibration time series.

In this study, we calibrate a conceptual karst model to 4 time series of observed groundwater levels. We show that by including topographic information in the model structure, the model is able to predict groundwater flooding, which was not observed during the calibration period.

STUDY AREA & DATA

This study is performed at a transect through the unconfined Chalk in the Pang catchment, which is a tributary of the River Thames in Berkshire, England. The transect of consists of 4 monitoring wells that are located along a mostly dry valley in the catchment and it follows the approximate a groundwater flow line. The lowest piezometer is located at Compton (CO), which can be seen as the start of the continuously flowing section of the river. In terms of hydrogeology, the system is composed of middle and lower Chalk, the latter continuously saturated with groundwater. The regional mean of hydraulic conductivity is 44.5 m per day.





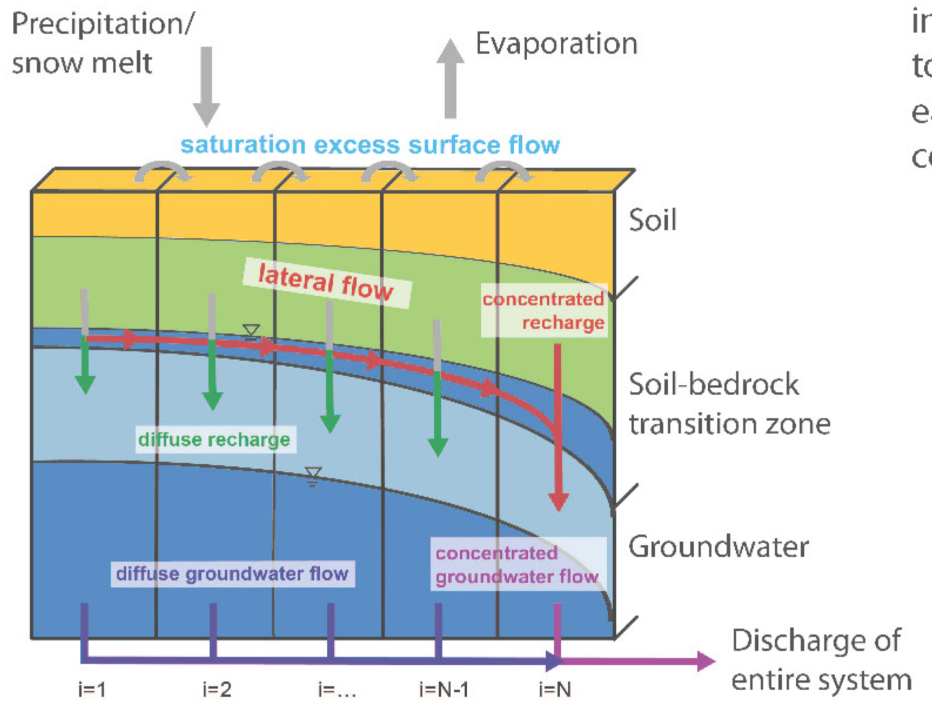
More information on study site in Ireson, A.M., Butler, A.P., 2013. A critical assessment of simple recharge models: Application to the UK Chalk. Hydrol. Earth Syst. Sci. 17, 2083–2096. doi:10.5194/hess-17-2083-2013

MODELLING AND CALIBRATION APPROACH

The simulation model considers the variability of karst system properties by statistical distribution functions. That way it simulates a range of variably dynamic pathways through the karst system. Stored water in the groundwater compartments of the model is transferred into water level using effective porosity and offset to account for the bias between zero mAOD (meters above ordnance datum) and zero of the simulations.

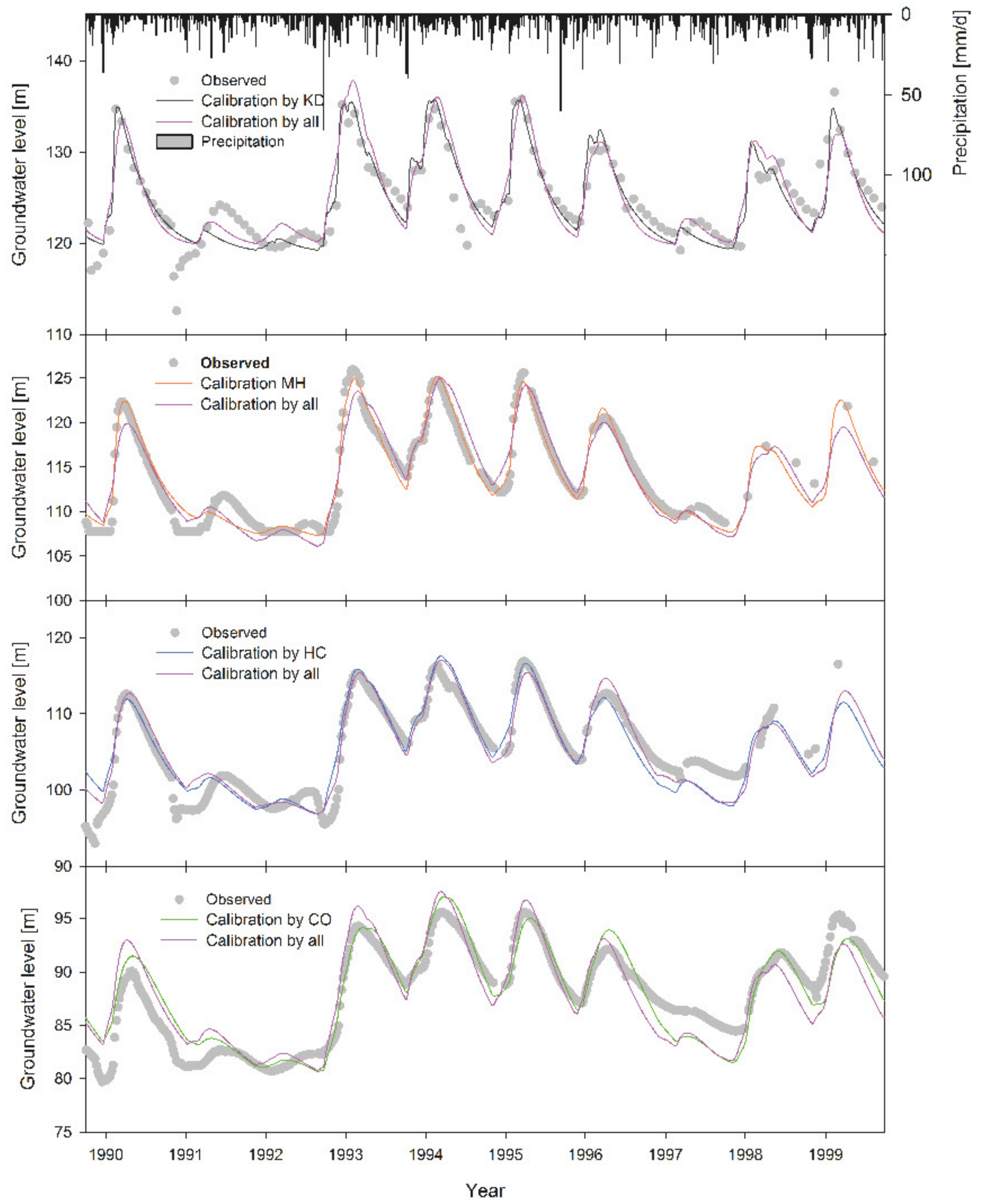
We calibrate the model with a 10-year period of observed water levels at 4 wells (10/1989 to 9/1999), during which no groundwater flooding events were documented. For calibration, we use the Shuffled Complex Evolution Metropolis algorithm and the informal Kling-Gupta efficiency measure (KGE), which also allows analysing the identifiability of the 15 model parameters.

Model described in Hartmann, A., Barberá, J.A., Lange, J., Andreo, B., Weiler, M., 2013. Progress in the hydrologic simulation of time variant recharge areas of karst systems – Exemplified at a karst spring in Southern Spain. Adv. Water Resour. 54, 149–160. doi:10.1016/j.advwatres.2013.01.010
Approach to include groundwater head simulations in Brenner, S., Coxon, G., Howden, N.J.K., Freer, J., Hartmann, A., 2016. A percentile approach to evaluate simulated groundwater levels and frequencies in a Chalk catchment in Southwest England. Nat. Hazards Earth Syst. Sci. Discuss. doi:10.5194/nhess-2016-386



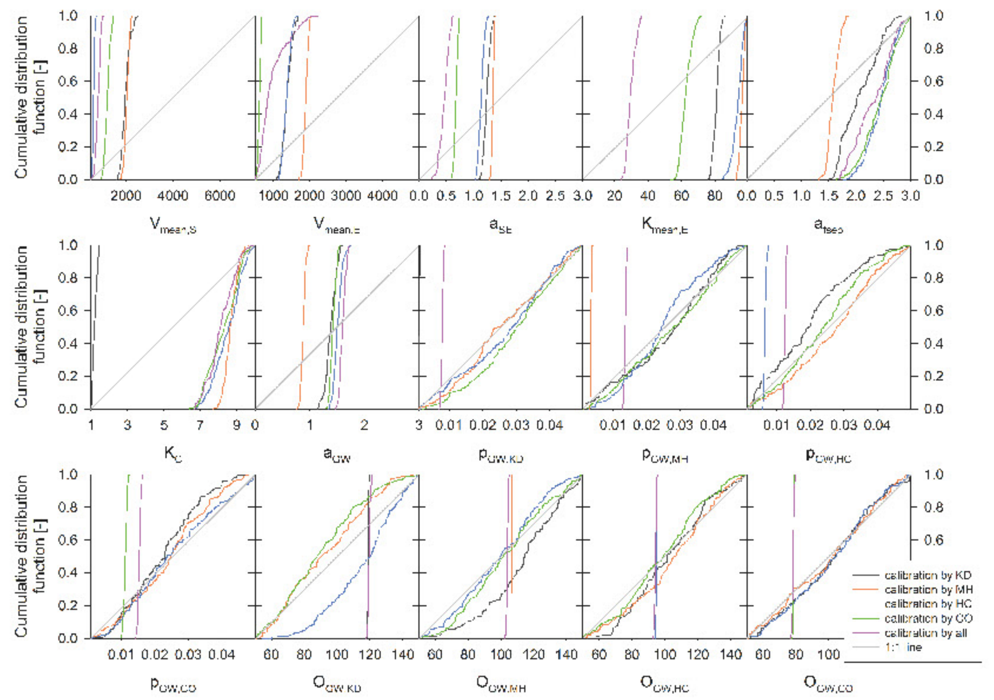
CALIBRATION RESULTS

To test its performance, the model is firstly calibrated individually to each of the 4 time series. Secondly, the model is calibrated to all 4 time series simultaneously. For both cases, acceptable performance is obtained (KGE=0.91-0.98 for the individual calibration, KGE=0.91 for the simultaneous calibration).



PARAMETER IDENTIFIABILITY

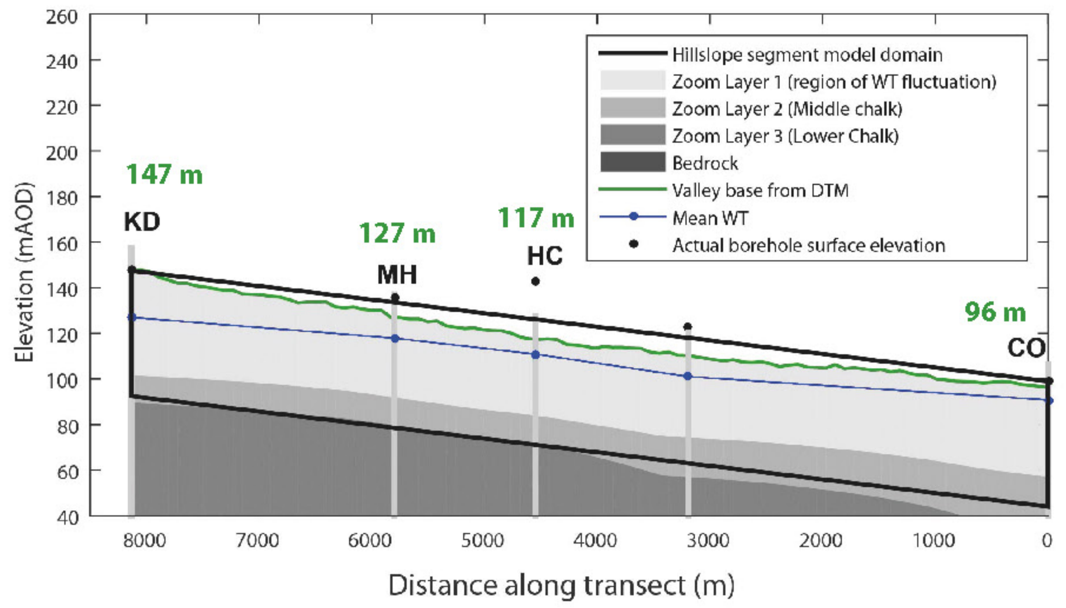
Deviation from a uniform posterior indicates parameter identifiability. The posteriors indicate non-identifiable parameters for the individual calibrations. Using all information simultaneously, we obtain identifiability for all model parameters.



MODEL ADAPTION FOR PREDICTION

After calibration and parameter identifiability analysis, the model is applied to the period 10/1999 to 9/2005. During that period, in 2001, groundwater flooding was observed at the boreholes MH and CO.

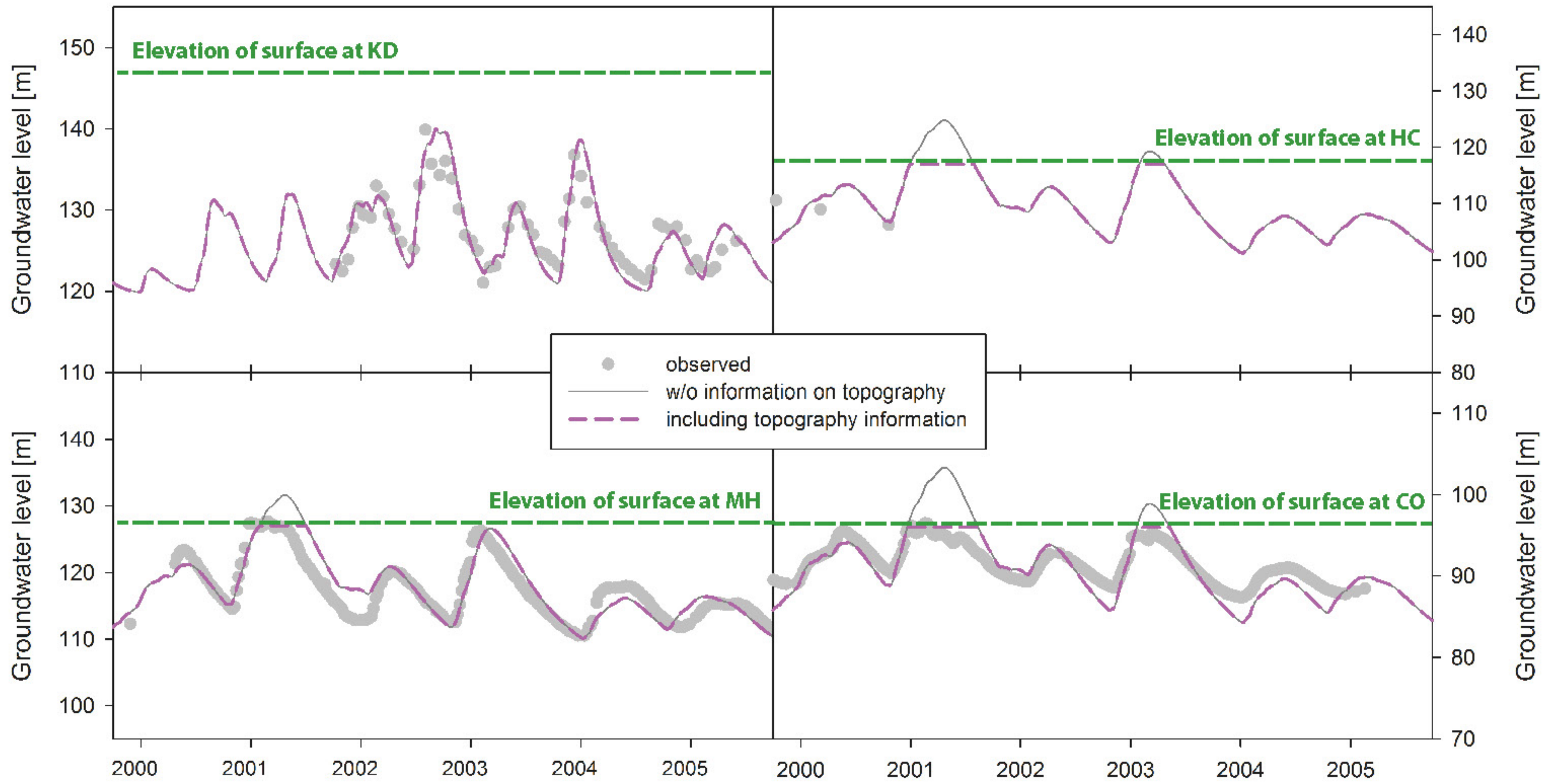
In order to account for groundwater flooding without having to include the groundwater flooding event into the calibration, topographic information is used to extract the surface elevation of each borehole and set as storage limit for the groundwater compartments of the model.



PREDICTION OF STATES THAT WERE NOT OBSERVED DURING CALIBRATION

Without including topographic information, the model still provides acceptable predictions for KD. But at HC, MH and CO, it predicts unrealistic groundwater levels during the groundwater flooding in 2001. The model performance is moderate (KGE=0.56).

When topographic information is included, predicted groundwater levels are limited by the surface and prediction performance increases (KG=0.74).



Excess groundwater is stored at the surface and adds to surface runoff. For the hydrological year 2000/2001, this additional surface runoff component can make up 9,9% to 49.6% of total discharge, depending on the spatial extent of the groundwater resurgence.

Conclusions

With this rather simple study, we could show how a lumped model can be prepared to predict system states that did not occur during calibration. In a changing world, predictions of extremes such as floods or droughts are indispensable for decision makers and water governance. Our approach provides some direction how these predictions could be obtained at regions with limited data availability where data hungry distrusted models cannot be applied. However, further research is necessary to improve our understanding of how hydrological systems are affected by changing boundary conditions, especially on mechanisms that trigger hydrological behaviour that is not included in historic observations.

Acknowldgements This research is part of the project "Global Assessment of Water Stress in Karst Regions in a Changing World" (HA 8113/1-1) funded by the Emmy Noether-Programme of the German Research Foundation (DFG).

[1]Andreas Hartmann, Assistant Professor
Chair of Hydrological Modeling and Water Resources
University of Freiburg
andreas.hartmann@hydrology.uni-freiburg.de
[2]Department of Civil Engineering
University of Bristol, UK
[3]School of Environment and Sustainability, Department of Civil and Geological Engineering,
Global Institute for Water Security, University of Saskatchewan, Canada