HYDRA Postgraduate Research Poster Meeting, University College London, UK, 17 December 2007

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RELATING CONCEPTUAL RAINFALL–RUNOFF MODEL STRUCTURE AND PARAMETERS TO CATCHMENT CHARACTERISTICS: A CASE STUDY ON THE UPPER LEE CATCHMENT

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ABSTRACT

The objectives of this study are to select a parsimonious lumped conceptual rainfall-runoff model describing accurately the hydrological behaviour within the 1040 km² Upper Lee catchment, UK and to use this to investigate how model structure and parameters depend on physical characteristics. A range of soil moisture accounting and routing models available within an existing Rainfall Runoff Modelling Toolbox (RRMT) are applied and an appropriate structure is selected. The selection criteria include overall calibration performance, the trade-off between high and low flow performance, and model complexity. A regionalisation methodology has been applied to the gauged catchments of the Upper Lee enabling estimation of flows at ungauged sites. The selected model is calibrated on 10 gauged sub catchments to obtain a set of parameters describing the hydrological behaviour within the region. Results indicate the capability of the regression model to predict hourly flow at ungauged points within the catchment and to improve a priori parameter estimates and hence decrease calibration time overheads. Results indicate the capability of the regression model to predict hourly flow at ungauged points within the catchment and to improve a priori parameter estimates and hence decrease calibration time overheads.

CONTENT OF RESEARCH

MOTIVATION:

Distributed models can represent the effects of spatially variable inputs making them an appropriate tool to investigate the role of spatial rainfall in runoff generation. However, their calibration is not always a straightforward task considering the large number of parameter values that need to be estimated. Regression methods could provide a priori parameter estimates for ungauged subcatchments.

PROBLEM:

- Identification of an appropriate model structure and a suitable parameter set for the case of Upper Lee.
- Investigate how model parameters depend on physical characteristics: Application of a regression model.
- Examination of the sensitivity of flow to variation in the regionalised model parameters.
- Does a priori parameter estimation improve performance?

CASE STUDY: DATA AND TOOLS

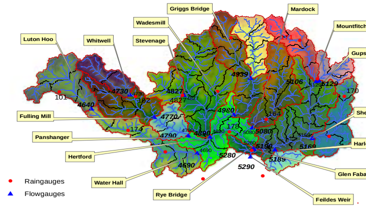


FIGURE 1. The Upper Lee catchment

The Upper Lee (Figure 1), 1040 km², varies in geology i.e. London clay, Chalk, and land cover, i.e. pervious and impervious areas.

RRMT (Figure 2) is a generic toolbox to produce parsimonious, conceptually lumped model structures with high level of model parameter identifiability [Wagener et al. 2003]. Structures with low or medium level of complexity can be implemented from a list of soil moisture accounting and routing modules.

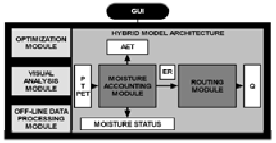


FIGURE 2. General Structure of the RRMT

MODEL IDENTIFICATION

The model structures used in the identification task are summarised in Table 1. Model identification was based on two different objective functions for high and low flows and their trade off.

TABLE 1. Soil moisture accounting and routing components

RRMT	Soil Moisture Acounting Components	Reference
SMA CWI	Catchment Wetness Index	Jakeman et al. 1993
SMA PDM	Probability Distributed Moisture	Moore 2007
SMA IC1	Penman storage	Wagener et al. 2003

RRMT	Routing Components	Reference
R 2PAR	2 reservoirs in parallel	Wagener et al. 2003
R 2PMP	2 reservoirs in parallel including macro-pores	Wagener et al. 2003
R 3 PAR	3 reservoirs in parallel	Wagener et al. 2003

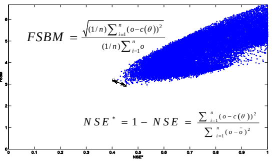


FIGURE 3. Objective functions and trade off

Different combinations were applied, and the results are presented in Table 2. The model structure which was identified is the PD4-2paT.

TABLE 2. Model identification and overall assessment of model structures

	Calibration	Validation	Trade Off	Complexity	Score
PD4-2par	0.30	0.31	0.16	5.00	4
PD4-2paT	0.23	0.24	0.13	6.00	5
PD4BP-2paT	0.29	0.32	0.17	7.00	4
PD4-3par	0.38	0.35	0.14	7.00	3
PD4-3paT	0.35	0.35	0.14	8.00	3
PD4BP-3paT	0.36	0.37	0.17	9.00	2
IC1-2paT	0.29	0.31	0.21	6.00	1
IC1-3paT	0.31	0.32	0.22	8.00	2
CWI-2par	0.35	0.36	0.13	6.00	3
CWI-3par	0.35	0.36	0.14	8.00	3
CWI-2pmp	0.36	0.38	0.14	8.00	2

REGIONALISATION METHOD

The PDM rainfall-runoff model was calibrated to 10 well gauged subcatchments of the Upper Lee. A step-wise multiple regression approach was used to relate the optimum model parameter estimates to physical catchment characteristics (Table 2).

As expected the regression equations are slightly less reliable than locally calibrated MPs within the calibration and validation period (Figure 4). As an example, Figure 5 illustrates the simulated flow times series using model parameters based on local calibration and the regionalisation method.

Table 2. Regression equations relating PDM parameters with catchment characteristics

Equation	Partial R	Total R²
c(max) = 25093 - 124.06 10⁻⁴ URBCONC - 6780.56 ln(RMED_2D)	-0.790 -0.940	0.886
b = 0.022 - 202.14 10⁻⁴ AREA + 3.593 URBEXT1990	-0.923 0.986	0.973
k(q) = -843.7 + 24.414 RMED_2D + 17.753 ln(URBEXT1990)	0.766 0.887	0.828
k(s) = 8755 + 3741.904 ln(BFIHOST) - 18151.5 URBEXT1990	0.620 -0.780	0.643
%(q) = 1.923 - 0.003 DPLBAR - 0.418 ln(ALTBAR) + 0.013 SPRHOST	-0.834 -0.950 0.977	0.982
T = 30.7 + 0.074 SAAR - 43.811 URBEXT1990 + 66.538 ln(PROPWET) + 4.1 ln(DPLBAR)	0.970 -0.989 0.993 0.997	0.995

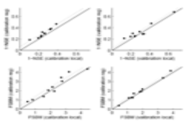


FIGURE 4. Performance using local calibrated and regional calibrated MPs (calibration and validation period)

SIMULATION RESULTS

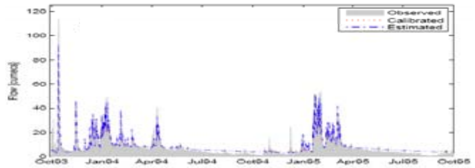


FIGURE 5. Time series of observed, local calibrated and regional estimated flow

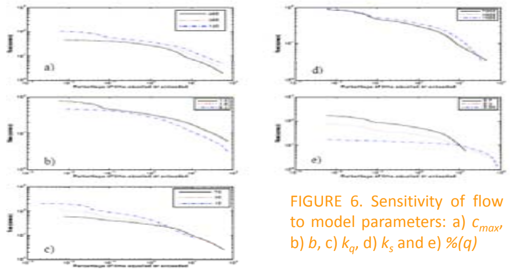


FIGURE 6. Sensitivity of flow to model parameters: a) c_{max}, b) b, c) k_q, d) k_s and e) $\%(q)$

Model parameters, when varied over their prior ranges revealed the relative impact of changes in hydrological behaviour (Figure 6). Variation of soil moisture parameters affected flow volume (location of the flow duration curve), Routing parameters are responsible for the gradient of the flow duration curve, resulting in the under/over estimation of flow.

Figure 7 and 8 illustrate the model parameter identification and simulation respectively. Regression models provided a priori model parameter estimates for application to a semi-distributed model scale. Good model performance was achieved, while the computation time was decreased.

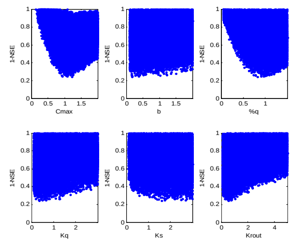
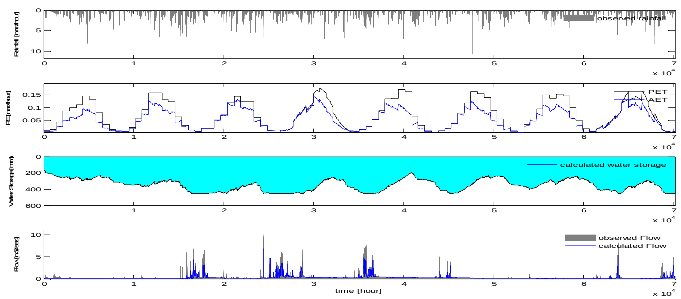


FIGURE 7. Model parameter multipliers

FIGURE 8. Time series of observed, local calibrated and regional estimated flow



CONCLUSIONS

- The PDM model is robust enough to reasonably simulate the hydrological behaviour of the Upper Lee catchment.
- A strong relationship was found between model parameters (MPs) and catchment characteristics (CCs) , which provides good a priori parameter estimates in ungauged catchment sites.
- The MP – CC relationships could be further used to estimate a priori MP sets of ungauged subcatchments, particularly when semi-distributed modelling is applied.
- A priori model parameter estimates decrease semi-distributed calibration time, while still resulting in good model performance.
- The next step is to investigate the significance of spatial variability of rainfall on runoff generation through a semi-distributed model.

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