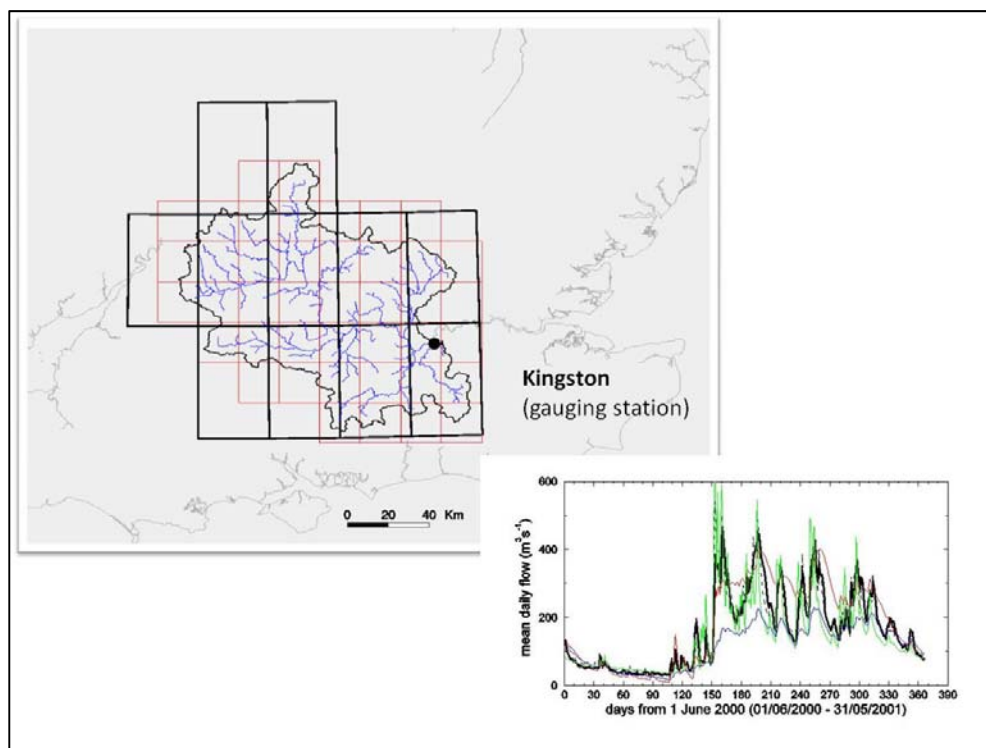




**Technical Report No. 53**

**FLOOD STUDIES AT THE RIVER BASIN SCALE:  
CASE STUDY OF THE THAMES AT KINGSTON (UK)**



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## 1. Introduction

The Thames catchment in Southern England was used as a test basin for modelling and testing of high flow extremes and floods. The catchment to the lowest gauging station has an area of 9948 km<sup>2</sup> with an annual average rainfall of 719 mm (1961-1990). The mean annual naturalised flow (gauged flow adjusted for water usage) is 35% of the annual average rainfall (i.e. 65% of rainfall falling on the catchment is lost through evaporation). The river basin hydrological model used was CLASSIC (Crooks and Naden, 2007), which is applied on a grid-square framework. The model has three main modules for soil moisture, soil drainage and channel routing with a grid to outlet structure in which simulated runoff from each grid square is routed directly to the catchment outlet. The catchment boundary, main rivers, modelling grid boxes (20 km) and grid boxes for Watch Forcing Data (0.5 degree) are shown in Figure 1, together with a map showing the location of the Thames catchment within Great Britain.

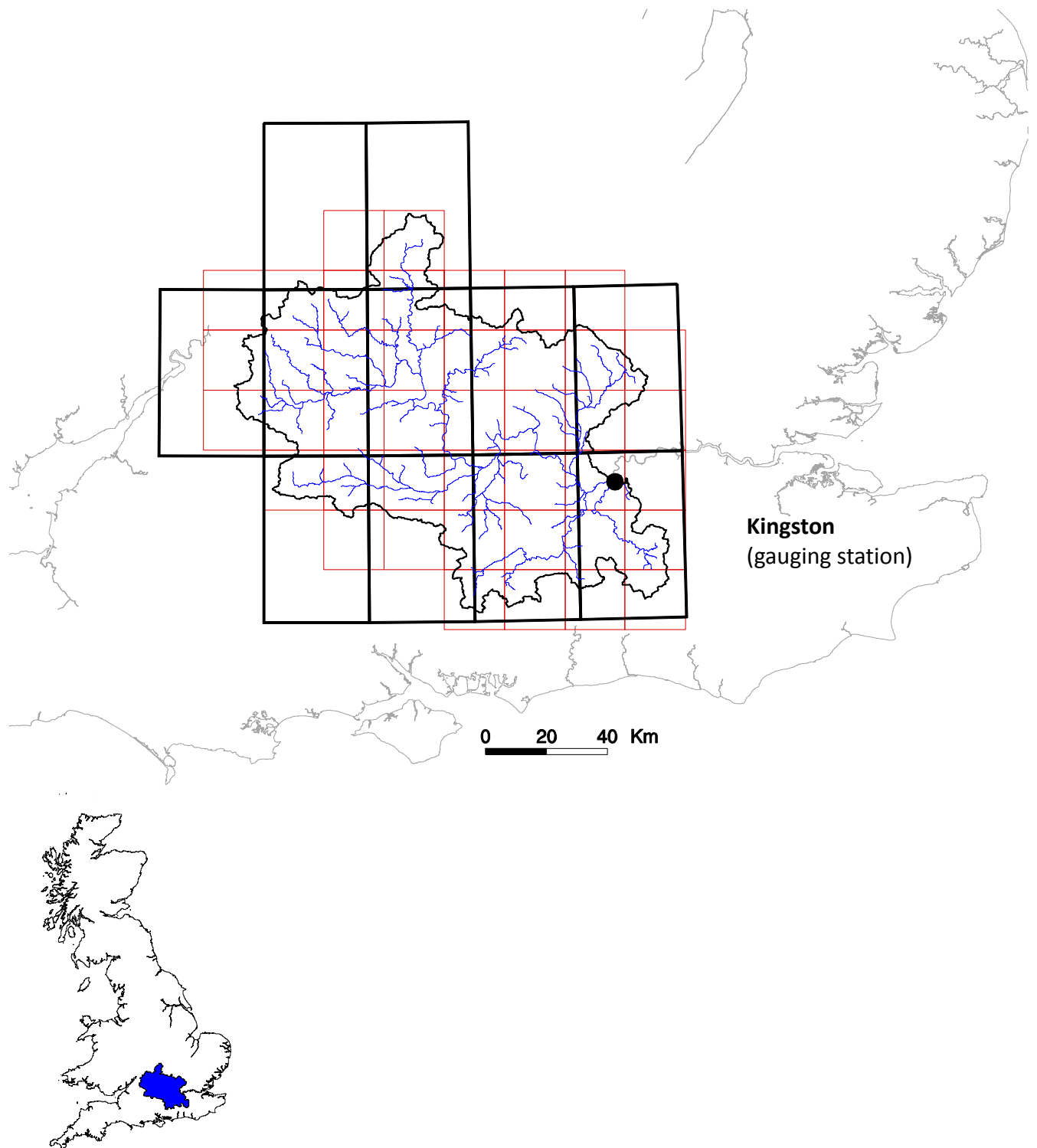


Figure 1 Catchment boundary for the River Thames to the lowest gauging station at Kingston; modelling grid boxes (20 km) are shown in red, Watch Forcing Data grid boxes (0.5 degree) in black. The map on the right shows the location of the Thames catchment within Great Britain.

Calibration of the model for the Thames is part of a two-stage procedure where a generalised method, developed for the whole of Great Britain using land use, soils and digital terrain databases is used initially, followed by fine tuning of the channel routing parameters to observed flow data. Objective

functions used in calibration include water balance (seasonal, annual and overall volume error), Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970), and fit of flow duration and flood frequency curves. Climatic inputs of rainfall and potential evaporation (PE) are required for each grid square. The mean daily average rainfall for a grid square is calculated from observed point data with monthly PE data obtained from MORECS (Met Office Rainfall and Evaporation Calculation System, Thompson et al., 1982), which uses a modified form of the Penman-Monteith equations.

## 2. Modelling with Watch Forcing Data

CLASSIC was run using local data (observed rainfall and MORECS PE) and Watch Forcing Data (WFD) for 1961 to 2001 and results compared. To run CLASSIC with WFD, area weights were applied to translate from the 0.5 degree WFD grid boxes to the 20 km grid boxes. The same model calibration was used with both sets of data as recalibration is not appropriate with the generalised calibration method developed for CLASSIC. This allows direct comparison of the impact of using different input data. Rainfall from WFD used combined data for rainfall and snow. Two sets of PE based on WFD data were used in the modelling: using Penman-Monteith equations (WFD\_Pen-Mon) and using the equation developed by Oudin (Oudin et al., 2005) based on mean daily temperature and latitude (WFD\_Oudin). Oudin PE was also calculated using local observed temperature data but as there was very little difference between the Oudin PE values calculated with WFD or local temperature data only WFD\_Oudin was used in the modelling. The impacts on the flow regime of using the different sets of input data on simulated flow are shown in Figure 2 (mean monthly input data and percentage difference on mean monthly flow), Figure 3 (flow duration curves), Figure 4 (flood frequency curves) and Figure 5 (average number of days per year above a flow threshold. Flood frequency is determined using a peaks-over-threshold method for an average of 3 peaks per year (POT3), Naden, 1993).

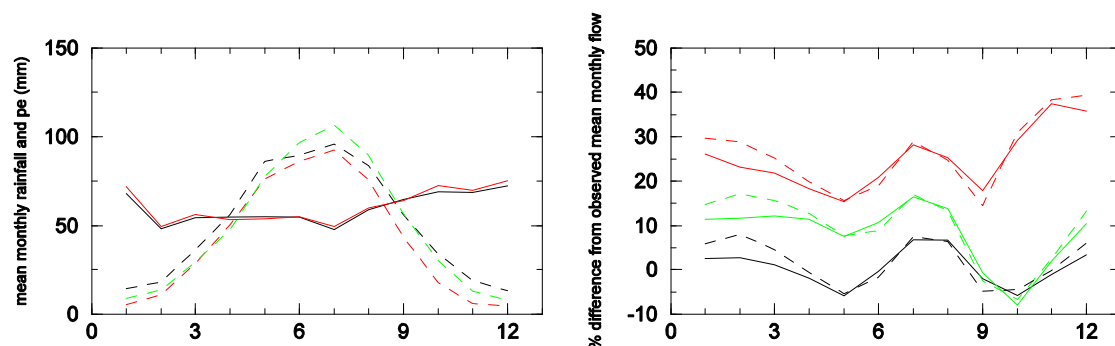


Figure 2, left, mean monthly rainfall and PE from local data and WFD: rainfall (solid lines), PE (dashed lines); local rainfall (black solid), WFD rainfall (red solid), local PE (black dashed), WFD\_Pen-Mon (red dashed), WFD\_Oudin (green dashed).

Figure 2, right, percentage difference between observed mean monthly flow and modelled using different combinations of input data: using local rainfall (solid lines), using WFD rainfall (dashed lines); local rainfall and local PE (black solid), WFD rainfall and local PE (black dashed); local rainfall and WFD\_Pen-Mon (red solid), WFD rainfall and WFD Pen-Mon (red dashed); local rainfall and WFD\_Oudin (green solid), WFD rainfall and WFD\_Oudin (green dashed).

Figure 2, left, shows that there is little difference between average monthly local and WFD rainfall but some differences between the three PE methods. The three sets of lines in Figure 2, right, show that the comparatively small differences in PE from the three methods (MORECS, WFD\_Pen-Mon and WFD\_Oudin) generate differences between observed and modelled mean monthly flow of up to 40%. The pattern of differences in flow reflects the relative differences between the sets of PE data.

WFD\_Pen-Mon values are less than MORECS in all months, hence there is always a positive difference between modelled and observed flows. The continuous underestimate of WFD\_Pen-Mon compared with MORECS results in the high percentage difference in mean monthly flow. The impact of the higher PE from WFD\_Oudin, compared with MORECS, from June to August is evident in the negative difference between modelled and observed flows by October.

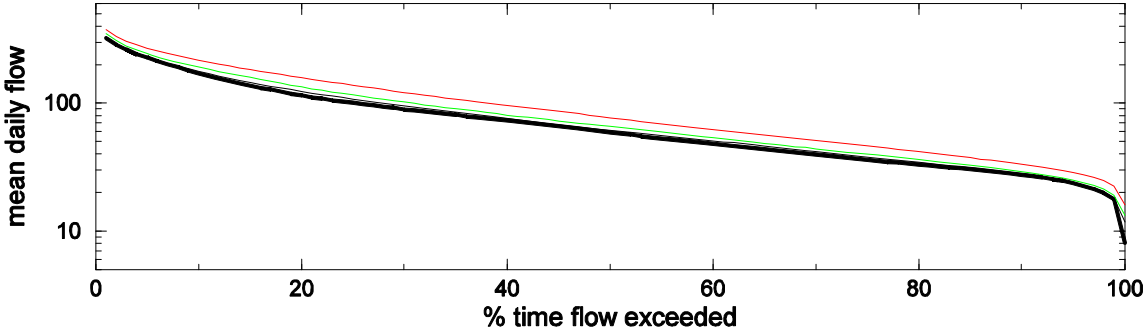


Figure 3 Flow duration curves (mean daily flow in  $m^3s^{-1}$ ). Observed flow (thick black line), modelled with local rainfall and local PE (thin black), modelled with WFD rainfall and WFD\_Pen-Mon (red), modelled with WFD rainfall and WFD\_Oudin (green).

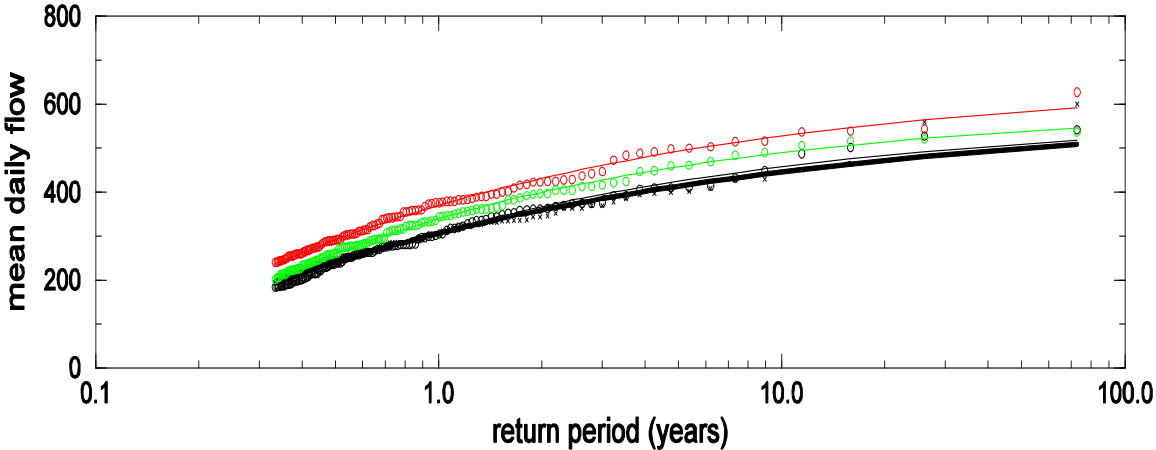


Figure 4 Flood peaks (POT3) and fitted flood frequency curves (mean daily flow in  $m^3s^{-1}$ ). Observed flow (black crosses and thick black line), modelled with local rainfall and local PE (black circles and thin black line), modelled with WFD rainfall and WFD\_Pen-Mon (red circles and red line), modelled with WFD rainfall and WFD\_Oudin (green circles and green line).

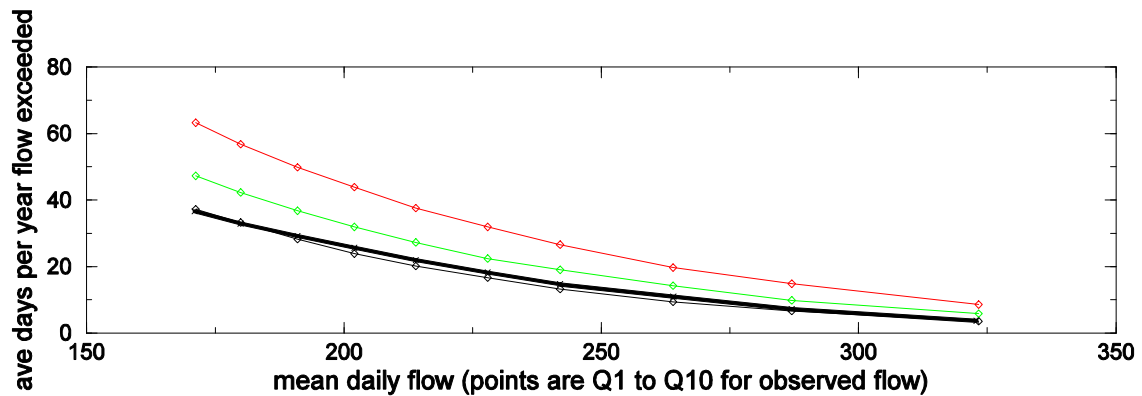


Figure 5 Average number of days per year flow exceeds a threshold, with the threshold defined by Q1 to Q10 (with  $Q_n$  observed flow exceeded  $n\%$  of the time); mean daily flow in  $m^3s^{-1}$ . Observed flow (thick black line), modelled with local rainfall and local PE (thin black), modelled with WFD rainfall and WFD\_Pen-Mon (red), modelled with WFD rainfall and WFD\_Oudin (green).

Figures 3, 4 and 5 show that, for the Thames catchment, the different PE series impact on modelled flow rates across the flow range, including the simulation of flood peaks. Although it is likely that using data series other than those with which the model was calibrated will result in higher differences between modelled and observed, if the balance between seasonal rainfall and PE data is not realistic then recalibration will result in neither sensible values of model parameters nor good model performance.

Results presented in Figure 2 to Figure 5 show that:

- Observed (local) and WFD mean monthly rainfall data are very similar
- PE calculated using Penman-Monteith equations with WFD is lower in all months compared with MORECS PE
- Oudin PE, being temperature based, has higher rates in the summer impacting on simulation of flows through the autumn
- Use of PE data, other than with local observed climate data (MORECS), leads to an overestimate of flow across the whole flow range, including flood flows
- The Thames catchment is very sensitive to differences in PE data – there is a critical balance between rainfall and evaporation.

### 3. Comparison between River Basin Hydrological Model and Global Models

Daily discharge data from three Global Models (GMs) were extracted for 1963 to 2001 for grid box 51.25N and 0.25W (which includes Kingston gauging station on the Thames) and statistics of flow compared with those from the River Basin Hydrological Model, CLASSIC. The three GMs are JULES (Land Surface Hydrological Model (LSHM)), WaterGap (Global Hydrological Model (GHM)) and MPI-HM (composite LSHM/GHM). Note different evaporation accounting schemes (and when relevant, different PE estimates) are used in the different GMs.

The analyses of daily discharge are shown in Figure 6, mean monthly flow, Figure 7, flow duration curves, Figure 8, mean annual flow for 1963 to 2001, Figure 9, flood frequency curves, Figure 10 flood hydrograph and Figure 11 average number of days above a threshold. The flood hydrograph shows flows through the winter of 2000/01 following a number of heavy rainfall events during the autumn of

2000, generally amounting to two to three times the 1961-1990 average for October and November over England and Wales (CEH and Met Office, 2001).

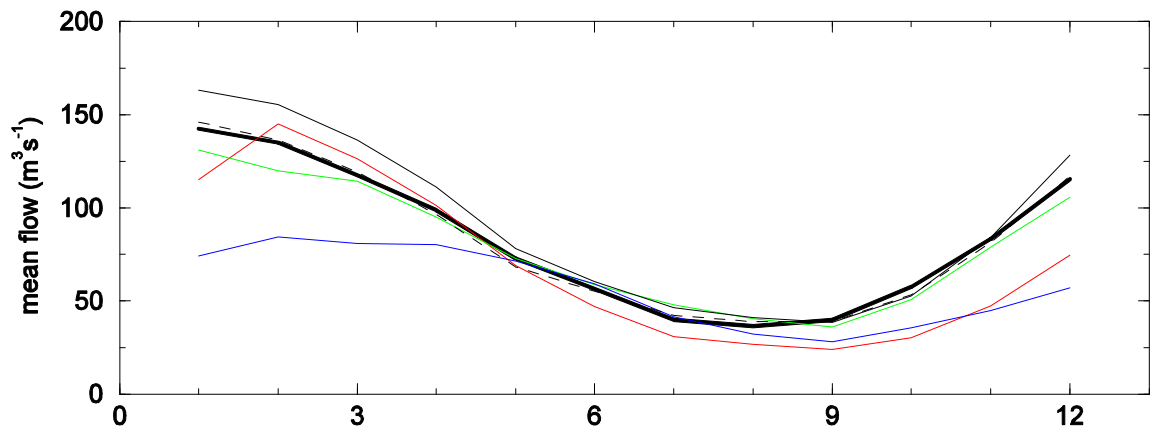


Figure 6 Mean monthly flow; observed (thick black), CLASSIC local data (dashed black), CLASSIC WFD (Oudin PE) (thin black), JULES (red), WaterGAP (green), MPI-HM (blue)

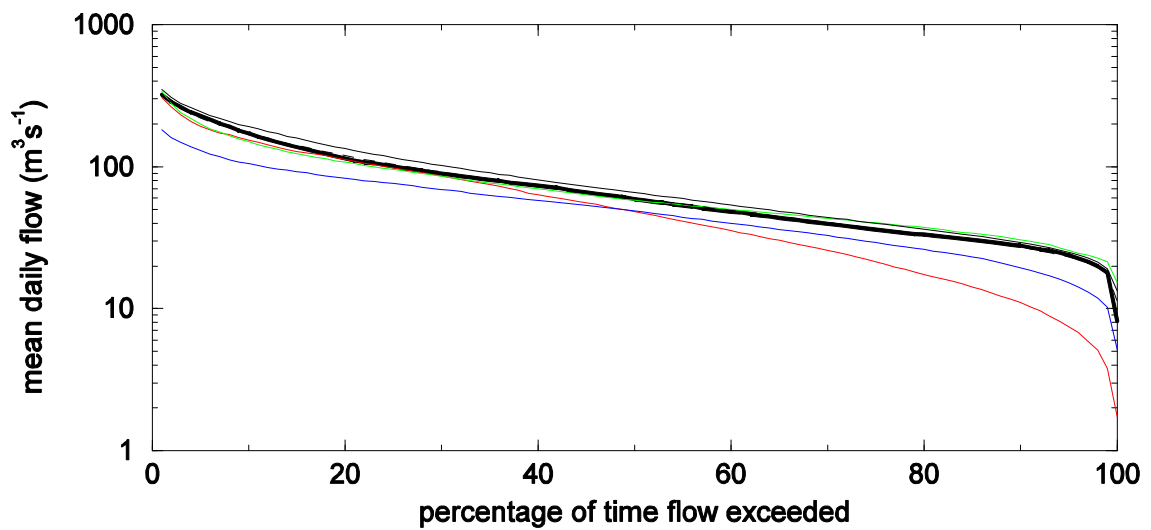


Figure 7 Flow duration curves; observed (thick black), CLASSIC local data (dashed black), CLASSIC WFD (Oudin PE) (thin black), JULES (red), WaterGAP (green), MPI-HM (blue)

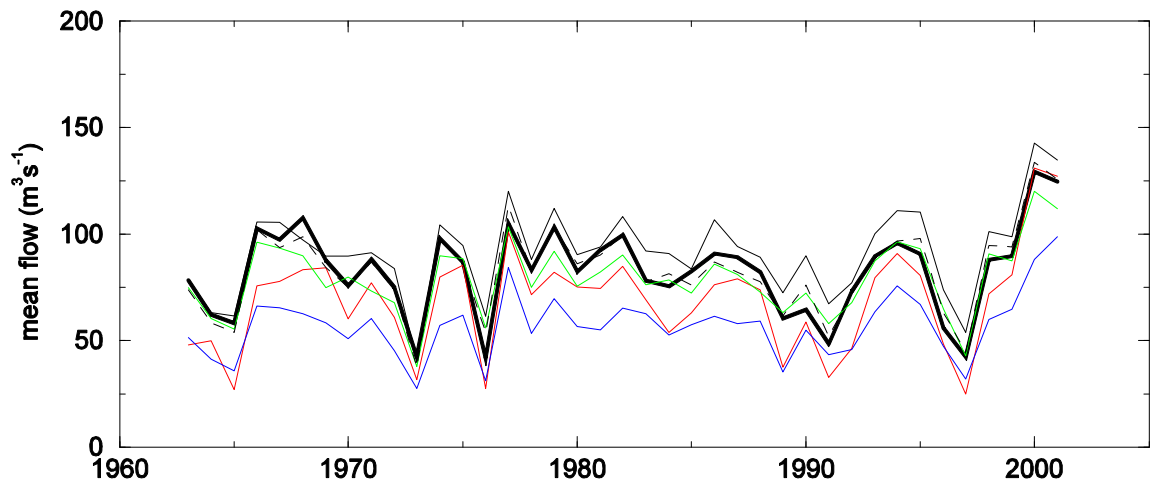


Figure 8 Mean annual flow (1963 to 2001); observed (thick black), CLASSIC local data (dashed black), CLASSIC WFD (Oudin PE) (thin black), JULES (red), WaterGAP (green), MPI-HM (blue)

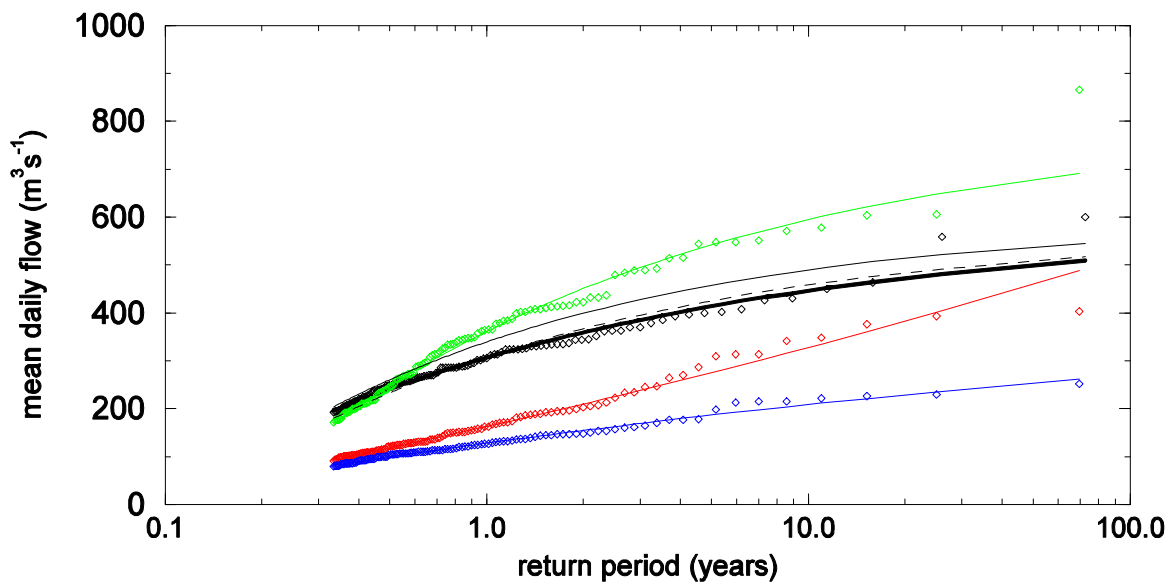


Figure 9 Flood peaks (POT3) and fitted flood frequency curves; observed (black circles and thick black line), CLASSIC local data (dashed black), CLASSIC WFD (Oudin PE) (thin black), JULES (red circles and red line), WaterGAP (green circles and green line), MPI-HM (blue circles and blue line). (For clarity flood peaks for CLASSIC with local and WFD data are not shown but are shown in Figure 4.)

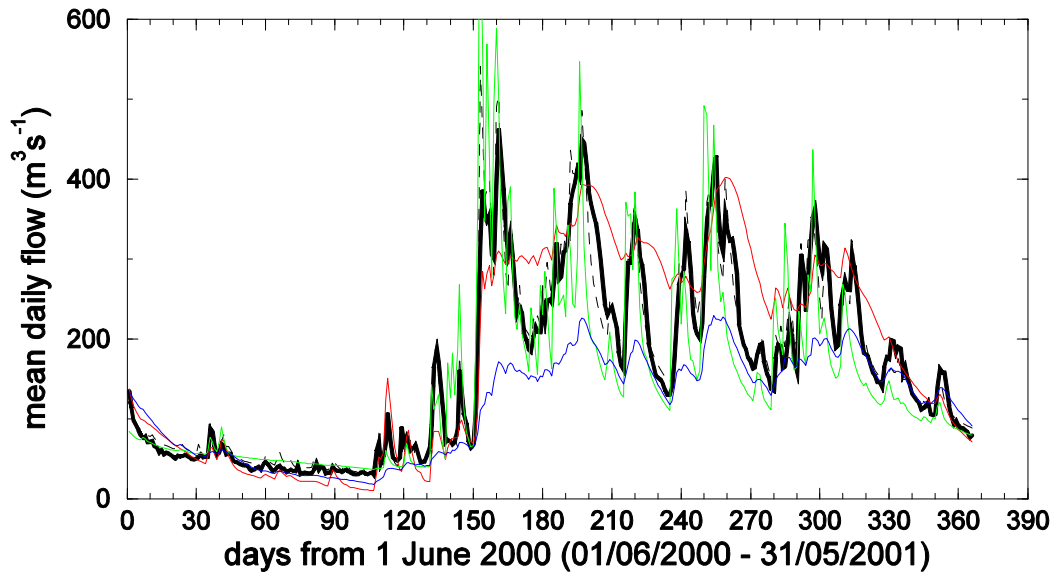


Figure 10 Flood hydrograph; observed (thick black), CLASSIC WFD (Oudin PE) (dashed black), JULES (red), WaterGAP (green), MPI-HM (blue). WaterGAP peak discharge 865 m<sup>3</sup>s<sup>-1</sup>.

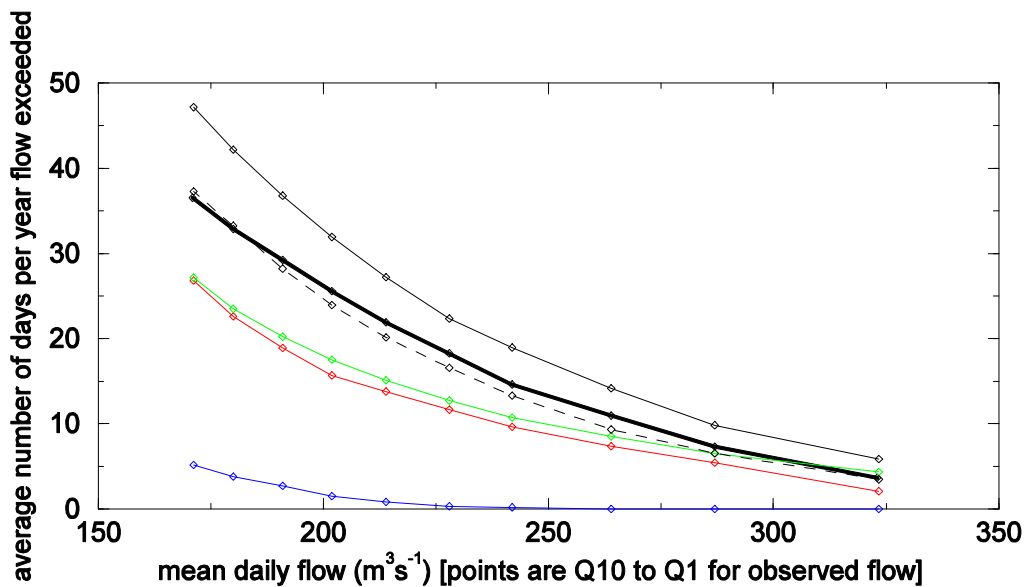


Figure 11 Average number of days per year flow exceeds a threshold, with the threshold defined by Q1 to Q10 where Q<sub>n</sub> is the observed flow exceeded n% of the time; observed (thick black), CLASSIC local data (dashed black), CLASSIC WFD (Oudin PE) (thin black), JULES (red), WaterGAP (green), MPI-HM (blue)

Comparison of statistics of mean daily flow from observed, modelled with an RBHM (using local observed and WFD data), LSHM, GHM and LSHM/GHM shows that:

- The GHM (WaterGAP) simulates well the seasonal variation (mean monthly flow) and flow range (flow duration curve)
- All GMs reproduce the year-to-year variation in flow but may consistently underestimate the mean annual flow (JULES and MPI-HM)

- None of the GMs reproduce well the flood frequency curve; the GHM overestimates the peak flows while the LSHM and LSHM/GHM underestimate the peaks
- The shape of the flood hydrograph is also difficult to reproduce with the GMs; the shape is too smoothed with the LSHM and LSHM/GHM and too peaked with the GHM
- The RBHM using either local observed data or WFD , compared with the three GMs considered, provides the best simulation of high flows and flood events
- For average flows the GHM, WaterGap, performs as least as well as the RBHM using WFD data
- The best overall simulation across the full flow range is provided by the RBHM using local observed data. This is partly to be expected given that observed data were used in the calibration and parameters are calibrated to simulate high flows
- The different simulations show the requirement for having a realistic seasonal balance between rainfall and PE and that how PE is estimated can impact on simulation of flows, including the high end of the flow range. Some of the differences in simulated hydrographs could result from their internal estimation of potential and actual evapotranspiration.

#### 4. References

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