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Evidence-based requirements for perceptualising intercatchment groundwater flow in hydrological models

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S1. Climatic variability of the study area

Fig. S1. illustrates the climatic and hydrologic baseline of the Thames at Kingston catchment.

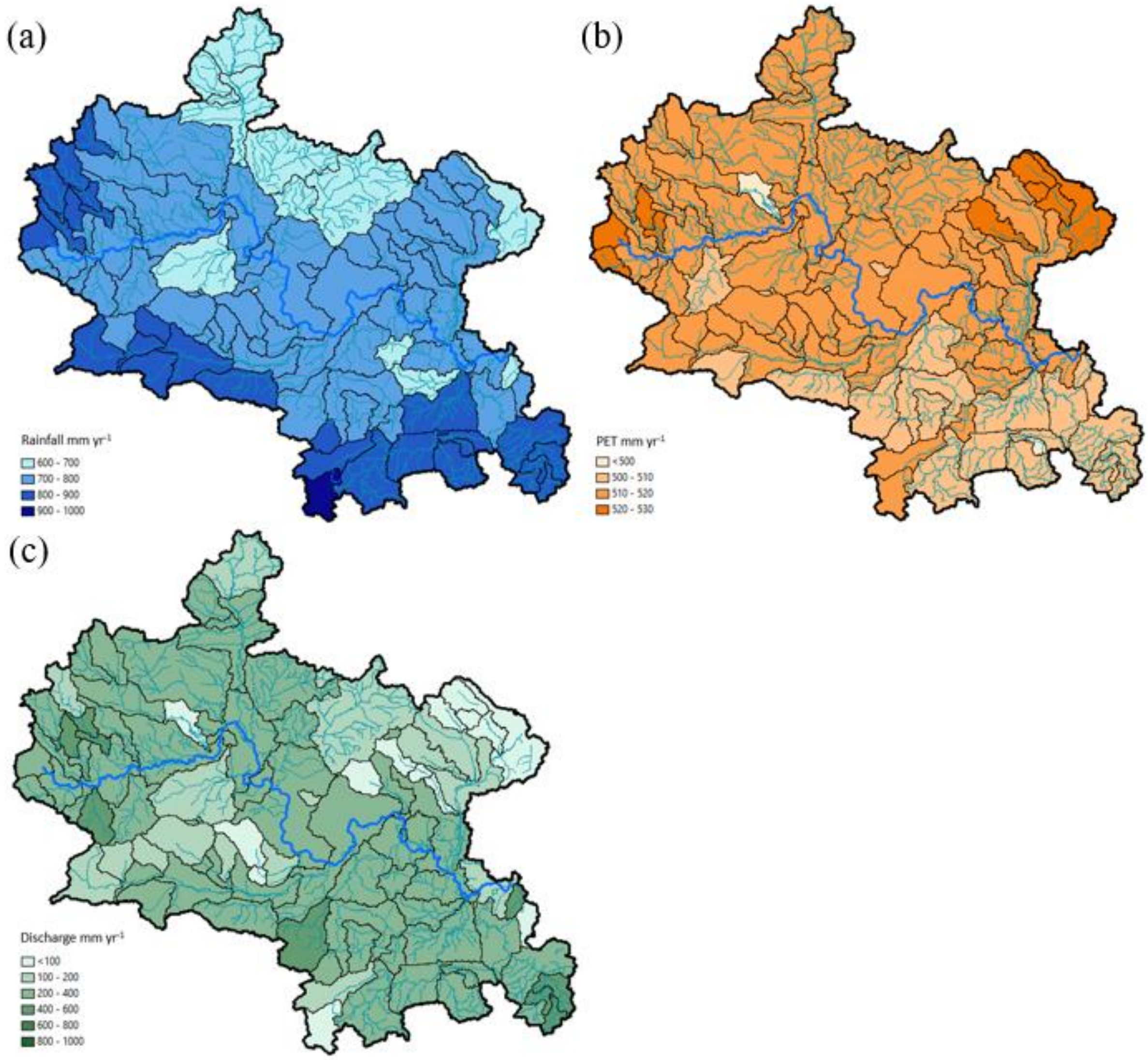

Figure S1: Maps of the Thames at Kingston catchment showing the River Thames at Kingston main river flowing west to east, in relation to (a) catchment mean annual rainfall (CEH-GEAR (Tanguy et al., 2019)), (b) catchment mean annual potential evapotranspiration (CHESS-PE (Robinson et al., 2016)), and (c) catchment mean annual river discharge (National River Flow Archive (Marsh and Hannaford, 2008)).

S2. Uncertainty evaluation of water balance metrics

To understand the potential errors that might be expected over an annual water balance (WB) timescale we used the 106.7 km^2 Coln at Bibury as an example catchment to calculate expected uncertainties in the precipitation (P), river discharge (Q), and actual evapotranspiration (AET) components of the WB. Using the heteroscedastic and independent error model method outlined in Lloyd et al. (2016) we constructed multiple representative timeseries of each of the WB components to quantify estimated uncertainties through time. For Q we applied a non-parametric LOcal Weighted regrESSion (LOWESS) approach to determine the resultant uncertainty bounds characteristics for a given flow magnitude from stage-discharge rating observations for this specific gauge (see Coxon et al., 2015 for LOWESS method). For P we used the relationship between P magnitude (daily) and the standard error determined for the 135.2 km^2 Brue catchment reported in Wood et al. (2000). Finally, for AET we used two papers that suggested, via both equation based and observed measurement methods, that typical uncertainties in catchment scale evapotranspiration was +/- 10-11% (Price et al., 2007; Jakimavičius et al., 2013). These were then each sampled, using their respective uncertainties, to construct 200 time series each of P, Q and E for the same length of the study period using the Lloyd et al. (2016) error model. By combining those we obtained 8,000,000 realisations of WB time series calculations with which we could calculate uncertainties in the annual WB estimates. These results are shown in Fig. S2 below and show that our expected maximal WB uncertainties sampled are in the order of +/- 30 mm yr^{-1} and thus considerably below what we call anomalous WBs within our intercatchment groundwater flow assessment in this paper.

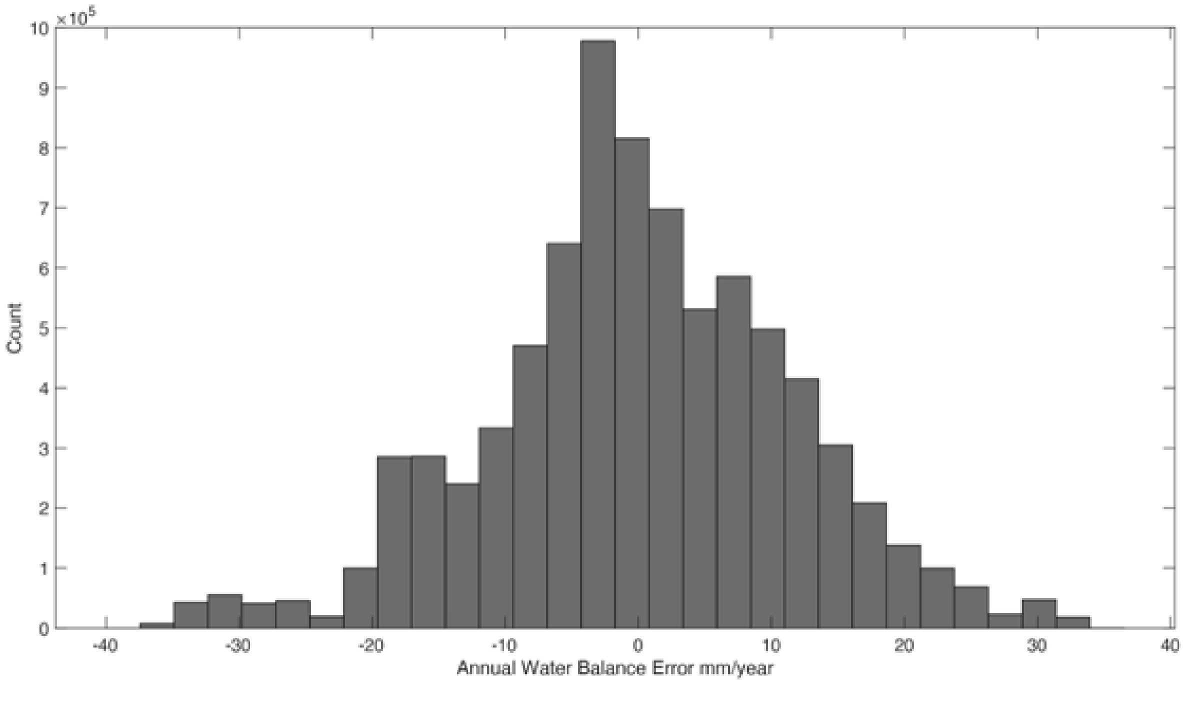

Figure S2: Distribution of 8,000,000 annual water balance evaluations from errors derived using 200 individually sampled P, AET and Q timeseries.

S3. Selection of 100 mm yr^{-1} water balance threshold

Figure S3 shows the sensitivity testing we undertook, trialling different values of water balance thresholds, to account for input data uncertainty. A reach water balance residual of +-50 mm yr^{-1} is equivalent to 7%, 75 mm yr^{-1} equivalent to 10%, 100 mm yr^{-1} equivalent to 14% and 125 mm yr^{-1} equivalent to 17% of the average annual catchment rainfall for the Thames at Kingston. Our uncertainty evaluation in Sect. S2 suggested maximum water balance uncertainties to be 30 mm yr^{-1}. However, given the high number of reaches exhibiting reach water balance residuals greater than even 75 mm yr^{-1} (10% of Kingston rainfall), and the minimal difference between using a review cut-off of 100 or 125 mm yr^{-1}, it was felt that 100 mm yr^{-1} (14% of Kingston rainfall) would be a suitable compromise. This assessment and decision was made in light of the input data uncertainties review in Sect. S3 and Sect. 6.3.1.

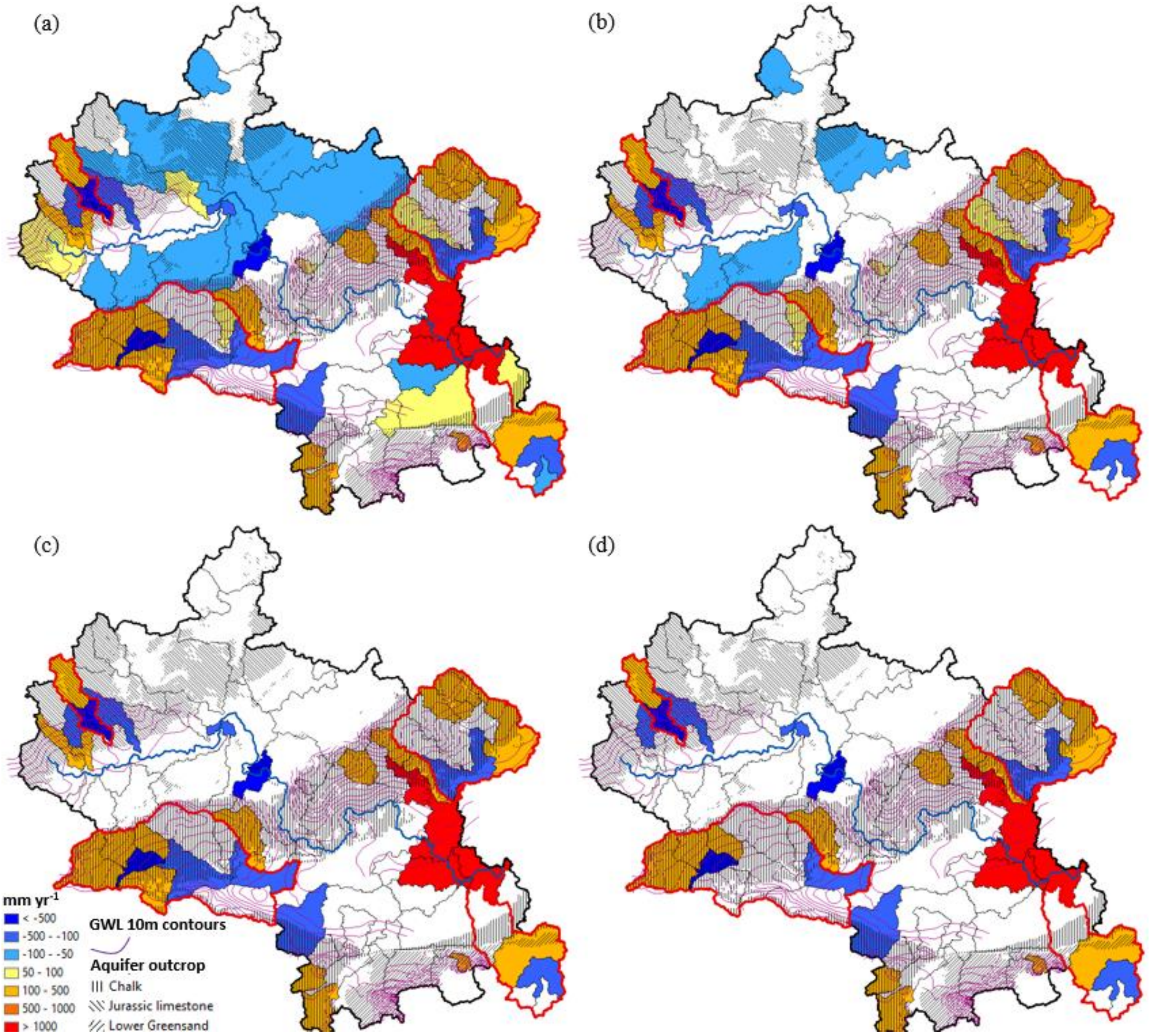

Figure S3: Annual average reach water balance metrics for the Thames at Kingston from 1994-2014 inclusive, showing unaccounted for annual water volume from precipitation after subtraction of actual evaporation and naturalised river flow (in millimetres per year), in relation to aquifer outcrop areas and median groundwater level contours for the same time period. A reach where the water balance residual is within (a) 50 mm, (b) 75 mm, (c) 100 mm and (d) 125 mm of balanced is considered to be conservative, to nominally account for data uncertainties. Catchments referred to in the text are outlined in red.

S4. Non-naturalised results

There is minimal difference between the non-naturalised and the naturalised results (Fig. S4, Fig. S5 and Fig. S6). A non-conservative water balance of >100 mm yr^{-1} is ‘corrected’ by naturalising the discharge series in only three of the 80 reaches. For the purposes of the analysis in our paper, focus has therefore been given to the naturalised results only, owing to their similarity to the non-naturalised results. The non-naturalised results are shown here, alongside the naturalised results, for information.

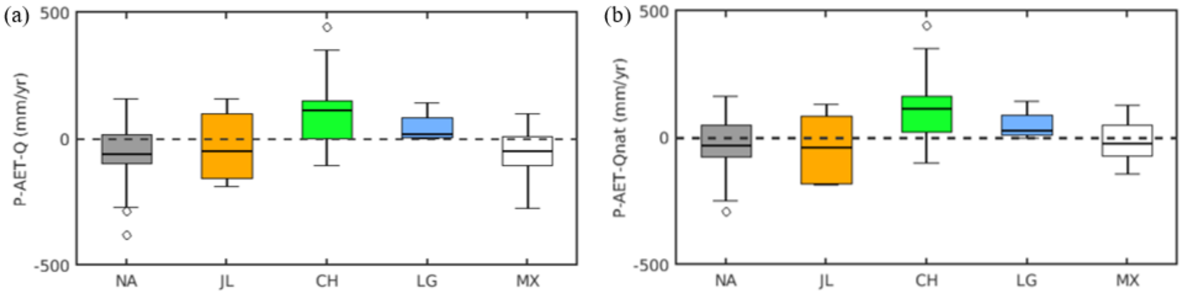

Figure S4: Distribution of annual average reach water balance metrics for each lithology for the Thames at Kingston reaches from 1994-2014 inclusive, showing unaccounted for annual water volume from precipitation after subtraction of actual evapotranspiration and (a) non-naturalised/(b) naturalised river flow (in millimetres per year). A positive water balance residual indicates a “losing” reach and a negative water balance residual a “gaining” reach at the annual time scale. The boxes show the interquartile interval, within which lies 50% of the data, and the horizontal line the median value. The whiskers show the minimum and maximum values excluding outliers. The plots are focussed in to +-500 mm yr^{-1}, thereby excluding some wider outliers. Reaches have been categorised based on >70% catchment geological coverage. CH = Chalk (n=23), JL = Jurassic Limestone (n=11), LG = Lower Greensand (n=4), NA = Non-aquifer (n=28) and MX = Mixed (n=14).

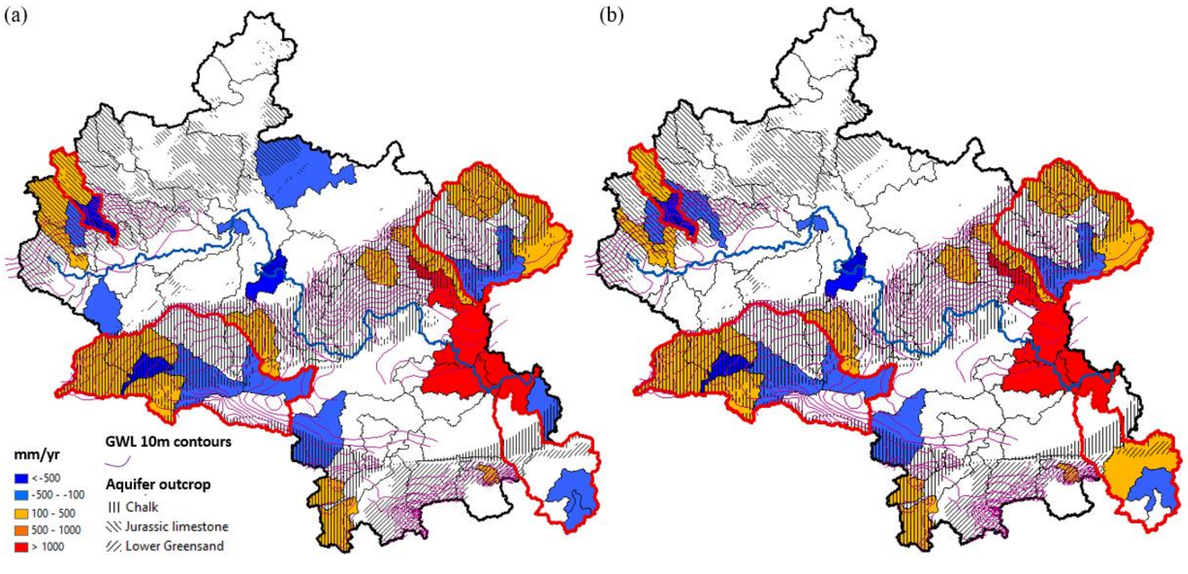

Figure S5: Annual average reach water balance metrics for the Thames at Kingston from 1994-2014 inclusive, showing unaccounted for annual water volume from precipitation after subtraction of actual evaporation and (a) non-naturalised and (b) naturalised river flow (in millimetres per year), in relation to aquifer outcrop areas and median groundwater level contours for the same time period. A reach where the water balance residual is within 100 mm of balanced is considered to be conservative, to nominally account for data uncertainties. Catchments referred to in the text are outlined in red.

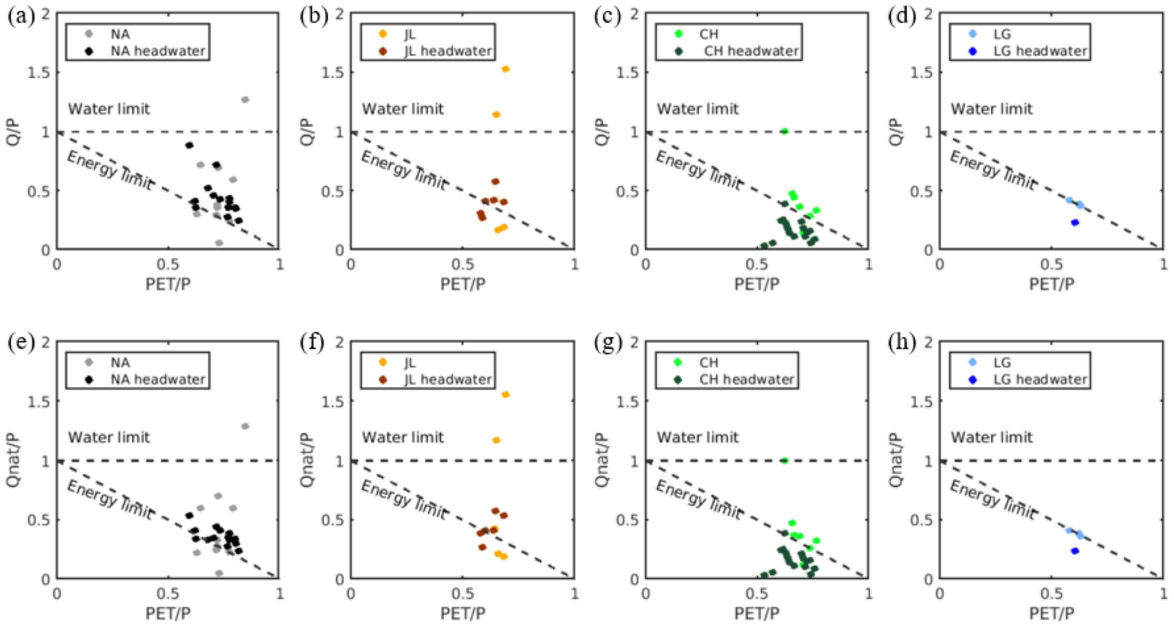

Figure S6: Annual average reach water balance metrics for the Thames at Kingston reaches from 1994-2014 inclusive, showing dimensionless reach runoff coefficient (river flow/precipitation) and dryness index (potential evapotranspiration/precipitation) in relation to the Water Limit, Energy Limit and their headwater (i.e. no upstream gauge) or 'non-headwater' location along the river, under non-naturalised (a) to d) and naturalised (e) to (h) conditions. Reach categorisations are based on >70% catchment geological coverage of NA = Non-aquifer (n=28), JL = Jurassic Limestone (n=11), CH = Chalk (n=23) and LG = Lower Greensand (n=4). The results from the three Lower Thames reaches are not shown on figures (a) and (e) as they have negative reach runoff coefficient results.

References

Jakimavičius, D., Kriaučiūnienė, J., Gailiušis, B. and Šarauskienė, D.: Assessment of uncertainty in estimating the evaporation from the Curonian Lagoon, Baltica, 26, 2, 177–186, http://dx.doi.org/10.5200/baltica.2013.26.18, 2013.

Price, R.M, Nuttle, W.K., Cosby, B.J. and Swart, K.: Variation and uncertainty in evaporation from a subtropical estuary: Florida Bay, Estuar Coast, 30, 497–506, https://doi.org/10.1007/BF02819396, 2007.

Wood, S. J., Jones, D. A. and Moore, R. J.: Accuracy of rainfall measurement for scales of hydrological interest, Hydrol. Earth Syst. Sci., 4, 531–543, https://doi.org/10.5194/hess-4-531-2000, 2000.