Influence of non-linearity in the storage-discharge relationship on discharge droughts

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During drought, most stream flow is derived from stored sources, primarily groundwater. In many catchments the relation between groundwater storage and discharge is non-linear, for example because the aquifer is unsaturated, because of variations in the conductivity of the aquifer or because of decreasing drainage density as a result of decreasing groundwater levels. This non-linearity increases the persistence and severity of droughts according to Eltahir & Yeh (1999). In this paper it is examined whether and how non-linearity in the storage-discharge relationship increases drought duration and severity.

The influence of non-linearity was examined by simulating long time series (10 * 1000 years) of outflow from reservoirs with increasing non-linearity. As input to the non-linear reservoirs recharge was simulated for two catchments: the sub-humid Pang catchment (UK) and the semi-arid Upper-Guadiana catchment (Spain). For the Pang catchment, first 38 years of observed precipitation and evapotranspiration was resampled to 10 * 1000 years using Nearest Neighbour resampling. Subsequently, recharge was calculated using a simple bucket-type model. For a more elaborate description see Peters (2003). For the Upper-Guadiana catchment first 58 years of recharge was simulated with a spatially distributed model and that was subsequently resampled to 10 * 1000 years.

The groundwater discharge is not simulated for these specific catchments, but for a range of reservoirs with different storage characteristics. Each reservoir is characterised by a reservoir coefficient j, which is expressed in days. Here only the results for a reservoir coefficient of 80~d will be presented. For a more full discussion see Peters (2003). For the simulation of the non-linear reservoirs the method developed by van de Griend et al. (2002) was used. The relation between the storage S and the discharge q is given by:

$$S = j(q)q$$

For each time step de reservoir coefficient j is recalculated as a function of the current discharge q. Using this formulation, van de Griend et al. (2002) derived the following recursive solution:

$$q(t+\Delta t) = e^{-\beta \Delta t} q(t) + \left(\beta - \beta^2 \frac{\Delta t}{2} \right) \int_t^{t+\Delta t} R(r) \mathrm{d}r$$

where t is time (d), R is the recharge (mm/d), $\beta = \frac{1}{j(q)b}$ and b is a parameter determining the non-linearity ($0 < b \leq 1$, where b = 1 is the linear case).

From the time series of groundwater recharge and discharge, droughts were derived using the threshold level approach, which means that a drought is defined as an excursion below a constant, predefined threshold. This is illustrated in Fig. 1.

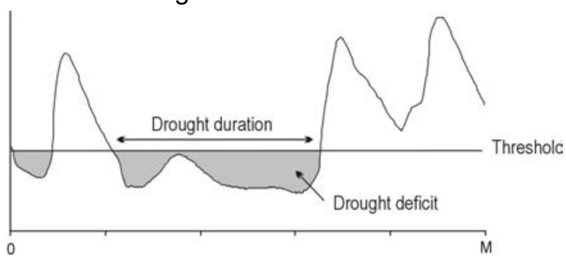

Figure 1. Definition of drought deficit and duration using the threshold level approach.

Fig. 2 shows the frequency distribution of the droughts using Weibull plotting positions for the recharge from the two catchments. From comparing the drought duration for the linear and non-linear reservoir (Fig. 2c and 2d), it is clear that the drought duration (and thus the persistence of droughts) did indeed increase under all circumstances. The drought severity, however, did not uniformly increase. For the recharge from the Pang catchment the drought deficit in fact decreased as a result of non-linearity for droughts with a return period lower than 20 years.

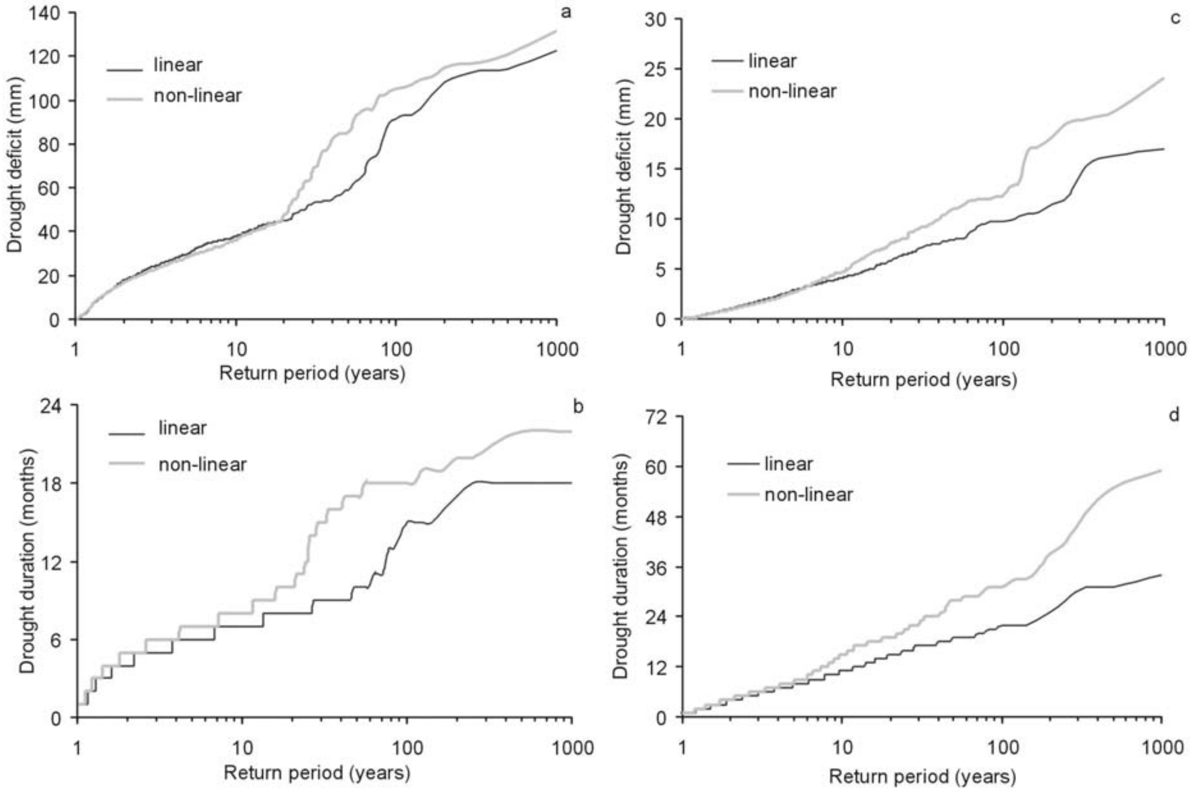

Figure 2. a) Drought deficit for the Pang catchment, b) drought duration for the Pang catchment, c) drought deficit for the Upper-Guadiana catchment and d) drought duration for the Upper-Guadiana catchment. All reservoirs have a reservoir coefficient or equivalent reservoir coefficient of 80 d.

References

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