Appendix A: Hymod model in NewAge-JGrass system

The NewAge system executes one Hymod model at each HRU and routes water downslope. Detailed description of the Hymod model is provided in many studies (Moore, 1985; Van Delft et al., 2009; Boyle et al., 2001; Formetta et al., 2011). In Hymod, each HRU is supposed to be a composition of storages of capability C (L) according to distribution (Moore, 1985):

$$F(C < c) = 1 - (1 - \frac{c}{C_{\max}})^{B_{\exp}}, \tag{A1}$$

where $F(C)$ represents the cumulative probability of a certain water storage capacity (C), $C_{\max}$ is the largest water storage capacity within each hillslope, and $B_{\exp}$ is the degree of variability in the storage capacity. As shown in the schematic diagram (Fig. A1), the precipitation exceeding $C_{\max}$ is sent directly to the volume available for surface runoff. If we call the precipitation volume in a time interval Δt, $J(t) := P(t)\Delta t$, then this "direct" runoff can be estimated according to the following:

$$R_{\mathrm{H}}(t) = \max(0, J(t) + C(t) - C_{\max}), \tag{A2}$$

where $C(t)$ defines the fraction of storages already filled at time t. The latter equation is true for any precipitation and storage level, even when the maximum storage $C_{\max}$ is not exceeded. When precipitation does not exceed $C_{\max}$, runoff volume can be produced by filling some of the smaller storages. The extent to which this happens can be derived by the knowledge of the storage distribution, Eq. (A1), the initial storage $C(t)$, and the precipitation $J(t)$. This residual runoff is, in fact, given by the following:

$$R(t) = \int_{C(t)}^{\min(C(t)+J(t), c_{\max})} F(c)\, \mathrm{d}c. \tag{A3}$$

An analytic expression for the integral in Eq. (A3) is available, which makes the computation easier. Water in storage is made available to evapotranspiration. Water going into the runoff volume, i.e., $R(t)$ and $R_{\mathrm{H}}(t)$, is further subdivided into a surface runoff volume and subsurface storm runoff. Surface runoff, in turn, is composed by the whole of $R_{\mathrm{H}}(t)$ and part of $R(t)$, and $R(t)$ is split according to a partition coefficient α such that the part $\alpha R(t)$ goes into surface runoff volume and $(1-\alpha)$ into the subsurface storm runoff volume. In Hymod, α is a calibration coefficient.

Finally, surface runoff volumes are routed through three linear reservoirs, and subsurface storm runoff volume is routed through a single linear reservoir. A summary of equations for the surface runoff is therefore as follows:

$$\frac{\mathrm{d}S_1(t)}{\mathrm{d}t} = \alpha R(t) + R_{\mathrm{H}}(t) - kS_1(t)Q_1(t) = \frac{S_1(t)}{k}, \tag{A4}$$

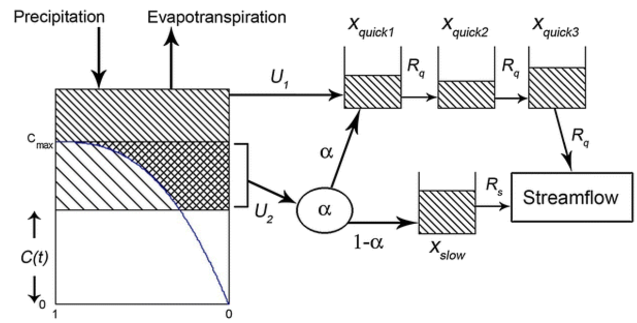

Figure A1. Schematic diagram of the Hymod model (adapted from Van Delft et al., 2009).

where S_1 (L^3) is the storage in the first of the linear reservoirs, and k (T) is the mean residence time in each of the reservoirs. Then, the following applies:

$$\frac{\mathrm{d}S_i(t)}{\mathrm{d}t} = Q_{i-1}(t) - kS_i(t)Q_i(t) = \frac{S_i(t)}{k} \tag{A5}$$

for the other two reservoirs, where S_i (L) with $i = 2, 3$ is the storage in the two remaining surface reservoirs. Subsurface storm runoff is then modeled by the following:

$$\frac{\mathrm{d}S_{\mathrm{sub}}}{\mathrm{d}t} = (1-\alpha)R(t) - k_{\mathrm{sub}}S_{\mathrm{sub}}(t), \tag{A6}$$

where S_{sub} (L^3) is the storage in the subsurface storm-flow system and k_{sub} (T) is its mean residence time. A water-budget equation can be written for the groundwater system as follows:

$$\frac{\mathrm{d}S_{\mathrm{g}}(t)}{\mathrm{d}t} = (J(t) - R(t) - R_{\mathrm{H}}(t)) - \mathrm{ET}(t) - Q_{\mathrm{g}}(t), \tag{A7}$$

where $S_{\mathrm{g}}(t)$ (L^3) is the groundwater storage, and $Q_{\mathrm{g}}(t)$ the groundwater flow which becomes surface flow at the closure of the HRU.

Summarizing, Hymod subdivides each HRU into three reservoirs: a groundwater reservoir (from where evapotranspiration and groundwater flow is allowed), a subsurface storm-water reservoir, and a surface runoff reservoirs set. Partition of precipitation into the three reservoirs is obtained by a calibration coefficient, α, and the use of a probability distribution function of storages' capacity, $F(c)$.

Appendix B: Model performance criteria

The model evaluation statistics used in the paper are the goodness-of-fit indices. The following indexes are used as objective function and comparison of estimations.

1. PBIAS is the measure of average tendency of estimated values to be large or smaller that their measured values. The value near to zero indicates high estimation,

whereas the positive value indicates the overestimation and negative values indicate model underestimation (Moriasi et al., 2007; Gupta et al., 1999).

$$\mathrm{PBIAS} = \frac{\sum_{i=1}^{n}(P_i - O_i)}{\sum_{i=1}^{n} O_i} 100 \tag{B1}$$

The PBIAS value ranges from −20 to 20 % is considered good, and values between ±20 and ±40 % and those greater than ±40 % are considered satisfactory and unsatisfactory respectively (Stehr et al., 2008).

2. Kling–Gupta efficiency (KGE) is developed by Gupta et al. (2009) to provide a diagnostically interesting decomposition of the Nash–Sutcliffe efficiency (and hence MSE), which facilitates the analysis of the relative importance of its different components (correlation, bias, and variability) in the context of hydrological modeling. Kling et al. (2012) proposed a revised version of this index. It is given by the following:

$$\mathrm{KGE} = 1 - \mathrm{ED}, \tag{B2}$$

$$\mathrm{ED} = \sqrt{(r-1)^2 + (vr-1)^2 + (\beta-1)^2}, \tag{B3}$$

where ED is the Euclidian distance from the ideal point, β is the ratio between the mean simulated and mean observed flows, r is the Pearson product-moment correlation coefficient, and v is the ratio between the observed (σ_o) and modeled (σ_s) standard deviations of the time series and takes account of the relative variability (Zambrano-Bigiarini, 2013). The KGE ranges from infinity to a perfect estimation of 1, but a performance above 0.75 and 0.5 is considered to be as good and intermediate, respectively (Thiemig et al., 2013).

3. Pearson correlation coefficient (r) – please refer to Moriasi et al. (2007). The correlation coefficient is best as much as it is close to 1.

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