ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Exercice n° HA 1006

Calage d'un modèle conceptuel semi-distribué en milieu de haute montagne
Annexe 1 : description du modèle hydrologique

GMS_SOCONT

When needed : see Schaefli, 2005 or Schaefli et al., 2005 for details.

The discharge simulation is carried out through a conceptual, semi-lumped model at a daily time step. The catchment is represented as a set of spatial units each of which is assumed to have a homogenous hydrological behaviour. A reservoir based modelling approach is used to simulate separately the hydrological response of each unit. The runoff contributions of all units are summed to provide the total discharge at the outlet of the entire catchment.

Discretisation of the catchment

The hydrological model has two levels of discretisation. The first level corresponds to the separation between the ice-covered part of the catchment and the not ice-covered part. Each of the two areas is characterized by its surface and its hypsometry.

The second level of discretisation consists of a set of elevation bands for each of the two parts of the catchment. For each elevation band, input time series (precipitation, temperature) are computed according to the mean elevation of the band. The corresponding runoff computation is carried out separately for each of the bands, the model depending on whether the band forms part of the ice-covered area or not.

The total runoff Q [$m^3\ s^{-1}$] from the catchment is therefore:

$$Q = \sum_{i=1}^{2} \sum_{j=1}^{n} Q_{i,j} \tag{1}$$

where i is an index for each of the two parts of the catchment and j an index for each of the n elevation bands. $Q_{i,j}$ [$m^3\ s^{-1}$] is the mean daily runoff from elevation band j and the catchment part i.

Meteorological data pre-processing

Temperature

The temperature time series for each elevation band is generated applying a constant lapse rate to the temperature series measured at the closest meteorological station. The temperature gradient is set equal to 0.65°C/100m, a value that is widely used for alpine areas and that corresponds well to the observed gradient between nearby meteorological stations.

Precipitation

The precipitation for each elevation band is interpolated based on the observed precipitation at the station Oberwald and the spatially interpolated mean annual precipitation for the period 1951-1980 given by (Spreafico M. et al., 1992).

Snow accumulation, snow and ice melt

For each elevation band of the catchment, the snow accumulation is computed. The solid and liquid precipitation is separated based on simple temperature threshold.

$$P_{snow} = P_{tot} \quad if \;\; T \le T_0$$
$$P_{liq} = P_{tot} \;\; if \;\; T > T_0 \tag{2}$$

where P_{tot} [mm d-1] is the total precipitation, P_{snow} [mm d-1] the solid and P_{liq} [mm d-1] the liquid precipitation. T [°C] is the mean daily air temperature and T_0 is the threshold temperature that is set to 0°C.

The time evolution of the snow storage can be written as:

$$\frac{H_{snow}(t)}{dt} = P_{snow}(t) - M_{snow}(t) \tag{3}$$

where H_{snow} [mm] is the snow layer height in mm of water equivalent and M_{snow} [mm $^{d-1}$] the actual snow melt.

The snowmelt is calculated according to a temperature-index approach.

$$M_{p,snow} = a_{snow}(T - T_0) \tag{4}$$

$$M_{snow} = \begin{cases} M_{p,snow} & if \;\; M_{p,snow} \le H_{snow} \\ H_{snow} & if \;\; M_{p,snow} > H_{snow} \end{cases} \tag{5}$$

where $M_{p,snow}$ is the potential snowmelt [mm d^{-1}], M_{snow} [mm d^{-1}] the actual snow melt and T_0 the threshold temperature for snowmelt that is set to 0°C.

For the ice-covered elevation bands, the same degree-day approach is used for the ice melt computation.

$$M_{p,ice} = a_{ice}(T - T_{crit}) \tag{6}$$

$$M_{ice} = \begin{cases} M_{p,ice} & if \;\; H_{snow} = 0 \\ 0 & if \;\; H_{snow} > 0 \end{cases} \tag{7}$$

where $M_{p,ice}$ [mm d^{-1}] is the potential ice melt. The actual ice melt M_{ice} [mm d^{-1}] is calculated depending on the snow storage, assuming that there is no ice melt if the glacier surface is covered by snow. Note that the ice storage is assumed to be infinite. This assumption is justified for short periods only (a few years). For longer simulation periods, the ice-covered area has to be re-evaluated regularly.

Runoff model

Ice-covered area

For the part of the catchment that is covered by glacier or isolated ice patches, the runoff model consists of a simple linear reservoir approach:

$$Q_{snow}(t_2) = Q_{snow}(t_1) \cdot e^{-\frac{t_2 - t_1}{k_{snow}}} + [P_{liq}(t_2) + M_{snow}(t_2)] \cdot (1 - e^{-\frac{t_2 - t_1}{k_{snow}}}) \tag{8}$$

$$Q_{ice}(t_2) = Q_{ice}(t_1) \cdot e^{-\frac{t_2 - t_1}{k_{ice}}} + M_{ice}(t_2) \cdot (1 - e^{-\frac{t_2 - t_1}{k_{ice}}}) \tag{9}$$

where $Q_{snow}(t_2)$ [mm d^{-1}] respectively $Q_{ice}(t_2)$ [mm d^{-1}] are the discharge from the snow resp. the ice reservoir at time step t_2 and $Q_{snow}(t_1)$ resp. $Q_{ice}(t_1)$ are the discharges at the previous time step. k_{snow} and k_{ice} are the time constants of the snow respectively the ice reservoir.

The total runoff from the ice-covered catchment area, Q_g, corresponds to the sum of the ice and snowmelt components:

$$Q_g = Q_{snow} + Q_{ice} \tag{10}$$

The runoff model for the ice covered area contains 4 parameters to calibrate: a_{ice}, a_{snow}, k_{ice} and k_{snow}.

Area not covered by ice

For each elevation band of this part of the catchment, an equivalent rainfall corresponding to the sum of liquid precipitation and snowmelt (eq. 4 & 5) is computed.

$$P_{eq} = P_{liq} + M_{snow} \tag{11}$$

Contrary to the glacierized area, the rainfall-runoff transformation in this part of the catchment has to take into account slow infiltration processes and direct runoff. The equivalent rainfall – runoff transformation is carried out by the model SOCONT, a conceptual reservoir-based model developed at the EPFL. It is composed by two reservoirs, a linear reservoir for the slow contribution and a non-linear reservoir for direct runoff. The equivalent rainfall is divided into infiltrated and net rainfall, supplying water to the slow respectively the direct runoff reservoir.

The slow reservoir has two possible outflows, the base flow Q_{base} and actual evapotranspiration *ET*. The net rainfall as well as the actual evapotranspiration is conditioned by the filling rate S/A of the slow reservoir according to equations 12 and 13.

$$P_{net} = P_{tot} \cdot \left(\frac{S}{A}\right)^{y} \tag{12}$$

$$ET = PET \cdot \left(\frac{S}{A}\right)^{x} \tag{13}$$

where ET [mm d^{-1}], PET [mm d^{-1}], P_{net} [mm d^{-1}], and P_{tot} [mm d^{-1}], are the actual and potential evapotranspiration, the net and total rainfall respectively. In the present application, the total rainfall corresponds to the equivalent rainfall (eq. 11). x and y are exponents of the filling rate. A [mm] is the maximum storage capacity of the reservoir and S [mm] the actual storage. The specific runoff q_{base} [mm d^{-1}] is related linearly to the actual slow storage S_{slow} [mm] through the reservoir coefficient k_{slow}.

$$\begin{aligned} q_{base} &= k_{slow} \cdot S_{soil} \\ Q_{base} &= q_{base} \cdot A_c \end{aligned} \tag{14}$$

where Q_{base} [m^3 s^{-1}] is the base flow and Ac [m^2] the catchment area.

The quick flow component Q_{quick} [m^3 s^{-1}] is modeled by a non-linear storage-discharge relationship:

$$Q_{quick} = \beta \cdot s^{1/2} \cdot H^{5/3} \tag{16}$$

where s is the slope of the catchment and β a parameter to calibrate.

The total runoff from the non ice-covered part of the catchment corresponds to the sum of the quick and the base flow:

$$Q_{ng} = Q_{base} + Q_{quick} \tag{17}$$

The model has 5 parameters A, k, x, y and β. According to previous studies (Consuegra D. and Vez E., 1996), the exponent x and y can be set to 0.5 and 2, respectively. The parameters A, k and β have to be calibrated. Several applications of the model (for example (Consuegra D. et al., 1998), (Guex F. et al., submitted)) have shown that this model is able to reproduce all the major characteristic of the discharge such as floods, flow-duration-curves or hydrological regime.

Schaefli, B., 2005. Quantification of modelling uncertainties in climate change impact studies on water resources : Application to a glacier-fed hydropower production system in the Swiss Alps. PhD Thesis, EPFL, Lausanne, 209 pp.

Schaefli, B., Hingray, B., Niggli, M. and Musy, A., 2005. A conceptual glacio-hydrological model for high mountainous catchments. Hydrology and Earth System Sciences, 9(1-2): 95-109.