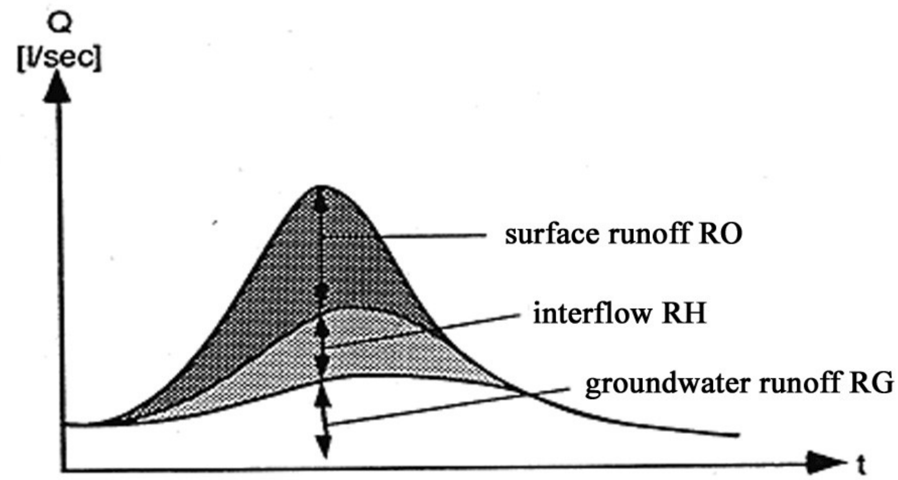
3.6 The runoff generation, runoff components and runoff concentration

The runoff is defined as the water volume per time unit (m^3/s or l/s) that flows of a catchment through a surface runoff profile (e.g. river profile) and possibly also through a subsurface way. The water which passes a gauged profile of a river originates from an area, the catchment area, which is defined by the watersheds. We have to differentiate between the surface and the subsurface catchment areas. The surface catchment area is defined by natural watersheds like mountain ridges. The dimension of the surface catchment area corresponds to the horizontal projection of the area which is enclosed by the watersheds. The subsurface catchment area is affected by the geological circumstances. The characteristics of the geological layers but also geological faults, cleavages or karsts can influence the water flow in a way, which make difficult to asses if all the water originating in a watershed is observed at the gauge or if there are inflows from and/or outflows to other catchments.



Composition of a runoff hydrograph from the surface runoff, the interflow and the groundwater runoff.

The equations of the runoff-generation module as integrated into Alpine3D.

This paragraph presents the equations of the water flows within the runoff-generation module of Alpine3D. The schematic representation of the water flows is displayed by the figure right-here. Such flows are computed for each grid point at each time step *dt* [h]. Table A3 summarizes the variables and parameters of the soil and runoff-generation modules.

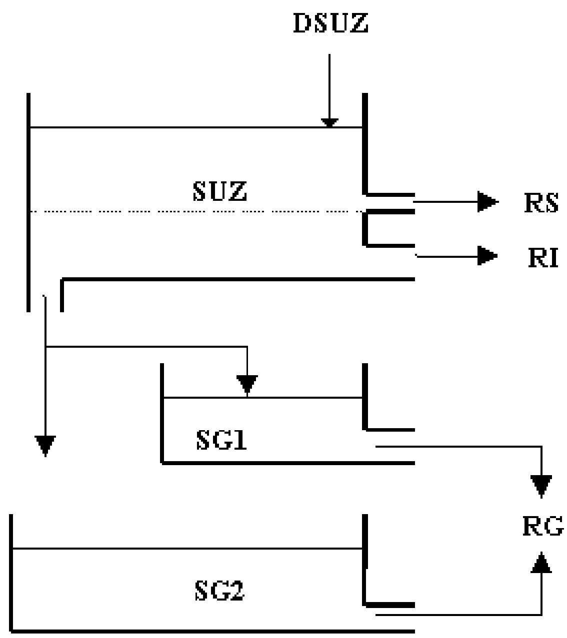


Table A2 Main variables and parameters of the soil and runoff-generation modules.

Name	Unit	Definition
State Variables		
DSUZ	$[mm \cdot dt^{-1}]$	Inflow into the runoff-generation module
SUZ	[mm]	Upper storage reservoir
PERC	$[mm \cdot dt^{-1}]$	Deep percolation rate
RS	$[mm \cdot dt^{-1}]$	Surface runoff
RI	$[mm \cdot dt^{-1}]$	Interflow
SG1	[mm]	Fast response groundwater reservoir
SG2	[mm]	1st order slow response groundwater reservoir
SG3	[mm]	2nd order slow response groundwater reservoir
GR1	$[mm \cdot dt^{-1}]$	Recharge of SG1
GR2	$[mm \cdot dt^{-1}]$	Recharge of SG2
GR3	$[mm \cdot dt^{-1}]$	Recharge of SG3
RG1	$[mm \cdot dt^{-1}]$	Fast response groundwater runoff component
RG2	$[mm \cdot dt^{-1}]$	Delayed groundwater runoff component
R_{TOT}	$[mm \cdot dt^{-1}]$	Total runoff
Tunable parameters		
SGR	[mm]	Threshold content of SUZ for generation of surface runoff
$SG1_{MAX}$	[mm]	Maximal content of the fast response groundwater reservoir SG1
K0	[h]	Storage coefficient for surface runoff
K1	[h]	Storage coefficient for interflow
K2	[h]	Storage coefficient for quick response baseflow
K3	[h]	Storage coefficient for delayed baseflow
$PERC_{MAX}$	$[mm \cdot dt^{-1}]$	Maximal deep percolation rate

The inflow *DSUZ* into the storages of the runoff-generation module is generated in the snow melting and vegetation modules of Alpine 3D. At a first stage, the storage reservoir *SUZ* is incremented by *DSUZ*:

$$SUZ_1(t) = SUZ(t-1) + DSUZ(t) \cdot dt \tag{3.6-2}$$

SUZ is emptied by deep percolation *PERC* into the reservoirs of the saturated zone of the soils *SG1*, *SG2*, *SG3,* by surface runoff RS, and by interflow RI:

$$SUZ_2(t) = SUZ_1(t) - PERC(t) \cdot dt \tag{3.6-3}$$

$$with \quad PERC(t) = MIN\left[\left(SUZ_1(t) \cdot dt^{-1}\right), PERC_{MAX}\right] \tag{3.6-4}$$

The maximum percolation rate $PERC_{MAX}$ is a tunable parameter. *PERC* (eq. 3.6-4) is limited by the content of *SUZ* obtained from equation (eq. 3.6-2). The generation of surface runoff *RS* (eq. 3.6-5) and interflow *RI* (3.6-5) depends on the content of the linear reservoir *SUZ*, as obtained from Equation (3.6-3):

$$RS(t) = \left(SUZ_2(t) - SGR\right) \cdot \left(1 - e^{-dt/K0}\right) \cdot dt^{-1} \quad if \quad SUZ_2(t) > SGR$$
$$RS(t) = 0 \quad if \quad SUZ_2(t) \le SGR \tag{3.6-5}$$
$$RI(t) = SUZ_2(t) \cdot \left(1 - e^{-dt/K1}\right) \cdot dt^{-1} \quad if \quad SUZ_2(t) > 0$$
$$RI(t) = 0 \quad if \quad SUZ_2(t) = 0$$

where *SGR* is a model parameter defining a threshold content of *SUZ* [mm] that must be exceeded to allow for surface runoff generation. The two storage coefficients *K0* and *K1* [h] are tuned through model calibration and adopted as catchment specific parameters to govern the generation of surface runoff and interflow, respectively.
The content of *SUZ* at the end of the time-step is equal to:

$$SUZ(t) = SUZ_2(t) - \left(RI(t) + RS(t)\right) \cdot dt \tag{3.6-6}$$

The recharge rates *GR1*, *GR2* and *GR3* of the groundwater storage reservoirs *SG1, SG2* and *SG3* are determined as a function of the deep percolation rate *PERC*, obtained from equation (3.6-4). The computation of the water flows within the groundwater storages and runoff components follows the method developed by Schwarze *et al.* (1999):

$$if \quad SG1(t) \ge SG1_{MAX} \quad \begin{aligned} GR1(t) &= 0 \\ GR2(t) &= PERC(t) \cdot 8/9 \\ GR3(t) &= PERC(t) \cdot 1/9 \end{aligned} \tag{3.6-7}$$

$$if \quad SG1(t) < SG1_{MAX} \quad \begin{aligned} GR1 &= MIN\left(PERC(t), GR1_{MAX}(t)\right) \\ GR2 &= \left(PERC(t) - GR1\right) \cdot 8/9 \\ GR3(t) &= \left(PERC(t) - GR1\right) \cdot 1/9 \end{aligned} \tag{3.6-8}$$

$$\text{with} \quad GR1_{MAX}(t) = \left[\frac{\left(SG1_{MAX} - SG1(t)\right)}{K2_H}\right] \tag{3.6-9}$$

where $SG1_{MAX}$ is a threshold factor that restricts the content of the quick response groundwater reservoir *SG1*. Equation (3.6-9) assures that $SG1_{MAX}$ is not exceeded during the time-step *dt*.
Equations 3.6-10 to 3.6-12 describe the computation of the change in storage of the three groundwater reservoir within *dt*.

$$SG1(t) = SG1(t-1) \cdot e^{-dt/K2} + \left[\left(1 - e^{-dt/k2}\right) \cdot GR1(t) \cdot K2\right] \tag{3.6-10}$$
$$SG2(t) = SG2(t-1) \cdot e^{-dt/K3} + \left[\left(1 - e^{-dt/k3}\right) \cdot GR2(t) \cdot K3\right] \tag{3.6-11}$$
$$SG3(t) = SG3(t-1) \cdot e^{-dt/K4} + \left[\left(1 - e^{-dt/k4}\right) \cdot GR3(t) \cdot K4\right] \tag{3.6-12}$$

The generation of the groundwater runoff components is governed by tuneable storage coefficients:

$$RG1(t) = \frac{SG1(t)}{K2} \tag{3.6-13}$$

$$RG2(t) = \frac{SG2(t)}{K3} + \frac{SG3(t)}{K4} \tag{3.6-14}$$

with $K4 = K3 \cdot 1/9$ (3.6-15)

K2 and *K3* are the storage coefficients [h] governing the generation quick response (*RG1*) and delayed (*RG2*) groundwater runoff, respectively. The additional reservoir *SG3* also generates a quick response groundwater component (*RG3*), whose storage coefficient *K4* is parameterized in function of *K3* (equation 3.6-15). The storage coefficients of the groundwater runoff components can be either tuned through model calibration or determined by an analysis of the hydrograph's recession curve (Schwarze *et al.* 1999).
The total runoff-generation R_{TOT} in the time-step *dt* is determined by adding all the components generated from the upper storage reservoir and the groundwater reservoirs:

$$R_{TOT}(t) = RS(t) + RI(t) + RG1(t) + RG2(t) \tag{3.6-16}$$

R_{TOT} is assumed to be instantaneously routed to the catchment outlet.