

EvalHid tool for evaluation of water resources.

Technical Manual v1.1

Last Modification: February 13th, 2017

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1. INTRODUCTION

Water resource assessment is a key aspect of water resource planning and management. There are two methodologies to evaluate water resources: naturalising streamflows and rainfall-runoff modelling. Both methodologies are often complementary and required. The software EVALuation of HYDric resources (EVALHID) is a computer module for the development of Rainfall-Runoff Models (RRM) in complex basins. The module consists of several types of models that can be selected based on the available data, the complexity of the basin and the user experience in the development and calibration of hydrological models. All the available models are aggregated with semi-distributed application. This program is integrated within AQUATOOL Decision Support System Shell (Andreu et al., 1996) for the development of models related to water resources planning and management.

2. MAIN FEATURES AND MODELS

The proposed approach represents a conceptual aggregation of semi-distributed models. This means that each basin modelled is subdivided into sub-basins and each sub-basin can be modelled using one of the hydrological models available in the program.

For each sub-basin to be modelled it is necessary to dispose time series of precipitation, potential evapotranspiration (ETP) and surface of the sub-basin. In order to develop a snow model, it is necessary to have time series of the air temperature. All these time series must be referred to the same period. Generally, it is also recommended to dispose measured data, such as naturalized streamflows, which will be useful for the calibration of the parameters of the model. These observed data are not indispensable for model simulation.

In summary, the main features of the program are the following:

- Availability of different RRM's applicable according to different factors.
- It also has several models to estimate the snowfall-runoff.
- It allows the development of models for large basins and complex systems.
- Time scale configurable and defined by the user.
- Possibility of modelling, for the sub-basins selected, only the surface runoff estimating the infiltration as an output of the program.
- Couple with SIMGES (management simulation model) and use it for the modelling of the groundwater runoff.

Figure 1 shows a simplified scheme of EvalHid operation. As the figure shows, the time data series files, a Model data file, a Configuration file and a Tags file are necessary. Additionally, in order to change any default filename users can create the *Apo_Archivos.inp* file for this purpose.

The Model data file contains all the information of the models: number of models, names, type of models, parameters, among others. The Configuration file contains aspects related to correction factors and units. The Tags file includes information about errors and other warnings messages that the program uses to advise the user of possible incidences. This last file comes with the installation of the program and it is not necessary to create it. All other input files can be generated by the user or with the program interface.

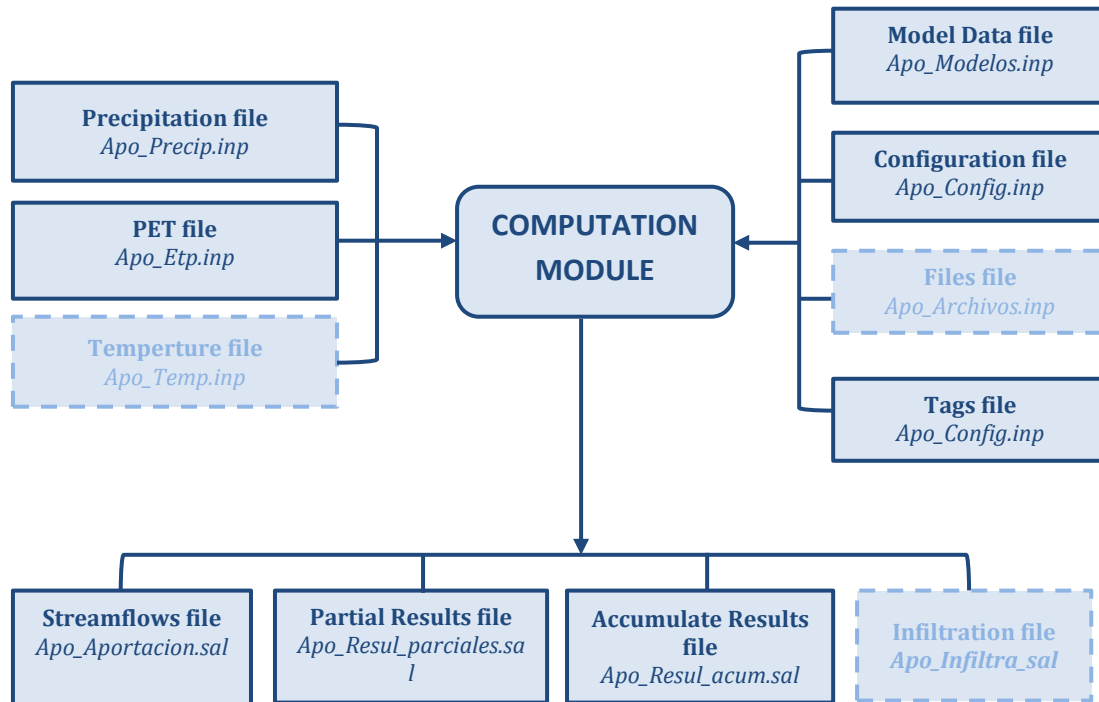


Figure 1: EvalHid operation scheme.

The outputs include several files: Partial Results, Accumulated Results, Streamflows and, optionally, Infiltrations. The Partial Results file contains, for each sub-basin modelled, the time series results of the state variables and flows according to the selected model. The Accumulated file presents the temporal accumulation of some of these variables. The Streamflows file assembles, for the time scale defined in the accumulation, the total accumulated runoff at each of the defined surface drainage points (or intermediate streamflow element in AQUATOOL). In the same way, the Infiltrations file collects infiltrations accumulated temporarily in the groundwater accumulation points (aquifer inputs). These last two concepts are explained below.

2.1. Available models

For each sub-basin, any of the available models in EvalHid can be chosen. A snow model can also be selected. The output of the snow model is called "liquid precipitation" and this is an input of the rainfall-runoff model. Initially, the available RRM's were Témez, HBV and Sacramento (see the Annexes for the different models). Each of them presents different levels of complexity in hydrological modelling and has been widely applied. The snow models have been denominated Snow N1 and Snow N2.

The Témez model (Témez, 1977) is a model of few parameters with a long trajectory of application in Spain for the evaluation of water resources. Its low number of parameters makes it particularly suitable in basins with a reduced number of data.

The HBV model (Bergström, 1995), which has a long tradition in Nordic countries, allows hydrological modelling without a great number of parameters, making it quite versatile on many occasions. The original model considers the snow modelling presented in this program as the Snow N1 model.

Finally, the Sacramento model (Burnash et al., 1973) also known as "SAC-SMA" is a model with a high number of parameters, up to 16, which allows hydrological processes to be modelled in great detail when data is widely available.

As mentioned, the Snow N1 model corresponds to the classic formulation of the snow HBV model. The interest of this model lies in its simplicity because it only needs a single parameter. The Snow N2 model is a little more complex because it considers the water content in the snow, thus considering two state variables and a greater number of parameters.

The mathematical formulation of each model and a detailed description is presented in the Annexes of this document.

For each sub-basin, the user must provide: surface, time series data of precipitations and PET. Optionally also time series data of air temperatures. In addition to the sub-basins in the model, surface accumulation points and groundwater accumulation points must be defined. The purpose of these ones is explained below.

2.2. Surface drainage points

The surface drainage points are used to obtain the runoff at a given point as the sum of the total surface runoff from several basins or sub-basins. In AQUATOOL this surface point corresponds with an intermediate streamflow element. Different surface drainage points can be defined. Within the tab with the information related to each sub-basin, the user can optionally define (in the EVALHID interface) a surface drainage point. Different sub-basins can share the same drainage point. Thus, the program, as an additional result, provides the accumulated surface runoff at each drainage point (or intermediate streamflow element) resulting from the addition of surface runoff from different sub-basins.

2.3. Groundwater accumulation points (or infiltrations)

EVALHID module allows modelling in a sub-basin only the surface component leaving the groundwater to be considered within other modelling tools available in SIMGES program or any other program that incorporates aquifer modelling. First, a set of groundwater drainage points must be defined (or aquifers in AQUATOOL). Subsequently, when a groundwater drainage point is indicated in a sub-basin, the production of surface runoff, soil moisture balance and infiltration is calculated. The latter variable is a result that is presented additionally and cumulatively for each groundwater drainage point. Several basins can share a single groundwater drainage point or infiltration aquifer. With this, the tool will not model the groundwater component in these sub-basins.

It is important to note that in Sacramento model the infiltration or percolation is calculated as a function of the water deficit in the lower part, so this variable cannot be estimated without modelling the underground runoff. However, in this model there is a parameter called SIDE. This parameter allows extracting from the groundwater runoff part of the flow that will not arrive to the river. In the EVALHID module, it is considered that if a sub-basin that is being modelled with Sacramento is assigned to an aquifer, the part of the runoff that is extracted with the parameter SIDE is the one that is considered in the results of infiltration to the aquifer.

2.4. Units

The input data to the model, i.e. the time series data of precipitation and PET, must be entered in mm. The time scale is defined in terms of time series data. In general, the most common is that these models are applied daily (or monthly) so the data from precipitation and PET files come in mm/day (or mm/month).

If the data of these files are presented in another temporal scale, it must be taken into account by the Configuration file, which allows modifying the model parameters changing units. The user should know the possibilities of the models being applied to another time scale.

On the other hand, the state variables of all models should be entered in mm, including, for example, the initial volume of the aquifer to be introduced in the Témex model. In this case, the real volume would be divided by the surface of the sub-basin.

By default, it is assumed that the surface of the sub-basin is entered in Km^2 . The Configuration file contains a coefficient that corrects the flow units, the product of the surface by the runoff (mm). The default option translates the final runoff into Hm^3 . If the user wants to get other units, the coefficient of the Configuration file must be modified.

ANNEX A.1. TÉMEZ MODEL DESCRIPTION

Témez model (Témez, 1977) belongs to the group of so-called aggregated models of river basin simulation (Estrela, 1992).

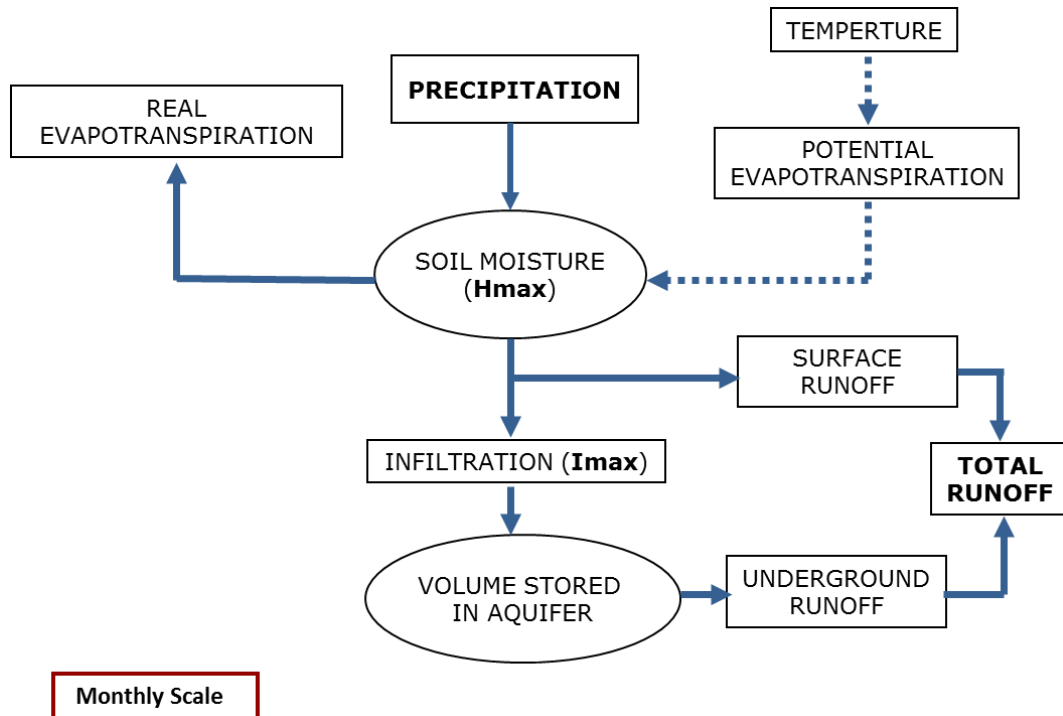


Figure 2: Conceptual schema of the simulation of the hydrological cycle of the Témez model.

The most commonly used time interval is monthly time step. However, as the theoretical development of the model is general, this model can be applied at any time interval (hourly, daily, monthly, or annual). In this case, it should be verified that the time periods employed provide a consistent response with the physical reality of the system.

The model considers the soil divided into two zones:

- Upper: unsaturated zone in whose pores water and air coexist, and its water content is assimilable to soil moisture.
- Lower or aquifer area, which is saturated and it works as an underground water storage that flows into the surface drainage network.

The moisture balance carried out by the model is constituted by the incoming precipitation flow (P_i), which is distributed among a series of outflows, intermediate flows and intermediate storage. The different components of flows and storages are illustrated in the following figure.

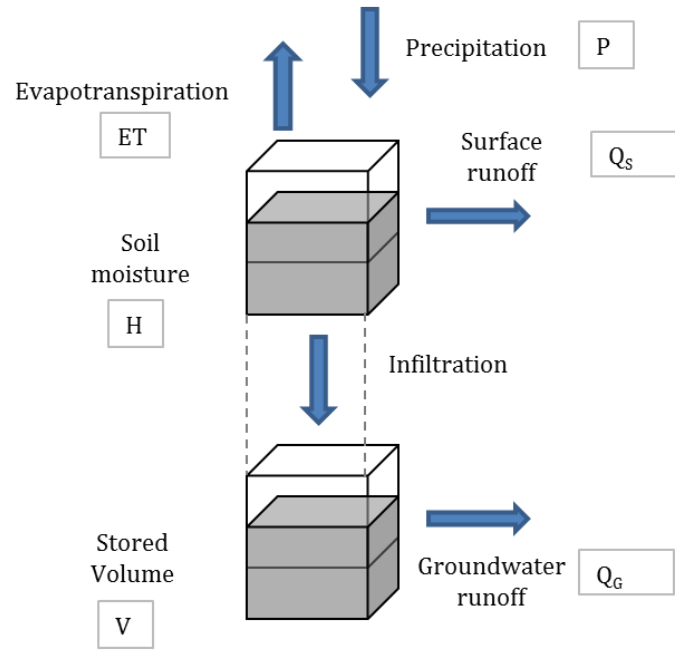


Figure 3: Scheme of flows and storage of the Témez model.

In the following lines, the state equations of the model are developed (Témez, 1977).

In the model, the water fraction which precipitates on the soil (P_t) is stored in the upper area (H_t), and the rest, the excess (T_t), is distributed between the surface runoff (Q_s) and the infiltration into the aquifer (I_t) (or recharge (R_t)).

The total excess (T_t) is calculated according to the following equations:

$$T_t = 0 \quad \text{if } P_t \leq P_0$$

$$T_t = \frac{(P_t - P_0)^2}{P_t - \delta_t - 2P_0} \quad \text{if } P_t > P_0$$

where:

$$\delta = H_{max} - H_{t-1} + PET_t$$

$$P_0 = C (H_{max} - H_{t-1})$$

being:

- H_{max} : the maximum soil storage capacity (mm), which depends on the soil features and vegetation where evapotranspiration takes place. The value of H_{max} increases as those factors that facilitate the retention of water in the soil and the thickness of the same that can be drained by evapotranspiration do.
- H_{t-1} : the soil storage (mm) at time t-1
- PET_t : the potential evapotranspiration (mm) in the time interval t. It is the maximum evapotranspiration that would be produced under optimal conditions of humidity.

- C: the start coefficient for the excess. A dimensionless factor, which takes values around 0.30 (Témez, 1977) and defines the start of the runoff before reaching the maximum soil moisture H_{max} .

Consequently, when the amount of rainfall is less than P_{0t} , all rainwater is stored as soil moisture, being susceptible to evapotranspiration, and the total excess is zero. From the value of P_{0t} , precipitation simultaneously increases the excess and the soil moisture component. As can be seen in Figure 5, the curve is not linear, starts from zero in $P = P_0$ and tends to $P - \delta$ for high rains.

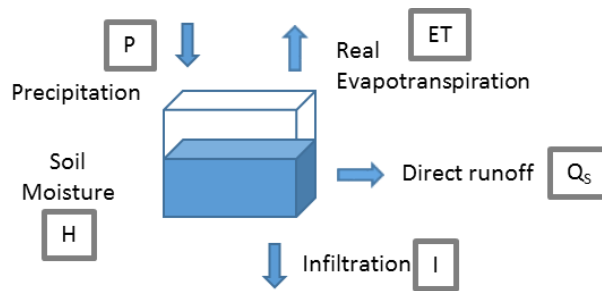


Figure 4: Transformation of precipitation into excess.

Once the excess (T_t) is estimated, the soil moisture at the end of each month is obtained by the following expression:

$$H_t = \max \left\{ \begin{array}{l} 0 \\ H_{t-1} + P_t - T_t - PET_t \end{array} \right.$$

The real evapotranspiration (ET_t) is obtained by the following expression:

$$ET_t = \min \left\{ \begin{array}{l} H_{t-1} + P_t - T_t \\ PET_t \end{array} \right.$$

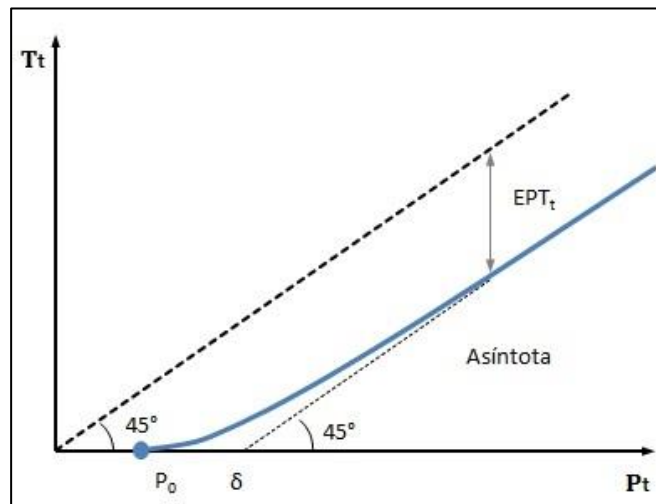


Figure 5: Excess curve.

The infiltration to the aquifer depends on the excess and the parameter called maximum infiltration (I_{max}). I_{max} expresses the maximum amount of water that can infiltrate the soil in one month. The infiltration can be computed with the following empirical expression:

$$I_t = I_{max} \cdot \frac{T_t}{T_t + I_{max}}$$

Infiltration increases as the excess increases. The infiltration tends asymptotically to its maximum, I_{max} . In addition, if the excess is zero, infiltration is also zero. The maximum infiltration (I_{max}) does not depend exclusively on the properties of the terrain, but also on the intensity and concentration of precipitation. It usually takes values between 100 mm/month and 400 mm/month depending on whether the rain is sporadic or persistent (Témez, 1977), although these should not be considered as limits to calibrate a model.

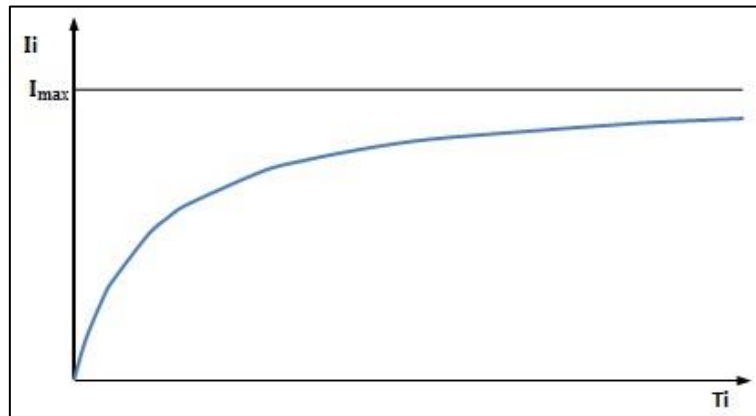


Figure 6: Infiltration to the aquifer vs existing excess curve.

The excess that does not infiltrate to the aquifer becomes surface runoff at the end of month t , according to the following expression:

$$Q_{S_t} = T_t - I_t$$

The groundwater runoff produced during month t (Q_{G_t}) is formed by the drainage of water stored in the aquifer (V_t) above the outlet threshold to the river network.

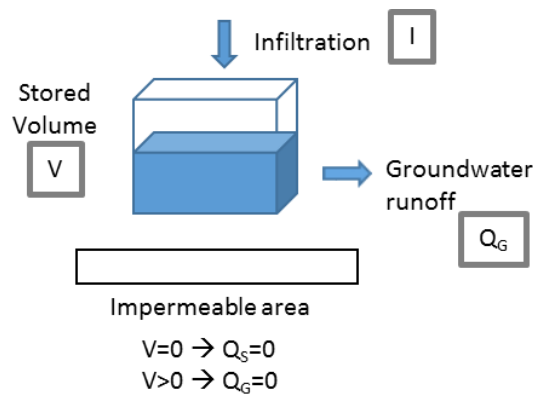


Figure 7: Groundwater runoff generation.

In order to simulate the behaviour of the aquifer, a single-celled model is proposed, which is based on an exponential function that represents the depletion curve of a spring. The state variable is the volume stored in the aquifer (V_t). The flow rate assigned to the surface network (Q_t) is obtained by the following expression:

$$Q_t = \alpha \cdot V_t$$

where

α is a constant with dimensions of $[T^{-1}]$

A mass balance equation is applied to the aquifer as the following ordinary differential equation:

$$I_t - Q_t = \frac{dV_t}{dt}$$

where

$I(t)$ are the inputs to the aquifer at time t (recharges)

$O(t)$ are the outputs of the aquifer at time t (releases)

$V(t)$ is the volume stored in the aquifer at time t

Substituting the first equation in the second one and considering $R(t)$ as the net recharge flow to the aquifer at time t :

$$R_t - \alpha \cdot V_t = \frac{dV_t}{dt}$$

This differential equation can be solved with the following expression:

$$V_t = V_0 e^{-\alpha \cdot t} + \frac{R}{\alpha} (1 - e^{-\alpha t})$$

Expressing the volume as a function of the flow and making $R=0$ gives an expression representing the aquifer depletion curve:

$$Q_t = Q_0 \cdot e^{-\alpha t}$$

The recharge (R) can be expressed as $R = S \cdot I_t$ (where S is the surface of the basin). In this way, the equation that determines the volume in the aquifer in month t would be the following:

$$V_t = V_{t-1} e^{-\alpha \cdot \Delta t} + \frac{S \cdot I_t}{\alpha} (1 - e^{-\alpha \Delta t})$$

The following table shows a summary of the parameters of the model and the ranges between which they can oscillate. Although values finally calibrated can exceed these limits.

	Hmax (mm)	C	I _{max} (mm)	Alfa (month ⁻¹)
Min	50	0.2	10	0.001
Max	250	1	150	0.9

Table 1: Parameter ranks of the Téméz model

ANNEX A.2. HBV MODEL DESCRIPTION

According to Garcia et al 2016: The integrated rainfall-runoff model HBV (Bergström, 1976, 1992) is composed of a humidity reservoir and two (upper and lower) soil storage reservoirs. The structure of the implemented model is presented in the Figure 8.

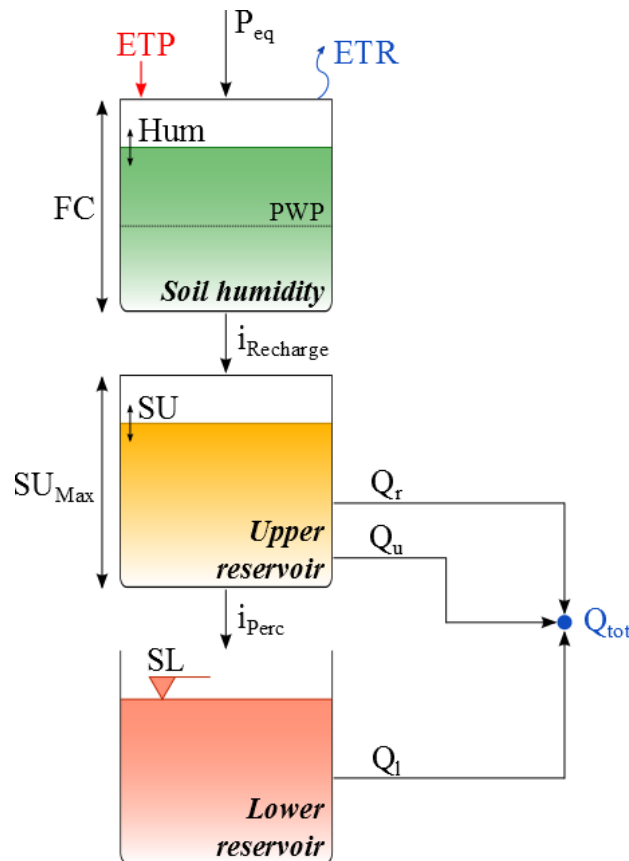


Figure 8: HBV model

Table 2: List of parameters and initial conditions for the HBV model

Name	Units	Description	Regular Range
A	m ²	Surface of the basin	>0
Beta	-	Model parameter (shape coefficient)	1 to 5
FC	m	Maximum soil storage capacity	0.050 to 0.65
PWP	-	Soil permanent wilting point threshold	0.030 to 1
SUMax	m	Upper reservoir water level threshold	0 to 0.10
Kr	1/d	Near surface flow storage coefficient	0.05 to 0.5
Ku	1/d	Interflow storage coefficient	0.01 to 0.4
Kl	1/d	Baseflow storage coefficient	0 to 0.15
Kperc	1/d	Percolation storage coefficient	0 to 0.8
HumIni	m	Initial humidity	-
SUIni	m	Initial upper reservoir water level	-
SLIni	m	Initial lower reservoir water level	-

The calculation of the recharge is carried out depending on a model parameter *Beta*, as presented in equation HBV.1. *ETR* is calculated as shown in equation HBV.2. Finally, the humidity of the soil (*Hum*) is performed taking into account the input (Equivalent precipitation,

P_{eq}) and outputs (Recharge intensity and ETR) as presented in equation HBV.3. Additionally, and based on Seibert (1997), parameter PWP is a rate related to parameter FC. Thus, the height of the soil permanent wilting point threshold is calculated multiplying PWP by FC.

$$i_{\text{Recharge}} = \left(\frac{\text{Hum}}{\text{FC}} \right)^{\text{Beta}} \cdot P_{eq} \quad (\text{HBV.1})$$

$$\begin{aligned} ETR &= ETP \cdot \frac{\text{Hum}}{(\text{PWP} \cdot \text{FC})} && \text{if } \text{Hum} < (\text{PWP} \cdot \text{FC}) \\ ETR &= ETP && \text{if } \text{Hum} \geq (\text{PWP} \cdot \text{FC}) \end{aligned} \quad (\text{HBV.2})$$

$$\begin{aligned} d\text{Hum}/dt &= (P_{eq} - i_{\text{Recharge}}) - ETR \\ \text{Hum} &\geq 0 \end{aligned} \quad (\text{HBV.3})$$

with i_{Recharge} : Reservoirs recharge intensity [L/T]; Hum : Humidity [L]; FC : Maximum soil storage capacity [L]; Beta : Model parameter (shape coefficient) [-]; P_{eq} : Equivalent precipitation [L/T]; ETR : Evapotranspiration [L/T]; ETP : Potential evapotranspiration [L/T]; PWP : Soil permanent wilting point threshold [-].

Then, near surface (or run-off) flow is calculated depending on the water level in the *Upper reservoir* (SU) and its threshold, as well as on a flow storage coefficient K_r .

$$\begin{aligned} Q_r &= K_r \cdot (SU - SU_{\text{Max}}) \cdot A && \text{if } SU > SU_{\text{Max}} \\ Q_r &= 0 && \text{if } SU \leq SU_{\text{Max}} \end{aligned} \quad (\text{HBV.4})$$

with Q_r : Near surface flow (or run-off flow) [L³/T]; K_r : Near surface flow storage coefficient [1/T]; SU : Upper reservoir water level [L]; SU_{Max} : Upper reservoir water level threshold [L]; A : Basin surface [L²].

The Upper reservoir (or interflow reservoir), corresponding to the upper soil storage and producing the interflow, is computed as follows:

$$\begin{aligned} dSU/dt &= i_{\text{Recharge}} - (K_{\text{perc}} + K_u) \cdot SU - Q_r/A \\ SU &\geq 0 \end{aligned} \quad (\text{HBV.5})$$

$$i_{\text{perc}} = K_{\text{perc}} \cdot SU \quad (\text{HBV.6})$$

$$Q_u = K_u \cdot SU \cdot A \quad (\text{HBV.7})$$

with K_{perc} : Percolation storage coefficient [1/T]; K_u : Interflow storage coefficient [1/T]; i_{perc} : Percolation intensity [L/T]; Q_u : Interflow [L³/T].

Afterwards, the lower reservoir (or baseflow reservoir), corresponding to the lower soil storage, is calculated as presented in equations HBV.8 and HBV.9

$$\begin{aligned} dSL/dt &= i_{\text{perc}} - K_l \cdot SL \\ SL &\geq 0 \end{aligned} \quad (\text{HBV.8})$$

$$Q_l = K_l \cdot SL \cdot A \quad (\text{HBV.9})$$

with SL : Lower reservoir water level [L]; K : Baseflow storage coefficient [1/T]; Q : Baseflow [L^3/T].

And finally the total outflow is:

$$Q_{tot} = Q_r + Q_u + Q_l \quad (\text{HBV.10})$$

with Q_{tot} : Total outflow [L^3/T].

The initial conditions associated to this model are $H_{snow_{ini}}$, WH_{ini} , Hum_{ini} , SU_{ini} and SL_{ini} . The parameters to adjust are CF_{max} , CFR , CWH , TT , $TTInt$, $TTSM$, $Beta$, FC , PWP , SU_{max} , K_r , K_u , K_l and K_{perc} . The parameter A is supposed to be constant.

The model inputs are the precipitation (P), the temperature (T) and the potential evapotranspiration (ETP). The output is the total discharge at the model outlet (Q_{tot}).

ANNEX A.3. SAC-SMA MODEL DESCRIPTION

According to Garcia et al 2016: The SAC-SMA (Figure 9) or SACRAMENTO hydrological model was developed in the 70's (Burnash et al., 1973; Burnash, 1995) to optimize humidity characteristics into the soil, distributed into different level, with rational percolation characteristics, for an efficient simulation of discharges. This model calculates the total discharge from the precipitation (P) and the potential evapotranspiration (ETP) depending on the parameters and initial conditions presented in Table 3.

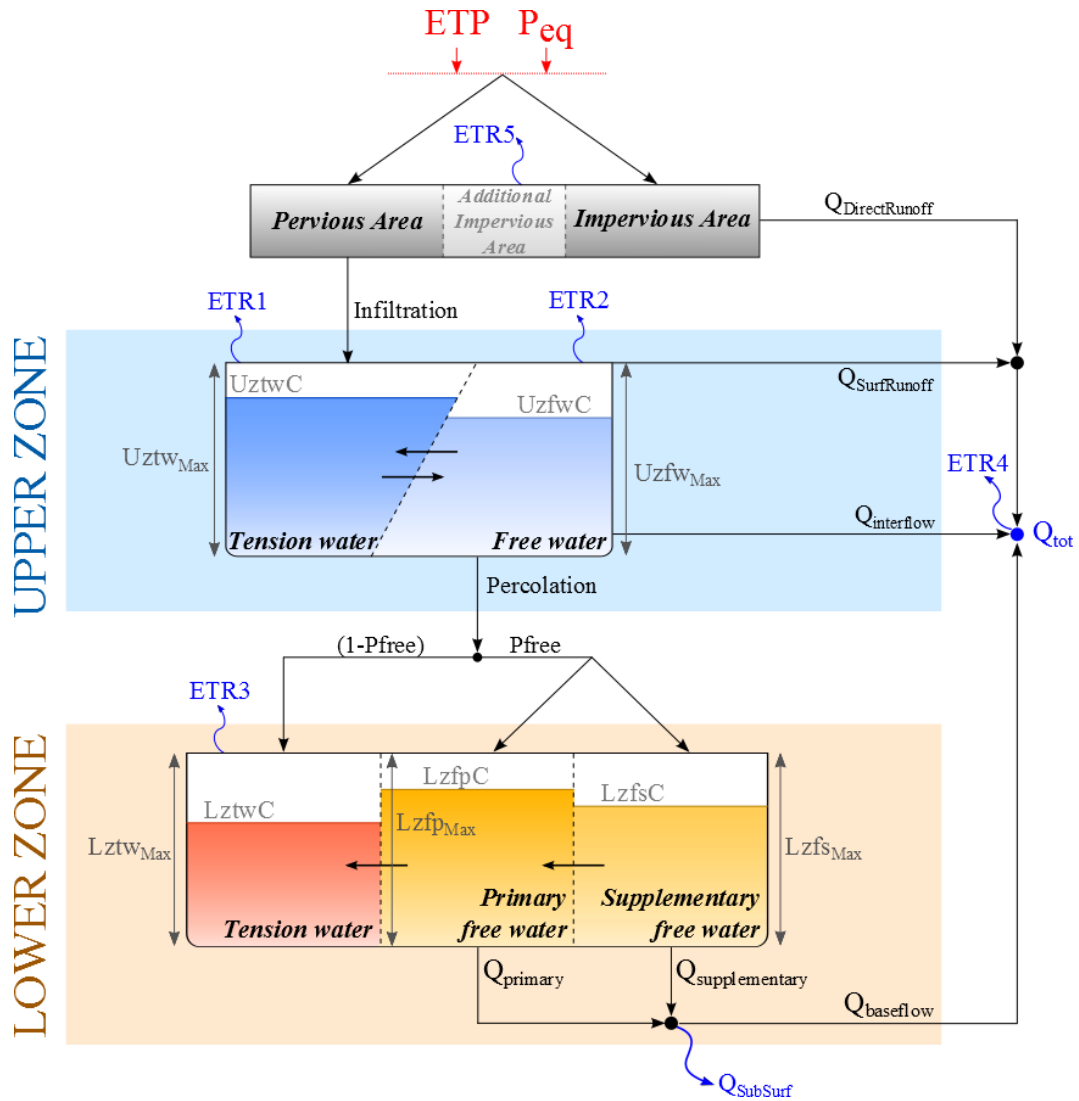


Figure 9: SAC-SMA model

Table 3: List of parameters and initial conditions for the SAC-SMA model

Name	Units	Description	Regular Range
A	m ²	Surface of the basin	>0
Adimp	-	Maximum fraction of an additional impervious area due to saturation	0 to 0.2
Pctim	-	Permanent impervious area fraction	0 to 0.05
Riva	-	Riparian vegetarian area fraction	0 to 0.2
UztwMax	m	Upper Zone Tension Water capacity	0.01 to 0.15
UzfwMax	m	Upper Zone Free Water capacity	0.005 to 0.10
Uzk	1/day	Interflow depletion rate from the Upper Zone Free Water storage	0.10 to 0.75
Zperc	-	Ratio of maximum and minimum percolation rates	10 to 350
Rexp	-	Shape parameter of the percolation curve	1 to 4
Pfree	-	Percolation fraction that goes directly to the Lower Zone Free Water storages	0 to 0.6
LztwMax	m	The Lower Zone Tension Water capacity	0.05 to 0.40
LzfpMax	m	The Lower Zone primary Free Water capacity	0.03 to 0.80
LzfsMax	m	The Lower Zone supplementary Free Water capacity	0.01 to 0.40
Rserv	-	Fraction of Lower Zone Free Water not transferable to Lower Zone Tension Water	0 to 1
Lzpk	1/day	Depletion rate of the Lower Zone primary Free Water storage	0.001 to 0.03
Lzsk	1/day	Depletion rate of the Lower Zone supplemental Free Water storage	0.02 to 0.3
Side	-	Ratio of deep percolation from Lower Zone Free Water storages	0 to 0.5
AdimIni	m	Initial Tension Water content of the Adimp area	-
UztwIni	m	Initial Upper Zone Tension Water content	-
UzfwIni	m	Initial Upper Zone Free Water content	-
LztwIni	m	Initial Lower Zone Tension Water content	-
LzfpIni	m	Initial Lower Zone Free supplementary content	-
LzfsIni	m	Initial Lower Zone Free primary content	-

When considering rainfall over a basin, two basic basin areas are taken into account:

- An impervious portion of the soil mantle covered by streams, lake surfaces, marshes and other impervious material directly linked to the streamflow network. This area produces impervious and direct runoff $Q_{DirectRunoff}$ from any rainfall.
- A pervious portion of the soil mantle which distributes rainwater to the next storages. In addition, the pervious area can produce runoff when rainfall rates are sufficiently heavy.

The basin may present permanent or temporarily impervious areas, determined by:

- The permanent impervious area fraction (**Pctim**).
- The maximum fraction of an additional impervious area due to saturation (**Adimp**). It represents the maximum portion of reservoirs and temporary watersheds contained in the basin.

Thus, the permanent pervious area fraction of the basin is calculated following equation SAC.1

$$Parea = 1 - (Pctim + Adimp) \quad (SAC.1)$$

with Parea : permanent pervious area fraction of the basin [-] ; Pctim : permanent impervious area fraction [-] ; Adimp : maximum fraction of an additional impervious area due to saturation [-].

It is worth mentioning that the behaviour of the additional impervious area might be purely pervious, purely impervious or mixed, depending on the storage of the permanent pervious and impervious areas. The pervious capacity (or fraction) of this area will decrease as the rainfall grows.

As shown in the Figure 9, the SAC model divides the soil in 2 zones:

- An **Upper Zone**, sub-divided in two areas that receive the infiltrated water from rainfall.
- A **Lower Zone**, sub-divided in 3 reservoirs, where the input is the percolation from the **Upper Zone**.

The main components of the model and their flow transfers are described below.

Upper Zone Tension Water storage

This storage represents the water bound by adhesion and cohesion in between the soil pores as well as the water intercepted by vegetation. The water can be only consumed by evapotranspiration.

The water that reaches this reservoir comes from the rain felt into the pervious area of the basin, but also from transfers from the **Upper Zone** Free Water storage.

The following concepts are defined for this reservoir:

- The **Upper Zone Tension Water Maximum** capacity (**UztwMax**) is the maximum Tension Water storage admissible in the **Upper Zone**.
- The **Upper Zone Tension Water Content** (**UztwC**) is the Tension Water stored in this **Upper Zone** at any given time.

If the relative content of Tension Water (ratio between its content and its maximum storage) is smaller than the relative content of Free Water, a transfer is produced from the Free Water storage to the Tension Water storage. The expressions of these ratios and the infiltration transfer are shown in equations SAC.2 to SAC.5:

$$T = \frac{UztwC}{UztwMax} \quad (SAC.2)$$

$$F = \frac{UzfwC}{UzfwMax} \quad (SAC.3)$$

$$Uztr = d \left(\frac{UzfwC \cdot UztwMax - UztwC \cdot UzfwMax}{UzfwMax + UztwMax} \right) / dt \quad \text{if } T < F \quad (SAC.4)$$

$$Uztr = 0 \quad \text{if } T \geq F \quad (SAC.5)$$

with T: relative content of **Upper Zone** Tension Water [-]; F: relative content of **Upper Zone** Free Water [-]; Uztr: infiltration transfer from the Free Water storage to the Tension Water storage [L/T]; UztwC: the **Upper Zone** Tension Water storage [L]; UztwMax: the **Upper Zone** Tension Water capacity [L]; UzfwC: the **Upper Zone** Free Water storage [L]; UzfwMax: the **Upper Zone** Free Water capacity [L].

Although free water is present during filling of **Upper Zone** Tension Water (by infiltration), this free water is rapidly transformed into **Upper Zone** Tension Water until tension water relative content requirements are satisfied.¹

In addition, when the **Upper Zone** Tension Water volume has been filled, excess moisture above the **Upper Zone** Tension Water capacity is accumulated in the **Upper Zone** Free Water.

Upper Zone Free Water storage

This storage represents the water not attached to the soil particles and free to move under gravitational forces. The water that reaches this reservoir comes from the infiltration of the **Upper Zone** Tension Water storage

The following concepts are defined:

- The **Upper Zone Free Water Maximum** capacity (**UzfwMax**) is the maximum Free Water storage admissible in the **Upper Zone**.
- The **Upper Zone Free Water Content** (**UzfwC**) is the Free Water stored in the **Upper Zone** at any given time.
- The **Interflow depletion rate** (**Uzk**) represents the portion of the **Upper Zone** Free Water that is transferred outside as interflow.

The water may be depleted by evapotranspiration, percolation to the **Lower Zone** or horizontal flow (surface runoff and interflow).

On the one hand, the percolation to the **Lower Zone** is computed prior to the interflow computation as it is its preferred path. It depends on the deficiency of the **Lower Zone** moisture volumes, on the soil properties, and on the water relative storage in this reservoir. The first 2 factors define the percolation demand from the **Lower Zone** (DDA). This demand represents the percolation in case of total percolation availability on the **Upper Zone** Free Water storage.

$$PBase = LzfpMax \cdot Lzpk + LzfsMax \cdot Lzsk \quad (SAC.6)$$

$$DEFR = \frac{(LztwMax - LztwC) + (LzfpMax - LzfpC) + (LzfsMax - LzfsC)}{LztwMax + LzfpMax + LzfsMax} \quad (SAC.7)$$

$$DDA = PBase \cdot (1 + Zperc \cdot DEFR^{Rexp}) \quad (SAC.8)$$

with PBase: the continuing percolation rate under saturated condition (maximal percolation) [L/T]; DDA: **Lower Zone** maximum percolation demand [L/T]; Zperc: ratio of

¹ http://www.nws.noaa.gov/oh/hrl/nwsrfs/users_manual/part2/pdf/23sacsma.pdf

maximum and minimum percolation rates [-]; DEFR: relative **Lower Zone** water deficiency [-]; Rexp: shape parameter of the percolation curve [-].

The effective percolation depends on the percolation demand and the ratio between the **Upper Zone** Free Water content and the **Upper Zone** Free Water capacity as shown in equation SAC.9. In addition, the effective percolation is limited by the humidity content in the **Upper Zone** and also by the deficiency in the **Lower Zone** (equations SAC.10 and SAC.11 respectively):

$$PERC = DDA \cdot \frac{UzfwC}{UzfwMax} \quad (SAC.9)$$

$$PERC \leq d(UzfwC)/dt \quad (SAC.10)$$

$$PERC \leq d[(LztwMax - LztwC) + (LzfpMax - LzfpC) + (LzfsMax - LzfsC)]/dt \quad (SAC.11)$$

with PERC: real percolation [L/T]; DDA: **Lower Zone** maximum percolation demand [L/T]; UzfwC: **Upper Zone** Free Water content [L]; UzfwMax: **Upper Zone** Free Water capacity [L].

On the other hand, the interflow occurs only when the rate of precipitation exceed the rate at which downward motion can occur from the **Upper Zone** Free Water. It depends on the water content and on its interflow depletion rate Uz_k, as shown in equation SAC.12:

$$Q_{interflow} = Uz_k \cdot UzfwC \cdot Parea \cdot A \quad (SAC.12)$$

with Q_{interflow}: interflow [L³/T]; Uz_k: interflow depletion rate from the **Upper Zone** Free water storage [T⁻¹]; UzfwC: **Upper Zone** Free Water content [L]; Parea : pervious area fraction of the basin [-]; A: surface of the basin [L²].

Moreover, when the **Upper Zone** Free Water storage is completely full and the precipitation intensity exceeds both the percolation rate and the maximum interflow drainage capacity, the excess precipitation results in surface runoff Q_{SurfRunoff}.

Lower Zone Tension Water storage

This storage represents the semi-saturated zone. It characterizes the volume of moisture in the lower soils which will be claimed by dry soil particles when moisture from a wetting front reaches that depth. The water is consumed through evapotranspiration, proportionally to the remaining ETP of the **Upper Zone** Tension Water storage.

The water reaching this reservoir comes from the **Upper Zone** percolation. One fraction (P_{free}) of this percolation goes directly to the Free Water storages, even if the Tension Water storage is not yet full, and the other fraction (1-P_{free}) goes to the Tension Water storage of the **Lower Zone** ². The water also reaches this storage from transfers between the other **Lower Zone** Free Water storages.

The following concepts are defined:

² If the Tension Water storage of the **Lower Zone** is completely full, then percolation goes entirely to the 2 Free Water storages

- The **Lower Zone Tension Water Maximum** capacity (**LztwMax**) is the maximum Tension Water storage admissible in the **Lower Zone**.
- The **Lower Zone Tension Water Content** (**LztwC**) is the Tension Water stored in the **Lower Zone** at any given time.

If the relative content of Tension Water (ratio between its content and its maximum storage) is smaller than the relative content of Free Water, the incoming excess is transferred from Free Water to Tension Water. The expressions of both ratios are shown in equations SAC.13 to SAC.15:

$$RFW = Rserv \cdot (LzfpMax + LzfsMax) \quad (SAC.13)$$

$$T = \frac{LztwC}{LztwMax} \quad (SAC.14)$$

$$F = \frac{LzfpC + LzfsC - RFW}{LzfpMax + LzfsMax - RFW} \quad (SAC.15)$$

with T: relative content of **Lower Zone** Tension Water [-]; F: relative content of **Lower Zone** Free Water [-]; RFW: **Lower Zone** Free Water not transferable to **Lower Zone** Tension Water, susceptible to become baseflow [L]; Rserv: fraction of **Lower Zone** Free Water not transferable to **Lower Zone** Tension Water[-].

If the relative content of the **Lower Zone** Tension Water is smaller than the relative fullness of the global **Lower Zone**, a water transfer DEL occurs from the **Lower Zone** Free Supplementary reservoir to the **Lower Zone** Tension Water reservoir, as described by the following equations:

$$R = \frac{LzfpC + LzfsC + LztwC - RFW}{LzfpMax + LzfsMax + LztwMax - RFW} \quad (SAC.16)$$

$$DEL = LztwMax \cdot d(R - T)/dt \quad (SAC.17)$$

with DEL: the Free-Tension Water transfer in the **Lower Zone** [L/T]; R: ratio between the available water for evapotranspiration and the total water content, in the whole **Lower Zone** [-]; RFW: **Lower Zone** Free Water not transferable to **Lower Zone** Tension Water, susceptible to become baseflow [L].

Lower Zone Primary and Supplementary Free Water storages

This storage represents the saturated zone of the subsoil, i.e. the aquifer. There are two types of **Lower Zone** Free Water: a primary type with a very slow draining providing baseflow over long periods of time, and a supplementary type which supplements the baseflow after a period of relatively recent rainfall.

The water that reaches these storages comes from the *Pfree* fraction of the percolation of the **Upper Zone** Free Water. This fraction is distributed into the primary and supplementary storages according to their deficiency of water.

The following concepts are defined:

- The **Lower Zone primary Free Water Maximum** capacity (**LzfpMax**) is the maximum primary water storage admissible in the **Lower Zone**.

- The **Lower Zone primary Free Water Content (LzfpC)** is the primary Free Water stored in the **Lower Zone** at any given time.
- The **Depletion rate of the Lower Zone primary Free Water storage (Lzpk)** is the portion of primary Free Water that drains as baseflow per day.
- The **Lower Zone supplementary Free Water Maximum capacity (LzfsMax)** is the maximum supplementary water storage admissible in the **Lower Zone**.
- The **Lower Zone supplementary Free Water Content (LzfsC)** is the supplementary Free Water stored in the **Lower Zone** at any given time.
- The **Depletion rate of the Lower Zone supplementary Free Water storage (Lzsk)** is the portion of supplementary Free Water that drains as baseflow per day.

The drained water leaving these two storages (primary flow $Q_{primary}$ and supplementary flow $Q_{supplementary}$) follows the Darcy's law and forms the baseflow of the **Lower Zone** $Q_{Lower\ Zone}$ as shown in equations SAC.18 to SAC.20:

$$Q_{primary} = Lzpk \cdot LzfpC \cdot Parea \cdot A \quad (SAC.18)$$

$$Q_{supplementary} = Lzsk \cdot LzfsC \cdot Parea \cdot A \quad (SAC.19)$$

$$Q_{Lower\ Zone} = Q_{primary} + Q_{supplementary} \quad (SAC.20)$$

with $Q_{primary}$: primary baseflow [L^3/T]; $Q_{supplementary}$: supplementary baseflow [L^3/T]; $Q_{Lower\ Zone}$: total baseflow produced in the **Lower Zone** [L^3/T]; $Lzpk$: depletion rate of the **Lower Zone** primary Free Water storage [T^{-1}]; $LzfpC$: **Lower Zone** primary Free Water Content [L]; $Lzsk$: depletion rate of the **Lower Zone** supplementary Free Water storage [T^{-1}]; $LzfsC$: **Lower Zone** supplementary Free Water Content [L]; $Parea$: pervious area fraction of the basin [-]; A : surface of the basin [L^2].

The model allows including baseflow losses, called subsurface flow $Q_{SubSurf}$, due to the existence of geological faults, fractured rocks, etc. that lead to filtrations throughout the aquifer. The *Side* parameter captures these losses as shown in equation SAC.21:

$$Q_{SubSurf} = Side \cdot Q_{baseflow} \quad (SAC.21)$$

with *Side*: ratio of deep percolation from **Lower Zone** Free Water storages [-], $Q_{baseflow}$: Lower Zone Free Water volume actually integrated to the channel outflow hydrographs [L^3/T]; $Q_{SubSurf}$: discharge lost into the aquifer [L^3/T].

And so this *Side* parameter is used to correct the baseflow as follows:

$$Q_{baseflow} = \frac{Q_{Lower\ Zone}}{1 + Side} \quad (SAC.22)$$

$$Q_{SubSurf} = Side \cdot \frac{Q_{Lower\ Zone}}{1 + Side} \quad (SAC.23)$$

Evapotranspiration

The real evapotranspirations are obtained from each Tension Water storage, from the transfers between Free Water and Tension Water storages, from riverside vegetation and from impervious areas. They are described hereafter.

- *ETR1*: evapotranspiration from the **Upper Zone** Tension Water reservoir. If this reservoir is not full, the evapotranspiration is proportional to its content (equation SAC.24):

$$ETR1 = ETP \cdot \frac{Uztc}{UztcMax} \leq Uztc \quad (SAC.24)$$

with ETP: potential evapotranspiration [L/T].

The remaining evapotranspiration demand RED and the updated content of water in the **Upper Zone** Tension Water reservoir *Uztc* are then calculated:

$$RED = ETP - ETR1 \quad (SAC.25)$$

$$d(Uztc)/dt = -ETR1 \quad (SAC.26)$$

- *ETR2*: evapotranspiration from the **Upper Zone** Free Water reservoir. This evapotranspiration is equal to the remaining RED left by the Tension Water reservoir, but it is limited by the **Upper Zone** Free Water content *UzfwC*:

$$ETR2 = \min\{RED; d(UzfwC)/dt\} \quad (SAC.27)$$

Then, the remaining evapotranspiration REDLz from the **Lower Zone** is:

$$REDLz = RED - ETR2 \quad (SAC.28)$$

The variation of the water content *UzfwC* in the **Upper Zone** Free Water reservoir is defined as follows:

$$d(UzfwC)/dt = -ETR2 \quad (SAC.29)$$

- *ETR3*: evapotranspiration from the **Lower Zone** Tension Water reservoir. The evapotranspiration availability corresponds to the remaining evapotranspiration demand in the **Lower Zone**. Evapotranspiration in this reservoir is proportional to the remaining evapotranspiration and to the **Lower Zone** Tension Water content, and inversely proportional to the Tension Water reservoirs' capacity of the **Upper Zone** and the **Lower Zone**:

$$ETR3 = REDLz \cdot \frac{Lztc}{UztcMax + LztcMax} \leq d(Lztc)/dt \quad (SAC.30)$$

- *ETR4*: evapotranspiration from the basin covered by riverside vegetation. Riverside vegetation absorbs the deficiency of potential evapotranspiration from the **Upper Zone** and the **Lower Zone**:

$$ETR4 = ETP - ETR1 - ETR2 - ETR3 \quad (SAC.31)$$

- *ETR5*: evapotranspiration from the impervious fraction of the basin.

$$ETR5 = ETR1 + (RED + ETR2) \cdot \frac{AdimC - UztwC - V_{ETR1}}{UztwMax + LztwMax} \quad (SAC.32)$$

$$V_{ETR1} = \int_{t1}^{t2} ETR1 \cdot dt \quad (SAC.33)$$

with AdimC: sum of the **Upper Zone** and **Lower Zone** Tension Water Content in the *Adimp* area [-]; V_{ETR1} : evapotranspired water from the **Upper Zone** Tension Water reservoir in a time step [L].

Each evapotranspiration value is weighted based on the portion of the basin area in which it is produced. The total evapotranspiration is finally:

$$ETR_{total} = [(ETR1 + ETR2 + ETR3) \cdot Parea + ETR4 \cdot Riva + ETR5 \cdot Adimp] \cdot A \quad (SAC.34)$$

with ETR_{total} : total evapotranspiration [L^3/T]; Parea: pervious area fraction of the basin [-]; Riva: riparian vegetarian area fraction [-]; Pctim: permanent impervious area fraction of the basin [-]; Adimp: maximum fraction of an additional impervious area due to saturation [-]; A: surface of the basin [L^2].

A more detailed guide about the SAC-SMA equations can be found on the following National Weather Service link:

http://www.nws.noaa.gov/iao/iao_SAC_SMA.php

ANNEX A.4. GR4J MODEL

According to Garcia et al 2016: The GR4J model is a global hydrological model with four parameters developed by Perrin et al. (2003). It is an empirical model (Figure 10), but its structure is similar to the conceptual models. It takes into account the humidity and contains two reservoirs (production and routing). Unit hydrographs are also associated for the hydrological behaviour of the basin.

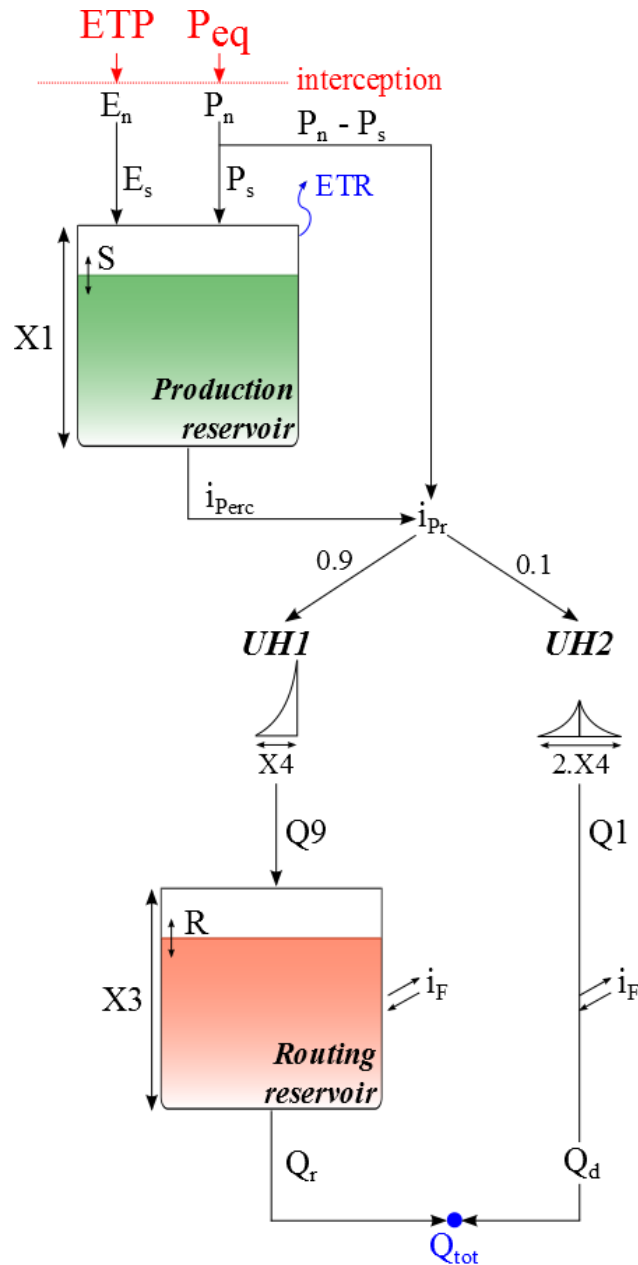


Figure 10: GR4J model

Table 4: List of parameters and initial conditions for the GR4J model

Name	Units	Description	Regular Range
A	m ²	Surface of the basin	>0
X1	m	Capacity of production store	0.01 to 1.2
X2	m	Water exchange coefficient	-0.005 to 0.003
X3	m	Capacity of routing store	0.01 to 0.5
X4	d	UH time base	-0.5 to 1
Slni	m	Initial water content in the production reservoir	-
Rlni	m	Initial water level in the routing reservoir	-

The first calculation is the neutralization of P_{eq} by ETP for determining a net intensity (P_n) and a net evapotranspiration (E_n) according to equations GR4.1.

$$\begin{aligned}
 P_n &= P_{eq} - ETP & \text{if } P \geq ETP \\
 E_n &= 0 \\
 P_n &= 0 & \text{if } P < ETP \\
 E_n &= ETP - P_{eq}
 \end{aligned}
 \tag{GR4.1}$$

with P_n : net rain intensity [L/T] ; P_{eq} : Equivalent precipitation [L/T] ; ETP : potential evapotranspiration [L/T] ; E_n : net evapotranspiration [L/T].

When P_n is not zero, a part (P_s) of P_n feed the production reservoir (S) as presented in equation GR4.2. Similarly, when E_n is not zero, an evapotranspiration (E_s) from the production reservoir is calculated depending on the water level in the production reservoir as described in equation GR4.3.

$$P_s = \frac{d}{dt} \frac{X_1 \cdot \left(1 - \left(\frac{S}{X_1}\right)^2\right) \cdot \tanh\left(\frac{P_n \cdot dt}{X_1}\right)}{1 + \left(\frac{S}{X_1}\right) \cdot \tanh\left(\frac{P_n \cdot dt}{X_1}\right)}
 \tag{GR4.2}$$

$$E_s = \frac{d}{dt} \frac{S \cdot \left(2 - \left(\frac{S}{X_1}\right)\right) \cdot \tanh\left(\frac{E_n \cdot dt}{X_1}\right)}{1 + \left(1 - \frac{S}{X_1}\right) \cdot \tanh\left(\frac{E_n \cdot dt}{X_1}\right)}
 \tag{GR4.3}$$

with P_s : rain intensity feeding the production reservoir [L/T]; X_1 : maximum capacity of production reservoir S [L] ; S : water content in the production reservoir [L]; E_s : evapotranspiration from the production reservoir [L/T].

The percolation ($iPerc$) flowing from the production reservoir is then calculated as follows:

$$iPerc = \frac{d}{dt} (S + (P_s - E_s) \cdot dt) \cdot \left(1 - \left(1 + \left(\frac{4}{9} \cdot \frac{(S + (P_s - E_s) \cdot dt)^4}{X_1}\right)\right)^{-\frac{1}{4}}\right)
 \tag{GR4.4}$$

with $iPerc$: percolation intensity [L/T].

Finally, the variation in the production reservoir S is obtained according to equation GR4.5:

$$\begin{aligned}
 dS/dt &= P_s - E_s - iPerc \\
 S &\geq 0
 \end{aligned}
 \tag{GR4.5}$$

The quantity of water (iPr) which goes to the routing reservoir is provided by:

$$iPr = iPerc + (Pn - Ps) \quad (GR4.6)$$

with iPr : intensity flowing to the routing reservoir [L/T].

Afterwards, for the calculation of unit hydrographs, iPr is divided in two flow components: 90% are routed by a unit hydrograph UH1 and a routing reservoir and 10% by a symmetrical unit hydrograph UH2. UH1 and UH2 depend on parameter X_4 , which is the base time.

The ordinates of the hydrographs are calculated from curves SH1 and SH2, which correspond to the cumulated hydrograph. SH1 and SH2 are defined depending on the time step t as presented in equation GR4.7 and GR4.8. The ordinates of UH1 and UH2 are then calculated.

$$\begin{aligned} SH1_t &= 0 & \text{if } t \leq 0 \\ SH1_t &= \left(\frac{t}{X_4}\right)^{\frac{5}{2}} & \text{if } 0 < t < X_4 \\ SH1_t &= 1 & \text{if } t \geq X_4 \end{aligned} \quad (GR4.7)$$

$$\begin{aligned} SH2_t &= 0 & \text{if } t \leq 0 \\ SH2_t &= \frac{1}{2} \cdot \left(\frac{t}{X_4}\right)^{\frac{5}{2}} & \text{if } 0 < t < X_4 \\ SH2_t &= 1 - \frac{1}{2} \cdot \left(2 - \frac{t}{X_4}\right)^{\frac{5}{2}} & \text{if } X_4 < t < 2 \cdot X_4 \\ SH2_t &= 1 & \text{if } t \geq 2 \cdot X_4 \end{aligned} \quad (GR4.8)$$

$$UH1_j = SH1_j - SH1_{j-1} \quad (GR4.9)$$

$$UH2_j = SH2_j - SH2_{j-1} \quad (GR4.10)$$

with SH1 : hydrograph 1 from S [-]; SH2 : hydrograph 2 from S [-]; t : time step [T]; X_4 : base time [T]; UH1 : hydrograph from SH1 [-]; UH2 : hydrograph from SH2 [-].

Then, at each time step k , outflows Q_9 and Q_1 from the two hydrographs correspond to the convolution of previous intensities according to the repartition provided by the discretized hydrograph and calculated as presented in equations GR4.11 and GR4.12.

$$Q_9 = 0.9 \cdot \sum_{j=1}^l (UH1_j \cdot iPr_{k-j-l}) \quad (GR4.11)$$

$$Q_1 = 0.1 \cdot \sum_{j=1}^m (UH2_j \cdot iPr_{k-j-l}) \quad (GR4.12)$$

with Q_9 : Unitary flow from the UH1 hydrograph; [L/T]; Q_1 : Unitary flow from the UH2 hydrograph [L/T]; M j : day (integer) [T]; l = integer value of $X_4 + 1$ [T] ; m = integer value of $2 \cdot X_4 + 1$ [T].

Then, an exchange function (iF) with the non-atmospheric outside produces an underground water exchange according to GR4.13 (physical interpretation of this function is not direct). Then, the routing reservoir (R) is emptied by a routing discharge (Qr') as described in equation GR4.14.

$$iF = \frac{d}{dt} X_2 \cdot \left(\frac{R}{X_3} \right)^{\frac{7}{2}} \quad (\text{GR4.13})$$

$$Qr' = \frac{d}{dt} (R + (Q9 + iF) \cdot dt) \cdot \left(1 - \left(1 + \left(\frac{R + (Q9 + iF) \cdot dt}{X_3} \right)^4 \right)^{-\frac{1}{4}} \right) \quad (\text{GR4.14})$$

with iF: exchange function [L/T]; X2: water exchange coefficient, positive for contributions, negative for losses due to infiltration or zero when no exchange is produced [L]; R: water level in the routing reservoir [L]; X3: one day capacity of routing reservoir [L]; Qr': unitary routing reservoir outflow [L/T].

The variation of the water level in the routing reservoir is:

$$\begin{aligned} dR/dt &= Q9 - iF - Qr \\ R &\geq 0 \end{aligned} \quad (\text{GR4.15})$$

The outflow Q1 from hydrograph UH2 has also the same exchange for providing the complementary flow Qd':

$$Qd' = Q1 + iF \quad (\text{GR4.16})$$

with Qd': unitary complementary outflow [L/T].

Finally, the model outflows are calculated as presented in equations GR4.17 and GR4.18 and the total flow at the outlet, Qtot, as presented in equation GR4.19:

$$Qr = Qr' \cdot A \quad (\text{GR4.17})$$

$$Qd = Qd' \cdot A \quad (\text{GR4.18})$$

$$Qtot = Qr + Qd \quad (\text{GR4.19})$$

with Qr: outflow from the routing reservoir; A: Basin surface [L²]; Qd: complementary outflow [L³/T]; Qtot: total outflow [L³/T].

The variables associated to this model are S_{ini} and R_{ini}. The parameters to adjust are X1, X2, X3 and X4. The parameter A is supposed to be constant after its calculation.

The model inputs are the equivalent precipitation (P_{eq}) and the potential evapotranspiration (ETP). The output is the total discharge at the model outlet (Q_{tot}).

ANNEX B.1. SNOW N-1 MODEL

According to Garcia et al 2016: The Snow N-1 model is part of the HBV model. In EvalHid, the original HBV model is divided into the HBV model described in a previous Annex and the Snow model presented in this one.

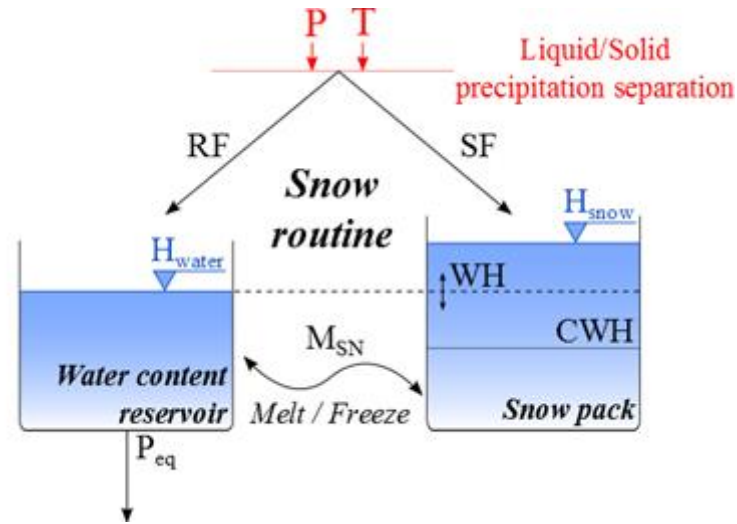


Figure 11: Snow N-1 model (from HBV model).

Table 5: List of parameters and initial conditions for the Snow N-1 model.

Name	Units	Description	Regular Range
A	m ²	Surface of the basin	>0
CFMax	mm/°C/day	Melting factor	0.5 to 20
CFR	-	Refreezing factor	0.05
CWH	-	Critical relative water content of the snow pack	0.1
TT	°C	Threshold temperature of rain/snow	0 to 3
TTInt	°C	Temperature interval for rain/snow mixing	0 to 3
TTSM	°C	Threshold temperature for snow melt	0
HsnowIni	m	Initial snow height	-

The precipitation is first divided into snowfall (SF) and rainfall (RF) as a function of the temperature (*equations SN1.1 to SN1.3*). If the observed temperature is lower than $TT - TTInt/2$, only solid snowfall is produced. If the temperature is higher than $TT + TTInt/2$, only rainfall is produced. If the observed temperature is found between these values, both rainfall and snowfall are produced.

$$RF = \alpha \cdot P \quad (SN1.1)$$

$$SF = (1 - \alpha) \cdot P \quad (SN1.2)$$

$$\alpha = 0 \quad \text{if } T < TT - TTInt/2$$

$$\alpha = \frac{T - (TT - TTInt/2)}{TTInt} \quad \text{if } TT - TTInt/2 < T < TT + TTInt/2 \quad (SN1.3)$$

$$\alpha = 1 \quad \text{if } T > TT + TTInt/2$$

with RF : rainfall [L/T]; α : separation factor; P : precipitation [L/T]; SF : snowfall [L/T]; T : temperature [°C]; TT : threshold temperature for rain/snow [°C]; $TTInt$: temperature interval for rain/snow mixing [°C].

The snowfall (SF) is used as input for the snow pack, varying its content as a function of melt or freezing. The snowmelt calculation is performed as follows:

$$\begin{aligned} M_{sn} &= CFMax \cdot (T - TTSM) && \text{if } T > TTSM \\ M_{sn} &= CFR \cdot CFMax \cdot (T - TTSM) && \text{if } T \leq TTSM \end{aligned} \quad (SN1.4)$$

$$\begin{aligned} dH_{snow}/dt &= SF - M_{sn} \\ M_{sn} &\leq SF + H_{snow}/dt \\ M_{sn} &\geq -H_{water}/dt \end{aligned} \quad (SN1.5)$$

with M_{sn} : snowmelt or freezing [L/T]; $CFMax$: degree-day melting factor [L/T/°C]; CFR : refreezing factor [-]; $TTSM$: critical snowmelt temperature [°C]; H_{snow} : snow height [L]; H_{water} : water content [L]; dt : time step [T].

In EvalHid tool $TTSM$ parameter is found in the configuration file.

The equivalent precipitation (P_{eq}) is produced by the water content of the snow (equations SN1.6 to SN1.8):

$$WH = H_{water}/H_{snow} \quad (SN1.6)$$

$$\begin{aligned} P_{eq} &= RF + H_{water}/dt && \text{if } H_{snow} = 0 \\ P_{eq} &= 0 && \text{if } H_{snow} > 0 \text{ et } WH \leq CWH \\ P_{eq} &= (WH - CWH) \cdot H_{snow}/dt && \text{if } H_{snow} > 0 \text{ et } WH > CWH \end{aligned} \quad (SN1.7)$$

$$dH_{water}/dt = RF + M_{sn} - P_{eq} \quad (SN1.8)$$

with WH : relative water content in the snow pack [-]; CWH : critical relative water content in the snow pack [-]; P_{eq} : equivalent precipitation [L/T].

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