
HBV light
version 2

User's Manual

Jan Seibert

**November 2005
Stockholm University
Department of Physical Geography
and Quaternary Geology**

**SLU
Department of Environmental Assessment
Uppsala**

**Oregon State University
Department of Forest Engineering
Corvallis, Oregon, USA**

**Uppsala University
Department of Earth Sciences
Hydrology**

E-mail: jan.seibert@natgeo.su.se

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PART 2 - The HBV model

Introduction

During the last 20 years the HBV-model (Bergström 1976) developed by the SMHI (Swedish Meteorological and Hydrological Institute) has become widely used for runoff simulations in Sweden (Bergström, 1990; 1992). Moreover, the model has been applied, sometimes in modified versions, in about 30 countries.

The idea behind this new version of the HBV model, *HBV light*, was to provide an easy to use Windows-version for research and education. The basic equations are in accordance with the SMHI-version HBV-6 (Bergström, 1992) with only two slight changes. Instead of using initial states the new version uses a 'warming-up' period. In the original version, only integer values are allowed for the routing parameter MAXBAS. This limitation has been removed in the new version. In order to keep the program as simple as possible, several functions found in the HBV-6 software were not implemented in the *HBV light* software. It is possible to use a correction of the long-term mean of potential evaporation values as proposed by Lindström and Bergström (1992). The *HBV-light* version provides two options which do not exist in the HBV-6 version. The first one is the possibility to include observed groundwater levels into the analysis and the second is the possibility to use a different response routine with a delay parameter.

The aim of this manual is to give a description about how to use the *HBV light* software and a short introduction into the HBV model.

A short description of the HBV model

The model simulates daily discharge using daily rainfall, temperature and potential evaporation as input. Precipitation is simulated to be either snow or rain depending on whether the temperature is above or below a threshold temperature, **TT** [°C]. All precipitation simulated to be snow, i.e. falling when the temperature is below **TT**, is multiplied by a snowfall correction factor, **SFCF** [-]. Snowmelt is calculated with the degree-day method (Equation 1). Meltwater and rainfall is retained within the snowpack until it exceeds a certain fraction, **CWH** [-], of the water equivalent of the snow. Liquid water within the snowpack refreezes according to Equation 2. Rainfall and snowmelt (**P**) are divided into water filling the soil box and groundwater recharge depending on the relation between water content of the soil box (**SM** [mm]) and its largest value (**FC** [mm]) (Equation 3). Actual evaporation from the soil box equals the potential evaporation if **SM/FC** is above **LP** [-] while a linear reduction is used when **SM/FC** is below **LP** (Equation 4). Groundwater recharge is added to the upper groundwater box (**SUZ** [mm]). **PERC** [mm d⁻¹] defines the maximum percolation rate from the upper to the lower groundwater box (**SLZ** [mm]). Runoff from the groundwater boxes is computed as the sum of two or three linear outflow equations depending on whether **SUZ** is above a threshold value, **UZZ** [mm], or not (Equation 5). This runoff is finally transformed by a triangular weighting function defined by the parameter **MAXBAS** (Equation 6) to give the simulated runoff [mm d⁻¹].

If different elevation zones are used the changes precipitation and temperature with elevation are calculated using the two parameters **PCALT** [%/100 m] and **TCALT** [°C / 100 m] (Equation 7 and 8).

The long-term mean of the potential evaporation, $E_{pot,M}$ for a certain day of the year can be corrected to its value at day t , $E_{pot}(t)$, by using the deviations of the temperature, $T(t)$, from its long-term mean, T_M , and a correction factor, C_{ET} [°C⁻¹] (Equation 9).

Please note that more information can be found in Part 2.

$$melt = CFMAX(T(t) - TT) \quad (1)$$

$$refreezing = CFR - CFMAX(TT - T(t)) \quad (2)$$

$$\frac{recharge}{P(t)} = \left(\frac{SM(t)}{FC} \right)^{BETA} \quad (3)$$

$$E_{act} = E_{pot} \min\left(\frac{SM(t)}{FC \cdot LP}, 1 \right) \quad (4)$$

$$Q_{GW}(t) = K_2 SLZ + K_1 SUZ + K_0 \max(SUZ - UZZ, 0) \quad (5)$$

$$Q_{sim}(t) = \sum_{i=1}^{MAXBAS} c(i) Q_{GW}(t-i+1) \quad (6)$$

$$\text{where } c(i) = \int_{i-1}^i \frac{2}{MAXBAS} \left| u - \frac{MAXBAS}{2} \right| \frac{4}{MAXBAS^2} du$$

$$P(h) = P_0 \left(1 + \frac{PCALT(h-h_0)}{10000} \right) \quad (7)$$

$$T(h) = T_0 - \frac{TCALT(h-h_0)}{100} \quad (8)$$

$$E_{pot}(t) = \left(1 + C_{ET}(T(t) - T_M) \right) E_{pot, M} \quad (9)$$

but $0 \leq E_{pot}(t) \leq 2 E_{pot, M}$

HBV light software

Hard- and software requirements

The software has been tested on Pentium PCs with Windows 95, Windows NT, Windows 2000 and Windows XP.

OBS! ACHTUNG! IMPORTANT! Make sure that the settings within Windows are in a way that a decimal point is a POINT (.) and not a comma (,) as it is, for instance, in the Swedish or German standard setting. The setting can be changed using (Settings-control panel-international), (Inställningar-kontrollpanelen-internationell-sifferformat), (Einstellungen-Systemsteuerung-Ländereinstellungen-Zahlenformat).

Installation

Follow the instructions on the screen. For each catchment the following directories are needed

..\catchmentname\data

ptq.dat

evap.dat

par.dat

clarea.dat

optional: t_mean.dat, ptcalt.dat, gw.dat and gwinfo.dat

..\catchmentname\results

The program can be started from the Explorer (*hbv*.exe*). However, it may be more comfortable to create a short cut to *HBV light*.

Data files (input)

All the following files have to be located in the directory `..\data\`

PTQ-file

The PTQ-file (`ptq.dat`) contains time series of daily precipitation [mm/day], temperature [°C] and discharge [mm/day]. The name of the input file is always `ptq.dat` and the format is as follows:

a) a header of two lines, the first one contains a name for the catchment (no comma allowed in this line), the second line is not used by the program.

b) Date (YYMMDD or YYYYMMDD), precipitation, temperature, discharge in one row per day (separated by commas)

example:

```
Hågaån (Lurbo)
Date, P, T, Q
950101,0.4,2.6,0.1
950102,0,1.7,0.08
950103,2.4,3.8,0.2
950104,5,7,1.5
....
```

Evaporation-file

The evaporation-file contains values for the potential evaporation [mm/day]. The evaporation file may contain ...

a) 12 values, i.e. long-term monthly mean values, and the daily values will be linear interpolated.

b) 365 values, i.e. long-term daily mean values

c) As many values as time steps in the PTQ-file, i.e. one value for each day

The name of this file is `evap.dat` and it has the following format:

one line (header) followed by the values (one value per row)

Example:

```
Pot. evap
0.1
0.5
```

2
2.6
....

Mean Temperature file

This file is optional. If it exists, the long-term mean of the potential evaporation for a certain day of the year will be corrected to its value at day t by using the deviations of the temperature from its long-term mean and a correction factor, C_{ET} . If the file does not exist, the parameter C_{ET} is not used.

The 'mean temperature'-file contains long-term mean values for the temperature [$^{\circ}\text{C}$]. The file may contain ...

a) 12 values, i.e. long-term monthly mean values, and the daily values will be linear interpolated.

b) 365 values, i.e. long-term daily mean values

The name of this file is `t_mean.dat` and it has the following format:

one line (header) followed by the values (one value per row)

Example:

```
Mean temperature
-7.5
-1
4.2
.....
```

PTCALT file

This file is optional. If it exists, time series of temperature and/or precipitations gradients are used instead of the constant values `TCALT` and/or `PCALT`.

The name of this file is `PTCALT.dat` and it has the following format:

two lines (header) followed by the values (date and one or two value(s) per row)

Example:

```
Catchmentname
date, PCALT, TCALT
960130, 10, 0.5
960131, 15, 0.6
.....
```

If time series are used for both `PCALT` and `TCALT`, the values for `PCALT` have to be in the second column and those for `TCALT` in the third column. If only for one of both a time serie

should be used, the file should only contain two columns (header = "date, TCALT" or "date, PCALT").

Result files

If the results of a model run are stored (see Menu-Change HBV.ini), then the results can be found in the directory **c:\jmodels\hbv\results** in two files: **resuxxx.dat** (time series of the different variables) and **sumxxx.txt** (summary), where xxx is the 'Model-Run-No'. The files of a previous model run are read by the program if the Model-Run-No is changed to the number of this previous run using the menu item Results-of number xxx. After changing the number, the results can be looked on as usually. Both files are in ASCII-format which make it possible to export them to any program as, for instance, EXCEL or GRAPHER.

If different vegetation and/or elevation zones are used, the time series of the simulations can be stored (see Menu-Change HBV.ini).

Values of different objective functions are calculated by the program and saved in the summary-file (Table 1).

Table 1. Objective functions

Objective function	Definition	Value for 'perfect' fit
Efficiency (<i>Reff</i>)	$1 - \frac{\sum (Q_{obs} - Q_{sim})^2}{\sum (Q_{obs} - \overline{Q_{obs}})^2}$	1
Efficiency using weighted errors ¹ (<i>Reff weighted</i>)	$1 - \frac{\sum w(Q_{obs}) (Q_{obs} - Q_{sim})^2}{\sum w(Q_{obs}) (Q_{obs} - \overline{Q_{obs}})^2}$	1
Efficiency using ln(Q) (<i>logReff</i>)	$1 - \frac{\sum (\ln Q_{obs} - \ln Q_{sim})^2}{\sum (\ln Q_{obs} - \overline{\ln Q_{obs}})^2}$	1
Coefficient of determination (<i>r2</i>)	$\frac{(\sum (Q_{obs} - \overline{Q_{obs}})(Q_{sim} - \overline{Q_{sim}}))^2}{\sum (Q_{obs} - \overline{Q_{obs}})^2 \sum (Q_{sim} - \overline{Q_{sim}})^2}$	1
Mean difference (<i>meandiff</i>)	$\frac{\sum (Q_{obs} - Q_{sim})}{No\ of\ days} \cdot 365$	0

¹ The weighting function $w(Q_{obs})$ has to be defined by the user

Menu items

Overview

Table 2. List over menu items

Main-menu	Sub-menu	Topic
-----------	----------	-------

HBV	about	Information about the program
	change HBV.ini (*)	Change settings
	quit	Quit program
WORK	Run	Start a model run
	Parameters (*)	Change parameter values
	Catchment (*)	Change catchment
RESULTS	of number xxx	Change the number to look on the results of a previous model run (previous runs are only available if these runs were saved, see HBV-ini)
	Graph (*)	Graphical output of the simulation
	Summary	Summary of the simulation (water balance and objective function values, see Table 1)
	GW levels(*)	Plot of measured groundwater levels and simulated water levels in the two groundwater boxes (SUZ + SLZ) (Note: only available if there is a file with groundwater data)
EXTRA	Monte Carlo runs (*)	Multiple model runs with random parameters
	Batch runs (*)	Multiple model runs with parameters read from a file
	GAP optimisation (*)	Optimisation using a genetic algorithm (and a subsequent local optimisation)

(*) More information is given below.

HBV.ini

You have the possibility to choose ...

a) ... whether you would like to save the results of the simulations (advantage: you can later look on the simulations again, disadvantage: this option increases the time needed for one simulation). Furthermore, you can decide to save the distributed simulations, *i.e.*, state and flows for the different elevation-vegetation-zones.

b) ... the maximal number of time steps (= days) of your PTQ-file. The highest possible number is 30000 (unless your PC has too little memory) (OBS! Only up to this maximal number are values read from the input files, you have to restart the program after changing this value in order to read more values)

c) ... the default for the number of time steps plotted on one graph (365 = one year is a suitable value)

d) ... the path to your working directory, *i.e.*, a directory where you have a subdirectory 'data' with all the input data files, and a subdirectory 'results' where all the results will be saved. If you change the path, the new input data files will be read immediately. Note that

most 'ini'-settings as well as the simulation period are stored individually for each catchment (=working directory).

e) ... whether you would like to use the standard version or an alternative model structure (e.g., an alternative response function with a delay, a three box version, a one box version, more or less 'semi-distribution' computations of the routines).

f) ... which additional objective functions you would like the program to compute:

Reff_intervall: R_{eff} is computed using n-day-mean values of Q_{obs} and Q_{min} , where n is given by the user (e.g. 7 = weekly mean values). Up to five different lengths of averaging may be used.

Reff_seasonal: R_{eff} is computed using only data during the part of the year between 'from' and 'to'.

Reff_weighted: R_{eff} is computed using a weighting function depending on Q_{obs} . The function is defined by the user through a look-up table. For runoff values between the given values the weights are interpolated linearly, the weights for the highest/lowest runoff values found in the table are used outside the covered range.

Parameters

Setting of all parameters, start and end of the simulation period and start of the 'warming-up'-period. The 'warming-up'-period is needed to get appropriate initial values of the different state variables for the start of the simulation period, the simulations during the 'warming-up'-period are neither stored nor used for any further analysis. You may load or save your parameter values if you like to go back to old values or to keep a parameter set for later use. The number of parameters to set changes depending on the number of elevation-/ vegetation zones. If the simulation results are stored (see Menu-HBV-HBV.ini), the name of the files are **resuxxx.dat** (time series of the different variables) and **sumxxx.txt** (summary) where xxx is the 'Model-Run-No'. If the distributed simulations are stored they can be found in a file named **disxxx.dat** (time series of the different variables).

Catchment

The catchment may be divided in up to 20 elevation- and 3 vegetation zones. For each elevation zone you have to specify the mean elevation. Moreover you have to set the reference elevation for both temperature and precipitation data. For each elevation-vegetation zone and for lakes you have to assign the portion of the entire catchment area. The OK button is disabled as long as the sum of all portions is not one.

Graph

Press PLOT and the results for the period specified by 'from...to' are plotted according to the chosen plot option (Table 3). If the 'same min/max ...' box is checked, then the axes are scaled in the same way for the entire simulation period, if not, the axes are scaled to match the plotted period. With PLOT NEXT(PREVIOUS) PERIOD the subsequent(preceding) period

(equal length as the actual one) is plotted. The numbers on the x-axis represent the number of days, looking on ‘from ... to ...’ you can easily see what period of time is plotted.

Table 3. List over ‘Plot-options’

Plot option	Graph	Plotted variable(s)
PTQ	Top	Accumulated difference between simulated and observed discharge (black, left axis) and measured temperature (red, right axis)
	Middle	Measured precipitation (blue, right axis) and simulated snow (as water equivalent, green, left axis)
	Bottom	Observed (blue) and simulated (red) discharge
Soil+E+Q	Top	Potential (blue) and actual (red) evapotranspiration
	Middle	Amount of water in the soil box, SM (red)
	Bottom	Observed (blue) and simulated (red) discharge
GW+Q	Top	Amount of water in the upper groundwater box, SUZ (blue)
	Middle	Amount of water in the lower groundwater box, SLZ (black)
	Bottom	Observed (blue) and simulated (red) discharge

GW levels

Plot of measured groundwater levels against the water level in the upper and/or lower groundwater box (SUZ, SLZ or SUZ+SLZ) depending on the setting in `gwinfo.dat` (upper plot) and of time series of measured (red circles) and simulated (green line) groundwater levels, where the simulated are calculated as a linear function of SUZ, SLZ or SUZ+SLZ. Note that the regression coefficients and the coefficient of determination are calculated from the entire simulated period and do not change when different time periods are plotted. For more information see ‘Use of groundwater levels’.

Monte Carlo

Setting of ranges for all parameters, start and end of the simulation period and start of the ‘warming-up’-period. You may load or save your parameter values if you like to go back to old values or to keep a parameter set for later use. Parameter values are chosen randomly within the given range and the model is run using these parameters. The simulation results (parameter values and values of the objective functions) are stored in a file with the name `multixxx.dat` where `xxx` is the ‘Model-Run-No’. This file contains both parameter values and simulation results (goodness-of-fit measures). For creating ‘dotty-plots’ it is recommended to open the file in Excel, Grapher or similar programs. If you use the same Model-Run-No as before the old file will be overwritten. The maximum number of model runs is given by ‘No of model runs’. However, the simulations may be stopped by pressing the ‘Stop runs’-button which appears after the ‘Start runs’-button has been pressed. By checking the ‘Save only if Ref>...’-box, the number of stored model runs can be reduced.

If you use the Monte Carlo option always with more than one vegetation zone, you have to choose for each parameter whether its value for each zone should be compute by random only (R) or whether its value should be equal for all zones (=), increase from zone 1 to 3 (<), or decrease (>). If there are different elevation zones the values for PCALT and TCALT are taken as shown in the Parameter-window.

TIP: Save your parameters into a file named `pmul.mul` in the data-directory. This file will be, if existing, read whenever you start 'Monte Carlo'. If there is no file with this name, an error message will be displayed for information, just continue and save the parameters as `pmul.mul` (unless you like to type in the values each time ☺). Other sets of parameter ranges might be saved in files with other names (extension *.mul).

Batch runs

Using the batch run option you can run the model for certain parameter sets. The parameter sets are read from a file named `batch.par`. In the first row of this file there may be a list of the different parameters, in the following lines there have to be the parameter values:

```
no, TT,CFMAX,SFCF,CFR,CWH,FC,LP,BETA,PERC,UZL,K0,K1,K2,MAXBAS,CET
1,1.3,5,0.7,0.05,0.1,185,125,3,1.2,69,0.29,0.12,0.07,2,0.1
2,1.5,5,0.7,0.05,0.1,185,125,3,1.2,69,0.29,0.12,0.07,2,0.1
3,1.3,6,0.7,0.05,0.1,185,125,3,1.2,69,0.29,0.12,0.07,2,0.1
```

.....

(note: the first column is a difference from earlier versions of HBV light)

The simulation results (parameter values and values of the objective functions) are stored in a file with the name `batchrun.dat`. The simulations may be stopped by pressing the 'Stop runs'-button which appears after the 'Start runs'-button has been pressed. The `batchrun.dat` file contains both parameter values and simulation results (goodness-of-fit measures). By checking the 'Save Qsim ...'-box, you can store the simulated discharge values. This may be useful if you want to compare simulations for a shorter period (note that daily values are stored, i.e. your file may get very large if you use too long periods). The runoff values are stored in additional columns to the right of the other results (timestep-no in first row)

If you use the "Batch Run" option two vegetation zones, you have to add the parameters (TT,CFMAX,SFCF,CFR,CWH,FC,LP,BETA) for zone two behind CET in the `batch.par`-file. For three zones the parameters have to be added once more. If there are different elevation zones the values for PCALT and TCALT are taken as shown in the Parameter-window.

GAP optimisation

Set the ranges for all parameters, start and end of the simulation period and start of the 'warming-up'-period. You may load or save your parameter values if you like to go back to old values or to keep a parameter set for later use. Parameter values are optimised within the given ranges. The results (parameter values and values of the objective functions) are stored

in a file with the name `GA_bestn.dat` and `GAcaln.par` where n is the population. The first file shows the progress of the calibration (last line is calibration result) and the latter is a parameter file ready to load into *HBV light* in the parameter window. Check 'Save details' to get more information about the calibration process (population in the different generations (`GAn_g.dat`, where n is the population and g is the generation), optimisations during the GA-part of the algorithm (`opticheck.dat`) and optimisation using the Powell method (`Powell best n.dat`, where n is the population).

TIP: Save your parameters into a file named `pmul.mul` in the data-directory. This file will be, if existing, read whenever you start 'GAP optimisation'. If there is no file with this name, an error message will be displayed for information, just continue and save the parameters as `pmul.mul` (unless you like to type in the values each time ☺). Other sets of parameter ranges might be saved in files with other names (extension `*.mul`).

Use of groundwater observations

Sometimes observed groundwater levels within the simulated catchment are available and it may be useful to include them into the analysis. *HBV light* allows you to do this in a simple way. Two more input files are required: `gw.dat` and `gwinfo.dat`. The observations have to be in the file `gw.dat` using the format as follows: header (one line with any text) followed by lines with `tube_ID` (integer), date (YYMMDD) and observed level (separated by comma). Up to 10 different tubes with up to 1000 observations per tube are allowed. All observations from one tube have to be grouped together and for each tube the observations have to be sorted according to their date.

Example:

```
station,date,level
2,690810,2.81
2,690824,2.86
2,690907,2.81
2,690921,2.78
20,690806,9.06
20,690820,9.04
....
```

In the file `gwinfo.dat` you have to specify by which box in the model you want simulate the GW-level observations at a certain tube. The format is a header (one line with any text) followed by one line per tube with tube ID and a number where the levels are simulated by SUZ for 1, by SLZ for 2 and by the sum SUZ+SLZ for 3.

Example:

```
station,box
```

2,2
3,1
4,2
20,3
....

The groundwater levels are simulated by a linear function of SUZ, SLZ or SUZ+SLZ. Therefore, after the usual precipitation-runoff simulation the coefficients of the linear regression are computed. The slope of the regression line is thought to represent some storage coefficient whereas the intercept is some offset (both values depend on the unit in which the groundwater observations are given).

The results of the groundwater simulations can be seen on a graph (see Menu-Results-GW levels) or in two files (gwparxxx.dat and gwsimxxx.dat, where xxx is the 'Model-Run-No') if the results of the model run were saved (see Menu-HBV-HBV.ini). If you run the Monte Carlo- or BatchRun-Option the regression coefficients and the coefficient of determination, r^2 , is stored together with the other results.

Alternative model structures

Only snow routine distributed

Only the computations in the snow routine are performed individually for each elevation-vegetation zone. The sum of rainfall and meltwater is added to one, lumped soil box.

SUZ-boxes distributed

One individual SUZ-box is used for each elevation-vegetation zone. However, the same parameters (K_0 , K_1 and UZL) are used for all SUZ-boxes.

Three box version

Instead of using two outflows from the upper groundwater box a third box on top of the other boxes, called STZ, is used. From each box there is one linear outflow computed from the water level and a constant (K_0 , K_1 and K_2 for STZ, SUZ and SLZ respectively). The flow from SUZ to SLZ is computed as before using PERC. The flow from STZ towards SUZ is calculated in the same way using the parameter UZL (now [mm d^{-1}]) as maximum flow rate.

The STZ (and SUZ)-box may be 'distributed', i.e. individual boxes for each elevation-vegetation zone may be used.

One box version

Instead of using two distinct boxes only one box with three outflows is used. The outflow is computed from the water level in this box. As long it is below PERC (now [mm]) only the lowest outflow (K_0) is active, as the level raises above PERC and respective UZL , the upper two outflows (K_1 and K_2) start to contribute.

Response routine with delay

In some situations, e.g. for catchments with deep groundwater, it may be necessary to introduce some delay in the response function. The alternative response function is used only if this possibility is chosen in Menu-HBV-HBV.ini.

There are two new parameters, DELAY and PART, on the other hand three parameters of the original versions are not used in the alternative response routine. The recharge coming from the soil routine is divided into two parts. The parameter PART [-] (0 to 1) gives the portion of the recharge which is added to the groundwater box 1, the remaining recharge generated on one day is evenly distributed over the subsequent period of DELAY [day] days added to box 2. From both boxes discharge is computed as a constant (K_1 and K_2) times water level (SUZ for box 1 and SLZ for box 2) and added before it is transformed by MAXBAS.

Note that in some files (parameter file, input-file for Batch Runs) the notation for the parameters does not change. In these files DELAY corresponds to PERC and PART to K_0 while UZL is written but not used.

Slopefactor version

The catchment is divided into elevation-vegetation-slope-azimuth zones. Both snow- and soil-routine computations are performed for each such zone.

For each zone, the degree-day factor and the potential evaporation are multiplied by the slope factor, f_{sl} .

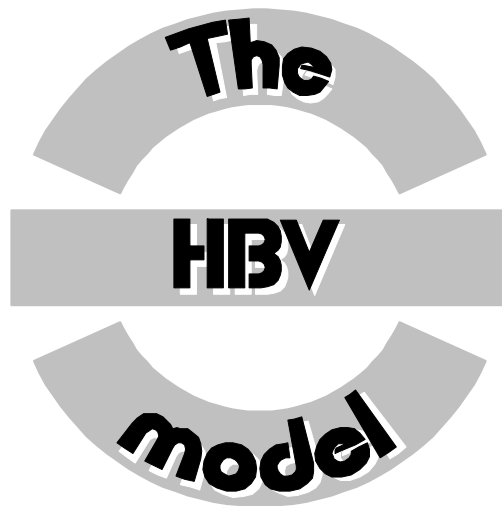
Different slopes (α) and azimuth (β , clockwise from N) are represented by the slope factor, f_{sl} , which is a function of slope, azimuth and day of the year (Equation X). K_{dir} is the daily direct solar radiation received by a slope or a plane and K_{diff} is the daily diffuse solar radiation.

$$f_{sl} = \frac{K_{dir}(\alpha, \beta) + K_{diff}}{K_{dir}(plane) + K_{diff}} \quad (X)$$

The fraction $K_{dir}(slope)/K_{dir}(plane)$ is computed using trigonometric relations (Dingman, 1993) and K_{diff} is assumed to be a constant fraction of K_{dir}

References

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- Dingman, S.L., 1993, *Physical hydrology*, Prentice Hall, Englewood Cliffs, New Jersey, USA, 575 pp.
- Lindström, G., and S.Bergström, 1992, Improving the HBV and PULSE-models by use of temperature anomalies, *Vannet i Norden*, Nr.1-1992, p. 16-23



The HBV model was developed at SMHI by Sten Bergström (Bergström, 1976).

HBV = "**H**ydrologiska **B**yråns **V**attenbalansavdelning"

The HBV model ...

- ... is a conceptual model for runoff simulation
- ... has a simple structure
- ... is semi-distributed, i.e., allows to divide the catchment into subbasins, elevation and vegetation zones
- ... is easy to understand, learn and apply
- ... has been applied to many catchments in Sweden and abroad
- ... provided good results in most applications
- ... has become a standard tool for runoff studies in the Nordic countries
- ... needs a moderate amount of input data
- ... can be run on a PC (286 or better)
- ... exists in different versions (Swedish, Norwegian, Finnish, Swiss, ...)

Schematic model structure

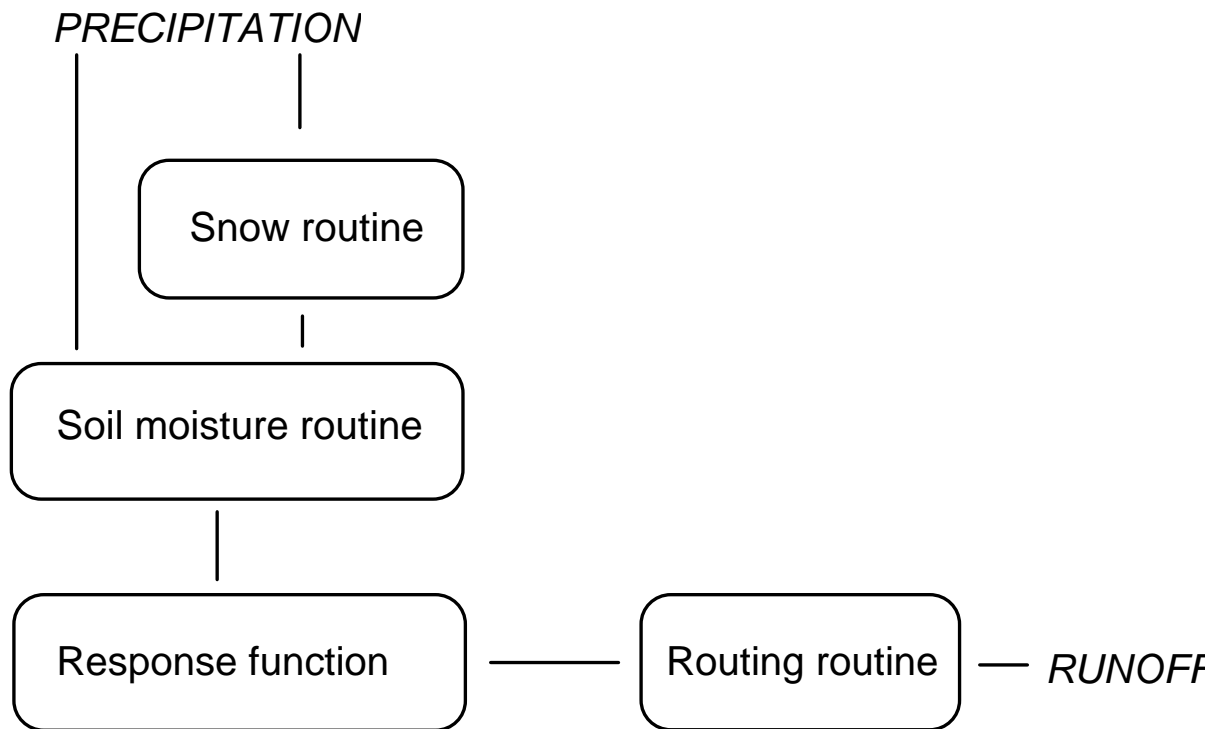


Figure 1. Schematic structure of the HBV model

Submodel	Input data	Output data
Snow routine	Precip., Temp.	Snow pack, snow-melt
Soil routine	Pot.Evap., precip., snowmelt	Act.Evap., 'soil moisture', groundwater recharge
Response function	Groundwater recharge, (pot.ET)	Runoff, 'Groundwater level'
Routing routine	Runoff	Simulated runoff

Input data

Precipitation

The areal average precipitation P_{area} is calculated as weighted mean of precipitation stations in and around the catchment.

$$P_{area} = \sum c_i P_i$$

The weight c_i of station i can be determined ...

- ... subjectively
- ... by Thiessen polygons
- ... by the isohyetal or the hypsometric method

The catchment can be divided into different elevation zones. For each zone the precipitation will be corrected according to the its increase with elevation above sea level (usually 10-20% per 100 m, parameter PCALT).

Temperature

Temperature data is needed in catchments with snow and is calculated as weighted mean of stations in and around the catchment.

When different elevation zones are used temperature will be corrected for elevation above sea level with usually -0.6°C per 100 m (parameter TCALT).

Potential evaporation

Estimates of the potential evaporation may be provided by calculations using, for instance, the Penman formula or measurements by evaporimeters. Normally monthly mean values are assumed to be sufficient. The long-term mean evaporation can be corrected by using the deviations of the temperature from its long-term mean.

$$E_{pot}(t) = (1 + C_{ET}(T(t) - T_M)) E_{pot,M} \quad (\text{BUT: } 2 E_{pot,M} \geq E_{pot}(t) \geq 0)$$

$E_{pot}(t)$ potential evaporation at day t [mm d^{-1}]

C_{ET} correction factor [$^\circ\text{C}^{-1}$]

$T(t)$ temperature at day t [$^\circ\text{C}$]

T_M long-term mean temperature for this day of the year [$^\circ\text{C}$]

$E_{pot,M}$ long-term mean evaporation for this day of the year [mm d^{-1}]

Snow routine

C_{FMAX} = degree-day factor ($\text{mm } ^\circ\text{C}^{-1} \text{ day}^{-1}$)

C_{FR} = refreezing coefficient

T_T = threshold temperature ($^\circ\text{C}$)

1. Accumulation of precipitation as snow if temperature $< T_T$ (T_T is normally close to 0°C)

2. Melt of snow starts if temperatures are above T_T calculated with a simple degree-day method.

$$\text{meltwater} = C_{FMAX} (T - T_T) \quad (\text{mm day}^{-1})$$

C_{FMAX} varies normally between 1.5 and $4 \text{ mm } ^\circ\text{C}^{-1} \text{ day}^{-1}$ (in Sweden), with lower values for forested areas. As approximation the values 2 and 3.5 can be used for C_{FMAX} in forested and open landscape respectively.

3. The snow pack retains melt water until the amount exceeds a certain portion (CWH, usually 0.1) of the water equivalent of the snow pack. When temperatures decrease below T_T this melt water refreezes again.

$$\text{refreezing meltwater} = C_{FR} C_{FMAX} (T_T - T)$$

(CFR 0.05)

NOTE :

- a) All precipitation that is simulated to be snow is multiplied by a correction factor, SFCF.
- b) These calculations are carried out separately for each elevation and vegetation zone.

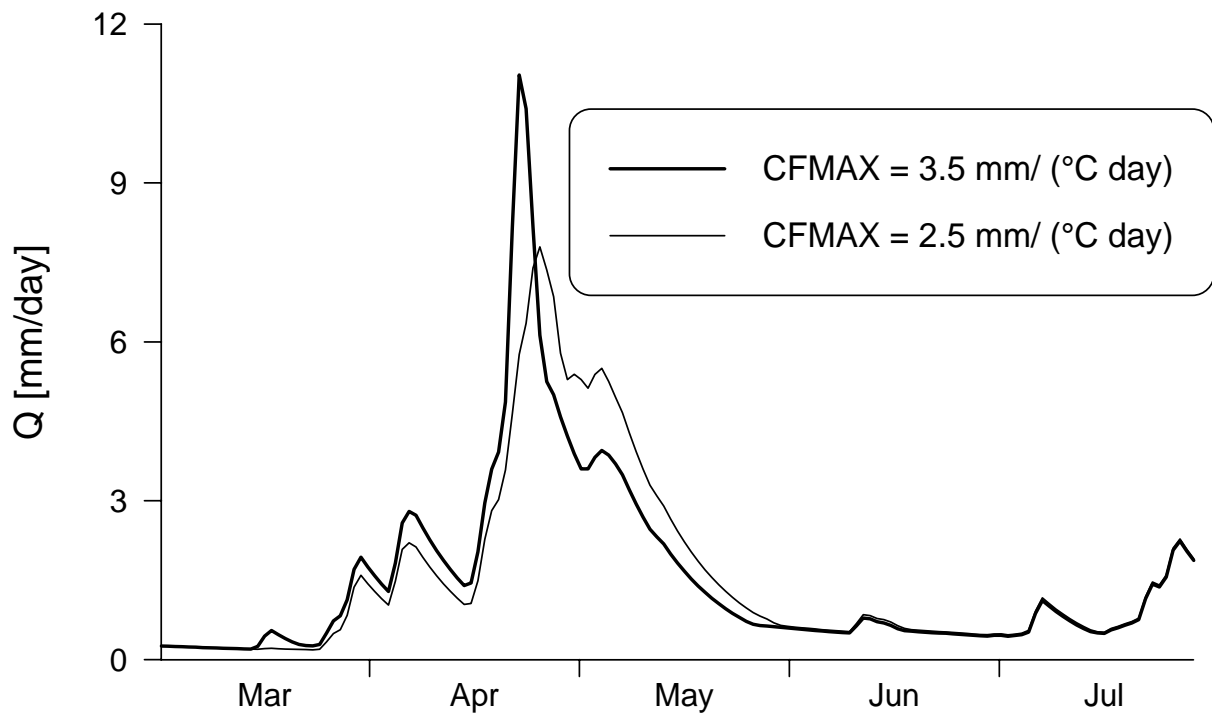


Figure 2. Example of simulations with different values for CFMAX, thick line: $CFMAX=3.5 \text{ mm } \text{°C}^{-1} \text{ day}^{-1}$, thin line: $CFMAX=2.5 \text{ mm } \text{°C}^{-1} \text{ day}^{-1}$.

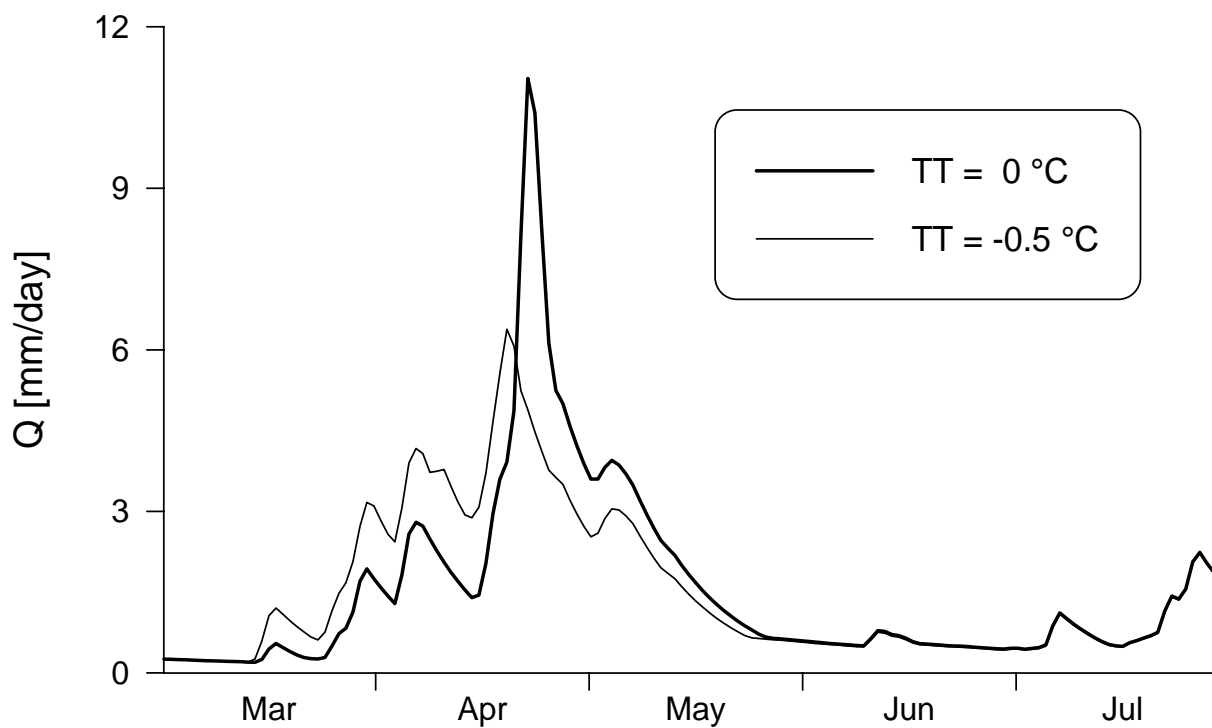


Figure 3. Example of simulations with different values for TT, thick line: $TT=0 \text{ °C}$, thin line: $TT=-0.5 \text{ °C}$.

Soil moisture routine

FC = maximum soil moisture storage (mm)

LP = soil moisture value above which ET_{act} reaches ET_{pot} (mm)

BETA= parameter that determines the relative contribution to runoff from rain or snowmelt (-)

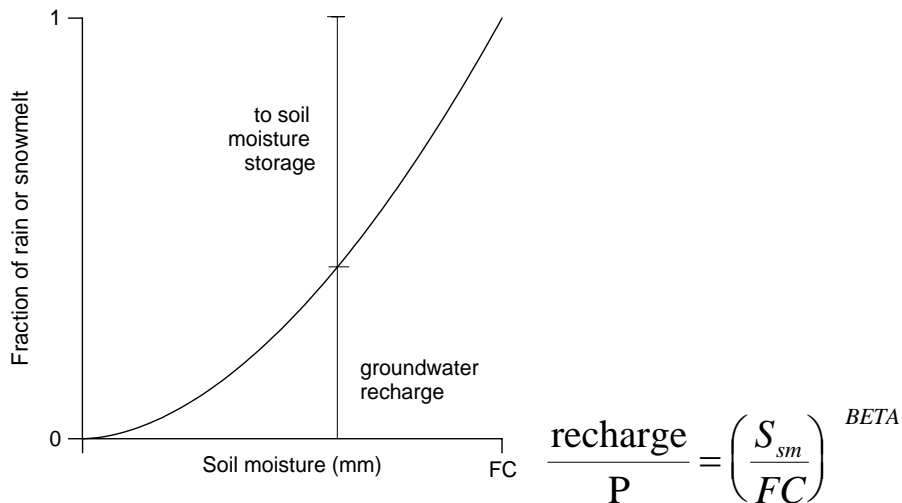


Figure 4. Contributions from rainfall or snowmelt to the soil moisture storage and to the upper groundwater zone

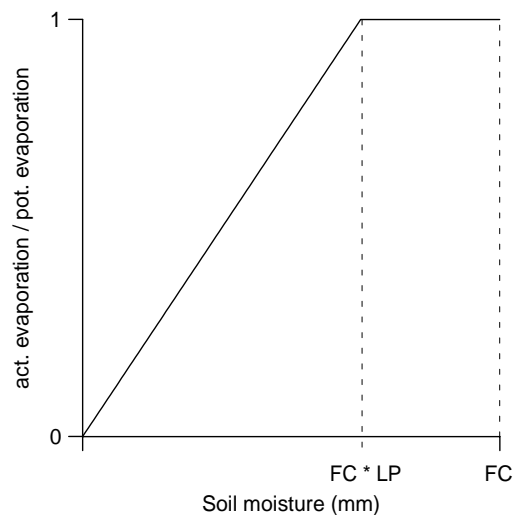


Figure 5. Reduction of potential evaporation depending on soil moisture storage

NOTE: FC is a model parameter and not necessarily equal to measured values of 'field capacity'

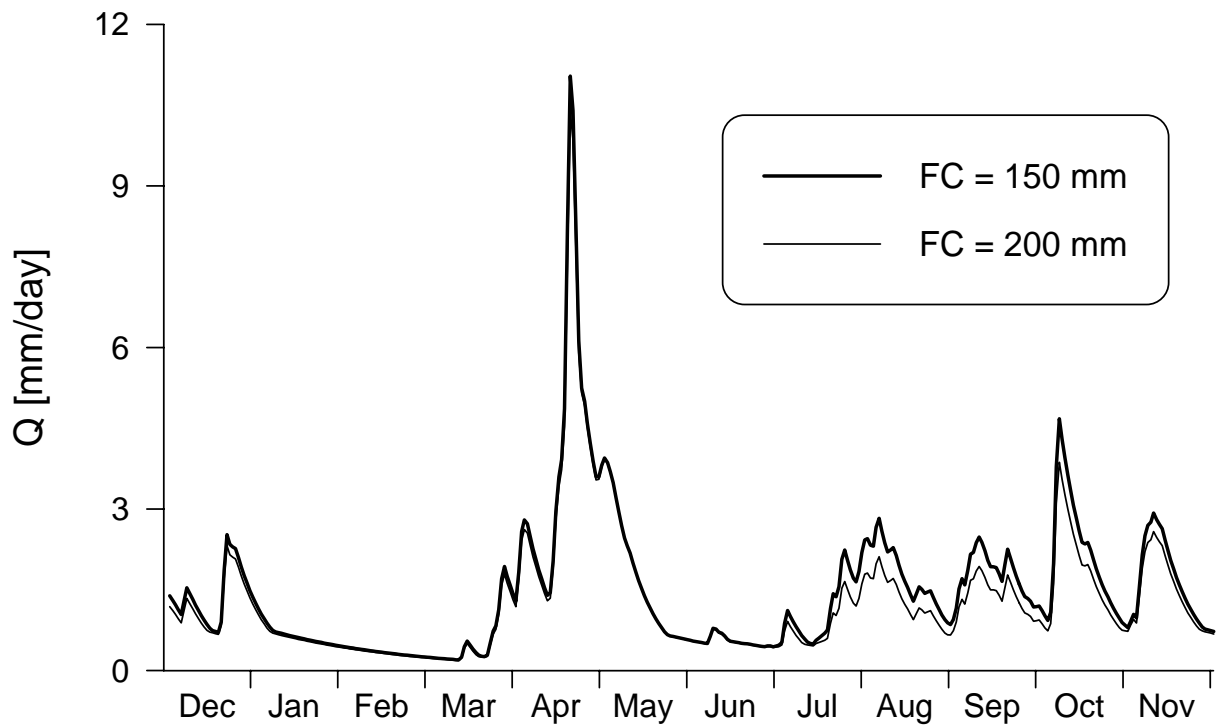


Figure 6. Example of simulations with different values for FC, thick line: FC=150 mm, thin line: FC=200 mm (LP=150 mm)

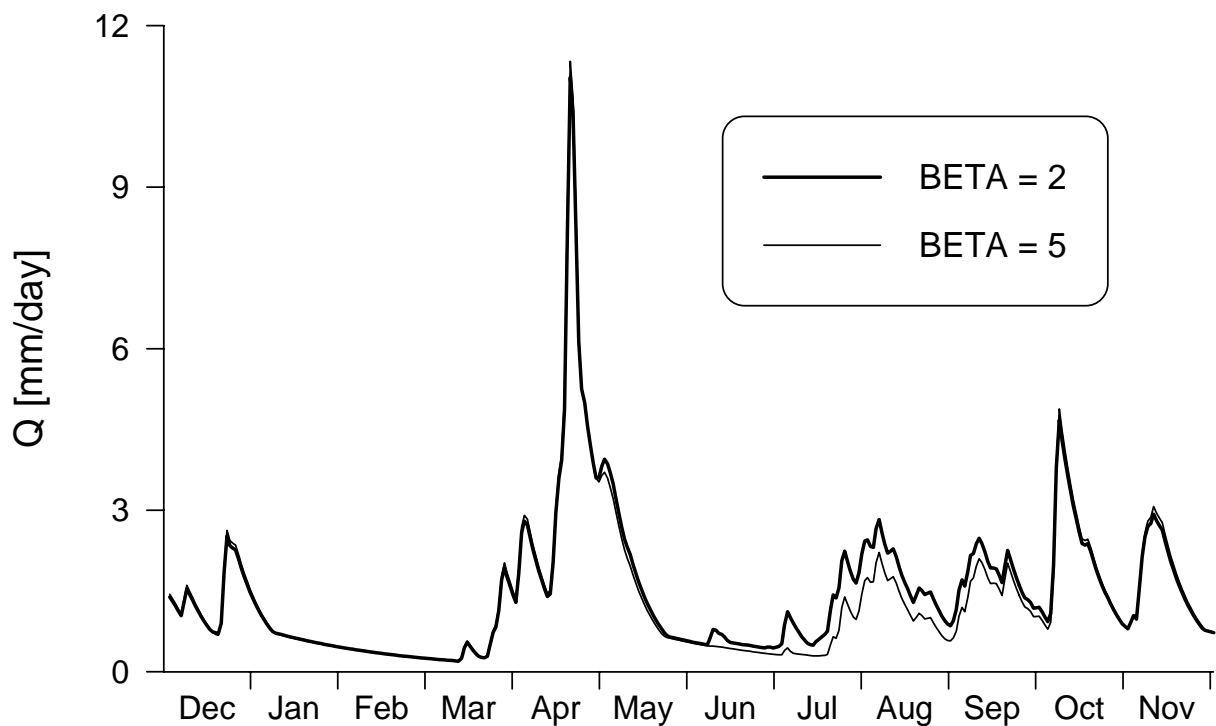
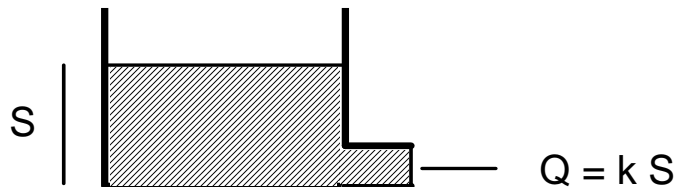


Figure 7. Example of simulations with different values for BETA, thick line: BETA= 2, thin line: BETA= 5.

Response function

Simple linear reservoir



The model of a single linear reservoir is a simple description of a catchment where the runoff $Q(t)$ at time t is supposed to be proportional to the water storage $S(t)$.

$$Q(t) = k \cdot S(t) \quad (*)$$

S = storage (mm)

Q = outflow (mm day⁻¹)

t = time (day)

k = storage (or recession) coefficient (day⁻¹)

(A realisation of a single linear reservoir is a box with a porous outlet, thus obtaining Equation (*) from Darcy's law.)

The water balance of the catchment is

$$P(t) = E(t) + Q(t) + \frac{d \cdot S(t)}{dt}$$

Ignoring precipitation and evapotranspiration gives

$$0 = Q(t) + \frac{d \cdot S(t)}{dt}$$

and together with (*) the differential equation

$$0 = \frac{d Q(t)}{dt} \frac{1}{k} + Q(t)$$

with the solution function

$$Q(t) = Q(t_0) \cdot e^{-(t-t_0)k}$$

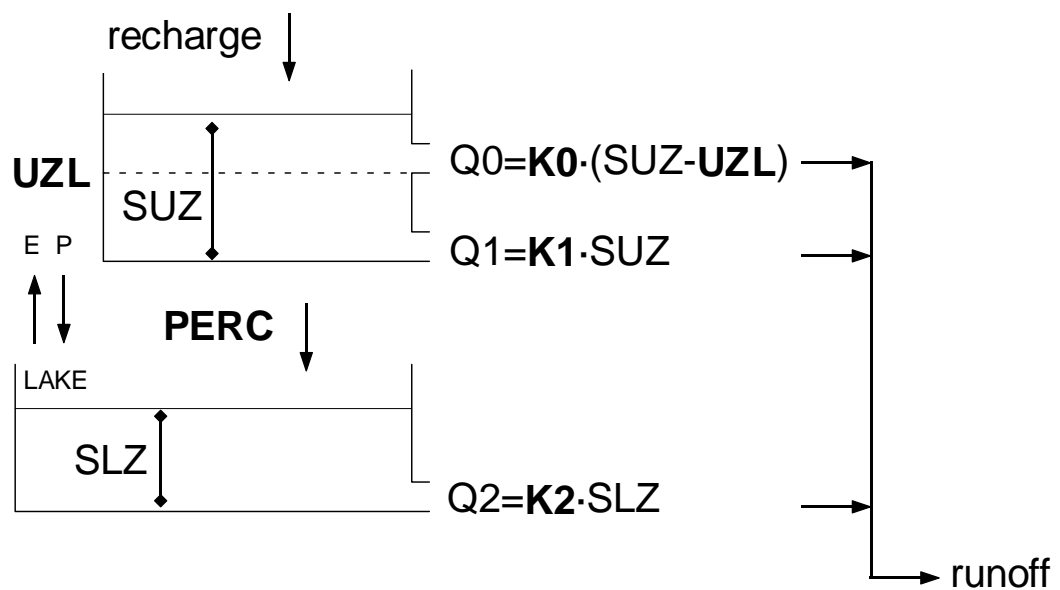
Response routine of the HBV model

Figure 8. Response function

recharge	= input from soil routine (mm day^{-1})
SUZ	= storage in upper zone (mm)
SLZ	= storage in lower zone (mm)
UZL	= threshold parameter (mm)
PERC	= max. percolation to lower zone (mm day^{-1})
K_i	= Recession coefficient (day^{-1})
Q_i	= runoff component (mm day^{-1})

NOTE:

- SUZ has no upper limit
- Q_2 can never exceed PERC SLZ can never exceed PERC/ K_2

Recession analysis

If $\ln Q$ is plotted against time during a dry period, the slopes of the hydrograph at different runoff values provide good first estimates of the response-function parameter.

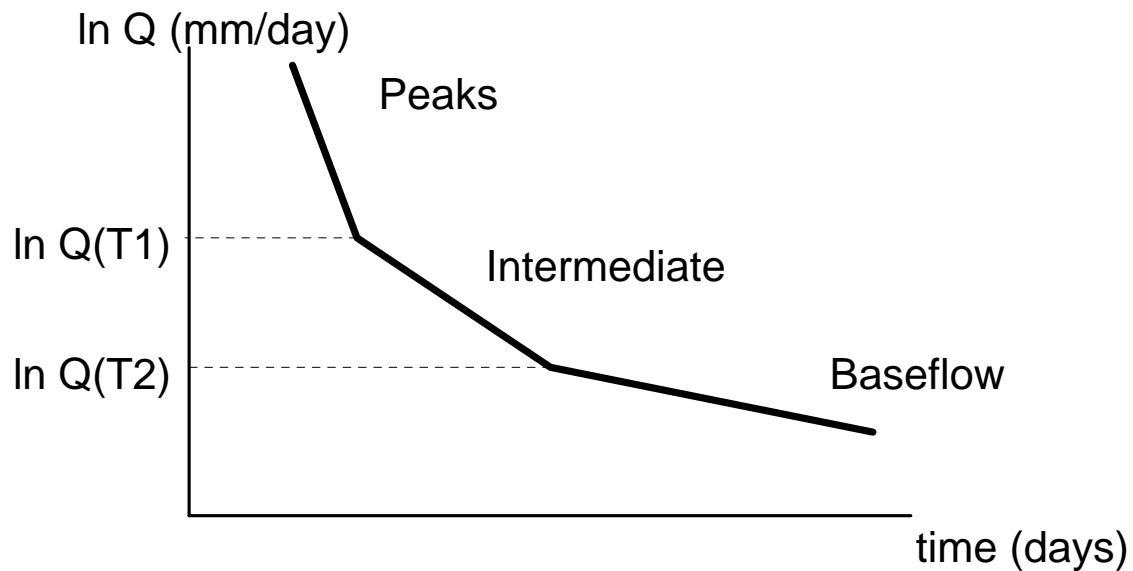


Figure 9. Schematic shape of recession in relation to the different parameter

Slope of the recession:

Peaks:	$K_0 + K_1 + K_2$
Intermediate:	$K_1 + K_2$
Baseflow:	K_2

Thresholds:

$Q(T1)$	PERC+K1UZL
$Q(T2)$	PERC

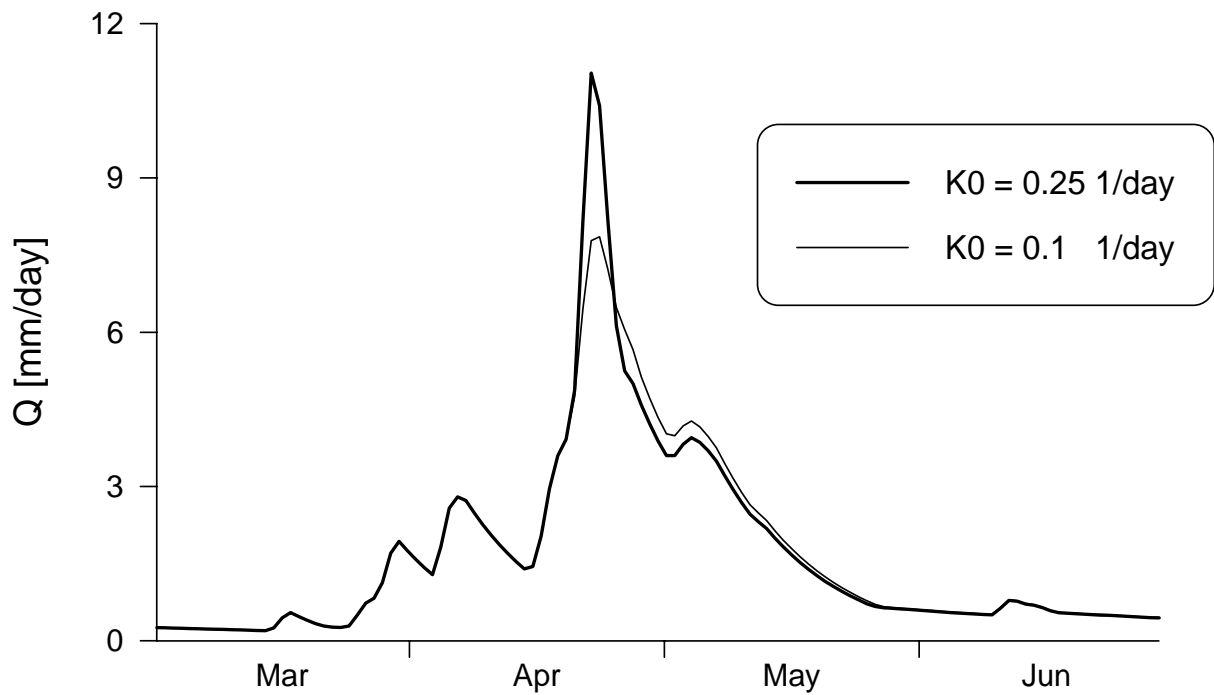


Figure 10. Example of simulations with different values for K_0 , thick line: $K_0=0.25$, thin line: $K_0=0.1$

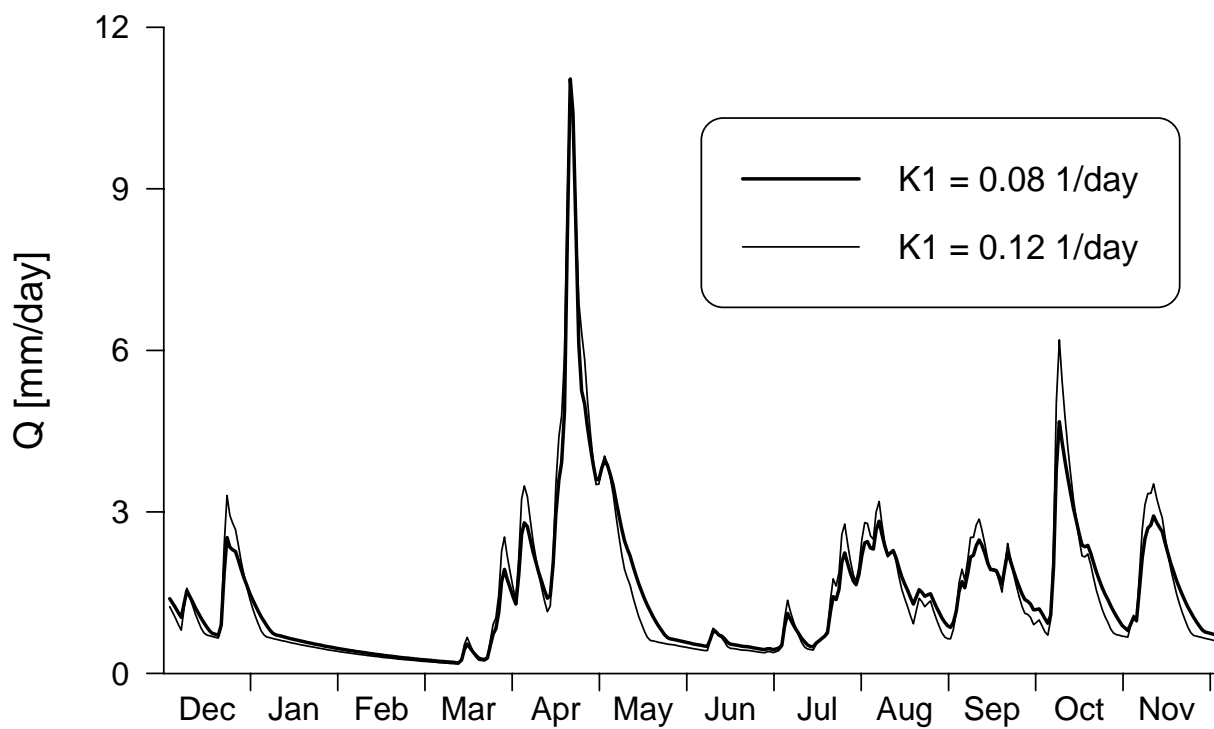


Figure 11. Example of simulations with different values for K_1 , thick line: $K_1=0.08$, thin line: $K_1=0.12$

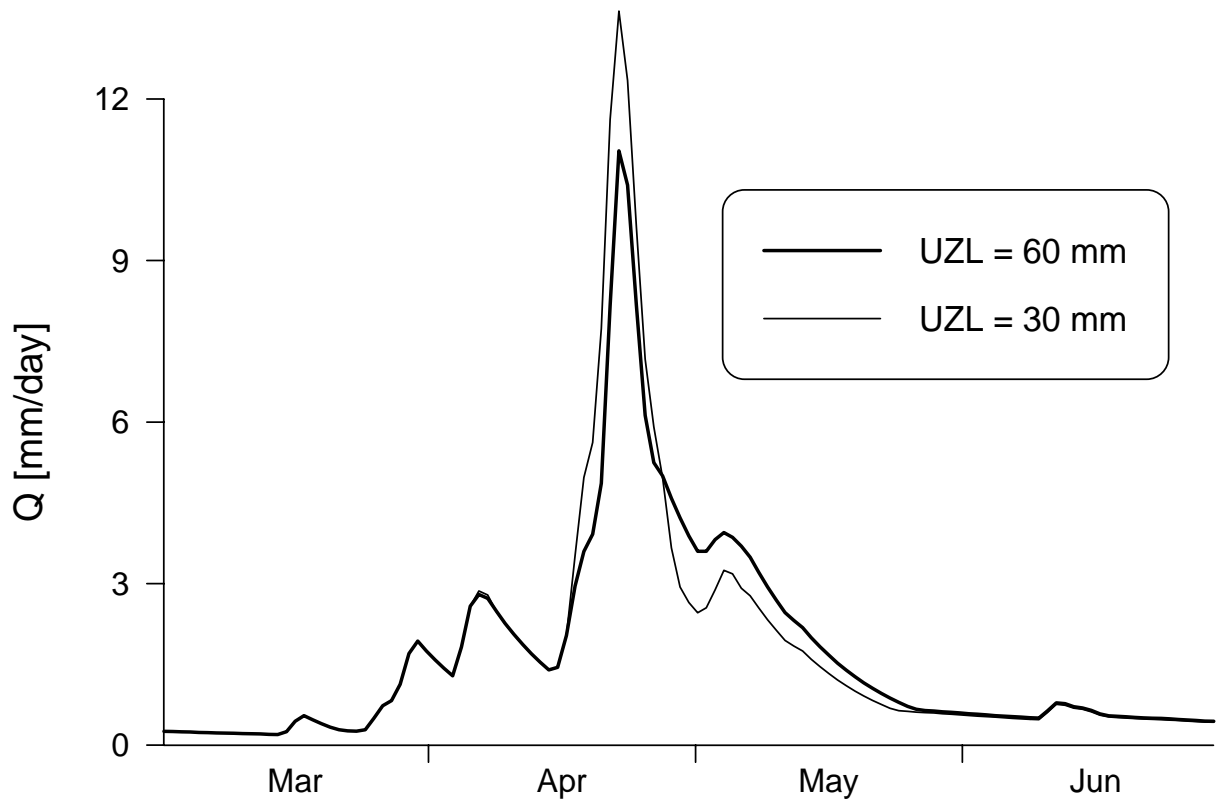


Figure 12. Example of simulations with different values for UZL, thick line: UZL=60 mm, thin line: UZL=30 mm

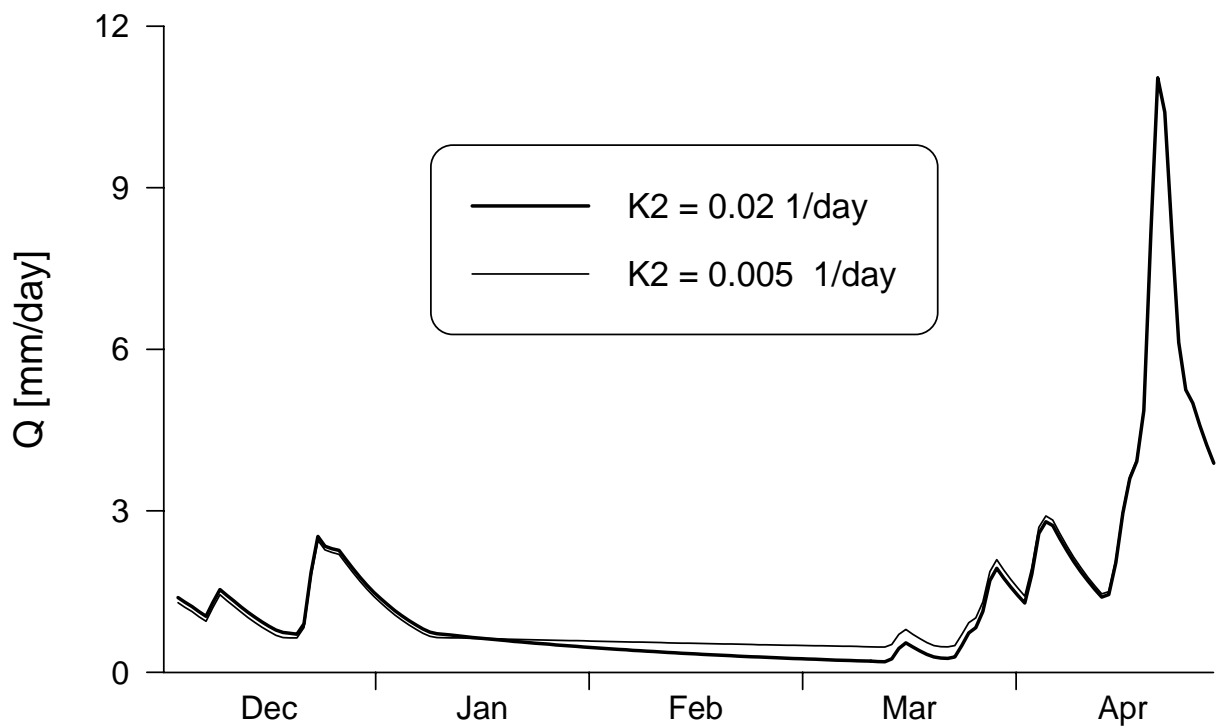


Figure 13. Example of simulations with different values for K_2 , thick line: $K_2=0.02$, thin line: $K_2=0.005$

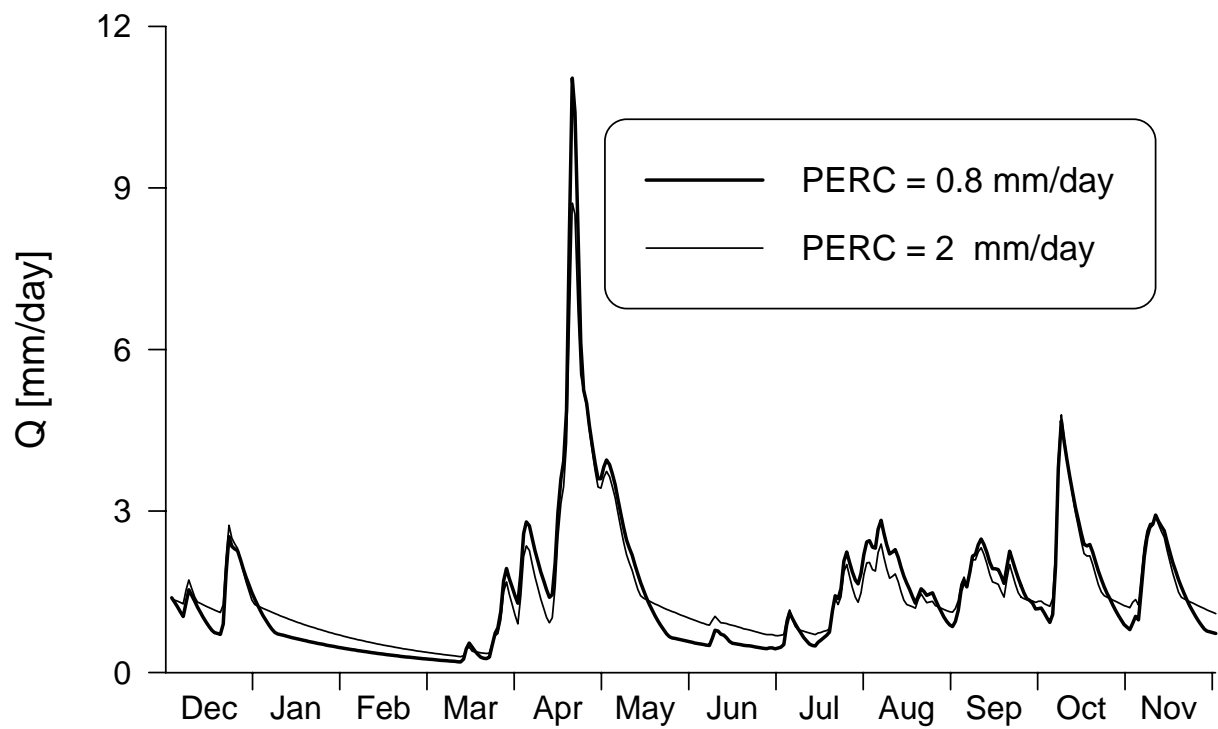


Figure 14. Example of simulations with different values for PERC, thick line: $\text{PERC} = 0.8 \text{ mm day}^{-1}$, thin line: $\text{PERC} = 2 \text{ mm day}^{-1}$

Routing routine

Transformation function

The generated runoff of one time step is distributed on the following days using one free parameter, MAXBAS, which determines the base in a equilateral triangular weighting function.

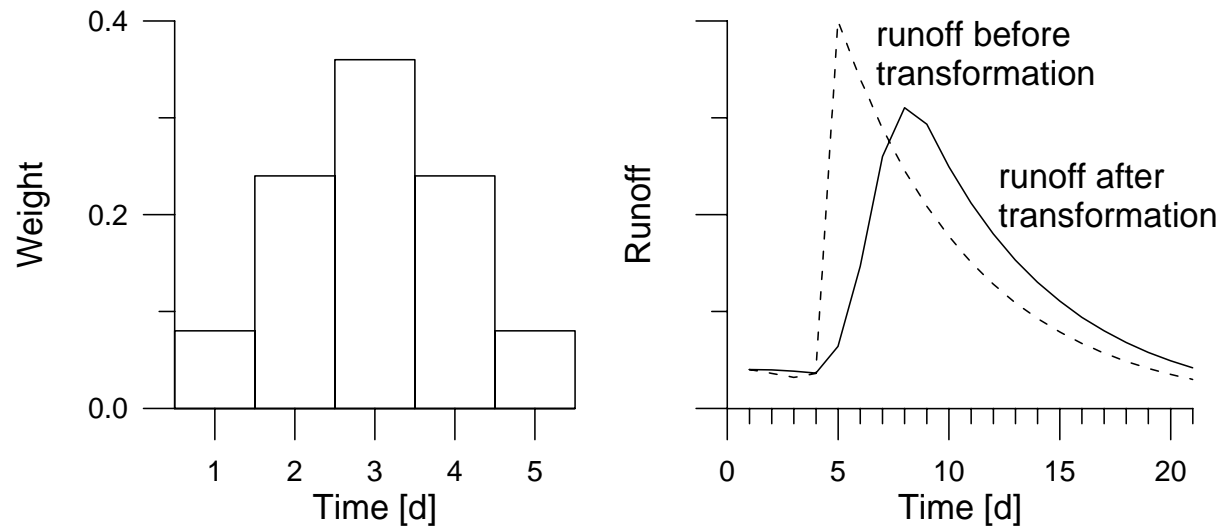


Figure 15. Example for a transformation with MAXBAS=5

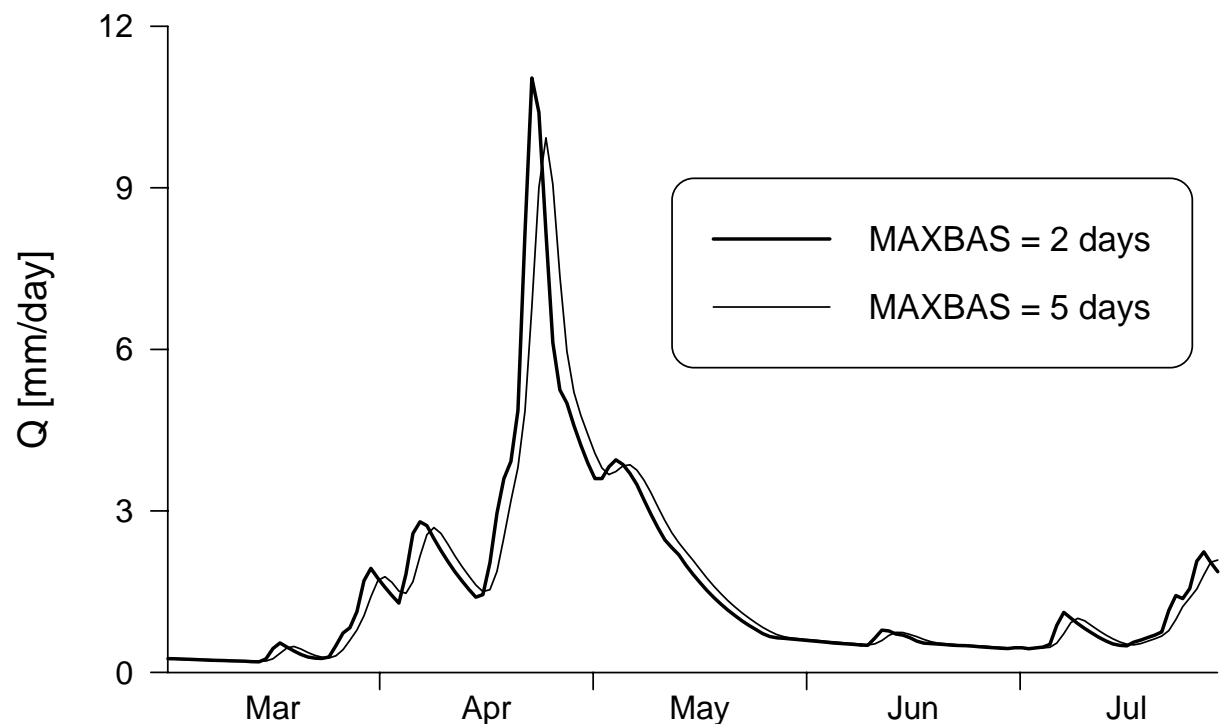


Figure 16. Example of simulations with different values for MAXBAS, thick line: MAXBAS=2 days, thin line: MAXBAS=5 days

Model calibration

The calibration of the model is usually made by manual try and error technique (Bergström, 1992).

Different criteria can be used to assess the fit of simulated runoff to observed runoff:

- visual inspection of plots with Q_{Sim} and Q_{Obs}
- accumulated difference
- statistical criteria

The coefficient of efficiency, R_{eff} , is normally used for assessment of simulations by the HBV model.

$$R_{eff} = 1 - \frac{\sum (Q_{Sim}(t) - Q_{Obs}(t))^2}{\sum (Q_{Obs}(t) - \bar{Q}_{Obs})^2}$$

R_{eff} compares the prediction by the model with the simplest possible prediction, a constant value of the observed mean value over the entire period.

$R_{eff} = 1$	Perfect fit, $Q_{Sim}(t) = Q_{Obs}(t)$ t
$R_{eff} = 0$	Simulation as good (or poor) as the constant-value prediction
$R_{eff} < 0$	Very poor fit

Unfortunately R_{eff} is often named R^2 in connection with the HBV model. This should be avoided as R^2 easily can be confused with r^2 (= coefficient of determination).

Note:

- + the calibration period should include a variety of hydrological events
- + normally 5 to 10 years sufficient to calibrate the model
- + validation: test of model performance with calibrated parameters for an independent period

Applications of the HBV model

The HBV model can be used ...

- ... to extend runoff data series (or filling gaps)
- ... for data quality control
- ... for water balance studies
- ... for runoff forecasting (flood warning and reservoir operation)
- ... to compute design floods for dam safety
- ... to investigate the effects of changes within the catchment
- ... to simulate discharge from ungauged catchments (?)
- ... to simulate climate change effects (?)

References

- Bergström, S., 1976, *Development and application of a conceptual runoff model for Scandinavian catchments*. SMHI RHO 7. Norrköping. 134 pp.
- Bergström, S., 1990, *Parametervärden för HBV-modellen i Sverige. Erfarenheter från modelkalibreringar under perioden 1975-1989*. SMHI HYDROLOGI No 28. Norrköping. 35 pp.
- Bergström, S., 1992, *The HBV model - its structure and applications*. SMHI RH No 4. Norrköping. 32 pp.