Vt 2011

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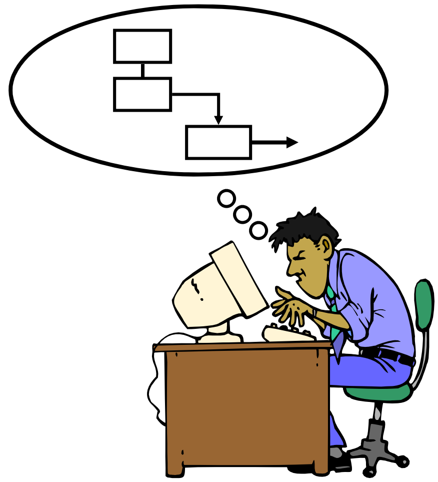
Introduction to hydrological modelling and the HBV model

How do we see reality?

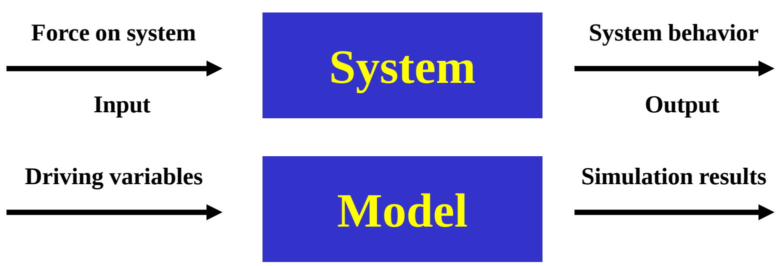
Figur 3.2. Vi väljer och omtolkar den information som vi sedan baserar våra subjektiva tankemodeller på. (Av Nils Peterson, ur Forskning och Framsteg.)

How does a hydrologist see reality?



System and model

A system is a group of components which form a whole, interaction between the components leads to a certain system behavior.



A model is a system which we have chosen to represent the essential characteristics of another system.

Why use a model?

- Forecast / Prediction
- Instead of expensive and time consuming measurements
- ’What happens if’ questions
- Summarize and test knowledge
- Education

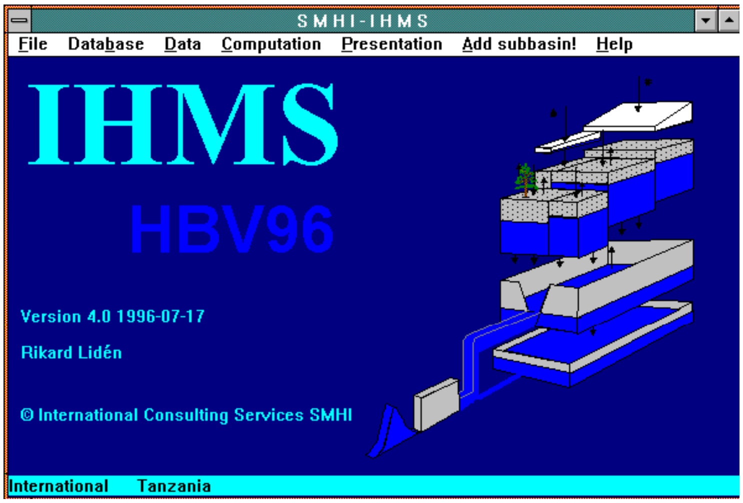
Classification of models

- Symbolic (mathematic) - scale- / analog model
- Empirical - conceptual - physical
- Linear - non-linear
- Lumped - distributed
- Deterministic – stochastic
- Static - dynamic
- Time-variant - time-invariant
- Event based - continuous
- Complete - partial
- General - special purpose

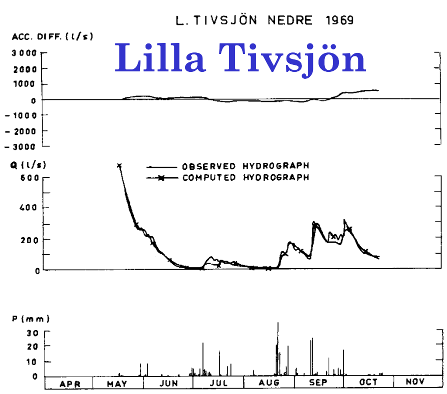
The HBV model …

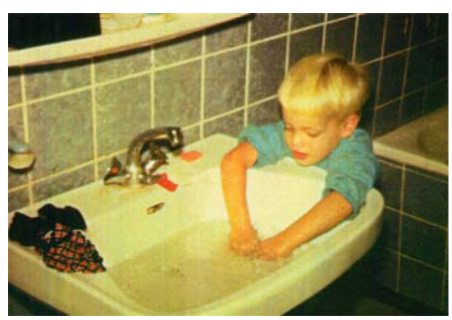
- … has been developed by Sten Bergström
- ... is a conceptual model for runoff simulation
- ... has a simple structure
- ... is semi-distributed, i.e., allows to divide the catchment into subbasins, elevation and vegetation zones
- ... is easy to understand, learn and apply
- ... has been applied to 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, ...)
- … (partly) used in other models

IHMS - Integrated Hydrological Modeling System



30+ years ago …





First sucessful application of the HBV-model (1972)

30+ years with the HBV-model - Lilla Tivsjön 2002

... whereas the HBV-model is still in pretty good shape

Input data

- Areal precipitation
  - Weighted mean
  - Elevation zones (lapse rate ~10% per 100 m)
- Temperature
  - Weighted mean
  - Elevation zones (lapse rate 0.6 ^{o}C per 100 m)
- Potential evaporation
  - Penman formula or measurements
  - Usually long-term monthly mean values

Input data (cont.)

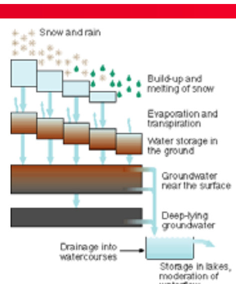
- Correction of long-term potential evaporation

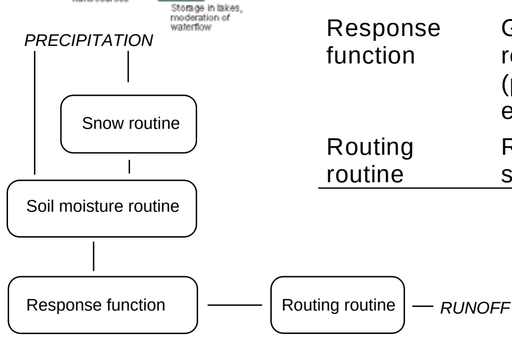
$$E_{pot}(t)=(1+C_{ET}(T(t)-T_M))\ E_{pot,M}$$

$$(\text{BUT: } 2\ E_{pot,M} \geq E_{pot}(t) \geq 0)$$

$E_{pot}(t)$	potential evaporation at day t [mm d^{-1}]
C_{ET}	correction factor [°C^{-1}]
$T(t)$	temperature at day t [°C]
T_M	long-term mean temperature for this day of the year [°C]
$E_{pot,M}$	long-term mean evaporation for this day of the year [mm d^{-1}]

Model structure





Routine	Input data	Output data
Snow routine	Precipitation, temperature	Snow pack, snow-melt
Soil routine	Pot. evaporation, precipitation, snowmelt	Act. evaporation, 'soil moisture', groundwater recharge
Response function	Groundwater recharge, (pot. evaporation)	Runoff to stream, 'Groundwater level'
Routing routine	Runoff to stream	Runoff at outlet

Snow routine

- Accumulation of precipitation as snow if temperature<T_T
- Degree-day method for snowmelt (degree-day factor C_{FMAX} [mm d^{-1} $^oC^{-1}$])

$M = C_{FMAX}(T - T_T)$ [mm d^{-1}]

C_{FMAX} typically around 4 mm d^{-1} $^oC^{-1}$, lower values for forested areas compared to open areas

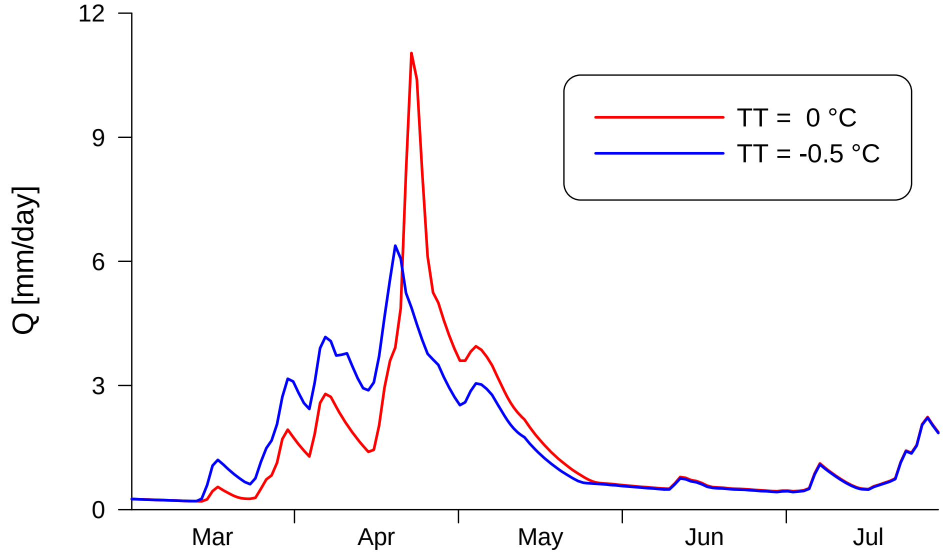
Snow routine (cont.)

- Snow pack retains melt water until amount exceeds a certain portion (C_{WH}, usually 0.1) of the water equivalent of the snow pack.
- When temperatures decreases below T_T water refreezes again

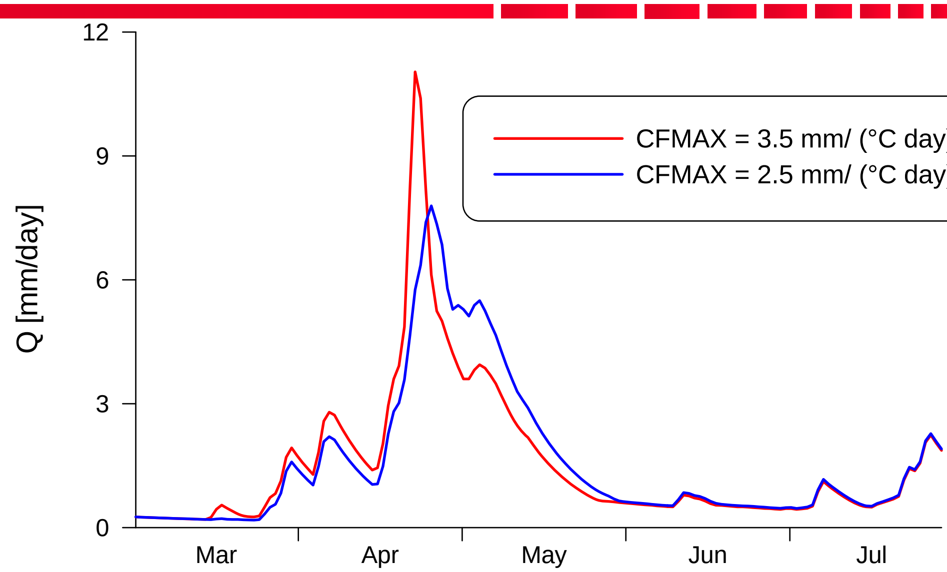
  $M = C_{FR}\, C_{FMAX}(T_T - T)$ [mm h^{-1}]

  C_{FR} = ~0.05 [-]
- All precipitation which is simulated to be snow is multiplied by a correction factor, S_{CF} [-]
- Calculations are carried out separately for each elevation and vegetation zone

Effect of T_T



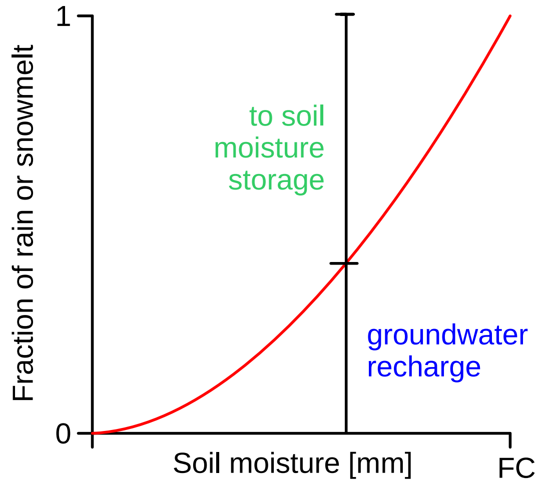
Effect of C_{FMAX}



Soil routine

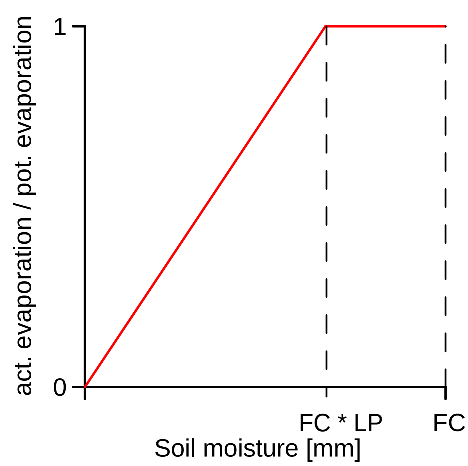
- F_C maximum soil moisture storage [mm]
- ß shape parameter [-]

$$\frac{\text{recharge}}{\text{P}} = \left(\frac{S_{sm}}{F_C}\right)^{\beta}$$

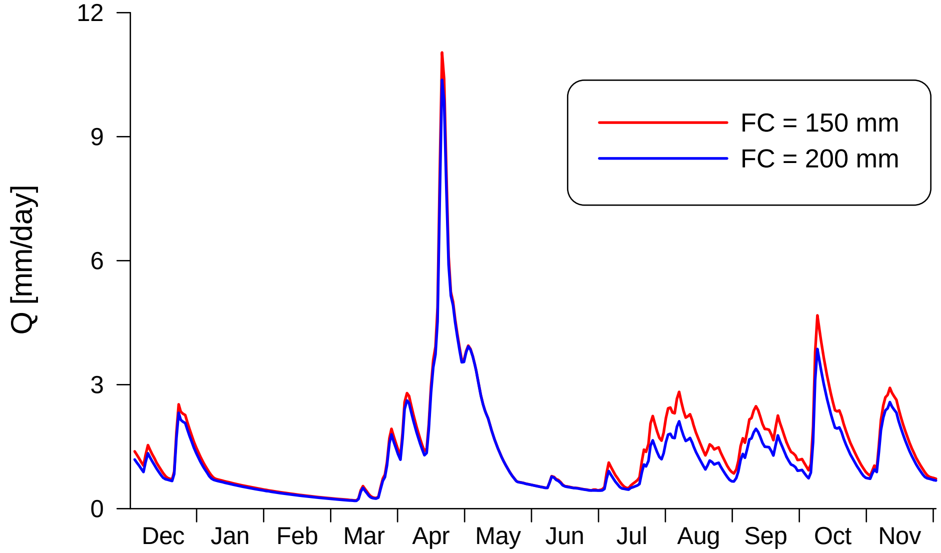


Soil routine (cont.)

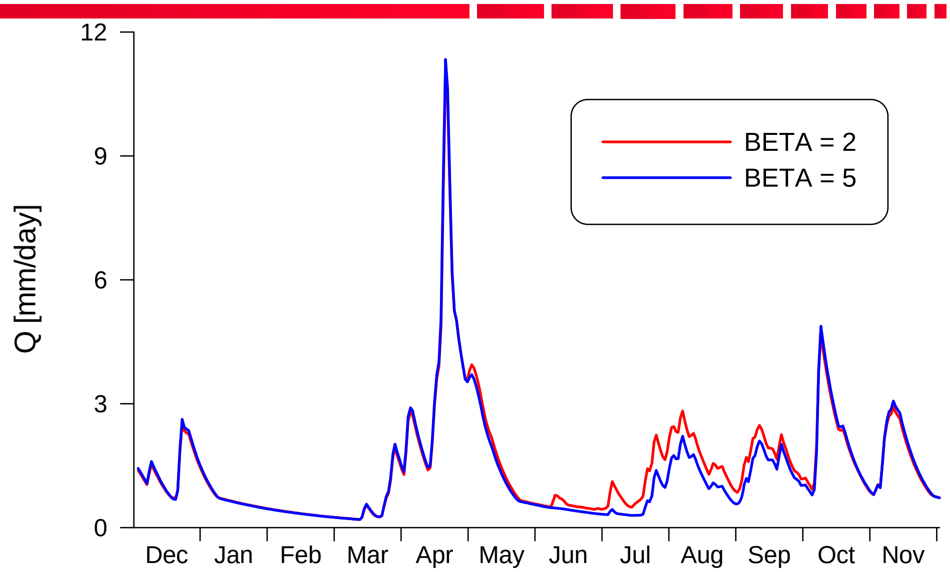
- F_C = maximum soil moisture storage [mm]
- L_P = factor defining reduction of evaporation [-]



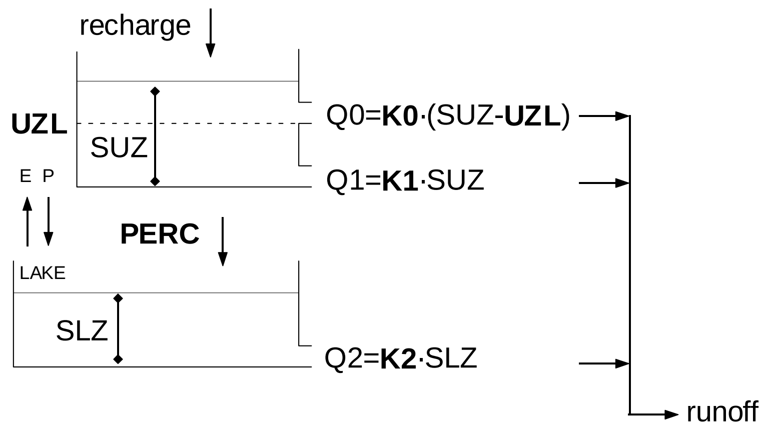
Effect of *FC*



Effect of β

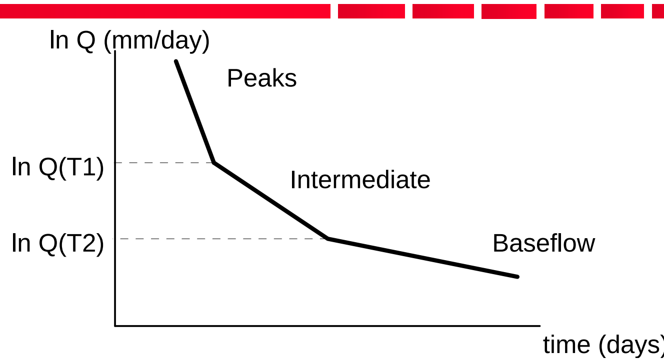


Response function



- 5 parameter, two boxes
- Upper box: shallow ground water, lower box: deeper groundwater

Response function (cont.)



- Slope of the recession:

  Peaks: $K_0 + K_1 + K_2$

  Intermediate: $K_1 + K_2$

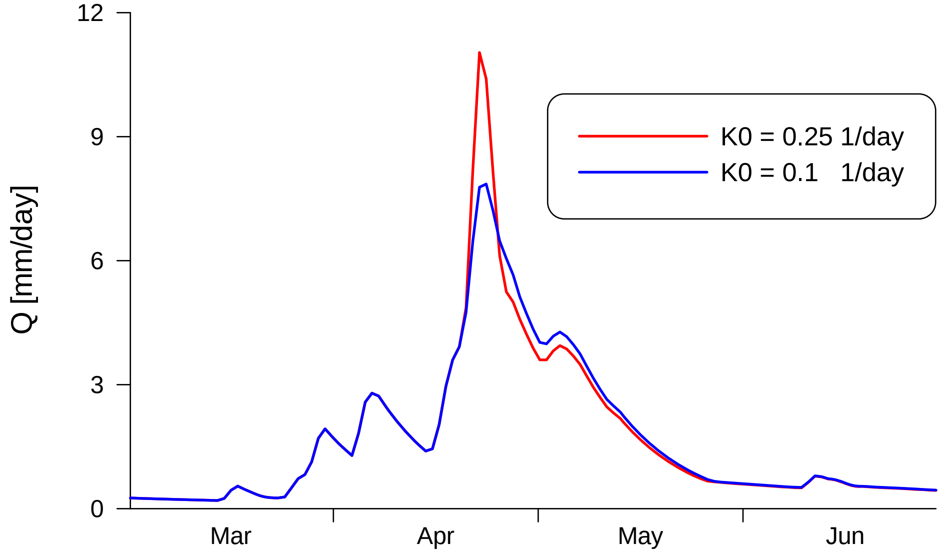
  Baseflow: K_2

- Thresholds:

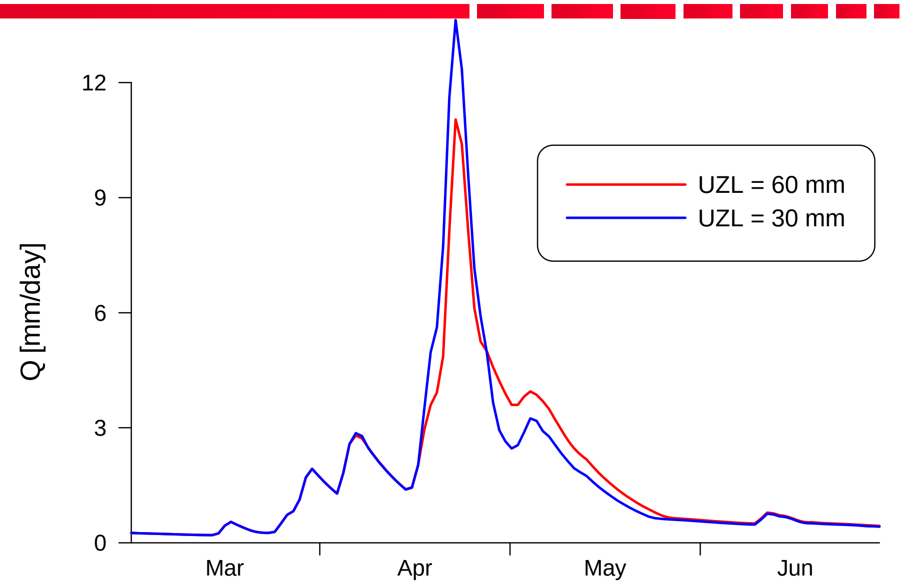
  $Q(T_1) = \sim P_{ERC} + K_1 U_{ZL}$

  $Q(T_2) = \sim P_{ERC}$

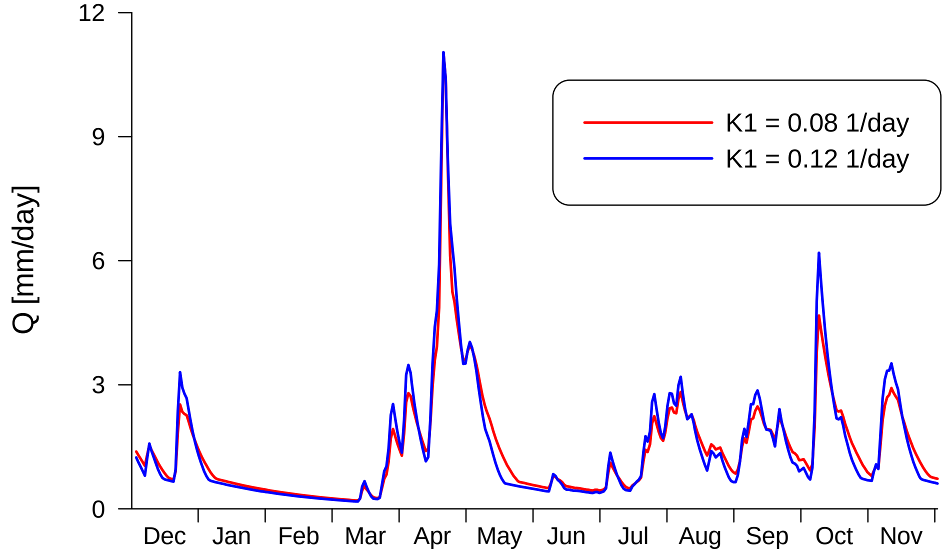
Effect of K_0



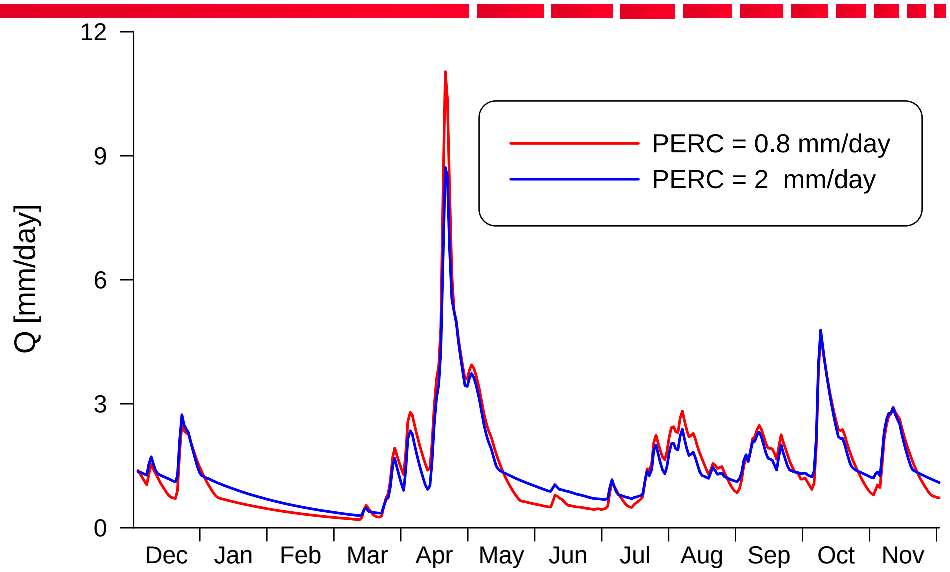
Effect of U_{ZL}



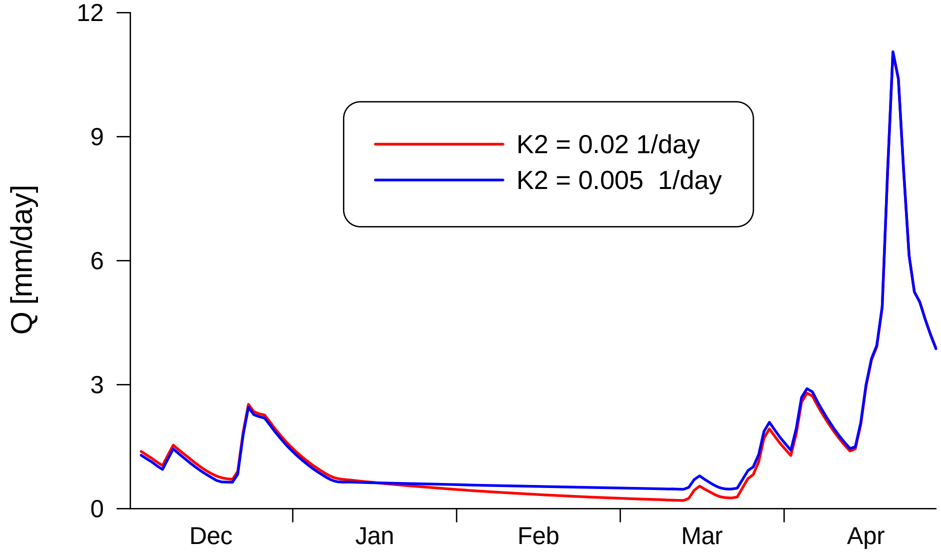
Effect of K_1



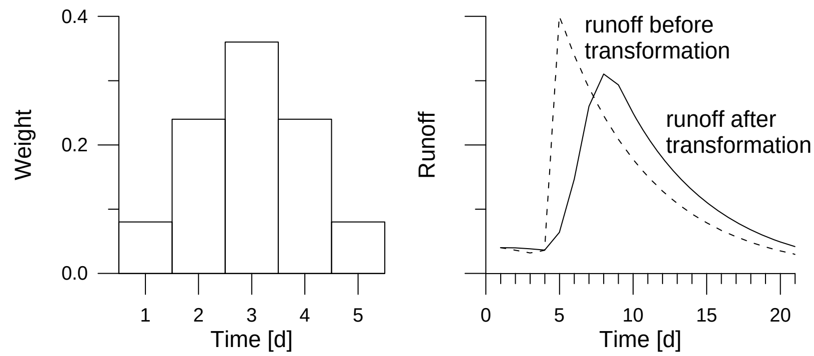
Effect of P_{ERC}



Effect of K_2

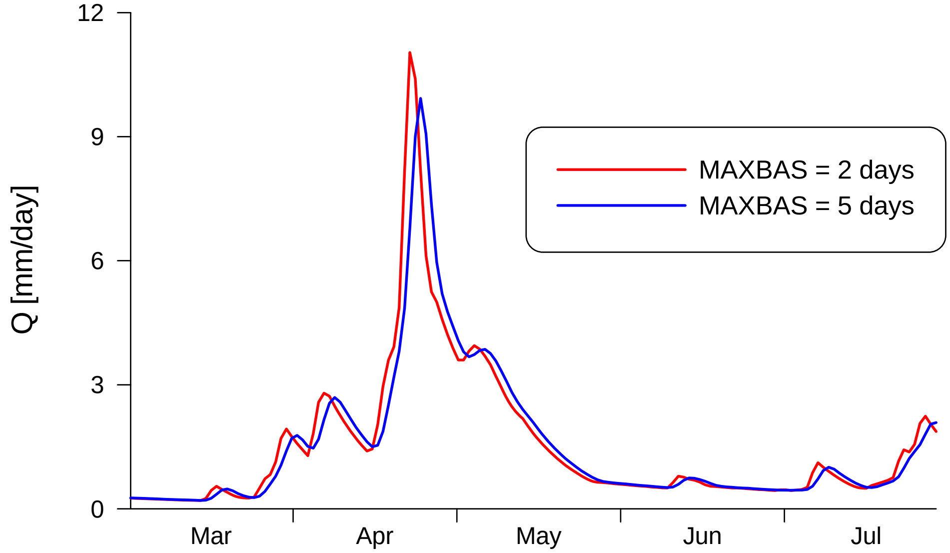


Routing routine

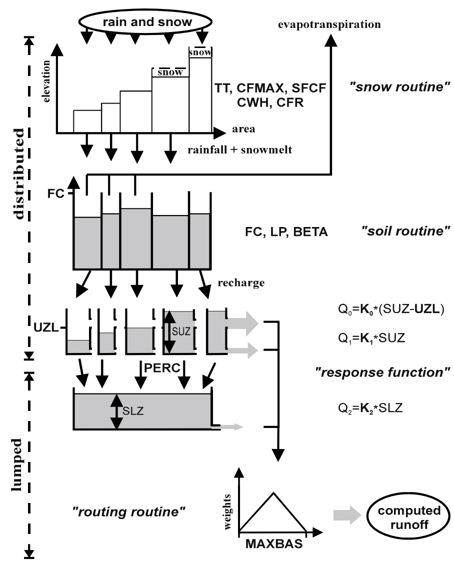


- One parameter: MAXBAS [d]
  base in an equilateral triangular weighting function

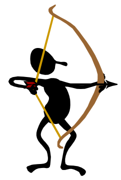
Effect of *MAXBAS*

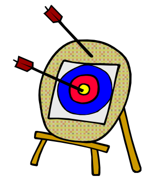


HBV overview



Calibration of the HBV model





- Trial-and-error or automatic calibration
- 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}
  - statistical criteria
- The coefficient of efficiency, R_{eff}, is normally used for assessment of simulations by the HBV model:

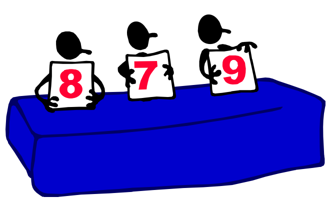
$$R_{eff} = 1 - \frac{\sum (Q_{Sim}(t) - Q_{Obs}(t))^2}{\sum (Q_{Obs}(t) - \overline{Q}_{Obs})^2}$$

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

R_{eff} not equal r^2 !!!

Calibration of the HBV model (cont.)

- Calibration period should include a variety of hydrological events
- Normally 5 to 10 years sufficient to calibrate the model
- Split-sample test: test of model performance with calibrated parameters for an independent period
- Different objective functions (e.g., efficiency based on log Q, or 'punishment' for volume error)



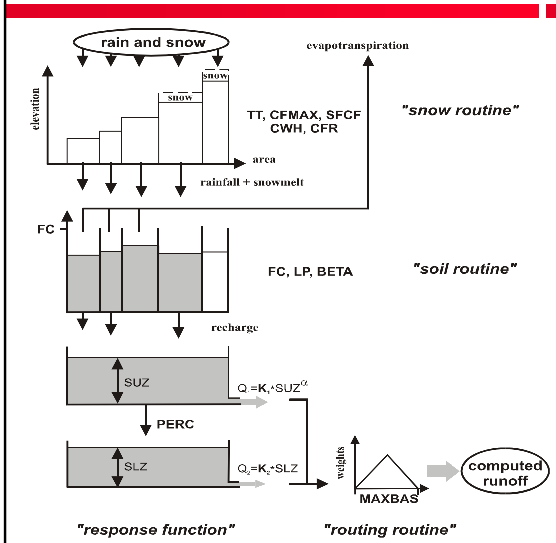
- Problems
  - Parameter uncertainty
  - Internal model consistency
  - Parameter values for ungauged catchments

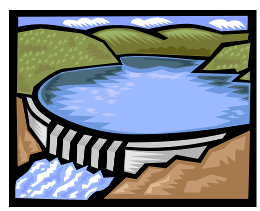
Applications of the HBV model

The HBV model is/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

Design flood calculations with the HBV model



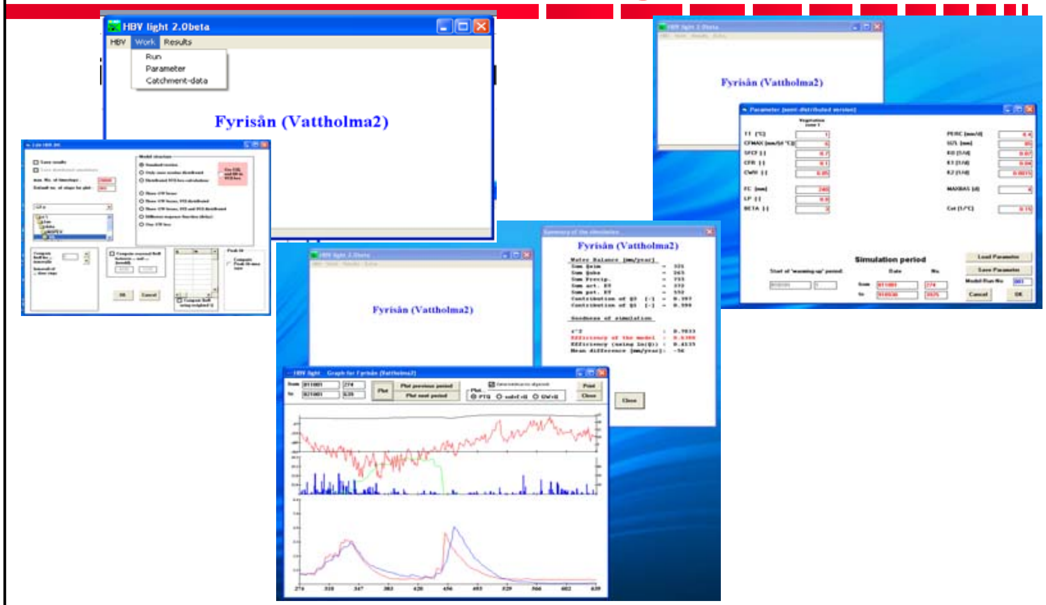


Calibration of model

Hypothetical precipitation and temperature

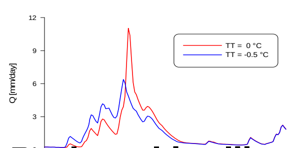
Simulation of design flood

HBV light screenshots

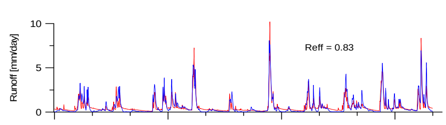


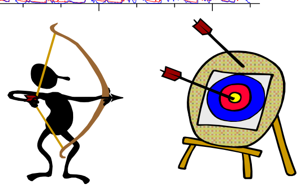
1. Beginners exercises

- **Calibration using synthetic data (HBVland)**



- **Real-world calibration**





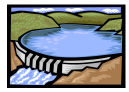
Example:

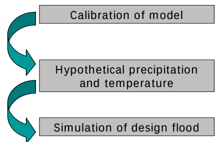
Calibrate the HBV model for the HBV-land catchment for the period 1981-09-01 to 1991-08-31 (warm-up period starting at 1981-01-01). This catchment behaves exactly as the HBV model sees the world, therefore you might be able to achieve a perfect fit (R_{eff}=1).

1. **Try to calibrate the model. It is a good idea to start with the snow routine to get the spring flood right, then work on the soil-routine parameters to get the water balance ok and finally fix the response function. You might have to do this in iterations.**
2. **During calibration look also on different variables, i.e. soil moisture, storage in the upper groundwater box, … .**
3. **Once you you have reached a perfect fit (or have received the 'true'parameter values by kindly asking your teacher), you may again change parameter values and study the effects of different parameter values**
4. **Change one (or two) of the following parameter: TT, CFMAX, FC, BETA, LP, K0, K1, K2, PERC, UZL, MAXBAS, SFCF.**
5. **Discuss - before running the model - what effect You expect (i.e. more runoff during spring, slower response to rain, …)**
6. **Run the model and look on the deviation of the simulated runoff (red line) from the 'recorded' runoff (blue line).**
7. **Make a note of each change of a parameter value and its effect to the simulation.**
8. **Change the parameter value back to its original value.**
9. **Continue with 3.**

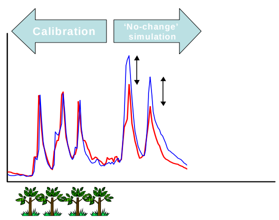
2. Advanced exercises

- **Calculation of design flood**





- **Estimation of land-use change effect**



Example:

A synthetic sequence of extreme precipitation has been derived by meteorologists (Table 1). Now it is your task to estimate the flood that this sequence would cause for the River Fyris at Vattholma (Uppland). In other words, you should estimate a design flood. You have decided to use the HBV model to solve this problem. Some friendly hydrologist put all necessary files together (most important the 'ptq.dat'–file with areal precipitation, temperature and observed runoff for an eleven-year period), but the model is far from well-calibrated.

You have to complete three steps:

1) Calibration

Change the following parameters in order to get an as good fit as possible between observed (blue) and simulated (red) runoff: TT, CFMAX, SFCF, FC, BETA, LP, K1, K2, PERC, MAXBAS (K0 och UZL should not be used (i.e. put them to zero), do not change the values for for CFR, CWH och CET (0.05, 0.1, 0.1)). Use the period 810901 to 870831 for calibration (with the 'warming-up' period starting at 810101).

2) Validering

Before you use your calibrated model for any prediction it is important that you test your parameter set for an independent time period. Use the period 870901 to 911231 for this test. Is the fit worse? Can you give an explanation? How will your design flood be affected?

3) Simulation of flood

Make a backup-copy of ptq.dat

Open the file ptq.dat in a text editor (or Excel)

Choose a period for which you replace the observed precipitation by the synthetic sequence (Table 1 or file extremprecip.xls)

Save the file (if you use Excel choose the format '*.csv' (colon-separated), but use the name "ptq.dat")

Restart HBV light and run the model. Check the peak value of your simulated flood.

Return to the backup-file, choose a different period and continue with 2. Do this 5-10 times.

What influences the size of the simulated flood?

Under which conditions becomes the simulated flood largest / smallest?

Table 1

Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14
P [mm]	5	5	5	5	5	10	10	40	120	30	10	10	5	5

3. Expert exercises

- **Recode snow routine**

- **Design your own interception routine**

Example:

Data from the Kassjöån basin in Medelpad, Sweden is used in this exercise. In the file ex5_snow7376.dat you find precipitation [mm], temperature [°C] and depth of the snow pack [mm water equivalent] (measured using a snow pillow). In each line of the file there is data from one day (six columns with year, month, day, precipitation, temperature, snow).

Simulation of snow accumulation and snow melt

Write a MATLAB program to simulate the accumulation and melting of snow according to the degree-day method. Include storage within the snow pack and refreezing into your snow routine (the snow pack can store water up to 10% of its water equivalent and the refreezing rate for this water is 20 times lower than the melting rate).

Plot both snow pack (simulated and measured) and the amount of water flowing into the soil against time (daily values).

Change the parameter values (degree-day factor, threshold temperature) to fit the simulated snow pack to the observed one.

Discuss the results and how they are influenced by the parameter values!

Some hints for the start :

Create Your own MATLAB-directory (e.g. 'c:\user\matlab' or x:\user\matlab)

Use Anteckningar / Notepad for writing of the program

Save your programs to this directory

Help MATLAB to find Your program by writing PATH(PATH,'c:\user\matlab')

some Matlab functions which You may find useful:

Load, plot, axis, title,xlabel ylabel

if .... (else ....) end

for .... end ,   Min, max