THE CLIMATE CHANGE IMPACT ON THE MESTA RIVER BASIN RUNOFF

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Abstract

The paper presents an attempt for assessment of the Climate Change impact on the Mesta river runoff (cross section Hadji Dimovo) using HBV mathematical model. The used version is developed for the project "Climate Change and Energy Production", a Nordic project aimed at evaluating the impacts of climate change on the water resources. The HBV model has a simple vegetation parameterisation including interception, temperature and evapotranspiration calculations, lake evaporation, lake routing, glacier mass balance simulation, special functions for climate change simulations etc. The HBV model can be classified as a semi-distributed conceptual model. The main input variables used in this report are the average monthly temperature, monthly totals of the precipitation, the potential evapotranspiration and the monthly discharges.
The River Mesta flows from North to South up to the Aegean Sea. Two different Climate Change scenarios are used (HadCM2 and ECHM4). The calculations are for years 2025, 2050 and 2100 using 30 years base period (1961 – 1990). The obtained results are promising and they show the potential possibility for the HBV model use to assess the climate change impact on the elements of hydrological cycle for the Bulgarian river basins using monthly data.
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Keywords: *hydrology, modelling, climate change, scenarios.*

1 INTRDUCTION

The HBV model originally developed at the Swedish Meteorological and Hydrological Institute in the first half of the seventies (Bergstrom, 1976) has gained widespread use for a large range of applications. It was applied with use of monthly data for the assessment of climate change impacts on the elements of hydrological cycle for the Bulgarian part of the Mesta River basin (cross section Hadji Dimovo, 2260 km^2). The Norwegian version of the model (Saelthun, 1999), developed for the project "Climate Change and Energy Production", is used for the present study.
The HBV model describes numerically the runoff processes occurring in a natural river basin. Simulation of the natural discharge means that the models are used to simulate runoff from meteorological data input available in the basin or in its neighbourhood. The HBV model consists of three main components: snow accumulation and melt, soil moisture accounting and generation of runoff and transformation of the hydrograph, while main input variables are air temperature, precipitation and potential evapotranspiration. The recorded monthly discharges were used for the model calibration. Two scenarios for climate change (HadCM2 and ECHM4) were used for three chosen years – 2025, 2050 and 2100.

The HBV model is widely used in many countries (Sweden, Norway, etc.). This paper presents a study for the application of the HBV model using monthly data for the Mesta River basin (cross section Hadji Dimovo) in Bulgaria and the obtained results.

2 MODEL DESCRIPTION

The HBV model can be classified as a semi-distributed conceptual model. It uses sub-basins as primary hydrological units, and within these an area-elevation distribution and a crude classification of land use (forest, open, lakes) is implemented. The model consists of three main components (fig 1):

(a) snow accumulation and melt subroutines;
(b) soil moisture accounting subroutines;
(c) response and river routing subroutines.

The main structure of the HBV model (Saelthun, 1999) is a sequence of sub-models as it is shown on fig. 1: snow, soil moisture, dynamic and routine. The model is further structured in altitude intervals. This subdivision can be applied only to the snow sub-model, or to the whole model. Even when the model distributed on altitude intervals, the parameters are generally the same for all sub-models. Interception, snow melt parameters and soil moisture capacity can however be varied according to vegetation type. The main input variables in the HBV model are temperature precipitation and potential evapotranspiration.

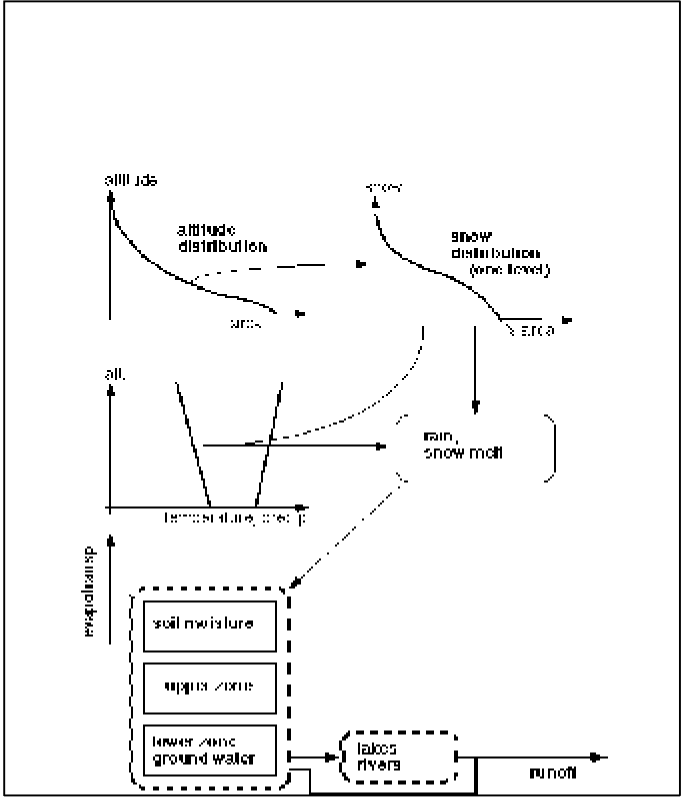

Fig. 1 Structure of the HBV model (Saelthun, 1996)

In the HBV model the air temperature is accepted as a determining factor whether precipitation accumulates in form of snow or enters the soil moisture zone. Snow accumulation in an altitude level starts when precipitation falls at temperature lower than certain threshold value.

It was found that a distributed description of the snow cover within an altitude interval performs better (Killingtveit & Aam, 1978). The actual form of the snow distribution is specified by its coefficient of variation.

Basically the HBV model uses a temperature index (degree-day) method for snowmelt calculation. The temperature index melt equation is

$$M = CX \cdot (T - TS) \cdot \Delta t \qquad \text{for} \quad T > TS$$
$$M = 0 \qquad T < TS \qquad (1)$$

where: **M** is the melt (in mm), **T** is the altitude level temperature during the time step Δt, **TS** the threshold temperature, and **CX** the temperature index.

Potential evapotranspiration can either be given as parameters to the model, or calculated by a temperature index method. In the first case, average potential evapotranspiration in mm/day is given for each month by parameters. By the temperature index method, the potential evapotranspiration is calculated for each time step using a simple temperature index method (Lindstrom et al, 1994).

A central part of the HBV model is the soil moisture zone. This zone receives melt water from snow, rain on snow and free areas and computes the storage of water in soil moisture, actual evapotranspiration and the net runoff generating as output. In addition water can be drawn up from the ground water zone to the soil moisture zone. Actual evapotranspiration is calculated based on the water content in this zone, and the percolation to the dynamical parts of the model as a function of the water content.

The runoff response routine is the part of the HBV model, which transforms excess water from the soil moisture zone to runoff. The runoff response function consists of two linear reservoirs. It also includes the effect of direct precipitation and evaporation on a part, which represents lakes, rivers and other wet areas in the catchment. The two linear reservoirs distributes the runoff in time and by choosing suitable values for the parameters.

The ordinary run or the climatic change simulation run where data from the different file called CLIMCHA.DAT (see below) is used. The type of runs mentioned above is controlled be the other file DEFAULT.DAT. This is a fixed format file presetting simulation options. Snow correction is applied according to original data.

CLIMCHA.DAT file is used in climate change runs to specify the climate change profile. The temperature change is given in ^{o}C, the precipitation as a correction factor, i.e. the number of precipitation days is not changed. The corrections are applied after the observed precipitation data has been corrected for catch losses according to precipitation/snow correction in the parameter file and the observed temperature. This is to avoid the areal precipitation to be artificially reduced due to reduced snowfall fraction (in the case of increased temperature). Sample CLIMCHA.DAT file is shown on table 1:

Table 1 Sample CLIMCHA.DAT file

Monts	**Temperature**	**Precipitation**
January	2.0	1.1
February	2.0	0.9
March	2.0	0.7
April	1.9	0.65
May	1.7	0.8
June	2.2	0.87
July	1.3	0.78
August	1.5	0.76
September	1.8	0.59
October	2.3	0.98
November	1.1	0.86
December	0.9	0.66

3 HYDROLOGICAL CONDITIONS IN THE MESTA RIVER BASIN

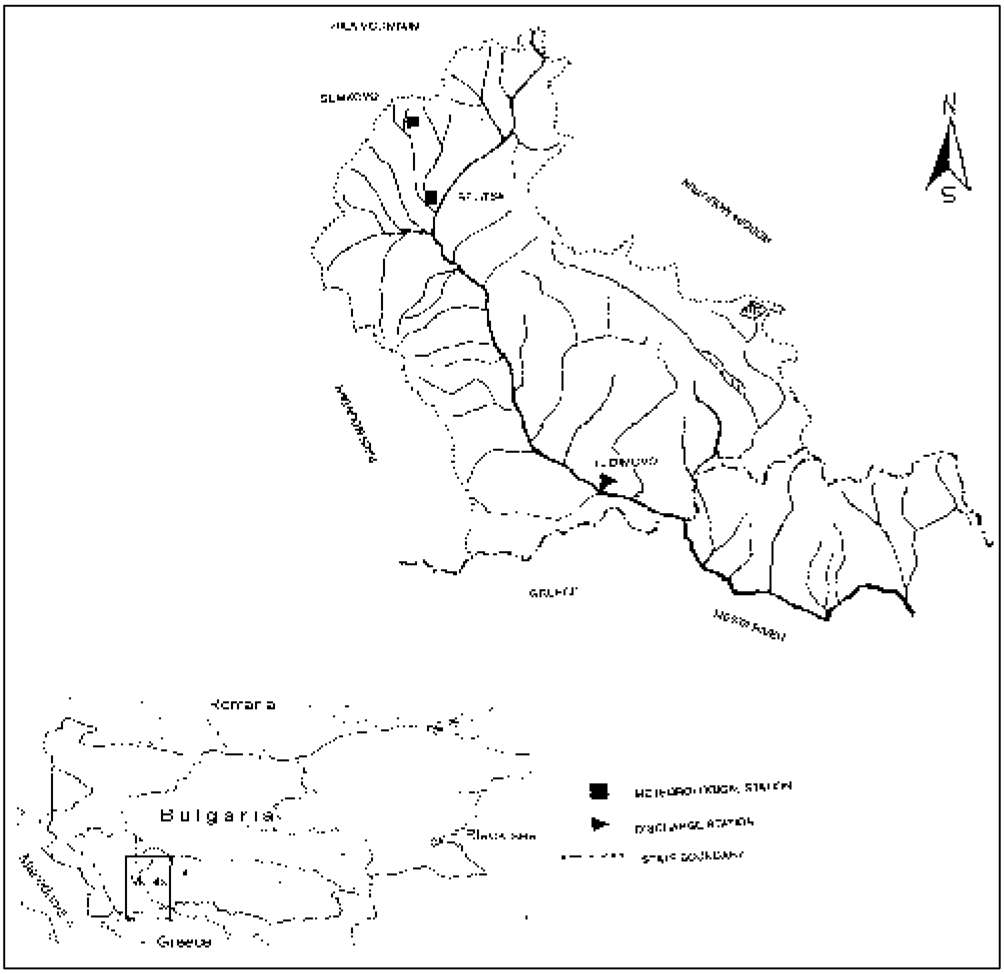

Fig. 2 Principle scheme of the Mesta River basin.

The Mesta river basin is the highest in Bulgaria compare with the other main river basins. It is situated in the South - West part of the country and surrounded by three relatively high mountains – Rila, Pirin and the Rhodops (Figure. 2). The Mesta river basin is relatively well isolated from the northern continental climate influence by the surrounding mountains. The climate of the region is under the influence of the Mediterranean one. The Mesta river is flowing from North to South through Bulgarian and Greek territory up to Aegean sea. The general catchment characteristics are shown in Table 2.

Table 2. The Mesta river catchment characteristics

Catchment characteristics	**Values**
Catchment area (km^2)	2260,0
Average slope of the river ($^{o}/_{oo}$)	22,4
Length of the river (km)	102,9
Altitude range of the catchment area (m a.s.l.)	390,0 – 2851
Forested area (%)	38,0

The floods on the Mesta river basin are mainly of snowmelt-rainfall type having peak discharge usually more than 5 times the average one. This situation is due to the complex natural hydrological conditions. The upper part has regular and stable snow cover during the winter because of the higher elevation (up to 2851 m a.s.l.). The melting process is going more than once during the winter – when Mediterranean cyclones are passing the region. Another problem making river flow modeling in the region more difficult and complex is related to the soil moisture conditions and evapotranspiration. This part of the country is semi-arid and during the summer significant precipitation volumes could not produce flood wave going most of all for infiltration and evapotranspiration. In the region, except for the three winter months the evaporated amounts are limited not by the energy but by the availability of water and the soil conditions. The latest is especially true for the lower part (river terraces) where the snow cover is occasional and the groundwater storage could be significant.

4 DATA BASE

A period of 30 years (1961 – 1990) with continuous monthly meteorological and hydrological measurements was chosen for the calibration of the HBV model. The source of information consisted of standard observation data - discharge, temperature and precipitation. Input data with a temporal resolution of one month were used for the simulations.

The historical temperature and precipitation information were taken from two meteorological stations:

“Bansko – 918 m a.s.l.
“Gotze Delchev” – 510 m a.s.l.

The recorded runoff data for the “Hadji Dimovo” (230.0 m a.s.l., Mesta River basin) discharge gauging stations (Fig. 2) were used for comparison of the observed and simulated hydrographs. The gauging station is located on the main river channel.

Air temperatures measured in standard thermometer shelters 2,0 m above the ground were used. Monthly totals of precipitation from standard rain gauges were used in the river basin. These values were divided by the number of the days for the respective month because originally the HBV model works with daily data as mentioned above, so all the input monthly data are assumed as average daily data.

Like input for the climate change calculations two scenarios were used (Alexandrov, 2002, Alexandrov & Genev, 2002). The used scenarios (HadCM2 and ECHM4) are for the same meteorological stations mentioned above. An example for the Bansko meteorological station is given on Table 2. Calculations were made for three different years – 2025, 2050 and 2100. The used monthly data for precipitation and temperature are first corrected with the values of different climate change scenarios and after that the HBV model was applied for the assessment of climate change impacts on the elements of hydrological cycle.

Table 3 An example for the different scenarios – station Bansko

Precip.	**Scenarios, year**					
Month	**ECHM4**	**HadCM2**	**ECHM4**	**HadCM2**	**ECHM4**	**HadCM2**
	2025	**2025**	**2050**	**2050**	**2100**	**2100**
	change%	change%	change%	change%	change%	change%
1	-1.4	-0.9	-2.7	-2	-5.4	-3.3
2	-3.7	-1.3	-6.9	-3	-14	-5.1
3	-2.6	-1.2	-4.9	-2.5	-10	-4.5
4	-5.3	-1.9	-9.8	-3.7	-19.9	-6.9
5	-4.8	-3.5	-8.8	-6.7	-17.9	-13
6	-1.8	-7.4	-3.4	-13.9	-6.9	-27.7
7	-4.5	-10.2	-8.3	-19	-16.7	-38.3
8	1.9	-12	3.6	-22.8	7.2	-45.3
9	-4.7	-8	-8.8	-14.9	-17.9	-30
10	-2.1	-3.6	-3.8	-6.8	-7.7	-13.4
11	-2.9	-3.8	-5.5	-7.4	-11	-14.2
12	0.6	-2.8	1.2	-5.8	2.3	-10.7
Season						
DJF	-1.5	-1.7	-2.8	-3.6	-5.7	-6.4
MAM	-4.3	-2.2	-7.9	-4.3	-15.9	-8.2
JJA	-1.5	-9.9	-2.7	-18.6	-5.4	-37.1
SON	-3.2	-5.1	-6	-9.7	-12.2	-19.3
Anual	**-2.6**	**-4.7**	**-4.9**	**-9.1**	**-9.8**	**-17.7**

Temp.	**Scenarios, year**					
Month	**ECHM4**	**HadCM2**	**ECHM4**	**HadCM2**	**ECHM4**	**HadCM2**
	2025	**2025**	**2050**	**2050**	**2100**	**2100**
	change (C^{o})	change (C^{o})	change (C^{o})	change (C^{o})	change (C^{o})	change (C^{o})
1	0.9	1	1.7	1.8	3.3	3.6
2	1.2	0.9	2.2	1.6	4.4	3.2
3	1.2	0.7	2.2	1.2	4.5	2.5
4	1	0.6	1.9	1.1	3.8	2.2
5	1.1	0.7	2	1.3	4	2.6
6	1.2	1	2.2	1.8	4.4	3.6
7	1.3	1.2	2.5	2.3	5	4.7
8	1.3	1.2	2.6	2.2	5.1	4.5
9	1.2	1.2	2.2	2.3	4.5	4.7
10	1.1	0.9	2.1	1.6	4.2	3.1
11	1.1	0.7	1.9	1.2	3.9	2.5
12	1	0.9	1.8	1.7	3.6	3.6
Season						
DJF	1	0.9	1.8	1.7	3.8	3.5
MAM	1.1	0.6	2	1.2	4.1	2.4
JJA	1.3	1.1	2.4	2.1	4.9	4.3
SON	1.1	0.9	2.1	1.7	4.2	3.5
Anual	**1.1**	**0.9**	**2.1**	**1.7**	**4.2**	**3.4**

5 RESULTS

A calibration period of thirty years (1961 – 1990) with monthly data was used for parameter evaluation of the HBV model, as it was mentioned above. This period is assumed as base period. After the calibration with the real monthly data the model was applied to calculate the assessment of climate change impacts on the elements of hydrological cycle for the Mesta River basin (cross section "Hadji Dimovo"). The numerical results for the accumulated volumes of the calibration (base) period are given in Table 3. They are for the whole chosen base period. The model gives opportunity calculations to be done for different periods (week, month, year etc.).

Table 3 Accumulated volumes the period 1961 – 1990.

Period	**R. Mesta (cross section "Hadji Dimovo")**	
	Qobs (mm)	Qsim (mm)
1961 - 1990	373.90	374.6

The main calibration criterion for the purposes of this study was difference between simulated and observed water volumes. As can be seen in table 3 the HBV model is well calibrated.

After the calibration the HBV model was applied for two different scenarios to three chosen years – 2025, 2050 and 2100. Monthly input data were used for the calculations. The obtained results are yearly and seasonal values for discharges (in m^3/s) and runoff volumes (in mm). The numerical results are given in table 4.

Table 4 Numerical results for the application of the HBV for differentclimate change scenarios and years.

Periods		**Struma River (cross section Marino pole)**			
		Scenario 1		**Scenario 2**	
		Q (m^3/s)	**Volume** (mm)	**Q** (m^3/s)	**Volume** (mm)
Base period (1961 – 1990)	Yearly	27.27	372.66	27.27	372.66
	Winter	27.02	92.29	27.02	92.29
	Spring	35.79	124.97	35.79	124.97
	Summer	24.41	85.27	24.41	85.27
	Autumn	20.30	70.13	20.30	70.13
Year 2025	Yearly	23.98	327.73	24.15	330.08
	Winter	22.87	79.83	23.52	80.34
	Spring	24.93	87.07	25.07	87.55
	Summer	23.62	81.61	23.82	82.27
	Autumn	23.18	79.19	23.40	79.92
Year 2050	Yearly	21.38	292.20	21.71	296.61
	Winter	20.56	71.82	20.85	72.80
	Spring	22.10	77.19	22.37	78.12
	Summer	20.92	72.26	21.26	73.44
	Autumn	20.76	70.96	21.14	72.23
Year 2100	Yearly	16.21	221.47	16.94	231.44
	Winter	16.00	55.88	16.62	58.05
	Spring	16.45	57.45	17.20	60.08
	Summer	15.60	53.84	16.37	56.55
	Autumn	15.90	52.77	16.62	56.76

The plots from the obtained results are given on figure 3 a and b.

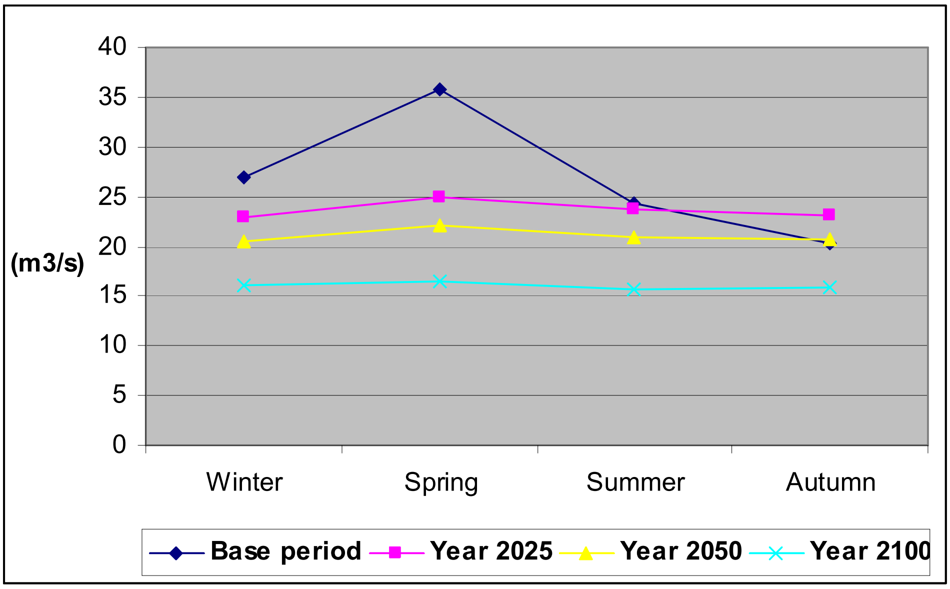

Fig. 3a Graphic results obtained using scenario HadCM2

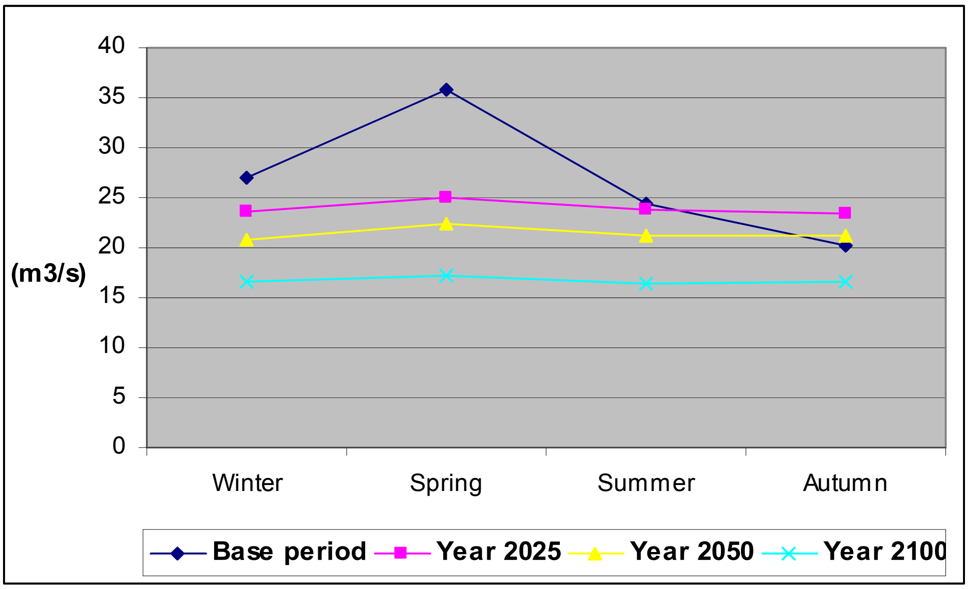

Fig. 3b Graphic results obtained using scenario ECHM4

6 CONCLUSIONS

The total volume of runoff during the calibration is well reproduced, which is of course natural, as this is one of the calibration criteria.

The weight of the used temperature and precipitation stations for the Mesta river basin (cross section “Hadji Dimovo”) is equal for each of them. The simulations could be additionally improved in future after analysing the real weight for runoff generation of each measurement station. It should be kept in mind that the winter precipitation data involving snowfall are strongly influenced by wind.

As can be seen from table 4 and fig. 3b the second scenario gives more optimistic results. That means the values of the discharges and volumes for all considered years and their seasons are higher than for the first scenario.

In the end should be mentioned that the obtained results are promising and they show the potential possibility for the HBV model use to assess the climate change impacts on the elements of hydrological cycle for the Bulgarian river basins using monthly data.

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References

Alexandrov, V. (2002): Climate Change on the Balkan Peninsula, Ecology and Future. 2-4, pp. 26-30 (in Bulgarian).

Alexandrov, V. & Genev M. (2002): Water Resources in Bulgaria under Climate Variability and Change. Proceedings of the XXI Conference of the Danubian Countries on the Hydrological Forecasting and Hydrological Bases of Water Management, Bucharest, Romania (CD version).

Bergstrom, S. (1976): Development and Application of a Conceptual Runoff Model for Scandinavian Catchments. Swedish Meteorological and Hydrological Institute, rep. RHO, Norrkoping.

Killingtveit, A. & Aam, S. (1978): En fordelt modell for snøkkumulering og -avsmelting. EFI/Institutt for Vassbygging, NTH Trondheim (in Norwegian).

Lindström, G., Gardelin, M. & Persson, M. (1994): Conceptual modelling of evapotranspiration for simulation of climate change effects. SMHI Report RH 10, Swedish Meteorological and Hydrological Institute, Norrköping.

Nash, J. E. & Sutcliffe, J. V. (1970): River flow forecasting through conceptual models. A discussion of principals. J. Hydrol. 10, 282-290.

Saelthun, N. R. (1999): The "Nordic" HBV Model. Description and documentation of the model version developed for the project Climate Change and Energy Production. NVE Publication 7, Norwegian Water Resources and Energy Administration, Oslo. ISBN 82-410-0273-4.