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- its structure and applications

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Abstract

It is now 20 years since the first presentation of results from the HBV model at the Nordic Hydrological Conference in Sandefjord in 1972. Since then the use of hydrological models has grown dramatically, and today they are standard tools for an increasing number of applications. The HBV model has followed this trend, and there are examples of applications in some 30 countries. The span of applications has also widened and covers today hydrological forecasting, spillway design, studies of effects of climate change, synoptic water balance mapping, simulations of groundwater response among others. The report describes the structure of the most widely used version of the HBV model and summarizes national and international experiences from its application.

Key words

Hydrological modelling, model structure, model calibration, rainfall/runoff modelling, snowmelt modelling, hydrological forecasting.

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TABLE OF CONTENTS

THE HBV MODEL
— its structure and applications

1. INTRODUCTION

The first successful run with an early version of the HBV hydrological model was carried out in the spring of 1972 (Bergström, 1972; Bergström and Forsman, 1973, Figure 1).

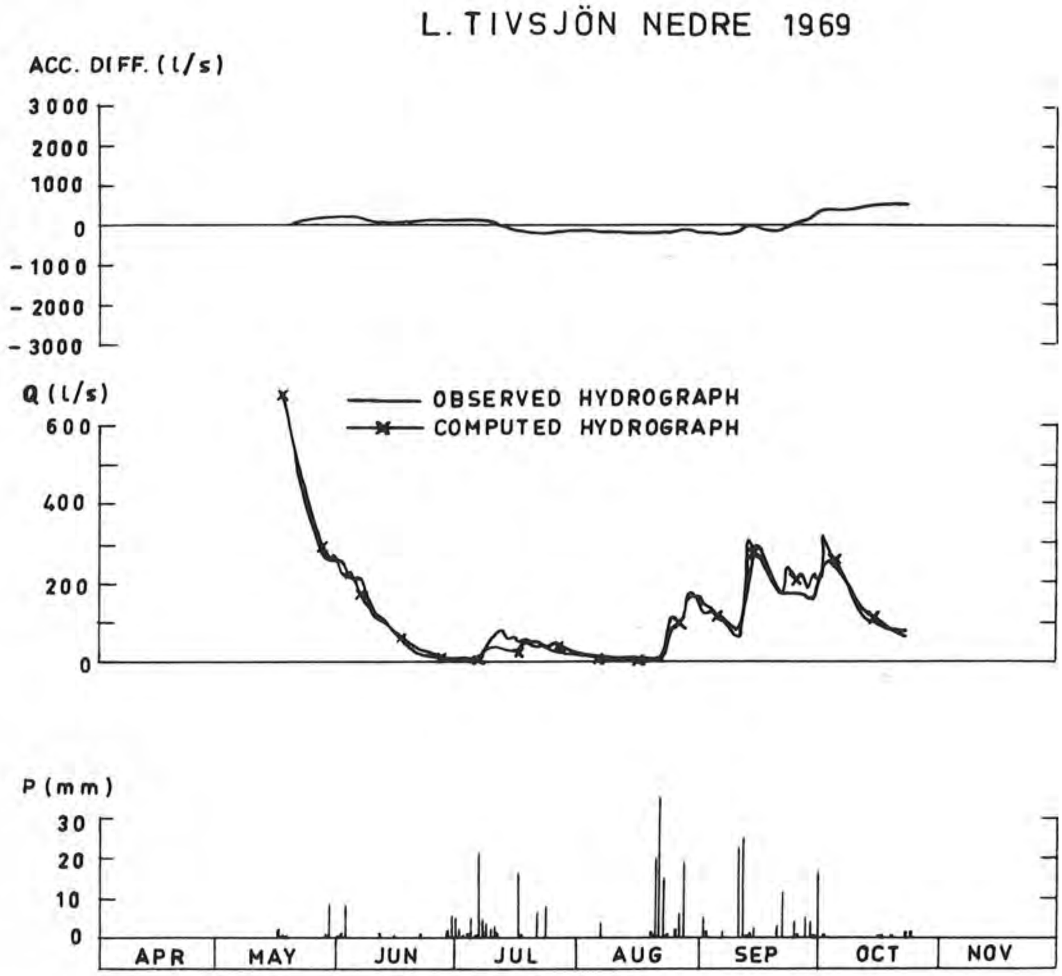


Figure 1. The first successful application of the HBV-1 model. Lilla Tivsjön research basin in Northern Sweden (14 km²). ACC. DIFF. = accumulated volume error, Q = runoff and P = precipitation.

This was the result of a short period of model development towards an operational model of reasonable complexity, and with a requirement on input data that could be met in most Swedish drainage basins. The goal was a conceptual model primarily to be used for hydrological forecasting. The development process continued with an increasing number of test applications and introduction of a routine for snow accumulation and melt (Bergström, 1975). In the early summer of 1975 the first operational forecasts were carried out.

The work on the HBV model followed, to a high degree, the ideas lined out by Nash and Sutcliffe (1970) among others, who saw the risk that increasing computer capacities may result in too complex model formulations, unless the significance of model components is carefully checked. This philosophy is responsible for the relative simplicity of the HBV model. A lot of modifications of the model have been tested, but few have been showed to improve the results. The basic ideas behind the model are discussed in more detail by Bergström (1991).

After twenty years the HBV model has become a standard tool for runoff simulations in the Nordic countries, and the number of applications in other countries is growing. Some of the applications abroad are carried out by, or in cooperation with, the Swedish Meteorological and Hydrological Institute using a standard computer code and the version six of the model (HBV-6). Such examples are the applications to five basins within the WMO project on intercomparison of models for snowmelt runoff (WMO, 1986) and a large number of applications to basins in Latin America (Häggström et al., 1990). Some other applications are carried out by modified codes or model versions which are totally rewritten. New standard codes with modified snow routines are, for example, in use in Norway, Finland and Switzerland. Many of the applications abroad can be considered as scientific tests of the model to judge its feasibility under specific conditions, but the number of operational applications is growing along with the development of user-friendly desk top computer systems.

The work with the HBV model has generated a number of useful by-products, as its general approach has proved to be a valuable tool for a large number of problems related to quantitative aspects of water resources. Its successor, the PULSE model, is used for hydrochemical simulations and simulations in ungauged catchments.

The intention of this report is to give a short description of the structure of the most commonly used model version at the SMHI and to summarize the 20 years of experience, in Sweden and abroad, under a wide span of geographical and climatological conditions. Work with the HBV model has been reported on numerous occasions and in a large number of scientific papers. The list of references in this report is far from complete but covers some key titles and a span of applications. It is the hope that this presentation will be of value for all those who are using the model or just have a general interest in hydrological modelling.

2. THE HBV MODEL AND ITS PARAMETERS

There is a large number of hydrological runoff models of varying complexity available in the world today (see, for example, WMO, 1986; Nemec, 1986). The HBV model can be said to belong to the second generation of computer-based models which is characterized by attempts to cover the most important runoff generating processes by as simple and robust structures as possible.

The HBV model can best be classified as a semi-distributed conceptual model. It uses subbasins as primary hydrological units, and within these an area-elevation distribution and a crude classification of land use (forest, open, lakes) are made (Figure 2). The subbasin option is used in geographically or climatologically heterogeneous basins. The HBV model consists of three main components:

subroutines for snow accumulation and melt,
subroutines for soil moisture accounting,
response and river routing subroutines.

The model has a number of free parameters, values of which are found by calibration. There are also parameters describing the characteristics of the basin and its climate which, as far as possible, remain untouched during model calibration. The use of subbasins opens the possibility to have a large number of parameter values for a whole basin. It is, however, wise to be restrictive in this respect, and in most applications there is only little variability in parameter values between subbasins.

Data requirements and corrections

The SMHI version of the HBV model is usually run with daily time steps, but higher resolution can be used if data are available. Input data are precipitation and, in areas with snow, air temperature. Other versions of the model may require more input data for the snow routine.

The soil moisture accounting procedure requires data on the potential evapotranspiration. Normally monthly mean standard values are sufficient, but more detailed data can also be used. The source of these data may either be calculations according to the Penman formula or similar, or measurements by evaporimeters. In the latter case it is important to correct for systematic errors before entering the model.

Areal averages of the climatological data are computed separately for each subbasin by a simple weighing procedure where the weights are determined by climatological and topographical considerations or by some geometric method like the Thiessen polygons. The climatological input is further corrected for elevation above sea level by constant lapse rates. The temperature lapse rate is usually set to -0.6 °C per 100 meter deviation from station level. The precipitation lapse rates are more site-specific and set by local climatological considerations. All model parameters for correction of input shall be regarded as confined.

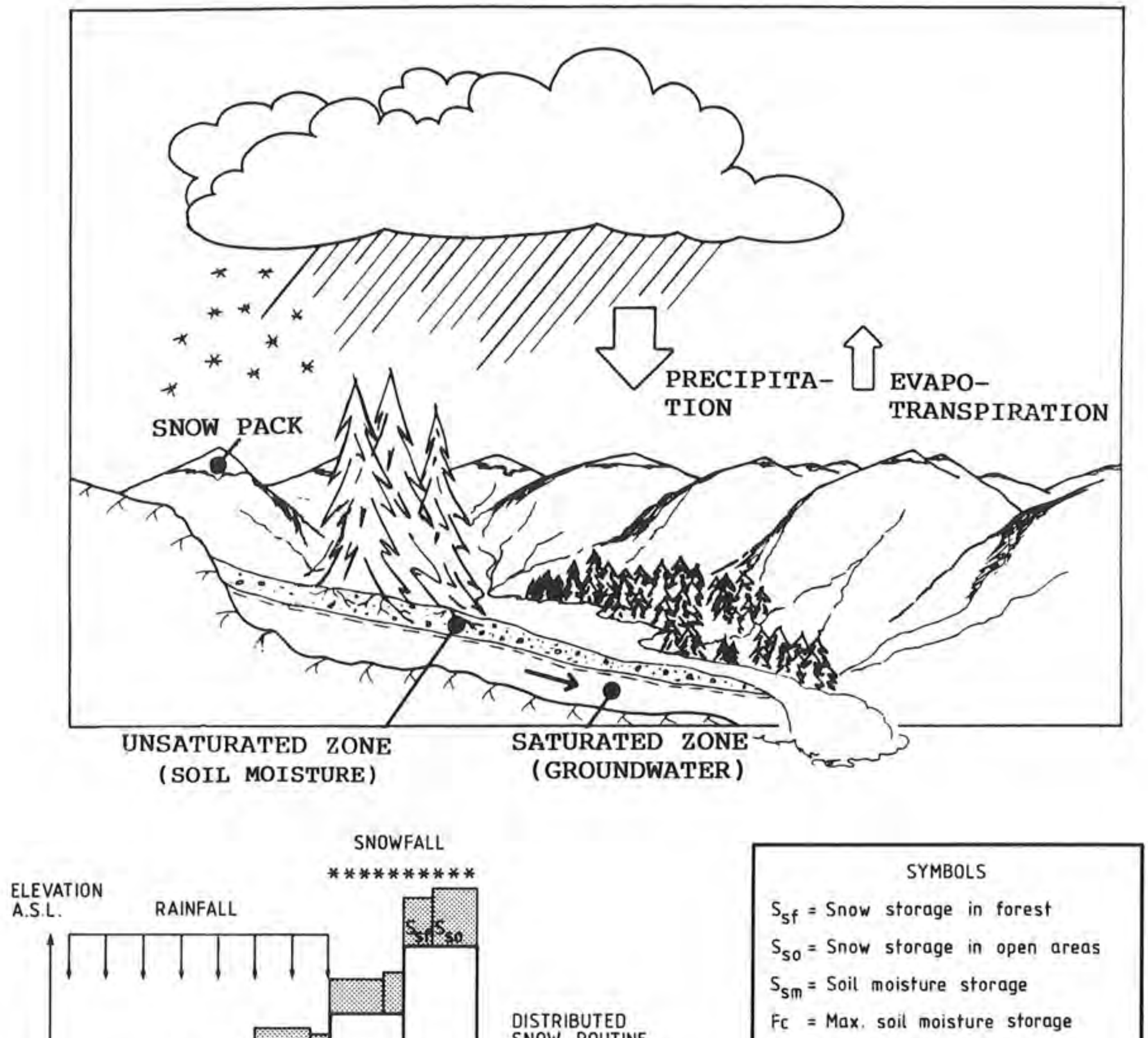


Figure 2. *The general structure of the SMHI version of the HBV model when applied to one subbasin.*

Snow

The snow routine of the model controls snow accumulation and melt and works separately for each elevation and vegetation zone. The precipitation accumulates as snow when the air temperature drops below a threshold value (TT). To account for undercatch of snow precipitation and winter evaporation, which is little known, snow accumulation is adjusted by a free parameter, C_{SF}, the snowfall correction factor.

Melt starts with temperatures above the threshold, TT, according to a simple degree-day expression:

$$MELT = C_{MELT} \cdot (T - TT) \tag{1}$$

where: MELT = snowmelt (mm/day)
C_{MELT} = degree-day factor (mm/°C · day)
TT = threshold temperature (°C).

The liquid water holding capacity of snow has to be exceeded before any runoff is generated. It is usually preset to 10 %. A refreezing coefficient, which is used to refreeze free water in the snow if snowmelt is interrupted, is fixed in the code.

Thus the snow routine of the HBV model has primarily three free parameters that have to be estimated by calibration: TT, C_{SF} and C_{MELT}. If a separation into vegetation zones is used, the number doubles. It is also common to use separate threshold temperatures for snow accumulation and melt.

The snow routine of the HBV model has been subject to major modifications in the Norwegian, Finnish and Swiss versions of the model. A statistical routine for redistribution of snow over the timber-line has, for example, been introduced by Killingtveit and Aam (1978), and several attempts have been made to introduce glacier-melt subroutines (see, for example, Braun and Aellen, 1990).

Soil moisture

The soil moisture accounting routine computes an index of the wetness of the entire basin and integrates interception and soil moisture storage. It is controlled by three free parameters, FC, BETA and LP, as shown in Figure 3. FC is the maximum soil moisture storage in the basin and BETA determines the relative contribution to runoff from a millimeter of rain or snowmelt at a given soil moisture deficit. LP controls the shape of the reduction curve for potential evaporation. At soil moisture values below LP the actual evapotranspiration will be reduced, as shown in Figure 3.

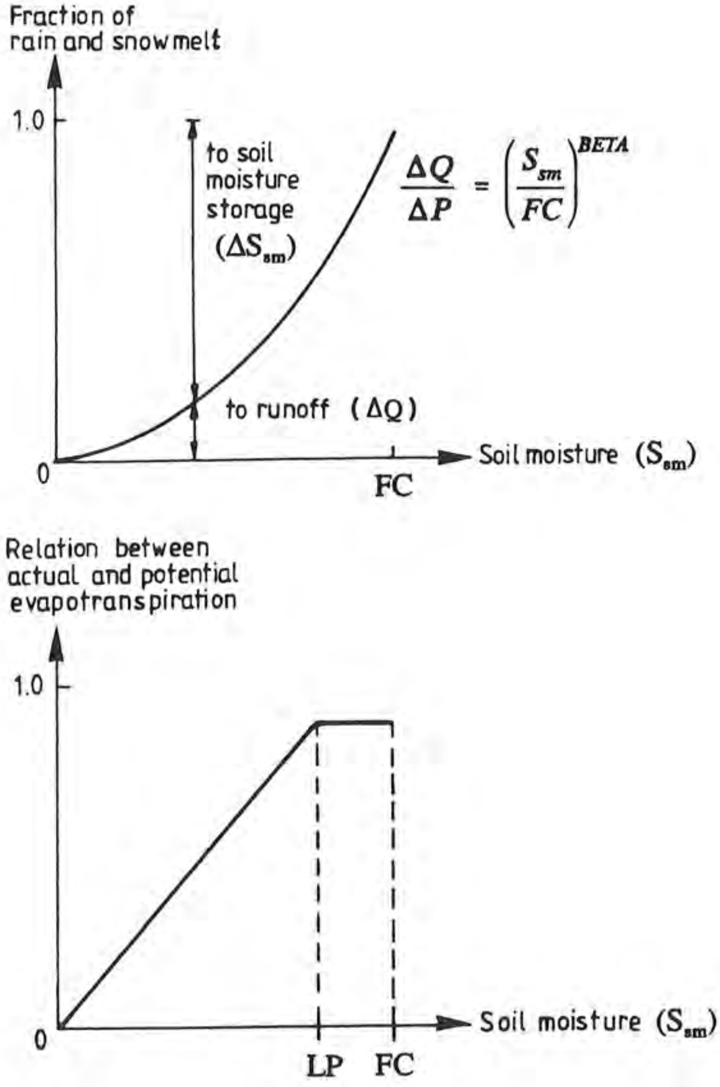


Figure 3. Summary of the soil moisture accounting routine of the HBV model. FC, LP and BETA are empirical parameters.

Recently a modification of the evapotranspiration routine has been introduced in order to improve the model performance when the spring and summer is much colder or warmer than normal (Lindström and Bergström, 1992). This routine accounts for temperature anomalies by a correction which is based on mean daily air temperatures and long term averages according to equation 2:

$$PE_A = \left(1 + C \cdot \left(T - T_M\right)\right) \cdot PE_M \tag{2}$$

where: PE_A = adjusted potential evapotranspiration,
C = empirical model parameter,
T = daily mean air temperature,
T_M = monthly long term average temperature,
PE_M = monthly long term average potential evapotranspiration.

The adjusted potential evapotranspiration is limited to positive values and is not allowed to exceed twice the monthly average. The routine has so far given very encouraging results in the eight basins where it has been tested.

Runoff response

The runoff response routine transforms excess water (ΔQ) from the soil moisture routine, to discharge for each subbasin (Figure 2). The routine consists of two reservoirs with the following free parameters: three recession coefficients, K_0, K_1 and K_2, a threshold, UZL, and a constant percolation rate, PERC. Finally there is a filter for smoothing of the generated flow. This filter consists of a triangular weighting function (Figure 4) with one free parameter, MAXBAS. There is also a Muskingum routing procedure available for flood routing.

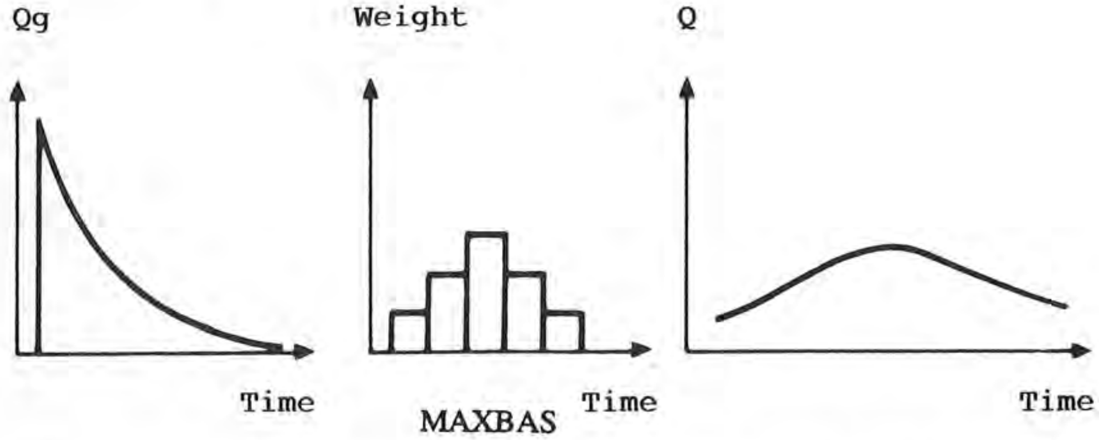


Figure 4. The filter used to smooth generated runoff (Qg) to obtain discharge (Q). MAXBAS is a model parameter.

Lakes in the subbasins are included in the lower model reservoir, but in later model versions lake routing can also be modelled explicitly by a storage discharge relationship. This is accomplished by subdivision into subbasins defined by the outlet of major lakes (Figure 5).

The relative large number of free parameters in the response routine of the HBV model (six) has focused the risk for overparameterization. Work is therefore in progress on a routine with less parameters (Harlin, 1992). Experience has, however, shown that it is rather easy to assess the parameters after some training. The use of an explicit lake routing routine has also proved to simplify the calibration of the recession parameters of the model, as most of the damping is accounted for by the lakes (Bergström et al., 1985).

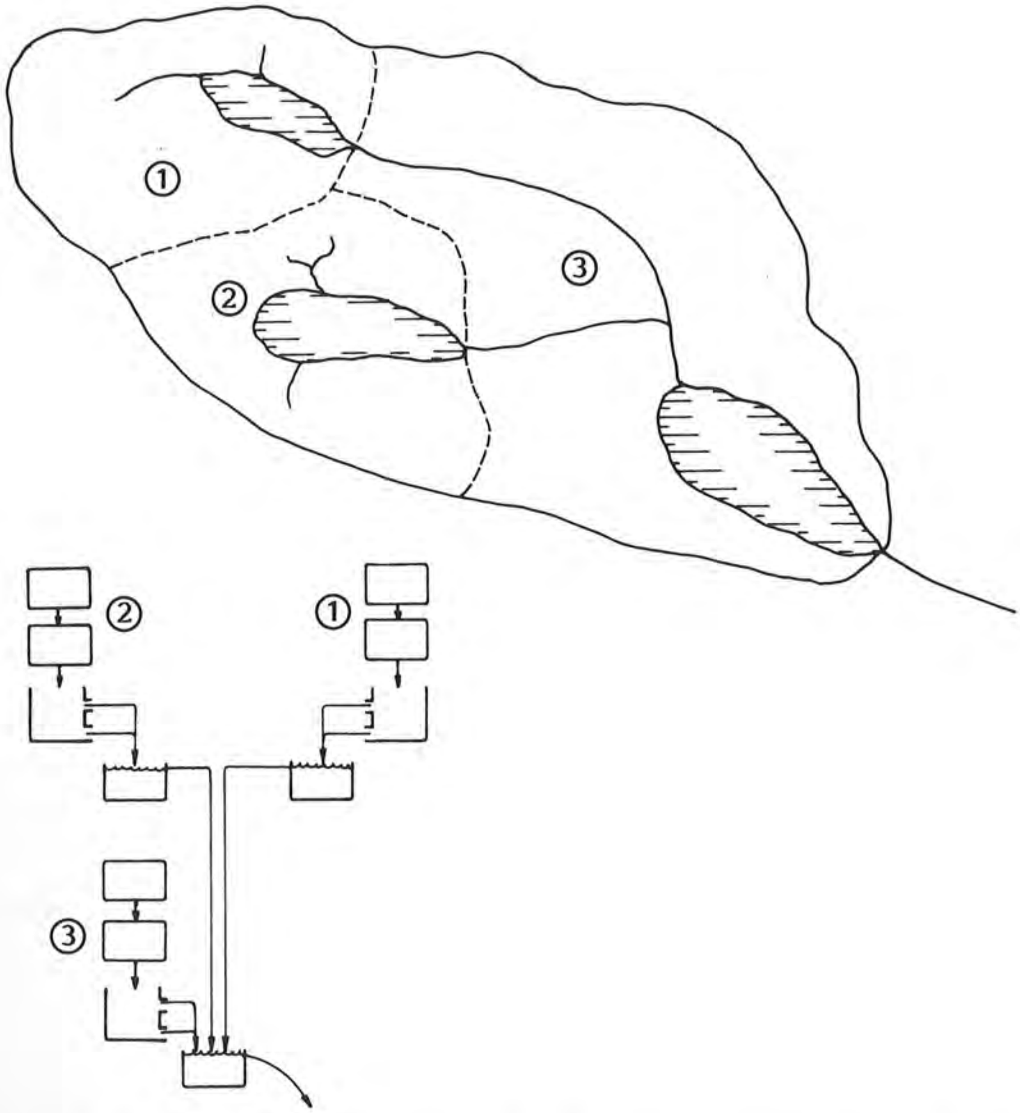


Figure 5. The subdivision of the model into submodels when an explicit lake routing routine is used.

3. MODEL CALIBRATION

The HBV model, in its simplest form with only one subbasin and one type of vegetation, has altogether 12 free parameters. The calibration of the model is usually made by a manual trial and error technique, during which relevant parameter values are changed until an acceptable agreement with observations is obtained. The judgement of the performance is also supported by a statistical criterion, normally the R^2-value according to Nash and Sutcliffe (1970):

$$R^2 = \frac{\Sigma \left(\bar{Q}_o - Q_o\right)^2 - \Sigma \left(Q_c - Q_o\right)^2}{\Sigma \left(\bar{Q}_o - Q_o\right)^2} \tag{3}$$

where:
Q_o = observed runoff
$\bar{Q}_o$ = mean of observed runoff
Q_c = computed runoff

R^2 has a value of 1.0, if the simulation and the observations agree completely, and 0 if the model does not perform any better than the mean value of the runoff record. Negative values can be the result of poor model performance or poor data.

Another useful tool for the judgement of model performance is a graph of the accumulated difference between the simulated and the recorded runoff. This graph reveals any bias in the water balance and is particularly useful in the initial stage of calibration, for example for assessment of the snow-fall corrections.

Recently an automatic calibration procedure has been developed (Harlin, 1991). This method is based on the experience from a large number of manual calibrations and will successively replace these in future applications. It is, however, not likely that the visual inspection and manual interaction can be entirely replaced because of the difficulties in finding a statistical criterion which is as flexible and general as the human eye. The subjective manner in which the model is calibrated entails a difficulty when trying to generalize model parameters, as the results to some degree are depending on the individual who was responsible for the calibration.

It is not possible to specify the required length of records needed for a stable model calibration for all kinds of applications. The important thing is that the record includes a variety of hydrological events, so that the effect of all subroutines of the model can be discerned. Normally 5 to 10 years of records is sufficient when the model is applied to Scandinavian conditions.

Optimal values of the parameters from model calibrations in Sweden have been summarized by Bergström (1990). These values are specific for the SMHI model version and can be used as a guide for further applications.

4. PRESENTATION OF RESULTS

Due to the limitations of the statistical criteria it is of great importance to have a clear presentation of the model output and to be able to compare it visually with observations. It is also very useful to be able to present graphs of inputs, the main water balance components and the volume error, expressed as accumulated difference between the simulation and observations. The different versions of the HBV model system have different options for presentation of input and output. In Figure 6 a standard presentation, which is fairly representative, is shown.

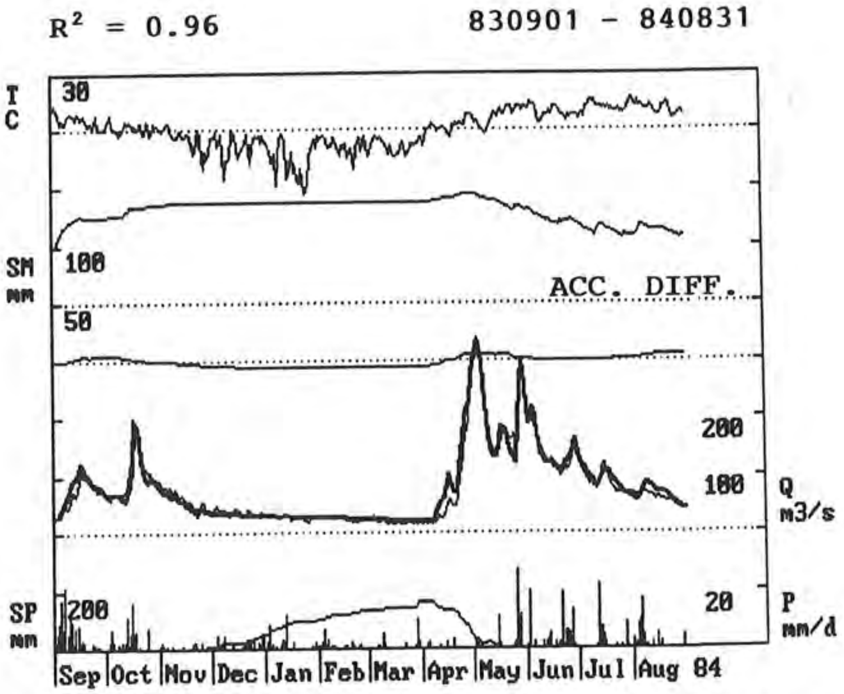


Figure 6. *Example of graphical presentation of output from a good model simulation in the Höljes basin in 1983-84. T = air temperature, SM = soil moisture, Q = runoff (thin line = observed, thick line = computed), SP = snowpack, P = precipitation.*

5. MAIN FIELDS OF APPLICATION OF THE HBV MODEL

Hydrological forecasting was the aim of the first operational applications of the HBV model. Since then the field of applications has widened and covers today real-time forecasting, control of data quality, extension of runoff records and filling in of gaps, design floods, synoptic water balance mapping, water balance studies, simulations of the effects of a changing climate and simulations of groundwater response. A successor to the HBV model, the PULSE model, is used for water quality studies and simulations in ungauged basins.

Real-time forecasting

In Scandinavia the need for flood warnings and reliable forecasts of the inflow to the reservoirs of the hydropower systems has stimulated the operational use of hydrological models. The forecasts are either short term, with a few days lead time, or long term, covering the whole snowmelt season (several months). For short term forecasting meteorological forecasts are often used as input to the models (see, for example, Björkenes, 1990). The long term forecasting is based on the present hydrological conditions, as described by the model, and a number of simulations with climatic data from the same season earlier years (Figure 7). The output from the model is then subject to a statistical analysis which can be used to judge the risk of flooding or the probability of refilling of a reservoir.

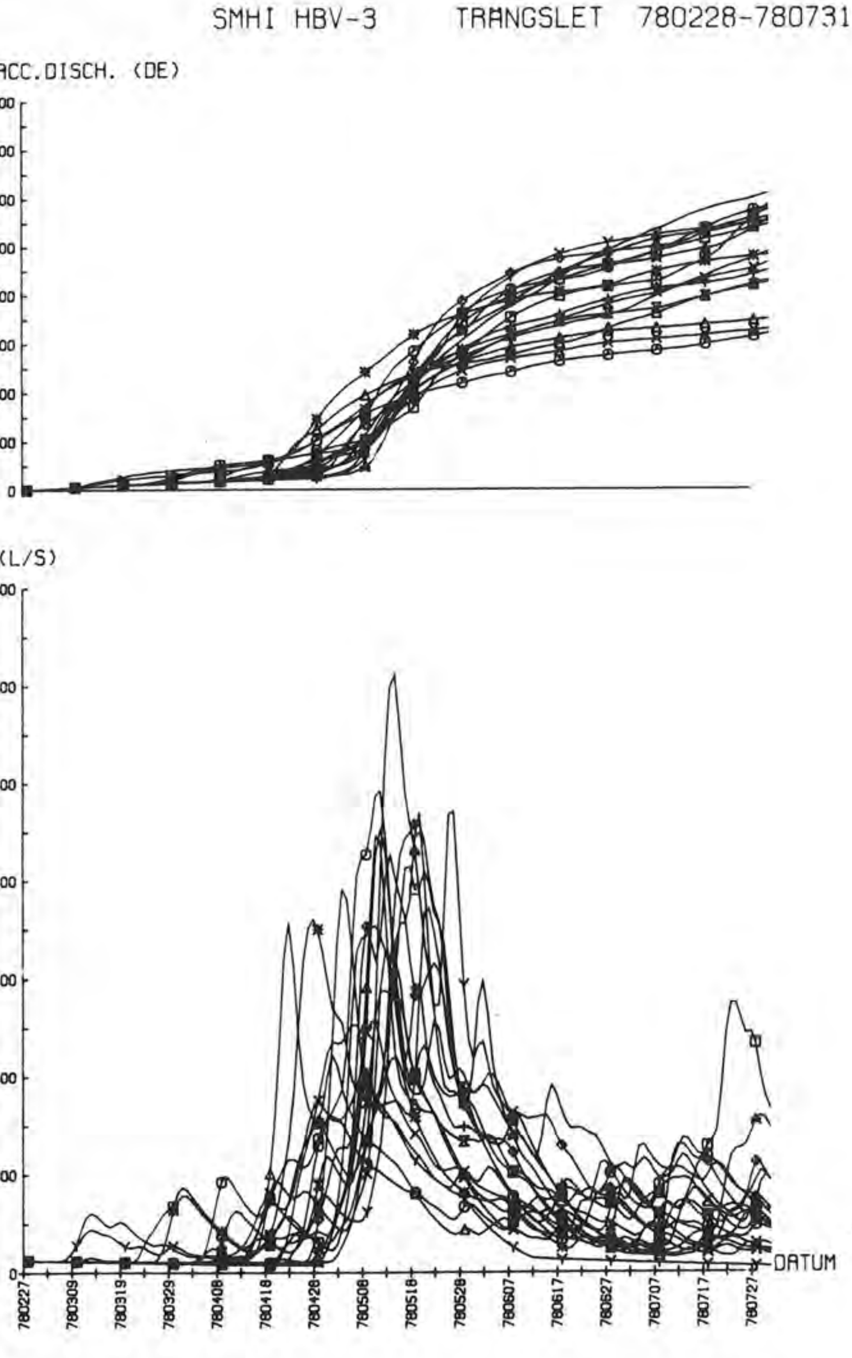


Figure 7. *Example of a long range hydrological forecast by the HBV model. The lower graphs show alternative discharge simulations and can be used to judge the risk for flooding. The upper graphs show the corresponding cumulative values and are useful for reservoir operation. (Trängslet basin, 4 483 km^2.)*

Spring is the main forecasting season in Scandinavia, but models are also in operation during rainfloods in summer and autumn. The Swedish basins where the HBV model is available for real-time forecasting are shown in Figure 8. These forecasts are produced either centralized by the Swedish Meteorological and Hydrological Institute or decentralized by river regulation enterprises or power companies.

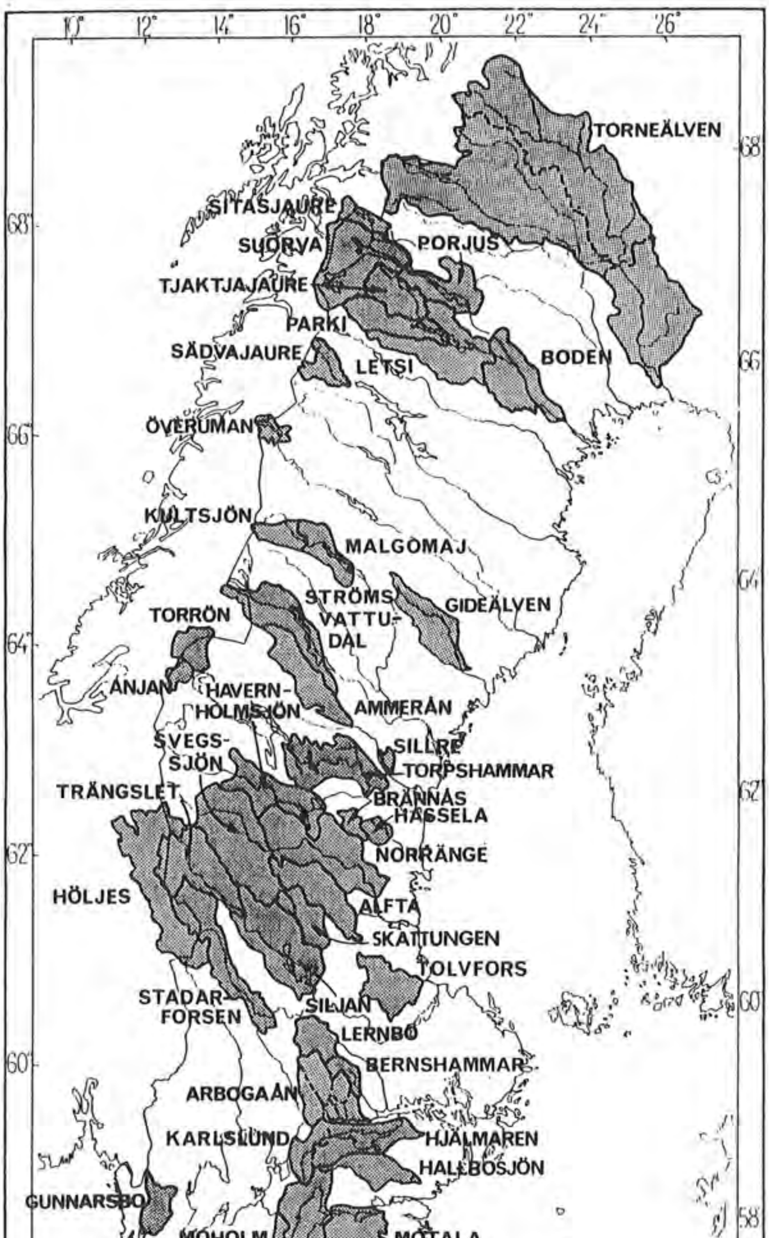


Figure 8. *Swedish basins where the HBV model is available for hydrological forecasting.*

Quality control, extension of runoff records and filling in of gaps

The HBV model is sometimes used as a tool for control of the quality of the runoff data of the Swedish national network. It has proved to be particularly useful for the correction of effects of ice-jamming on the records. The model output helps to decide whether a change in the observed water level has any relation to snowmelt or rain. There are also examples where the model has helped to identify inhomogeneities in the runoff records.

The extension of runoff records and filling in of gaps are straightforward applications of hydrological models. The methods are very useful in areas where the climatological records are more complete than the hydrological ones.

Design floods

In 1990 new guidelines for the computation of spillway design floods were adopted in Sweden (Flödeskommittén, 1990). The Swedish Committee on Design Flood Determination closely analysed possible approaches to the design problem and concluded that hydrological modelling in combination with reservoir simulation was the most feasible method for a multi-reservoir system with a mix of snowmelt and rain floods.

The guidelines are based on prescribed regional design sequences of precipitation, corrected for basin size, elevation and time of the year, and a hydrological model. The guidelines are tailored to the Swedish hydro-electric power system, which is characterized by a large number of reservoirs. Therefore reservoir operation strategies are also considered. For high hazard dams the most critical timing of all flood generating factors is found by an iterative simulation where the design precipitation is systematically inserted, at all possible locations, into a climatological record of ten years, and the response of the levels of the reservoirs is analysed.

In order to meet the requirements of the new guidelines a computer system has been worked out by the Swedish Meteorological and Hydrological Institute, where the HBV model provides the hydrological input to the reservoirs (Figure 9). In Norway a simplified version of the HBV model is in use for a similar purpose (Andersen et al., 1983).

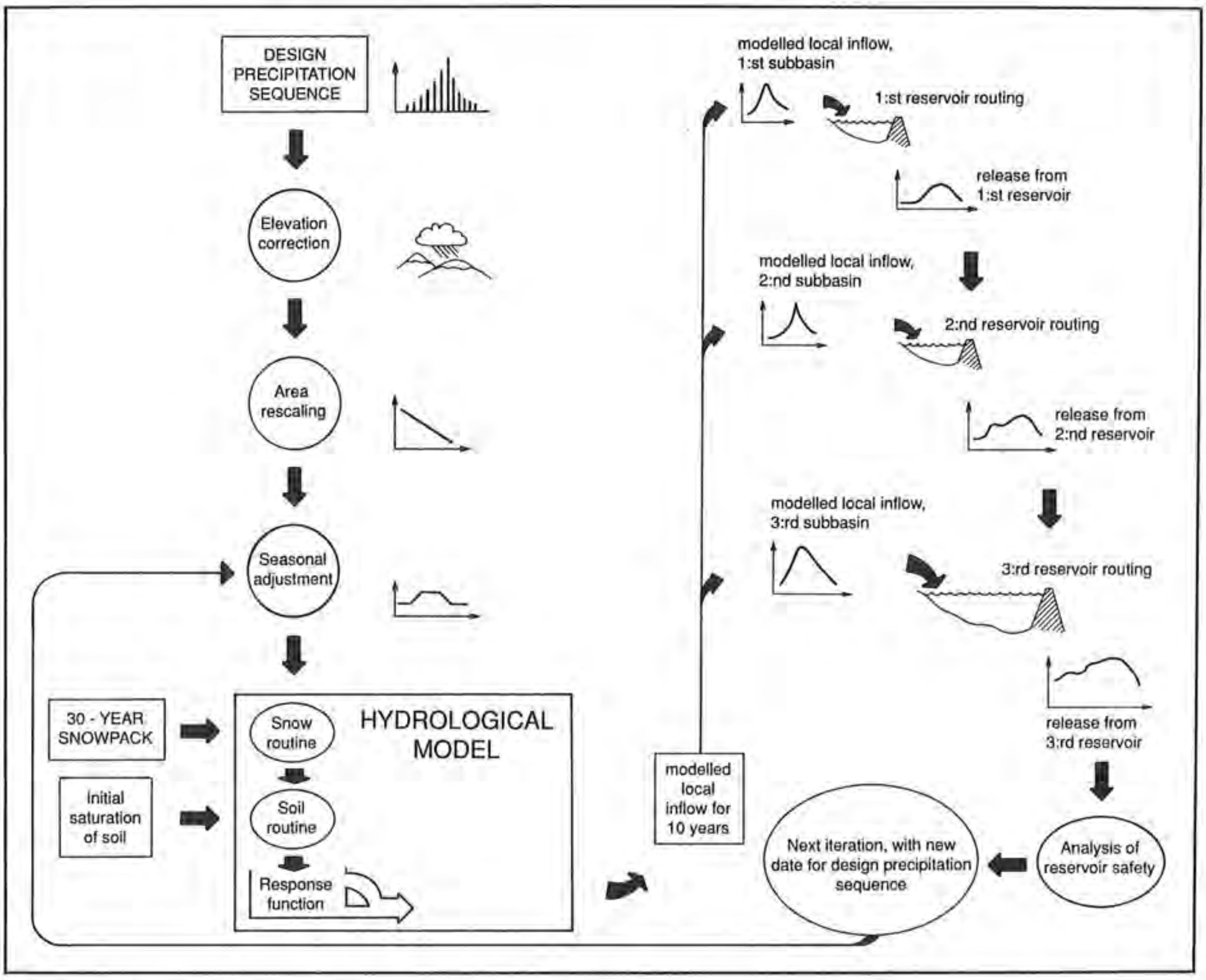
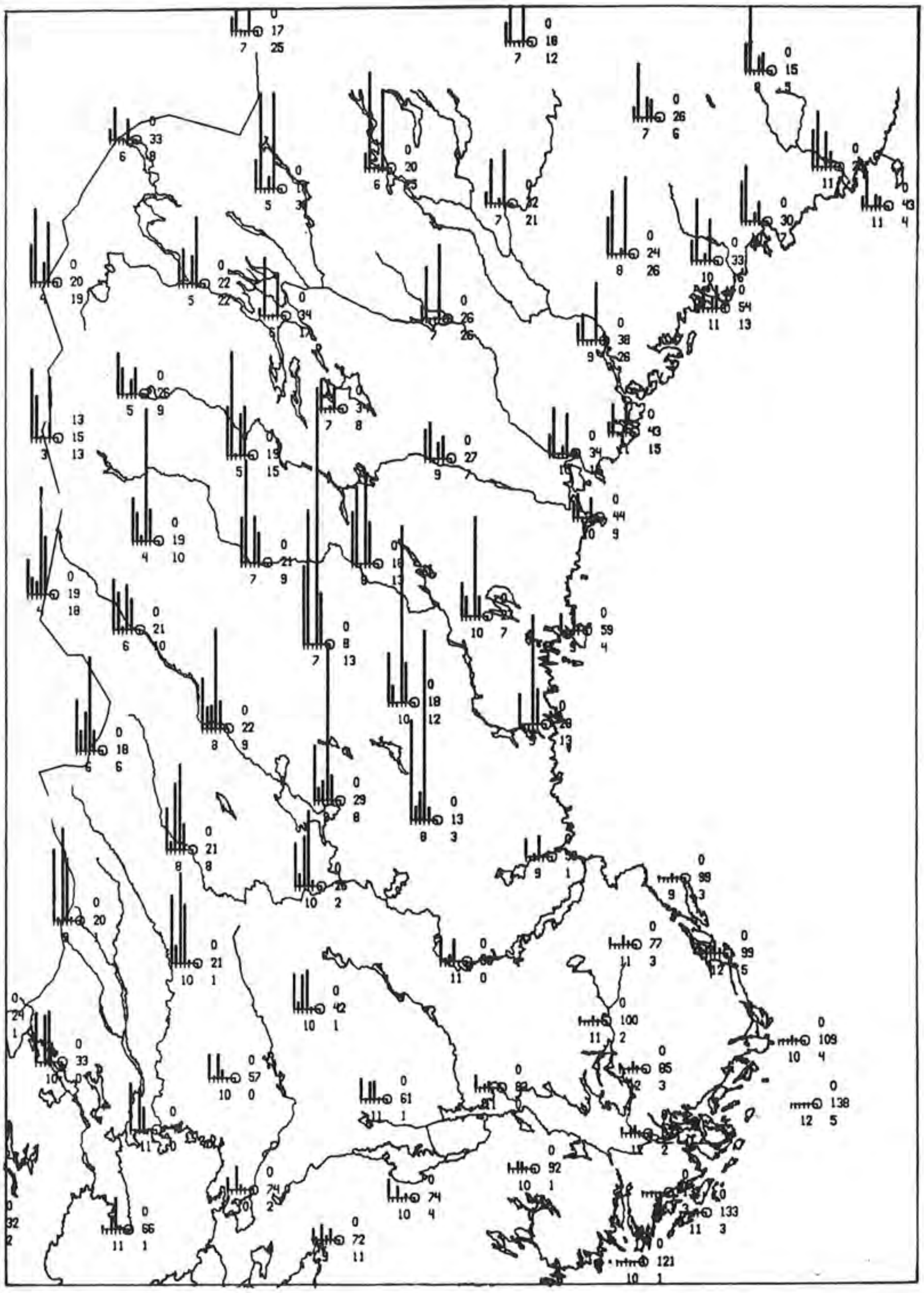


Figure 9. Schematic presentation of the simulation of design floods by an iterative process according to the new Swedish guidelines.

Synoptic water balance mapping

A number of research projects, or spin-off products, have been generated by the HBV model. One of the most important of these is the development of an operational synoptic water balance map, which is produced daily by the Swedish Meteorological and Hydrological Institute (Bergström and Sundqvist, 1982). This map illustrates the hydrological situation in the country by symbols describing snowpack, soil moisture deficit and runoff generation (Figure 10). It has proved to be a useful tool to get a quick overview of the hydrological situation in the country.



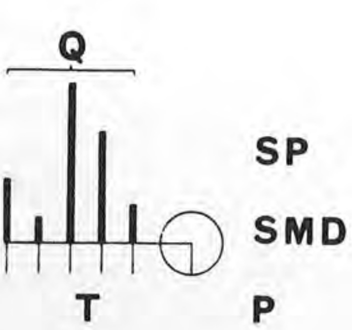


Figure 10.
Synoptic water balance map from a flood in September, 1985 in Central Sweden.
SP = modelled snow water equivalent,
SMD = modelled soil moisture deficit,
Q = modelled runoff generation (5 days),
P = observed precipitation,
T = observed air temperature.

Water balance studies

In connection with the work on spillway design guidelines the HBV model was used in a nationwide study of the interaction and timing of flood generating processes. This study revealed the importance of critical timing and had great impact on the final guidelines (Brandt, et. al., 1987, Figure 11).

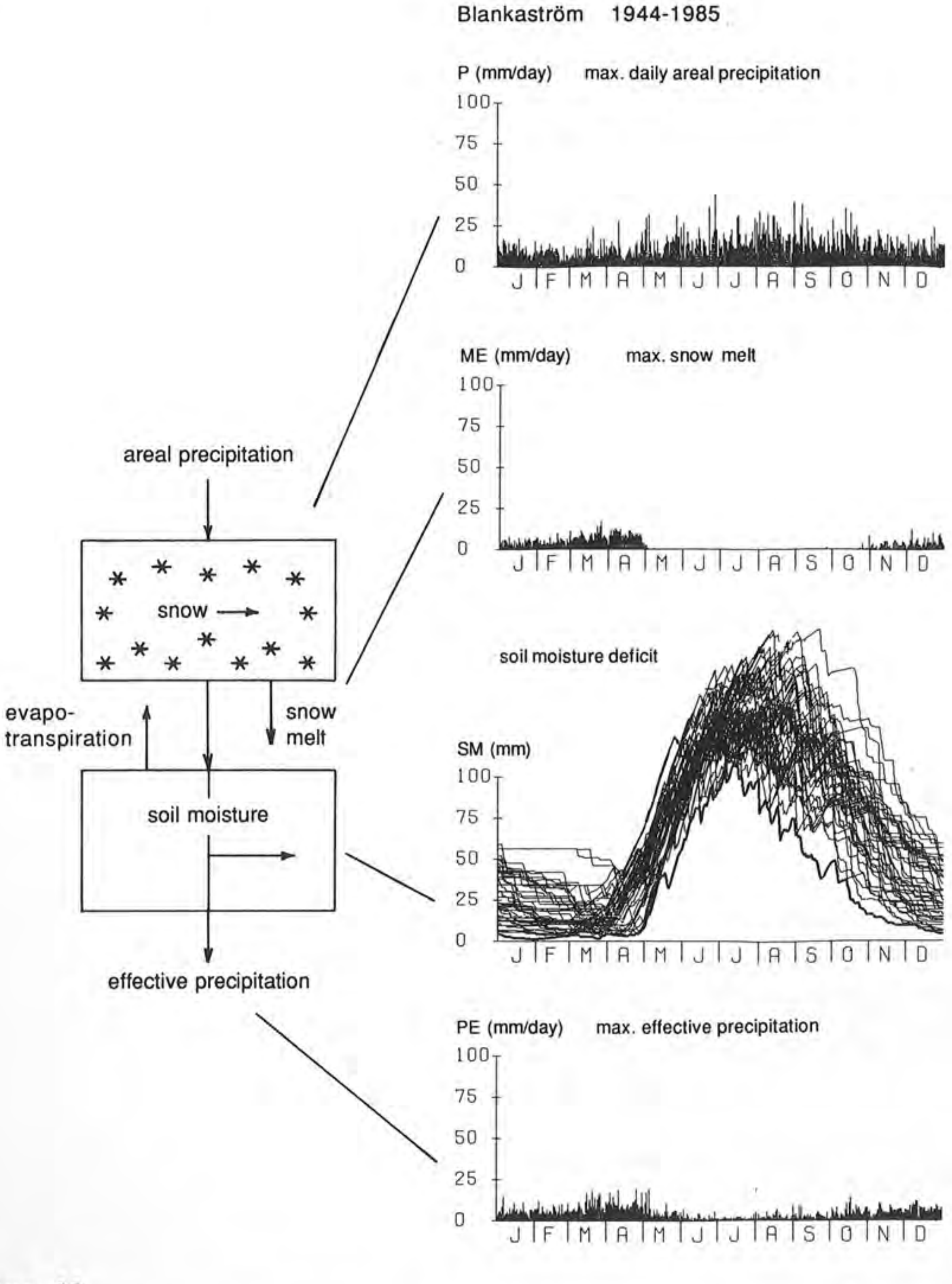


Figure 11.
Extreme water balance components for the Blankaström basin (3 446 km^2) in the south of Sweden for the years 1944-85. The extraction from the HBV model is illustrated to the left. Note that all graphs are of identical scale. (From Brandt, 1990.)

The modelling technique has also been used for the computation of soil moisture statistics in connection with studies on forest damage (Grahn et al., 1985) and for analyses of the effects of forest management on runoff (Brandt et. al., 1988). Jutman (1992) used the HBV model concept for the production of a new runoff map of Sweden.

Studies of the effects of a changing climate

The growing concern about the risk for a changing climate and its effects on our water resources has started a discussion on the possible use of hydrological models as an analysis tool. The HBV model has been used in this respect in Norway (Saelthun et al., 1990) and in Finland (Vehviläinen and Lohvansuu, 1991). In this type of application the problem of local interpretation of climate scenarios, model stationarity and possible feedback mechanisms by vegetation have to be carefully considered.

Groundwater simulations

Another spin-off of the HBV model is a model for simulation of groundwater response to climatological input (Bergström and Sandberg, 1983, Figure 12). These simulations required a modification of the saturated zone of the model. Thanks to the success in the attempts to model groundwater response, the synoptic water balance map has been complemented by a synoptic map of the groundwater reservoirs.

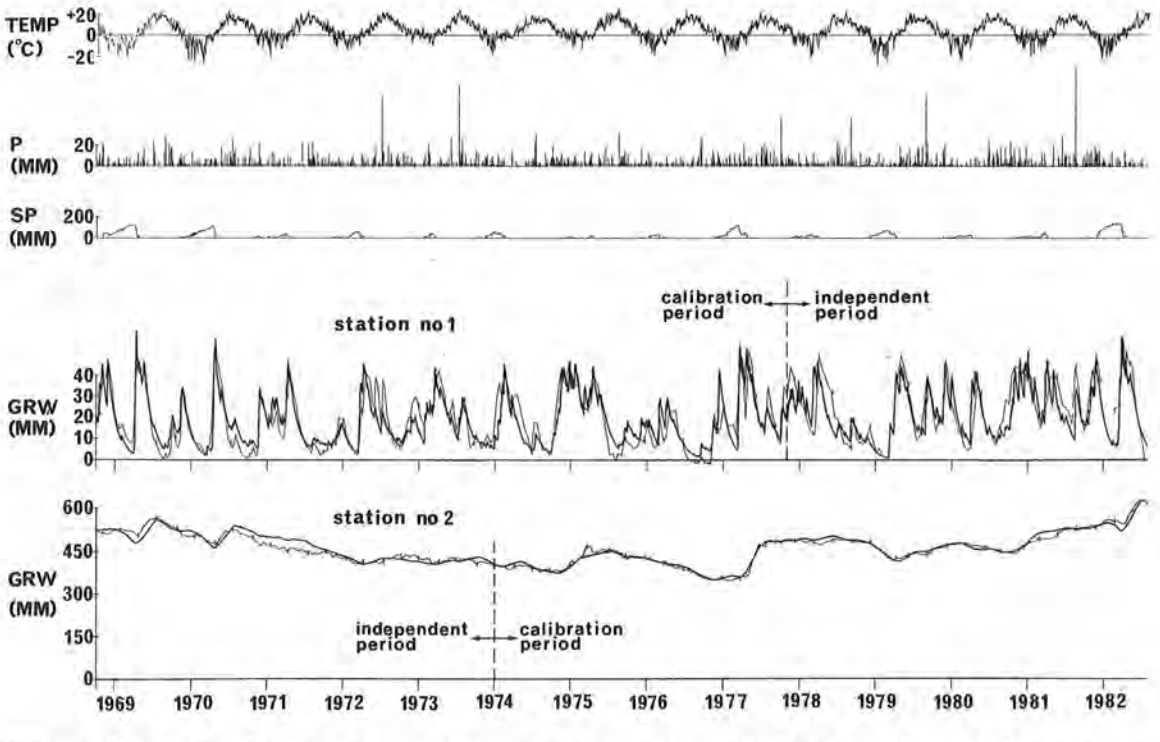


Figure 12. Simulation of groundwater response in a shallow aquifer in till soil (station No. 1) and a deep esker aquifer (station No. 2) in Central Sweden. (From Bergström and Sandberg, 1983.) The graphs show the dynamics of the storage in the aquifers.

Water quality and simulations in ungauged basins, the PULSE model

The modification of the HBV model used for groundwater simulations was the starting point for the development of a new model generation, the PULSE model. The PULSE model has most of its subroutines in common with the HBV model but has a better representation of the shallow groundwater and is thus more feasible for hydrochemical simulations. It is used for studies of short term variability in stream flow acidity (Bergström et al., 1985), modelling of transport of non-point source pollution (Brandt, 1990) and has also become widely used for the simulation of runoff in ungauged catchments after generalization of the model parameters (Johansson, 1986).

6. APPLICATIONS OF THE HBV MODEL IN THE WORLD

Below follows a summary of those applications of the HBV model that are known to the author today (1992) and some key references (Table 1, Figure 13). The presentation is based on work that has been carried out by, or in cooperation with, the Swedish Meteorological and Hydrological Institute and reports that have reached us. We know that the model has been applied in more than these 30 countries (Greenland counted separately) and therefore more applications are likely to exist. In the table an attempt is also made to classify the main objectives of the applications although this is not always very straightforward since there exist overlapping objectives.

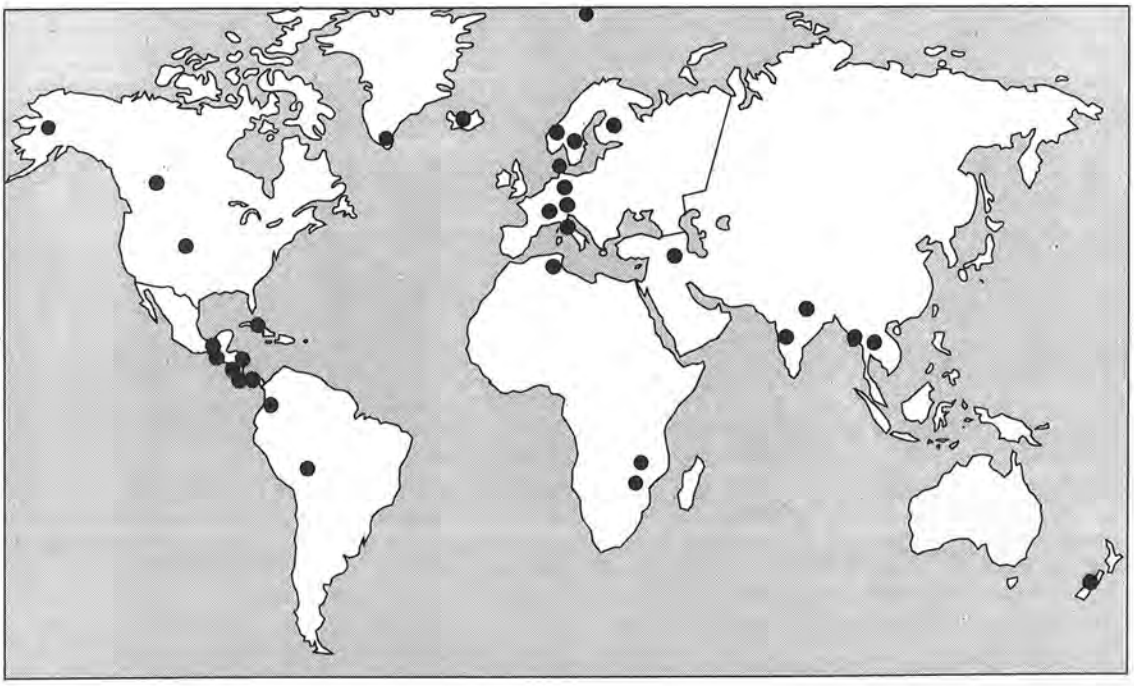


Figure 13. Countries or regions where the HBV model is known to have been applied until 1992.

Table 1. *Known applications of the HBV model in the world.*

	EUROPE
Sweden:	Some 100 basins for hydrological forecasting and computation of design floods (Bergström, 1976; Häggström, 1989; Bergström, 1990). Some 50 applications of the PULSE model for environmental studies and production of runoff records (Brandt, 1990).
Norway:	Some 50 basins for hydrological forecasting and studies of the effects of a changing climate. Norwegian version of the model (Killingtveit and Aam, 1978; Saelthun and Taksdal, 1988; Saelthun, 1990; Saelthun et al., 1990; Killingtveit et al., 1990). Scientific test of Norwegian version in Svalbard (Bruland, 1991).
Finland:	Some 20 basins for hydrological forecasting and studies of the effects of a changing climate, Finnish version (Vehviläinen, 1986 and 1992; Vehviläinen and Lohvansuu, 1991).
Denmark:	Scientific test of early version (Houmøller, 1976).
Iceland:	Scientific test of SMHI version (Bergström et al., 1982).
France:	WMO intercomparison of models of snowmelt runoff (WMO, 1986). WMO real-time intercomparison of hydrological models (WMO, 1987).
Italy:	Scientific test of SMHI version (Capovilla, 1990).
Poland:	WMO intercomparison of models of snowmelt runoff (WMO, 1986).
Switzerland:	WMO intercomparison of models of snowmelt runoff (WMO, 1986, SMHI version). Scientific test of the model in four basins (Renner and Braun, 1990; Braun and Aellen, 1990, Swiss version). Hydrological forecasting in the Rhine (Jensen and Braun, 1990).
	NORTH AMERICA
Canada:	WMO intercomparison of models of snowmelt runoff (WMO, 1986). WMO real-time intercomparison of hydrological models (WMO, 1987).
USA:	WMO intercomparison of models of snowmelt runoff (WMO, 1986). WMO real-time intercomparison of hydrological models (WMO, 1987). Scientific test of SMHI version (Hinzman and Kane, 1991).
Greenland:	Scientific test of Norwegian version (Bruland, 1991).

LATIN AMERICA

Bolivia: Hydrological forecasting, SMHI version (Johansson et al., 1987).

Colombia: Hydrological forecasting, SMHI version (Häggström et al., 1988).

Costa Rica: Hydrological forecasting, SMHI version (Johansson et al., 1985; Häggström et al., 1990).

Cuba: Hydrological forecasting, SMHI version (Rodriguez et al., 1991).

El Salvador: Hydrological forecasting, SMHI version (Häggström et al., 1990).

Guatemala: Hydrological forecasting, SMHI version (Häggström et al., 1990).

Honduras: Hydrological forecasting, SMHI version (Häggström et al., 1990).

Nicaragua: Hydrological forecasting, SMHI version (Häggström et al., 1990).

Panama: Hydrological forecasting, SMHI version (Häggström et al., 1990; Espinosa, 1991).

ASIA

Burma: Scientific test of SMHI version (Gyaw and Persson, 1985).

India: Scientific test of SMHI version (Bhatia et al., 1984).

Iraq: Hydrological forecasting, SMHI version (unofficial report).

Nepal: Scientific test of the Swiss version (Braun and Demierre, 1991). Water supply study, Norwegian version (Løvoll and Bellingmo, 1991).

Thailand: Hydrological forecasting, SMHI version (Harlin, 1990).

AFRICA

Tunisia: Scientific test, local version (Berndtsson et al., 1985).

Malawi: Hydrological forecasting, Norwegian version (Killingtveit and Brate, 1992).

Zimbabwe: Siltation studies, Norwegian version (Bøe Olsen, N.R., 1987).

OCEANIA

New
Zealand: Scientific test of local model version (Moore and Owens, 1984).

The applications in table 1 cover a large number of basins (in the order of 200) in different climatological and geographical regions, and the basins are ranging in size from less then one up to 40 000 km^2. Thanks to the subbasin option there is no theoretical upper limit in size. In Figure 14 is shown a sample of model simulations under the very different geographical and climatological conditions in Sweden, Poland, Iceland, India, Canada, Costa Rica and Bolivia for the same hydrological year of 1974-75. The graphs are taken from different applications and are therefore presented by different graphical systems. In all these plottings the computed runoff is represented by a thicker line than the observed runoff.

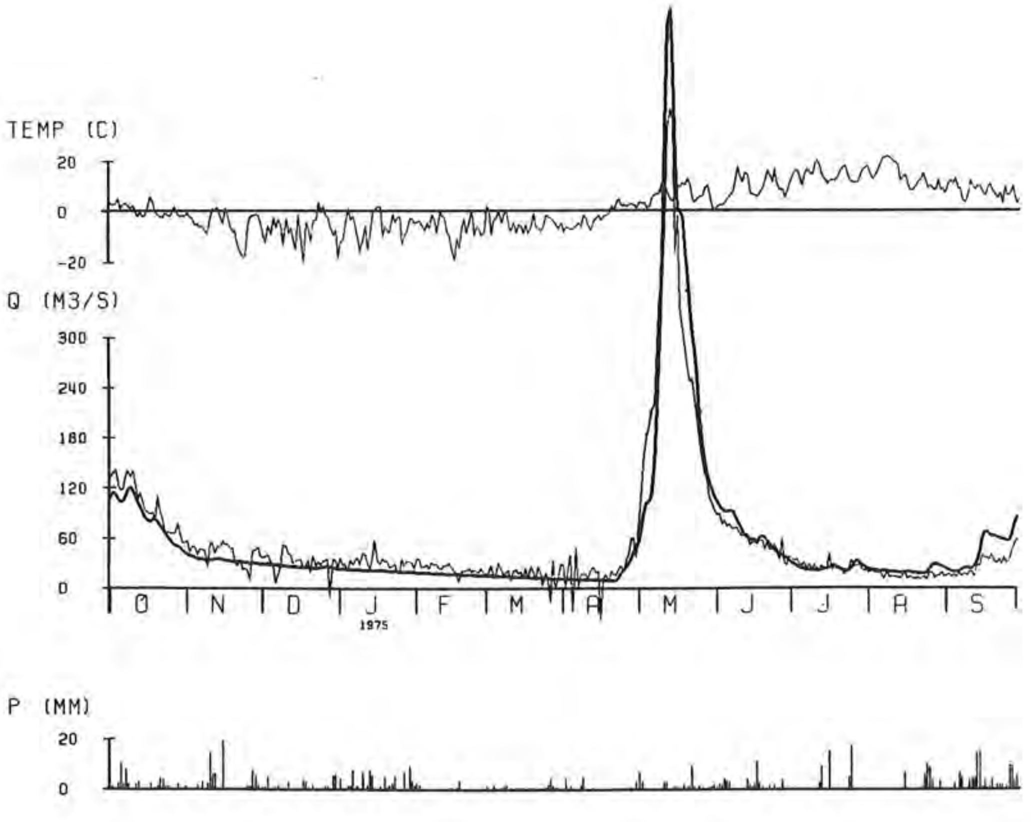


Figure 14a. Example of simulation by the HBV model in Sweden for the Trängslet basin in the river Dalälven for the hydrological year of 1974-75. The basin size is 4 483 km^2 and the model is divided into two submodels.

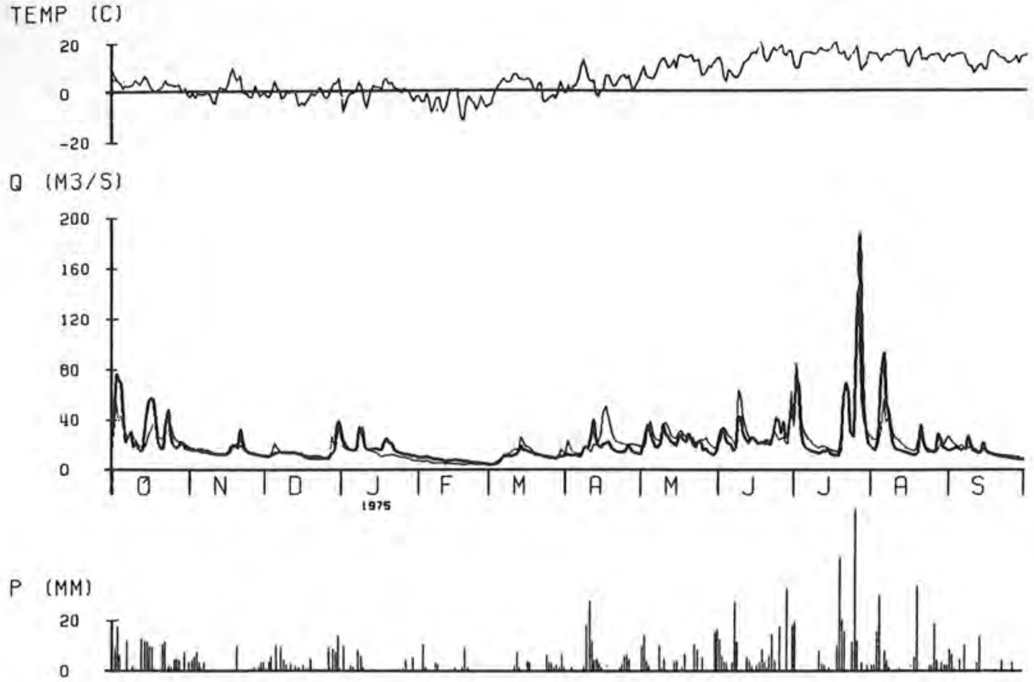


Figure 14b. *Example of simulation by the HBV model in Poland for the Dunajec basin for the hydrological year of 1974-75. The basin size is 681 km² and the model is divided into two submodels.*

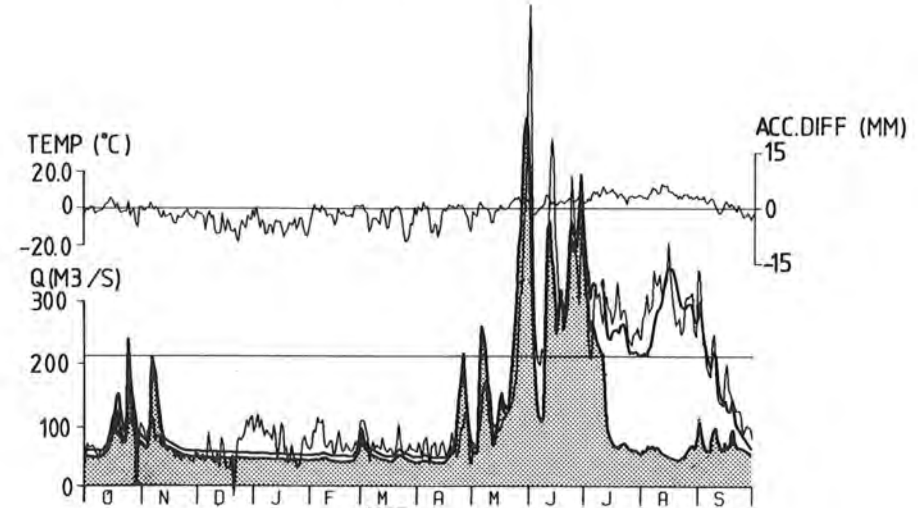


Figure 14c. *Example of simulation by the HBV model in Iceland for the Burfell basin in river Thjorsa for the hydrological year of 1974-75. The basin size is 2 890 km² and the model is divided into three submodels. One of these submodels represent glaciers. The shaded area represents simulated runoff from the part of the basin that is not covered by glaciers. (From Bergström et al., 1982.)*

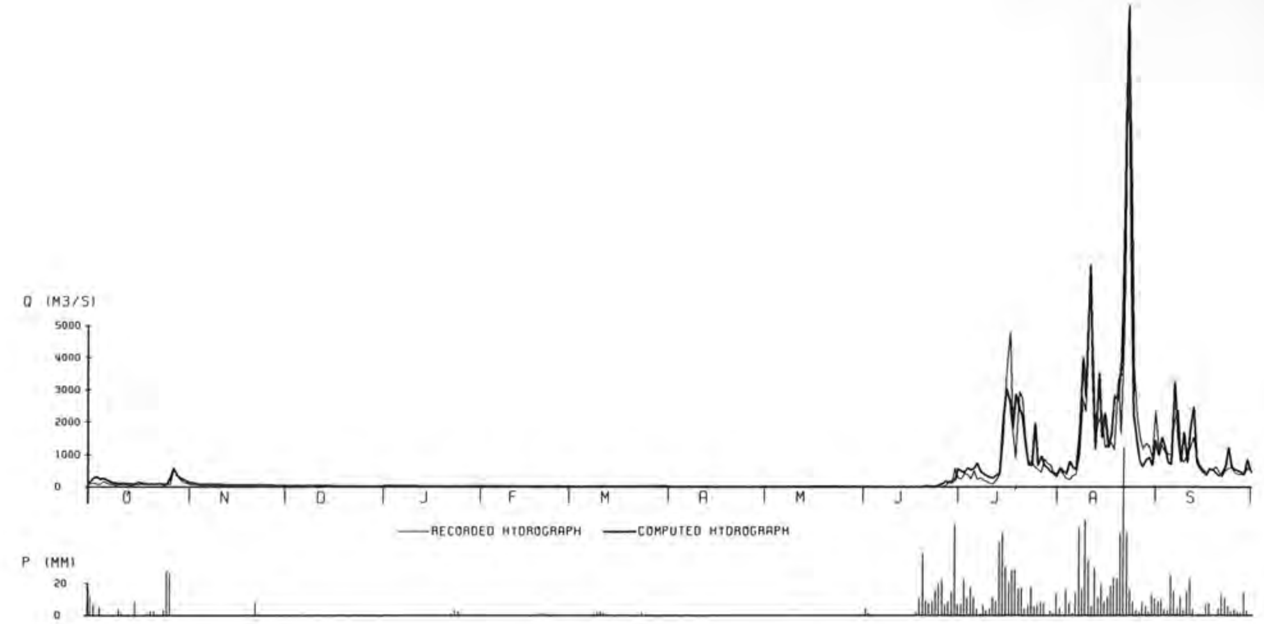


Figure 14d. Example of simulation by the HBV model in India for the Upper Narmada in Jabalpur for the hydrological year of 1974-75. The basin size is 16 576 km² and the model is divided into five submodels. (From Bhatia et al., 1984.)

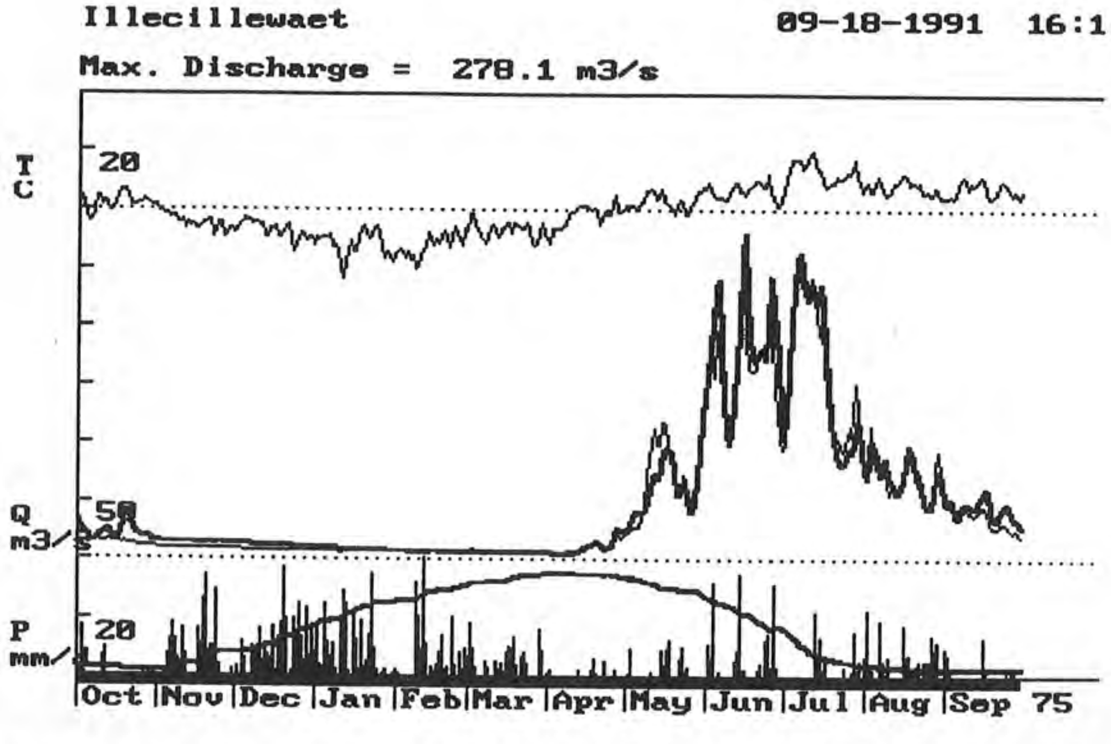


Figure 14e. Example of simulation by the HBV model in Canada for the Illecillewaet basin in the Rocky Mountains for the hydrological year of 1974-75. The basin size is 1 155 km² and the model is divided into two submodels.

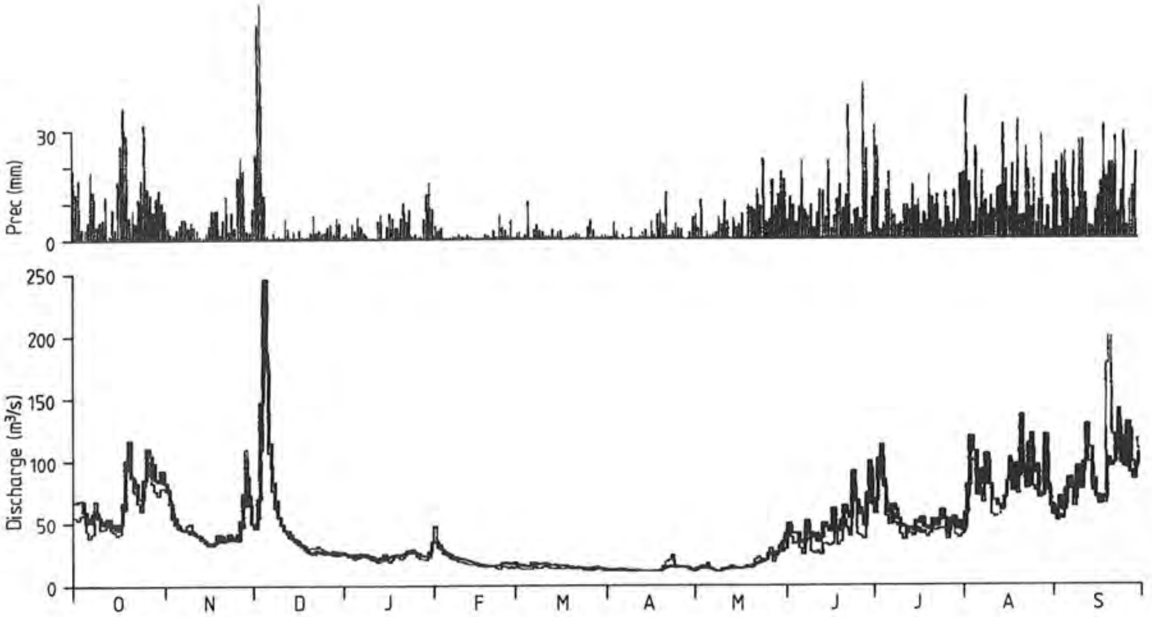


Figure 14f. *Example of simulation by the HBV model in Costa Rica for the Cachi basin for the hydrological year of 1974-75. The basin size is 785 km^2 and the model is divided into nine submodels. (Published with permission from Instituto Costarricense de Electricidad.)*

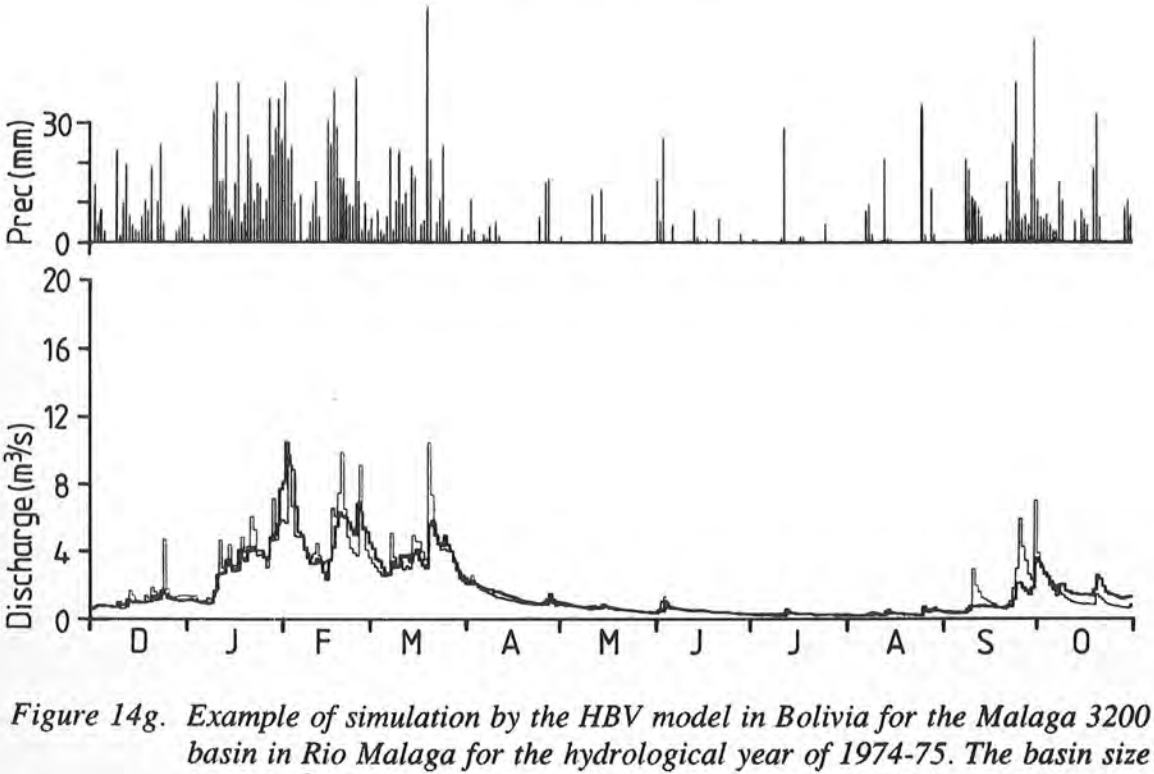


Figure 14g. *Example of simulation by the HBV model in Bolivia for the Malaga 3200 basin in Rio Malaga for the hydrological year of 1974-75. The basin size is 39 km^2 and the model is run without subdivision. (From Johansson et al., 1987.)*

From Figure 14 it is clear that the HBV model is very general and gives reasonable results under a wide span of geographical and climatological conditions. The differences are accounted for either by the set up of the model structure or its calibration. The parameter values of the model vary a lot between basins and regions, and it is not easy to relate these to physical properties except for in a few special cases. The snow melt routine is empirical, and this is reflected in differences in the melt factor between regions. 2 - 3 mm/°C · day are normal values in Sweden while the corresponding values for Iceland are around 6 mm/°C · day. The difference is explained by the windy and moist climate in Iceland and thus the effective energy exchange at the snow surface.

The soil moisture routine has proved to be very efficient and flexible with its three free parameters. It is capable of describing soil moisture recovery after very long dry periods, such as in India, and it works well in the humid tropical climate of Central America as well as in the cold climate of Northern Scandinavia. A clear relationship between climate soil conditions and the maximum soil moisture storage can (FC) be found. FC has a value of 25 mm in Iceland where a soil cover is practically lacking, between 100 and 300 mm in Sweden and around 350 mm in the application in India.

7. COMPUTER SYSTEM

Thanks to the relative simplicity of the structure of the HBV model the demand for computer power is low and can be met by most modern desk top computers. The SMHI version of the model is normally operated in a PC-environment, but there are also main frame versions available. The code contains subprograms for input data control, model calibration, hydrological forecasting and computation of design floods in systems of reservoirs. The computer time for a simulation of a single basin model over a ten year period is in the order of minutes on a 386 processor, while design flood simulations for larger systems or automatic calibrations can be completed after some ten hours. More powerful computers and more effective programming will decrease the demand for computer time considerably.

8. TRAINING

Although the HBV model has an uncomplicated structure and user-friendly computer systems are available, it is not recommended to apply it without a thorough insight into its structure. All models of this kind contain complex interactions and feed-back mechanisms, which requires a dynamic way of thinking to be fully understood. It is also important to have a sound philosophy when choosing subbasins and climate stations and when correcting input data according to undercatch, elevation and other systematic errors. The introduction of an automatic calibration procedure replaces a lot of manual work but should not be used without a full understanding of the model. A final visual check of the calibration results must be made to avoid unpleasant surprises in future applications.

The Swedish Meteorological and Hydrological Institute has carried out a number of training courses in connection with applications abroad and decentralization of the national forecasting system (Figure 15). Courses aimed at the hydro-electric power industry have also been carried out by the Norwegian Hydrodynamic Laboratories. Experience has shown that, after proper training, the user of the model is self-sufficient and can go on with new applications without further assistance.

Figure 15. Training course for Central American hydrologists from six nations at the headquarters of the Swedish Meteorological and Hydrological Institute in 1988. (Photo: Svante Lindblad, SMHI.)

9. CONCLUDING REMARKS

The large number of applications of the HBV model in the world has proved that this relatively simple conceptual model is surprisingly general. The key processes seem to be described in a reasonable way for the conditions under which they are applied. The model has also the advantage of limited demand on data coverage and computer facilities which makes it very versatile.

The low complexity of the model has made it easy to teach others how to use it and to install it in a number of countries. There are also several examples where scientists have been able to reproduce the model code just from a description in the literature.

The existence of different versions of the HBV model and different groups who apply it makes generalization of parameter values difficult. The parameter values are depending on the type of input data used, computational details in the model and, to some degree, on the calibration skill of the user.

The field of applications of the HBV model is growing and shows that the conceptual philosophy that it represents is very useful for the solution of a large number of problems related to water resources.

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