THE APPLICATION OF THE HBV RUNOFF MODEL TO THE FILEFJELL RESEARCH BASIN

by S Bergström and S Jönsson

SMHI Rapporter

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THE APPLICATION OF THE HBV RUNOFF MODEL TO THE FILEFJELL RESEARCH BASIN

BACKGROUND

In 1975 the work with conceptual runoff models at the Swedish Meteorological and Hydrological Institute came into a new phase as the HBV-2 model was applied to the local inflow to a few reservoirs in northern Sweden (Bergström and Jönsson 1975, 1976). Along with this work the need for better data for the verification of the different assumptions in the snowroutine was strongly felt. Therefore the performance of the model has now been studied in the Filefjell Representative Basin in Norway in cooperation with the Norwegian Water Resources and Electricity Board, who provided the data and other necessary information about the catchment.

This work can be looked upon as a contribution to a joint Nordic IHP collaboration project. The results might also be of interest for the proposed Regional IHP Project on Northern Research Basins and to the proposed WMO Project on Intercomparison of Conceptual Snowmelt Models.

In the future the results from a large spectrum of catchments with different physigraphic settings will increase the possibilities to apply the model to rivers, where streamflow data are missing.

The investigation was carried out in three steps.

1. The HBV-2 model was first run with parameters obtained from the map and experience in other catchments without analysing the recorded hydrograph in the Filefjell Basin.
2. The model was calibrated, modified and calibrated again until an acceptable agreement was achieved between the observed and computed hydrographs.
3. The fitted model, in this case two different models, was tested on an independent set of data.
4. An extensive study of the error function was carried out to investigate the response of the model to perturbations of two or three parameters simultaneously.

MODEL STRUCTURE

The structure of the basic HBV-2 model has been described by Bergström and Forsman (1973) and the snowmelt routine by Bergström (1975) and Bergström and Jönsson (1975). A schematic picture of the model is shown in fig. 1.

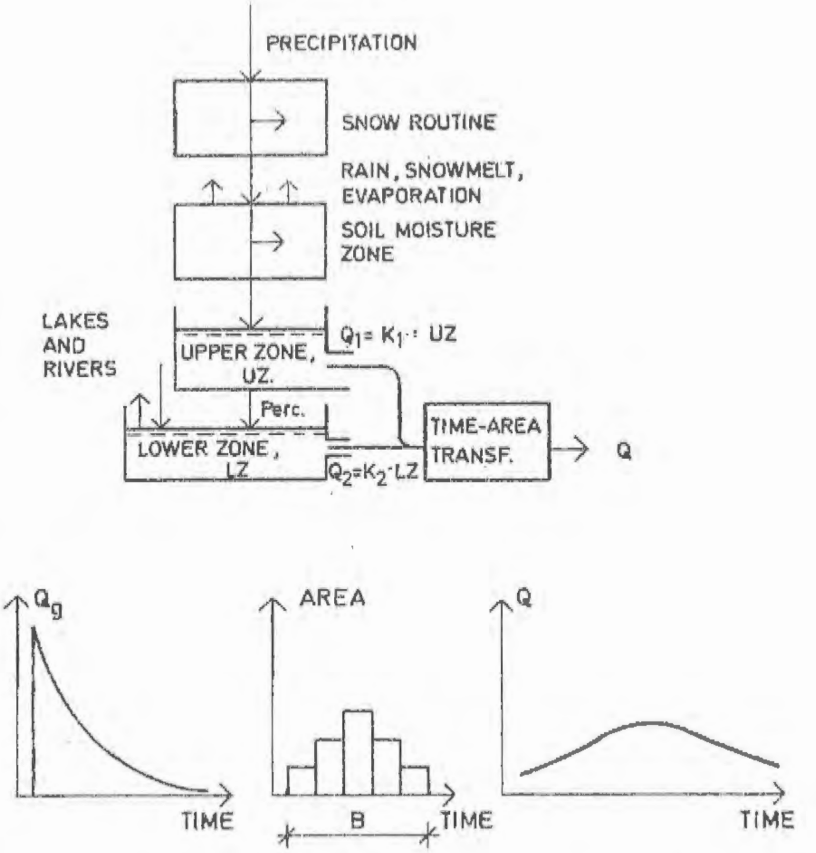


Fig. 1. The structure and time-area transformation of the HBV-2 model.

The variable time-area transformation procedure discussed by Bergström (1975) has not been used in this work due to the very short time of concentration in the catchment.

The snowmelt routine is essentially a degree-day approach with a melt rate according to equation (1).

$$M = C_o(1 + C_{eff} \cdot \sum M)\ (T - T_o) \qquad (1)$$

where

M = snowmelt in mm

C_o = initial degree-day factor

C_{eff} = rate of increase of the degree-day factor

T = mean daily temperature

T_o = threshold value of the temperature

In order to account for the distribution of the snowpack caused by the altitude range in the catchment the snowroutine is devided into ten elevation bands and the temperature and precipitation values are adjusted in each band according to lapse rates, T_{lapse} and P_{lapse}, and the area-elevation curve. A snow-fall correction factor, C_{sf}, is used on the precipitation values if snow is accumulating, to account for the aerodynamic effect around the gauges and poor representativeness. Meltwater is retained in the snowpack as free liquid water when snowmelt starts. This is represented by a factor C_{wh}, water holding capacity, and by another parameter, W_b, bottom storage.

THE FILEFJELL BASIN AND DATA BASE

The catchment has been described in great detail by the Norwegian National Committee for the IHD (1973). Some characteristics are given in table 1, and a map is shown in fig. 2.

Table 1. Characteristics of the Filefjell basin.

Drainage area	154 km^2
Lakes	9,3 %
Soil	Morain, exposed bedrock
Predominant vegetation cover	Deciduous forest, bare mountain
Altitude range 915 - 1815 m.a.s.l.	

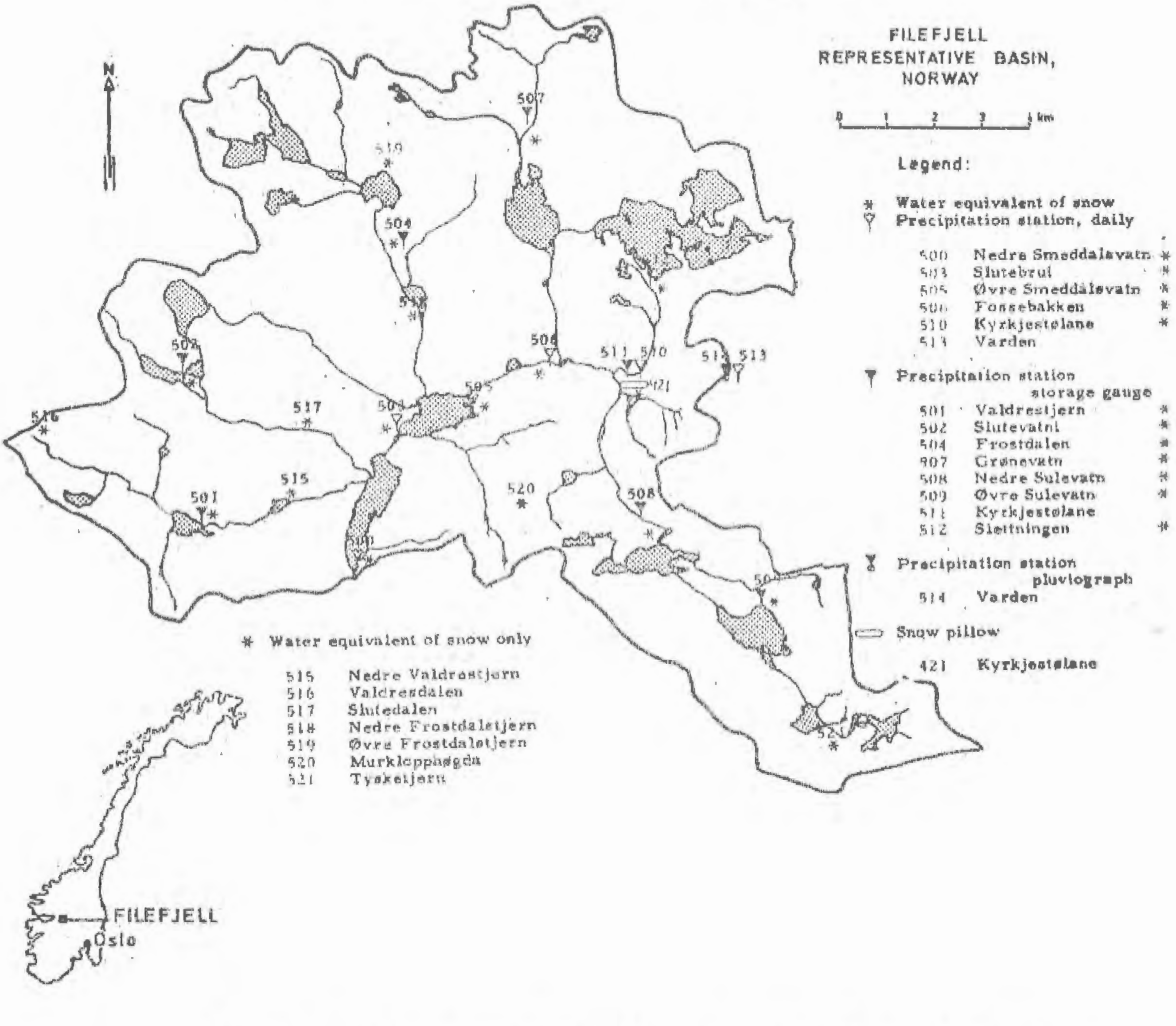


Fig. 2. The Filefjell Basin. (From Norwegian National Committee for the IHD, 1973).

The number of precipitation and temperature stations in this study was limited by the need for long continuous, homogeneous series. Four precipitation stations and one temperature station, all situated in the central valley, were used (table 2). Each precipitation station was given the weight 0.25 when computing the areal mean.

Table 2. Precipitation and temperature stations.

500 Nedre Smeddalsvatn	Precip., daily totals
503 Slutebrui	" " "
506 Fossebakken	" " "
513 Varden	" " "
	Temperature, daily means.

Monthly totals of potential evaporation computed by Penman's formula were provided by the Norwegian Water Resources and Electricity Board.

FITTING CRITERION

Careful visual inspection of the observed and computed hydrographs has been the most important way to judge the performance of the model and to decide which parameters to adjust during the calibration.

If the initial variance is defined as

$$F_o^2 = \Sigma (Q_{OBS} - \overline{Q_{OBS}})^2$$

where Q_{OBS} = observed discharge

$\overline{Q_{OBS}}$ = mean observed discharge

and
$$F^2 = \Sigma (Q_{OBS} - Q_{COMP})^2 \qquad (2)$$

where Q_{COMP} = computed discharge

then a relative measure of the goodness of fit, ranging from minus infinity to + 1, can be expressed as:

$$R^2 = \frac{F_o^2 - F^2}{F_o^2} \qquad (3)$$

This criterion gives a good estimate of the overall fit of the model but it can not be used blindly as will be shown in a following section. It has been used as a complement to visual inspection only.

Another useful tool is a graph of the accumulated difference between the two hydrographs expressed as:

$$a_i = \sum_{t=o}^{i} (Q_{COMP_t} - Q_{OBS_t}) \qquad (4)$$

where a_i = value of the accumulated difference on the i:th day.

Inspection of a_i has proved to be a very convenient way of controlling the errors in volumes over relatively long periods. It is also a help when it is difficult to tell one hydrograph from the other in the plotted output.

INITIAL TEST WITH THE HBV-2 MODEL

In order to get a better feeling for how close we have come to the solution of the problem with catchments that are completely lacking discharge data, the parameters were set at values that seemed to be reasonable according to our experience from other catchments in Sweden and inspection of the map. The first test run with these parameters gave an R^2-value of 0.76. The model managed to reconstruct the general runoff pattern fairly well but missed the volumes completely. It is evident that the snowfall correction factor, C_{sf}, being one of the most important parameters, unfortunately is very difficult to generalize, especially as it interacts with the rainfall-altitude correction. The recession coefficient for the upper zone, K_1, also caused problems as we did not have enough experience to estimate it properly from catchment characteristics. Another complication, that was later realized, was the presence of three exponential components in the recession limb of the hydrograph.

DISCUSSION OF THE RESPONSE FUNCTION

The response function is the part of the model that forms the hydrograph from excess water passing the soil moisture zone in fig. 1. Two of its parameters K_1 and K_2 are estimated, or at least given a first estimate, from plottings of recession curves and investigation of its slopes. As can be seen from fig. 3, these plottings showed three exponential components in Filefjell instead of two, which is the maximum possible number with the HBV-2 model. Therefore a modification of the model was necessary.

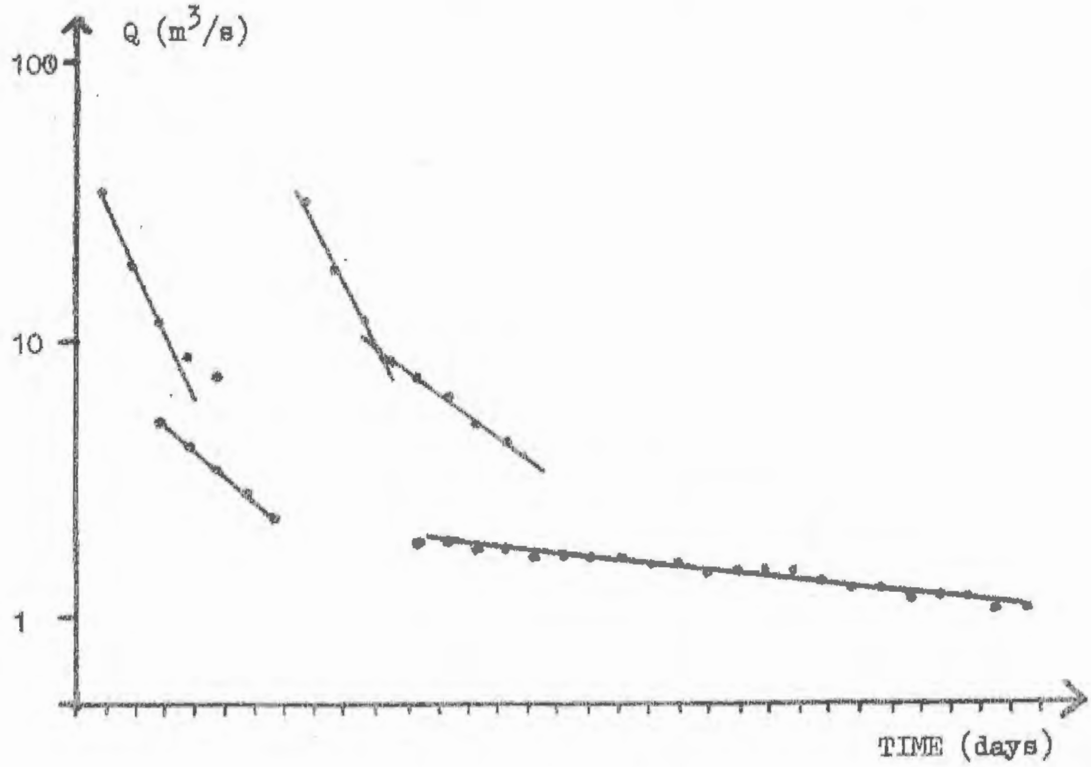


Fig. 3. Recession curves in the Filefjell basin.

Recession curves are commonly used in this type of models and often accepted without any discussion about their physical relevance. It is, however, important to bear in mind that the coefficients are found through analysis of the hydrograph at the outlet of the basin and therefore empirical constants only. Their values are a product of all the processes on the ground, in the ground, and down through the system of streams, rivers and lakes. Therefore a description of the model like the one in fig. 1 is misleading. It gives the false impression of runoff being generated first in two reservoirs, with some storage discharge constants, and then being transformed on its way down to the outlet without effect on the recession slopes. If this were true the recession coefficients should be independent of the size of the area as all areal effects should be handled by the time-area transformation. To our experience the recession coefficients are increasing as the catchment size is decreasing, even if the pattern is very irregular. The response function in fig. 1 is thus more a convenient way of describing the whole conglomerate of effects in the basin than a physical description of all its details.

THE HBV-3 MODEL

As a consequence of the above discussion a simple modification of the HBV-2 model was tested as seen in fig. 4.

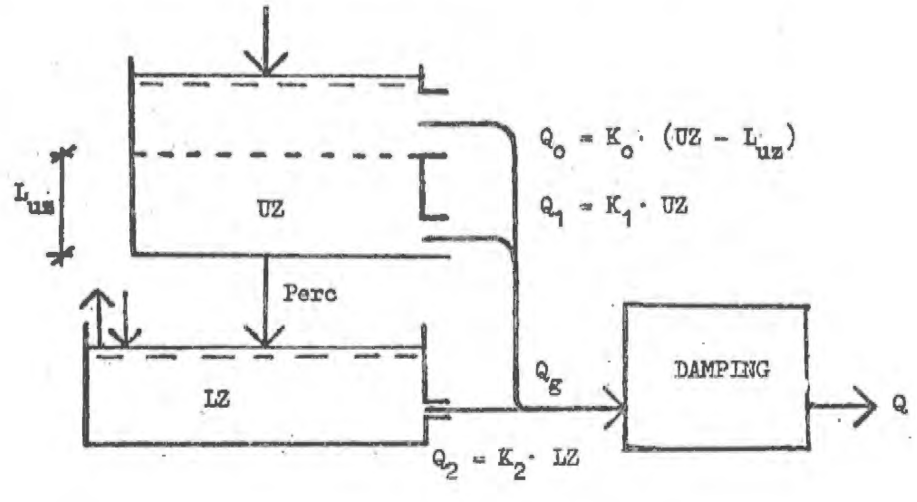


Fig. 4. The response function of the HBV-3 model.

Generally speaking the structure can be justified as follows: When the catchment is very wet and still receives a considerable amount of water the drainage capacity is rising abruptly as the water is finding new ways down to the river. This is the situation if the content in the upper zone, UZ, in fig. 4 exceeds a threshold value L_{uz}. Water is then drained away with a higher coefficient, K_o,

giving the third component in the response function. This is a truly lumped approach that only considers the average state in the basin. The model is constructed from our analysis at the outlet. Our explanation of the cause and effect is therefore not verified by the results of the model. There might be other ways of justifying the same structure or achieving similar results with other structures.

THE HBV-4 MODEL

On the other hand one can argue that the quick component in fig. 3 must be caused by the very high proportion of bare mountain in the catchment (~ 43 %). Therefore another model, HBV-4, was attempted in order to throw more light on the problem. The structure of the response function is shown in fig. 5.

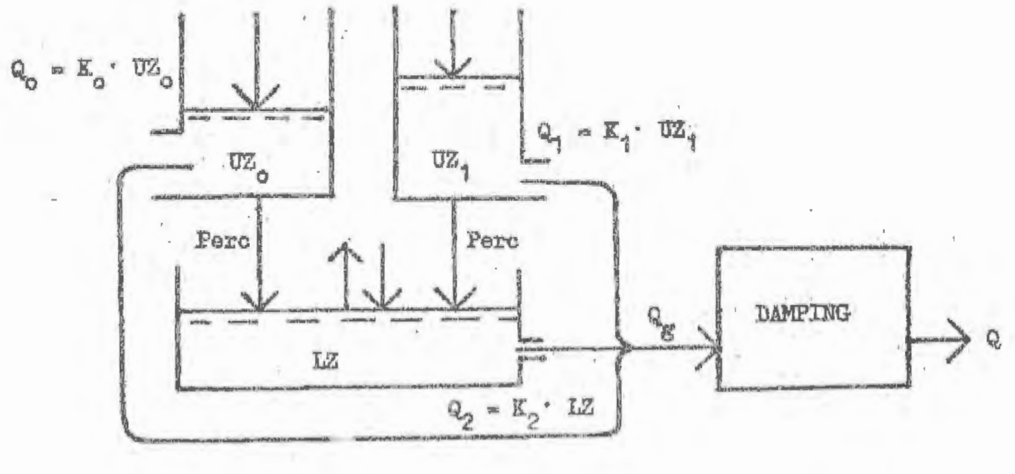


Fig. 5. The response function in the HBV-4 model.

One part of the model was assumed to represent the upper parts of the basin with bare mountain while the other is a description of the lower areas with more vegetation. In addition to the distribution of the response function maximum available water in the soil moisture zone, Fc, was distributed linearly between Fc_{max} at the bottom of the valley and Fc_{min} in the highest parts of the basin.

It is important to note the difference between these two ways of approaching the problem. In the HBV-3 model we analyse the lumped response at the outlet and then use the K_o value in a lumped response function. The physical interpretation is not a determining factor for the results. In the HBV-4 model, however, the K_o value is still obtained from a lumped analysis but the output from the model is depending on our physical interpretation of the system. We use results from the outlet and move a bit further upstreams into the system and try to apply it there.

CALIBRATION AND TEST OF THE MODELS

The two versions, HBV-3 and HBV-4, were calibrated with successive runs and visual inspection in a way described by Bergström and Jönsson (1975). The length of the calibration period was four years, September 1967 to August 1971.

The fitted models were then tested on our independent set of data over the period September 1971 to September 1974. The results expressed as R^2-values are shown in table 3 together with the number of runs needed for the calibration.

Table 3. Results expressed as R^2-values with the HBV-3 and HBV-4 models.

	HBV-3	HBV-4
Calibration (1967 - 71)	0.88	0.85
Test (1971 - 74)	0.86	0.83
Number of runs	9	2

The calibration of the HBV-4 model could be completed with just two runs because most of its parameter values were taken from the HBV-3 version and recession analysis.

Table 3 indicates that the HBV-3 version is superior to HBV-4. This is in agreement with our own subjective judgement of the plotted hydrographs. In particular the HBV-4 version seemed to model the recession part after a snowmelt period poorly, as the combination of delayed snowmelt and quick recession in the upper parts of the basin gave a too drastic drop of the recession limb.

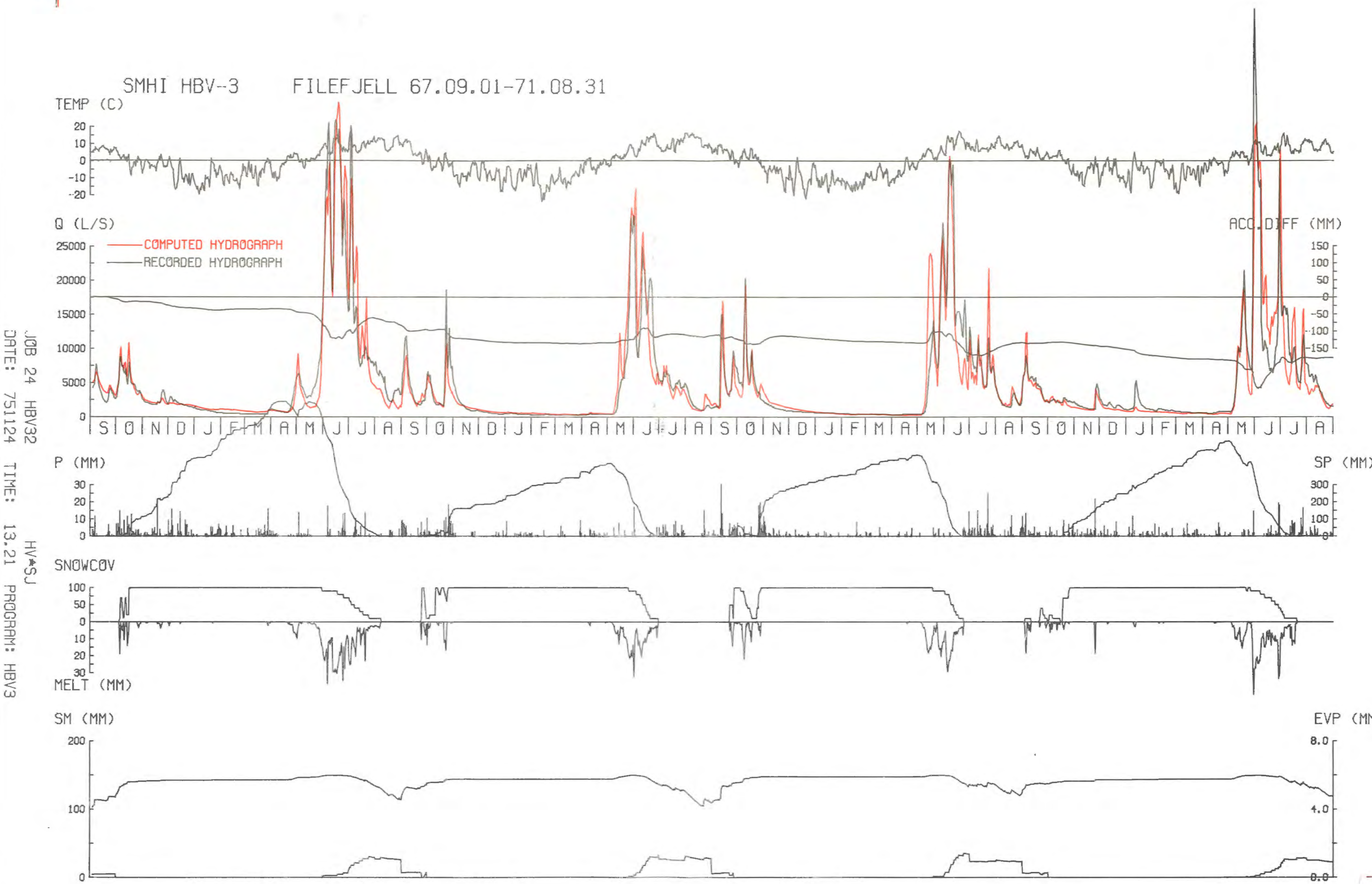
The fact that we assumed a constant proportion of the basin being subject to quick response in the HBV-4 model also made it difficult to fit both small and high peaks simultaneously. In the final compromise the model overestimated floods of low magnitude and underestimated high floods.

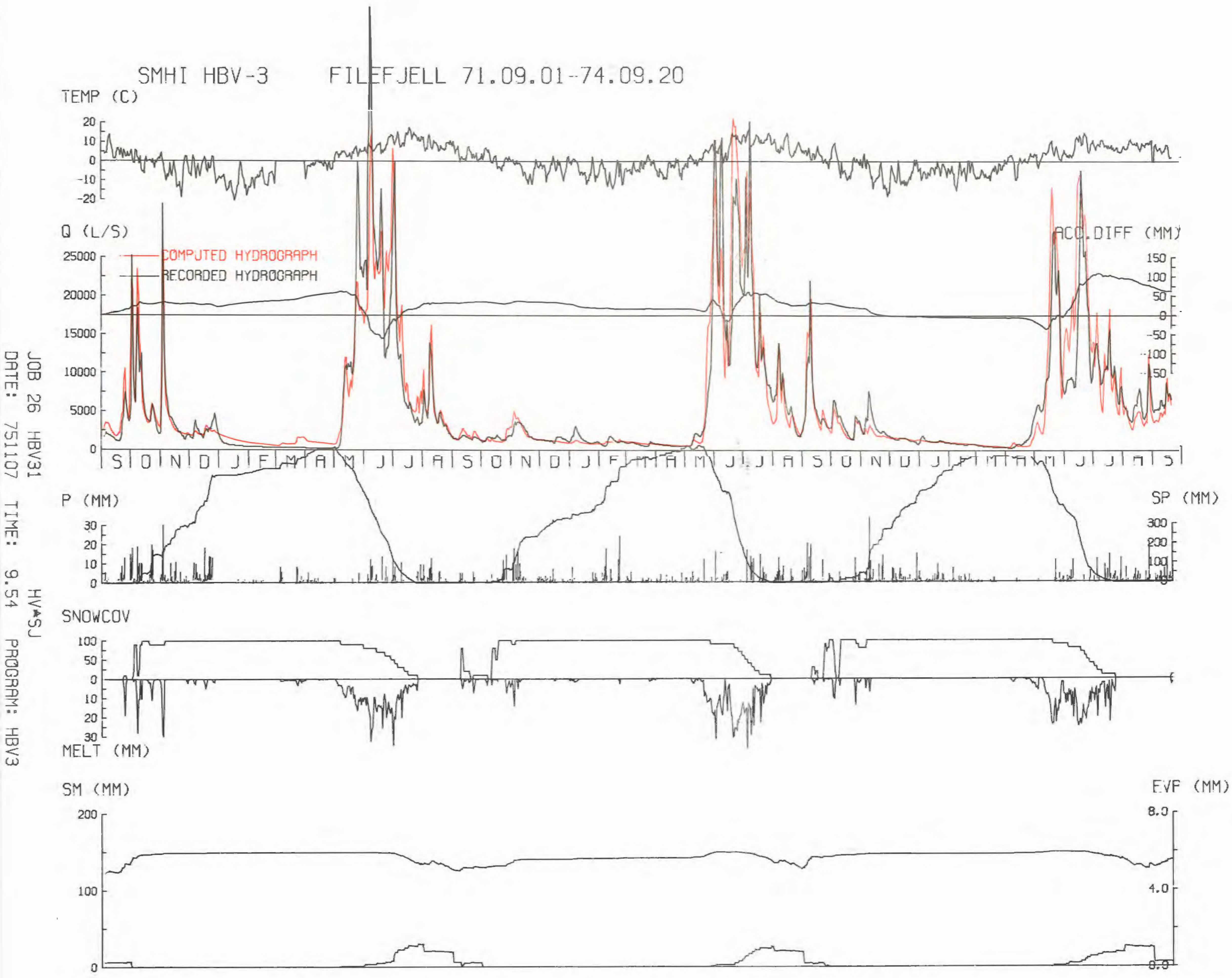
The total performance of the HBV-3 model can be studied in fig. 6 and 7 on the following pages. The symbols in these figures are:

TEMP	= daily means of temperature, one station (°C)
Q	= computed (red, and observed (black) discharge (l/s)
ACC. DIFF.	= accumulated difference (mm)
P	= precipitation, four stations (mm)
SP	= average water equivalent of snow in the catchment as computed by the model (mm)
SNOWCOV	= area covered by snow in the model (%)
MELT	= yield from the snow routine including rain when this routine is operating (mm)
SM	= soil moisture state in the model (mm)
EVP	= computed actual evaporation (mm).

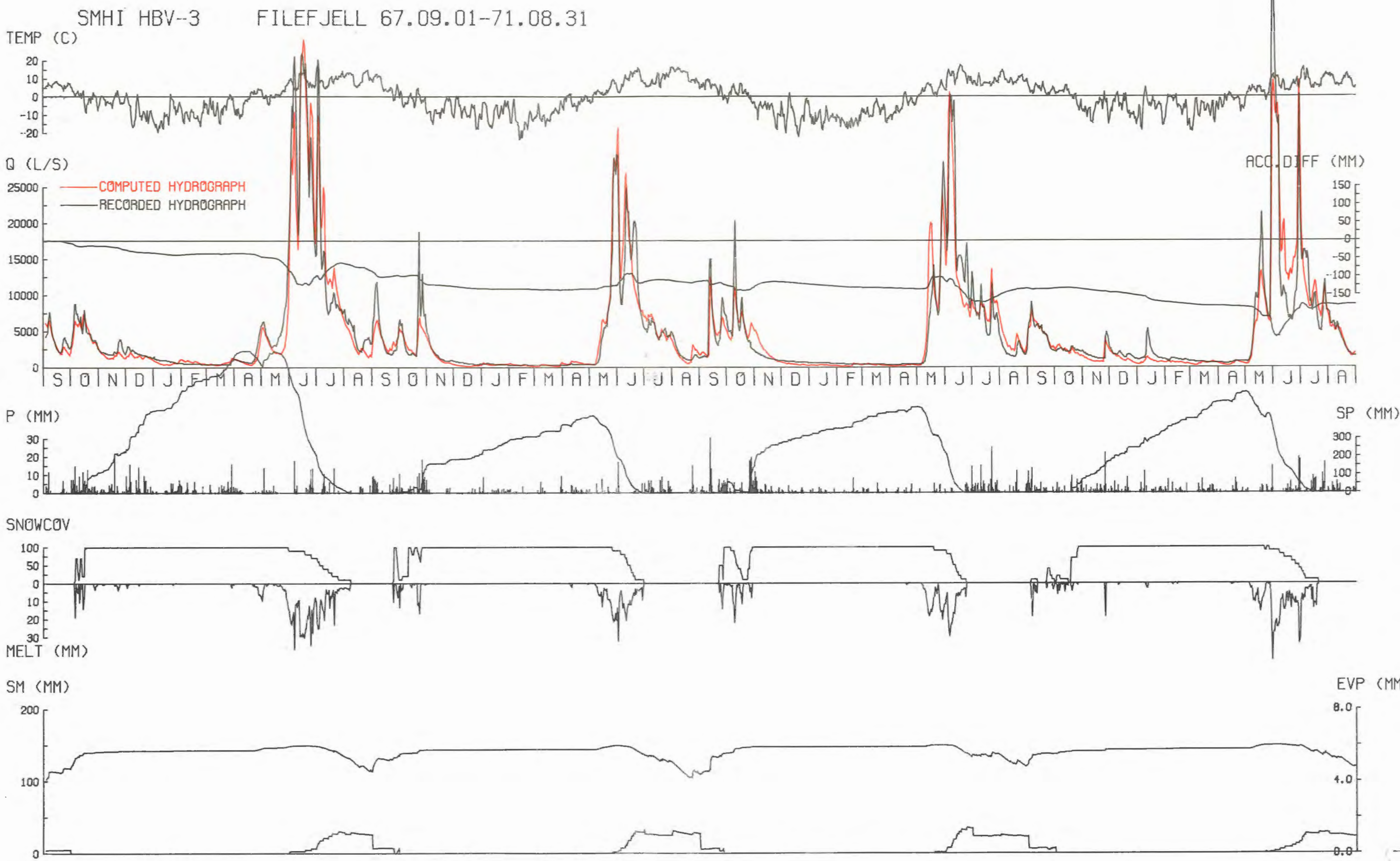
Fig. 6. The calibration period in the Filefjell basin.

Fig. 7. The test period in the Filefjell basin. (Following pages.)


SMHI HBV-3 FILEFJELL 67.09.01-71.08.31
TEMP (C)
Q (L/S)
COMPUTED HYDROGRAPH
RECORDED HYDROGRAPH
ACC. DIFF (MM)
S Ø N D J F M A M J J A S Ø N D J F M A M J J A S Ø N D J F M A M J J A S Ø N D J F M A M J J A
P (MM)
SP (MM)
SNOWCOV
MELT (MM)
SM (MM)
EVP (MM
JOB 24 HBV32
DATE: 751124 TIME: 13.21 PROGRAM: HBV3
HV*SJ



SMHI HBV-3 FILEFJELL 71.09.01-74.09.20
TEMP (C)
Q (L/S)
COMPUTED HYDROGRAPH
RECORDED HYDROGRAPH
ACC.DIFF (MM)
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S
P (MM)
SP (MM)
SNOWCOV
MELT (MM)
SM (MM)
EVP (MM)
JOB 26 HBV31
DATE: 751107 TIME: 9.54 PROGRAM: HBV3
HV*SJ



JOB 24 HBV32 HV*SJ
DATE: 751124 TIME: 13.21 PROGRAM: HBV3

The parameters in the HBV-3 model are shown in table 4. Some of these parameters were not fitted but kept at their initial values. P_{lapse} and T_{lapse}, for example, were recommended by the Norwegian Water Resources and Electricity Board, and K_o, K_1 and K_2 were found through analysis of recession curves.

Table 4. Parameters in the Filefjell basin.

P_{lapse}	= 12 %/100 m
T_{lapse}	= – 0.6 °C/100 m
C_{sf}	= 1.7 (snowfall correction)
C_o	= 2.5 mm/(°C · day) (eq. 1)
C_{eff}	= 0 (eq. 1)
T_o	= – 1 °C (eq. 1)
C_{wh}	= 5 % (water holding capacity in snow)
W_b	= 10 mm (bottom storage in snow)
B	= 2 days (fig. 1)
Fc	= 1.0 (corresponding to 150 mm)[1]
Lp	= 150 mm[1]
Beta	= 2.0[1]
Perc	= 0.6 mm/day[1]
K_o	= 840 l/s/mm (fig. 4)
K_1	= 200 l/s/mm (fig. 4)
K_2	= 50 l/s/mm (fig. 4)
L_{uz}	= 20 mm (fig. 4)

1) See, for example, Bergström and Forsman (1973).

ERROR FUNCTION STUDIES

Studies of the error function response has been carried out earlier with the HBV-2 model in a few catchments (Bergström and Forsman, 1973, Bergström 1975). These studies have proved to be a very useful way of analysing the relative importance of each parameter or a combination of parameters. It must be stressed, however, that the method must not be applied blindly. Some knowledge about the position of the parameter in the model structure is necessary. A parameter that is important for the level of low flow during winter will undoubtedly have less effect on the absolute error, expressed as F^2, than will a parameter controlling the timing of the spring flood. The errors are of different order of magnitude, but still both paramters are equally important in the overall model. Another problem is the fact that as F^2 is a rather rigid criterion, its minimum doesn't always coincide with the best fit according to our visual inspection. Finally we have the problem of investigating more than 2 parameters simultaneuosly. In this report an attempt is made to study 3 parameters with a four dimensional technique, but more parameters will envolve a lot of computor work and is difficult to visualize.

In the following the topography of F^2 (eq. 2) reduced by a factor 10^{-10} is shown with isolines having the equidistance 0.02 in cases sensitivity is low, and 0.1 if the model is more sensitive to the parameters. This differentiation was found to be necessary for the visualization of the results. The fitted values used in fig. 6 and 7 are shown by a cross in the following figures. The translation from F^2- to R^2-values can be made through eq. 2 with $F^2_o \cdot (10^{-10}) = 8.31338$ or by table 5. The studied period was 1967 – 71.

Table 5. Transformation from F^2- to R^2-values.

$F^2 \cdot (10^{-10})$	R^2
0.85	0.8978
0.90	0.8917
0.95	0.8857
1.00	0.8797
1.05	0.8737
1.10	0.8677
1.15	0.8617
1.20	0.8557

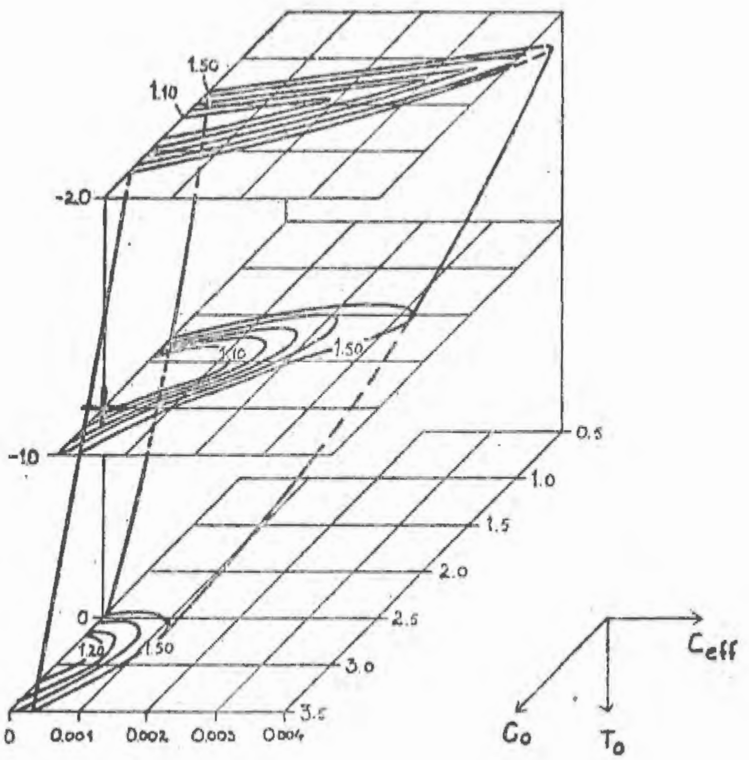


Fig. 8. The response of F^2 to C_o, T_o and C_{eff}. Equidistance = 0.1. Model values: C_o = 2.5, T_o = 1.0, C_{eff} = 0.

PARAMETERS IN THE SNOW ROUTINE

C_o, T_o and C_{eff}

These parameters were studied simultaneously in a four-dimensional representation (three parameters and F^2), as shown in fig. 8. The distance between the isolines is 0.10. As can be seen from the figure, the model is highly sensitive to changes in C_o, provided T_o is kept at a constant value. There seems to be some correlation between T_o and C_o making it possible to absorb a detoriation in one parameter with a change in the other. Still, the value of T_o differs significantly from zero. C_{eff} is evidently not improving the model at all. This is in agreement with the study by Bergström (1975) in a Swedish basin with quite different characteristics. The conclusion is thus that although a parameter, having the same effect as C_{eff} on the melting process, is justified by field measurements, it is generally not detectable at the outlet of the catchment.

C_{wh} and W_b

These two parameters are both effecting water retention, as snowmelt starts. The error function is mapped in fig. 9 with an equidistance of 0.02. The valley is very flat and in agreement with the results by Bergström (1975). The interpretation of these small changes in the error function is difficult due to uncertainties in the representativeness of the fitting criteria. An example of this will be shown, when the parameters Perc and K_2 are mapped in a following section.

W_b / C_{wh}	0	10	20	30	40
0.00	1.2555	1.0962	1.0615	1.0151	0.9908
0.03	1.1115	1.0428	1.0097	0.9903	0.9952
0.05	1.0497	1.0157	0.9880	0.9963	1.0145
0.08	1.0246	1.0119	0.9992	1.0248	1.0548
0.10	1.0249	1.0246	1.0347	1.0704	1.1187

Fig. 9. The response of F^2 to C_{wh} and W_b. Equidistance = 0.02.
Model values: C_{wh} = 0.05, W_B = 10.

PARAMETERS IN THE SOIL MOISTURE ROUTINE

Beta, Lp and Fc

The three parameters in the soil moisture routine are studied in fig. 10 with an equidistance of 0.02. It is not surprising that these parameters are less sensitive than those affecting snowmelt, C_o, T_o and C_{eff}, as the spring flood peaks are the cause of the major part of the initial variance. The soil moisture deficit is also less important in this mountaineous basin. Fig. 10 indicates, however, that these three parameters are fairly orthogonal, which is a satisfactory result. The same parameters have been studied in other catchments by Bergström and Forsman (1973) and Bergström (1975), but this is the first time a four dimensional representation is made.

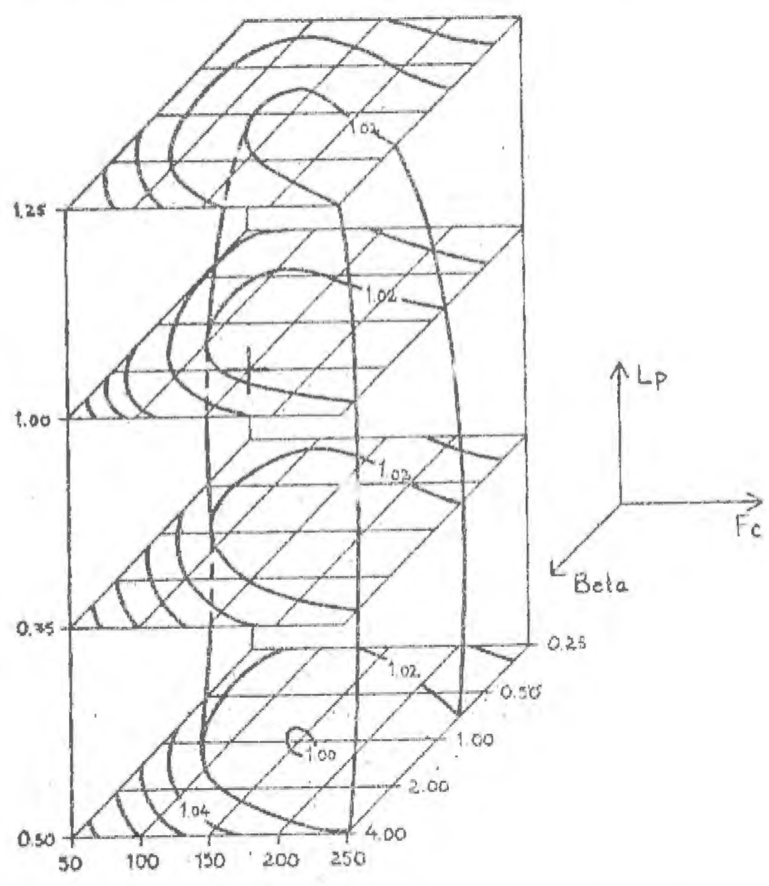


Fig. 10. The response of F^2 to Beta, Lp and Fc. Equisistance = 0.02. Model values: Beta = 2.0, Lp = 1.0, Fc = 150.

PARAMETERS IN THE RESPONSE FUNCTION

These parameters were studied thoroughly in order to investigate the effect of the introduction of the third runoff component in the model. The earlier discussion of the response function as regards recession coefficients and time area distribution also made it interesting to try to trace any interaction between the parameters concerned.

K_o, K_1 and L_{uz}

A four-dimensional representation is made in fig. 11. There seems to be some interaction between K_o and L_{uz}. The response surface has the shape of an ellipse, the axis of which is changing with L_{uz} in the intervals studied. The explanation is that at low values of L_{uz}, K_o will become increasingly important compared to K_1 (see fig. 4), while at high L_{uz}-values the situation is the opposite. If L_{uz} is zero, we are back at the HBV-2 model, and $(K_o + K_1)$ will take over the role of K_1 in fig. 1. At high L_{uz}-values K_o will not effect the model at all, and K_1 will have the same function as in the original HBV-2 version. The fitted values were $K_o = 840$, $K_1 = 200$ and $L_{uz} = 20$. As can be seen from fig. 11, they are not optimum values in the F^2 sense of this term. Therefore the model was run with $K_o = 1000$, $K_1 = 250$ and $L_{uz} = 50$, and the hydrograph was studied again visually. Subjectively the hydrograph looked slightly better at the former parameter values. To throw more light on this question the independent test period was also run with this last set of parameters. The difference from the results with the earlier set of parameters was hardly discernible. The R^2-values from this comparison are shown below.

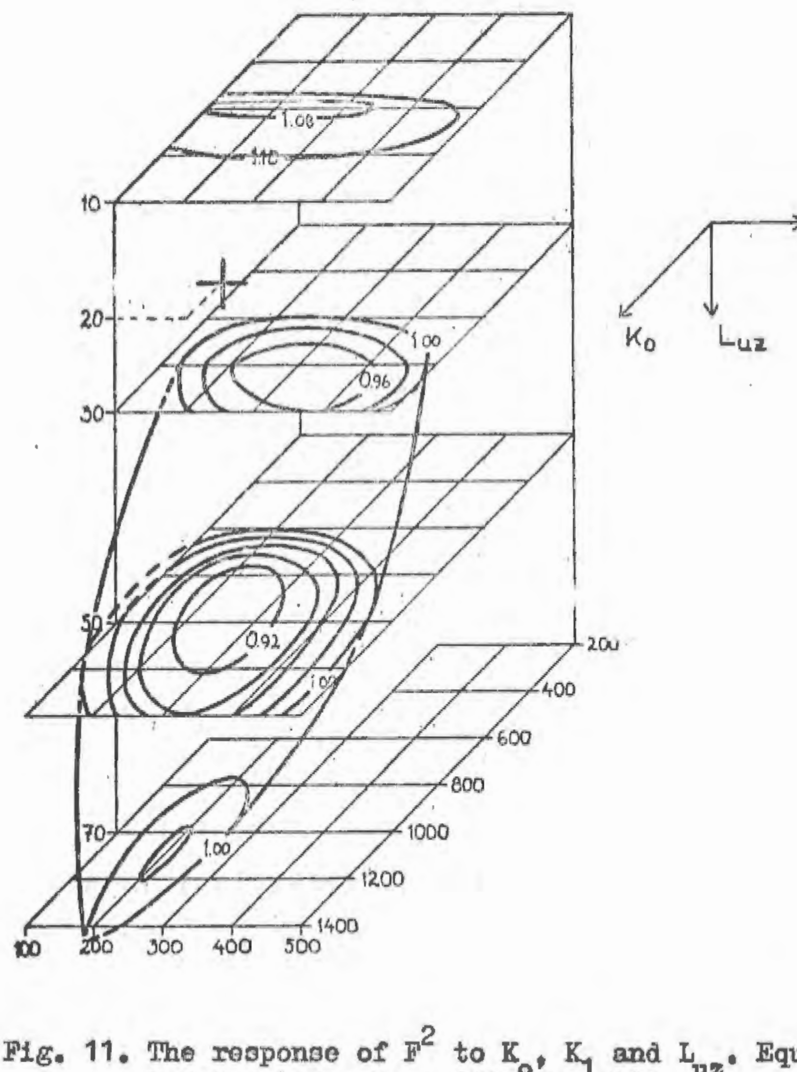


Fig. 11. The response of F^2 to K_o, K_1 and L_{uz}. Equidistance = 0.02. Model values: $K_o = 840$, $K_1 = 200$, $L_{uz} = 20$.

	1967 - 1971	1971 - 1974
Calibrated set of parameters	0.8778	0.8623
Modified set of parameters	0.8927	0.8614

The conflict between our subjective judgement and the R^2-value emphasized the need for a better criterion of fit, and the risk with blind search if the representativeness of this criterion is poorly explored.

K_o, K_1 and B

In fig. 12 the effect of perturbations of K_o and K_1 is studied in connection with the base in the time-area distribution, B, (fig. 1). B can be said to represent the time of concentration in the basin. As can be seen from the figure, the fitted value of B = 2.0 is a good estimate, but there is some possibility to compensate erroneous B-values with an adjustment of K_o, if the F^2-value is used as our sole criterion of fit. A visual inspection of the hydrographs will, however, reveal that the computed and observed recession limbs are not parallell any longer, if the recession coefficient is used this way as a tuning parameter. Both K_o and K_1 are significantly improving the model. The original HBV-2 model is obtained, if we let K_1 equal zero and try to fit the model with K_o and B.

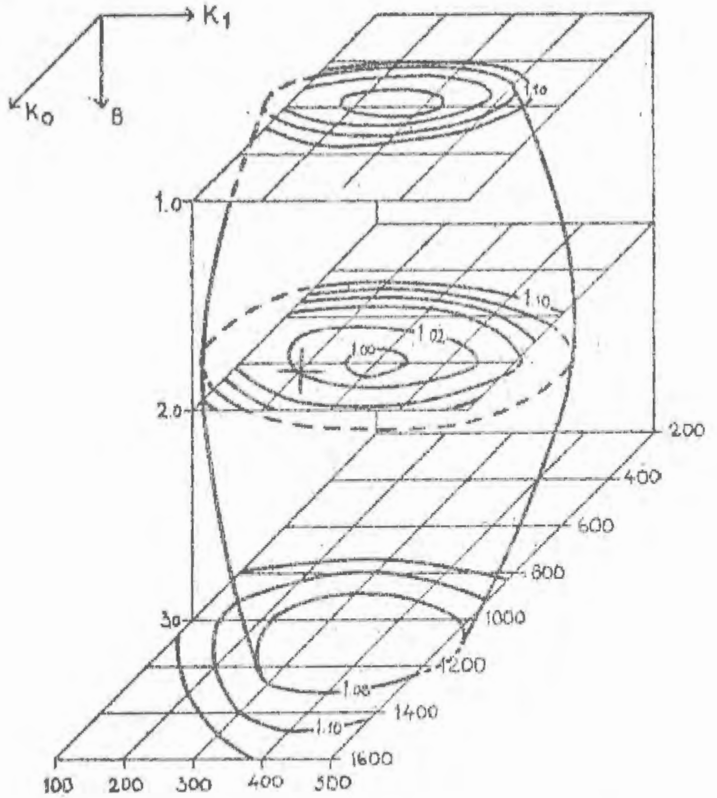


Fig. 12. The response of F^2 to K_o, K_1 and B. Equidistance: 0.02. Model values: K_o = 840, K_1 = 200, B = 2.

Perc and p

Although the lake percentage, p, is a parameter derived from studies of the map, it can be interesting to study how sensitive the model is to this estimate. As this parameter is one effecting recharge of the lower zone, it is natural to study it together with the percolation capacity, Perc. The results in fig. 13 show that there is a pronounced correlation between these parameters and that the sensitivity of the model is rather small.

Perc / p	0.0	0.5	1.0	1.5	2.0
0.00	1.2924	1.2071	1.1411	1.0899	1.0538
0.05	1.1303	1.0645	1.0164	0.9849	0.9679
0.10	1.0291	0.9820	0.9524	0.9392	0.9436
0.15	0.9882	0.9601	0.9498	0.9562	0.9787
0.20	1.0093	0.9999	1.0085	1.0355	1.0737

Fig. 13. The response of F^2 to Perc and p. Equidistance = 0.02.
Model values: Perc = 0.6, p = 0.1.

Perc and K_2

These two parameters represent another interesting pair, as the maximum level in the lower zone can be shown to be proportional to the relation Perc/K_2 (Bergström and Forsman, 1973). It is therefore not surprising that the error function topography shows strong dependence between these two parameters, as shown in fig. 14. What is more surprising is the fact that the least F^2-value is found at a K_2-value of 170, that is rather close to the fitted value of K_1, which was 200. This caused us to run the model at these parameter values and make a visual inspection of the hydrographs. The R^2-value obtained was 0.8931, which shall be compared with 0.8778 for the fitted period. The plotting is shown in fig. 15 for the judgement of the reader. As can be seen if compared with fig. 6, the new parameters tend to concentrate on the adjustment of some erroneously modelled peaks, while the long low flow recession part, that was meant to be controlled by these parameters, is destroyed. This is a situation, when errors of one order of magnitude are masking errors of a lower order. The risk when relying blindly on one single criterion of fit is emphasized once again.

K_2 / Perc	10	50	90	130	170	210	250	290
0	1.0369	1.0291	1.0430	1.0595	1.0769	.	.	.
1	1.0304	0.9524	0.9632	0.9855	1.0097	.	.	.
2	1.1328	0.9436	0.9289	0.9440	0.9666	.	.	.
3	1.3171	0.9817	0.9232	0.9211	0.9362	0.9576	0.9811	1.0049
4	1.5355	1.0396	0.9264	0.9026	0.9089	0.9264	0.9495	0.9745
5	.	.	.	0.9058	0.8995	0.9121	0.9336	0.9590
6	.	.	.	0.9321	0.9115	0.9177	0.9367	0.9618
7	.	.	..	0.9695	0.9335	0.9323	0.9479	0.9717

Fig. 14. The response of F^2 to K_2 and Perc. Equidistance = 0.02. Model values: K_2 = 50, Perc = 0.6.

Fig. 15. The calibration period with modified values of Perc and K_2. The initially fitted period is shown in fig. 7. (Following page .)

AREA-ELEVATION LAPSE PARAMETERS

When distributing the model over an area-elevation curve sem very crude estimates of the temperature lapse, T_{lapse}, and precipitation lapse, P_{lapse}, with altitude have to be made. The values must be very approximate due to the great variability caused by inversions and other complex meteorological factors. Fortunately the random errors in these parameters can be damped out to some extent by the long snow accumulation period, even if this certainly is not true for T_{lapse} during snowmelt. (In the follwing figures the program was modified slightly, which is the reason why the calibrated F^2-values do not coincide with the ones showed earlier.)

T_o and T_{lapse}

T_o was thought to be the parameter that best could compensate for perturbations in T_{lapse}. The mapping of the error function is shown in fig. 16. Interdependence is strong, but T_{lapse} deviates significantly from 0. This means that the area-elevation correction cannot be accounted for by the threshold parameter T_o alone. The assumed value of T_{lapse} and the fitted value of T_o did not lie far from the optimum in the F^2-sense. Adjustment of these values is not advisable considering the uncertainty in the F^2-criterion itself, and the loss of degrees of freedom, if we give T_{lapse} the status of a free parameter.

T_{lapse} \ T_o	0	-0.5	-1.0	-1.5	-2.0	-2.5	-3.0
-0.00	2.4387	3.2802	4.7241	7.0543	9.2334	.	.
-0.30	1.3079	1.4641	1.9773	2.8460	4.2630	.	.
-0.60	1.4029	1.0011	0.9748	1.2362	1.7852	2.6464	3.9447
-0.90	2.5742	1.7550	1.2094	0.8946	0.9055	1.2149	1.7196
-1.20	3.8130	2.9987	2.3162	1.6205	1.4468	0.9544	1.0439
-1.50	.	.	3.4947	2.7352	2.0529	1.5598	1.2603
-1.80	.	.	4.5539	3.7665	3.1075	2.4280	1.9813

Fig. 16. The response of F^2 to T_o and T_{lapse}. Equidistance = 0.1
Model values: T_o = - 1.8, T_{lapse} = - 0.6.

C_{sf} and P_{lapse}

The snow-fall correction factor, C_{sf}, was assumed to give the strongest interdependence with P_{lapse}. As can be seen from fig. 17, the situation is very much the same as when studying T_o and T_{lapse}.
The conclusions are therefore similar. C_{sf} cannot account for the precipitation-lapse effect in the Filefjell basin. There is of course a possibility that a combination of other parameters can, but using P_{lapse} does not mean introducing too much complexity into the model, as long as we derive a fixed value from information outside the hydrograph used for the calibration of the model.

P_{lapse} \ C_{sf}	1.3	1.5	1.7	1.9	2.1
0.04	2.5785	1.9933	1.5108	1.1933	1.0731
0.08	1.9832	1.4535	1.1174	1.0079	1.0727
0.12	1.5082	1.1291	0.9748	1.0691	1.3412
0.16	1.1882	0.9822	1.0522	1.3288	1.8761
0.20	1.0244	1.0267	1.2709	1.8419	2.6675

Fig. 17. The response of F^2 to C_{sf} and P_{lapse}. Equidistance = 0.1. Model values: C_{sf} = 1.7, P_{lapse} = 0.12.

CONCLUSIONS

The application of the model in the Filefjell Basin led us to some conclusion concerning the model structure and the relative importance of its parameters.

The original HBV-2 model had to be modified with the introduction of a third runoff component. A completely lumped modification proved to be better than a more distributed one.

Once the model was modified the calibration was relatively simple. The most important parameters were those in the snow-routine and the recession coefficients in the response function. One of the biggest problems when trying to apply the model to ungauged catchments seems to be the empirical coefficients that we are forced to use when extrapolating precipitation observations to areal values.

The soil moisture routine is less important in this alpine catchment because evaporation is low. A fictive value of the available water, Fc, of 150 mm was assumed but the maximum deficit in the

soil moisture zone in the model was less than 50 mm during the seven years in the period.

The conflict between subjective visual inspection and optimum parameters in the least squares-sense is a strong indication that fitting criterions must not be used blindly, unless their capability of representing the agreement between the observed and computed hydrographs is explored rigorously.

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