Model calibration and frequency analyzes

Jochen Hochrainer

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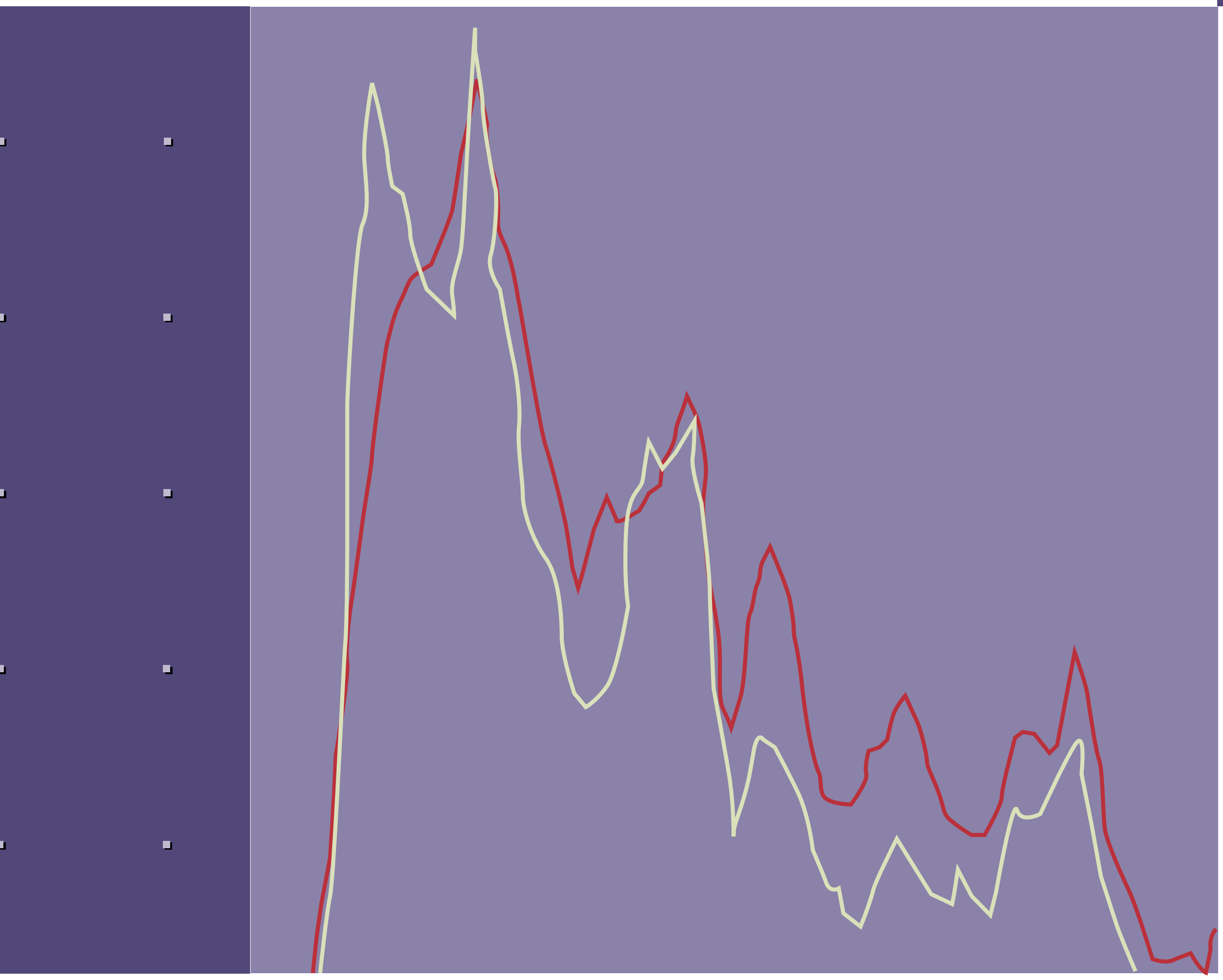
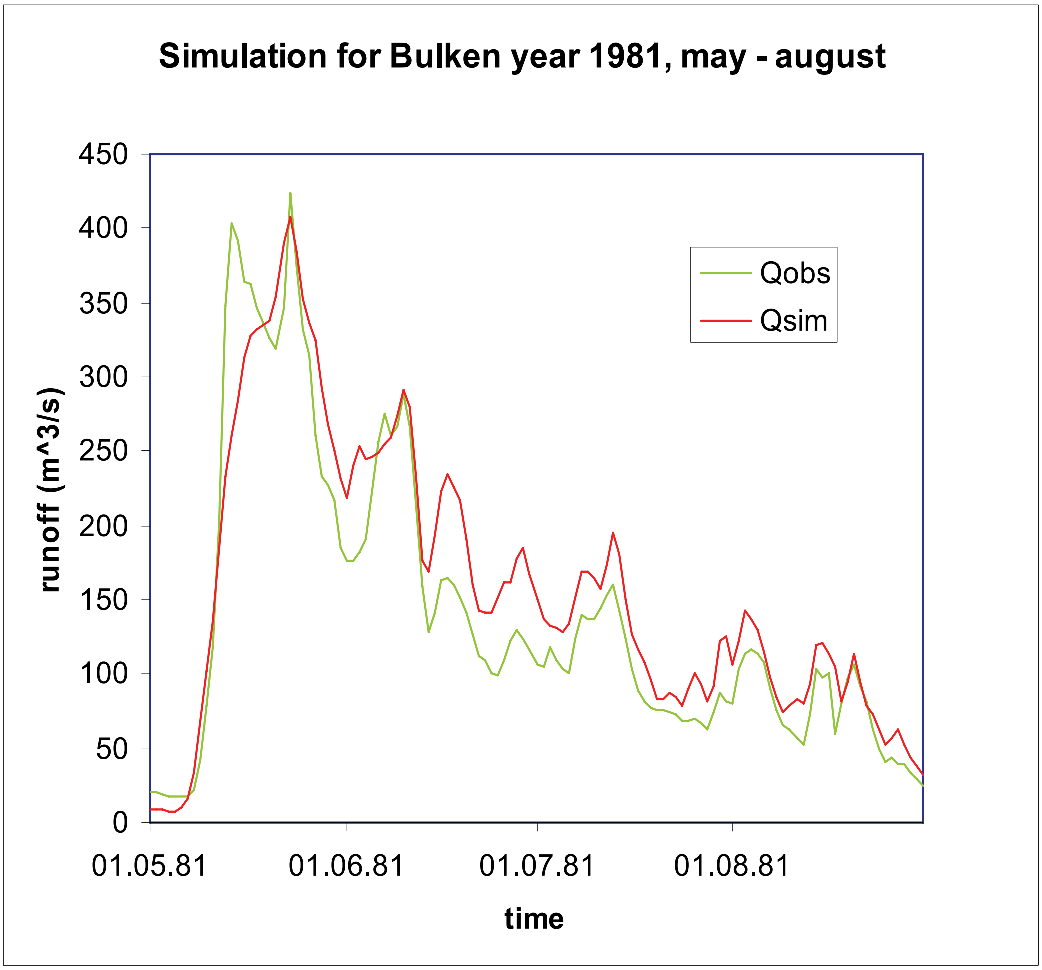


REPORT

Model calibration and frequency analyzes

Practical traineeship at NVE, Jan - Apr 2005



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Model calibration and frequency analyzes

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Summary: The report summarizes the results of a traineeship, which is a part of a study at University of Freiburg, Germany. The assignment was defined by a collaboration project between NVE and the Wasserwirtschaftsamt Kempten in Germany, aimed at comparing the precipitation-runoff models used at these institutions. A secondary part of the report describes flood frequency analyses for Norwegian discharge series, to determine warning levels.

The traineeship was supervised by Hege Hisdal, Elin Langsholt and Stein Beldring.

Keywords: Hydrological models, HBV-model, calibration, frequency analyzes

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1. Introduction

This report summarizes the assignments from my practical training at NVE (Norwegian Water Resources and Energy Directorate) in Oslo in the period 10 January – 11 April 2005. The traineeship is part of my studies at University of Freiburg as a 3 month practical training is required due to the examination regulations. The practical traineeship was supported by the European Leonardo da Vinci programme. My supervisors at NVE were Hege Hisdal, Elin Langsholt and Stein Beldring.

Most of the time during the traineeship was spent on a project between NVE and the Wasserwirtschaftsamt Kempten (WWA Kempten) in Germany to compare the Precipitation-Runoff-models (PR-models) used at these institutions (HBV model [1] at NVE and Fgmod at WWA Kempten). Chapter 2 describes the work on that project.

Operationally the HBV model at NVE is used for stream flow and especially flood forecasts. The required input data for the model are:

1. Temperature and precipitation observations (to update the model) and observed runoff to correct the simulated runoff.
2. Temperature and precipitation forecasts.

The meteorological data are provided by the Norwegian Meteorological Institute. The warning levels for floods are related to the recurrence interval of the predicted stream flow as follows:

- Flood, the flow in one or more rivers is expected to exceed a recurrence interval of 5 years;
- Major flood, the flow in one or more rivers is expected to exceed the 50-year flood.

During the traineeship I did flood frequency analyzes for several Norwegian discharge time series to get the required warning levels (Chapter 3).

In addition I spent 3 days on field work including measurements of discharge and sediment transport as well as GPR measurements of sediment cores.

In the last chapter (Chapter 4) some final comments are given.

2. Comparison of the Precipitation-Runoff-models HBV and Fgmod

2.1 Organisation of work

The aim of the project between NVE and WWA Kempten is to compare the performance of the HBV model [1] (used at NVE) with Fgmod (used at WWA Kempten). Therefore both models were calibrated for the same catchments and the model performance compared with respect to floods (peak magnitude, peak timing) and low flow cases. Criteria for the model performance are Nash-Sutcliff-efficiency criterion (1970):

$$E = 1 - \frac{\sum (Qobs - Qsim)^2}{\sum (Qobs - \overline{Qobs})^2},$$

Bias, which is the sum of differences between simulated and observed runoff divided by the total runoff, and visual fit between observed and simulated runoff. To see how the models perform for catchments in Norway as well as in Germany, originally two Norwegian and two German catchments were selected. The catchments in each country have different topographic characteristics (lowlands, mountains) to see how the models manage different landscapes.

Table 1 Test catchments for model comparison.

No.	Country	Name	Size	Character
N-1	Norway	Bulken	1102	Western Norway, Forest and alpine mountain (47 – 1587 m above sealevel)
N-2	Norway	Knappom	1625	Eastern Norway, Wetlands and forest (180 – 780 m above sealevel)
N-3	Norway	Engeren	400	Eastern Norway, Wetlands, forest and mountain (472 – 1139 m above sealevel)
G-1	Germany	Kempten	954	Iller, alpine (656 – 2600 m above sealevel)
G-2	Germany	Wiblingen	2040	Iller, lowland (468 – 2600 m above sealevel)

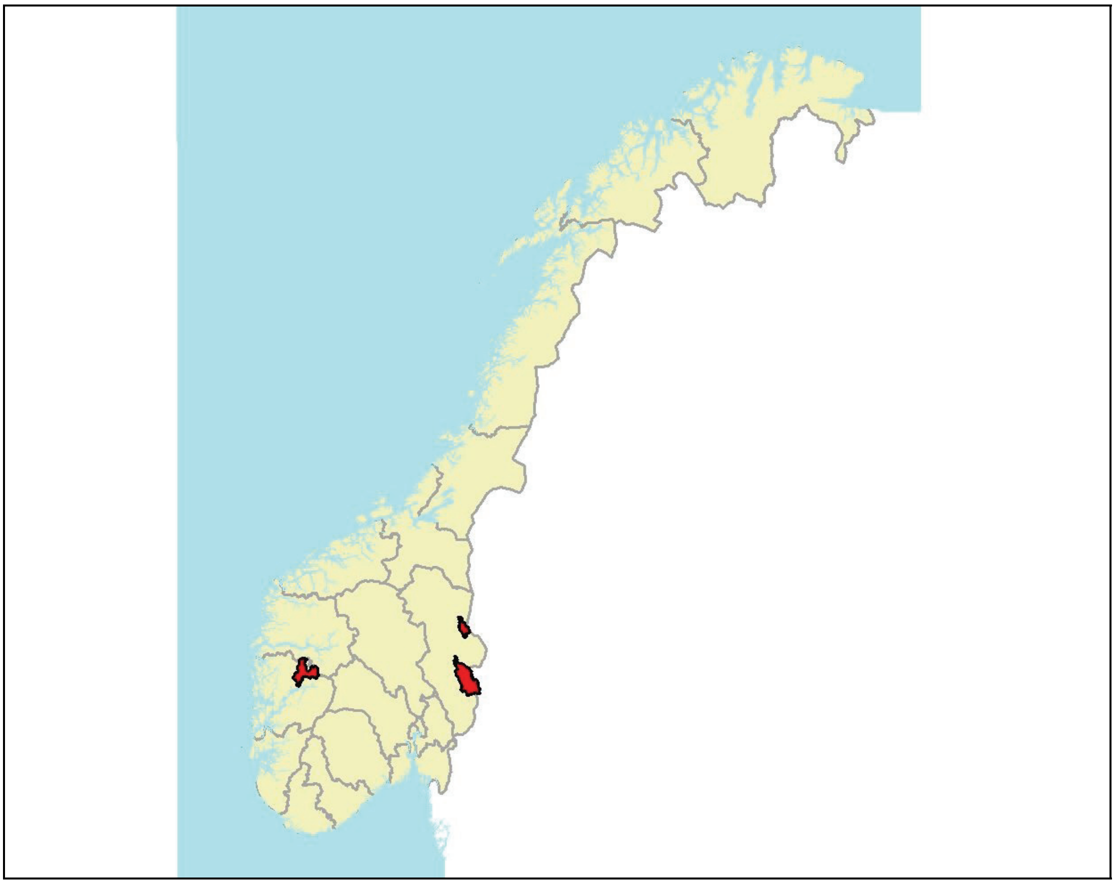

Figure 1 The map shows Norway with national and county borders. The test catchments are illustrated as red areas.

Figure 2 The map shows the location of the German gauging stations as red dots.

During the work on Knappom, one of the Norwegian stations, problems with the meteorological data were found (see 2.2.4). Therefore it was decided to use another Norwegian catchment and Engeren was selected. The comparison is done on Bulken and Engeren (Norway), and Kempten and Wiblingen (Germany). The test catchments are listed in table1. Figure 1 shows the location of the Norwegian catchments and Figure 2 shows the location of the German gauging stations.

To avoid the problems of different meteorological forecasts in Norway and Germany and as it is not the aim to assess the quality of meteorological forecasts but the quality of the PR-models, only historical data are used. For model calibration and validation data from about 20 years are used. This time period is split into one period (10 years) for calibration of the model, i.e. finding the parameter set that gives best result, and one period for validation (where the model is tested for an independent time period that not was used for calibration). Calibration of the HBV model is done with PEST [2], a commercial parameter estimation routine. PEST searches for the best parameter set for the model using the least squared error between observed and simulated values as criteria. As PEST doesn't find global but local minima of the least squared error, it is recommended to run PEST with several different sets of starting values for the parameters to end up in different minima, so one can choose the best parameter set.

For data storage and exchange a WebStorage is provided by the WWA Kempten.

2.2 Calibration and validation, HBV, for the Norwegian catchments

2.2.1 Structural data of the Norwegian catchments

The required structural data for the HBV model are area, hypsographic curve, area in each elevation zone (for the model the whole area of the catchment is divided into 10 elevation zones), lake and glacier area in each elevation zone, as well as vegetation type in each elevation zone. The structural data at NVE is available in 5 gridded geographical data sets with spatial resolution 1 km^2: elevation, potential tree line elevation, percent of grid cell covered by lakes, percent of grid cell covered by glaciers and percent of grid cell covered by forest.

The required hydroclimatological data are temperature (ºC), precipitation (mm) and observed discharge (m^3/s). For the temperature and precipitation stations the elevation above sea level is required. September was chosen as the starting date both for the calibration and validation, because the snow reservoirs are assumed to be empty at that time. The HBV model is a continuous model which operates with different storages (e.g. soil moisture, linear storages) that have certain states for each time step. As it is difficult to estimate good starting values for these storages the model needs some time to stabilize before good simulation results are achieved. Therefore the model was not updated with observed runoff data from September till December the first year in calibration. As a result the starting phase was not used for the error function calculation.

The parameters used by the HBV model are provided by two parameter files. The main parameters, which are most sensitive for the calibration process, are located in the *param.dat* file, whereas the parameters in the *vegtype.dat* file, which describe the vegetation types in the elevation zones, are not so sensitive for calibration [1]. For each catchment the parameter files are enclosed in Appendix A or B.

2.2.2 Bulken

The catchment above the gauging station Bulken is located in Western Norway and is characterized by forest and alpine mountains. The catchment area is 1102 km^2; the highest point is 1587 m and the lowest point (gauging station) 47 m amsl (above mean sea level).

Input data

The temperature and precipitation data used for the calibration are provided by the two synoptic stations Voss-Bø (125 m) and Reimegrend (590 m). Both stations are located in the catchment and give both temperature and precipitation. The total time period for calibration and validation is 1 September 1980 till 31 December 2004 (calibration period 1 September 1980 – 31 May 1990, validation period 1 January 1991 – 31 December 2004).

Construction work at the outlet of Lake Vangsvatnet where the gauging station Bulken is located started in June 1990. A new rating curve was established from 1 January 1991. Because of this there was discontinuity in the runoff data from June to December 1990. Therefore the end of the calibration period was chosen to be 31 May 1990. To have some time to stabilize the model, the validation period started at 1 September 1990, but the error functions where calculated from 1 January 1991.

The HBV model can not handle a change of meteorological stations during the model run. Therefore when one station is replaced by another, the data from the new station has to be adjusted to the data from the old station. This is done by adding the difference between monthly averages.

In the calibration period the station Reimegrend had missing temperature and precipitation data from October 1989 - May 1990. For this period, data from Voss-Bø were used to fill the gap. The data were corrected by applying the difference of the monthly averages between the two stations, calculated for the normal period 1961-1990.

Both meteorological stations were disused in the validation period, Reimegrend only has data until 31 October 1998 and Voss-Bø until 31 Mars 2003. Instead, to new stations were established in the catchment: Mjølfjell (695 m) with data from 1 June 1999 and Vossevangen (54 m) with data from 1 February 2004.

After Reimegrend was disused data from Voss-Bø was used instead from November 1998 - May 1999. The data has been corrected by the differences of the monthly averages. In the period from June 1999 - December 2004 corrected data from Mjølfjell were used for Reimegrend.

From April 2003 - January 2004 only data from Mjølfjell were available and for this period only one temperature and precipitation input series were used. During this period there were also gaps in the data, lasting from 2 to 15 days. To fill these gaps, precipitation data were used from station Jordalen and temperature data were used from station Modalen II (October -December 2003) and station Eidfjord (January 2004).

After Voss-Bø was disused adjusted data from Vossevangen were used for Voss-Bø from February 2004 - December 2004. As Vossevangen was in operation only for some months, no long time monthly averages were available for the time series and the adjustment to Reimegrend was done using altitude gradients (-0,6ºC/100 m for temperature and 3%/100 m for precipitation).

Model calibration and validation

The calibration of the HBV model for Bulken was done for the period 1 September 1980 – 31 May 1990. The parameter set received from PEST was tested for the independent validation period 1 January 1991 – 31 December 2004.

For Bulken 14 different start parameter sets were tested for calibration. Table 2 shows the error functions both for the calibration and validation period for the best parameter set found. The *param.dat* file and *vegtype.dat* file for Bulken are enclosed in Appendix A.

Table 2 Error functions for best parameter set for Bulken.

Calibration Period		Validation Period	
Error functions:		Error functions:	
rel.dif**2	500.09	rel.dif**2	840.73
difference	-12.28	difference	2052.38
F2-value	17902.30	F2-value	25701.98
R2-value	0.86	R2-value	0.84
R2-log	0.88	R2-log	0.84
Bias	-0.00	Bias	0.07

Both the good results according to the error functions (R2-value, i.e. Nash-Sutcliff coefficient and Bias) and the visual inspection of the graph, where observed and simulated runoff are plotted against time (Figure 3), indicate a very good model performance.

The discharge at Bulken is characterized by strong fluctuations through the whole year. It is affected a by spring flood due to snow melt in addition to strong rain events during the whole summer and autumn. In the wintertime low flow situations are dominating.

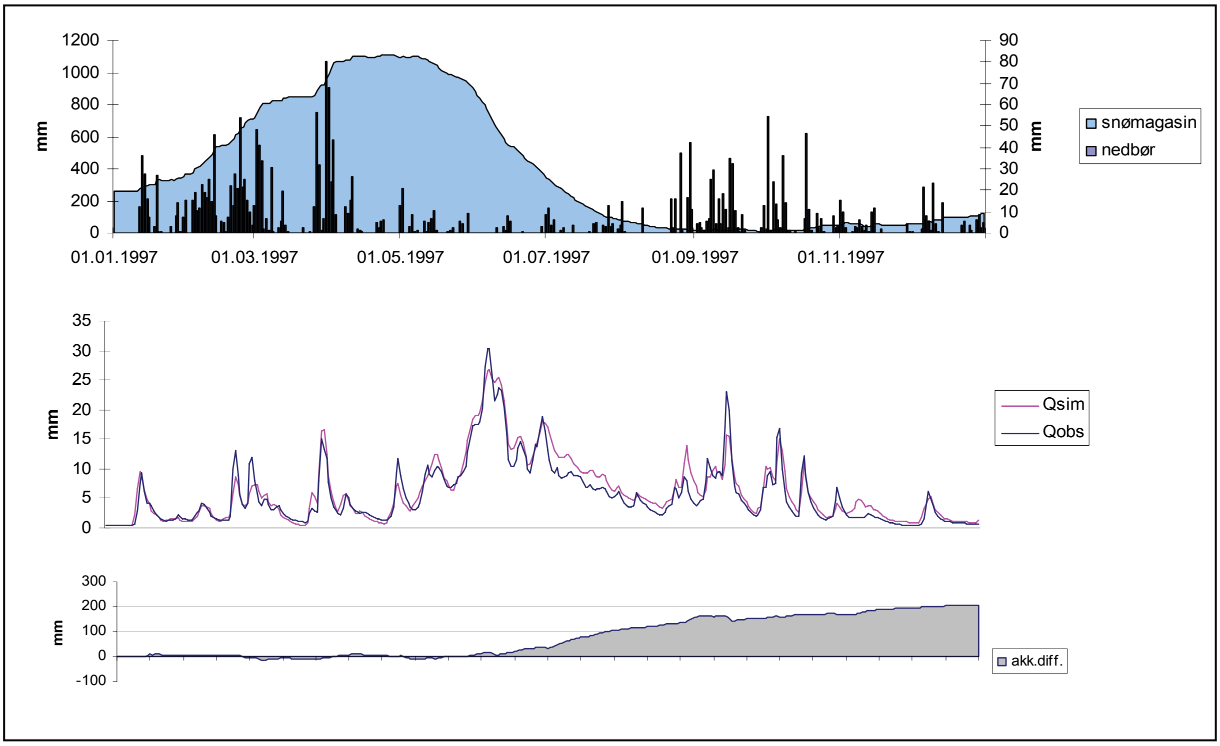

Figure 3 Simulated and observed runoff at discharge gauge Bulken for the year 1997.

The model shows a good dynamic by following the fluctuations and the different flow situations very well. The flood peaks are simulated very well with respect to timing and magnitude, although in some cases the maximum values are underestimated a little. Both in flood and low flow situations the simulated values are close to the observed ones.

As expected, the model performance slightly decreases in the validation period and the error functions do not give quite as good results as for the calibration period, but the difference is not very large and the model shows a good performance also in this period. Figure 3 gives an example of a good fit between observed and simulated runoff during one year (1997, validation period).

Also at times when the synoptic stations have changed or data from other stations are adapted the model is able to simulate the discharge very well. This is also valid for periods were the model only runs with one temperature and precipitation series. The HBV model seems to be robust for small changes in meteorological data.

For future operational flood forecasting, the old synoptic stations will be replaced by the new ones, Voss-Bø by Vossevangen and Reimegrend by Mjølfjell. This will be done by changing the elevation of the synoptic stations in the parameter file of the model.

2.2.3 Knappom

The catchment above the gauging station Knappom is located in Eastern Norway and is characterized by wetlands and forest. The catchment area is 1625 km²; the highest point is 780 m and the lowest point (gauging station) 180 m amsl.

Input data

For the calibration of Knappom the two synoptic stations Flisa (184 m) and Rena-Haugedalen (240 m) were used. Station Flisa is located near the gauging station Knappom and Rena outside the catchment borders a little north of the catchment. Originally the calibration period was chosen from 1 September 1980 – 31 August 1990 and the validation period from 1 January 1991 – 31 December 2004.

In the calibration period the temperature series of Flisa had missing values for the whole of August 1987 and May 1989. The gaps were not filled as Rena had data for these periods.

During the validation period the station Flisa was replaced by a new station, Flisa II (185 m), nearby the old station. The series of Flisa lasts until 31 December 1998 and the series of Flisa II starts at 22 November 2003. The gap of almost 5 years was filled in using temperature data from Rena and precipitation data from Vermundsjøen. During the period where temperature data only was provided by Rena this series also had missing values (2 September – 9 September 2000, 26 October – 2 November 2001, 8 October – 15 October 2003). These gaps, lasting about one week each, were filled in with temperature data from the station Evenstad.

Model calibration and validation

Similar to Engeren the runoff at Knappom is characterized by a maximum snowmelt season in April/May and low flow in the winter. During the summer and especially the autumn the runoff is often affected by strong rainfall events resulting in additional discharge peaks. The rainfall in the summer and the autumn has large interannual variability. The runoff peaks as a result of heavy rainfall can reach the level of the spring flood.

By calibrating the model for the period 1 September 1980 – 31 August 1990 the best parameter set for Knappom resulted in R2-values of 0.82, but by testing the model for the independent validation period, the model performance strongly decreased (R2-value: 0.73). Changing the calibration and validation period did not improve the result (new validation period: 1 September 1980 – 31 August 1990). One reason for the relatively large difference between the R2-values for the calibration and validation period could be climatic change. Warmer winters in the nineties resulted in reduced snow storage. By calibrating the model for certain basic characteristics in the discharge, the model performance will decrease in the validation period if these conditions have changed. Therefore it was decided to calibrate the model for a period that includes climate characteristics of the eighties and the nineties to adjust the model to both climatic situations. The new calibration period was chosen from 1 January 1982 – 31 December 1992. The validation period was also split into two parts in order to catch both climatic situations. The first part was from 1 January 1977 – 31 December 1981 and the second part from 1 January 1993 – 31 December 1998. The end of the validation period was chosen to be December 1998 to avoid inhomogeneity in the meteorological time series due to changes in the stations.

By this the model performance was slightly improved (Table 3). The *param.dat* file and *vegtype.dat* file for Knappom are enclosed in Appendix A.

Table 3 Error functions for best parameter set for Knappom.

Calibration Period		Validation Period	
Error functions:		Error functions:	
rel.dif**2	1121.17	rel.dif**2	1264.76
difference	-1.10	difference	221.78
F2-value	1984.28	F2-value	2898.39
R2-value	0.84	R2-value	0.74
R2-log	0.68	R2-log	0.67
Bias	-0.00	Bias	0.02

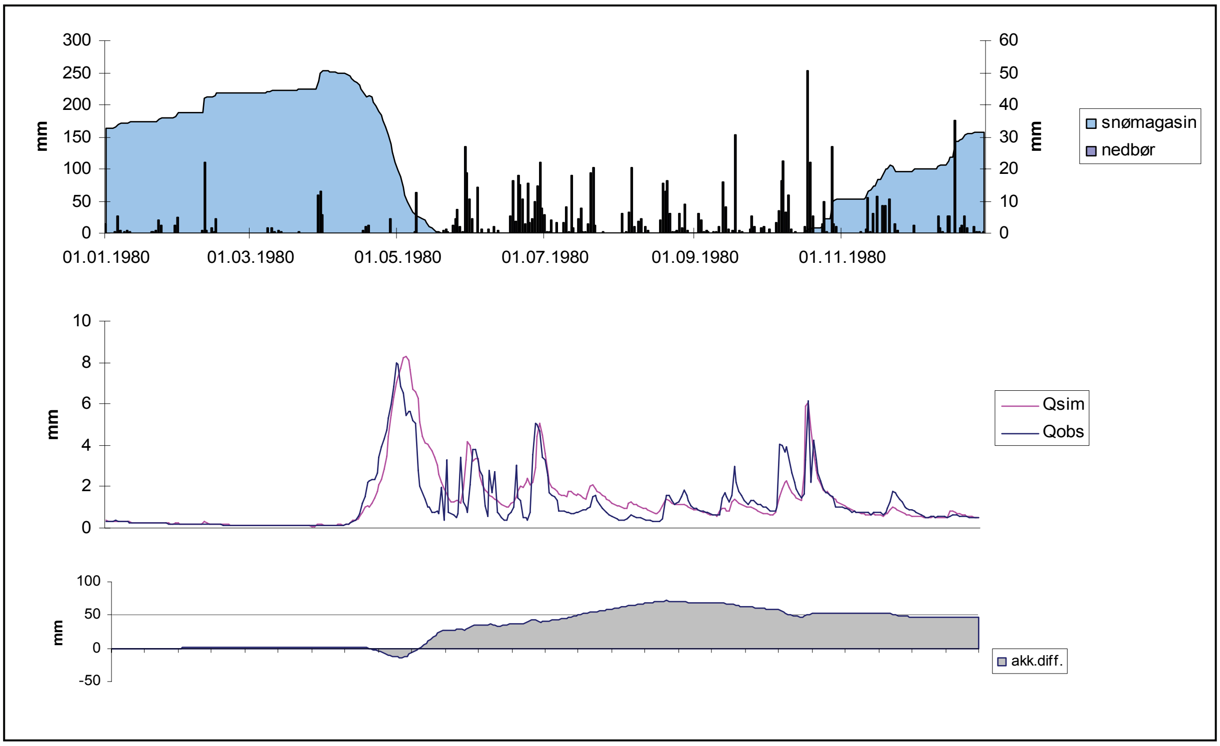

Figure 4 Simulated and observed runoff at discharge gauge Knappom for the year 1980.

Especially in the validation period the model often smoothed the runoff when there were stronger fluctuations in the observed runoff. In addition the runoff in the summertime was often overestimated at low flow situations and in several cases the model was not able to reproduce runoff peaks due to rainfall, especially in the autumn. Figure 4 shows a typical simulation result for a year in validation period (1980).

Another problem was that the historical runoff data are not very reliable. A possible source for error is inhomogeneity due to ice reduction. The runoff data also seem to have a trend which is not reflected in the meteorological data. As it would be out of the scope for this traineeship to go carry out quality control tests it was decided to calibrate another catchment with more reliable runoff data. Engeren was chosen as a replacement for Knappom for model comparison.

2.2.4 Engeren

The catchment above the gauging station Engeren is located in Eastern Norway and is characterized by wetlands, forest and mountain. The catchment area is 400 km²; the highest point is 1139 m amsl and the lowest point (gauging station) 472 m amsl.

Input data

The input data for the model is supplied by the synoptic station Drevsjø (672 m), near the northern border of the catchment which provides temperature and precipitation data and by the two precipitation gauges Heggeriset-Nordstrand (481 m) and Gløtvola (696 m) both located within the catchment.

The model was calibrated for the period 1 September 1980 – 31 August 1990 and validated for the period 1 January 1991 – 31 August 2004. There are some missing data in the observed temperature and precipitation series of Drevsjø. The gaps in the temperature series were filled in with data from the station Rena (August 1987 – August 2002) and Trysil (from December 2002).

The discharge series from the gauge Engeren has missing data from 13 Mars – 22 July 1996. This period was not used for the error function calculation.

Model calibration and validation

For calibration of Engeren 17 different start parameter sets where used. Interestingly, the best parameter set received by PEST was for a parameter file where the lake area was equally distributed in all elevation zones and only one vegetation type per elevation zone was used. For a parameter file where the lake area was distributed in the elevation zones according to observations and two vegetation types per elevation zone were used, the result was not quite as good.

Table 4 shows the error functions for the best parameter set (same lake area in all elevation zones). The *param.dat* file and *vegtype.dat* file for Engeren are enclosed in Appendix A. Table 5 shows the results from the other parameter set (distribution of lake area according to reality). For the model comparison the parameter set with equally distributed lake area was chosen, because the best result from the model should be used.

Table 4 Error functions for best parameter set for Engeren (lake area equally distributed in all elevation zones).

Calibration Period	Validation Period
Error functions:	Error functions:
rel.dif**2 307.67 difference 0.33 F2-value 1635.01 R2-value 0.90 R2-log 0.88 Bias 0.00	rel.dif**2 466.77 difference -837.00 F2-value 3586.77 R2-value 0.84 R2-log 0.86 Bias -0.10

Table 5 Error functions for a parameter set for Engeren where the lake area is distributed in the elevation zones according to observations.

Calibration Period		Validation Period	
Error functions:		Error functions:	
rel.dif**2	261.45	rel.dif**2	432.02
difference	-1.23	difference	-819.65
F2-value	1759.01	F2-value	3705.56
R2-value	0.89	R2-value	0.83
R2-log	0.90	R2-log	0.87
Bias	-0.00	Bias	-0.10

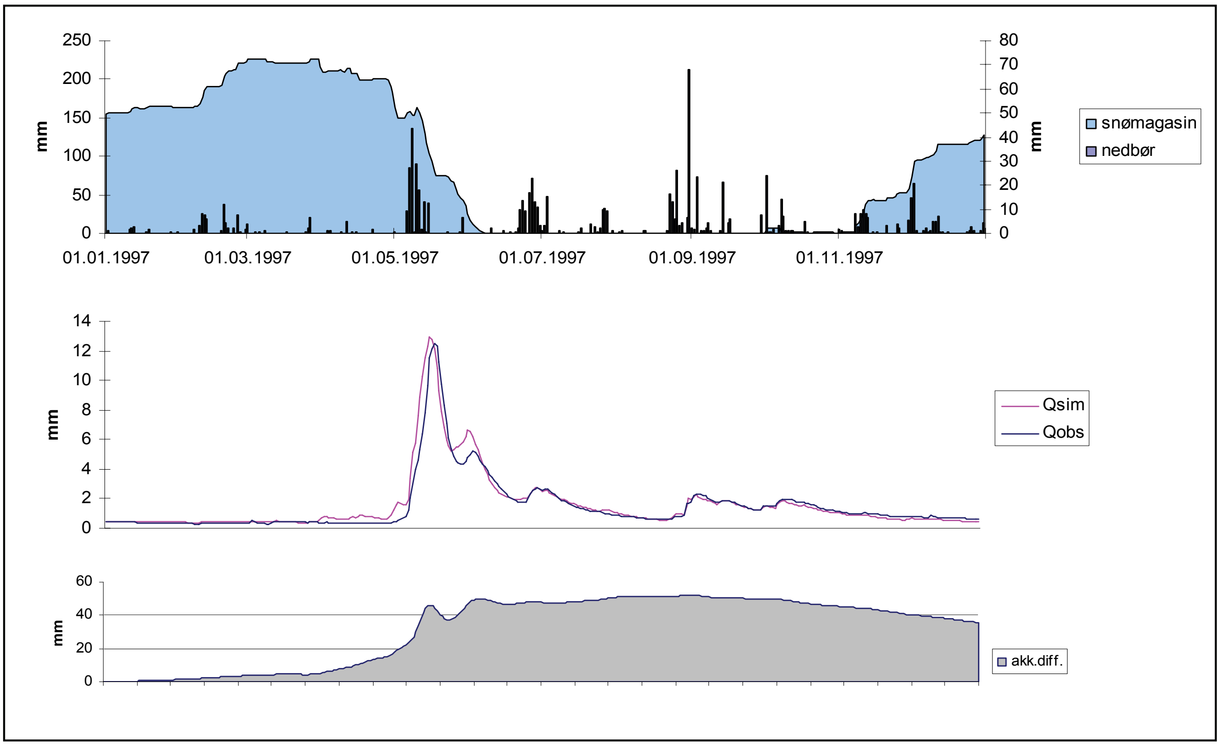

Figure 5 Simulated and observed runoff at discharge gauge Engeren for the year 1997.

Both the error functions and the visual inspection of the plotted runoff values indicate a very good model performance, with a very high Nash-Sutcliff coefficient of 0.90.

The annual runoff pattern at Engeren is characterized by a high maximum in May/June due to snowmelt and often some higher runoff values during the autumn because of heavier rainfall. During the rest of the year the runoff is very constant at a small level. Figure 5 gives a typical example for the runoff during one year (1997, validation period).

The plot shows a very good fit between observed and simulated runoff both in flood and low flow situations. The very good result of the model calibration may be due to the small annual fluctuations in runoff. In general the discharge is quite smooth and the model doesn't have problems in following it. The flood peaks (mainly the spring flood due to snowmelt) could be simulated very well with respect to timing and magnitude, although in some cases the maximum values are underestimated by about 25 %.

Again, in the validation period the model performance decreased a little compared to the calibration period, but also for this period the results are good.

2.3 Calibration and validation, HBV, for the German catchments

2.3.1 Structural data of the German catchments

The required structural data (area, hypsographic curve and area, lake, glacier area and vegetation type in each elevation zone) for the German catchments was obtained from a digital elevation model and from the CORINE Land Cover 2000 project, which provides data for the land cover of Germany in a raster with different spatial resolutions (here a resolution of 1 km² was used).

The catchment of the gauging station Kempten is a part of the catchment of the gauging station Wiblingen, but for the model run the catchments are treated individually with gauging stations at Kempten and Wiblingen, respectively. For the calibration of Wiblingen no additional runoff data from Kempten is used.

The areas of the catchments found by the 1 km² raster and a shape file containing the borders of the catchments differ from the official numbers. For Wiblingen an area of 2154 km² was found, which is more than 5 percent larger than the official 2040 km². The overestimation may be due to the shape file containing the border of the catchement. In this file the catchment includes the area until the inflow of the Iller into the Donau, whereas in reality the gauging station Wiblingen is located a little upstream. But as the German model Fgmod applied by WWA Kempten also uses an area which is overestimated by about 5 percent (2163 km²), the 2154 km² were used in the HBV model. For Kempten the error in the estimated area is lower. The value found, 948 km², differs less than 1 percent from the official value of 954 km² and was therefore kept for the model calculations. The value used for Fgmod by WWA Kempten equals 958 km².

2.3.2 Kempten

The catchment above the gauging station Kempten is located in South-Germany at the Austrian border (a small part of the catchment belongs to Austria) and has an alpine character. The highest point is 2639 m and the lowest point 658 m amsl.

Input data

The input data for the model is supplied by 5 meteorological stations which provide both temperature and precipitation series: Kempten (Wst, 705 m), Isny (712 m), Oberstaufen-Kalzhofen (800 m), Hindelang-Unterj. (Akkst, 1053 m) and Oberstdorf (Wst, 806 m).

The calibration period is from 1 September 1980 to 31 August 1990 and the validation period from 1 September 1990 to 30 April 2004. Two of the meteorological stations did not have data for the whole period. For these series the gaps were not filled in as there were always other stations which had data for the period. The gaps in the temperature series always coincided with the gaps in the precipitation series, and vice versa. The series with gaps are Oberstaufen (Sept. 1980 – Sept. 1983 and Oct. 2001 – April 2004) and Hindelang (November 1999 – April 2004).

Model calibration and validation

The runoff at the gauging station Kempten is characterized by large fluctuations during the whole year and there is no typical time for the maximum annual discharge. In general there are high peaks in the spring, often provoked by a mixture of snow melt and rainfall and high peaks in the summer, autumn and winter, due to rainfall. If there is heavy rainfall, the annual maximum value can even occur during wintertime. During the autumn and winter the flow is at the lowest level.

For the calibration of Kempten, 15 different start parameter sets were used and the results for the best parameter set are shown in table 6. The *param.dat* file and *vegtype.dat* file for Kempten are enclosed in Appendix B.

Table 6 Error functions for best parameter set for Kempten.

Calibration Period		Validation Period	
Error functions:		Error functions:	
rel.dif**2	236.06	rel.dif**2	339.11
difference	1.60	difference	195.85
F2-value	4773.74	F2-value	8788.77
R2-value	0.89	R2-value	0.88
R2-log	0.87	R2-log	0.85
Bias	0.00	Bias	0.01

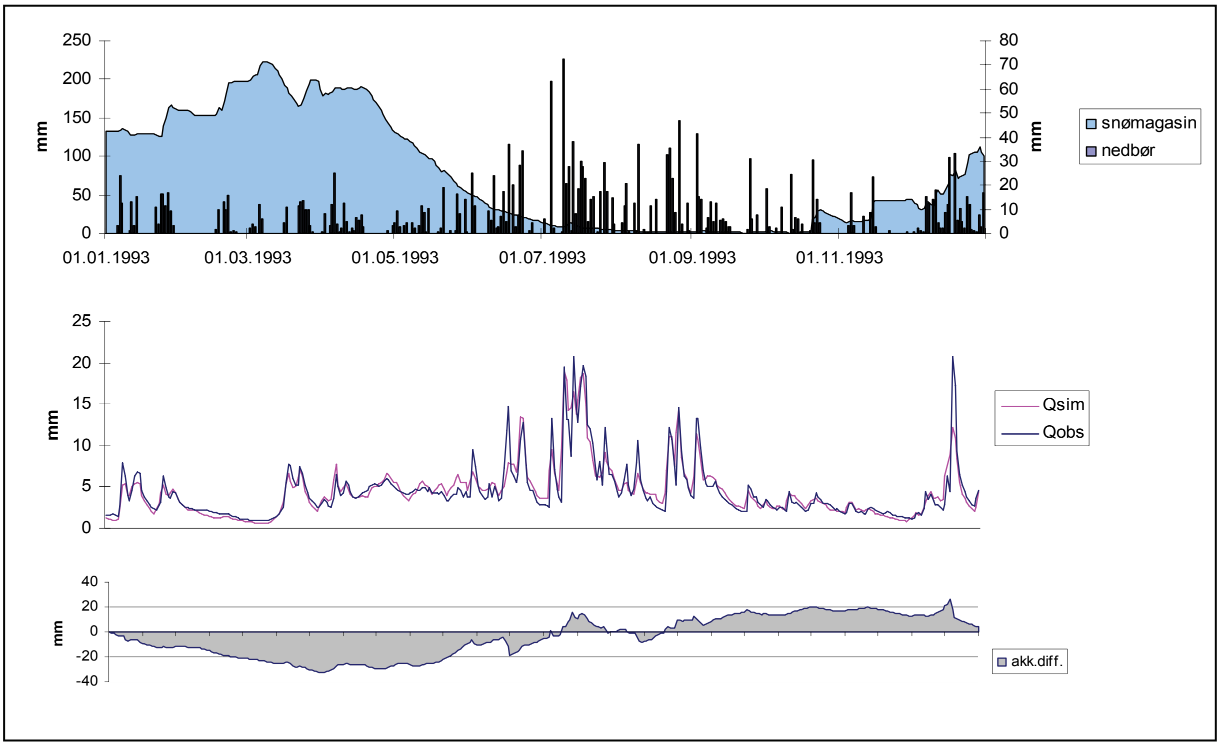

Figure 6 Simulated and observed runoff at discharge gauge Kempten for the year 1993.

Both the statistical error functions and the visual inspection of the plotted observed and simulated runoff indicate a very good model performance. For the validation period the R2-value only has a minor decrease and stays on a high level of 0.88. Also, the bias increases only from 0 to 1 percent.

Figure 6 gives a good example of the annual fluctuations in runoff (here 1993, validation period). The model shows a good dynamic and follows the often fast changing runoff very well. Both in flood and low flow situations the simulated runoff is very close to the observed. Also, the peaks could be simulated very well with respect to timing and magnitude, only in a very few cases the peak values were a little underestimated.

As there where series from 5 meteorological stations available for the catchment Kempten, the area precipitation and temperature could be estimated very well. The good model performance confirms that it is import to have a good quality in the input data to get good results from the model and that an increased number of meteorological stations can improve the model performance.

2.3.3 Wiblingen

The catchment above the gauging station Wiblingen is located in South-Germany with a small part in Austria. It contains some mountains but mainly is characterized by lowlands with forest and open land. The highest point is 2639 m and the lowest point 469 m amsl.

Input data

The input data for the model are time series from the same 5 meteorological stations used for Kempten and 4 additional stations: Ulm (Awst, 571 m), Aulendorf-Spiegler (560 m), Schemmerhofen-Ingerking (519 m), Memmingen (610 m), Kempten (Wst, 705 m), Isny (712 m), Oberstaufen-Kalzhofen (800 m), Hindelang-Unterj. (Akkst, 1053 m) and Oberstdorf (Wst, 806 m).

The period for the model calibration was chosen to be 1 September 1980 to 31 August 1990 and for the validation from 1 September 1990 to 30 April 2004. Three meteorological stations did not have data for the complete period. For these series the gaps were not filled as there were always other stations which had data for the period. The series with gaps are Schemmerhofen (September 1980 – December 1986), Oberstaufen (Sept. 1980 – Sept. 1983 and Oct. 2001 – April 2004) and Hindelang (November 1999 – April 2004).

Model calibration and validation

The runoff at the gauging station Wiblingen has in general the same pattern as at station Kempten. It is affected by the same processes (high peak in spring due to a mixture of snow melt and rainfall and additional high peaks in the rest of the year as a result of rainfall). To compare the runoff between Kempten and Wiblingen, Figure 7 shows the discharge for the same year (1993, validation period) as it was chosen for Kempten (Figure 6). The main difference in the discharge between these stations is the magnitude. The runoff values at Wiblingen are about half as high as at Kempten, in relation to the catchment area. The fact that the catchment Wiblingen includes the catchment Kempten and the runoff at Wiblingen equals about half the runoff at Kempten (in mm), indicates, that most of the discharge of the Iller at gauge Wiblingen comes from the mountain area located in the catchment Kempten.

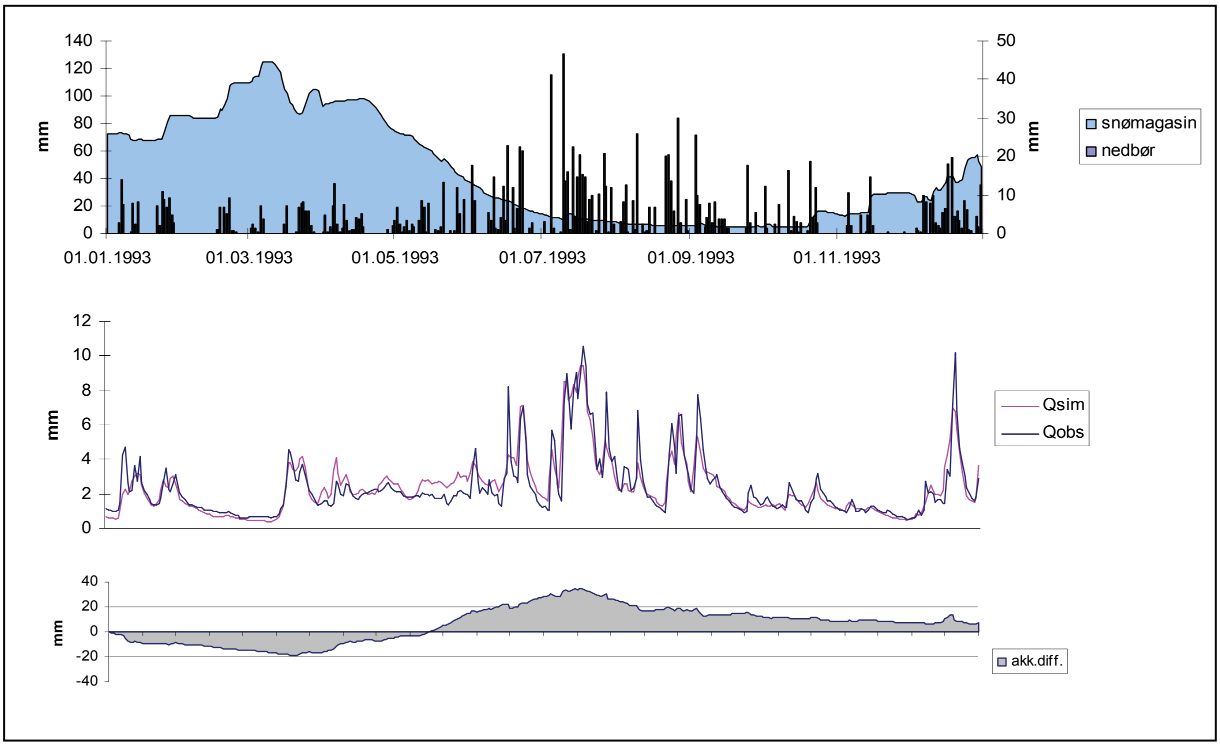

Figure 7 Simulated and observed runoff at discharge gauge Wiblingen for the year 1993.

Table 7 Error functions for best parameter set for Wiblingen.

Calibration Period		Validation Period	
Error functions:		Error functions:	
rel.dif**2	364.68	rel.dif**2	396.43
difference	211.15	difference	598.84
F2-value	1900.63	F2-value	2994.75
R2-value	0.87	R2-value	0.85
R2-log	0.86	R2-log	0.85
Bias	0.03	Bias	0.05

For the calibration of Wiblingen, 25 different start parameter sets were used and the results for the best parameter set are shown in table 7. The *param.dat* file and *vegtype.dat* file for Wiblingen are enclosed in Appendix B.

For Wiblingen the statistical error functions are not quite as good as for Kempten. Especially, the bias shows that the runoff is generally overestimated a little, both for calibration and validation period. But the accumulated difference between simulated and observed runoff does not differ more than 5% from the total observed runoff for both periods, which is a good result. The R2-value for calibration period equals 0.87, which is a very good, and decreases only a little for validation period. This indicates a good model performance.

The visual inspection of the plotted observed and simulated runoff (Fig. 7) confirms the good results of the error functions. In general the simulated runoff is very close to the observed, although in some cases the difference is bigger than for Kempten. The peaks could be simulated very well with respect to timing and magnitude and only in a few cases the peak values were a little underestimated.

3. Flood Frequency Analyzes

During the traineeship I did flood frequency analyzes for 67 stations to get the required warning levels for these stations. Different properties of the historical runoff series had to be calculated: The discharge values for the recurrence interval of 5 and 50 years and the annual mean flood. The latter is defined as the average of the annual daily peak stream flows, as well as the corresponding water levels.

The first step was to control the historical runoff series for gaps. It is important to look at the plotted runoff values around the gaps because if the annual peak value seems to be within the missing values, this year can't be used in the calculations. After this, the mean annual flood could be calculated. The next step was to find an appropriate distribution function for the annual maxima (positively skewed). The plotting positions of the observed values were calculated using the Gringorton (1963) plotting formula:

$$P(x) = \frac{i - 0.44}{n + 0.12}.$$

The plotting positions correspond to the recurrence frequencies. The return frequencies of the observed values were plotted together with different distribution functions (see example Fig. 7). Then it was decided which distribution function that fitted the observed data best. In most cases the General Extreme Value (GEV), the Gamma 3 (GAM3) and the Log-normal 3 (LN3) distributions were found to give the best fit.

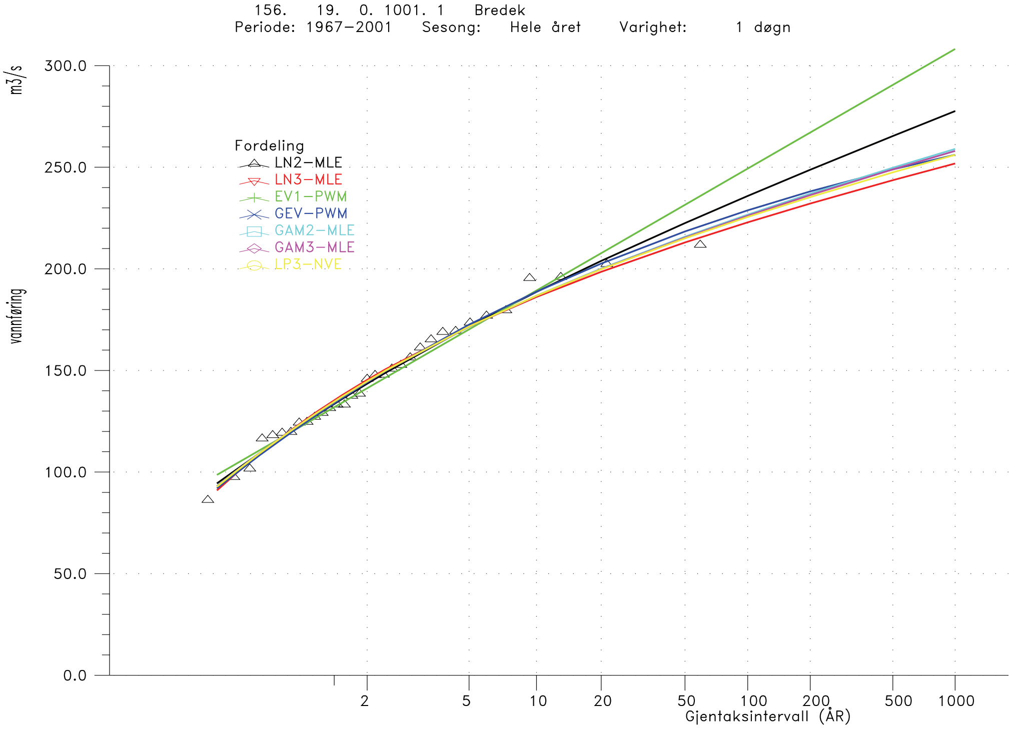

Figure 7 Plotting positions of observed annual peak flows together with several distribution functions for the runoff series at station Bredek.

The runoff values with return periods of 5 and 50 years were calculated using this function. Figure 7 shows the plot of the runoff series at station Bredek. Here the Log-normal 3 was selected as the best fitt distribution. The warning levels are as follows: 172 m³/s for a 5-year return period and 213 m³/s for a 50-year return period. The mean annual flood is 147 m³/s.

The corresponding water levels were obtained from the rating curve (Figure 8), which gives the relation between water level and discharge. Table 8 shows the water levels and runoff values for series Bredek.

Table 8 Water levels and runoff values for the annual mean flood and return periods of 5 and 50 years for the runoff series Bredek.

return period	mean flood	5 years	50 years
water level (m)	2.42	2.55	2.73
runoff (m³/s)	147	172	213

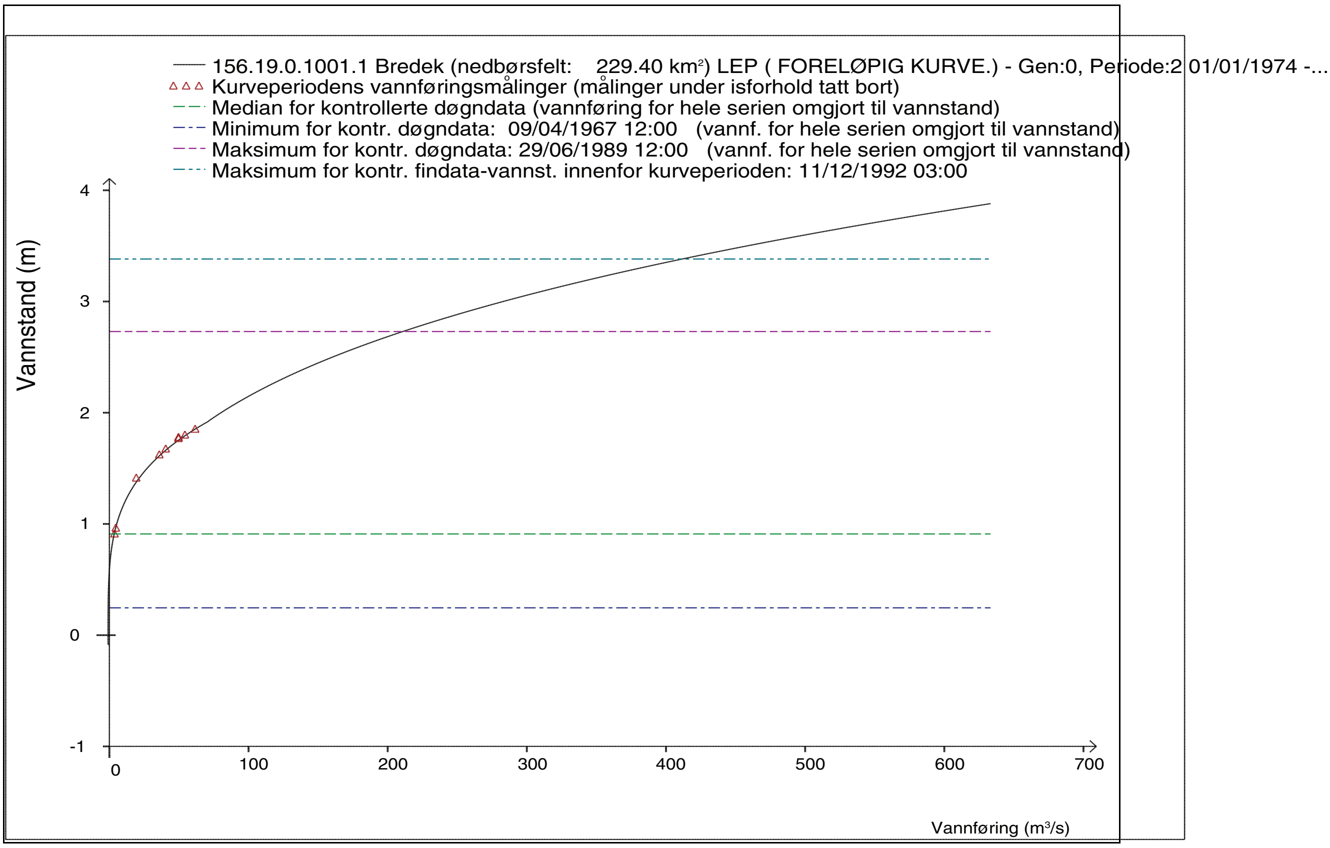

Figure 8 The rating curve gives the water level - runoff relation for station Bredek.

For the flood frequency analyzes all available years of data were used for catchments without any regulations. In case of regulations in the catchment, the time period used for the calculations started after the last change in the regulations.

To avoid too high uncertainty only time series with a length of at least 25 years were used to calculate the runoff value with a recurrence interval of 50 years. For a return period of 5 years only series with at least 10 years were used. Of the 67 time series, frequency analyzes to find the 5 and 50 year return period was only possible for 37 series.

Seven series had data for at least 10 years and the 5 year return period could be calculated. Nine series had data between 5 and 10 years which is too few for frequency analyzes, but the mean annual flood was calculated.

The last 18 series could not be used for any calculations, because at some stations only water levels were observed and no rating curve existed or there were too few or no data available at all.

All calculations were done with NVE software. Printouts of the results of the frequency analyzes and rating curves were collected in folders for use at the flood forecasting central office at NVE.

4. Final Comments

For the calibration of the catchments, PEST has shown to be a very good routine. The parameter values found by PEST gave generally very good model results. But as mentioned before, it was necessary to run PEST with several different initial parameter sets, as the error minimum found by it was a local one and the result from only one run can be very bad. By running PEST with 10 different start parameter sets, usually about three good parameter sets were obtained. For Bulken, I tried to improve the results from PEST by adjusting some parameters manually. I succeeded to improve the model performance with respect to the R2-value (increase of 0.01), but at the same time the model performance decreased with respect to the bias. Therefore it was decided to keep the results from PEST as the best found parameter set.

In the beginning, only parameters from the *param.dat* file were used for the calibration. From this file 15 parameters in addition to the weights of the temperature and precipitation series were calibrated. But it has shown that the results could be improved, when also parameters from the *vegtype.dat* file were used in the calibration process. Therefore, from this file up to 25 parameters were calibrated for each catchment.

References

[1] HBV-modell

Sælthun, N.R. 1996. The Nordic HBV model. *Norwegian Water Resources and Energy Administration Publication 7*, Oslo, 26 pp.

[2] PEST

Doherty, J., Brebber, L. and Whyte, P. 1998. *PEST. Model independent parameter estimation*. Watermark Computing, 185 pp.

Appendix A

param.dat file and *vegtype.dat* file for Bulken

param.dat file:

```
START  1bulken
  2    0            2    PNO       Number of precipitation stations
  2    0  Voss           PID1      Identification for precip station 1
  2    0        125.     PHOH1     Altitude precip station 1
  2    0 .54170960000    PWGT1     Weight precipitation station 1
  2    0  Reimegrend     PID2
  2    0        590.     PHOH2
  2    0 .43273210000    PWGT2
  2    0            2    TNO       Number of temperature stations
  2    0  Voss           TID1      Identification for temp station 1
  2    0        125.     THOH1     Altitude temp station 1
  2    0 .33767540000    TWGT1     Weight temp station 1
  2    0  Reimegrend     TID2      Identification for temp station 2
  2    0        590.     THOH2     Altitude temp station 2
  2    0 .72483120000    TWGT2     Weight temp station 2
  2    0            1    QNO       Number of discharge stations
  2    0  Bulken         QID       Identification for discharge station
  2    0           1.    QWGT      Scaling factor for discharge
  2    0     1102        AREAL     Catchment area                       [km2]
  2    4        0.000    MAGDEL    Regulation reservoirs                [1]
  2    5       47.000    HYPSO ( 1,1), low point             [m]
  2    6      320.000    HYPSO ( 2,1)
  2    7      520.000    HYPSO ( 3,1)
  2    8      655.000    HYPSO ( 4,1)
  2    9      770.000    HYPSO ( 5,1)
  2   10      860.000    HYPSO ( 6,1)
  2   11      973.000    HYPSO ( 7,1)
  2   12     1060.000    HYPSO ( 8,1)
  2   13     1150.000    HYPSO ( 9,1)
  2   14     1245.000    HYPSO (10,1)
  2   15     1587.000    HYPSO (11,1), high point
  2   16        0.000    HYPSO ( 1,2), Part of total area below HYPSO (1,1) = 0
  2   17        0.100    HYPSO ( 2,2)
  2   18        0.200    HYPSO ( 3,2)
  2   19        0.300    HYPSO ( 4,2)
  2   20        0.400    HYPSO ( 5,2)
  2   21        0.500    HYPSO ( 6,2)
  2   22        0.600    HYPSO ( 7,2)
  2   23        0.700    HYPSO ( 8,2)
  2   24        0.800    HYPSO ( 9,2)
  2   25        0.900    HYPSO (10,2)
  2   26        1.000    HYPSO (11,2), Part of total area below HYPSO (11,1) = 1
  2   27        0.000    BREPRO( 1), Glacier area, part of total area, below HYPSO( 1,1)
(=0.0)
  2   37        0.000    BREPRO(2), Glacier area, part of total area, below HYPSO(2,1)
  2   37        0.000    BREPRO(3), Glacier area, part of total area, below HYPSO(3,1)
  2   37        0.000    BREPRO(4), Glacier area, part of total area, below HYPSO(4,1)
  2   37        0.000    BREPRO(5), Glacier area, part of total area, below HYPSO(5,1)
  2   37        0.000    BREPRO(6), Glacier area, part of total area, below HYPSO(6,1)
  2   37        0.000    BREPRO(7), Glacier area, part of total area, below HYPSO(7,1)
  2   37        0.000    BREPRO(8), Glacier area, part of total area, below HYPSO(8,1)
  2   37        0.000    BREPRO(9), Glacier area, part of total area, below HYPSO(9,1)
  2   37        0.020    BREPRO(10), Glacier area, part of total area, below HYPSO(10,1)

  2   37        0.030    BREPRO(11), Glacier area, part of total area, below HYPSO(11,1)
  2   38
  2   39      270.000   NDAG      Day no for conversion of glacier snow to ice
  2   40 1.1575440000   TX        Threshold temperature for snow/rain          [C]
  2   41 -.2692383000   TS        Threshold temperature fo no melt            [C]
  2   42 3.9120340000   CX        Melt index                               [mm/deg/day]
  2   43        0.01    CFR       Refreeze efficiency                         [1]
  2   44        0.08    LV        Max rel. water content in snow              [1]
  2   45 1.5373010000   PKORR     Precipitaion correction for rain            [1]
  2   46 1.0638850000   SKORR     Additional precipitation corection for snow at gauge [1]
  2   47                GRADALT   Altitude for change in prec. grad.          [m]
  2   48                PGRAD1    Precipitation gradient above GRADALT        [1]
```

```
2   49        0.02    CALB      Ageing factor for albedo                 [1/day]
2   50        0.33    CRAD      Radiation melt component                     [1]
2   51        0.33    CONV      Convection melt component                    [1]
2   52        0.33    COND      Condensation melt component                  [1]
2   60         1.1    CEVPL     Lake evapotranspiration adjustment fact      [1]
2   61         0.5    ERED      Evapotranspiration red. during interception  [1]
2   62        30.0    ICEDAY    Lake temperature time constant               [d]
2   63 -.8547947000   TTGRAD    Temperature gradient for days without precip [deg/100 m]
2   64 -.6000000000   TVGRAD    Temperature gradient for days with precip    [deg/100 m]
2   65 .00345916280   PGRAD     Precipitation altitude gradient             [1/100 m]
2   66       1.500    CBRE      Melt increase on glacier ice                 [1]
2   67       0.000    EP        EP( 1), Pot evapotranspiration, Jan    [mm/day] or [1]
2   68       0.000    EP        EP( 2), Pot evapotranspiration, Feb    [mm/day] or [1]
2   69       0.000    EP        EP( 3)
2   70       0.000    EP        EP( 4)
2   71       1.800    EP        EP( 5)
2   72       2.200    EP        EP( 6)
2   73       1.700    EP        EP( 7)
2   74       1.500    EP        EP( 8)
2   75       1.100    EP        EP( 9)
2   76       0.000    EP        EP(10)
2   77       0.000    EP        EP(11)
2   78       0.000    EP        EP(12)), Pot evapotranspiration, Dec    [mm/day] or [1]
2   79 178.94270000   FC        Maximum soil water content          [mm]
2   80         0.7    LPDEL     Pot.evapotr when content = FC*FCDEL  [1]
2   81 1.0000000000   BETA      Non-linearity in soil water zone     [1]
2   82         100    INFMAX    Maximum infiltration capacity        [mm/day]

2   85 .34628370000   KUZ2      Quick time constant upper zone       [1/day]
2   86 32.249500000   UZ1       Threshold quick runoff               [mm]
2   87 .17374020000   KUZ1      Slow time constant upper zone        [1/day]
2   88 1.4784350000   PERC      Percolation to lower zone            [mm/day]
2   89 .02725408300   KLZ       Time constant lower zone             [1/day]
2   90        0.00    ROUT      (1), Routing constant (lake area, km2)
2   91        0.00    ROUT      (2), Routing constant (rating curve const)
2   92        0.00    ROUT      (3), Routing constant (rating curve zero)
2   93        0.00    ROUT      (4), Routing constant (rating curve exp)
2   94        0.00    ROUT      (5), Routing constant (drained area ratio)
2   95        0.00    DECAY     (1), Feedback constant
2   96        0.00    DECAY     (2), Feedback constant
2   97        0.00    DECAY     (3), Feedback constant
2   98        0.17    CE        Evapotranspiration constant          [mm/deg/day]
2   99        0.3     DRAW      "draw up" constant                   [mm/day]
2  100       60.4     LAT       Latitude                             [deg]
2  101       -0.6     TGRAD(1)  Temperature gradient Jan             [deg/100m]
2  102       -0.6     TGRAD(2)  Temperature gradient Feb             [deg/100m]
2  103       -0.6     TGRAD(3)  Temperature gradient Mar             [deg/100m]
2  104       -0.6     TGRAD(4)  Temperature gradient Apr             [deg/100m]
2  105       -0.6     TGRAD(5)  Temperature gradient May             [deg/100m]
2  106       -0.6     TGRAD(6)  Temperature gradient Jun             [deg/100m]
2  107       -0.6     TGRAD(7)  Temperature gradient Jul             [deg/100m]
2  108       -0.6     TGRAD(8)  Temperature gradient Aug             [deg/100m]
2  109       -0.6     TGRAD(9)  Temperature gradient Sep             [deg/100m]
2  110       -0.6     TGRAD(10) Temperature gradient Oct             [deg/100m]
2  111       -0.6     TGRAD(11) Temperature gradient Nov             [deg/100m]
2  112       -0.6     TGRAD(12) Temperature gradient Dec             [deg/100m]
2  113        20.0    SPDIST    Uniformly distributed snow acc       [mm]
2  114       110.0    SMINI     Inital soil moisture content         [mm]
2  115       100.0    UZINI     Initial upper zone content           [mm]
2  116       110.0    LZINI     Initial lower zone content           [mm]
2  121          2     VEGT(1,1) Vegetation type 1, zone 1
2  122           1      VEGT(2,1) Vegetation type 2, zone 1
2  123         0.33     VEGA(1)   Vegetation 2 area, zone 1           [1]
2  124         0.110  LAKE(1)    Lake area,         zone 1           [1]
2  125           2      VEGT(1,2) Vegetation type 1, zone 2
2  126           1      VEGT(2,2) Vegetation type 2, zone 2
2  127         0.17      VEGA(2)   Vegetation 2 area, zone 2           [1]
2  128         0.030  LAKE(2)    Lake area,         zone 2           [1]
2  129           2      VEGT(1,3) Vegetation type 1, zone 3
2  130           1      VEGT(2,3) Vegetation type 2, zone 3
2  131         0.20     VEGA(3)   Vegetation 2 area, zone 3           [1]
2  132         0.000  LAKE(3)    Lake area,         zone 3           [1]
2  133           2      VEGT(1,4) Vegetation type 1, zone 4
2  134           1      VEGT(2,4) Vegetation type 2, zone 4
2  135         0.40      VEGA(4)   Vegetation 2 area, zone 4           [1]
2  136         0.010  LAKE(4)    Lake area,         zone 4           [1]
2  137           1      VEGT(1,5) Vegetation type 1, zone 5
```

```
  2  138            2     VEGT(2,5) Vegetation type 2, zone 5
  2  139          0.34     VEGA(5)   Vegetation 2 area, zone 5           [1]
  2  140          0.000  LAKE(5)   Lake area,         zone 5            [1]
  2  141            1     VEGT(1,6) Vegetation type 1, zone 6
  2  142            2     VEGT(2,6) Vegetation type 2, zone 6
  2  143          0.14    VEGA(6)   Vegetation 2 area, zone 6            [1]
  2  144          0.010  LAKE(6)   Lake area,         zone 6            [1]
  2  145            1     VEGT(1,7) Vegetation type 1, zone 7
  2  146            2     VEGT(2,7) Vegetation type 2, zone 7
  2  147          0.020   VEGA(7)   Vegetation 2 area, zone 7            [1]
  2  148          0.010  LAKE(7)   Lake area,         zone 7            [1]
  2  149            1     VEGT(1,8) Vegetation type 1, zone 8
  2  150            0     VEGT(2,8) Vegetation type 2, zone 8
  2  151          0.0     VEGA(8)   Vegetation 2 area, zone 8            [1]
  2  152          0.040  LAKE(8)   Lake area,         zone 8            [1]
  2  153            1     VEGT(1,9) Vegetation type 1, zone 9
  2  154            0     VEGT(2,9) Vegetation type 2, zone 9
  2  155          0.0     VEGA(9)   Vegetation 2 area, zone 9            [1]
  2  156          0.010  LAKE(9)   Lake area,         zone 9            [1]
  2  157            1     VEGT(1,10) Vegetation type 1, zone 10
  2  158            0     VEGT(2,10) Vegetation type 2, zone 10
  2  159          0.0     VEGA(10)   Vegetation 2 area, zone 10          [1]
  2  160          0.030  LAKE(10)   Lake area,         zone 10          [1]
FINIS
```

vegtype.dat file:

```
Type       no   ICMAX   CXREL  TSDIFF  CVSNOW   FCREL   LPDEL   EPVAR
Mountain    1 .10000  1.2129  .75462     0.5  .59459  1.0000      0.5
Forest      2 1.5406  1.1043  -.4065     0.3  1.4922  1.0000      1.0
Shrub       3 1.0000  1.0000  0.0000     0.4  .80000  .70000      0.8
Rock        4 .05000  1.0000  0.0000     0.5  .20000  1.0000      0.1
Meadows     5 .10000  1.0000  0.0000     0.3  .50000  .80000      1.0
```

***param.dat* file and *vegtype.dat* file for Knappom**

param.dat file:

```
START  1knappom
  2   0           2    PNO       Number of precipitation stations
  2   0  Rena          PID1      Identification for precip station 1
  2   0        240.    PHOH1     Altitude precip station 1
  2   0 .43553110000   PWGT1     Weight precipitation station 1
  2   0  Flisa         PID2
  2   0        185.    PHOH2
  2   0 .59237110000   PWGT2
  2   0           2    TNO       Number of temperature stations
  2   0  Rena          TID1      Identification for temp station 1
  2   0        240.    THOH1     Altitude temp station 1
  2   0 .17269620000   TWGT1     Weight temp station 1
  2   0  Flisa         TID2      Identification for temp station 2
  2   0        185.    THOH2     Altitude temp station 2
  2   0 .49410490000   TWGT2     Weight temp station 2
  2   0           1    QNO       Number of discharge stations
  2   0  Knappom       QID       Identification for discharge station
  2   0         1.0     QWGT      Scaling factor for discharge
  2   0      1625.0     AREAL     Catchment area                       [km2]
  2   4       0.000    MAGDEL    Regulation reservoirs                [1]
  2   5     180.000    HYPSO ( 1,1), low point             [m]
  2   6     271.000    HYPSO ( 2,1)
  2   7     310.000    HYPSO ( 3,1)
  2   8     340.000    HYPSO ( 4,1)
  2   9     376.000    HYPSO ( 5,1)
  2  10     411.000    HYPSO ( 6,1)
  2  11     444.000    HYPSO ( 7,1)
  2  12     479.000    HYPSO ( 8,1)
  2  13     511.000    HYPSO ( 9,1)
  2  14     555.000    HYPSO (10,1)
  2  15     780.000    HYPSO (11,1), high point
  2  16       0.000    HYPSO ( 1,2), Part of total area below HYPSO (1,1) = 0
  2  17       0.100    HYPSO ( 2,2)
  2  18       0.200    HYPSO ( 3,2)
  2  19       0.300    HYPSO ( 4,2)
  2  20       0.400    HYPSO ( 5,2)
  2  21       0.500    HYPSO ( 6,2)
  2  22       0.600    HYPSO ( 7,2)
  2  23       0.700    HYPSO ( 8,2)
  2  24       0.800    HYPSO ( 9,2)
  2  25       0.900    HYPSO (10,2)
  2  26       1.000    HYPSO (11,2), Part of total area below HYPSO (11,1) = 1
  2  27       0.000    BREPRO( 1), Glacier area, part of total area, below HYPSO( 1,1)
(=0.0)
  2  37       0.000    BREPRO(11), Glacier area, part of total area, below HYPSO(11,1)
  2  38
  2  39     270.000    NDAG      Day no for conversion of glacier snow to ice
  2  40 .08566936100   TX        Threshold temperature for snow/ice           [C]
  2  41 1.4682300000   TS        Threshold temperature fo no melt             [C]
  2  42 3.1161500000   CX        Melt index                              [mm/deg/day]
  2  43        0.02    CFR       Refreeze efficiency                          [1]
  2  44        0.08    LV        Max rel. water content in snow               [1]
  2  45 1.3768970000   PKORR     Precipitaion correction for rain             [1]
  2  46 1.0000000000   SKORR     Additional precipitation corection for snow at gauge [1]
  2  47                GRADALT   Altitude for change in prec. grad.           [m]
  2  48                PGRAD1    Precipitation gradient above GRADALT         [1]
  2  49        0.02    CALB      Ageing factor for albedo                 [1/day]
  2  50        0.33    CRAD      Radiation melt component                     [1]
  2  51        0.33    CONV      Convection melt component                    [1]
  2  52        0.33    COND      Condensation melt component                  [1]
  2  60         1.1    CEVPL     Lake evapotranspiration adjustment fact      [1]
  2  61         0.5    ERED      Evapotranspiration red. during interception  [1]
  2  62        30.0    ICEDAY    Lake temperature time constant               [d]
  2  63 -.8539126000   TTGRAD    Temperature gradient for days without precip [deg/100 m]
  2  64 -.3962217000   TVGRAD    Temperature gradient for days with precip    [deg/100 m]
  2  65 2.4000000E-4   PGRAD     Precipitation altitude gradient             [1/100 m]
  2  66       1.500    CBRE      Melt increase on glacier ice                 [1]
  2  67       0.100    EP        EP( 1), Pot evapotranspiration, Jan    [mm/day] or [1]
  2  68       0.200    EP        EP( 2), Pot evapotranspiration, Feb    [mm/day] or [1]
  2  69       0.300    EP        EP( 3)
  2  70       0.800    EP        EP( 4)
```

```
2   71        1.500    EP        EP( 5)
2   72        2.800    EP        EP( 6)
2   73        2.800    EP        EP( 7)
2   74        2.300    EP        EP( 8)
2   75        1.500    EP        EP( 9)
2   76        0.700    EP        EP(10)
2   77        0.200    EP        EP(11)
2   78        0.100    EP        EP(12)), Pot evapotranspiration, Dec    [mm/day] or [1]
2   79 272.04000000    FC        Maximum soil water content           [mm]
2   80        1.0      FCDEL     Pot.evapotr when content = FC*FCDEL  [1]
2   81 1.3865770000    BETA      Non-linearity in soil water zone     [1]
2   82       100.00    INFMAX    Maximum infiltration capacity        [mm/day]

2   85 .25095400000    KUZ2      Quick time constant upper zone       [1/day]
2   86 31.287480000    UZ1       Threshold quick runoff               [mm]
2   87 .05001002200    KUZ1      Slow time constant upper zone        [1/day]
2   88 .93933140000    PERC      Percolation to lower zone            [mm/day]
2   89 .01164802800    KLZ       Time constant lower zone             [1/day]
2   90        0.00     ROUT      (1), Routing constant (lake area, km2)
2   91        0.00     ROUT      (2), Routing constant (rating curve const)
2   92        0.00     ROUT      (3), Routing constant (rating curve zero)
2   93        0.00     ROUT      (4), Routing constant (rating curve exp)
2   94        0.00     ROUT      (5), Routing constant (drained area ratio)
2   95        0.00     DECAY     (1), Feedback constant
2   96        0.00     DECAY     (2), Feedback constant
2   97        0.00     DECAY     (3), Feedback constant
2   98        0.17     CE        Evapotranspiration constant          [mm/deg/day]
2   99         0.5     DRAW      "draw up" constant                   [mm/day]
2  100         61      LAT       Latitude                             [deg]
2  101       -0.6      TGRAD(1)  Temperature gradient Jan            [deg/100m]
2  102       -0.6      TGRAD(2)  Temperature gradient Feb            [deg/100m]
2  103       -0.6      TGRAD(3)  Temperature gradient Mar            [deg/100m]
2  104       -0.6      TGRAD(4)  Temperature gradient Apr            [deg/100m]
2  105       -0.6      TGRAD(5)  Temperature gradient May            [deg/100m]
2  106       -0.6      TGRAD(6)  Temperature gradient Jun            [deg/100m]
2  107       -0.6      TGRAD(7)  Temperature gradient Jul            [deg/100m]
2  108       -0.6      TGRAD(8)  Temperature gradient Aug            [deg/100m]
2  109       -0.6      TGRAD(9)  Temperature gradient Sep            [deg/100m]
2  110       -0.6      TGRAD(10) Temperature gradient Oct            [deg/100m]
2  111       -0.6      TGRAD(11) Temperature gradient Nov            [deg/100m]
2  112       -0.6      TGRAD(12) Temperature gradient Dec            [deg/100m]
2  113        20.0     SPDIST    Uniformly distributed snow acc       [mm]
2  114         5.0     SMINI     Inital soil moisture content         [mm]
2  115         0.0     UZINI     Initial upper zone content           [mm]
2  116         5.0     LZINI     Initial lower zone content           [mm]
2  121           2     VEGT(1,1) Vegetation type 1, zone 1
2  122           5     VEGT(2,1) Vegetation type 2, zone 1
2  123        0.33    VEGA(1)   Vegetation 2 area, zone 1            [1]
2  124        0.02    LAKE(1)   Lake area,         zone 1            [1]
2  125           2     VEGT(1,2) Vegetation type 1, zone 2
2  126           5     VEGT(2,2) Vegetation type 2, zone 2
2  127        0.16    VEGA(2)   Vegetation 2 area, zone 2            [1]
2  128        0.05    LAKE(2)   Lake area,         zone 2            [1]
2  129           2     VEGT(1,3) Vegetation type 1, zone 3
2  130           5     VEGT(2,3) Vegetation type 2, zone 3
2  131        0.19    VEGA(3)   Vegetation 2 area, zone 3            [1]
2  132        0.02    LAKE(3)   Lake area,         zone 3            [1]
2  133           2     VEGT(1,4) Vegetation type 1, zone 4
2  134           5     VEGT(2,4) Vegetation type 2, zone 4
2  135        0.17    VEGA(4)   Vegetation 2 area, zone 4            [1]
2  136        0.00    LAKE(4)   Lake area,         zone 4            [1]
2  137           2     VEGT(1,5) Vegetation type 1, zone 5
2  138           5     VEGT(2,5) Vegetation type 2, zone 5
2  139        0.21    VEGA(5)   Vegetation 2 area, zone 5            [1]
2  140        0.01    LAKE(5)   Lake area,         zone 5            [1]
2  141           2     VEGT(1,6) Vegetation type 1, zone 6
2  142           5     VEGT(2,6) Vegetation type 2, zone 6
2  143        0.20    VEGA(6)   Vegetation 2 area, zone 6            [1]
2  144        0.00    LAKE(6)   Lake area,         zone 6            [1]
2  145           2     VEGT(1,7) Vegetation type 1, zone 7
2  146           5     VEGT(2,7) Vegetation type 2, zone 7
2  147        0.27    VEGA(7)   Vegetation 2 area, zone 7            [1]
2  148        0.00    LAKE(7)   Lake area,         zone 7            [1]
2  149           2     VEGT(1,8) Vegetation type 1, zone 8
2  150           5     VEGT(2,8) Vegetation type 2, zone 8
2  151        0.29    VEGA(8)   Vegetation 2 area, zone 8            [1]
2  152        0.00    LAKE(8)   Lake area,         zone 8            [1]
```

```
  2  153          2     VEGT(1,9) Vegetation type 1, zone 9
  2  154          5     VEGT(2,9) Vegetation type 2, zone 9
  2  155       0.31    VEGA(9)   Vegetation 2 area, zone 9            [1]
  2  156       0.00    LAKE(9)   Lake area,         zone 9            [1]
  2  157          2     VEGT(1,10) Vegetation type 1, zone 10
  2  158          5     VEGT(2,10) Vegetation type 2, zone 10
  2  159       0.32    VEGA(10)   Vegetation 2 area, zone 10          [1]
  2  160       0.00    LAKE(10)   Lake area,         zone 10          [1]
FINISH
```

vegtype.dat file:

```
Type       no   ICMAX   CXREL  TSDIFF  CVSNOW   FCREL   LPDEL   EPVAR
Mountain    1 .10000  1.0000  0.0000     0.5  .50000  .80000     0.5
Forest      2 2.5000  .84479  -1.526     0.3  3.0000  1.0000     1.0
Shrub       3 1.0000  1.0000  0.0000     0.4  .80000  .70000     0.8
Rock        4 .10000  1.0000  0.0000     0.5  .20000  1.0000     0.1
Meadows     5 .10000  1.2113  .22514     0.3  .28057  .99500     1.0
```

param.dat file and *vegtype.dat* file for Engeren

param.dat file:

```
START  1engeren
  2    0           3    PNO       Number of precipitation stations
  2    0  Drevsjø        PID1      Identification for precip station 1
  2    0        672.    PHOH1     Altitude precip station 1
  2    0 .19675400000    PWGT1     Weight precipitation station 1
  2    0  Heggeriset     PID2
  2    0        481.    PHOH2
  2    0 .55309810000    PWGT2
  2    0  Gløtvola       PID3      Identification for precip station 3
  2    0        696.    PHOH3     Altitude precip station 3
  2    0 .26935640000    PWGT3     Weight precipitation station 3
  2    0           1    TNO       Number of temperature stations
  2    0  Drevsjø        TID1      Identification for temp station 1
  2    0        672.    THOH1     Altitude temp station 1
  2    0         1.0    TWGT1     Weight temp station 1
  2    0           1    QNO       Number of discharge stations
  2    0  Engeren        QID       Identification for discharge station
  2    0          1.    QWGT      Scaling factor for discharge
  2    0      400.0      AREAL     Catchment area                       [km2]
  2    4        0.000    MAGDEL    Regulation reservoirs                [1]
  2    5      472.000    HYPSO ( 1,1), low point             [m]
  2    6      579.000    HYPSO ( 2,1)
  2    7      692.000    HYPSO ( 3,1)
  2    8      765.000    HYPSO ( 4,1)
  2    9      806.000    HYPSO ( 5,1)
  2   10      832.000    HYPSO ( 6,1)
  2   11      866.000    HYPSO ( 7,1)
  2   12      906.000    HYPSO ( 8,1)
  2   13      952.000    HYPSO ( 9,1)
  2   14     1012.000    HYPSO (10,1)
  2   15     1139.000    HYPSO (11,1), high point
  2   16        0.000    HYPSO ( 1,2), Part of total area below HYPSO (1,1) = 0
  2   17        0.100    HYPSO ( 2,2)
  2   18        0.200    HYPSO ( 3,2)
  2   19        0.300    HYPSO ( 4,2)
  2   20        0.400    HYPSO ( 5,2)
  2   21        0.500    HYPSO ( 6,2)
  2   22        0.600    HYPSO ( 7,2)
  2   23        0.700    HYPSO ( 8,2)
  2   24        0.800    HYPSO ( 9,2)
  2   25        0.900    HYPSO (10,2)
  2   26        1.000    HYPSO (11,2), Part of total area below HYPSO (11,1) = 1
  2   27        0.000    BREPRO( 1), Glacier area, part of total area, below HYPSO( 1,1)
(=0.0)
  2   37        0.000    BREPRO(2), Glacier area, part of total area, below HYPSO(2,1)
  2   37        0.000    BREPRO(3), Glacier area, part of total area, below HYPSO(3,1)
  2   37        0.000    BREPRO(4), Glacier area, part of total area, below HYPSO(4,1)
  2   37        0.000    BREPRO(5), Glacier area, part of total area, below HYPSO(5,1)
  2   37        0.000    BREPRO(6), Glacier area, part of total area, below HYPSO(6,1)
  2   37        0.000    BREPRO(7), Glacier area, part of total area, below HYPSO(7,1)
  2   37        0.000    BREPRO(8), Glacier area, part of total area, below HYPSO(8,1)
  2   37        0.000    BREPRO(9), Glacier area, part of total area, below HYPSO(9,1)
  2   37        0.000    BREPRO(10), Glacier area, part of total area, below HYPSO(10,1)

  2   37        0.000    BREPRO(11), Glacier area, part of total area, below HYPSO(11,1)
  2   38
  2   39      270.000    NDAG      Day no for conversion of glacier snow to ice
  2   40 .96422240000    TX        Threshold temperature for snow/ice            [C]
  2   41 .11047680000    TS        Threshold temperature fo no melt              [C]
  2   42 4.8042720000    CX        Melt index                               [mm/deg/day]
  2   43        0.01     CFR       Refreeze efficiency                           [1]
  2   44        0.06     LV        Max rel. water content in snow                [1]
  2   45 1.2795450000    PKORR     Precipitaion correction for rain              [1]
  2   46 1.1643520000    SKORR     Additional precipitation corection for snow at gauge [1]
  2   47                 GRADALT   Altitude for change in prec. grad.            [m]
  2   48                 PGRAD1    Precipitation gradient above GRADALT          [1]
  2   49        0.02     CALB      Ageing factor for albedo                  [1/day]
  2   50        0.33     CRAD      Radiation melt component                      [1]
  2   51        0.33     CONV      Convection melt component                     [1]
  2   52        0.33     COND      Condensation melt component                   [1]
  2   60         1.1     CEVPL     Lake evapotranspiration adjustment fact       [1]
```

```
2   61         0.5     ERED      Evapotranspiration red. during interception   [1]
2   62        30.0     ICEDAY    Lake temperature time constant                [d]
2   63 -.6000000000    TTGRAD    Temperature gradient for days without precip [deg/100 m]
2   64 -.5509499000    TVGRAD    Temperature gradient for days with precip    [deg/100 m]
2   65 .03226876100    PGRAD     Precipitation altitude gradient              [1/100 m]
2   66        1.500    CBRE      Melt increase on glacier ice                  [1]
2   67        0.000    EP        EP( 1), Pot evapotranspiration, Jan    [mm/day] or [1]
2   68        0.000    EP        EP( 2), Pot evapotranspiration, Feb    [mm/day] or [1]
2   69        0.000    EP        EP( 3)
2   70        0.000    EP        EP( 4)
2   71        1.900    EP        EP( 5)
2   72        2.300    EP        EP( 6)
2   73        2.100    EP        EP( 7)
2   74        1.900    EP        EP( 8)
2   75        1.200    EP        EP( 9)
2   76        0.000    EP        EP(10)
2   77        0.000    EP        EP(11)
2   78        0.000    EP        EP(12)), Pot evapotranspiration, Dec    [mm/day] or [1]
2   79 108.70380000    FC        Maximum soil water content            [mm]
2   80         0.7     FCDEL     Pot.evapotr when content = FC*FCDEL  [1]
2   81 1.2480900000    BETA      Non-linearity in soil water zone      [1]
2   82       100.00    INFMAX    Maximum infiltration capacity         [mm/day]

2   85 .15039260000    KUZ2      Quick time constant upper zone        [1/day]
2   86 100.00000000    UZ1       Threshold quick runoff                [mm]
2   87 .02704992600    KUZ1      Slow time constant upper zone         [1/day]
2   88 .75514810000    PERC      Percolation to lower zone             [mm/day]
2   89 .00464031350    KLZ       Time constant lower zone              [1/day]
2   90         0.00    ROUT      (1), Routing constant (lake area, km2)
2   91         0.00    ROUT      (2), Routing constant (rating curve const)
2   92         0.00    ROUT      (3), Routing constant (rating curve zero)
2   93         0.00    ROUT      (4), Routing constant (rating curve exp)
2   94         0.00    ROUT      (5), Routing constant (drained area ratio)
2   95         0.00    DECAY     (1), Feedback constant
2   96         0.00    DECAY     (2), Feedback constant
2   97         0.00    DECAY     (3), Feedback constant
2   98         0.17    CE        Evapotranspiration constant           [mm/deg/day]
2   99         0.3     DRAW      "draw up" constant                    [mm/day]
2  100         61.7    LAT       Latitude                              [deg]
2  101        -0.6     TGRAD(1)  Temperature gradient Jan              [deg/100m]
2  102        -0.6     TGRAD(2)  Temperature gradient Feb              [deg/100m]
2  103        -0.6     TGRAD(3)  Temperature gradient Mar              [deg/100m]
2  104        -0.6     TGRAD(4)  Temperature gradient Apr              [deg/100m]
2  105        -0.6     TGRAD(5)  Temperature gradient May              [deg/100m]
2  106        -0.6     TGRAD(6)  Temperature gradient Jun              [deg/100m]
2  107        -0.6     TGRAD(7)  Temperature gradient Jul              [deg/100m]
2  108        -0.6     TGRAD(8)  Temperature gradient Aug              [deg/100m]
2  109        -0.6     TGRAD(9)  Temperature gradient Sep              [deg/100m]
2  110        -0.6     TGRAD(10) Temperature gradient Oct              [deg/100m]
2  111        -0.6     TGRAD(11) Temperature gradient Nov              [deg/100m]
2  112        -0.6     TGRAD(12) Temperature gradient Dec              [deg/100m]
2  113         20.0    SPDIST    Uniformly distributed snow acc        [mm]
2  114         70.0    SMINI     Inital soil moisture content          [mm]
2  115         30.0    UZINI     Initial upper zone content            [mm]
2  116         70.0    LZINI     Initial lower zone content            [mm]
2  121           2    VEGT(1,1) Vegetation type 1, zone 1
2  122           0    VEGT(2,1) Vegetation type 2, zone 1
2  123         0.0    VEGA(1)   Vegetation 2 area, zone 1            [1]
2  124         0.036  LAKE(1)   Lake area,         zone 1            [1]
2  125           2    VEGT(1,2) Vegetation type 1, zone 2
2  126           0    VEGT(2,2) Vegetation type 2, zone 2
2  127         0.0    VEGA(2)   Vegetation 2 area, zone 2            [1]
2  128         0.036  LAKE(2)   Lake area,         zone 2            [1]
2  129           2    VEGT(1,3) Vegetation type 1, zone 3
2  130           0    VEGT(2,3) Vegetation type 2, zone 3
2  131         0.0    VEGA(3)   Vegetation 2 area, zone 3            [1]
2  132         0.036  LAKE(3)   Lake area,         zone 3            [1]
2  133           2    VEGT(1,4) Vegetation type 1, zone 4
2  134           0    VEGT(2,4) Vegetation type 2, zone 4
2  135         0.0    VEGA(4)   Vegetation 2 area, zone 4            [1]
2  136         0.036  LAKE(4)   Lake area,         zone 4            [1]
2  137           2    VEGT(1,5) Vegetation type 1, zone 5
2  138           0    VEGT(2,5) Vegetation type 2, zone 5
2  139         0.0    VEGA(5)   Vegetation 2 area, zone 5            [1]
2  140         0.036  LAKE(5)   Lake area,         zone 5            [1]
2  141           2    VEGT(1,6) Vegetation type 1, zone 6
2  142           0    VEGT(2,6) Vegetation type 2, zone 6
```

```
  2  143        0.0     VEGA(6)   Vegetation 2 area, zone 6             [1]
  2  144        0.036   LAKE(6)   Lake area,         zone 6             [1]
  2  145          2     VEGT(1,7) Vegetation type 1, zone 7
  2  146          0     VEGT(2,7) Vegetation type 2, zone 7
  2  147        0.0     VEGA(7)   Vegetation 2 area, zone 7             [1]
  2  148        0.036   LAKE(7)   Lake area,         zone 7             [1]
  2  149          2     VEGT(1,8) Vegetation type 1, zone 8
  2  150          0     VEGT(2,8) Vegetation type 2, zone 8
  2  151        0.0     VEGA(8)   Vegetation 2 area, zone 8             [1]
  2  152        0.036   LAKE(8)   Lake area,         zone 8             [1]
  2  153          5     VEGT(1,9) Vegetation type 1, zone 9
  2  154          0     VEGT(2,9) Vegetation type 2, zone 9
  2  155        0.0     VEGA(9)   Vegetation 2 area, zone 9             [1]
  2  156        0.036   LAKE(9)   Lake area,         zone 9             [1]
  2  157          5     VEGT(1,10) Vegetation type 1, zone 10
  2  158          0     VEGT(2,10) Vegetation type 2, zone 10
  2  159        0.0     VEGA(10)   Vegetation 2 area, zone 10           [1]
  2  160        0.036   LAKE(10)   Lake area,         zone 10           [1]
FINISH
```

vegtype.dat file:

```
Type       no   ICMAX   CXREL  TSDIFF  CVSNOW   FCREL   LPDEL   EPVAR
Mountain    1 .10000  1.0000  0.0000     0.5  .50000  .80000      0.5
Forest      2 1.9908  .68595  .35658     0.3  .99690  .62449      1.0
Shrub       3 1.0000  1.0000  0.0000     0.4  .80000  .70000      0.8
Rock        4 .10000  1.0000  0.0000     0.5  .20000  1.0000      0.1
Meadows     5 .10000  1.0241  -.0894     0.3  .49416  .82390      1.0
```

Appendix B

param.dat file and *vegtype.dat* file for Kempten

param.dat file:

```
START  1kempten
  2    0            5    PNO       Number of precipitation stations
  2    0  Kempten        PID1      Identification for precip station 1
  2    0        705.     PHOH1     Altitude precip station 1
  2    0 .06811859200    PWGT1     Weight precipitation station 1
  2    0  Isny           PID2      Identification for precip station 2
  2    0        712.     PHOH2     Altitude precip station 2
  2    0 .23106430000    PWGT2     Weight precipitation station 2
  2    0  Oberstaufen    PID3      Identification for precip station 3
  2    0        800.     PHOH3     Altitude precip station 3
  2    0 .13080720000    PWGT3     Weight precipitation station 3
  2    0  Hindelang      PID4      Identification for precip station 4
  2    0       1053.     PHOH4     Altitude precip station 4
  2    0 .20622590000    PWGT4     Weight precipitation station 4
  2    0  Oberstdorf     PID5      Identification for precip station 5
  2    0        806.     PHOH5     Altitude precip station 5
  2    0 .57031560000    PWGT5     Weight precipitation station 5
  2    0            5    TNO       Number of temperature stations
  2    0  Kempten        TID1      Identification for temp station 1
  2    0        705.     THOH1     Altitude temp station 1
  2    0 .16558520000    TWGT1     Weight temp station 1
  2    0  Isny           TID2      Identification for temp station 2
  2    0        712.     THOH2     Altitude temp station 2
  2    0 .14414690000    TWGT2     Weight temp station 2
  2    0  Oberstaufen    TID3      Identification for temp station 3
  2    0        800.     THOH3     Altitude temp station 3
  2    0 .77379380000    TWGT3     Weight temp station 3
  2    0  Hindelang      TID4      Identification for temp station 4
  2    0       1053.     THOH4     Altitude temp station 4
  2    0 .19871250000    TWGT4     Weight temp station 4
  2    0  Oberstdorf     TID5      Identification for temp station 5
  2    0        806.     THOH5     Altitude temp station 5
  2    0 .22802370000    TWGT5     Weight temp station 5
  2    0            1    QNO       Number of discharge stations
  2    0  Kempten        QID       Identification for discharge station
  2    0           1.    QWGT      Scaling factor for discharge
  2    0      948        AREAL     Catchment area                        [km2]
  2    4        0.000    MAGDEL    Regulation reservoirs                 [1]
  2    5      658.000    HYPSO ( 1,1), low point               [m]
  2    6      731.000    HYPSO ( 2,1)
  2    7      796.000    HYPSO ( 3,1)
  2    8      866.000    HYPSO ( 4,1)
  2    9      954.000    HYPSO ( 5,1)
  2   10     1085.000    HYPSO ( 6,1)
  2   11     1224.000    HYPSO ( 7,1)
  2   12     1372.000    HYPSO ( 8,1)
  2   13     1546.000    HYPSO ( 9,1)
  2   14     1782.000    HYPSO (10,1)
  2   15     2639.000    HYPSO (11,1), high point
  2   16        0.000    HYPSO ( 1,2), Part of total area below HYPSO (1,1) = 0
  2   17        0.100    HYPSO ( 2,2)
  2   18        0.200    HYPSO ( 3,2)
  2   19        0.300    HYPSO ( 4,2)
  2   20        0.400    HYPSO ( 5,2)
  2   21        0.500    HYPSO ( 6,2)
  2   22        0.600    HYPSO ( 7,2)
  2   23        0.700    HYPSO ( 8,2)
  2   24        0.800    HYPSO ( 9,2)
  2   25        0.900    HYPSO (10,2)
  2   26        1.000    HYPSO (11,2), Part of total area below HYPSO (11,1) = 1
  2   27        0.000    BREPRO( 1), Glacier area, part of total area, below HYPSO( 1,1)
(=0.0)
  2   37        0.000    BREPRO(2), Glacier area, part of total area, below HYPSO(2,1)
  2   37        0.000    BREPRO(3), Glacier area, part of total area, below HYPSO(3,1)
  2   37        0.000    BREPRO(4), Glacier area, part of total area, below HYPSO(4,1)
  2   37        0.000    BREPRO(5), Glacier area, part of total area, below HYPSO(5,1)
  2   37        0.000    BREPRO(6), Glacier area, part of total area, below HYPSO(6,1)
```

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2   37        0.000    BREPRO(7), Glacier area, part of total area, below HYPSO(7,1)
2   37        0.000    BREPRO(8), Glacier area, part of total area, below HYPSO(8,1)
2   37        0.000    BREPRO(9), Glacier area, part of total area, below HYPSO(9,1)
2   37        0.020    BREPRO(10), Glacier area, part of total area, below HYPSO(10,1)

2   37        0.030    BREPRO(11), Glacier area, part of total area, below HYPSO(11,1)
2   38
2   39      270.000   NDAG      Day no for conversion of glacier snow to ice
2   40 .96637180000   TX        Threshold temperature for snow/rain             [C]
2   41 -.1091748000   TS        Threshold temperature fo no melt               [C]
2   42 2.0000000000   CX        Melt index                                [mm/deg/day]
2   43        0.05    CFR       Refreeze efficiency                            [1]
2   44        0.08    LV        Max rel. water content in snow                 [1]
2   45 1.1660660000   PKORR     Precipitaion correction for rain               [1]
2   46 1.0020430000   SKORR     Additional precipitation corection for snow at gauge [1]
2   47                GRADALT   Altitude for change in prec. grad.             [m]
2   48                PGRAD1    Precipitation gradient above GRADALT           [1]
2   49        0.02    CALB      Ageing factor for albedo                   [1/day]
2   50        0.33    CRAD      Radiation melt component                       [1]
2   51        0.33    CONV      Convection melt component                      [1]
2   52        0.33    COND      Condensation melt component                    [1]
2   60         1.1    CEVPL     Lake evapotranspiration adjustment fact        [1]
2   61         0.5    ERED      Evapotranspiration red. during interception    [1]
2   62        30.0    ICEDAY    Lake temperature time constant                 [d]
2   63 -.6018555000   TTGRAD    Temperature gradient for days without precip [deg/100 m]
2   64 -.5493348000   TVGRAD    Temperature gradient for days with precip    [deg/100 m]
2   65 0.0000000000   PGRAD     Precipitation altitude gradient              [1/100 m]
2   66        1.500   CBRE      Melt increase on glacier ice                   [1]
2   67        0.100   EP        EP( 1), Pot evapotranspiration, Jan    [mm/day] or [1]
2   68        0.200   EP        EP( 2), Pot evapotranspiration, Feb    [mm/day] or [1]
2   69        0.300   EP        EP( 3)
2   70        0.800   EP        EP( 4)
2   71        1.500   EP        EP( 5)
2   72        2.800   EP        EP( 6)
2   73        2.800   EP        EP( 7)
2   74        2.300   EP        EP( 8)
2   75        1.500   EP        EP( 9)
2   76        0.700   EP        EP(10)
2   77        0.200   EP        EP(11)
2   78        0.100   EP        EP(12)), Pot evapotranspiration, Dec    [mm/day] or [1]
2   79 178.22500000   FC        Maximum soil water content           [mm]
2   80        0.7     LPDEL     Pot.evapotr when content = FC*FCDEL  [1]
2   81 1.9180900000   BETA      Non-linearity in soil water zone     [1]
2   82        100     INFMAX    Maximum infiltration capacity        [mm/day]

2   85 .58490770000   KUZ2      Quick time constant upper zone       [1/day]
2   86 28.370610000   UZ1       Threshold quick runoff               [mm]
2   87 .13754690000   KUZ1      Slow time constant upper zone        [1/day]
2   88 3.0000000000   PERC      Percolation to lower zone            [mm/day]
2   89 .05431537200   KLZ       Time constant lower zone             [1/day]
2   90        0.00    ROUT      (1), Routing constant (lake area, km2)
2   91        0.00    ROUT      (2), Routing constant (rating curve const)
2   92        0.00    ROUT      (3), Routing constant (rating curve zero)
2   93        0.00    ROUT      (4), Routing constant (rating curve exp)
2   94        0.00    ROUT      (5), Routing constant (drained area ratio)
2   95        0.00    DECAY     (1), Feedback constant
2   96        0.00    DECAY     (2), Feedback constant
2   97        0.00    DECAY     (3), Feedback constant
2   98        0.17    CE        Evapotranspiration constant          [mm/deg/day]
2   99        0.3     DRAW      "draw up" constant                   [mm/day]
2  100       47.6     LAT       Latitude                             [deg]
2  101       -0.6     TGRAD(1)  Temperature gradient Jan             [deg/100m]
2  102       -0.6     TGRAD(2)  Temperature gradient Feb             [deg/100m]
2  103       -0.6     TGRAD(3)  Temperature gradient Mar             [deg/100m]
2  104       -0.6     TGRAD(4)  Temperature gradient Apr             [deg/100m]
2  105       -0.6     TGRAD(5)  Temperature gradient May             [deg/100m]
2  106       -0.6     TGRAD(6)  Temperature gradient Jun             [deg/100m]
2  107       -0.6     TGRAD(7)  Temperature gradient Jul             [deg/100m]
2  108       -0.6     TGRAD(8)  Temperature gradient Aug             [deg/100m]
2  109       -0.6     TGRAD(9)  Temperature gradient Sep             [deg/100m]
2  110       -0.6     TGRAD(10) Temperature gradient Oct             [deg/100m]
2  111       -0.6     TGRAD(11) Temperature gradient Nov             [deg/100m]
2  112       -0.6     TGRAD(12) Temperature gradient Dec             [deg/100m]
2  113        20.0    SPDIST    Uniformly distributed snow acc       [mm]
2  114       120.0    SMINI     Inital soil moisture content         [mm]
2  115         0.0    UZINI     Initial upper zone content           [mm]
2  116        30.0    LZINI     Initial lower zone content           [mm]
```

```
  2  121            5     VEGT(1,1) Vegetation type 1, zone 1
  2  122            2     VEGT(2,1) Vegetation type 2, zone 1
  2  123          0.049   VEGA(1)   Vegetation 2 area, zone 1            [1]
  2  124          0.026  LAKE(1)   Lake area,         zone 1            [1]
  2  125            5     VEGT(1,2) Vegetation type 1, zone 2
  2  126            2     VEGT(2,2) Vegetation type 2, zone 2
  2  127          0.198    VEGA(2)   Vegetation 2 area, zone 2            [1]
  2  128          0.006  LAKE(2)   Lake area,         zone 2            [1]
  2  129            5     VEGT(1,3) Vegetation type 1, zone 3
  2  130            2     VEGT(2,3) Vegetation type 2, zone 3
  2  131          0.237   VEGA(3)   Vegetation 2 area, zone 3            [1]
  2  132          0.030  LAKE(3)   Lake area,         zone 3            [1]
  2  133            5     VEGT(1,4) Vegetation type 1, zone 4
  2  134            2     VEGT(2,4) Vegetation type 2, zone 4
  2  135          0.343    VEGA(4)   Vegetation 2 area, zone 4            [1]
  2  136          0.002  LAKE(4)   Lake area,         zone 4            [1]
  2  137            5     VEGT(1,5) Vegetation type 1, zone 5
  2  138            2     VEGT(2,5) Vegetation type 2, zone 5
  2  139          0.484    VEGA(5)   Vegetation 2 area, zone 5            [1]
  2  140          0.000  LAKE(5)   Lake area,         zone 5            [1]
  2  141            5     VEGT(1,6) Vegetation type 1, zone 6
  2  142            2     VEGT(2,6) Vegetation type 2, zone 6
  2  143          0.603   VEGA(6)   Vegetation 2 area, zone 6            [1]
  2  144          0.000  LAKE(6)   Lake area,         zone 6            [1]
  2  145            5     VEGT(1,7) Vegetation type 1, zone 7
  2  146            2     VEGT(2,7) Vegetation type 2, zone 7
  2  147          0.571   VEGA(7)   Vegetation 2 area, zone 7            [1]
  2  148          0.000  LAKE(7)   Lake area,         zone 7            [1]
  2  149            1     VEGT(1,8) Vegetation type 1, zone 8
  2  150            2     VEGT(2,8) Vegetation type 2, zone 8
  2  151          0.385   VEGA(8)   Vegetation 2 area, zone 8            [1]
  2  152          0.000  LAKE(8)   Lake area,         zone 8            [1]
  2  153            1     VEGT(1,9) Vegetation type 1, zone 9
  2  154            2     VEGT(2,9) Vegetation type 2, zone 9
  2  155          0.137   VEGA(9)   Vegetation 2 area, zone 9            [1]
  2  156          0.000  LAKE(9)   Lake area,         zone 9            [1]
  2  157            1     VEGT(1,10) Vegetation type 1, zone 10
  2  158            4     VEGT(2,10) Vegetation type 2, zone 10
  2  159          0.256   VEGA(10)   Vegetation 2 area, zone 10          [1]
  2  160          0.000  LAKE(10)   Lake area,         zone 10          [1]
FINIS
```

vegtype.dat file:

```
Type       no   ICMAX   CXREL  TSDIFF  CVSNOW   FCREL   LPDEL   EPVAR
Mountain    1 .12675  1.7845  .43923     0.5  .38172  1.0000      0.5
Forest      2 2.3572  1.2407  -.8628     0.3  2.7687  .50000      1.0
Shrub       3 1.0000  1.0000  0.0000     0.4  .80000  .70000      0.8
Rock        4 .06657  1.3338  -1.950     0.5  .10666  .50000      0.1
Meadows     5 .19371  1.2721  -2.000     0.3  .17483  1.0000      1.0
```

param.dat file and *vegtype.dat* file for Wiblingen

param.dat file:

```
START  1wiblingen
  2    0            9    PNO       Number of precipitation stations
  2    0  Ulm            PID1      Identification for precip station 1
  2    0        571.     PHOH1     Altitude precip station 1
  2    0 .03410726200    PWGT1     Weight precipitation station 1
  2    0  Aulendorf      PID2      Identification for precip station 2
  2    0        560.     PHOH2     Altitude precip station 2
  2    0 .00614962640    PWGT2     Weight precipitation station 2
  2    0  Schemmerhf.    PID3      Identification for precip station 3
  2    0        519.     PHOH3     Altitude precip station 3
  2    0 .00186608520    PWGT3     Weight precipitation station 3
  2    0  Memmingen      PID4      Identification for precip station 4
  2    0        610.     PHOH4     Altitude precip station 4
  2    0 .10754300000    PWGT4     Weight precipitation station 4
  2    0  Kempten        PID5      Identification for precip station 5
  2    0        705.     PHOH5     Altitude precip station 5
  2    0 .11189990000    PWGT5     Weight precipitation station 5
  2    0  Isny           PID6      Identification for precip station 6
  2    0        712.     PHOH6     Altitude precip station 6
  2    0 .22593670000    PWGT6     Weight precipitation station 6
  2    0  Oberstaufen    PID7      Identification for precip station 7
  2    0        800.     PHOH7     Altitude precip station 7
  2    0 .01569455100    PWGT7     Weight precipitation station 7
  2    0  Hindelang      PID8      Identification for precip station 8
  2    0       1053.     PHOH8     Altitude precip station 8
  2    0 .25108510000    PWGT8     Weight precipitation station 8
  2    0  Oberstdorf     PID9      Identification for precip station 9
  2    0        806.     PHOH9     Altitude precip station 9
  2    0 .33770870000    PWGT9     Weight precipitation station 9
  2    0            9    TNO       Number of temperature stations
  2    0  Ulm            TID1      Identification for temp station 1
  2    0        571.     THOH1     Altitude temp station 1
  2    0 .01263112800    TWGT1     Weight temp station 1
  2    0  Aulendorf      TID2      Identification for temp station 2
  2    0        560.     THOH2     Altitude temp station 2
  2    0 .04050949700    TWGT2     Weight temp station 2
  2    0  Schemmerhf.    TID3      Identification for temp station 3
  2    0        519.     THOH3     Altitude temp station 3
  2    0 .11593730000    TWGT3     Weight temp station 3
  2    0  Memmingen      TID4      Identification for temp station 4
  2    0        610.     THOH4     Altitude temp station 4
  2    0 .00892891770    TWGT4     Weight temp station 4
  2    0  Kempten        TID5      Identification for temp station 5
  2    0        705.     THOH5     Altitude temp station 5
  2    0 .12228280000    TWGT5     Weight temp station 5
  2    0  Isny           TID6      Identification for temp station 6
  2    0        712.     THOH6     Altitude temp station 6
  2    0 .20849080000    TWGT6     Weight temp station 6
  2    0  Oberstaufen    TID7      Identification for temp station 7
  2    0        800.     THOH7     Altitude temp station 7
  2    0 1.0000000000    TWGT7     Weight temp station 7
  2    0  Hindelang      TID8      Identification for temp station 8
  2    0       1053.     THOH8     Altitude temp station 8
  2    0 .69547150000    TWGT8     Weight temp station 8
  2    0  Oberstdorf     TID9      Identification for temp station 9
  2    0        806.     THOH9     Altitude temp station 9
  2    0 .10237740000    TWGT9     Weight temp station 9
  2    0            1    QNO       Number of discharge stations
  2    0  Wiblingen      QID       Identification for discharge station
  2    0           1.    QWGT      Scaling factor for discharge
  2    0      2154       AREAL     Catchment area                      [km2]
  2    4       0.000     MAGDEL    Regulation reservoirs               [1]
  2    5     469.000     HYPSO ( 1,1), low point             [m]
  2    6     566.000     HYPSO ( 2,1)
  2    7     640.000     HYPSO ( 3,1)
  2    8     678.000     HYPSO ( 4,1)
  2    9     711.000     HYPSO ( 5,1)
  2   10     743.000     HYPSO ( 6,1)
  2   11     819.000     HYPSO ( 7,1)
  2   12     913.000     HYPSO ( 8,1)
  2   13    1132.000     HYPSO ( 9,1)
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   2   14     1491.000    HYPSO (10,1)
   2   15     2639.000    HYPSO (11,1), high point
   2   16        0.000    HYPSO ( 1,2), Part of total area below HYPSO (1,1) = 0
   2   17        0.100    HYPSO ( 2,2)
   2   18        0.200    HYPSO ( 3,2)
   2   19        0.300    HYPSO ( 4,2)
   2   20        0.400    HYPSO ( 5,2)
   2   21        0.500    HYPSO ( 6,2)
   2   22        0.600    HYPSO ( 7,2)
   2   23        0.700    HYPSO ( 8,2)
   2   24        0.800    HYPSO ( 9,2)
   2   25        0.900    HYPSO (10,2)
   2   26        1.000    HYPSO (11,2), Part of total area below HYPSO (11,1) = 1
   2   27        0.000    BREPRO( 1), Glacier area, part of total area, below HYPSO( 1,1)
(=0.0)
   2   37        0.000    BREPRO(2), Glacier area, part of total area, below HYPSO(2,1)
   2   37        0.000    BREPRO(3), Glacier area, part of total area, below HYPSO(3,1)
   2   37        0.000    BREPRO(4), Glacier area, part of total area, below HYPSO(4,1)
   2   37        0.000    BREPRO(5), Glacier area, part of total area, below HYPSO(5,1)
   2   37        0.000    BREPRO(6), Glacier area, part of total area, below HYPSO(6,1)
   2   37        0.000    BREPRO(7), Glacier area, part of total area, below HYPSO(7,1)
   2   37        0.000    BREPRO(8), Glacier area, part of total area, below HYPSO(8,1)
   2   37        0.000    BREPRO(9), Glacier area, part of total area, below HYPSO(9,1)
   2   37        0.000    BREPRO(10), Glacier area, part of total area, below HYPSO(10,1)

   2   37        0.000    BREPRO(11), Glacier area, part of total area, below HYPSO(11,1)
   2   38
   2   39      270.000   NDAG      Day no for conversion of glacier snow to ice
   2   40 .73234470000   TX        Threshold temperature for snow/rain           [C]
   2   41 .46913270000   TS        Threshold temperature fo no melt             [C]
   2   42 2.6169560000   CX        Melt index                               [mm/deg/day]
   2   43         0.05   CFR       Refreeze efficiency                          [1]
   2   44         0.08   LV        Max rel. water content in snow               [1]
   2   45 .81192630000   PKORR     Precipitaion correction for rain             [1]
   2   46 1.0000000000   SKORR     Additional precipitation corection for snow at gauge [1]
   2   47         1250   GRADALT   Altitude for change in prec. grad.           [m]
   2   48 .00408769430   PGRAD1    Precipitation gradient above GRADALT         [1]
   2   49         0.02   CALB      Ageing factor for albedo                 [1/day]
   2   50         0.33   CRAD      Radiation melt component                     [1]
   2   51         0.33   CONV      Convection melt component                    [1]
   2   52         0.33   COND      Condensation melt component                  [1]
   2   60          1.1   CEVPL     Lake evapotranspiration adjustment fact      [1]
   2   61          0.5   ERED      Evapotranspiration red. during interception  [1]
   2   62         30.0   ICEDAY    Lake temperature time constant               [d]
   2   63 -.5127715000   TTGRAD    Temperature gradient for days without precip [deg/100 m]
   2   64 -.6067750000   TVGRAD    Temperature gradient for days with precip    [deg/100 m]
   2   65 .07749183500   PGRAD     Precipitation altitude gradient             [1/100 m]
   2   66        1.500   CBRE      Melt increase on glacier ice                 [1]
   2   67        0.100   EP        EP( 1), Pot evapotranspiration, Jan    [mm/day] or [1]
   2   68        0.200   EP        EP( 2), Pot evapotranspiration, Feb    [mm/day] or [1]
   2   69        0.300   EP        EP( 3)
   2   70        0.800   EP        EP( 4)
   2   71        1.500   EP        EP( 5)
   2   72        2.800   EP        EP( 6)
   2   73        2.800   EP        EP( 7)
   2   74        2.300   EP        EP( 8)
   2   75        1.500   EP        EP( 9)
   2   76        0.700   EP        EP(10)
   2   77        0.200   EP        EP(11)
   2   78        0.100   EP        EP(12)), Pot evapotranspiration, Dec    [mm/day] or [1]
   2   79 146.50320000   FC        Maximum soil water content            [mm]
   2   80          0.7   LPDEL     Pot.evapotr when content = FC*FCDEL  [1]
   2   81 1.0000000000   BETA      Non-linearity in soil water zone      [1]
   2   82          100   INFMAX    Maximum infiltration capacity         [mm/day]

   2   85 .33647940000   KUZ2      Quick time constant upper zone        [1/day]
   2   86 22.935940000   UZ1       Threshold quick runoff                [mm]
   2   87 .06836783500   KUZ1      Slow time constant upper zone         [1/day]
   2   88 .72749680000   PERC      Percolation to lower zone             [mm/day]
   2   89 .02899410200   KLZ       Time constant lower zone              [1/day]
   2   90         0.00   ROUT      (1), Routing constant (lake area, km2)
   2   91         0.00   ROUT      (2), Routing constant (rating curve const)
   2   92         0.00   ROUT      (3), Routing constant (rating curve zero)
   2   93         0.00   ROUT      (4), Routing constant (rating curve exp)
   2   94         0.00   ROUT      (5), Routing constant (drained area ratio)
   2   95         0.00   DECAY     (1), Feedback constant
   2   96         0.00   DECAY     (2), Feedback constant
```

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  2   97        0.00    DECAY     (3), Feedback constant
  2   98        0.17    CE        Evapotranspiration constant           [mm/deg/day]
  2   99        0.3     DRAW      "draw up" constant                    [mm/day]
  2  100       47.9     LAT       Latitude                              [deg]
  2  101       -0.6     TGRAD(1)  Temperature gradient Jan              [deg/100m]
  2  102       -0.6     TGRAD(2)  Temperature gradient Feb              [deg/100m]
  2  103       -0.6     TGRAD(3)  Temperature gradient Mar              [deg/100m]
  2  104       -0.6     TGRAD(4)  Temperature gradient Apr              [deg/100m]
  2  105       -0.6     TGRAD(5)  Temperature gradient May              [deg/100m]
  2  106       -0.6     TGRAD(6)  Temperature gradient Jun              [deg/100m]
  2  107       -0.6     TGRAD(7)  Temperature gradient Jul              [deg/100m]
  2  108       -0.6     TGRAD(8)  Temperature gradient Aug              [deg/100m]
  2  109       -0.6     TGRAD(9)  Temperature gradient Sep              [deg/100m]
  2  110       -0.6     TGRAD(10) Temperature gradient Oct              [deg/100m]
  2  111       -0.6     TGRAD(11) Temperature gradient Nov              [deg/100m]
  2  112       -0.6     TGRAD(12) Temperature gradient Dec              [deg/100m]
  2  113        20.0    SPDIST    Uniformly distributed snow acc        [mm]
  2  114       100.0    SMINI     Inital soil moisture content          [mm]
  2  115         0.0    UZINI     Initial upper zone content            [mm]
  2  116        30.0    LZINI     Initial lower zone content            [mm]
  2  121            5     VEGT(1,1) Vegetation type 1, zone 1
  2  122            2     VEGT(2,1) Vegetation type 2, zone 1
  2  123          0.315   VEGA(1)   Vegetation 2 area, zone 1             [1]
  2  124          0.009  LAKE(1)   Lake area,           zone 1          [1]
  2  125            5     VEGT(1,2) Vegetation type 1, zone 2
  2  126            2     VEGT(2,2) Vegetation type 2, zone 2
  2  127          0.255    VEGA(2)   Vegetation 2 area, zone 2             [1]
  2  128          0.016  LAKE(2)   Lake area,         zone 2            [1]
  2  129            5     VEGT(1,3) Vegetation type 1, zone 3
  2  130            2     VEGT(2,3) Vegetation type 2, zone 3
  2  131          0.165   VEGA(3)   Vegetation 2 area, zone 3             [1]
  2  132          0.002  LAKE(3)   Lake area,         zone 3            [1]
  2  133            5     VEGT(1,4) Vegetation type 1, zone 4
  2  134            2     VEGT(2,4) Vegetation type 2, zone 4
  2  135          0.180    VEGA(4)   Vegetation 2 area, zone 4             [1]
  2  136          0.008  LAKE(4)   Lake area,         zone 4            [1]
  2  137            5     VEGT(1,5) Vegetation type 1, zone 5
  2  138            2     VEGT(2,5) Vegetation type 2, zone 5
  2  139          0.158    VEGA(5)   Vegetation 2 area, zone 5             [1]
  2  140          0.005  LAKE(5)   Lake area,         zone 5            [1]
  2  141            5     VEGT(1,6) Vegetation type 1, zone 6
  2  142            2     VEGT(2,6) Vegetation type 2, zone 6
  2  143          0.233   VEGA(6)   Vegetation 2 area, zone 6             [1]
  2  144          0.002  LAKE(6)   Lake area,         zone 6            [1]
  2  145            5     VEGT(1,7) Vegetation type 1, zone 7
  2  146            2     VEGT(2,7) Vegetation type 2, zone 7
  2  147          0.335   VEGA(7)   Vegetation 2 area, zone 7             [1]
  2  148          0.014  LAKE(7)   Lake area,         zone 7            [1]
  2  149            5     VEGT(1,8) Vegetation type 1, zone 8
  2  150            2     VEGT(2,8) Vegetation type 2, zone 8
  2  151          0.528   VEGA(8)   Vegetation 2 area, zone 8             [1]
  2  152          0.000  LAKE(8)   Lake area,         zone 8            [1]
  2  153            1     VEGT(1,9) Vegetation type 1, zone 9
  2  154            2     VEGT(2,9) Vegetation type 2, zone 9
  2  155          0.540   VEGA(9)   Vegetation 2 area, zone 9             [1]
  2  156          0.000  LAKE(9)   Lake area,         zone 9            [1]
  2  157            1     VEGT(1,10) Vegetation type 1, zone 10
  2  158            4     VEGT(2,10) Vegetation type 2, zone 10
  2  159          0.137   VEGA(10)   Vegetation 2 area, zone 10           [1]
  2  160          0.000  LAKE(10)   Lake area,         zone 10          [1]
FINIS
```

vegtype.dat file:

```
Type        no   ICMAX   CXREL  TSDIFF  CVSNOW   FCREL   LPDEL   EPVAR
Mountain    1 .43292  .96958  -1.054     0.5  .18101  .50000      0.5
Forest      2 1.0000  1.1462  1.7849     0.3  3.0000  .50000      1.0
Shrub       3 1.0000  1.0000  0.0000     0.4  .80000  .70000      0.8
Rock        4 .25045  .50428  1.7291     0.5  .15073  .79509      0.1
Meadows     5 .25118  .73600  .26931     0.3  .18988  1.0000      1.0
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