

APPLICATION OF THE INTEGRATED HYDROLOGICAL MODELLING SYSTEM IHMS-HBV TO PILOT BASIN IN LATVIA

SMHI LHMA

**APPLICATION OF THE INTEGRATED
HYDROLOGICAL MODELLING SYSTEM
IHMS-HBV TO PILOT BASIN IN LATVIA**

Final report

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1. INTRODUCTION

1.1 General

This report describes calibration and application of the IHMS-HBV model on a daily time step to Lielupe River basin in Latvia. The Swedish Meteorological and Hydrological Institute (SMHI) have as consultant been responsible for the set-up, calibration, training and delivery of the Integrated Hydrological Model System with the HBV-model (IHMS-HBV). The Swedish Board for Investment and Technical Support (BITS) financed the project. The training and transfer of technology were addressed to the Latvian Hydrometeorological Agency (LHMA).

1.2 Background

Co-operation between the national hydrometeorological institutes in Estonia (EMHI) and Latvia (LHMA) and SMHI is ongoing. With financial support from BITS a management training course was carried out at SMHI during spring 1992 and in the beginning of 1993 the project BALTMET started up. The main objective of BALTMET was to give improved hydrometeorological services in the Baltic countries by making it possible for the institutes to give general weather forecasts and warnings using up to date technology.

Following the training course a three year co-operation agreement was signed and high priority project areas were listed. Among the problems facing EMHI and LHMA were at project start-up the need for a modern computer model for current water resources estimation, hydrological forecasts for hydropower operation, catchment water balance for the possibility of computing available water and water balance for ungauged basins and flood forecasts and warning.

1.3 Project objectives

The overall development objectives of the project is to support the water resources and environmental strategy planning in Latvia by strengthening the capacity of LHMA to undertake hydrological forecasts and evaluations.

The specific objectives are to transfer knowledge about the basic design, applications, performance and data requirements of operational hydrological models in use at SMHI and to calibrate and install the IHMS-HBV model to a pilot basin so that it can be used in operational work and adapted for relevant hydrological applications. The Lielupe River basin was selected as pilot basin in Latvia. Examples of model application to Lielupe River are rationalisation of existing hydrological network, control of runoff data quality, extending discharge series and filling in of gaps in run-off series, calculation of substance-transport in rivers, calculation of mean discharge from unmeasured subbasins, flood-forecasting for flood warning and extreme flood studies among others.

2. THE HBV HYDROLOGICAL MODEL

2.1 Model structure and data requirements

The HBV hydrological model was developed at SMHI and the first applications to hydropower developed rivers were made in the early seventies (Bergström, 1976). The model is normally run on daily values of rainfall and air temperature and monthly estimates of potential evapotranspiration. The model contains routines for snow accumulation and melt, soil moisture accounting, runoff generation and a simple routing procedure (Figure 1). It can be used in a distributed mode by dividing the catchment into subbasins. Each subbasin is then divided into zones according to altitude, lake area, glaciers and vegetation.

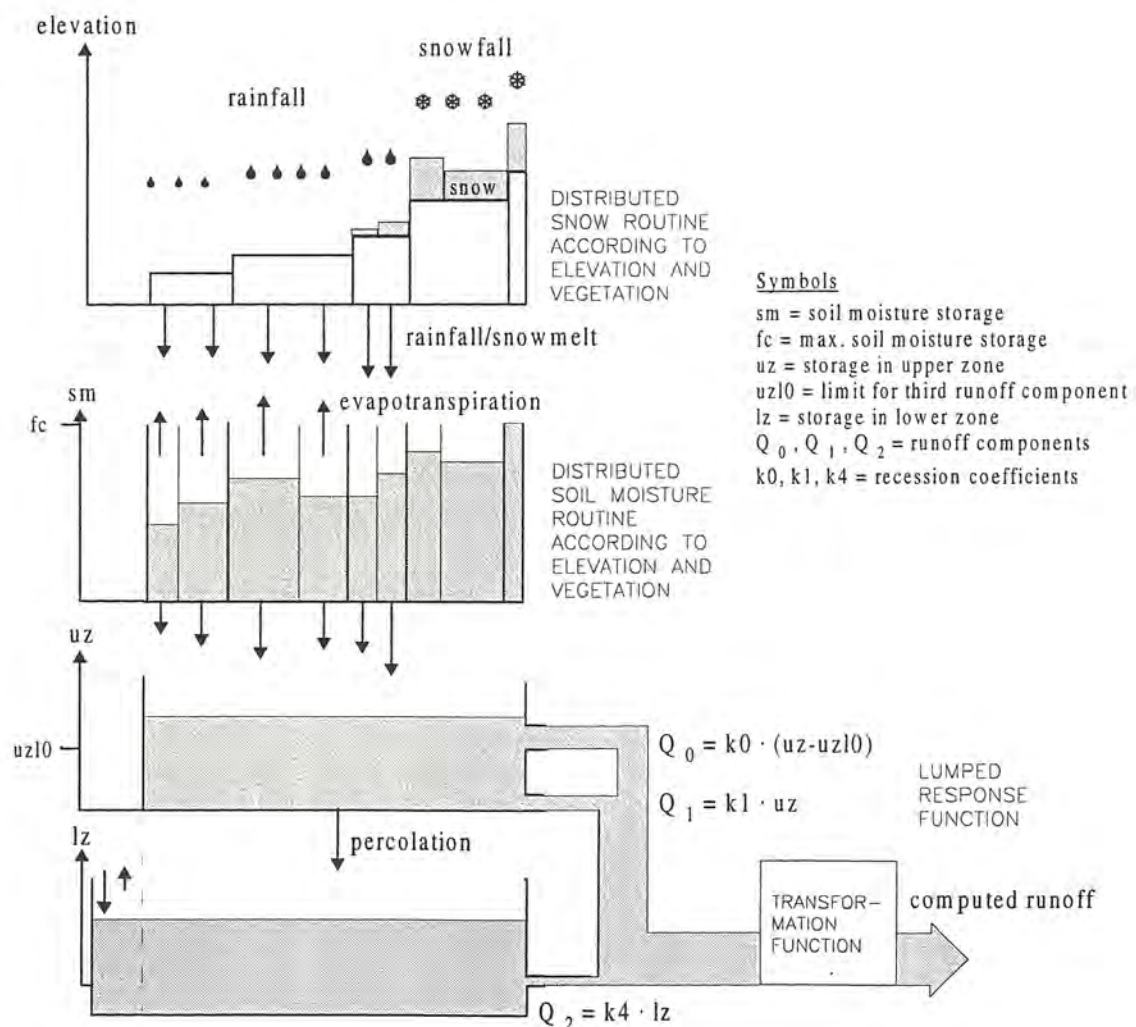


Figure 1. The general structure of the HBV model when applied to one subbasin.

2.1.1 Snow

Snowmelt is calculated separately for each elevation and vegetation zone according to the degree-day equation:

$$Q_m(t) = CFMAX \cdot (T(t) - TT) \quad (1)$$

where: Q_m = snowmelt
 $CFMAX$ = degree-day factor
 T = mean daily air temperature
 TT = threshold temperature for snowmelt.

Because of the porosity of the snow, some rain and meltwater can be retained in the pores. In the model, a retention capacity of 10 % of the snowpack water equivalent is assumed. Only after the retention capacity has filled, meltwater will be released from the snow. The snow routine also has a general snowfall correction factor (SFCF) which adjusts for systematic errors in calculated snowfall and winter evaporation.

2.1.2 Soil moisture

Soil moisture dynamics are calculated separately for each elevation and vegetation zone. The rate of discharge of excess water from the soil is related to the weighted precipitation and the relationship depends upon the computed soil moisture storage, the soil saturation threshold (FC) and the empirical parameter β , as given in equation 2. Rain or snowmelt generates small contributions of excess water from the soil when the soil is dry and large contributions when conditions are wet (Figure 2).

$$Q_s(t) = \left(\frac{S_{sm}(t)}{FC} \right)^\beta \cdot P(t) \quad (2)$$

where: Q_s = excess water from soil,
 S_{sm} = soil moisture storage,
 FC = soil saturation threshold,
 P = precipitation, and
 β = empirical coefficient.

The actual evapotranspiration is computed as a function of the potential evapotranspiration and the available soil moisture (Eq. 3, Figure 2):

$$E_a(t) = \begin{cases} \frac{E_p \cdot S_{sm}(t)}{LP} & \text{if } S_{sm} \leq LP \\ E_p & \text{if } S_{sm} > LP \end{cases} \quad (3)$$

where: E_a = actual evapotranspiration
 E_p = potential evapotranspiration
 LP = S_{sm} threshold for E_p

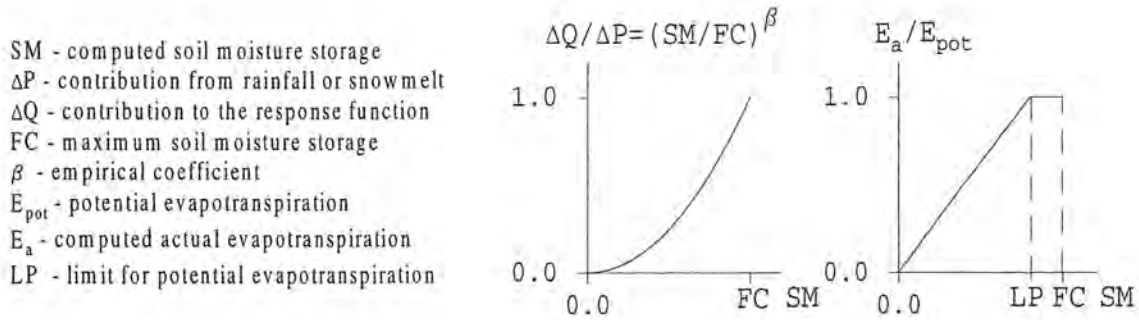


Figure 2. Schematic presentation of the soil moisture accounting subroutine.

2.1.3 Runoff response

Excess water from the soil and direct precipitation over open water bodies in the catchment area generate runoff according to equations (4) and (5).

$$Q_u(t) = \begin{cases} S_{uz}(t) \cdot (K_0 + K_1) - K_0 \cdot UZL & \text{if } S_{uz} > UZL \\ K_1 \cdot S_{uz}(t) & \text{if } S_{uz} \leq UZL \end{cases} \quad (4)$$

$$Q_l(t) = K_4 \cdot S_{lz}(t) \quad (5)$$

where: Q_u = runoff generation from upper response tank
 K_0, K_1, K_4 = recession coefficients
 UZL = storage threshold between K_0 and K_1
 S_{uz} = storage in upper response tank
 $PERC$ = percolation rate between the tanks
 Q_l = runoff generation from lower response tank
 S_l = storage in lower response tank

In order to account for the damping of the generated flood pulse ($Q = Q_0 + Q_1$) in the river, a simple routing transformation is made. This is a filter with a triangular distribution of weights with the base length MAXBAS. There is also an option of using the Muskingum routing routine to account for the river flow hydraulics.

Lakes in the subbasins are included in the lower response tank, but can also be modelled explicitly by a storage discharge relationship. This is accomplished by subdivision into subbasins defined by the outlet of major lakes. The use of an explicit lake routing routine has also proved to simplify the calibration of the recession parameters of the model, as most of the damping is accounted for by the lakes.

2.2 Model applications

The HBV model was originally developed for inflow forecasting to hydropower reservoirs in Scandinavian catchments, but has now been applied in more than 30 countries all over the world (Figure 3). Despite its relatively simple structure, it performs equally well as the best known model in the world (see WMO, 1986 and 1987).

Some examples of model applications are: inflow and flood forecasting and computation of design floods in totally about 170 basins in Scandinavia (Häggström, 1989; Bergström et al., 1989; Harlin, 1992; Killingtonveit and Aam, 1978; Vehviläinen, 1986), modelling the effects of clearcutting in Sweden (Brandt et al., 1988), snowmelt flood simulation in Alpine regions (Capovilla, 1990; Renner and Braun, 1990; Braun and Lang, 1986), hydrological modelling in Arctic permafrost environment (Hinzman and Kane, 1991),

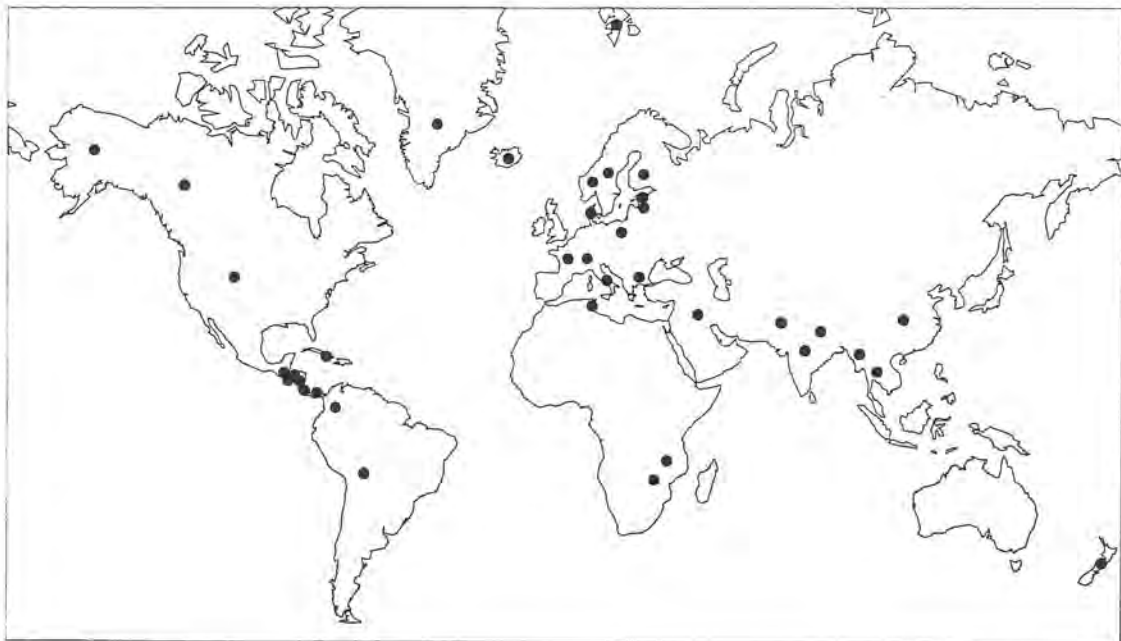


Figure 3. Countries or regions where the HBV model is known to have been applied.

inflow forecasting to a dam in River Indus (Sanner et al., 1994) and flood forecasting in Central America (Häggström et al., 1990).

2.3 Model calibration

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

$$R^2 = \frac{\sum (\bar{Q}_o - Q_o)^2 - \sum (Q_c - Q_o)^2}{\sum (\bar{Q}_o - Q_o)^2} \quad (6)$$

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

R^2 has a value of 1.0, if the simulated and the recorded hydrographs agree completely, and 0 if the model only manages to produce the mean value of the runoff record. Another useful tool for the judgement of model performance is a graph of the accumulated difference between the simulated and the recorded runoff. This graph reveals any bias in the water balance and is often used in the initial stages of calibration, for example for assessment of the snow parameters.

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

The HBV model is a conceptual model lumping many heterogeneous catchment characteristics into rather simple linear and non-linear equations. Although model components clearly represent individual hydrological processes, flow-generating pulses should not be interpreted as emanating from exact locations in the catchment. The model formulation has been developed so that the integrated response of all flow pulses during a time step is captured. Parameter values are therefore integrated and specific for each catchment and can not easily be obtained from point measurements in the field.

2.4 The forecasting procedure

The HBV model is often used for either short or long range forecasting. Before the day of forecast the model is run on observed input data until the time step (day) before the forecast. If there is a discrepancy between the computed and observed hydrographs during the last days of run, updating of the model should be considered. The HBV model is normally updated by an iterative procedure during which the input data a few days prior to the day of forecast is adjusted. Updating should always be done with caution, since the updating procedure may introduce additional uncertainty over the forecast period.

Short range forecasts are usually made in flood situations. The runoff development is forecasted until the culmination has passed. A meteorological forecast is used as input, and there is a possibility to use alternative precipitation and temperature sequences in the same run. This is often desirable due to the often low accuracy of quantitative meteorological forecasts, especially as concerns precipitation.

Long range forecasts are mainly used for two purposes: prediction of peak flow and of runoff volume. For operating hydropower reservoirs, the remaining inflow to a given date is often the most interesting figure, while in other basins the interest is concentrated towards the distribution of peak flows. The latter aspect is, of course, the most important if flood damage is the main problem. On the other hand, for some rivers, low flow forecasts can be the most interesting ones. The forecast uses precipitation and temperature data from corresponding periods of preceding years as input. Usually data from at least 10 years are used. The distribution of different simulations gives an indication of the probability that a given value will be exceeded. The volume forecast is supplemented with a statistical interpretation of the result.

2.5 Model calculation of river discharge

Information on river discharge is often needed in more detail than long term mean values. The discharge varies a lot during a year and also from one year to another. Since water flow measuring stations are expensive to run it is often easier to calculate the discharge at points without flow metering using a rainfall-runoff model. Normally measurements of precipitation and temperature are made more frequent than measurements of water discharge. After input of precipitation and mean temperature and information of subbasin elevation and distribution of lakes, open land and forest the HBV-model can calculate river discharge for any catchment without discharge measurements.

First the model has to be calibrated for catchments with discharge measurements. It is during the calibration process important to find variables valid for the whole region. For obtaining this, calibrations and verifications are made for all discharge stations in the region, trying to find variable values that gives acceptable results everywhere. These variables are then used for calculation of discharge in catchments in the region without discharge measurements. This method gives values with some uncertainty, and therefore only weekly or monthly values are proper. The method is, however, often the only possible way of getting information of the discharge and runoff, for example, in areas without

possibility to install a stream gauging station or when information is needed for years that already have passed. The method is also a less costly alternative to discharge stations.

3. THE IHMS-HBV MODEL APPLICATION TO LIELUPE RIVER BASIN IN LATVIA

3.1 The climate and hydrology in Latvia

The total area of the Republic of Latvia is 64 000 km².

At West and Northwest the border is the Baltic Sea and the Gulf of Riga. The distance between Northern and Southern border is 210 km and Western and Eastern border 450 km. The variation in altitude differ from the Baltic sea level up to 312 m above sea level. The territory with altitude over 200 m covers only 2.5% of the total area of Latvia, (LVU, 1975).

All the territory of Latvia is within one climatic region - moderately mild and moist. Winters are cold with average January temperatures from -2°C in the Western part to -7°C in the Eastern. Summer is temperate with average July temperatures reaching 16°-18°C respectively.

Winds are predominant Southwest during the whole year and air humidity is high. The largest amount of precipitation falls on the Western and South-western parts of the highest hills (Vidzemes, Kurzemes, Aluksnes) - 700-800 mm/annual, while this value decreases to 550-600 mm/annually in the lower plains (Zemgales, Piejuras). Only 20-30% of the total precipitation falls during the cold winter months. The highest yield of rainfall is in July and August.

Snow cover has an average duration of 80 to 90 days in the territory of Latvia. It is usually formed in the beginning of December in the Eastern part of the Republic, and in the last days of December in the Western part. The maximum depth of snow cover appears at the beginning of spring. The distribution is rather irregular. Highest value of snow depth is observed in the Eastern and North-eastern part - 20-40 cm with a duration of about 4 months. In the Western part of Latvia snow cover reaches only 10-20 cm with a duration of 2 months. Stable snow cover is not established every year.

There are 761 rivers longer than 10 km in Latvia. Total length of all rivers (included also the smallest ones) is 37 500 km. Mean density of rivers in Latvia is around 0.58 km on 1 km². River net covers the land more or less proportionally. Densest net of the rivers is located on the slopes of the hills with a large amount of precipitation, and on the Eastern and Southern plains with clay soils. There is a predominance of small rivers in Latvia. Only 13 rivers have a watershed with an area of more than 2000 km².

Latvian rivers have a hydrological regime typical to most of the east-European rivers with the maximum flood during spring. More than 50% of the annual runoff is generated from snow melt, 30% from rainfall events and the remaining 20% from

groundwater discharge during low flow periods. During summer the discharge is low with periodical increases due to rainfall. Increase in discharge can also be observed during intensive rainfall period in autumn.

The Lielupe basin (Figure 4) is essentially a conspicuously flat valley plain stretching out from the Gulf of Riga. The watershed is defined by Kurzemes- and Zemaitija hills to the West and Southwest, and the Svetonia- and Augszemes hills to the East and Southeast. On the North-eastern side - the watershed towards the Daugava basin - the two river basins are separated by a difference in altitude of only a few meters.

The main part of the landscape is very flat. Altitude differences are small, with the highest points reaching over 150 m situated in the Zemaitija- and Svetonia hills. At the Musa-Nemunelis plains altitude has dropped to 60 m, and over the last 60 kilometres from Jelgava down to the mouth the altitude is, with few exceptions, below 10 m.

The climate in the Lielupe basin is cool-temperate. Winters are cold with average January temperatures around -5°C and snow from beginning /mid December to the end of March/ beginning of April. Summers are temperate with average July temperatures reaching 17 to 18°C .

The predominant wind direction is South-west (more West during the summer and South during the winter), with the main part of the precipitation arriving with low pressures coming in over the Baltic Sea from the Atlantic Ocean.

Situated in rain-shadow in the East and North-east part of the Kurzeme (in Latvia) and Zemaitija (in Lithuania) hills, precipitation in Lielupe basin is moderate, reaching about 600 mm per year (594 mm in Bauska). With regard to the 1951-1993 average, the precipitation is evenly distributed over the year. Rainfall is, however, more abundant during summer and autumn, with 63% of the total amount during the six month's period from June to November.

Variation in precipitation between years is moderate. During the 1980s, the driest year (1984) received 484 mm, while the most humid year (1980) got 711 mm of precipitation (figures from Bauska).

Evapotranspiration is about 400 mm/year, with the main portion (ca 320 mm) during the vegetation period. This leaves about 200 mm/year for runoff.

Due to the generally low gradient of the river channels in the basin, the basin is made up by a lot of small tributaries. The rivers in the basin are slow flowing with shallow river channels. At the confluence of rivers Musa and Memele - at the town of Bauska - the Lielupe is about 75-100 m wide and more than 5 m deep in the middle. Speed of flow here is roughly 0.2-0.3 m/s. In the lower reaches of the river, the width ranges among 100 and 300 m and in some places up to 600 m. The depth is from 2.5 to 9 m, (IVL Report, 1992).

Starting in the area between Mezotne and the city of Jelgava, the level of Lielupe River is normally within a few meters above sea level. From here and down to the river mouth the gradient of the river is five to ten centimetres per kilometre, and occasions of high water level in the Gulf of Riga have a damming effect on the flow of the river.

The first limnigraph not affected by the sea level is situated in the village of Mezotne, located between Bauska and Jelgava. The average discharge (1920-1993) of the Lielupe river at Mezotne is 56.8 m³/s, (6.0 l/s*km²), with a drainage basin of 9 390 km². The calculated discharge at the river mouth in the Gulf of Riga is 110 m³/s, corresponding to 6.2 l/s*km².

Monthly runoff is, due to melting snow, highest in April. Rain floods of less intensity do also occur during the autumn. Runoff is low through the vegetation season, from May to September.

3.2 The IHMS-HBV model application to the Lielupe River

3.2.1 Basin subdivision

The total catchment of the Lielupe River is 17 600 km². In the model application the basin is divided into 13 subbasins (Table 1 and Figure 4).

Table 1. Subbasin division of Lielupe river basin.

Subbasin (name)	Total area (km ²)	Local area (km ²)
Sudrabkalni	313	313
Mazzalve	1180	1180
Tabokine	2690	1198
Bauska	5320	5320
Mezotne	9390	1380
Apsites	600	600
Bramberge	330	330
Uzini	632	632
Dupsi	519	519
Balozi	904	904
Jelgava	11900	2510
Kalnciems	16500	1614
Jurmala	17600	1100

The strategy for the subbasin division is mainly based on location of discharge stations. Water level registrations and discharge measurements are performed from 10 of the subbasins. Runoff data from these stations are used for calibration of the model parameters.

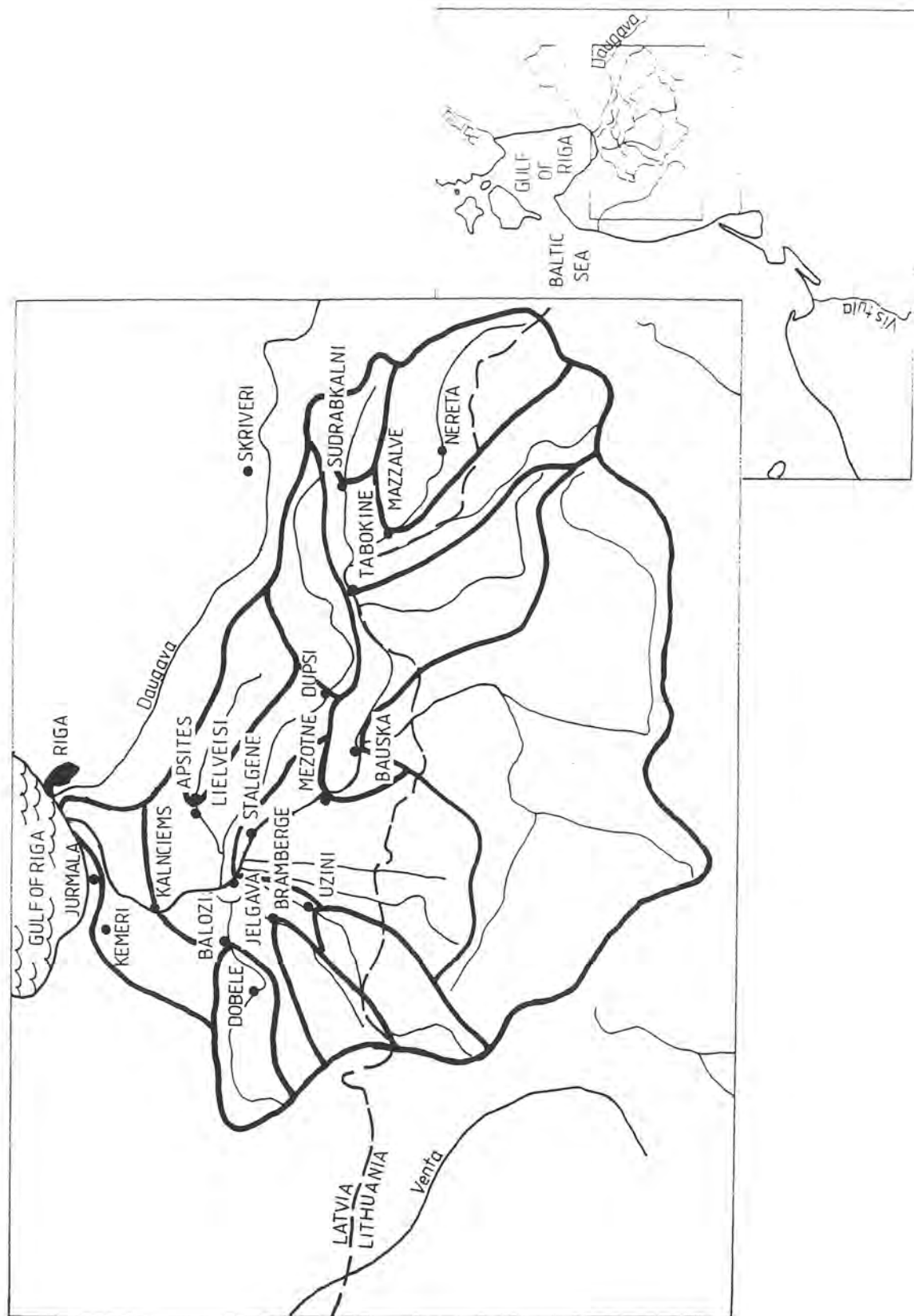


Figure 4. The Lielupe catchment, basin subdivision and location of precipitation, temperature and discharge stations.

Three subbasins, Jelgava, Kalnciems and Jurmala, are located in the most downstream part of Lielupe River basin. During high sea level in the Gulf of Riga the water levels are affected by the sea level. Water level registration and discharge measurements are for that reason useless to fulfil and consequently no data for calibration are available. From these subbasin model parameters are decided according to calibration from surrounding basins with runoff data available for calibration.

3.2.2 Analysis of input data

Precipitation is the source of streamflow generation and consequently the most important input parameter to the HBV model. Furthermore, temperature data and long term estimates of potential evapotranspiration are needed as input. In the model application to Lielupe River 18 precipitation stations and 5 temperature stations in the territory of Latvia for the period January 1, 1984 to December 31, 1993 were used, figure 4. Although large part of the Lielupe Basin is located in Lithuania no stations have been used from this area. Thiessen polygons and the figures over the isohyetal pattern over the catchment were used for calculation of the station weights. A summary of the total station weights in Lielupe Basin area are presented in Table 2.

Table 2. *Precipitation and temperature stations and weights used in the HBV model application for the calibration period 1984 - 1993.*

Station (Type)	Precipitation Weight(%)	Temperature Weight(%)	Annual average precipitation (mm)
Bauska (P,T)	21.4	54.9	590.2
Dupsi (P)	15.9	-	592.5
Mazzalve (P)	9.7	-	600.8
Mezotne (P)	6.3	-	587.6
Nereta (P)	8.8	-	692.3
Sudrabkalni (P)	4.1	-	755.7
Tabokine (P)	3.9	-	728.6
Bramberge (P)	1.8	-	561.4
Uzini (P)	2.7	-	637.0
Kalnciems (P)	2.4	-	676.8
Balozi (P)	0.5	-	617.2
Apsites (P)	1.7(→1993-02-01)	-	728.4
Lielveisi (P)	1.7(1993-02-28→)	-	657.1
Stalgene (P)	3.8	-	430.3
Kemeris (P)	1.6	-	684.0
Jurmala (P,T)	1.6	6.0	620.4
Jelgava (P,T)	6.5	16.6	583.7
Dobele (P,T)	7.3	8.3	589.6
Skriveri (T)	-	14.2	-

The double mass technique was used to check homogeneity of the precipitation and discharge records. This technique takes advantage of the fact that the mean accumulated precipitation for the number of gauges is not very sensitive to changes at individual stations because many of the errors compensate each other, however the cumulative curve for a single gauge is immediately affected by a change at the station.

The mean accumulated precipitation for all other stations is plotted on the X-axis against that for the gauge being studied, which is plotted on the Y-axis. If the double mass curve has a change in slope at some point in time, it indicates a break in homogeneity. A jag in the double mass curve can be caused by missing values at the observed station or by seasonal differences in the precipitation pattern. The slope of the curve is proportional to the intensity, i.e. if the observed station records exactly as much as mean of the rest, the curve follows the diagonal. If the station records more, the slope will be steeper and if it records less, the double mass curve will lie below the diagonal.

All double mass curves from Lielupe basin are presented in Appendix A. Some of the curves show signs of inhomogeneity. Figure 2, 4 and 12 in Appendix A with curves from the three precipitation stations Dupsi, Mezotne and Stalgene respectively show a decrease in the precipitation registration during the control period. This decrease can be, as in case of Dupsi and Mezotne with a slow decrease giving a bended curve, due to trees growing higher and higher in the vicinity of the station or, as in the case of Stalgene with a very rapid decrease during the year of 1992, due to a change of location of the precipitation collector. Figure 10 in Appendix A with double mass curve from precipitation station Kalnciems show a slow increase of precipitation registrations during the control period. This is probably due to changes in the area surrounding the registrator as concerning vegetation, buildings, etc.

Despite this inhomogeneous situation for the above mentioned stations no corrections within the data periods were made. Data from homogeneous stations with reliable data, as for instance Bauska, Nereta, Tabokine, Uzini and Balozī were used with a major extent in the calibration process.

Monthly mean values of potential evapotranspiration were compiled from evaporimeter pan measurements at stations Kemerī and Zosenī, Table 3.

Table 3. Mean evapotranspiration (mm/day) data used in the HBV model application.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Zosenī	0.00	0.10	0.31	1.20	2.01	2.53	2.35	1.91	1.25	0.65	0.08	0.00
Kemerī	0.00	0.00	0.37	1.30	3.23	4.27	3.85	3.10	1.87	0.88	0.08	0.00

3.2.3 Calibration

Data bases of precipitation, runoff, temperature and areas for all subbasins were compiled. A description of geographical zones with altitude and type of vegetation for each subbasin was fulfilled and introduced in the list of parameters.

Calibration was carried out against runoff data for the period 1988-01-01 to 1993-12-31, with verification period 1984-01-01 to 1987-12-31. In the calibration process the R^2 -value of model fit together with the accumulated difference between the simulated and recorded runoff was used to check model performance. The modelled and observed hydrographs were plotted and visually inspected.

3.2.4 Model results

Figures 1 to 10 in Appendix B are printouts from model results for the 10 calibrated subbasins in Lielupe Basin. The plot period in Appendix B, 1989-10-01 -- 1991-11-30, is selected for all subbasins.

Table 4. Span of the most important model parameter values for the 10 calibrated subbasins in Lielupe River.

Parameter	Value	Function
<u>Snow routine</u>		
SFCF	1.0-1.13	Snowfall correction factor
TT	-0.2- 0.4	Threshold temperature for snowmelt
CFMAX	3.5-4.6	Degree-day factor
<u>Soil Routine</u>		
FC	170-350	Maximum soil water capacity
LP	0.4-0.9	Threshold for potential evapotranspiration
BETA	2.8-4.0	Empirical coefficient
<u>Upper response tank</u>		
Ko	0.01-0.13	Flood recession parameter
K1	0.04-0.1	Intermediate flow recession parameter
UZL	15-40	Flood recession threshold
<u>Lower response tank</u>		
PERC	0.1-0.5	Ground water percolation
K4	0.0002-0.01	Base flow recession parameter

Results of R^2 -values of model fit for the calibrated subbasins on the Lielupe Basin over the whole data period were more or less acceptable with exception of one subbasin,

Uzini, with an R^2 -value of 0.32. Performance criteria over individual subbasins are presented in Table 5.

The total runoff from Lielupe River over the year is dominated by snowmelt with a sharp increase of river discharge during spring. Increase of discharge can also be observed as cause of intensive rainfall in autumn. Low discharge is observed during summer with only periodical increases due to heavy rainfall.

The HBV model can simulate the hydrology of the Lielupe River with acceptable but not good model performance. Mean R^2 value for whole Lielupe basin is 0.60 for the calibration period and 0.65 for the verification period. Good results have been obtained for the subbasins Sudrabkalni (0.80-0.80), Mazzalve (0.61-0.70) and Balozī (0.66-0.75). The most important precipitation stations used in the calibration process for these subbasins are of good quality as for instance Nereta and Dobeļe (Appendix A, Figures 5 and 16) with homogenous records for the whole calibration and verification period.

Table 5. R^2 values of model fit for the modelled outflow from the calibrated subbasins on the Lielupe Basin.

Subbasin	Calibration period	R^2	Verification period	R^2
Sudrabkalni	880101-931031	0.80	840101-931031	0.80
Mazzalve	880101-931231	0.61	840101-931231	0.70
Tabokine	880101-931231	0.62	840101-931231	0.68
Bauska	880101-931231	0.57	840101-931231	0.63
Mezotne	880101-931231	0.49	840101-931231	0.66
Apsites	880101-930210	0.61	840101-930210	0.66
Bramberge	880101-931231	0.64	840101-931231	0.61
Uzini	880101-931231	0.39	840101-931231	0.32
Dupsi	880101-931231	0.61	840101-931231	0.65
Balozī	880101-931231	0.66	840101-931231	0.75

Calibration result of subbasin Uzini is not acceptable, Appendix B, Figure 8. The R^2 - value is only 0.39 for the calibration period and 0.32 for the verification period. Major part of this subbasin is located outside Lithuania and consequently no precipitation stations within the subbasin are available in the calibration process. The best located precipitation station, Uzini, has a very consistent record (Appendix A, Figure 9) and would normally give an acceptable model result. Uncertainties in the runoff measurements with current meters and in estimation of and use of rating curves for calculation of discharge will also affect model result.

Other subbasins with bad model result are Bauska and Mezotne. Bauska is the most wide subbasin in Lielupe catchment but totally without any representative precipitation

or temperature station. This fact will affect model result drastically and an acceptable agreement between recorded and modelled hydrographs will be very hard to achieve. Mezotne is another big subbasin without representative precipitation stations inside the area.

Normally, there are stable snow covers during winter in the Lielupe Basin with spring floods in the middle of March. The period used for calibration was warmer than normal with no or only low coverage of snow in the catchment. Consequently the spring flood did not reach its typical shape.

Good and reliable runoff measurements are essential. Without homogeneous runoff data it is very difficult to achieve a reasonable model result. Fluctuation of the air temperature during winter is a predominance for the accumulation of the large amount of sludge and ice in the Latvian rivers. The sludge makes it almost impossible to measure a correct water discharge with the type of propeller current meters used in the Latvian hydrological network. During summer growth of reed and other macrophytes in the river is considerable. This vegetation together with low water velocity makes flow current metering difficult. The Latvian current meters are normally of no use during these periods with slow summer discharges and consequently many of the rating curves are uncertain at low water levels. An utter discussion concerning discharge data quality is presented in the project report from homogeneity tests on discharge stations in Latvia and Estonia (Losjö and Wittgren, 1994).

3.2.5 Model applications

The main application of HBV model in the Lielupe Basin is to perform short-range runoff forecasts for the stations Mezotne and Bauska. These forecasts are to be used in a flood warning system which will enable authorities to warn the people who are being affected and to protect property threatened by the flood. Model results allow a forecast quite sufficiently. An example of short range forecast for the station Bauska has been made after model calibration. Long-range forecast based on statistical information from the database can be made for all calibrated subbasins. These forecasts are to be used for estimation of accumulated runoff from the snow cover during the spring period.

The HBV model will be a help in the check of quality of discharge measurements and runoff data of the Latvian national network. The calibration work showed that a more intense study must be made for example at the discharge station Uzini where a remarkable bad model result was achieved in spite of a homogeneous precipitation station. It can also be used for correction of ice-jam on the records. The model is furthermore able to identify inhomogeneities in the runoff records and to fill in gaps in the discharge series.

Due to the sea influence on the water level and discharge value downstream the discharge station Mezotne the modelled daily runoff will be uncertain. The main aim of the model set-up for this part of the river is to simulate monthly mean discharge for the unmeasured subbasins Jelgava, Kalnciems and Jūrmala. These values can then be used

to estimate total runoff from Lielupe River basin, important when exchange of water in the Gulf of Riga or the whole Baltic Sea is investigated or when total amount of nutrients or pollutions transported to the sea is calculated.

4. DISCUSSION

The HBV model was able to describe the mean flow of the Lielupe Basin with an explained variance, R^2 , of 0.60. This is a result of the good coverage of precipitation and temperature input data in the Latvian part of the Lielupe Basin but no stations at all in the Lithuanian part. Model application will most probably be improved if data from the Lithuanian part of Lielupe Basin can be included in the data base and used in future model applications. The poorest model performance was for site Uzini ($R^2=0.32$) and the best model result was achieved for site Sudrabkalni ($R^2=0.80$).

During the calibration process it was found that the quality of input data, discharge as well as precipitation and temperature, is a very important factor to achieve a good model result. The divergent model result from Uzini indicate that it is of great importance to more closely examine the input data used in the calibration.

5. CONCLUSIONS AND RECOMMENDATIONS

All the specific project objectives have been met and the following general conclusions have been made:

- The project has improved the hydrological information in the Latvian part of Lielupe basin through quality control of ten years of daily historical hydrometeorological data.
- The Integrated Hydrological Model System (IHMS) has been applied to the Lielupe basin. The IHMS gives possibilities to compute long continuous series of runoff at different sites within the basin and as a result different flow characteristics can be obtained for the different sites. The IHMS also gives possibilities to perform flood forecasts in a flood warning system for the Lielupe basin. Furthermore IHMS can be used to calculate mean river discharge from unmeasured parts of the Lielupe basin where river water level is affected by the sea.
- When representative temperature and precipitation data are available the HBV-model, included in the IHMS, performs well in the Lielupe basin. Even when there are no available temperature and precipitation data for parts of the basin, as for the basin area located in Lithuania, it is possible to have a fair model performance.

- The transfer of knowledge within the project in the maintenance of the model system has been very successful. The LHMA personnel is now capable to operate the IHMS as well as setup, calibrate and apply the system for new basins of interest.

The following recommendations are made:

- Hydrometeorological data from the Lielupe basin area located in Lithuania should be included in the IHMS database to improve model performance for this part of the river and the model parameters should be updated. The results from the HBV-model could considerably be improved if the quality and consistency of the meteorological data are increased.
- Due to doubt of quality of runoff data it is important to make further analysis of water level registrations, discharge measurements and rating curves.
- A prolongation of the hydrometeorological data base and input of real-time data is a prerequisite condition to enable the real-time runoff forecasting application.
- The knowledge of operating the IHMS-system should be spread further among the LHMA personnel and be maintained through operational use and new applications.

6. ACKNOWLEDGEMENT

Appreciation is expressed to the LHMA staff in Riga and the SMHI personnel at the division of Environment & Energy Services in Norrköping, for help and assistance during the project. Special thanks to Mr Evginij Zaharchenko for valuable back-up in Latvia and to Mr Bengt Carlsson, Ms Barbro Johansson and Mr Magnus Persson for support during on-the-job training. Dr Joakim Harlin gave useful advises throughout the project. Ms Barbro Johansson and Ms Eva-Lena Ljungkvist assisted in the layout of the figures.

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APPENDIX A

Double mass plots of the precipitation stations

The first part of the paper discusses the importance of understanding the cultural context of the research. It highlights the need for researchers to be sensitive to the values and beliefs of the communities they are studying. This is particularly important in the field of health research, where cultural differences can significantly impact the effectiveness of interventions.

The second part of the paper focuses on the methodology used in the study. It describes the process of selecting participants and the various data collection methods employed. The authors emphasize the importance of using a mix of qualitative and quantitative methods to gain a comprehensive understanding of the research topic.

The third part of the paper presents the findings of the study. It discusses the results of the data analysis and how they relate to the research objectives. The authors provide a detailed account of the challenges they faced during the research process and how they overcame them.

The final part of the paper offers conclusions and recommendations for future research. It suggests ways in which the findings of the study can be applied in practice and identifies areas for further investigation.

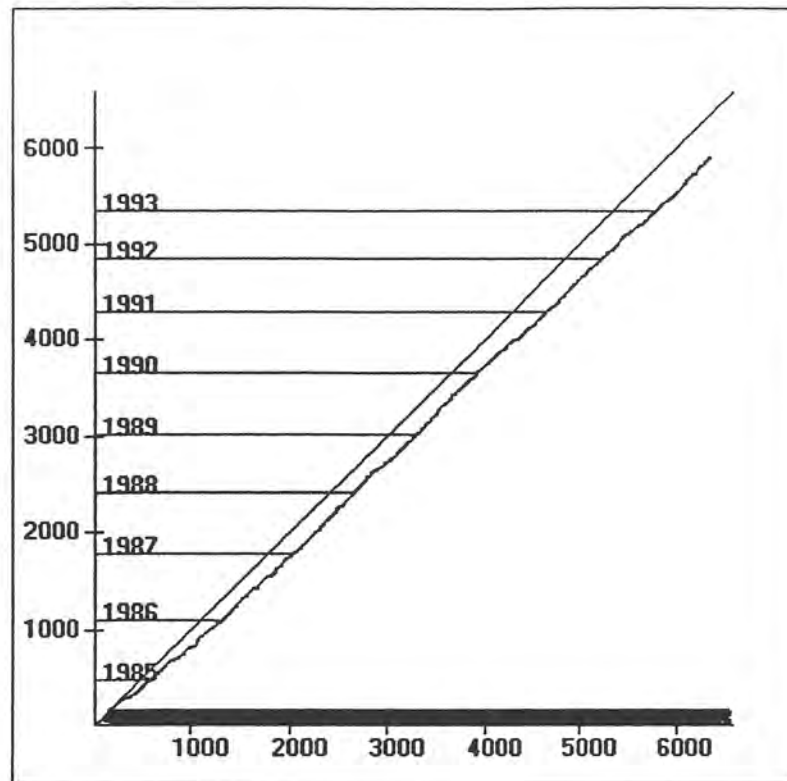


Figure 1 Bauska 19840101 - 1993123

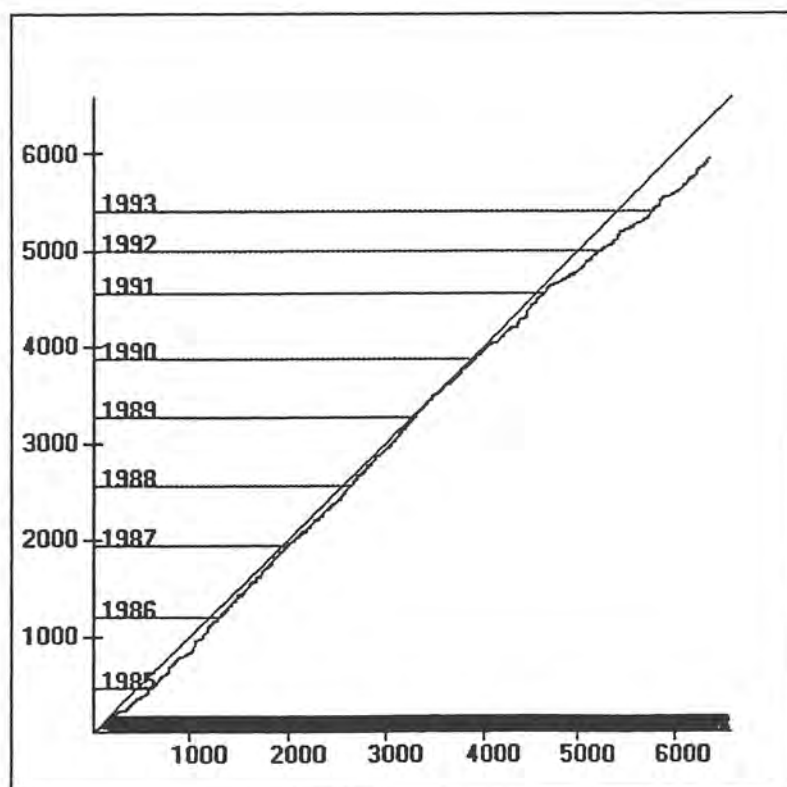


Figure 2 Dupsi 19840101 - 19931231

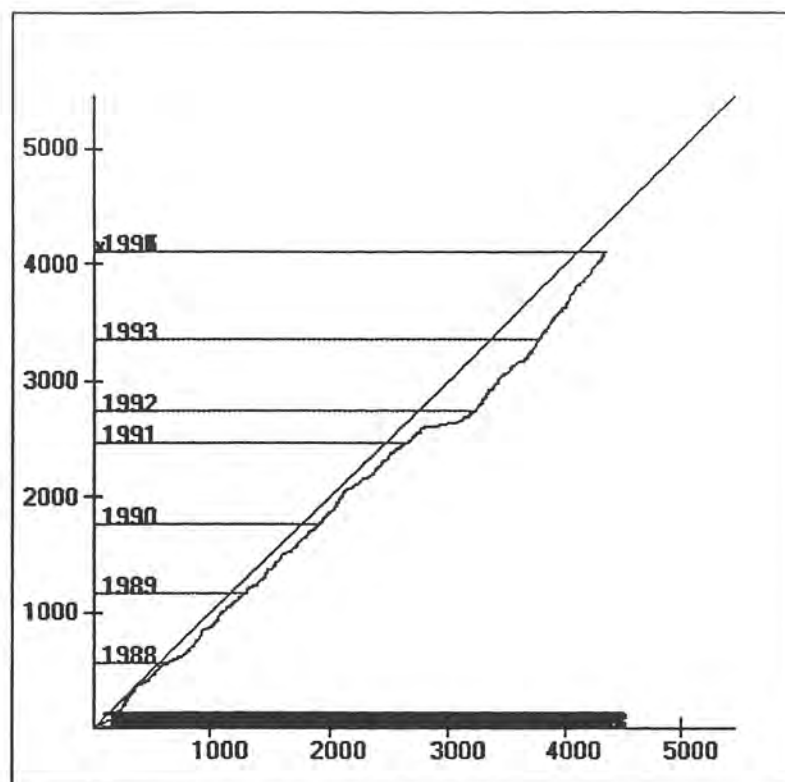


Figure 3 Mazzalve 19870101 - 19931231

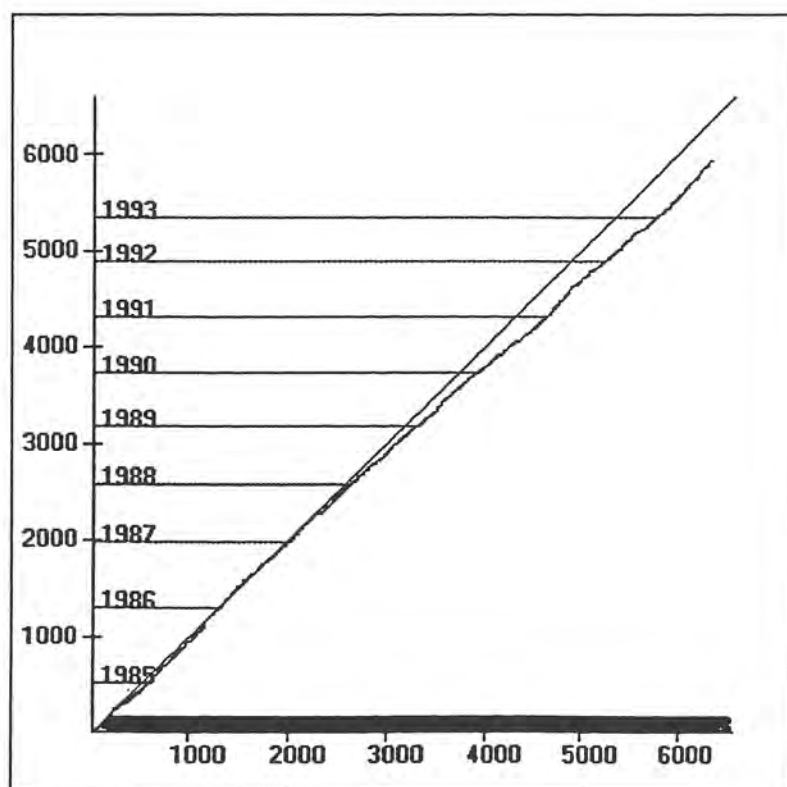


Figure 4 Mezotne 19840101 - 19931231

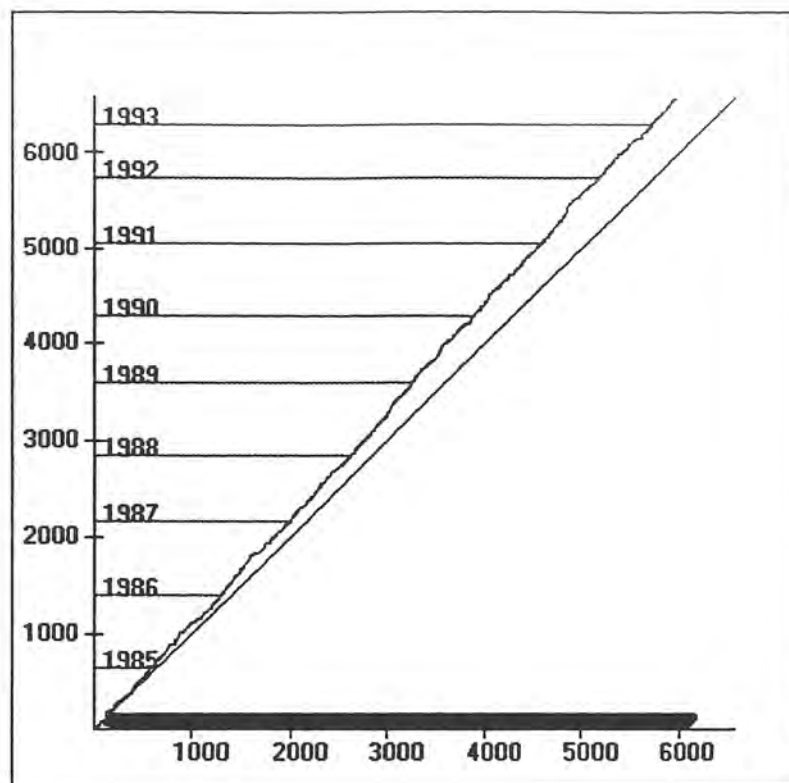


Figure 5 Nereta 19840101 - 19931231

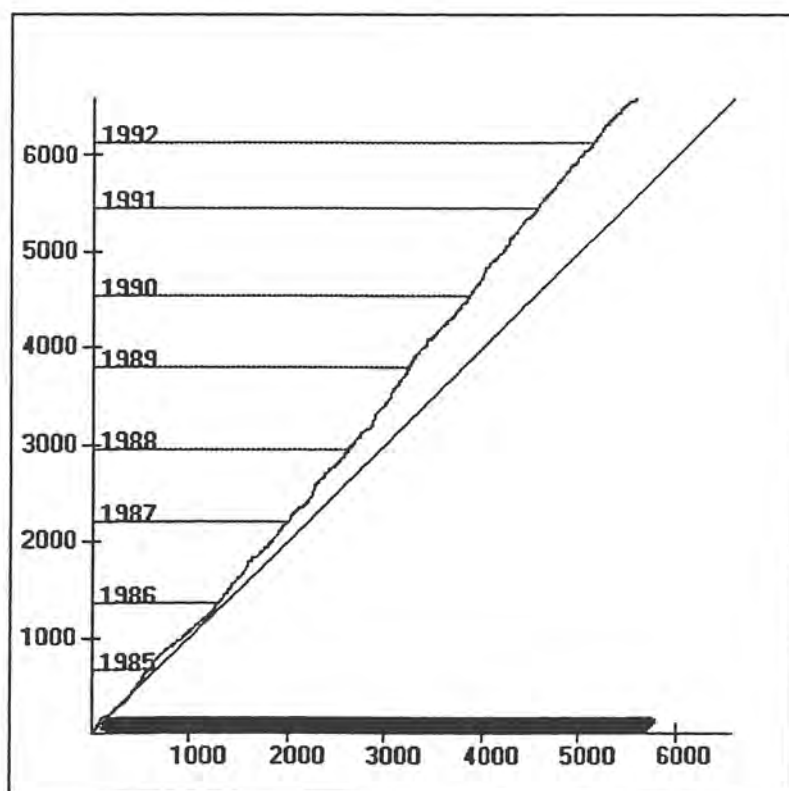


Figure 6 Sudrabkalni 19840101 - 19931231

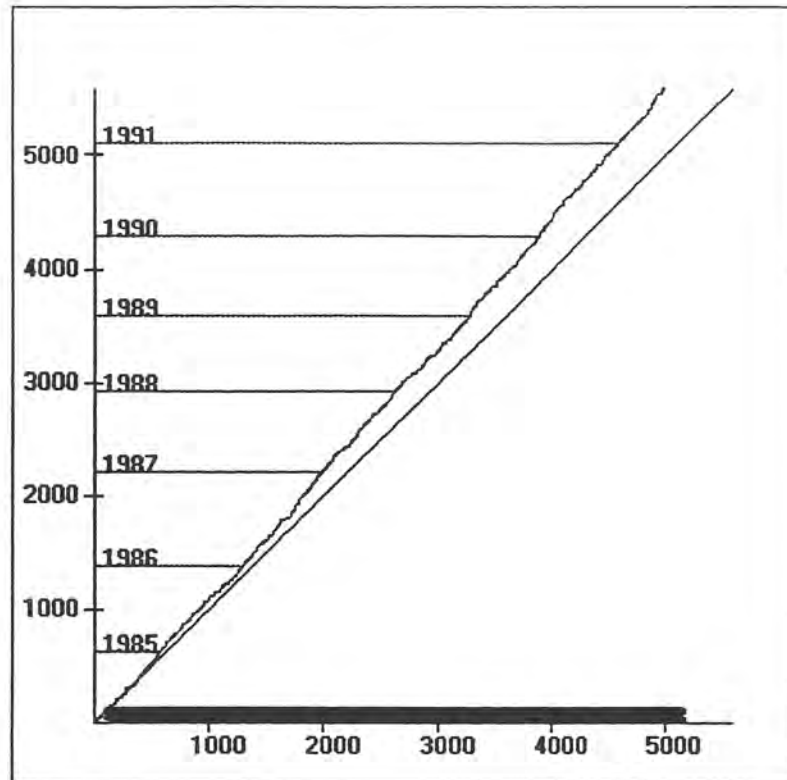


Figure 7 Tabokine 19840101 - 19920430

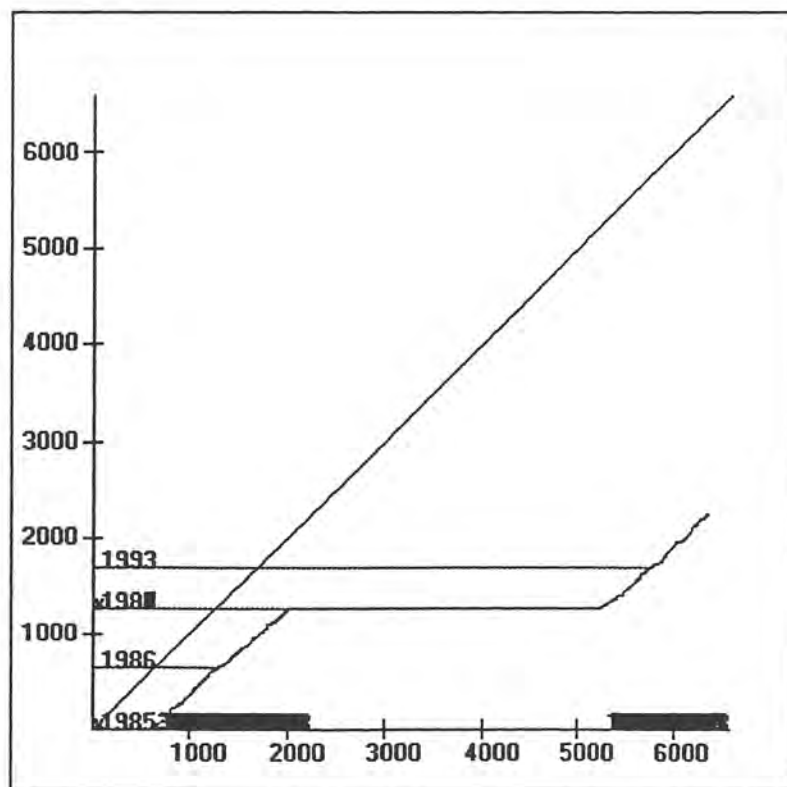


Figure 8 Bramberge 19840101 - 19931231

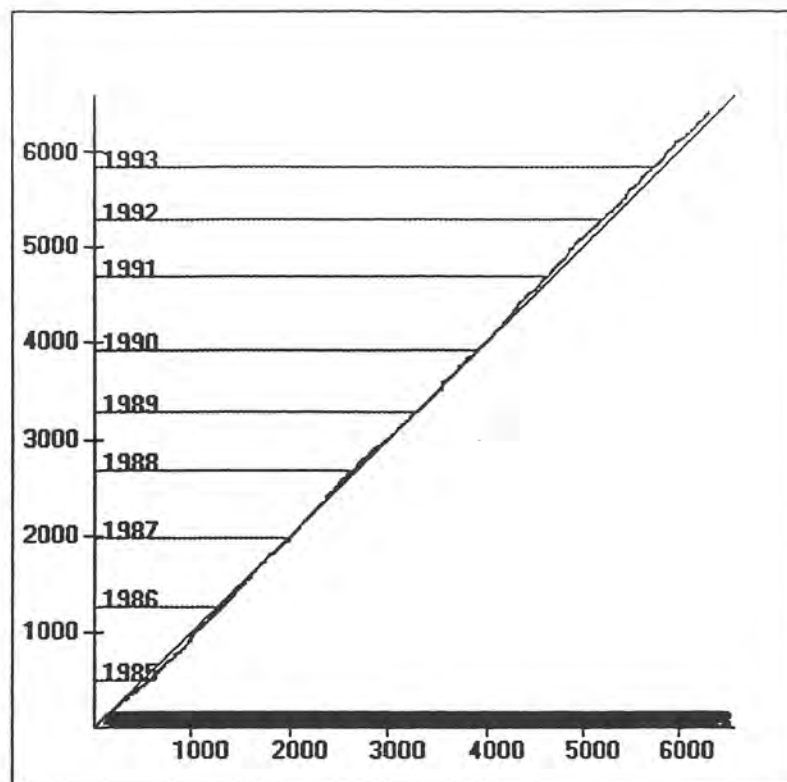


Figure 9 Uzini 19840101 - 19931231

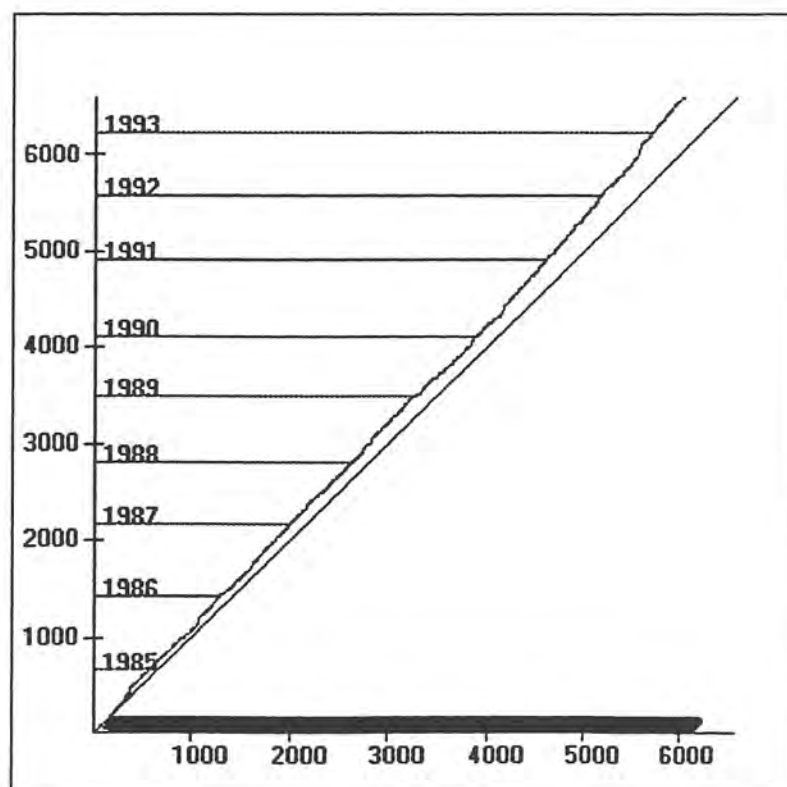


Figure 10 Kalnciems 19840101 - 19931231

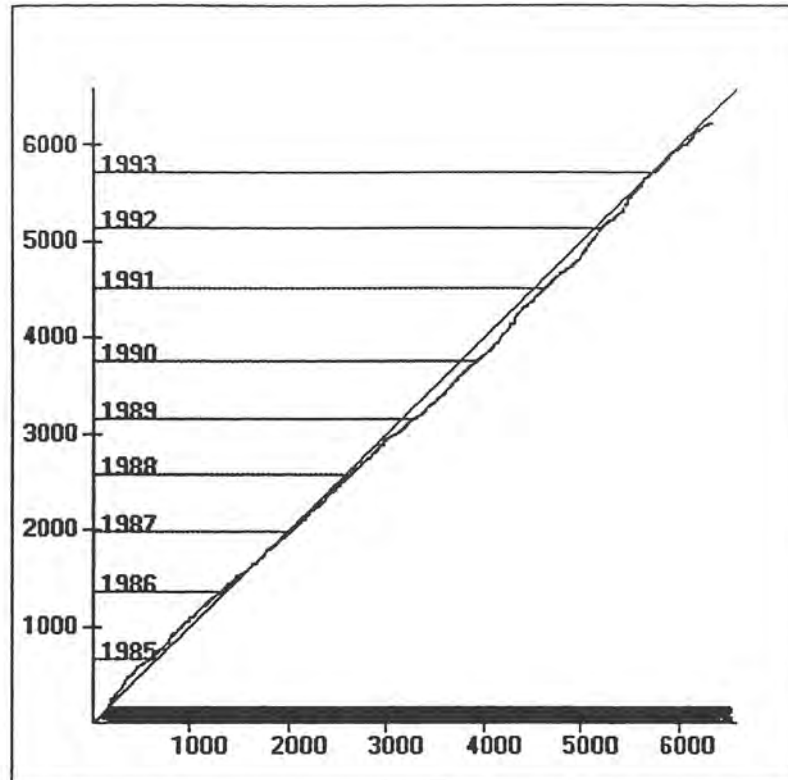


Figure 11 Balози 19840101 - 19931231

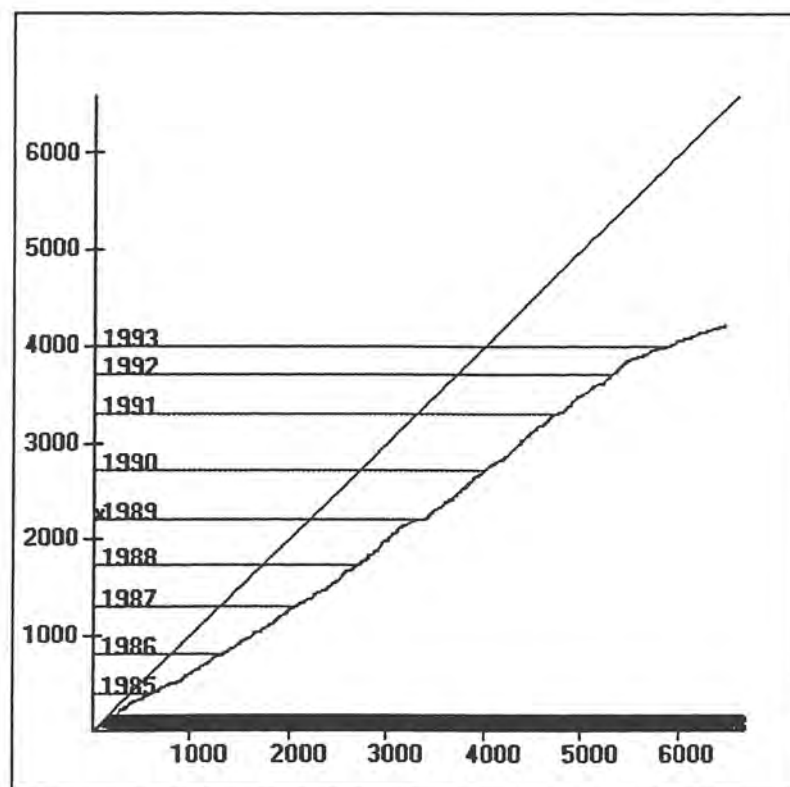


Figure 12 Сталгене 19840101 - 19931231

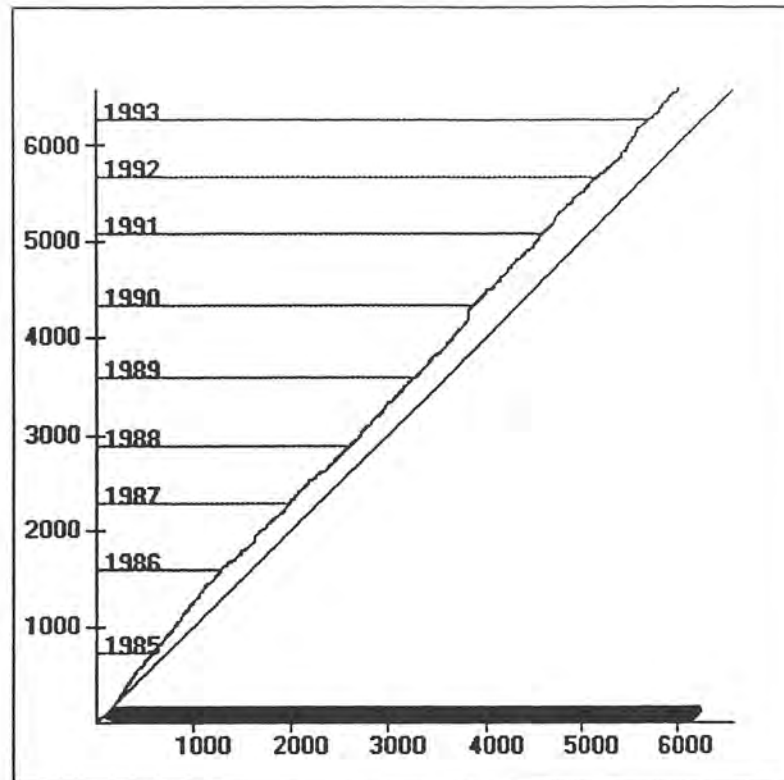


Figure 13 Kemer 19840101 - 19931231

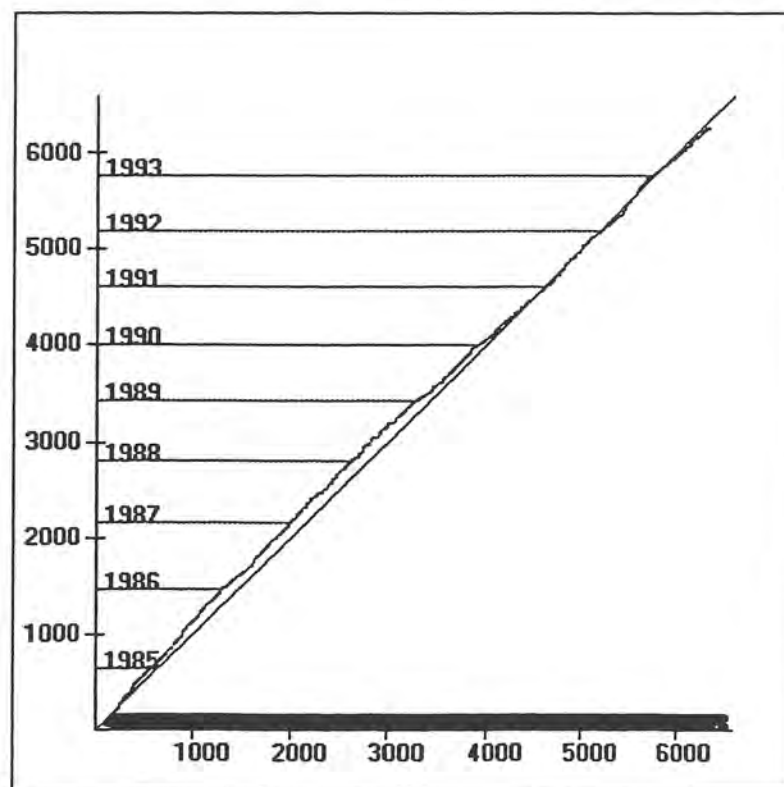


Figure 14 Jurnal 19840101 - 19931231

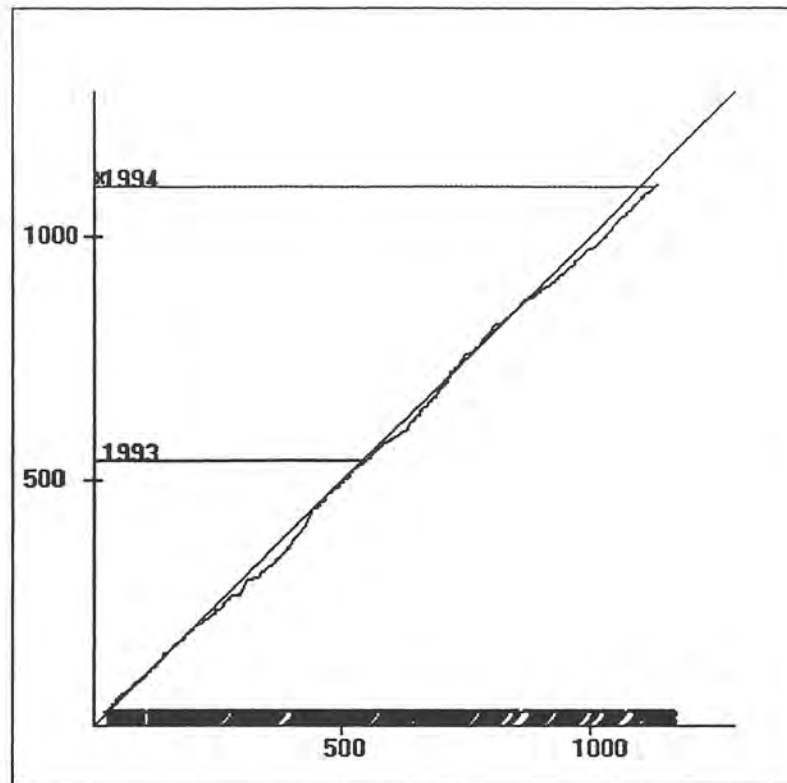


Figure 15 Jelgava 19920101 - 19931231

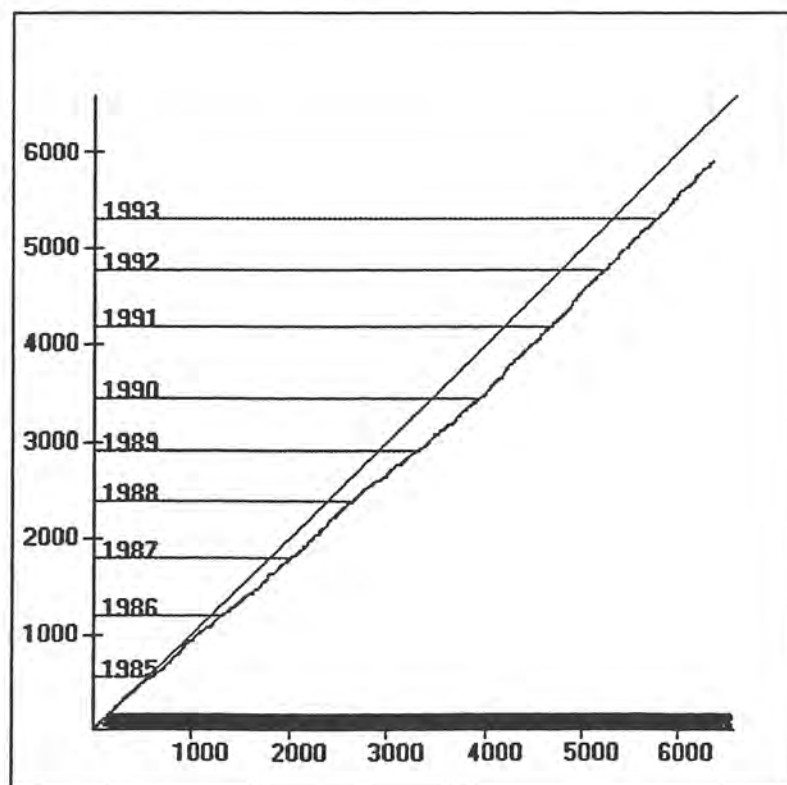


Figure 16 Dobeles 19840101 - 19931231

APPENDIX B

Calibration plots 1989-10-01 -- 1991-11-30

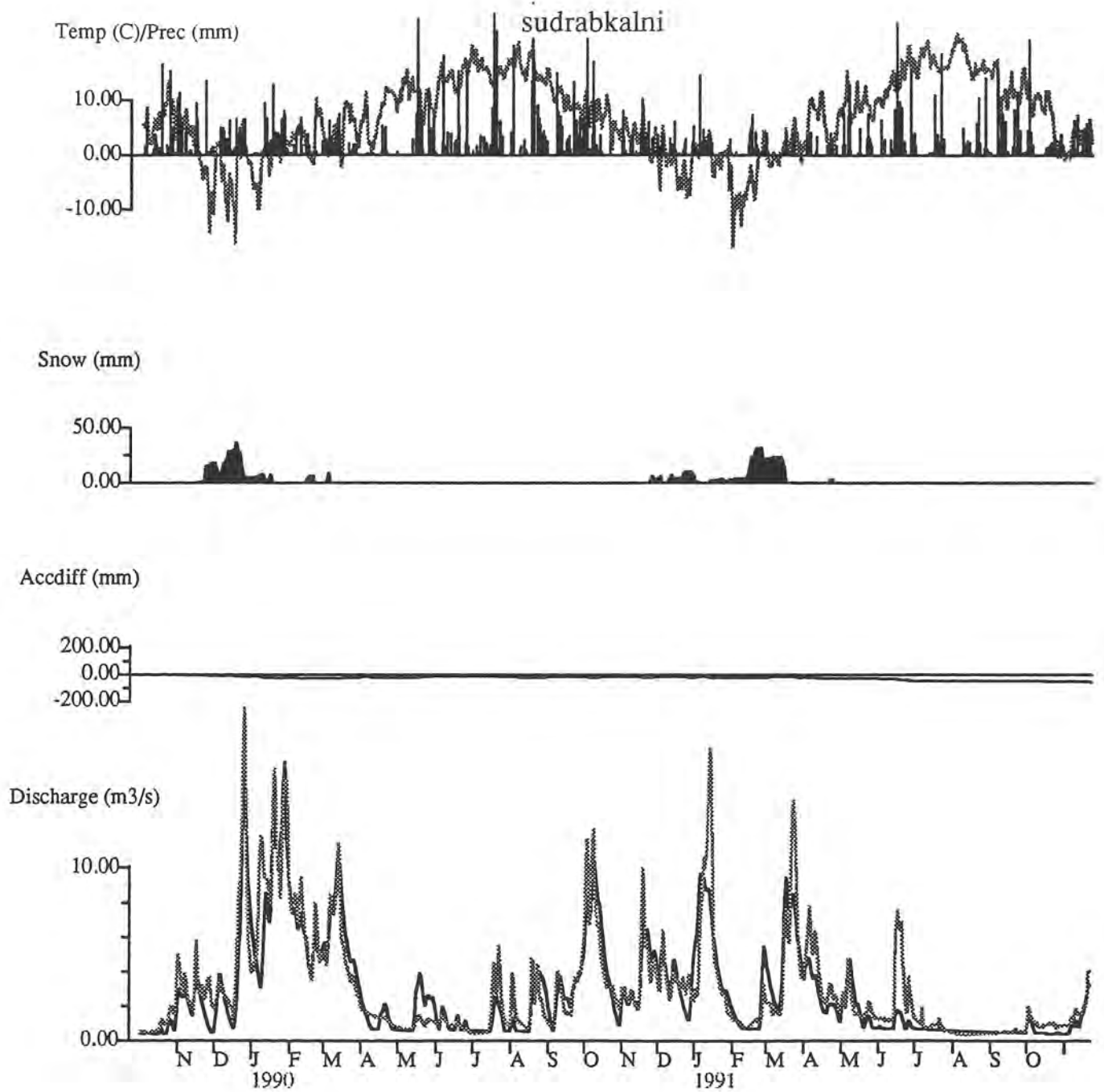


Figure 1 Model performance, Sudrabkalni basin.

- | | |
|---------|--|
| Graph 1 | Temperature - grey line |
| | Precipitation - black bars |
| Graph 2 | Water content in snow |
| Graph 3 | Accumulated difference between recorded and computed discharge |
| Graph 4 | Recorded discharge - grey line |
| | Computed discharge - black line |

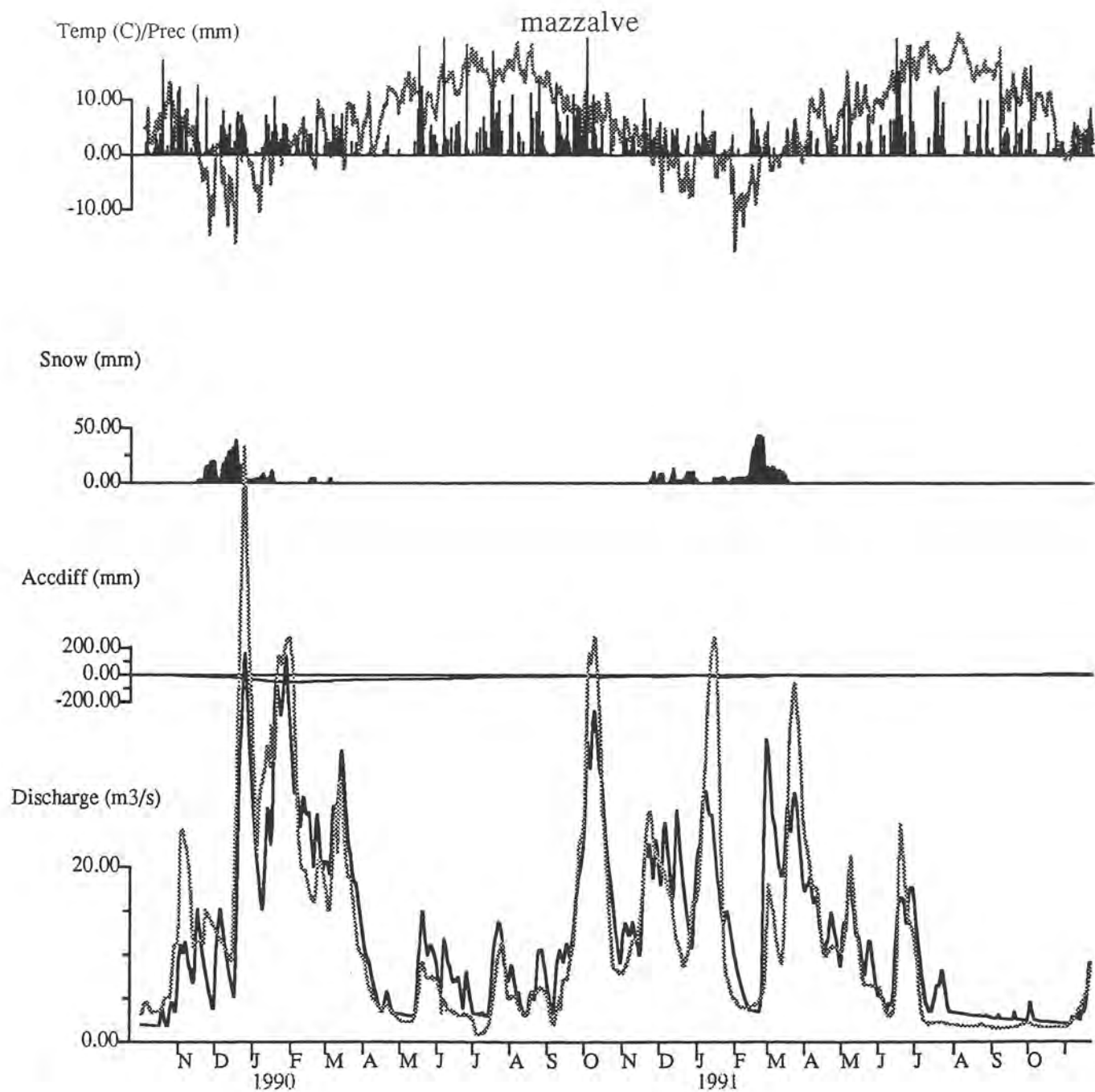


Figure 2 Model performance, Mazzalve basin.

- | | |
|---------|--|
| Graph 1 | Temperature - grey line |
| | Precipitation - black bars |
| Graph 2 | Water content in snow |
| Graph 3 | Accumulated difference between recorded and computed discharge |
| Graph 4 | Recorded discharge - grey line |
| | Computed discharge - black line |

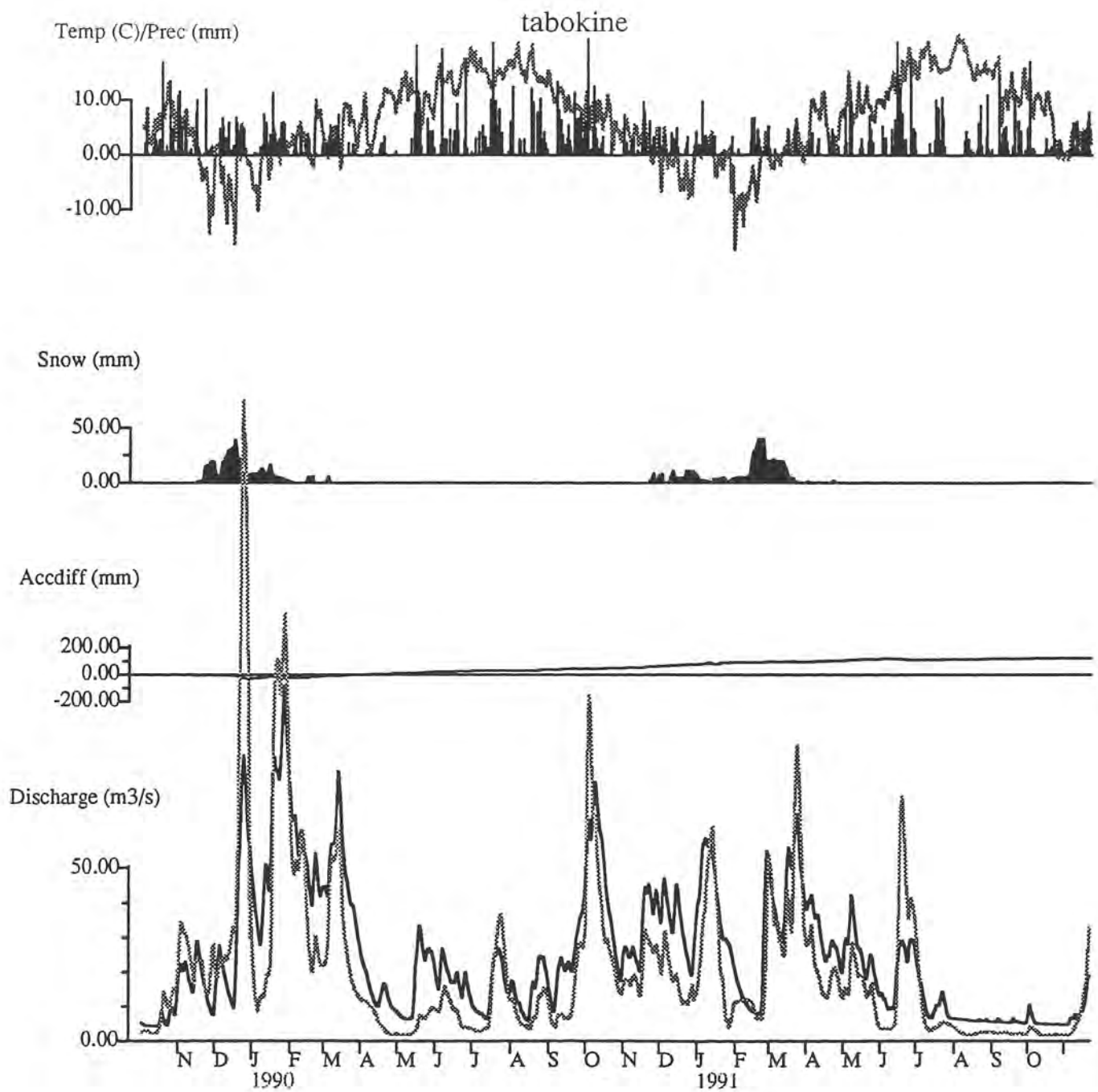


Figure 3 Model performance, Tabokine basin.

- | | |
|---------|--|
| Graph 1 | Temperature - grey line |
| | Precipitation - black bars |
| Graph 2 | Water content in snow |
| Graph 3 | Accumulated difference between recorded and computed discharge |
| Graph 4 | Recorded discharge - grey line |
| | Computed discharge - black line |

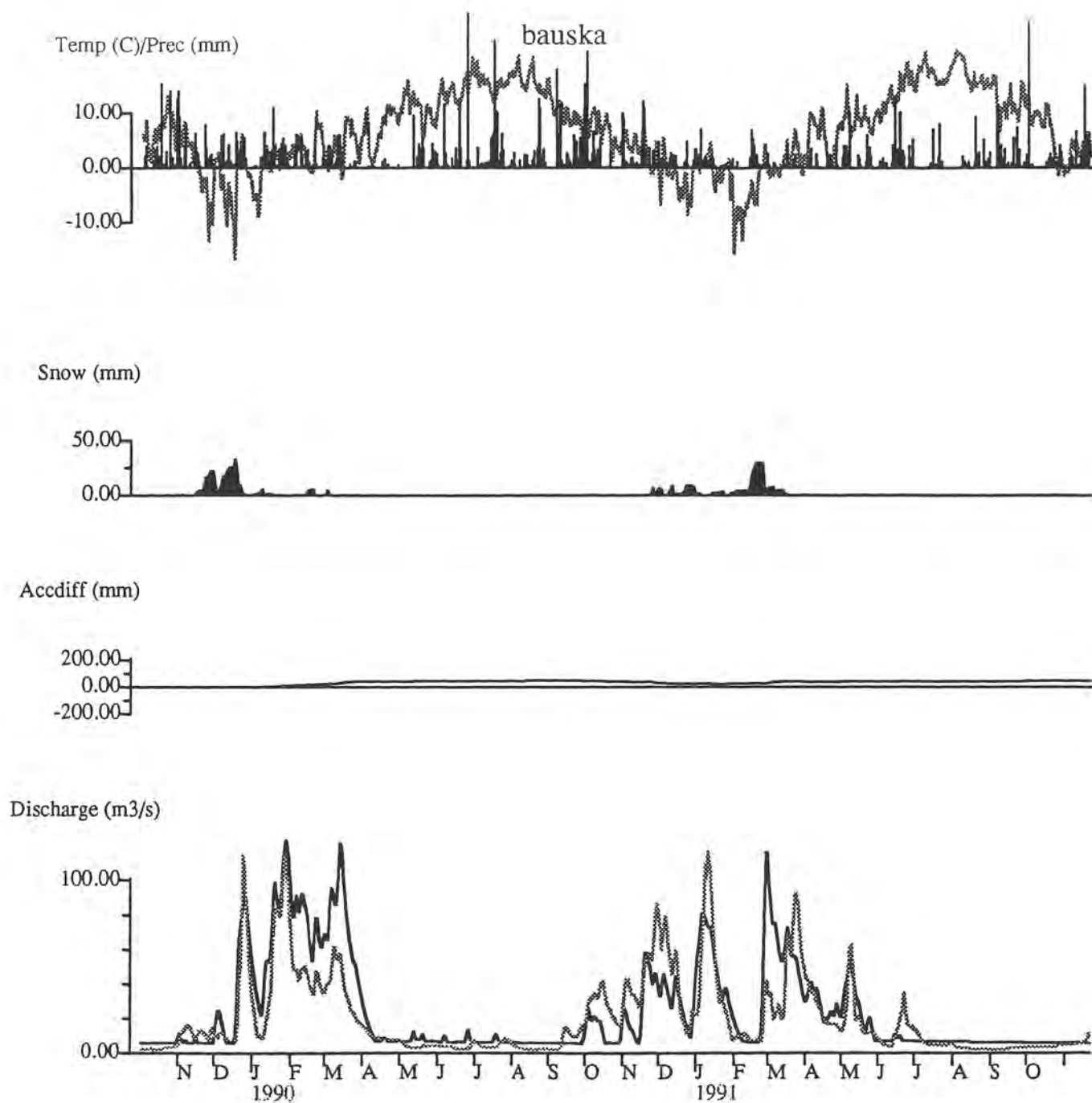


Figure 4 Model performance, Bauska basin.

- | | |
|---------|--|
| Graph 1 | Temperature - grey line |
| | Precipitation - black bars |
| Graph 2 | Water content in snow |
| Graph 3 | Accumulated difference between recorded and computed discharge |
| Graph 4 | Recorded discharge - grey line |
| | Computed discharge - black line |

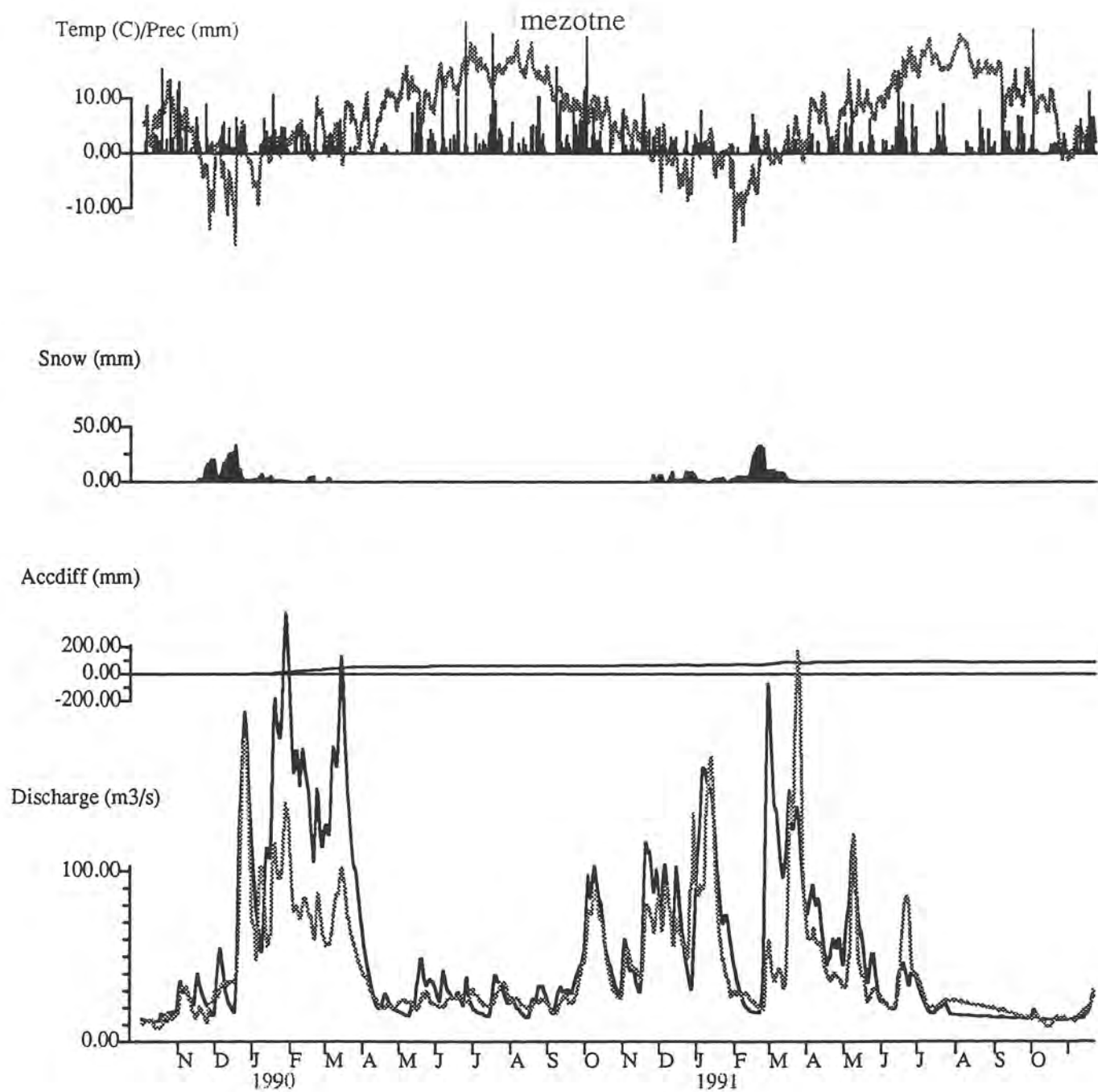


Figure 5 Model performance, Mezotne basin.

- | | |
|---------|---|
| Graph 1 | Temperature - grey line
Precipitation - black bars |
| Graph 2 | Water content in snow |
| Graph 3 | Accumulated difference between recorded and computed discharge |
| Graph 4 | Recorded discharge - grey line
Computed discharge - black line |

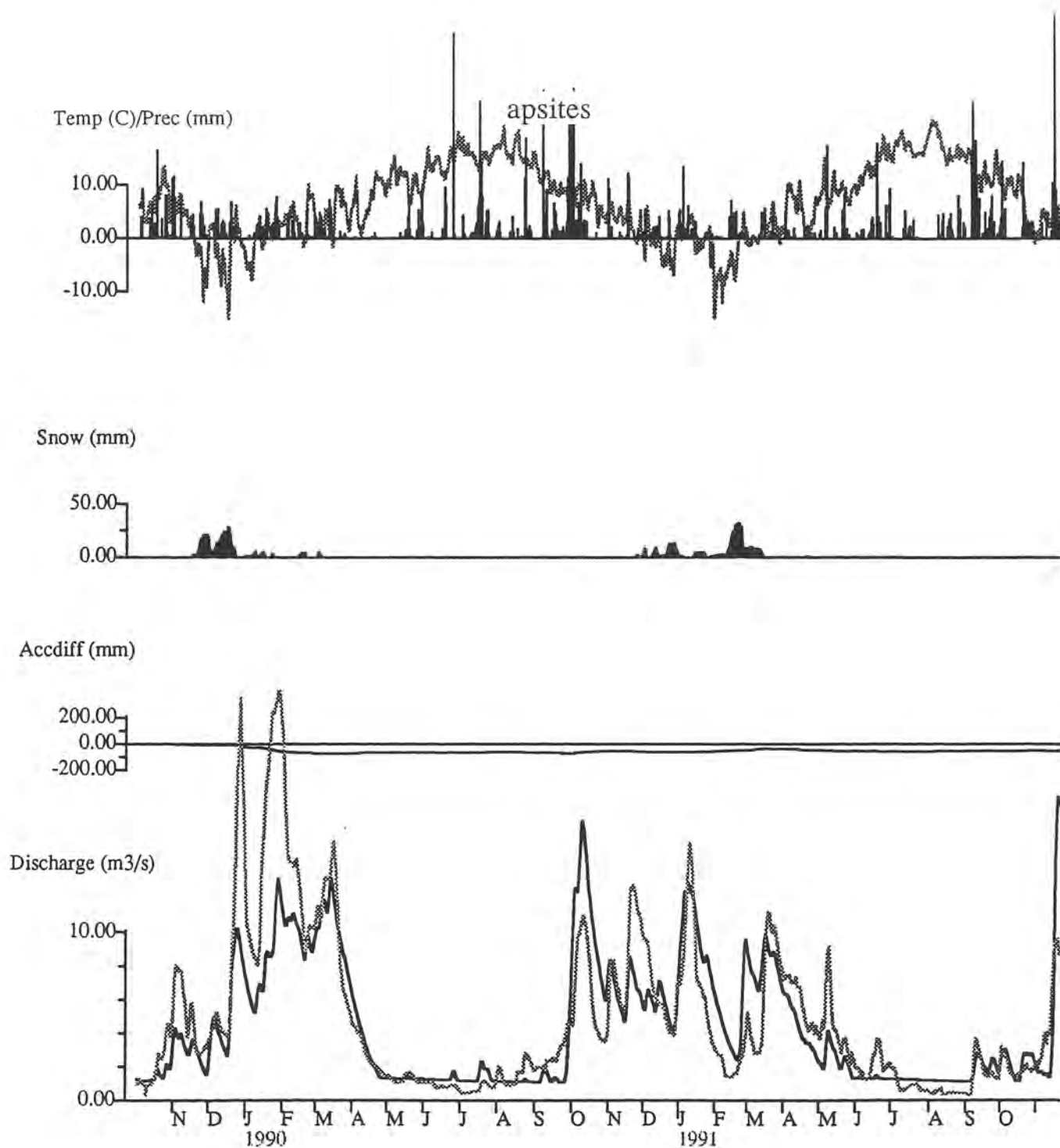


Figure 6 Model performance, Apsites basin.

- | | |
|---------|--|
| Graph 1 | Temperature - grey line |
| | Precipitation - black bars |
| Graph 2 | Water content in snow |
| Graph 3 | Accumulated difference between recorded and computed discharge |
| Graph 4 | Recorded discharge - grey line |
| | Computed discharge - black line |

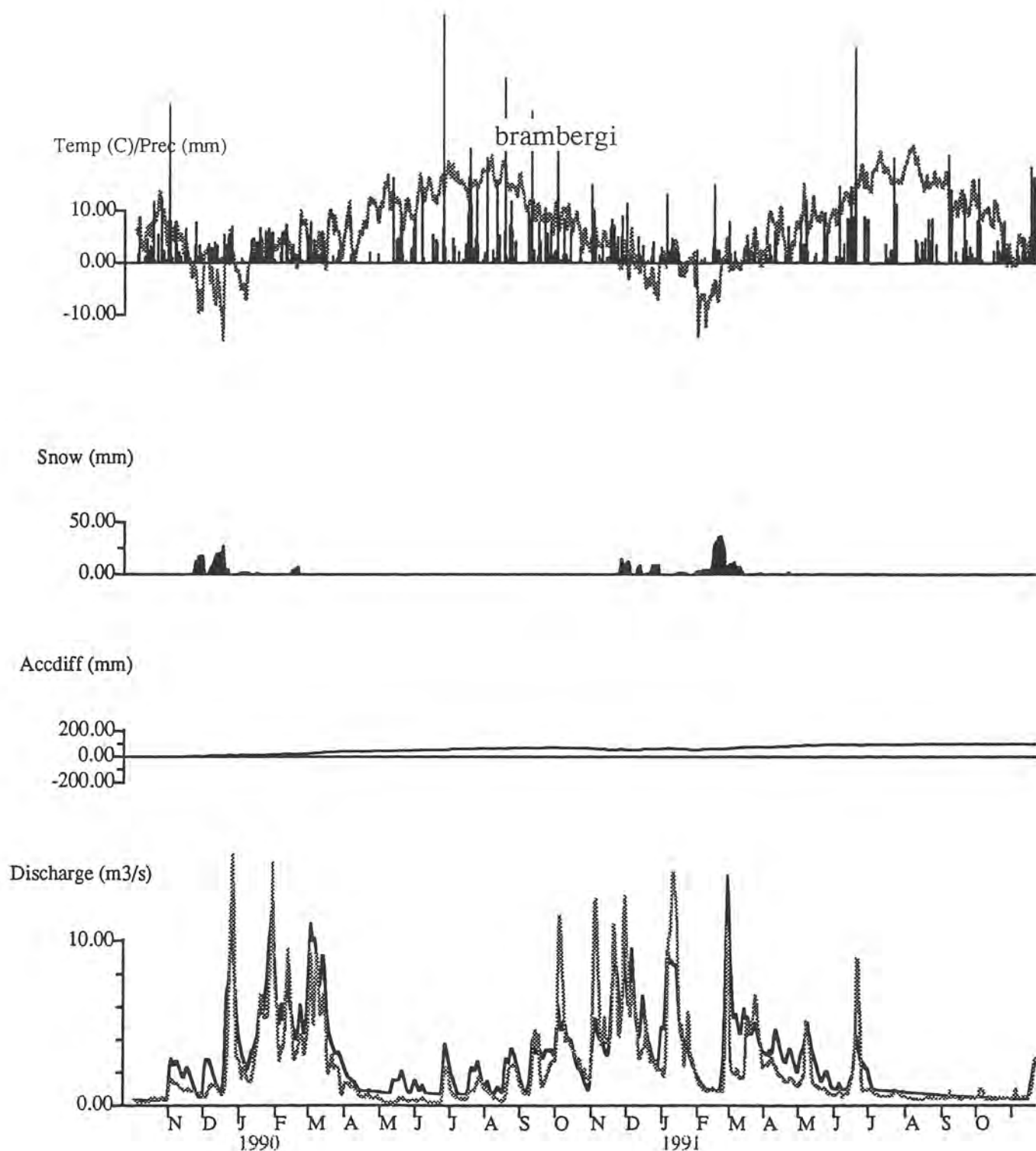


Figure 7 Model performance, Brambergi basin.

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|---------|--|
| Graph 1 | Temperature - grey line |
| | Precipitation - black bars |
| Graph 2 | Water content in snow |
| Graph 3 | Accumulated difference between recorded and computed discharge |
| Graph 4 | Recorded discharge - grey line |
| | Computed discharge - black line |

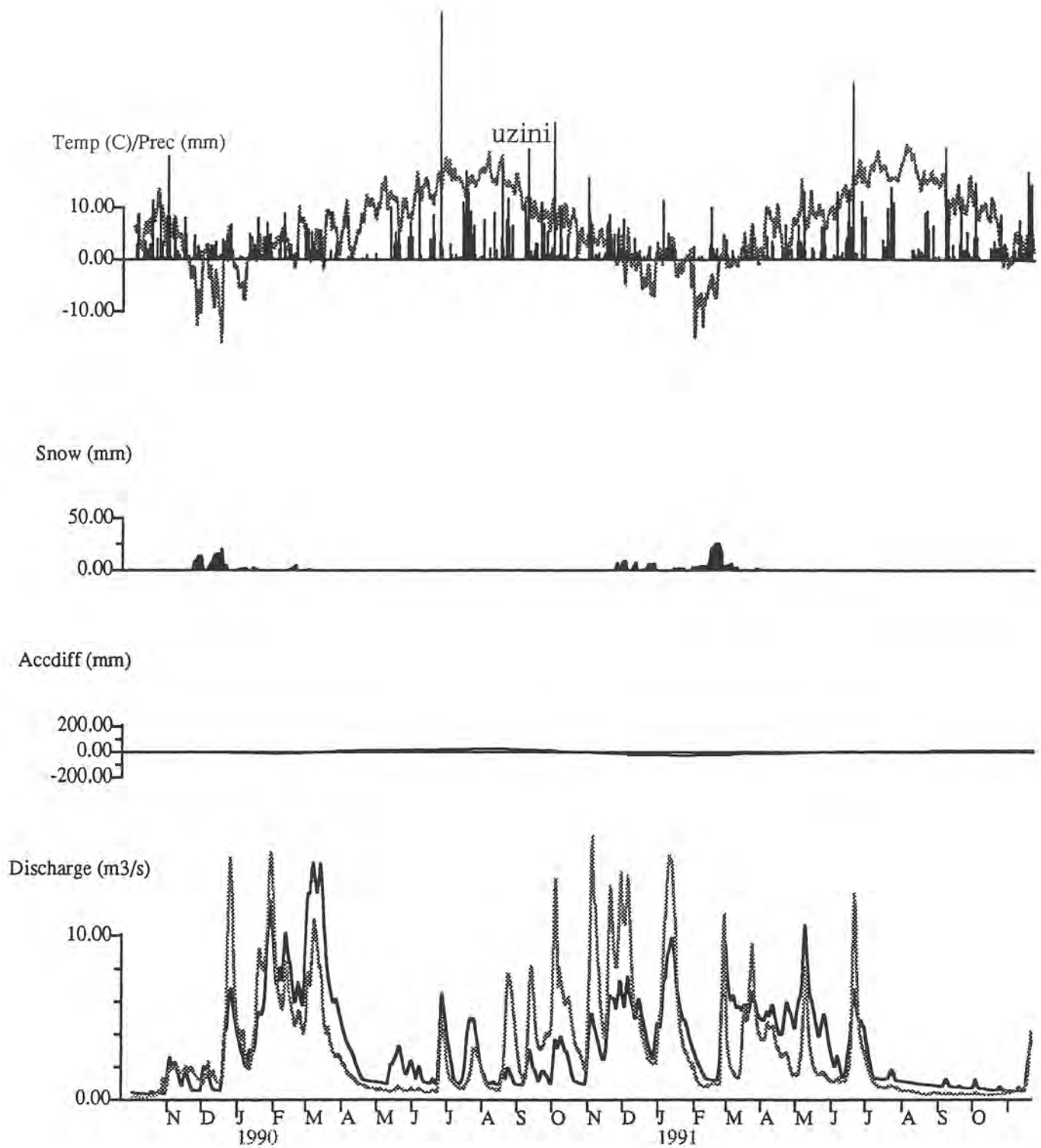


Figure 8 Model performance, Uzini basin.

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| Graph 1 | Temperature - grey line |
| | Precipitation - black bars |
| Graph 2 | Water content in snow |
| Graph 3 | Accumulated difference between recorded and computed discharge |
| Graph 4 | Recorded discharge - grey line |
| | Computed discharge - black line |

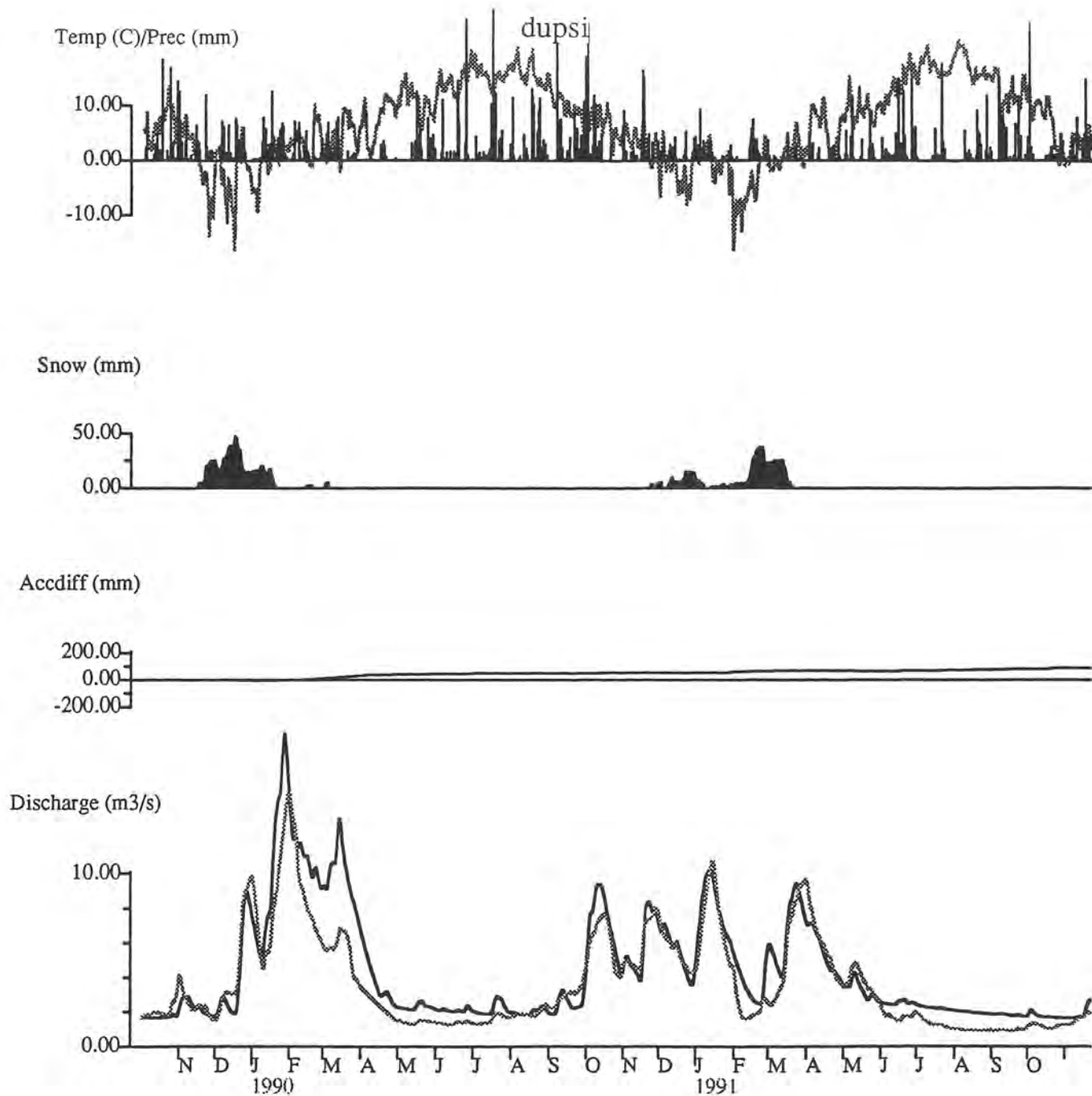


Figure 9 Model performance, Dupsi basin.

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|---------|--|
| Graph 1 | Temperature - grey line |
| | Precipitation - black bars |
| Graph 2 | Water content in snow |
| Graph 3 | Accumulated difference between recorded and computed discharge |
| Graph 4 | Recorded discharge - grey line |
| | Computed discharge - black line |

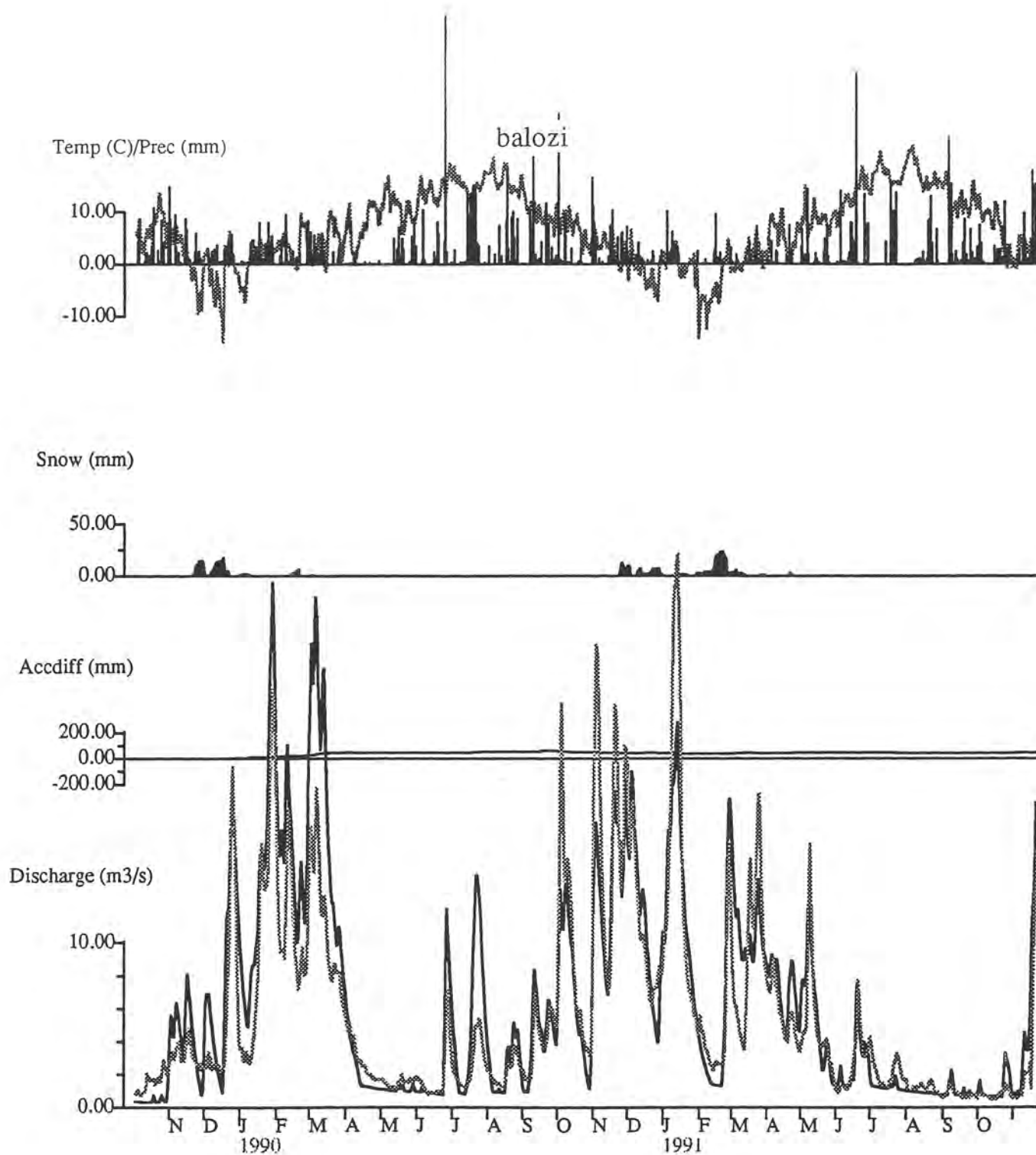


Figure 10 Model performance, Balozi basin.

- | | |
|---------|--|
| Graph 1 | Temperature - grey line |
| | Precipitation - black bars |
| Graph 2 | Water content in snow |
| Graph 3 | Accumulated difference between recorded and computed discharge |
| Graph 4 | Recorded discharge - grey line |
| | Computed discharge - black line |

