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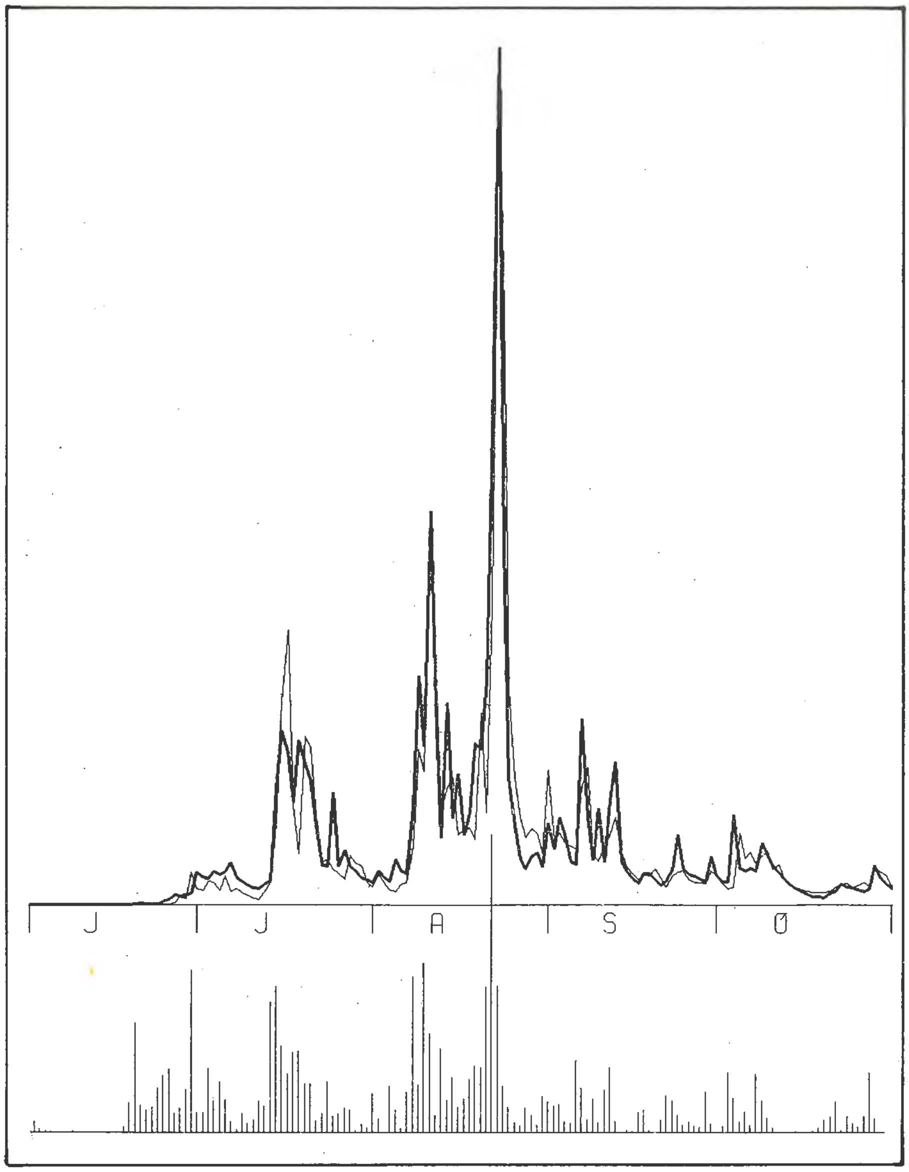

APPLICATION OF THE DISTRIBUTED HBV-6 MODEL TO THE UPPER NARMADA BASIN IN INDIA

by P.K Bhatia (IIT Delhi), S. Bergström and M. Persson (SMHI)

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SMHIs tryckeri, Norrköping 1984

Issuing Agency	Report number
SMHI Box 923 S-601 19 NORRKÖPING SWEDEN	RHO 35
	Report date March 1984

Author (s)

P.K. Bhatia, S. Bergström, and M. Persson

Title (and Subtitle)

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Abstract

The application of the HBV-6 conceptual runoff model to the Upper Narmada basin is summarized. The work includes an extensive investigation of the homogeneity of the precipitation stations and a discussion on the estimates of the potential evapotranspiration. A comparison between a lumped and a distributed model structure is made. Finally is shown how the model can be transformed into a set of nomograms for day-to-day simulations without support from computer.

Key words

Conceptual runoff modelling
Narmada River
Nomogram technique
Hydrological forecasting

Supplementary notes	Number of pages	Language
	40	English

ISSN and title APPLICATION OF THE DISTRIBUTED HBV-6 MODEL TO THE UPPER NARMADA BASIN IN INDIA
0347-7827 SMHI Reports Hydrology and Oceanography RHO 35

Report available from:

SMHI
Box 923
S-601 19 NORRKÖPING
Sweden

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Report on Phase-II of the institutional collaboration between IIT-Delhi, India, and SMHI, Norrköping, Sweden, on Water Resources Development - Hydrological Forecasting

Introduction

The basic need for river basins development, both at the planning and management stages, is the evaluation of temporal and spatial water availability in the region. In India, while planning, it is generally experienced that river runoff records at a particular site in the basin are either lacking or too short for reliable statistical analysis. Missing data of critical highflow periods at the desired site are also frequent problems. Often, however, there is a relatively long period of rainfall data available in the basin. In this situation, mathematical models conceptually representing the land phase of the hydrologic cycle are very useful. These models can be used to simulate runoff response of the catchment by quantifying the most dominant physical processes through a series of mathematical functions, combined together to represent the time-variant interaction of the processes. These models continuously account for the water in storage in the basin, relate loss functions for the rainfall to current condition of the basin, and are capable of continuous simulation of flow for as long a period of time as there are input data available.

Another very common application of rainfall-runoff models is for forecasting purposes. The lead time of the forecast is then depending on the reliability of the weather forecast available and on the dynamics of the river system. A river with a very damped response is thus easier to forecast than one with quick response to rainfall or snowmelt. For long range forecasting, historic climate records can be fed into the model, and the forecast can be based on a statistical analysis of several sequences of computed hydrographs.

Several rainfall-runoff simulation models, viz. the Stanford Watershed Model (Linsley and Crawford, 1960), the SSARR model (Rockwood, 1958), the Dawdy and O'Donell model (Dawdy and O'Donell, 1965), the Boughton model (Boughton, 1966), the Hydrocomp Simulation Program (Hydrocomp Inc., 1969), the UBC model (Quick and Pipes, 1972), the HBV-model (Bergström, 1976), the TANK model (Sugawara, 1961), and the NWSRFS (NOAA, 1972) etc., have been developed since the late 1950ies.

The complexity of these models varies over a wide range, which also entails variable demands as concerns computer facilities and input data. The HBV-model developed by the Swedish Meteorological and Hydrological Institute (Bergström, 1976) is one of the simpler models in the range but has proved to yield satisfactory results for both forecasting and simulation. Its formulation is easily understood, and computer and input data demands are moderate. The model is run on daily values of rainfall and monthly values of the potential evapotranspiration. If the snow-routine of the model is to be used, it requires mean daily air temperatures as well.

The number of process parameters to be estimated during the calibration procedure is kept low by means of the very extensive investigations of the error function response surfaces which were carried out when the model was developed. The model can be made operational on any small computer or advanced desk calculator.

The first operational versions of the HBV-model were two lumped versions named HBV-2 and HBV-3. Nowadays a distributed version, HBV-6, is used for most applications of the model in Sweden. In Norway, the HBV-3 version is normally used with a statistically distributed snow routine.

Under Phase-I of Indo-Swedish Collaboration Project on Water Resources Development and Hydrological Forecasting, the lumped HBV-3 model was applied to the upper Narmada basin (catchment area = 16 576 km^2) in Madhya Pradesh in India (Bergström and Chaturvedi, 1980). This application showed encouraging results, but errors were introduced both by the incomplete data base and the large spatial variability of factors governing the rainfall-runoff process. So under Phase-II of the project, HBV-6, the distributed version of the model, was proposed.

This report summarizes the application of the HBV-6 model to the Upper Narmada basin. This version of the model accounts for variations of rainfall over the basin by dividing the basin into subbasins. It simulates the runoff volume from each subbasin independently and then combines it to calculate the total hydrograph. The approach, though increasing computation time, was felt to be the only way of handling this large size basin with this type of model. It demands, however, a more complete data base than was available for the application under Phase-I. A simulation by a lumped version of the model, carried out with the data base available for Phase II, showed, however, surprisingly close agreement with the distributed model. Finally an attempt has been made to transform the model into a set of nomograms for day-to-day simulation of runoff.

Description of the HBV-model

The HBV-model is a conceptual runoff model for continuous calculation of runoff. Input data are observations of precipitation, air temperature and estimates of potential evapotranspiration. The time scale is normally one day but shorter intervals can be used. The evaporation values used are normally monthly averages. Air temperature data are used for snow accumulation and ablation calculations only and can be omitted in snowfree areas.

The HBV-6 version provides options for geographical zoning and different vegetation cover. A schematic sketch of a HBV-3 model is shown in Figure 1, which may also serve as an illustration of a HBV-6 submodel.

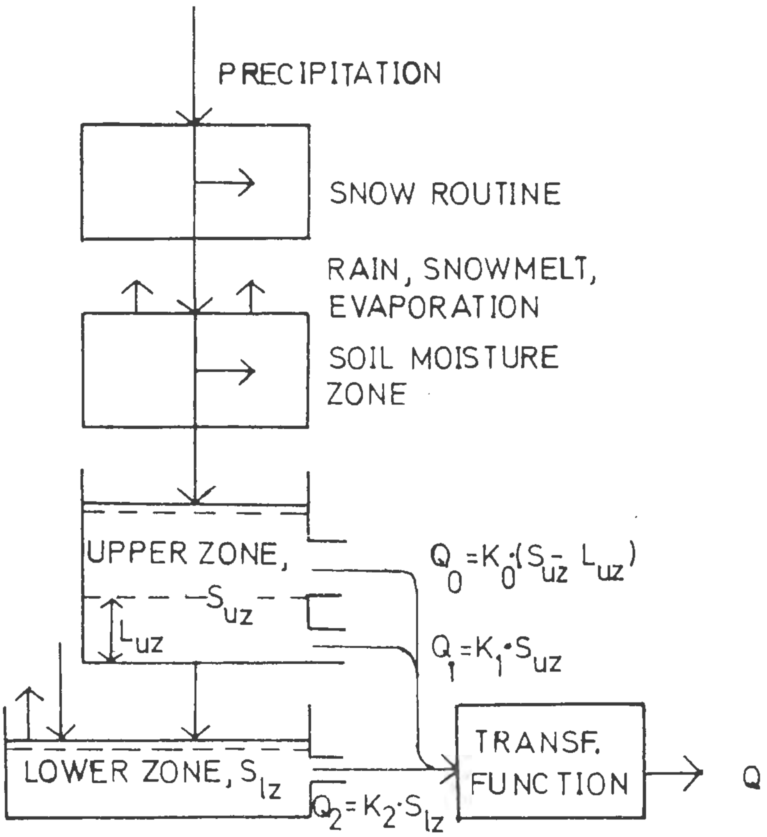


Figure 1. The structure of the HBV-6 submodel.

The model consists of subroutines for snow accumulation and melt, a soil moisture accounting procedure, routines for runoff generation, and finally a simple routing procedure. The snow routine is based on a degree-day approach with lapse rates of climatological data according to the hypsographic curve. It is, however, omitted in this application.

The soil moisture accounting routine is the main part controlling runoff formation. This routine is based on three parameters, β, L_p and Fc, as shown in Fig. 2. β is controlling the contribution to the response function ($\Delta Q/\Delta P$) or increase in soil moisture storage ($1-\Delta Q/\Delta P$) from each millimetre of rainfall or snowmelt, L_p is a value above which evapotranspiration reaches its potential value, and Fc is the maximum soil moisture storage in the model. In order to avoid problems with non-linearity the soil moisture routine is fed by snowmelt and rainfall mm by mm.

S_{sm} – computed soil moisture storage
ΔP – contribution from rainfall or snowmelt
ΔQ – contribution to the response function/runoff
Fc – maximum soil moisture storage
β – empirical coefficient
E_p – potential evapotranspiration
E_a – computed actual evapotranspiration
L_p – limit for potential evapotranspiration

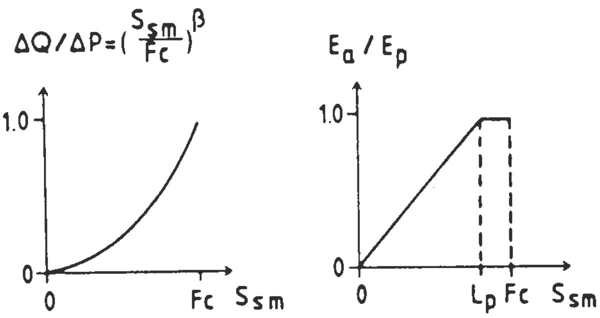


Figure 2. Schematic presentation of the soil moisture accounting subroutine.

The routine will have the effect that the contribution to runoff from rain or snowmelt is small when the soil is dry (low S_{sm}-values) and great at wet conditions. The actual evapotranspiration decreases as the soil dries out.

For catchments of considerable elevation range, the altitude effect on precipitation is accounted for by division of sub-basins into elevation zones and application of a precipitation lapse rate (P_{lapse}) for each zone. The corrections are made from the average altitude of the precipitation stations to the mean altitude of each zone. There is also an option for a general precipitation correction factor in case systematic errors in these data are obvious.

In the Narmada basin application no precipitation correction factors or lapse rates were used.

The runoff generation routine is the response function which transforms excess water from the soil moisture zone to runoff. It also includes the effect of direct precipitation and evaporation on a part (p_w) which represents lakes, rivers and other wet areas. The function consists of one upper and one lower quasi-linear reservoir, as shown in Figure 3. These are the origin of the quick and slow runoff components of the hydrograph.

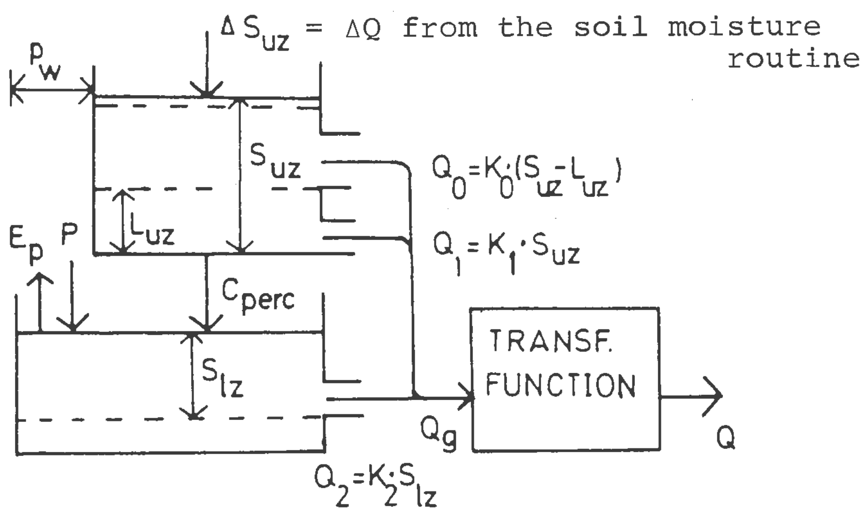


Figure 3. The response function of the HBV-6 submodel.

The upper zone may be interpreted as follows: If yield from the soil exceeds a certain percolation capacity (C_{perc}), the water will start to drain through more superficial channels and thus reach the rivers and streams with a higher drainage coefficient (K_1). At a storage in the upper zone exceeding L_{uz}, even more rapid drainage according to K_o will start. The lower zone, on the other hand, represents the total groundwater storage of the catchment contributing to the base flow.

Each one of the subbasins has individual soil moisture accounting procedures and response functons. The runoff is generated independently from each one of the subbasins and is then routed through a transformation function in order to get a proper shape of the hydrograph. The transformation function is a simple filter technique with a triangular distribution of weights, as shown in Figure 4. If a translation of the hydrograph due to travel time is needed, this is accounted for by a parameter BLAG. Finally the discharge from each subbasin is combined by superposition to arrive at total discharge at the outlet.

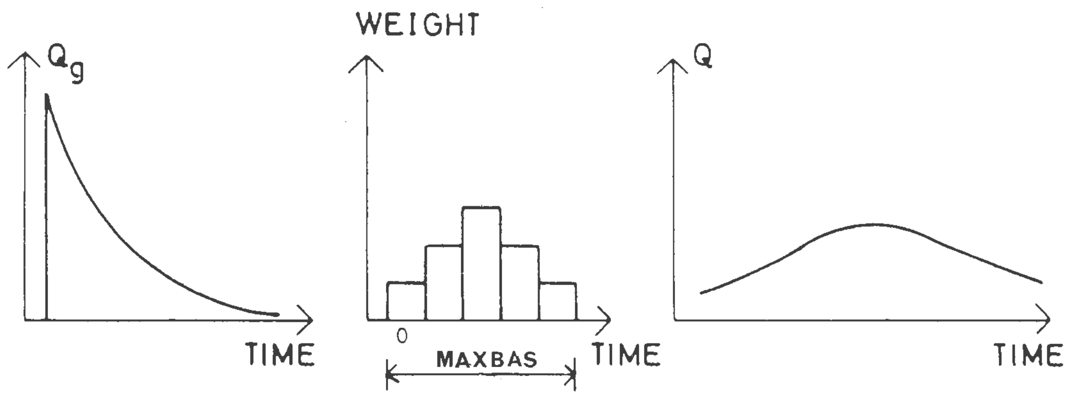


Figure 4. Schematic presentation of the effect of the transformation function on the computed hydrograph.

Recently a slightly modified version of the response function has been used for groundwater simulations in Sweden (Bergström and Sandberg, 1983). Explicit groundwater simulations have not been made under Phase-II of this project.

Subdivision of the Narmada basin

The 16 576 km^2 of the Upper Narmada basin were subdivided into five subbasins, 4183, 4780, 1802, 2612, and 3199 km^2 respectively, as shown in Figure 5. In the same figure is shown a schematic sketch of the HBV-6 model with corresponding subdivision into submodels. The subdivision of the model makes it possible to calibrate submodels as well as the total model, if the data base is appropriate. Due to lacking runoff data this was not possible in this application.

The subdivided model makes it possible to use separate model parameters in each basin. It is strongly recommended, however, that the use of multiple parameter settings is restricted so that the number of free parameters is kept as low as possible.

Data base

In Phase-II of the project the number of precipitation stations was increased from 5 to 13. Runoff data were taken from Jamtara and values of the potential evapotranspiration first from the station Sagar but later changed to Jabalpur according to Rao et al. (1976). Out of the 9 years of data available it was decided to use 5 for calibration of the model (1963 - 1967) and the last 4 for the independent test of model performance (1973 - 1976).

The homogeneity of the precipitation records were tested by means of double-mass plottings using a program system developed by Westman (1982), as shown in Figure 6. This test resulted in the exclusion of station No. 6 (Baijag) and correction of obvious errors in some of the data for some periods at some stations. One such example is the beginning of the calibration period for station No. 1. There are several possible breaks in the homogeneity suggested by Figure 6, for example for stations No. 2 and 7. After close examination of the data we could not, however, find any justification for further amendments. Station No. 13 was tested in a second test without any homogeneity problems.

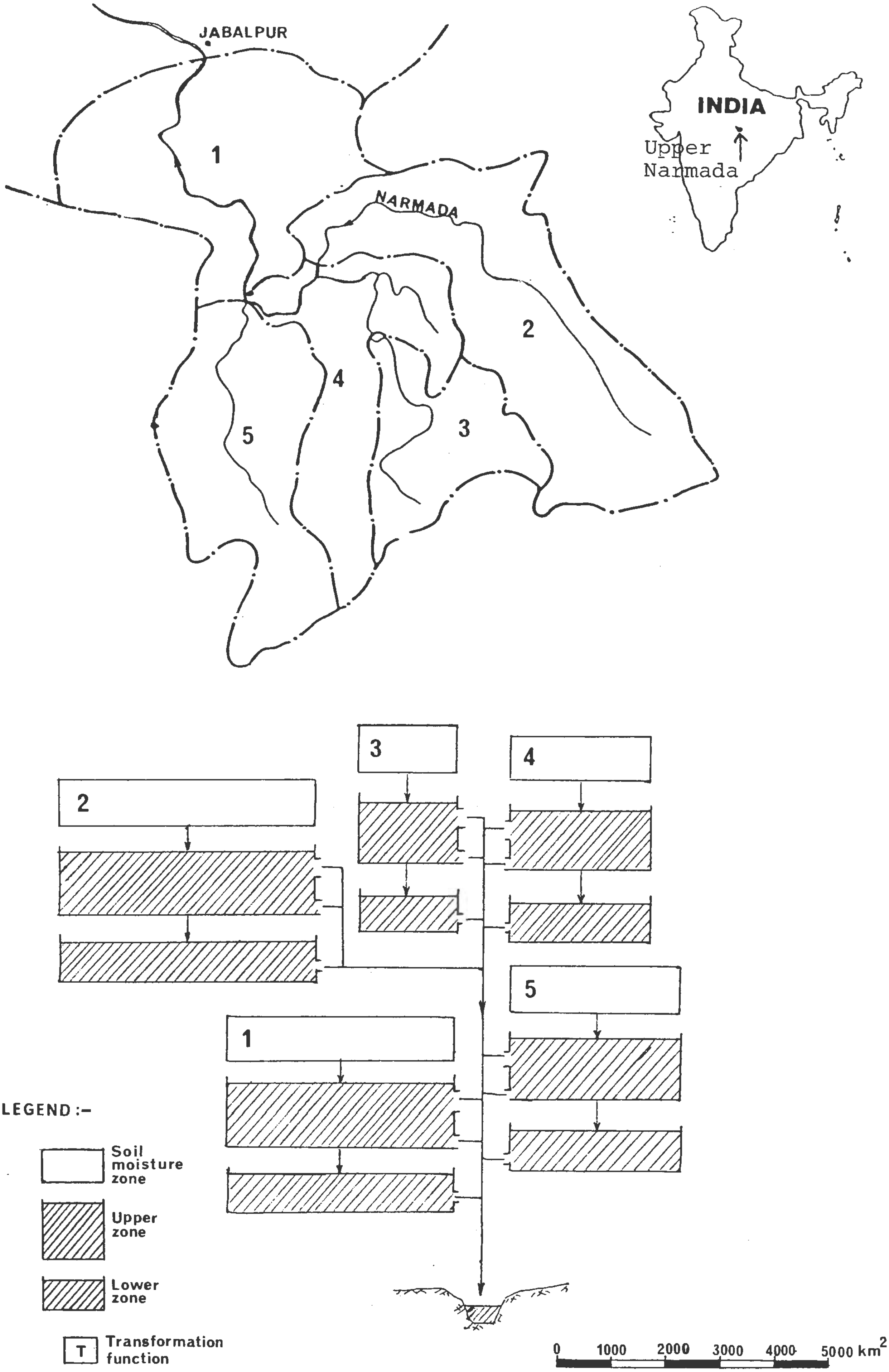


Figure 5. Subdivision of the Upper Narmada basin for application of the HBV-6 model.

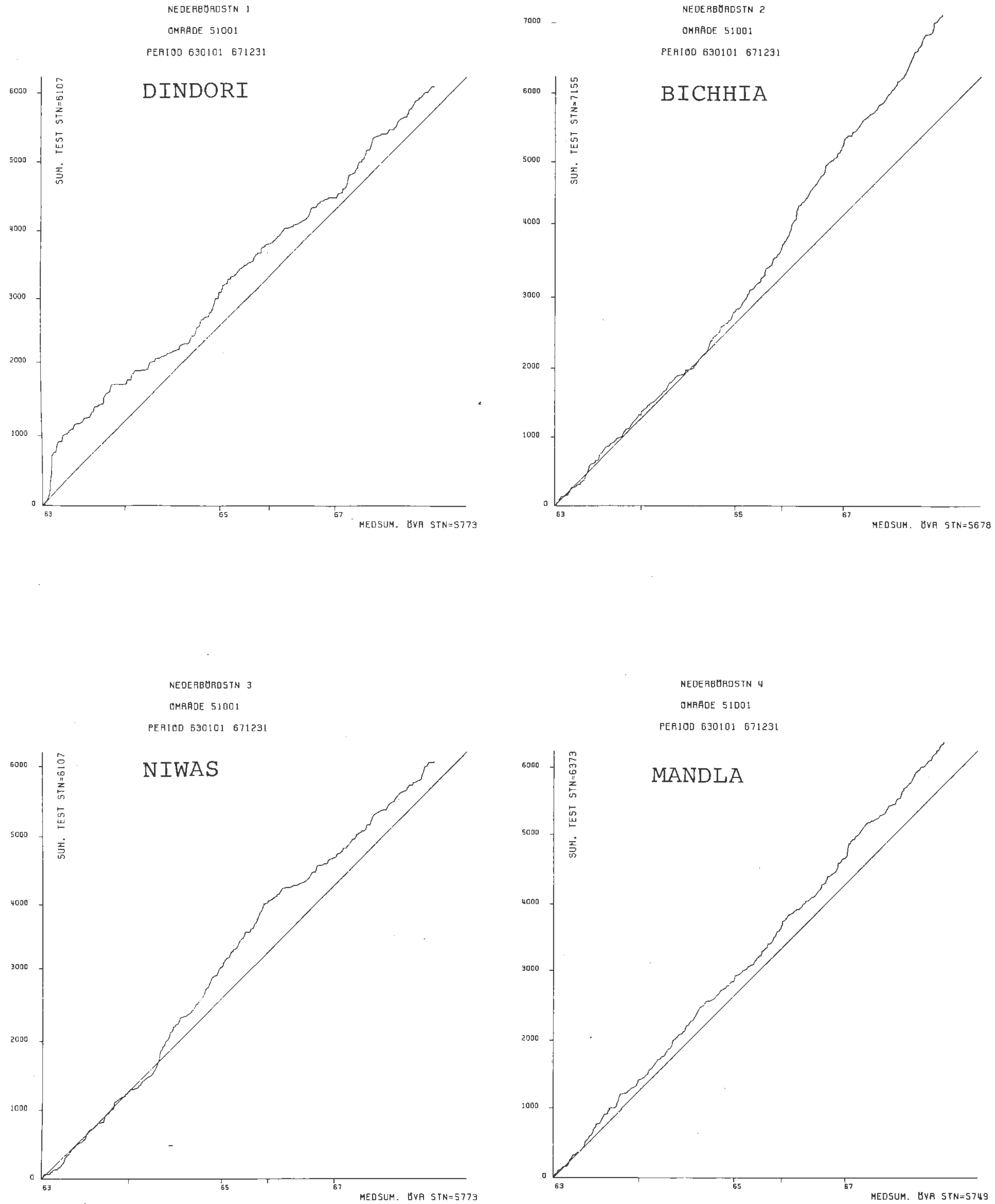


Figure 6. Double-mass plots of 12 of the precipitation stations. The test station along the vertical axis, the mean of the others along the horizontal axis.

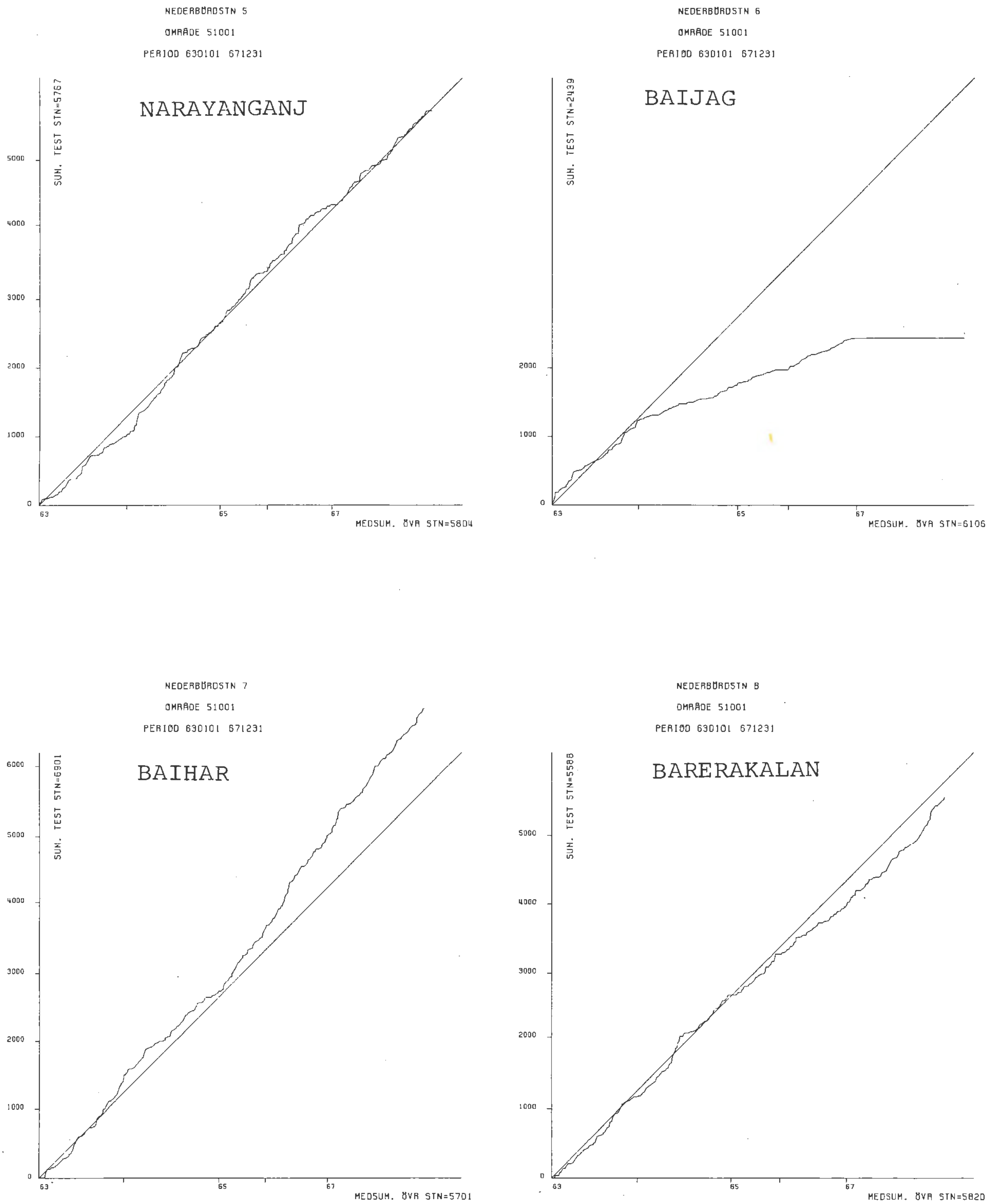


Figure 6 (continued). Double-mass plots of 12 of the precipitation stations. The test station along the vertical axis, the mean of the others along the horizontal axis.

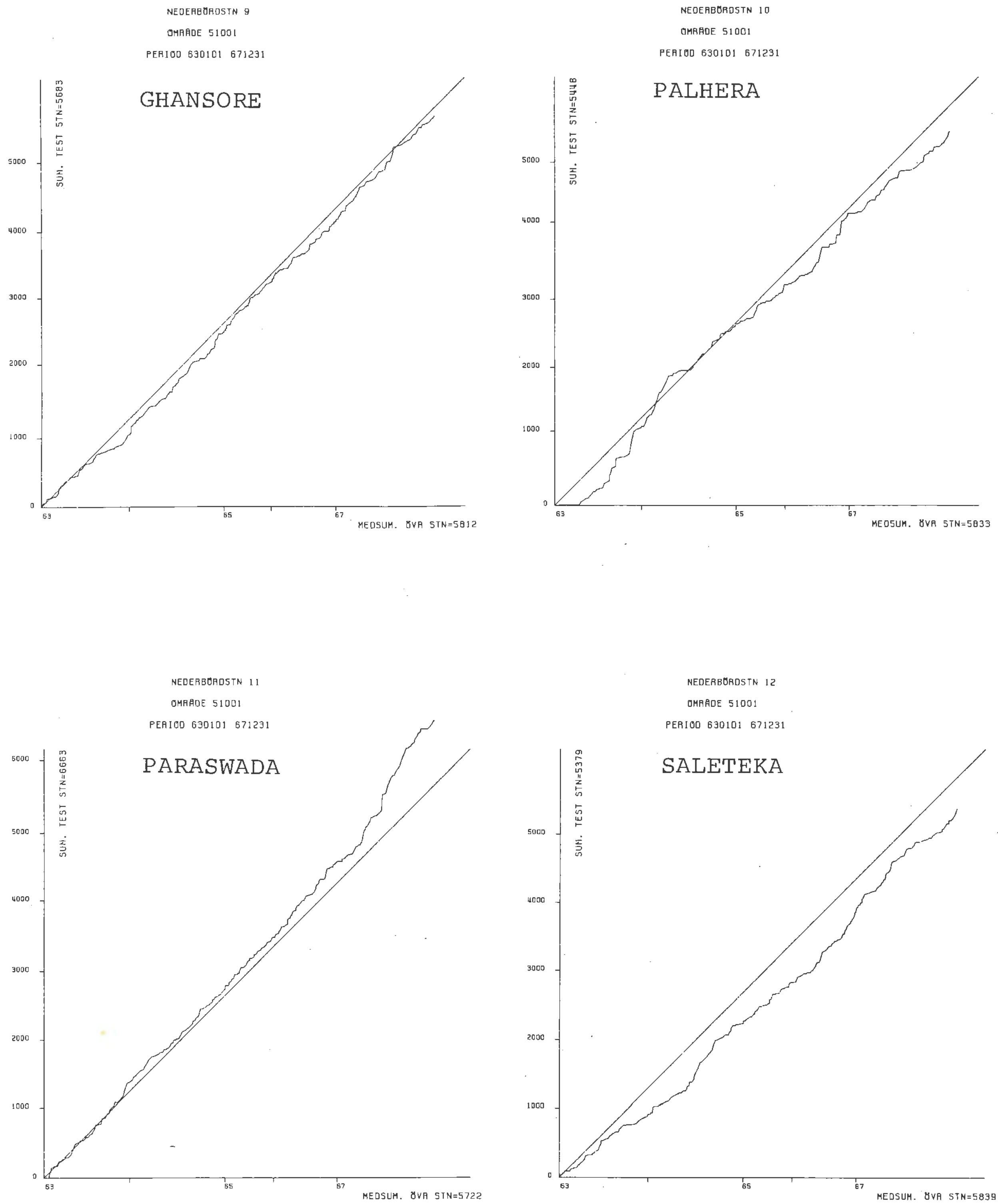


Figure 6 (continued). Double-mass plots of 12 of the precipitation stations. The test station along the vertical axis, the mean of the others along the horizontal axis.

Areal precipitation values for each subbasin were computed by the Thiessen-polygon method, as shown in Figure 7. The names,, numbers and weights of each precipitation station are given in Table 1. As can be seen in this table, station No. 2, Bichhia, has a high average weight and is thus very important for the simulation results. Therefore it is a bit disturbing that the double-mass plot of Bichhia indicates the possibility of insufficient homogeneity. Bichhia is further situated in the part of the basin with maximum rainfall, which may be one reason for volume problems when calibrating the model. It is also obvious that station No. 6, Baijag, would have been very useful, if an acceptable record were available. The exclusion of Baijag has resulted in a very biased distribution of weights with as much as 26 % of the average weight on station No. 1, Dindori.

Table 1. Summary of the precipitation stations and their weights in individual subbasins.

Precipitation station		Station weights for subbasin					Average weight for the entire basin
No.	Name	1	2	3	4	5	
1	Dindori	0.00	0.72	0.28	0.17	0.00	0.26
2	Bichhia	0.00	0.00	0.66	0.44	0.16	0.17
3	Niwas	0.15	0.12	0.00	0.07	0.00	0.08
4	Mandla	0.10	0.01	0.00	0.17	0.13	0.08
5	Narayan-ganj	0.23	0.01	0.00	0.00	0.00	0.06
6	Baijag			Omitted			
7	Baihar	0.00	0.00	0.00	0.00	0.24	0.05
8	Barera-kalan	0.25	0.00	0.00	0.00	0.00	0.06
9	Ghansore	0.27	0.00	0.00	0.00	0.00	0.07
10	Palhera	0.00	0.00	0.06	0.15	0.19	0.07
11	Paraswada	0.00	0.00	0.00	0.00	0.15	0.03
12	Saleteka	0.00	0.00	0.00	0.00	0.13	0.03
13	Shahpura	0.00	0.14	0.00	0.00	0.00	0.04

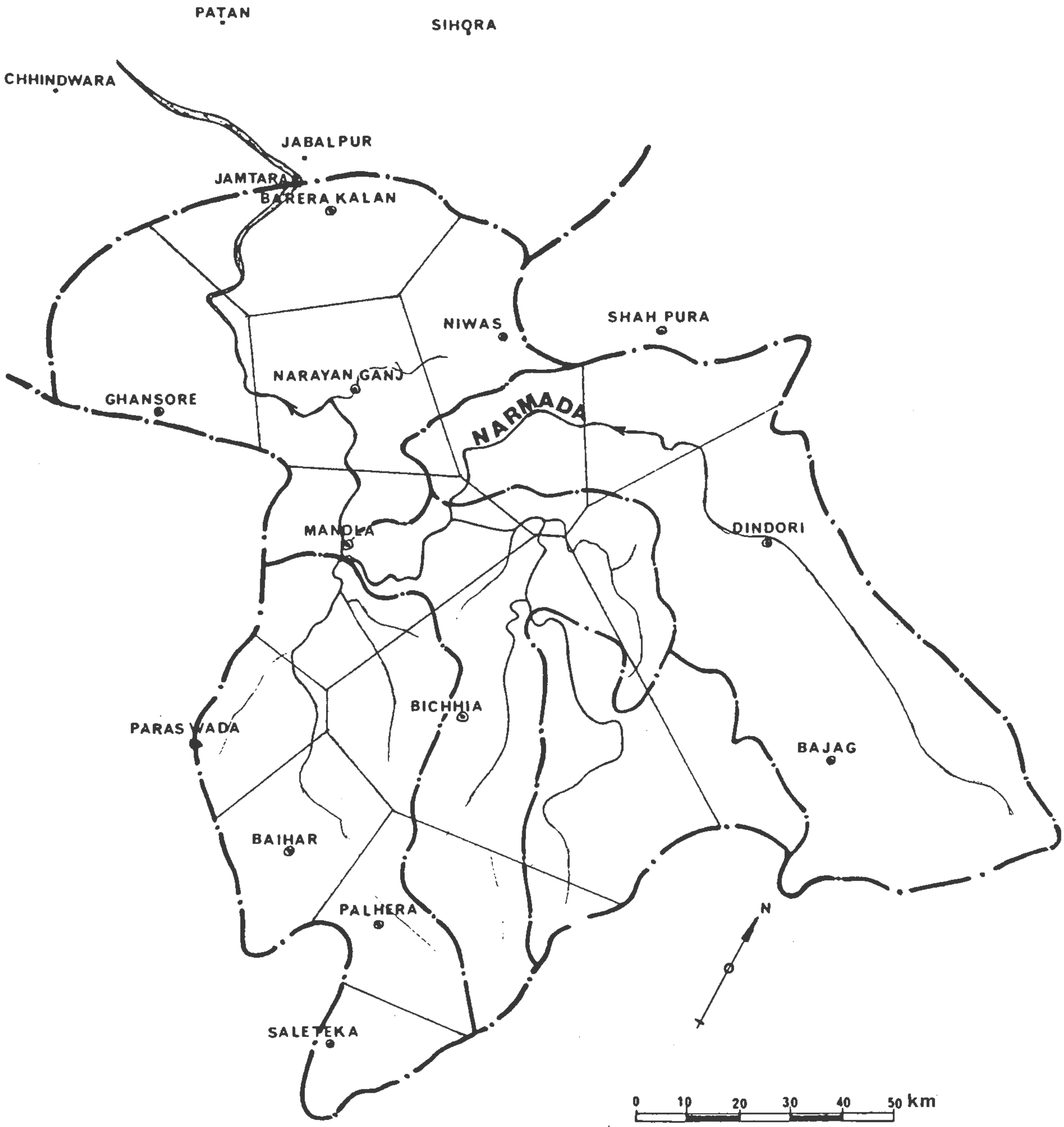


Figure 7. Basin subdivision, Thiessen-polygons, and location of the precipitation stations.

In case runoff data were missing for a period of time, a negative value was inserted, and the period was omitted when computing the criterion of fit.

Calibration of the model

The model was calibrated by a manual trial and error procedure, combined with mapping of the topography of the response surface of the error function.

Three main criteria of fit were used:

1) Visual inspection of the computed and observed hydrographs.

2) A continuous plot of the accumulated difference between the computed and the observed hydrographs expressed as

$$\text{ACC.DIFF} = \Sigma(Q_c - Q_o)\cdot c$$

where Q_c = computed runoff
Q_o = observed runoff
t = time
c = a constant transforming to mm over the basin.

3) The explained variance around the mean expressed as

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

where

$$\bar{Q}_o = \frac{1}{n} \sum_t Q_o$$ n = the number of days

In addition to these prime criteria, the calibration process was supported by plots of the observed and computed flow duration curves and scatter diagrams of maximum daily flows for each month.

The calibration was based on the five years 1963 - 1967, while four years were saved as an independent test period.

It was soon realized that one of the main problems would be to handle a large positive volume error which was increasing the value of ACC. DIFF. each monsoon. After several trials with various values of Fc, LP and β we realized that it was not possible to match the water balance, even if potential values of evapotranspiration were used during the monsoon without reduction for soil moisture deficit. We therefore decided to make a special study on the effect of various estimates on the potential evapotranspiration.

As mentioned in a previous chapter, the work was started based on values of the potential evapotranspiration from Rao (1976) and valid for the station Sagar. The average yearly value for this station is 1 543 mm/year. The corresponding value for Jabalpur is 1 448 mm/year, but they show a slightly different seasonal pattern. An independent source of information is The World Water Balance Atlas (Kovzel, 1968), which shows values between 1 750 mm and 2 000 mm per year. These somewhat confusing results and the fact that we were in serious trouble as concerns the volume error made us decide to try three approaches.

1) Original evapotranspiration data from Sagar.

2) Evapotranspiration data from Sagar with a correction factor to arrive at an annual total of 1 800 mm.

3) Evapotranspiration data from Jabalpur with a correction factor to arrive at an annual total of 1 800 mm.

Results from 1963 are shown in Figure 8. These results are representative for the whole record and show that the modified data from Jabalpur are preferable. We do not, however, claim that these data are correct, only that these data were preferable for this application with all its possible other error sources, which may effect the volumes. Figure 8 also shows that the level of the storage in the soil moisture zone immediately before onset of the monsoon is very little

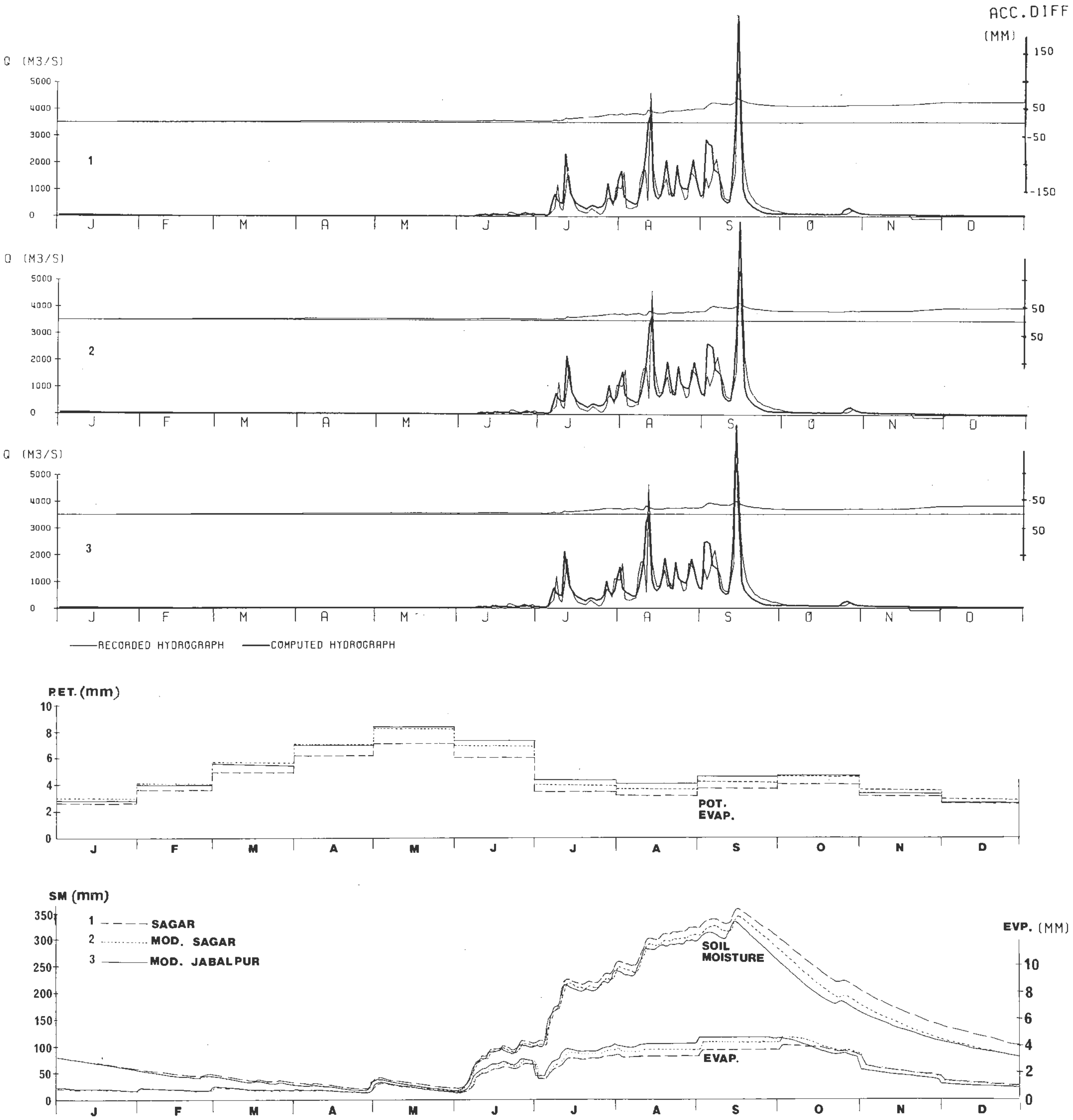


Figure 8. The effect on the modelling results from three alternative sets of evapotranspiration data.

sensitive to the choice of evapotranspiration data and that the most interesting evapotranspiration values are those during the monsoon. This further means that the total amount of potential evapotranspiration in a year is of less importance than its seasonal distribution.

The calibration of the HBV-6 model was finalized within some 15 computer runs. The final parameter values are summarized in Table 2 and plottings are shown in Figure 9. Note that negative values have been inserted for missing runoff data. A scatter diagram of monthly maximum flows and the flow duration curves are shown in Figure 10. The final value of R^2 was 0.79 for the five years, which is a compromize between a high R^2-value and a relatively low volume error. A slightly higher R^2-value can be obtained, but then a larger value of ACC. DIFF. has to be accepted.

Table 2. Final parameter values after calibration of the model.

Parameter type	Unit	Parameter value in subbasin				
		1	2	3	4	5
Fc	mm	300	500	500	400	300
L_p	mm	100	200	200	150	100
β	-	1.50	1.50	1.50	1.50	1.50
C_{perc}	mm	0.70	0.70	0.70	0.70	0.70
L_{uz}	mm	20	20	20	20	20
K_o	%	100	100	100	100	100
K_1	%	20	20	20	20	20
K_2	%	2	2	2	2	2
MAXBAS	Day	1	1	1	1	1
BLAG	Day	0	1	1	1	1

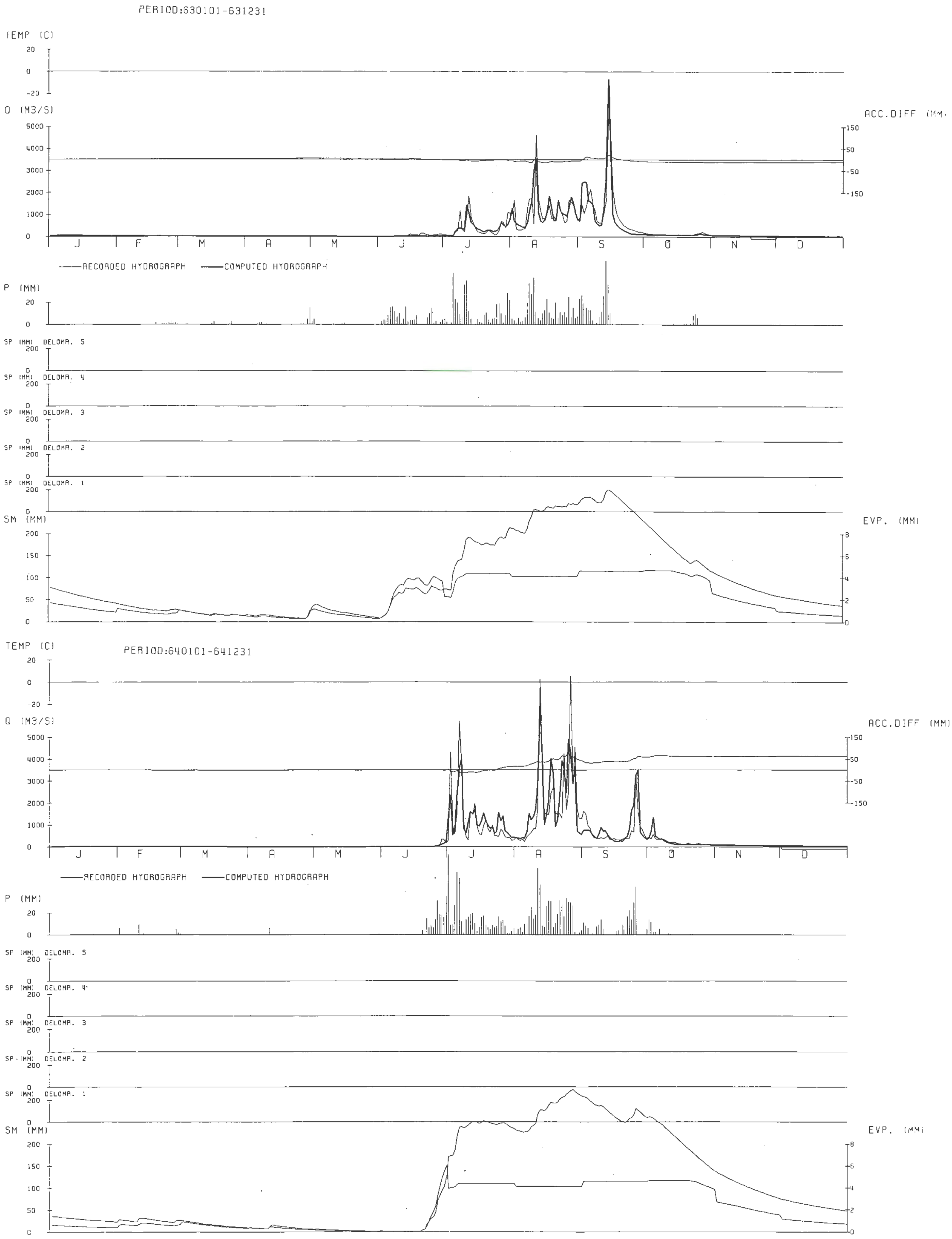


Figure 9. Calibration plottings in the Narmada basin (1963 - 1964).

SM = soil moisture storage
EVP = actual evapotranspiration
(SP indicates snowpack and is absent in this basin)

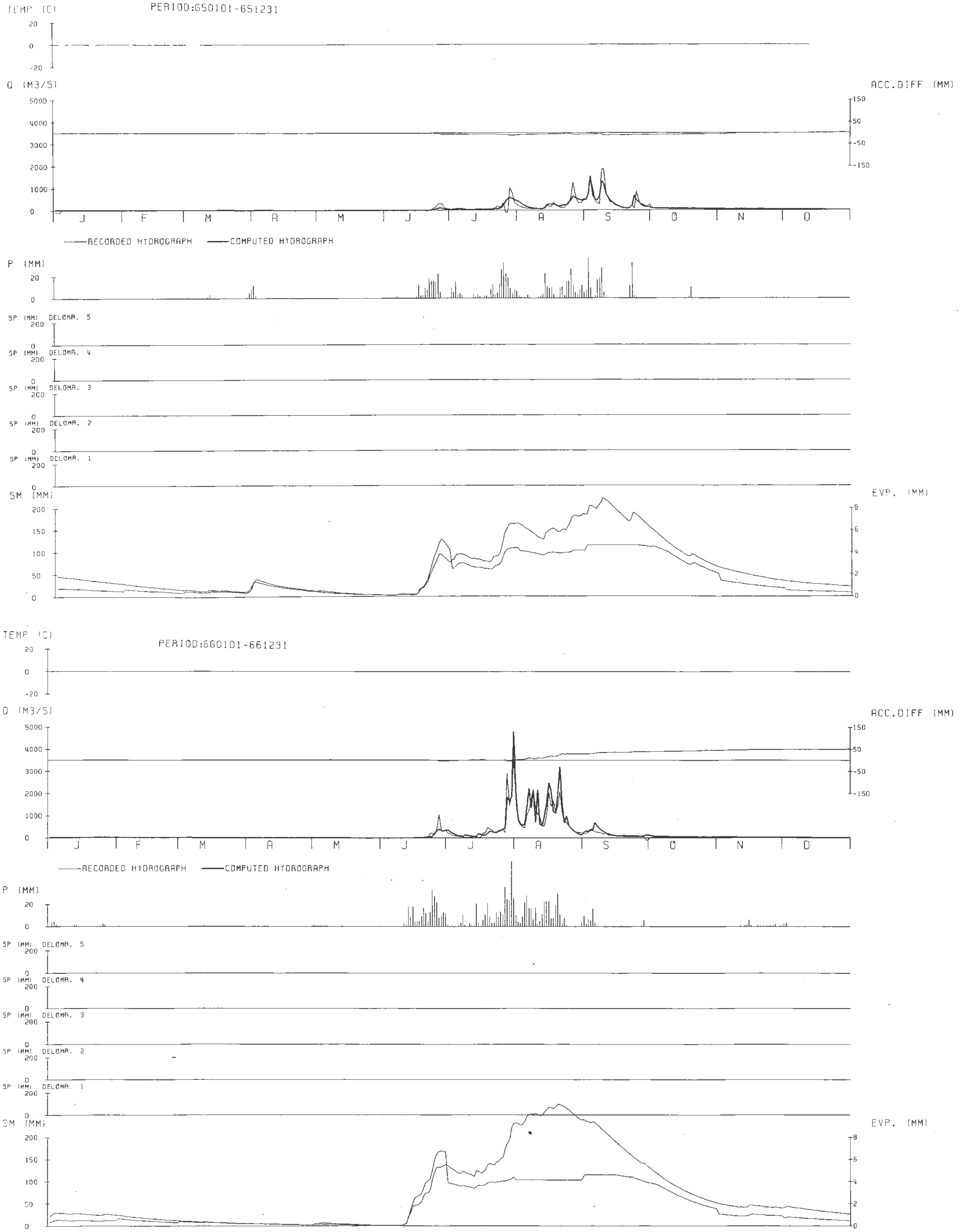


Figure 9 Calibration plottings in the Narmada basin (1965 - 1966).
(cont.) SM = soil moisture storage
EVP = actual evapotranspiration
(SP indicates snowpack and is absent in this basin)

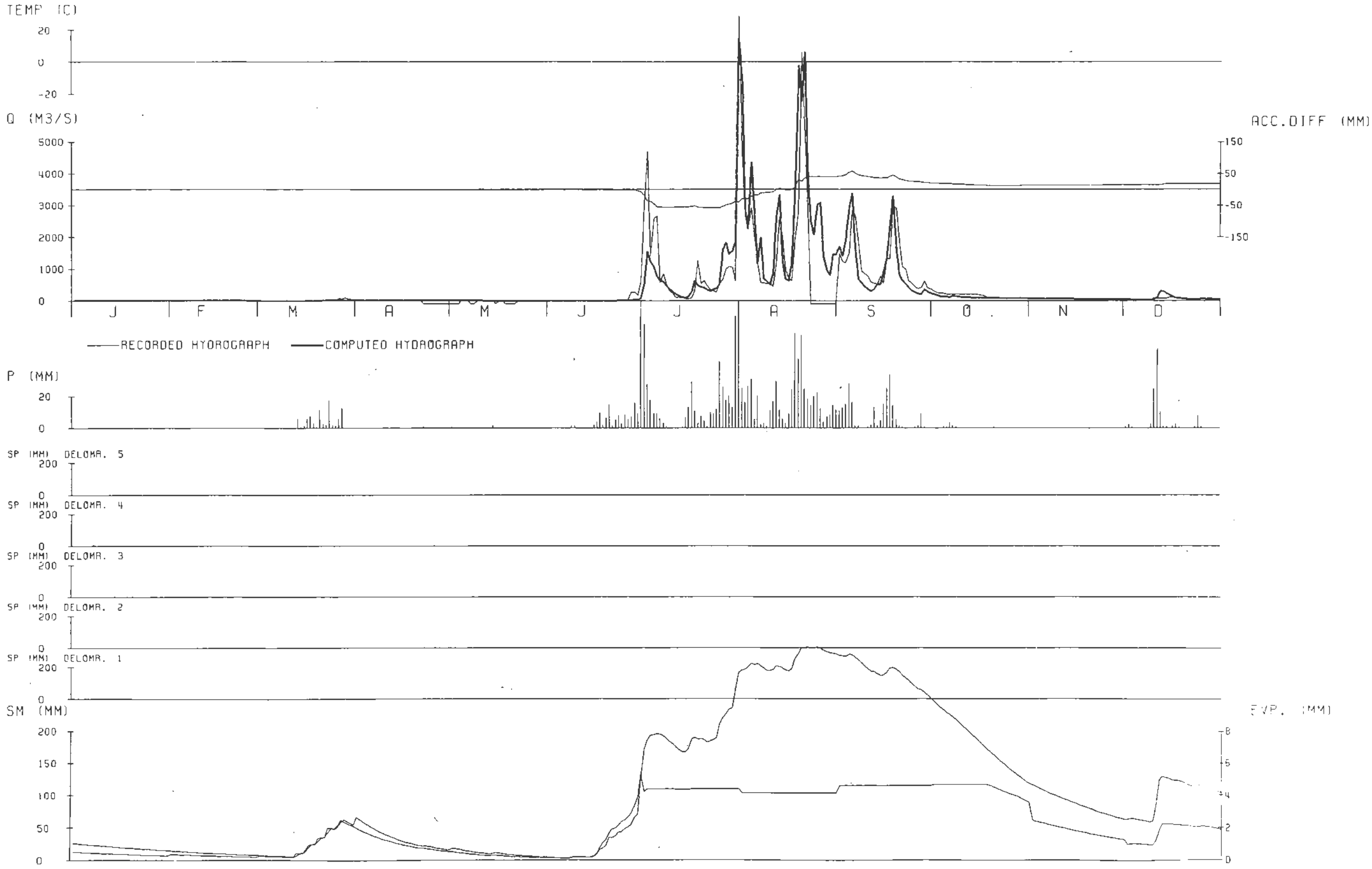
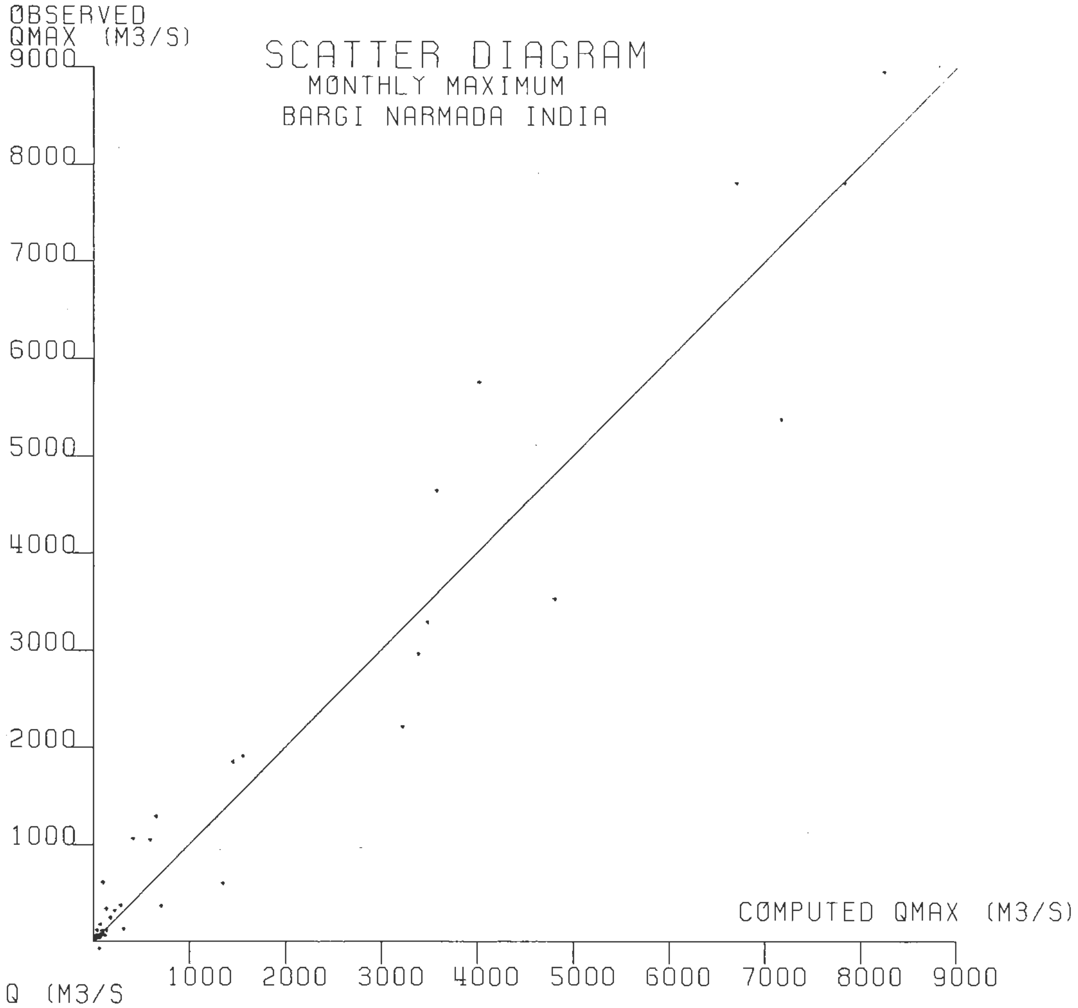


Figure 9. Calibration plottings in the Narmada basin (1967).
(cont.)   SM = soil moisture storage
EVP = actual evapotranspiration
(SP indicates snowpack and is absent in this basin)



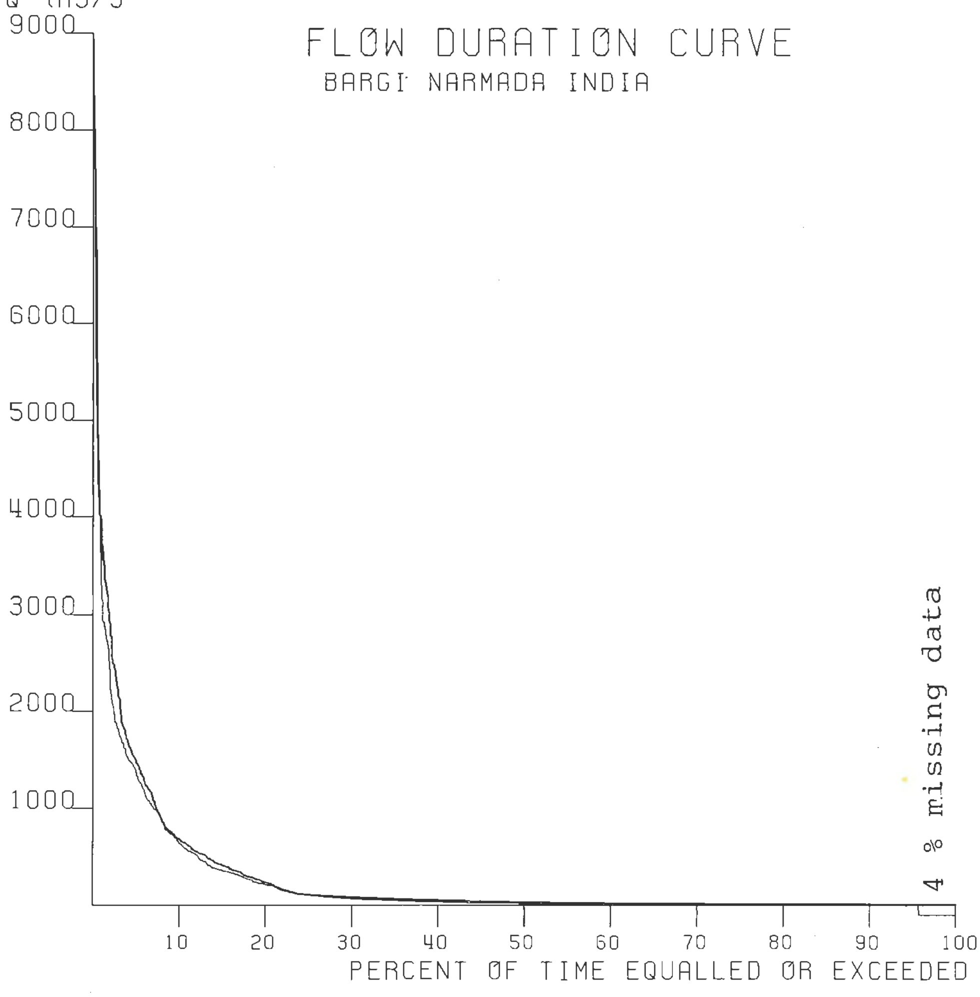


Figure 10. Scatter diagram of maximum monthly flows and flow duration curves for the calibration period (1963 - 1967).

Independent test of the model

Prior to the final test run of the model on the independent data sequence 1973 - 1976 double-mass plottings were performed on its precipitation records. The results were rather discouraging. The independent period showed to contain more missing data than the calibration period, as shown in Figure 11. We decided to exclude the year 1973 and to fill in the gaps in the remaining records by neighbouring station as far as possible to have at least a three year period. The year 1975 proved to have the most complete data coverage.

The results from the test period are shown on Figure 12 - 13. The corresponding value of R^2 is 0.81.

It is evident that the model still is suffering from a tendency to overestimate the total volumes, even if the error is relatively small. It is also evident that the more complete data in 1975 are reflected in the results. The peak in 1975 is well described in spite of the fact that no peak of this magnitude was encountered in the calibration period.

Test of a lumped model structure

In order to verify whether the distributed approach or merely the better data base are the cause of the increased performance of the model from Phase I to Phase II of the project, a lumped model structure was finally run. The parameter values were taken as averages of those found during calibration of the distributed model. The surprising results are shown in Table 3.

Table 3. Comparison, expressed as R^2-values, between the distributed and the lumped model approach.

	Calibration period	Verification period
Distributed model	0.79	0.81
Lumped model	0.74	0.83

The conclusion of the comparison, which is also supported by visual inspection of the simulations, is that there is no significant improvement when using a distributed approach in the Narmada Basin.

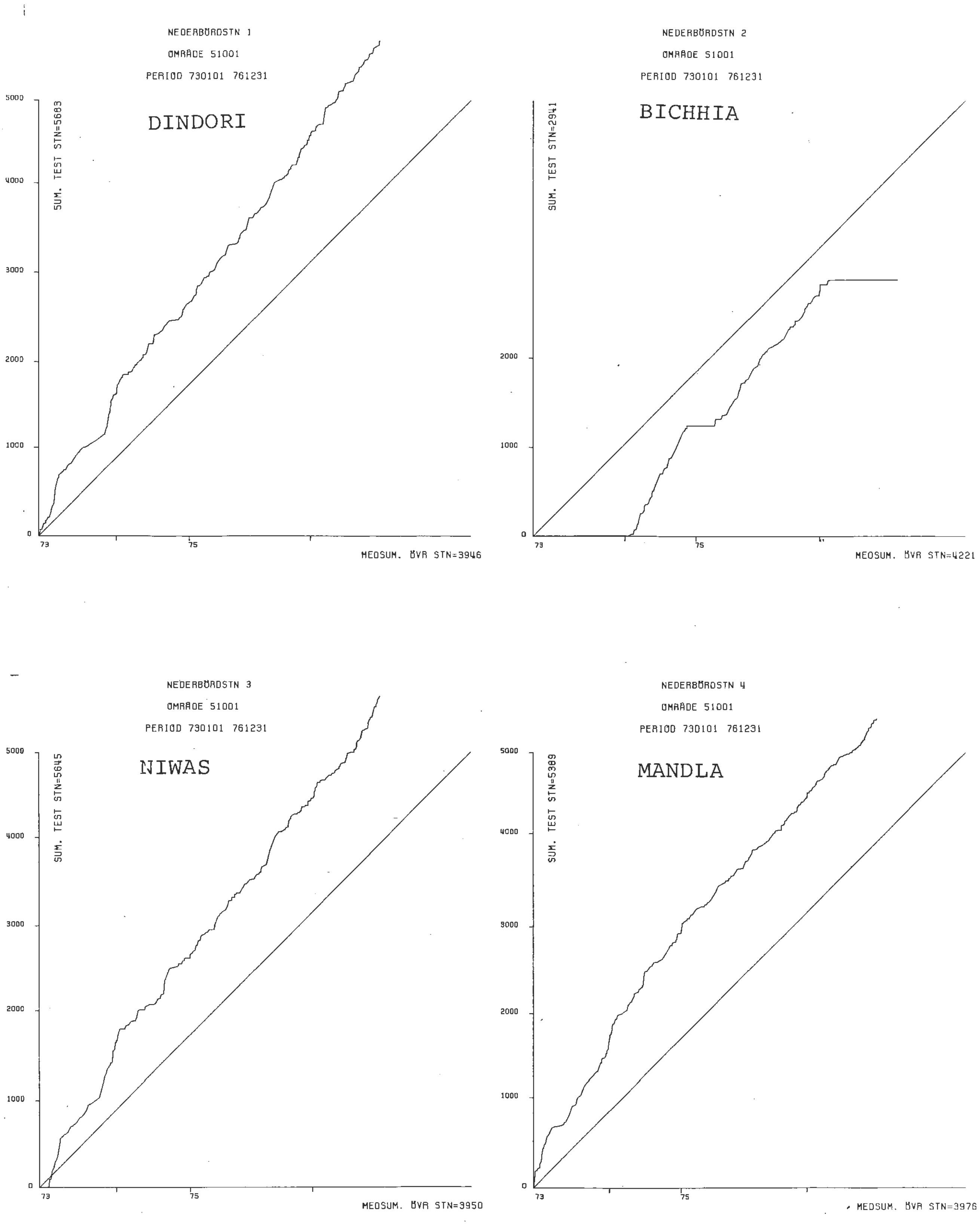


Figure 11. Double-mass plots of the precipitation stations in the independent test period. The test station along the vertical axis, the mean of the others along the horizontal axis.

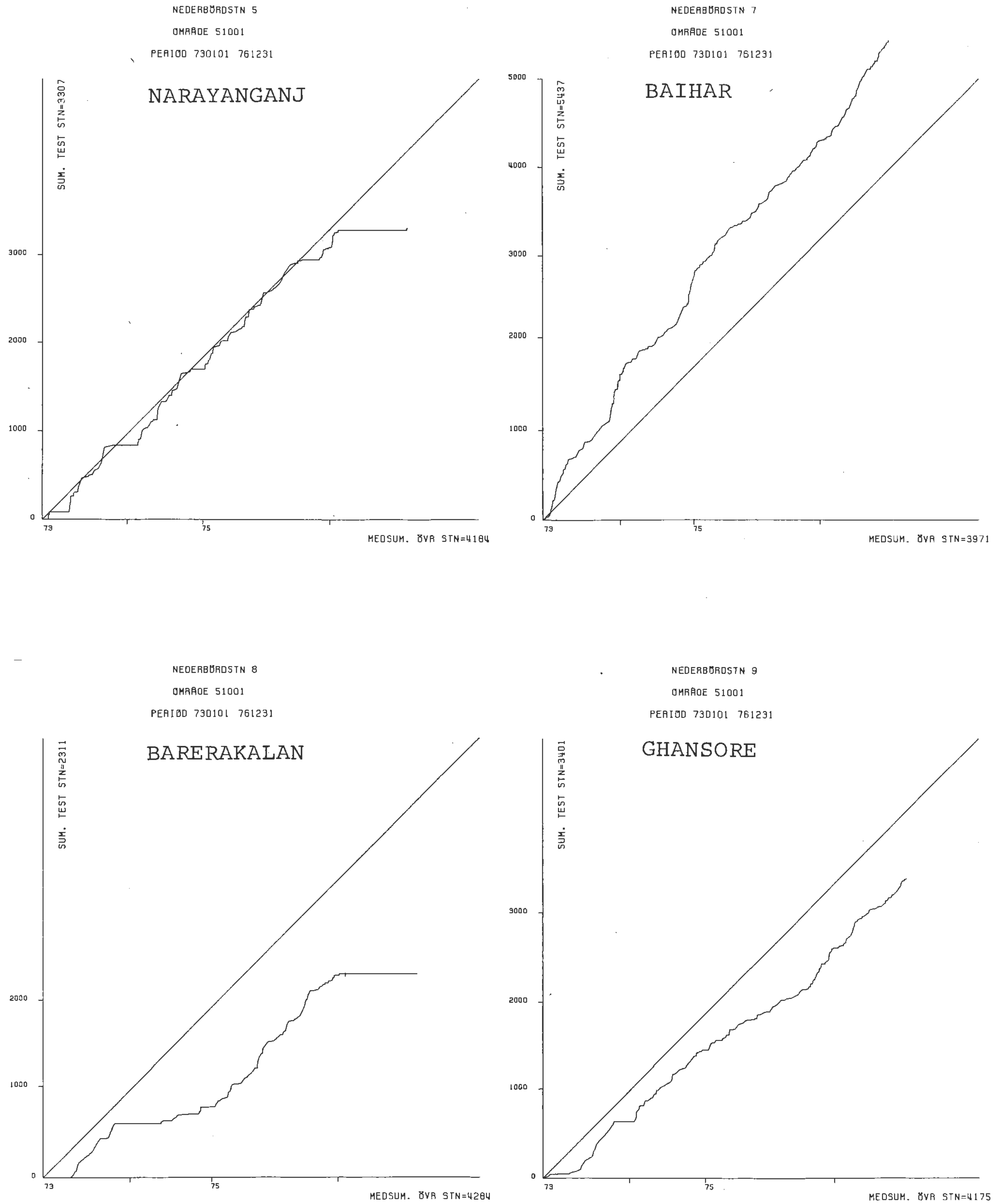


Figure 11. (cont.) Double-mass plots of the precipitation stations in the independent test period. The test station along the vertical axis, the mean of the others along the horizontal axis.

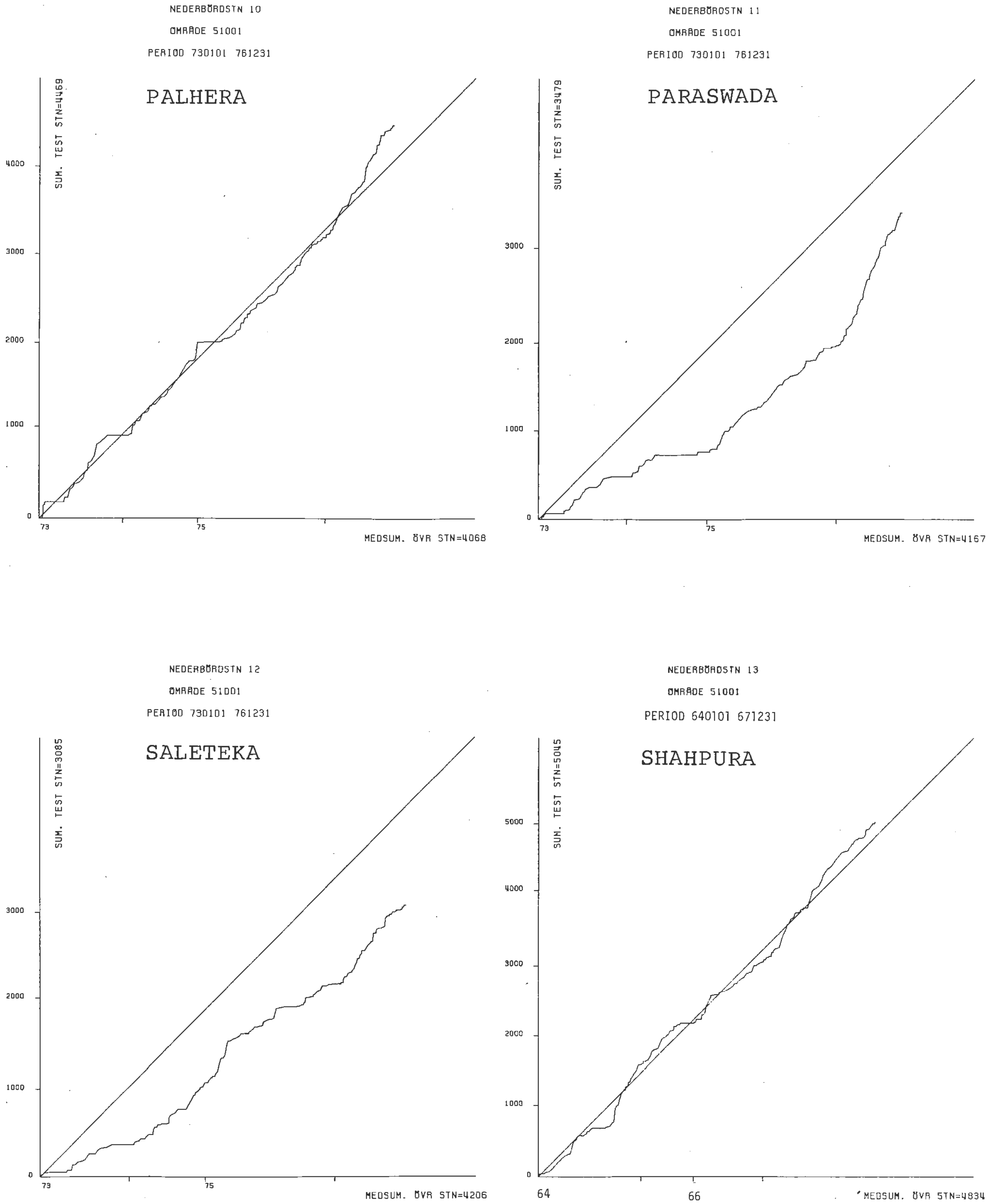


Figure 11. (cont.) Double-mass plots of the precipitation stations in the independent test period. The test station along the vertical axis, the mean of the others along the horizontal axis.

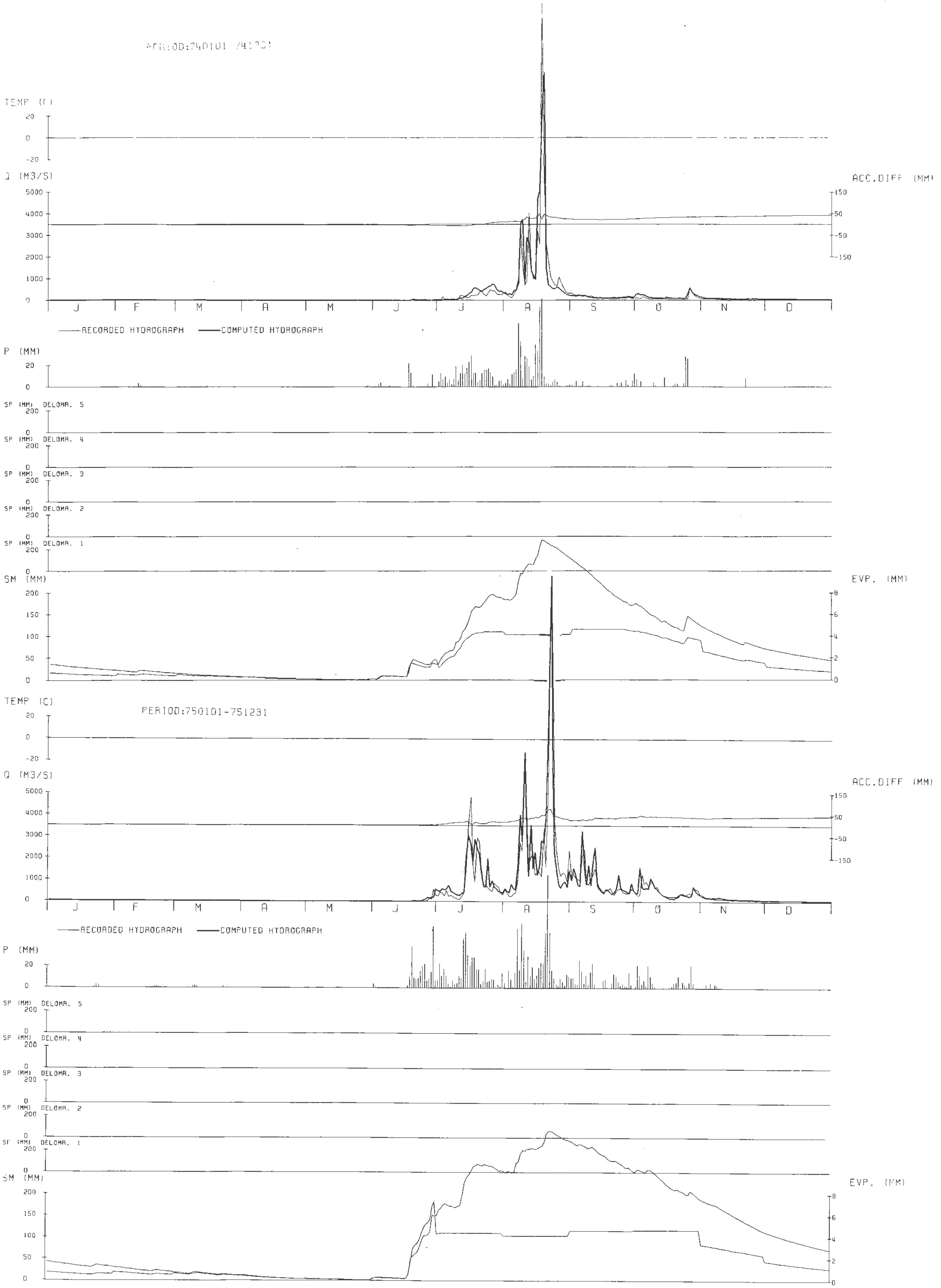


Figure 12. Test period plottings in the Narmada basin (1974 - 1975).

SM = soil moisture storage
EVP = actual evapotranspiration
(SP indicates snowpack and is absent in this basin)

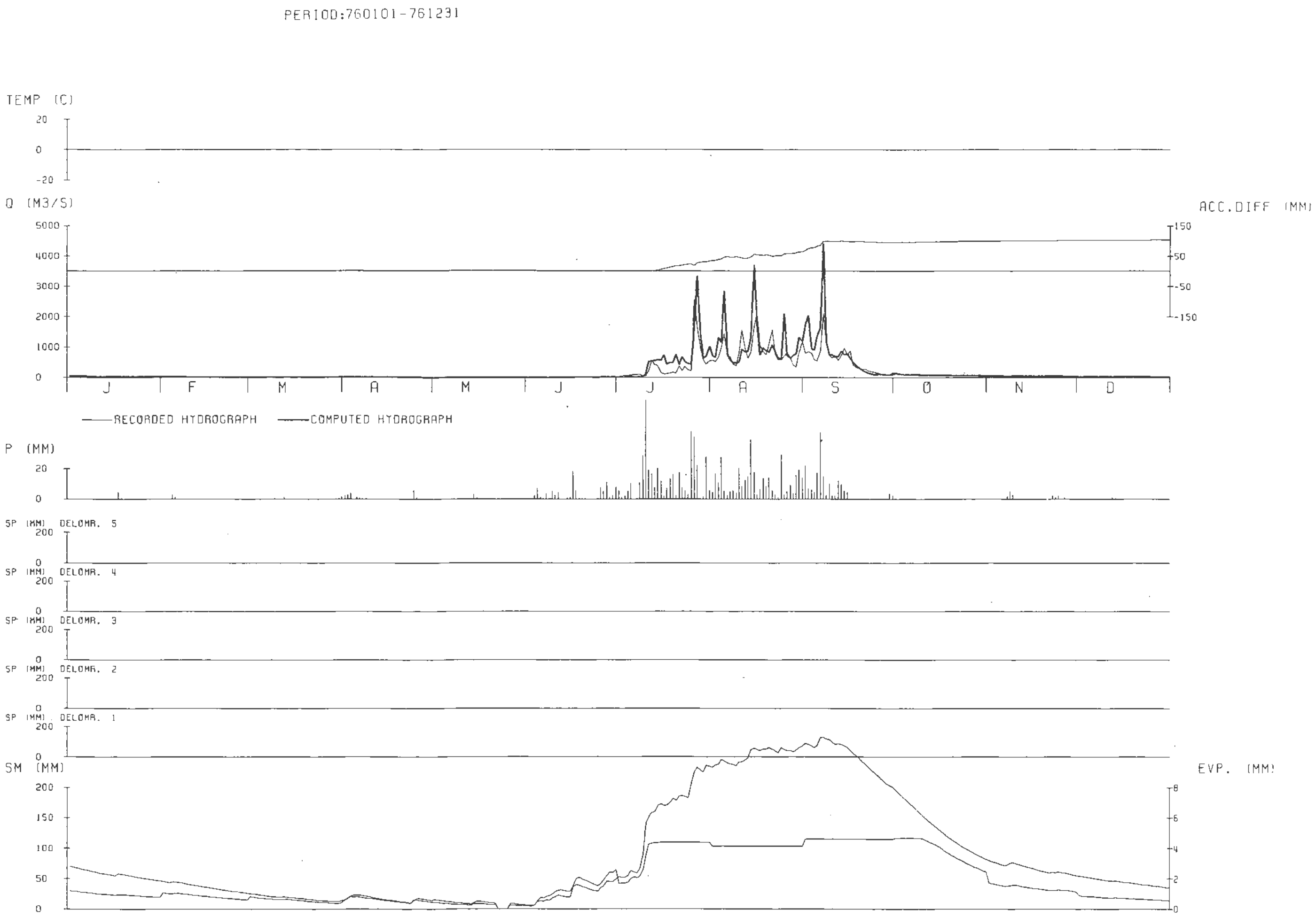
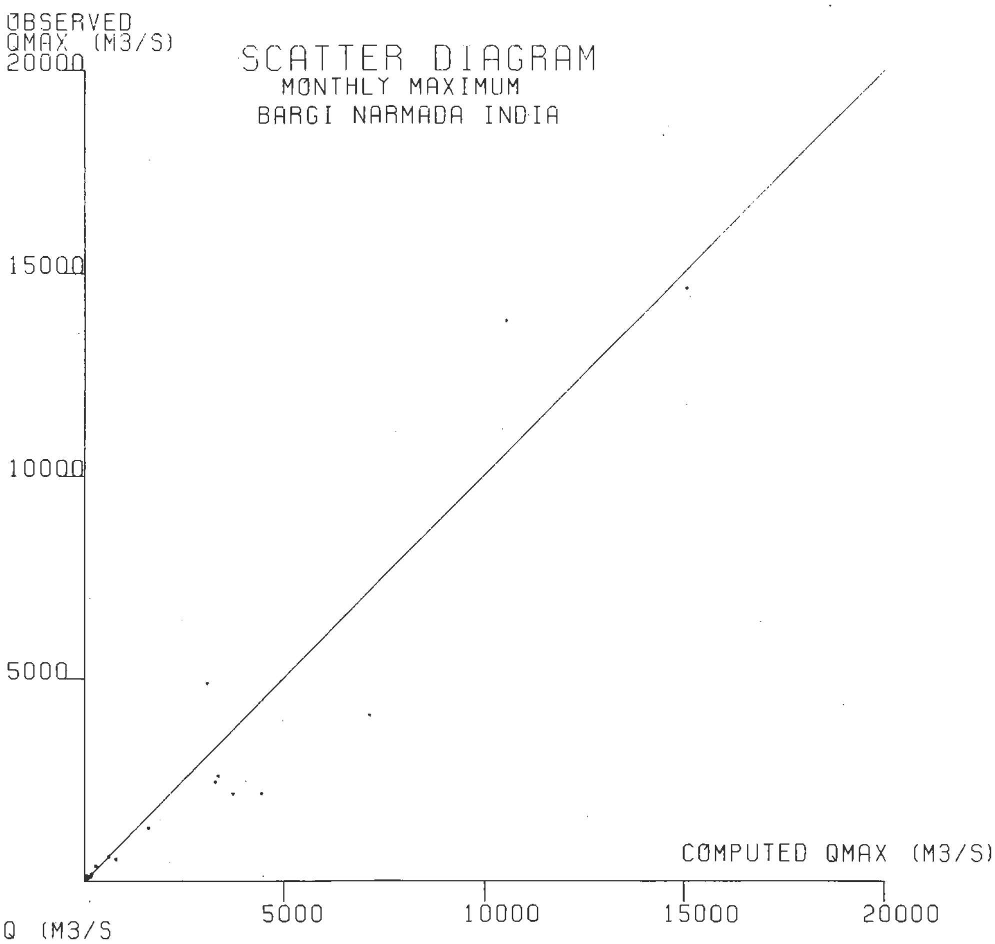


Figure 12. Test period plottings in the Narmada basin (1976).
(cont.) SM = soil moisture storage
EVP = actual evapotranspiration
(SP indicates snowpack and is absent in this basin)



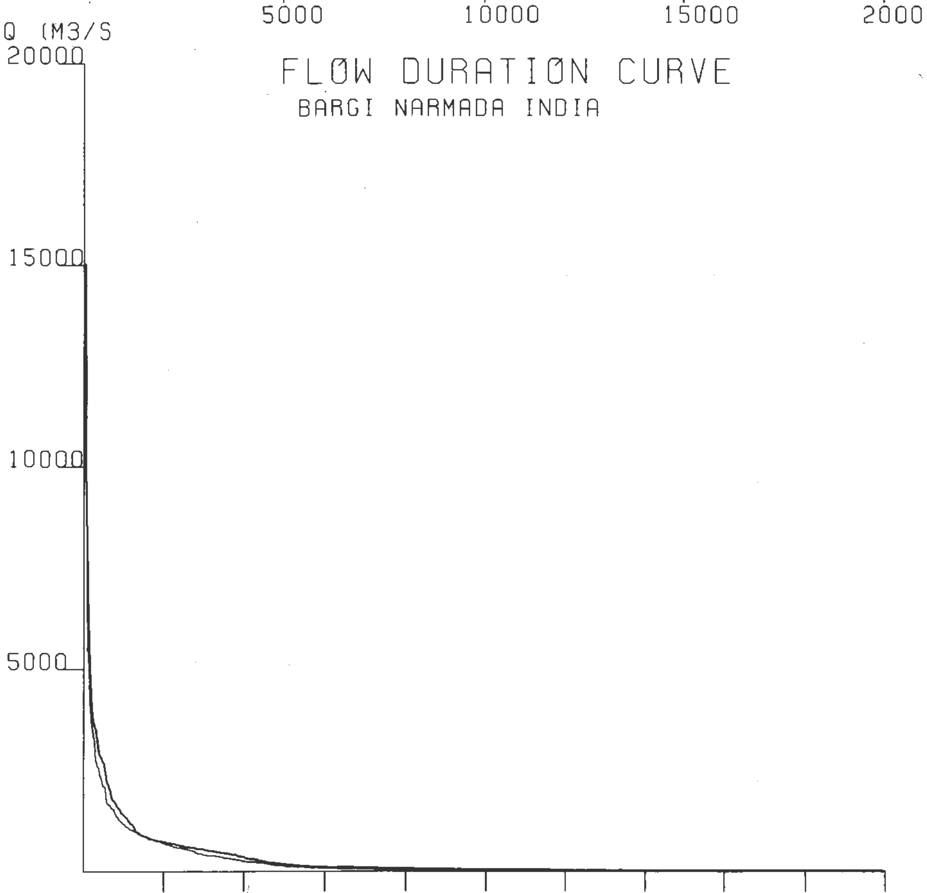


Figure 13. Scatter diagram of maximum monthly flows and flow duration curves for the test period (1974 - 1976).

Transformation of the model into a set of nomograms

The response of the model to rainfall is governed by its state variables, which, in a general form, can be expressed as:

$$Q = f(P, S_{sm}, S_{uz}, S_{lz}, S_T)$$

with

Q = runoff

P = precipitation

S_{sm} = soil moisture state in the model

S_{uz} = storage in the upper zone of the model

S_{lz} = storage in the lower zone of the model

S_T = state in the transformation function.

Due to the quick response of runoff to precipitation in this particular basin, the transformation function is not very important when analysing daily data (MAXBAS = 1 in Table 2). A simple translation of one day for four of the subbasins seems to be the only routing procedure needed to turn generated runoff into discharge (BLAG = 1 in Table 2).

The storage components of the upper zone, S_{uz}, and the lower zone, S_{lz}, are further strongly related to runoff, Q, although this relationship is not unique due to nonlinearities caused by the use of a constant percolation capacity, C_{perc}.

The above two considerations together with the fact that a lumped model seemed to perform equally well as the distributed one, made us believe that the runoff response to rainfall approximately be expressed as:

$$Q(t) \approx f(P(t-1), S_{sm}(t-2), Q(t-1))$$

where t = time in days (24 h).

The interpretation of this equation is that the runoff on a given day is uniquely depending of the precipitation and runoff on the previous day and the computed soil moisture state on the beginning of that day (or on the end of day t-2). The advantage of the simplified equation is that it may entail the possibility to transform the model into a graphical representation by a set of nomograms.

After some attempts, a set of nomograms was constructed on the basis of synthetic rainfall records, which were run through the lumped version of the model with variable initial conditions. It was soon found out that a practical way would be to use three nomograms and two simple arithmetic expressions. Due to the simplifications there was some scatter when plotting the graphs, but these were not considered to be serious.

The set of nomograms is presented in Figures 14 - 16, and the procedures when calculating runoff is given below:

1. Start with a given value of Q(t-1) and $S_{sm}(t-2)$. Enter nomogram 1 (Figure 14) with the actual precipitation value for the last 24 hours, P(t-1), and arrive at the runoff value Q(t).

2. Enter nomogram 2 (Figure 15) with P(t-1) and arrive at an intermediate soil moisture state S'_{sm}.

3. Compute a new intermediate soil moisture state as:

$$S''_{sm} = \frac{S'_{sm} + S_{sm}(t-2)}{2}$$

4. Enter nomogram 3 (Figure 16) with S''_{sm} and arrive at a value of the actual evapotranspiration of day (t-1), EVP(t-1).

5. Compute the soil moisture state for day t-1 as:

$$S_{sm}(t-1) = S''_{sm} - EVP\ (t-1).$$

6. Put $S_{sm}(t-2) = S_{sm}(t-1)$ and $Q(t-1) = Q(t)$ and return to 1. for simulation of next day.

In Figure 17 simulations by the nomogram technique are compared to computer simulations by the lumped model version. A scatter diagram of model simulations by the lumped model versus nomogram simulations is shown in Figure 18. As can be seen, the agreement is good with deviations of a smaller order of magnitude than between the model simulations and the observed hydrographs. Due to the quick response of the model in this basin the effect of runoff on the previous day is very small and does not change at values higher than 900 m^3/s.

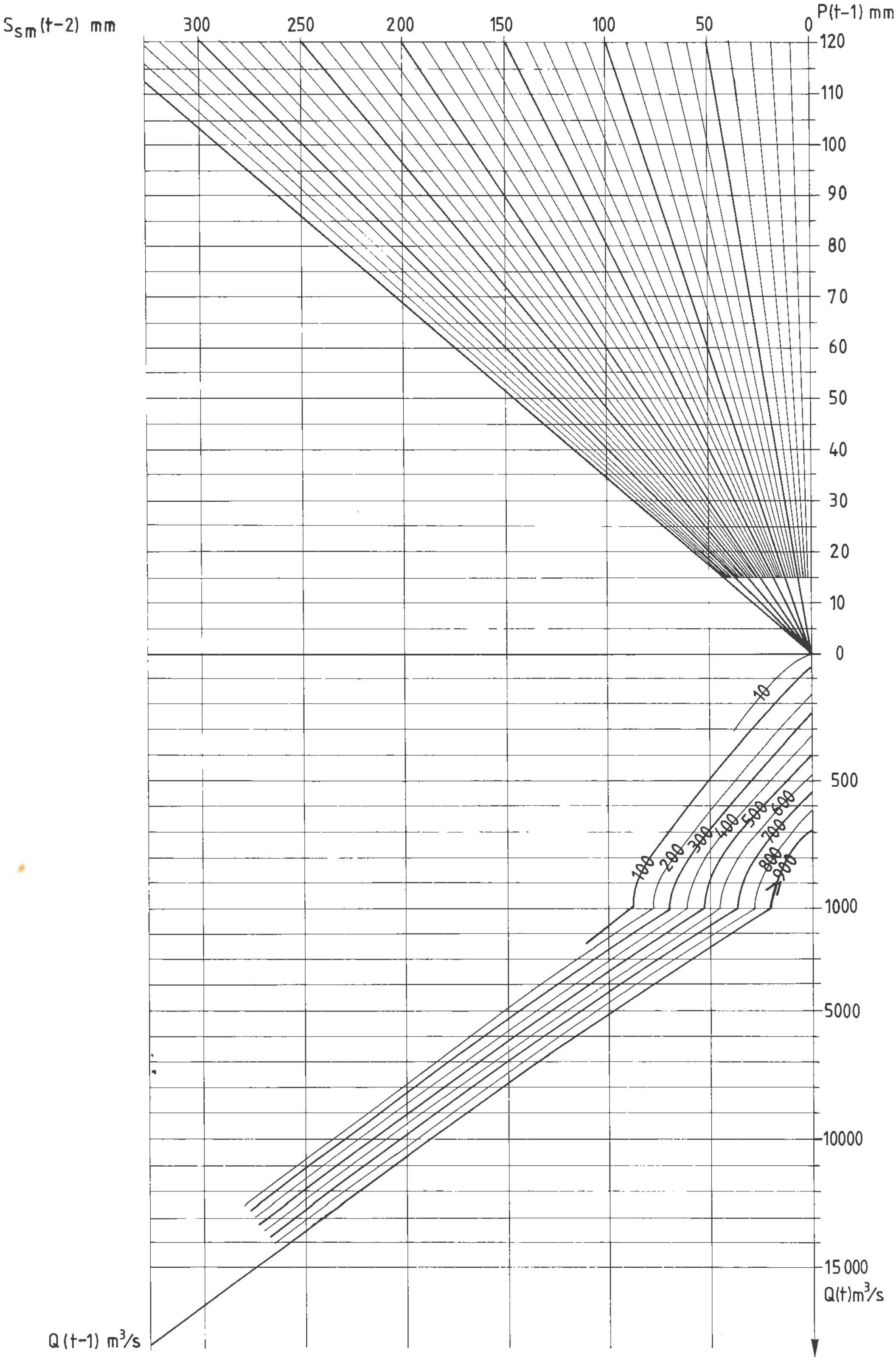


Figure 14. Nomogram 1. Estimation of Q(t) from P(t-1), S_{sm}(t-2), and Q(t-1).

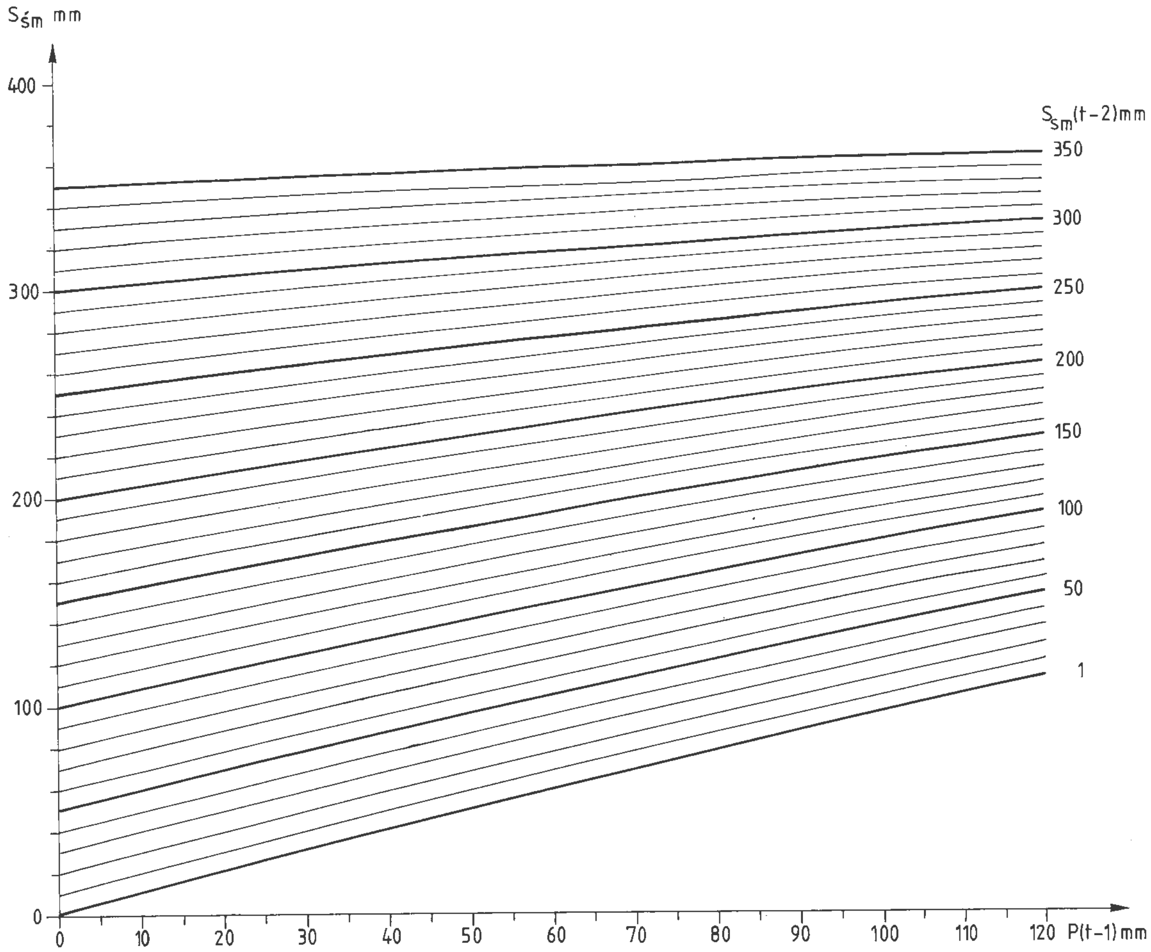


Figure 15. Nomogram 2. Estimation of S'_{sm} from P(t-1) and $S_{sm}(t-2)$.

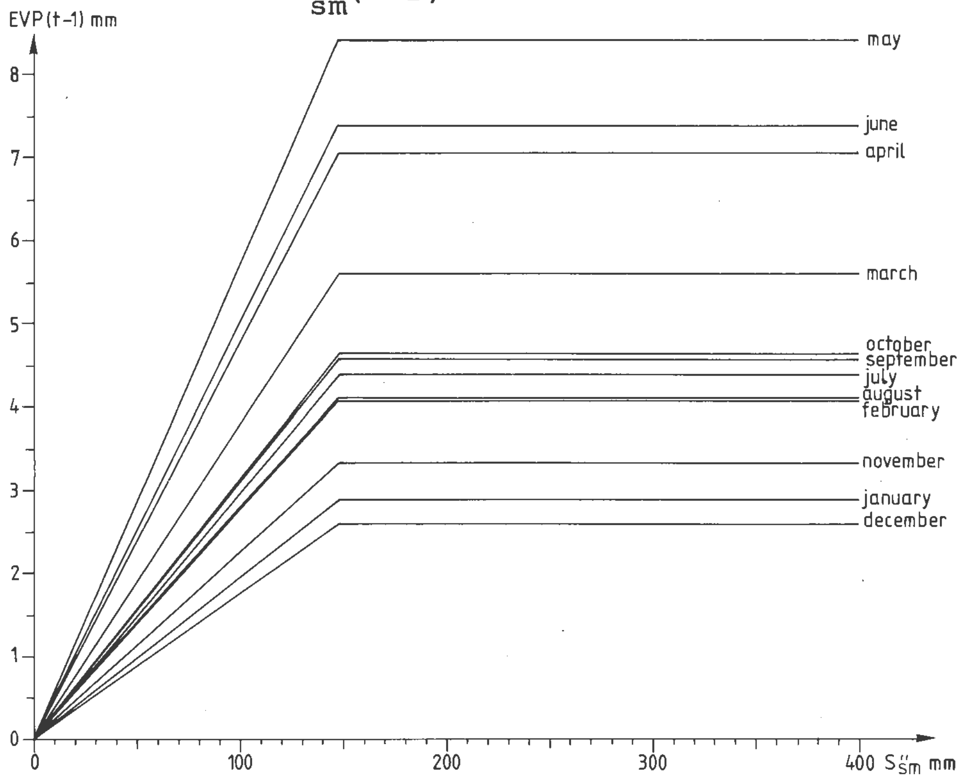


Figure 16. Nomogram 3. Estimation of EVP(t-1) from S''_{sm} and month of the year.

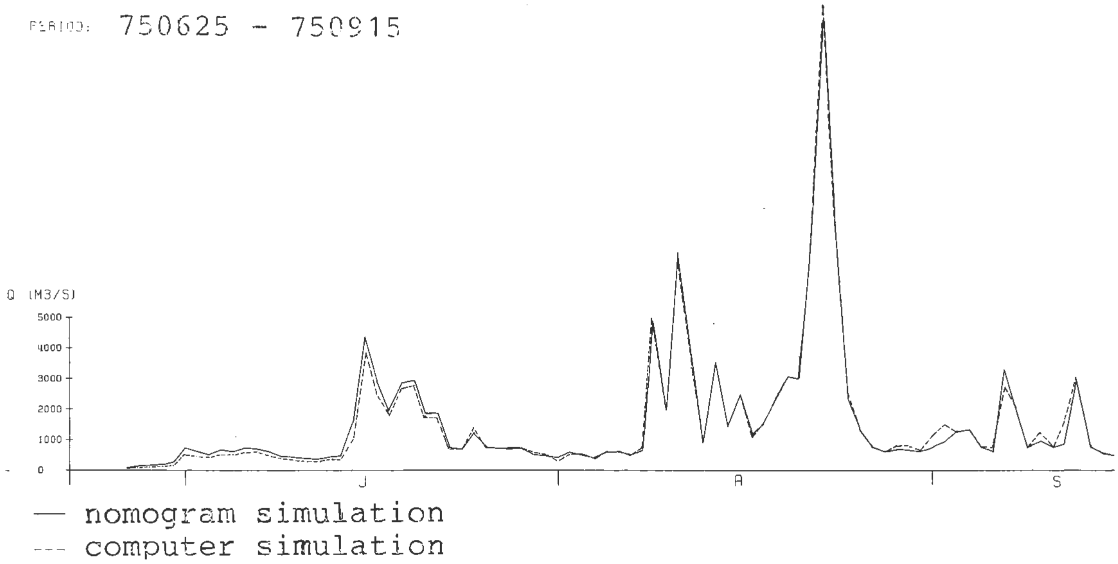


Figure 17. Comparisons between simulations by the nomogram technique and computer simulations by the lumped model version.

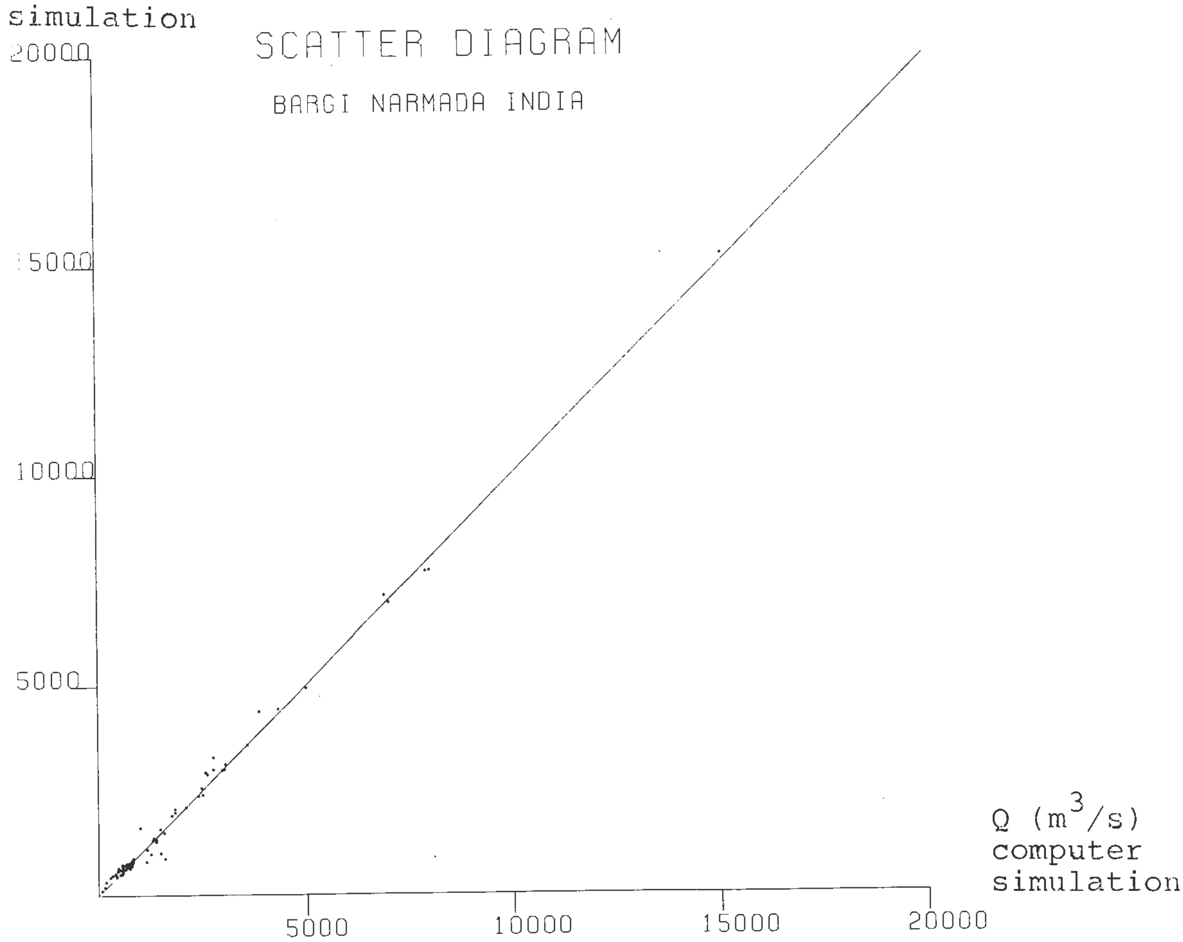


Figure 18. Simulation by the nomogram technique plotted against computer simulations by the lumped model version. (Daily data.)

Needless to say, the use of the graphical representations of the model has the advantage that forecasts and shorter simulations can be performed without any computer support. The six steps needed can be reduced to four (1, 4, 5, and 6) if there is no rain, and to three (4, 5, and 6) if only soil moisture is of interest during a dry spell. Because of the low variability of the soil moisture conditions immediately before the onset of the monsoon, the model can be at rest during the dry season, and the computation can start up in May or June.

It has to be strongly emphazised that this set of nomograms is derived uniquely for this particular basin and this particular set of input data. The shape of the nomograms will be different in another basin, and it will be much more complicated to construct a nomogram in a basin with slow response or with a significant snowmelt component.

Summary and discussion

The results from the calibration of the distributed HBV-6 model are encouraging, and the model accounts for some 80 % of the initial variance of runoff in the Upper Narmada basin. The increase in performance from the lumped model in Phase-I of the project is considerable. The main cause of this improvement is the better coverage of precipitation data. The switch from a lumped to a distributed model structure did not result in a significantly better simulation.

The choice of the potential evapotranspiration data during the monsoon proved to be very critical for the overall performance of the model, while the values during the dry season are not as critical. This means that the seasonal distribution of the estimates of the potential evapotranspiration is more important than the annual totals.

Due to the quick response of the basin to rainfall and the absence of snow, it has been possible to transform the model into a set of nomograms and two simple arithmetic operations. The performance of this procedure is comparable to that of the lumped model version. It is possible to run the model for the Upper Narmada river with the set of nomograms in this report and without support from a computer.

Acknowledgements

This work was carried out with funds from the Swedish International Development Agency (SIDA). Thanks are also due to Professor M.C. Chaturvedi, co-ordinator of the project from IIT-Delhi, and to the SMHI staff for valuable technical support during different stages of Phase-II of this project, in particular to Barbro Johansson for constructing the nomograms, and to Vera Kuylenstierna for typing the manuscript.

The valuable assistance from our data suppliers, India Meteorological Department, Central Water Commission, and the Madhya Pradesh Irrigation Department is finally acknowledged, as well as the support from Uttar Pradesh Irrigation Department.

REFERENCES

Bergström, S., and M.C. Chaturvedi
Institutional Collaboration between IIT, Delhi, and SMHI, Norrköping, on Water Resources Development - Hydrological Forecasting - Report on Phase-I and plans for Phase-II, SMHI, Norrköping, 1980

Bergström, S.
Development and Application of a Conceptual Runoff Model for Scandinavian Catchments
Swedish Meteorological and Hydrological Institute
Report No. RHO 7, Norrköping, 1976

Boughton, W.C.
A Mathematical Model for Relating Runoff to Rainfall with Daily Data
Trans. Inst. Engrs. (Australia), 7:83, 1966

Bergström, S., and G. Sandberg
Simulation of Groundwater Response by Conceptual Models - Three Case Studies
Nordic Hydrology, pp 71 - 81, 1983

Dawdy, D.R, and T. O'Donell
Mathematical Models of Catchment Behaviour
Proc. ASCE, Journal of Hydraulics Division
HY 4. 91:123, 1965

Hydrocomp Inc.
Operation Manual, 2nd Ed.,
Palo Alto, Hydrocomp, 1969

Kovzel, A., Ed.
Atlas of World Water Balance
Gidrometeoizdat, Leningrad, 1968

Linsley, R.K., and N.H. Crawford
Computation of a Synthetic Streamflow Record on a Digital Computer
IASH Pub. No. 51, pp 526 - 538, 1960

NOAA
National Weather Service Forecast System
Forecast Procedures
Technical Memorandum NWS Hydro-14
Washington, Silver Spring, Maryland, December, 1972

Quick, M.C., and A. Pipes
Daily and Seasonal Runoff Forecasting with a Water Budget Model
International Symposia on the Role of Snow and Ice in Hydrology Measurement and Forecasting
Banff, Alberta, UNESCO/WMO, September, 1972

Rao, K.N., C.J. George, and K.S. Ramasastri
The Climatic Water Balance of India
Memoirs of the India Meteorological Department, Vol. XXXII, Part III, Delhi-110006, India

Rockwood, D.M., Application of Streamflow Synthesis and Reservoir Regulation - SSARR - Program to Lower Mekong River
Pub. No. 80, FASIT Symposium, Tucson, Arizona, pp 329 - 344, December, 1958

Sugawara, M.
On the Analysis of Runoff Structure about Several Japanese Rivers
Jpn. J. Geophysics, 2, 1961

Westman, S-E.
Metod för homogenitetskontroll av meteorologiska och hydrolgoiska observationsserier
Rapport nr HO 1, Swedish Meteorolgical and Hydrological Institute (SMHI) Norrköping, Sweden, 1982

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