



ASSESSMENT OF SURFACE WATER RESOURCES IN THE MANYAME CATCHMENT – ZIMBABWE

Streamflow Gauging and Conceptual
Hydrological Modelling

Department of Water



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TABLE OF CONTENTS

PREFACE	1
1. INTRODUCTION	2
2. BASIN DESCRIPTION	4
3. HYDROMETRY. DATA	6
3.1. Current meter gaugings	6
3.2. Runoff data	6
3.3. Rainfall data	7
4. MODEL DESCRIPTION	9
4.1. Model routines	10
4.2. River channel and reservoir routing. Abstraction	11
4.3. Verification criteria	12
4.4. Forecasting	13
5. CALIBRATION	17
5.1. Basin subdivision	17
5.2. Results	18
6. FORECASTING	22
7. CONCLUSIONS	26
REFERENCES	27
APPENDICES	

Appendix 1. Maps.

Appendix 2. Current meter gaugings.

Appendix 3. Calibration description.

PREFACE

This report is on the Manyame Water Resources Assessment for Development Project. The aim of the project was to establish an improved hydrological network in the catchment, a mathematical model of its hydrological regime and a hydrological forecasting system for the preparation of river and flood or drought forecasts.

The project activities were coordinated by the Hydrological Branch of the Ministry of Lands, Agriculture and Water Development in conjunction with the Swedish Meteorological and Hydrological Institute. The foreign currency part of the agreement was funded by the Swedish Agency for International Technical and Economic Cooperation (BITS) up to a ceiling of SEK 2 936 200. The Government of Zimbabwe met all the other local expenses.

The specialists involved in the project from the Swedish side were Barbro Johansson, who was the project leader, Katarina Losjö (modelling), Nils Sjödin (stream flow gaugings and checking ratings of stations), Christer Jonsson (stream flow gaugings and checking rating of stations), Magnus Persson (modelling and computing expert) and Joakim Harlin, who is the director of the international projects at SMHI.

All members of staff in the Hydrological Branch, Zimbabwe, were involved in the project but the main participants were Gilbert Mawere, Chief Hydrologist and director of the project, Joseph Merka, project officer and Remigio Chikwanha who was also a project officer. Joseph Merka and Remigio Chikwanha were the ones who were responsible for building the cableway structures and also for carrying out stream flow gaugings together with SMHI specialists. In addition, these two also attended a training course on the HBV model at the SMHI headquarters in Norrköping, Sweden and in conjunction with the SMHI specialists, managed to calibrate the model for 9 subcatchments of the Manyame river.

Acknowledgements

The project could not have been carried out without the involvement of a large number of people. The Data Processing Section and the Water Rights Section of the Hydrological Branch, and the Meteorological department provided important data. Shumirai Mudyanavana and Robert Muchakazi collected and punched large amounts of rainfall data. The staff of the Hydrological Branch constructed cableways and carried out current meter gaugings. The Department of Works, City of Harare provided dam level data. Their contribution is gratefully acknowledged.

1. INTRODUCTION

The Government of the Republic of Zimbabwe recognises the importance of the assessment and development of national water resources for the overall development of the country. Following the recent droughts of the eighties and early nineties, the Government realized the urgent need to strengthen its data base on water resources in the country in order to enable the optimum utilization of national water resources. The strategy adopted by the Government was to improve the data base by hydrological monitoring of a key river basin and then later on to use the technology thus developed on other river basins in the country. The Manyame river basin was chosen as the key river basin and this gave rise to the Manyame Water Resources Assessment for Development Project.

The Manyame Water Resources Assessment for Development Project was intended to establish an improved hydrological network in the Manyame river catchment, a mathematical model of its hydrological regime and a hydrological forecasting system for the preparation of river and flood or drought forecasts. It was intended to upgrade the capacity of the Hydrological Branch of the Ministry of Lands, Agriculture and Water Development to enable it to provide an improved and reliable data base on water resources for the optimum development and utilization of the available water resources. The project duration was from June 1993 to June 1995.

Zimbabwe has a surface area of approximately 384 000 square kilometres. The country is divided into six hydrological zones (see Map A1.1 in Appendix 1). There are altogether over 800 hydrological stations with hydrological data. Out of these stations there are 301 operational stations with autographic water level recorders. There are also 169 operational stations equipped with gauge posts. The rest of the stations have either been replaced or inundated by dams or closed. The Manyame river catchment has 20 operational stations equipped with autographic water level recorders.

One unique feature of Zimbabwean flow gauging stations is that nearly all have hydraulic structures or gauging weirs. These hydraulic structures are rated by hydraulic formulae. There was until recently no extensive programme to check the reliability of these ratings by current metering. Within the notch capacity, these structures normally measure flows accurately. At higher flows, especially during floods, they tend to get drowned and as a result, flows above notch capacity are estimated by extrapolation. As such, flood peaks and total runoff are not known accurately. One of the main aims of the project was therefore to determine flows above notch capacity for the selected network of primary stations in the Manyame, and to verify the rating below notch capacity. The task should then continue for all the other gauging stations nationally.

There are four Government dams in the upper reaches of the Manyame river catchment. These are Harava dam, Seke dam, Lake Chivero and Manyame dam, (see Map A1.2 in Appendix 1). All of these dams are classified as major dams. Two of them, Chivero and Manyame, supply water to the city of Harare, including Chitungwiza and Norton. In addition they are the source of water for irrigation. The other two (Seke and Harava) are entirely for water supply. There is another major dam, Mazwikadei, on the Mukwadzi river which is one of the major tributaries of the Manyame river. This dam is for irrigation supply only.

The problems to be addressed in the project were as follows;

1. Reviewing the hydrological network on the Manyame river catchment and establishing a primary network of stations, which will permit a reliable assessment of the water resources of the catchment.
2. Improving the reliability of the ratings of those stations.
3. Establishing a mathematical model of the catchment (in this case, the HBV model).
4. Establishing a hydrological forecasting centre in Harare to prepare and disseminate river and flood forecasts to users.
5. Training of national staff.

The project was carried out by the Hydrological Branch of the Ministry of Lands, Agriculture and Water Development in conjunction with the Swedish Meteorological and Hydrological Institute (SMHI).

The work of the Swedish Meteorological and Hydrological Institute (SMHI) was;

1. to advise the Hydrological Branch on the selection of primary stations and the rating of these stations.
2. in cooperation with the hydrological branch, calibrate, install and test a stream flow forecasting system, the IHMS, for the Manyame catchment on a personal computer at the Hydrological Branch in Harare.
3. Train 2 Zimbabwean Hydrologists in calibrating and operating the forecasting system at the SMHI headquarters in Norrköping, Sweden.

The situation expected at the end of the project was;

1. An improved operational hydrological system on the Manyame river and its tributaries with stations providing accurate information.
2. A mathematical model (the IHMS) of the Manyame river catchment for the preparation of river and flood forecasts.
3. Adequately trained staff in the use of the mathematical model and in current meter rating of hydrological stations.

The results of the project are expected to benefit;

- a) policy makers and planners who will receive reliable information/data on available water resources to plan development works in the optimum utilization of such resources for the social and economic benefit of the nation.
- b) dam managers/operators who will be able to operate their dams more effectively to satisfy the water needs of the towns and irrigators.
- c) the population through the reduction of damages from exceptionally high floods and also the harmful effects of droughts.

2. BASIN DESCRIPTION

The basin of the Manyame river is located between the 15 degrees and 35 minutes and the 18 degrees and 20 minutes south latitude and between the 30 degrees and the 31 degrees and 30 minutes east longitude. The catchment area of the river is 14 181 square kilometres. It is located within the hydrological zone C (see Map A1.1 Appendix 1). It is also located within Mashonaland Central and Mashonaland West Provinces. There are several important towns within the basin of the river. These include Harare (the capital city of Zimbabwe), including Chitungwiza, Norton, Banket, Chinhoyi (the provincial capital of Mashonaland West), Raffingora, Mutorashanga and Guruve. There are also several smaller administrative centres within the basin.

The Manyame river rises approximately 7 km due west of Marondera at an altitude of 1640 metres above mean sea level. The river drains in a westerly direction for approximately 150 km and then in a northerly direction for approximately 240 km until it crosses into Mozambique at an altitude of 340 metres above mean sea level. The total length of the river is therefore 388 km (Map A1.2, Appendix 1).

The river flows from its source for about 52 km through mostly commercial farming areas and parts of Seke Communal Lands up to the point it enters Harava dam. The river then enters Seke dam which is immediately downstream of Harava dam. Major tributaries along this stretch of the Manyame river are the Musitwe and the Ruwa. The Ruwa river drains directly into Harava dam.

From Seke dam, the river flows for about 10 km up to its confluence with the Nyatsime river. The Nyatsime river flows through mostly communal areas and a few commercial farms. The stretch between Seke dam and the confluence of the Manyame with the Nyatsime river is comprised of mostly commercial farms and parts of Chitungwiza. This stretch is also characterized by granite outcrops.

15 km downstream of the confluence with the Nyatsime it enters lake Chivero. This is a man made lake. Major tributaries along this stretch include the Mukuvisi and the Marimba. The catchment area of these two tributaries includes the city of Harare. Lake Chivero was built on a gorge in the Hunyani Hills.

From lake Chivero, the river flows into lake Manyame. This is also a man made lake. Gwebi river and Muzururu river are two major tributaries of Manyame river on this stretch. They both drain directly into lake Manyame. This part of the Manyame river basin is exclusively commercial farming area except for recreational areas and game parks around the two lakes.

From lake Manyame the river progressively starts changing its course to a northerly direction and flows northwards by the time it reaches Chinhoyi. This part of the basin is made up of commercial farming areas and Zvimba communal lands.

35 km north of Chinhoyi is the confluence with Mkwadzi river. This part of the basin is characterized by the Romwe Hills and the Hunyani Range to the left of the river. This part is also made up exclusively of commercial farming areas. On the Mkwadzi river

is found a major dam, the Mazwikadei, whose water is used for irrigation.

From its confluence with the Mukwadzi, the river flows through a gorge between Mtemwa Range and the Hunyani Range of mountains and then continues in a northeasterly direction through commercial farming areas for about 50 km. A major tributary of Manyame river on this stretch is the Mesitwe river. The river then changes direction and starts flowing in a westerly/northwesterly direction through the Nyakapupu area for 20 km. This part of the basin is predominantly mountainous and covers parts of Kachuta Communal Lands.

The course then changes back to a northerly direction up to the confluence with the Mano river. This part of the basin covers the Guruve Communal Lands, Kachuta Communal Lands and the Dande Communal Lands. The area is very hilly and has poor soils. Major tributaries of the Manyame on this stretch are the Karoi and the Mano rivers.

From its confluence with the Mano, the river flows for about 20 km up to its confluence with the Dande river, which is about 20 km from the border with Mozambique. On this stretch the river becomes wider. This part of the basin is made up mostly of a mixture of woodlands and savannah grass lands.

Agricultural activity in the basin of the Manyame river is very high. Almost 80% of the area of the basin is made up of commercial farms and communal lands. The main crops which are grown in the basin of the Manyame river are maize, soya beans, cotton, tobacco and wheat. Wheat is grown in the cool dry season under irrigation. Other crops grown in the basin are sugar beans, flowers and green vegetables including tomatoes and onions.

The basin of the Manyame river consists mainly of granitized basement rocks. These are cut from north south by the Great Dyke, which is 500 km long and 5 km wide and stands out above the surrounding granites. Infracambian schists, sandstones and quartzites outcrop to the west of Harare. A few scattered outcrops of cretaceous conglomerates occur to the north of the basin.

The rainy season starts in late November and ends in April. Most of the rainfall in the basin is caused by the Inter Tropical Convergence Zone when it moves over Zimbabwe from the north. The mean annual rainfall for the basin is between 600 mm and 900 mm (Map A1.3, Appendix 1). The mean annual runoff for the catchment ranges from 140 mm around the Harare area to 160 mm in the mid catchment area and down to 40 mm downstream of the Zambezi escarpment.

3. HYDROMETRY. DATA.

3.1. Current meter gaugings

Most runoff stations in Zimbabwe consist of weirs, which are rated by means of empirical weir formulae (Figure 3.1). Within the notch capacity these formulae should be fairly accurate, but for high flows direct measurements are required to establish the rating curve. At a few stations, the weirs have not been constructed exactly according to the rules for sharp-crested weirs, and in these cases current meter gaugings should be used to verify the rating curve also below the notch capacity.

Due to the conditions of Zimbabwean rivers, cable ways were considered necessary to perform current meter gaugings. As part of the project, they were installed at five crucial stations; one upstream of the Harava dam (C81), one on the Nyatsime just upstream of the confluence with the Manyame (C23), one on the Manyame and one on the Mukwadzi just upstream of their confluence (C74 and C75), and one rather far downstream on the Manyame (C57/C64) representing some 70% of the total of the Manyame catchment (see Map A1.2, Appendix 1).

Current meter gaugings were performed in January, February and March 1994 and in January and February 1995. Unfortunately, neither in 1994 nor in 1995, were there any high flows of such duration that they could be gauged. Consequently no current meter gaugings were made above notch capacity, except at C57/C64 where the notch capacity is low. Too few gaugings have been performed to draw any safe conclusions on the functions of the stations below notch capacity. However, the impression is that at stations of good construction and in good condition (like C81), the empirical rating tables agree well with the current meter gaugings, while at stations where the construction is not quite according to standard design (like C23) there are deviations. To be sure of an accurate rating of the Zimbabwean runoff stations, the current meter gaugings should continue, and also be extended to other stations.

A more detailed description of the gaugings is given in Appendix 2.

3.2. Runoff data

The network of runoff stations is dense, especially in the regions with large commercial farms. Long records are often available. Most stations are equipped with recorders, and charts are changed weekly. Manual readings of water levels are made when the charts are changed, and once or twice in between. Due to the hydraulic structures, the rating remains fairly stable, even if sediment may accumulate upstream of the structures. There may be some systematic errors due to an inaccurate rating table, but one does not get the random errors that occur when there is a control section which is altered by large floods. At a few stations where the downstream gradient is low, the levels may be affected by backwater even at rather low flows. However, in general the data quality appears to be high. The errors that sometimes occur in the data processing are easily detected (see also Appendix 3).



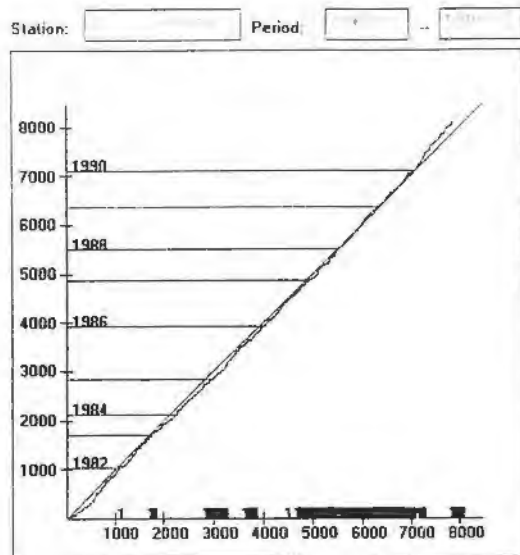
Figure 3.1. The gauging weir at the hydrological station C74.

In the Hydrological Branch all runoff data are stored on computer media. This data can be transferred to diskettes for use in PC applications. As the observed levels are stored, new runoff values can be computed, also for past years, if an adjustment of the rating table is made.

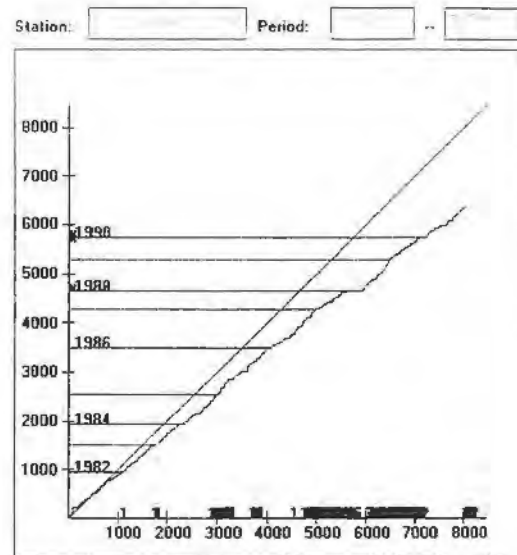
3.3. Rainfall data

Rainfall data is collected by the Meteorological Department. Except for some key stations, data is stored on paper only. For this project large amounts of daily rainfall data had to be punched. As there is high spatial variation in daily rainfall, as many stations as possible should be used to estimate areal precipitation.

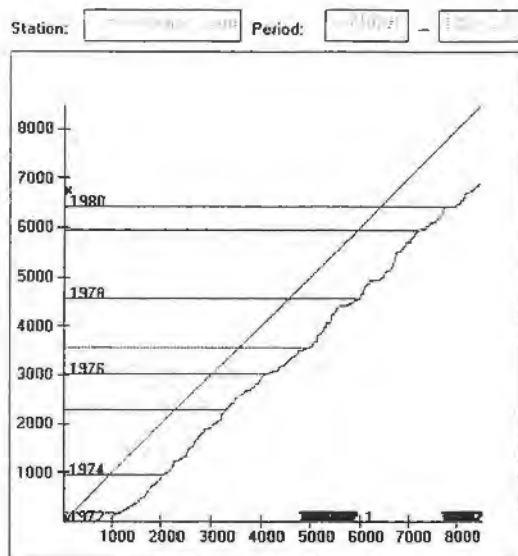
To check the quality and homogeneity of the stations, so-called double mass plots were used. Accumulated rainfall for one station was plotted against the accumulated mean for the surrounding stations. For most stations the homogeneity was acceptable, for some it was very good and a few stations were discarded during certain periods. Figure 3.2a-c shows examples of stations of different quality.



a)



b)



c)

a) Harare Belvedere for 1981-1990. A homogeneous station.

b) Chitswedemo school for 1981-1990. A station of normal and acceptable quality.

c) Chitswedemo school for 1971-1980. There are too many uncertainties in the observations for the station to be useful, especially during 1977 and 1978.

Figure 3.2. Double mass plots for some rainfall stations. Along the y-axis is the accumulated precipitation for the investigated station, and along the x-axis the accumulated mean of the surrounding stations. A small x along the y-axis denotes missing data.

4. MODEL DESCRIPTION

The HBV model is a conceptual runoff model for continuous computation of river discharge. It was developed at the Swedish Meteorological and Hydrological Institute in the 1970s (Bergström, 1976), and has since then been used for a number of applications (Bergström, 1992). The structure of the model is relatively simple, and computer and input data demands are moderate. A system for hydrological forecasting, based on the model, is available for personal computers (Integrated Hydrological Modelling System, IHMS).

For catchments with no snow, the model is built around two routines, the soil moisture routine and the response routine (Figure 4.1). For areas with snow, there is a special snow routine. Input data are precipitation, long-term means of potential evapotranspiration and, for snow simulations, temperature. Areal values are determined as a weighted mean of observed data from meteorological stations. Usually the model is run with daily timesteps, but shorter timesteps down to one hour can be used. Large catchments with varying characteristics, can be divided into subcatchments, with the model set up for each of them. The IHMS includes routing calculations, operation schedules for reservoirs, rating curves for lake outlets and abstraction of water.

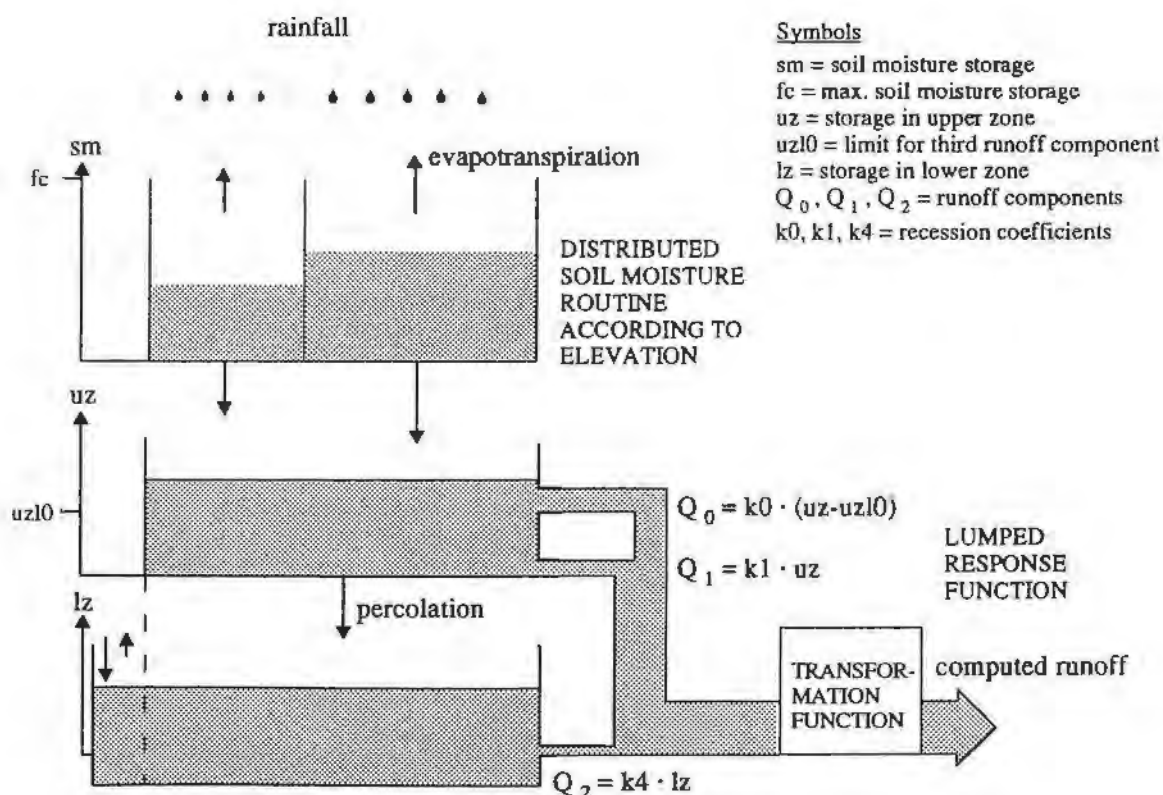


Figure 4.1. The HBV model for catchments with no snow.

The model parameters are determined through a calibration process, where the parameters are adjusted until simulated and observed runoff show a good agreement. Preferably some 10 years of data should be used for the calibration and another 5 years for verification. Often such long records of runoff are not available, and one has to be satisfied with shorter periods. It is however important that the calibration period contains years with low rainfall as well as years with high rainfall.

4.1 Model routines

Soil moisture routine

The soil moisture routine is the main part controlling runoff formation. Input is areal rainfall and potential evapotranspiration. If there is a fixed relationship between altitude and rainfall the catchment can be divided into different elevation zones, and the soil moisture routine is run for each one of them. The routine is based on the three parameters β , LP and FC, as shown in Figure 4.2. β is controlling the contribution to the response routine ($\Delta Q/\Delta P$) or the increase in soil moisture storage ($1-\Delta Q/\Delta P$) from each mm of rainfall. LP is a soil moisture value above which evapotranspiration reaches its potential value, and FC is the maximum soil moisture storage in the model.

The routine will have the effect that the contribution to runoff from rainfall is small when the soil is dry (low soil moisture values), and great at wet conditions. The actual evapotranspiration decreases as the soil dries out.

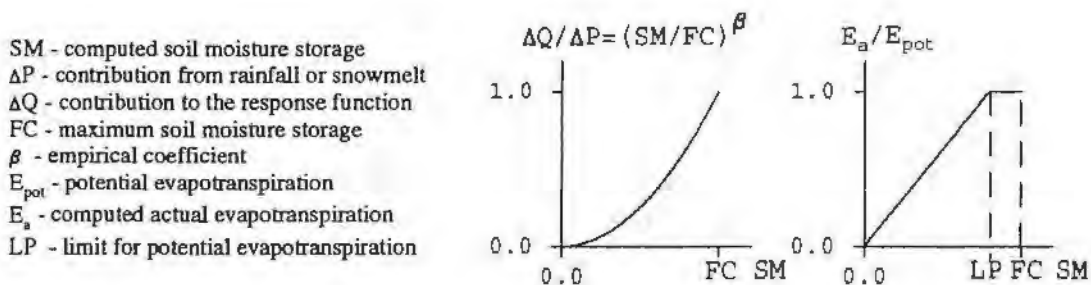


Figure 4.2. The soil moisture routine.

Response routine

The response routine transforms excess water from the soil moisture routine (ΔQ) to runoff. It also includes the effect of direct rainfall and evaporation on a part which represents lakes, rivers and other wet areas. The function consists of one upper and one lower quasi-linear reservoir as shown in Figure 4.1. These are the origin of the quick and slow response runoff components of the hydrograph.

Yield from the soil moisture routine will be added to the storage in the upper reservoir. As long as there is water in the upper reservoir, water will percolate to the lower

reservoir. At high yield from the soil, percolation is not sufficient to keep the upper reservoir empty, and the generated discharge will have a contribution directly from the upper reservoir, which will represent drainage through more superficial channels. At a storage in the upper reservoir exceeding $uzl0$, even more rapid drainage will start. The lower reservoir, on the other hand, represents the groundwater storage of the catchment, contributing to the base flow.

Transformation function

The runoff from the response routine is routed through the transformation function to consider the distribution of travel times from different parts of the subbasin. The transformation function is based on a simple filter technique with a triangular distribution of the weights, as shown in Figure 4.3.

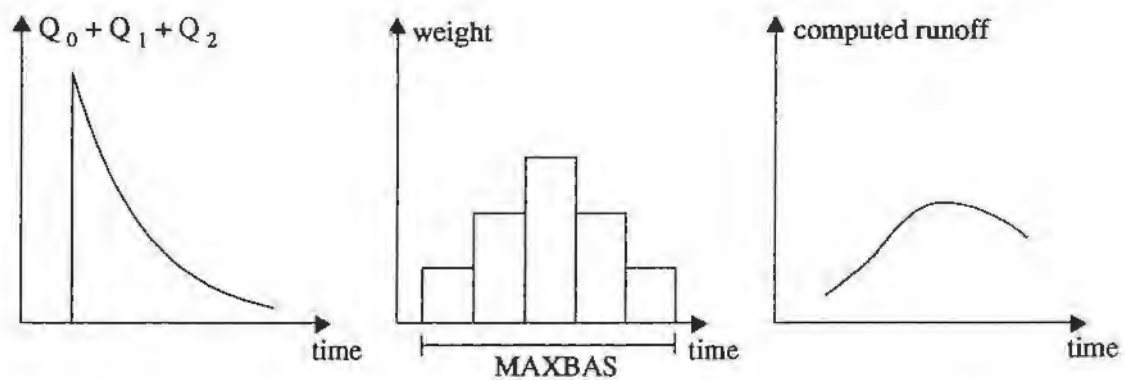


Figure 4.3. The transformation function.

4.2 River channel and reservoir routing. Abstraction.

Abstraction from flow

A special routine handles abstraction from flow. The abstraction rate is given as a mean value in m^3/s that may vary between years as well as with the time of the year. It is normally assumed that the abstracted water is not returned to the river.

River routing

As a river catchment is divided into subbasins, the HBV model is set up separately for each subbasin. The subbasins are then linked together and the outflow from the upstream ones are routed through the downstream ones. A Muskingum routine can be used for the river routing.

Reservoirs/lakes

The catchment should be divided in such a way that large reservoirs are located at the outlet of a subbasin. The model routines compute the inflow to the reservoir, including rainfall on and evaporation from the reservoir itself. A regulation schedule or a rating curve is then used to compute the outflow from the reservoir. The regulation schedule relates the outflow to reservoir levels and to the time of the year. It is also possible to include abstraction from the reservoir.

4.3 Verification criteria

When calibrating the model, three main criteria of fit are used.

- Visual inspection of the observed and computed hydrograph.
- A continuous plot of the accumulated difference between the computed and the observed runoff.
- The R^2 -value according to Nash and Sutcliffe (1970):

$$R^2 = \frac{\Sigma(\bar{Q}_0 - Q_0)^2 - \Sigma(Q_c - Q_0)^2}{\Sigma(\bar{Q}_0 - Q_0)^2} \quad \text{where}$$

Q_0 = observed runoff

$\bar{Q}_0$ = mean of observed runoff

Q_c = computed runoff

R^2 has a value of 1.0, if the simulation and the observations agree completely, and 0 if the model does not perform any better than the mean value of the runoff record.

4.4 Forecasting

When the model has been set up and calibrated for a catchment, it can be used to forecast the runoff. The model is then run up to the first day of the forecast, using observed rainfall data. This will give the initial conditions from which to start. If observed runoff is available, the model performance should be checked, and if the computed runoff deviates from the observed, the model should be updated, to give a good agreement on the day before the forecast. The updating is done on the rainfall data.

There are two types of forecasts available. One is the short-range forecast, which is based on a meteorological forecast. It is normally made for up to five days, as meteorological forecasts are not reliable for longer periods. The accuracy in the forecasted rainfall amount is often low. It is therefore advisable to introduce some upper

and lower limits for the forecast. Figure 4.4 shows an example of a short-range forecast of the inflow to the Chivero and Manyame reservoirs, using three alternative rainfall sequences. The forecasted inflow can be converted to reservoir levels if the abstraction and release of water from the reservoirs can be quantified. The levels in Figure 4.4 are, both during the simulated and forecasted period, computed with the assumption that the abstraction from the Manyame is $1.1 \text{ m}^3/\text{s}$ and that the release of water is $0.25 \text{ m}^3/\text{s}$. No water is released from the Chivero. The observed inflow in January is estimated from the observed outflow from the Manyame, and observed weekly reservoir levels. Consequently, observed and computed values cannot be expected to agree on a daily basis, only on a weekly basis.

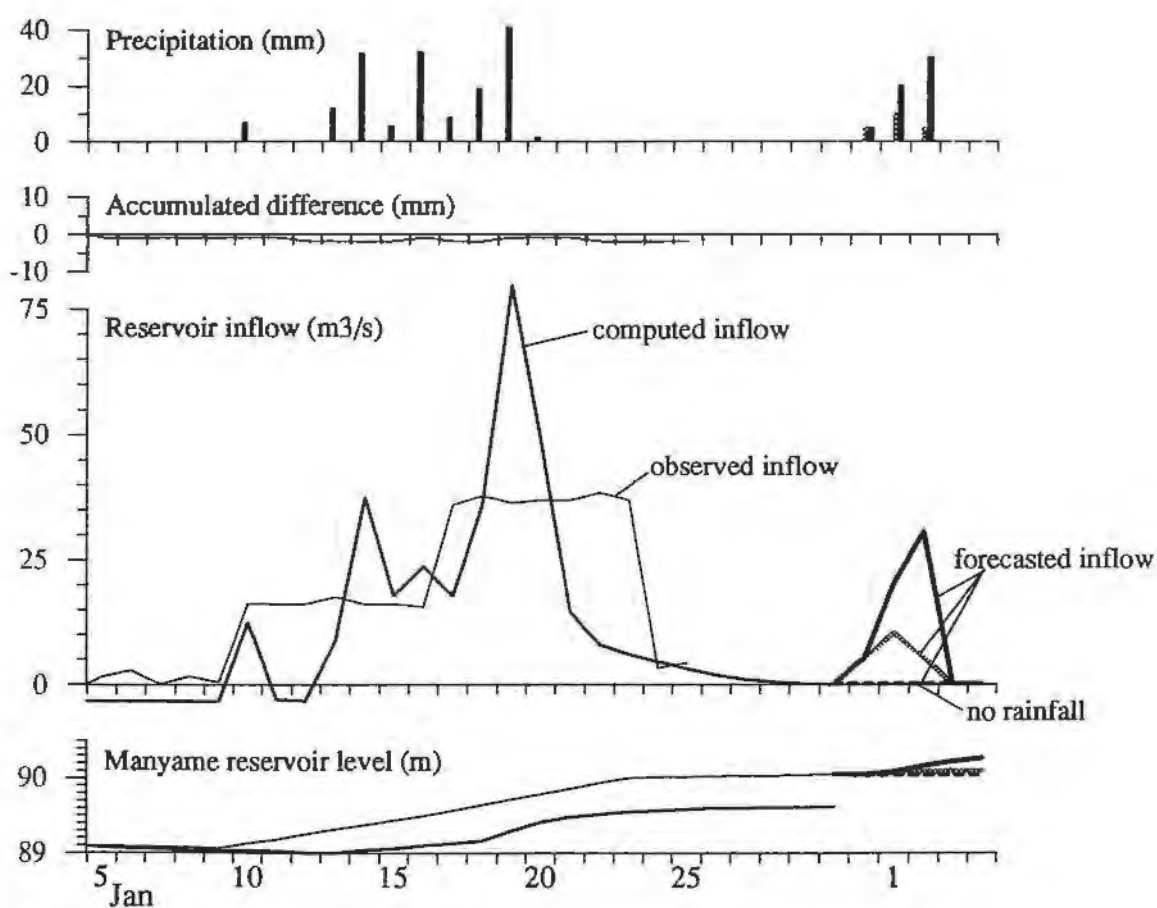


Figure 4.4. Short-range forecast of the inflow to the Manyame and Chivero reservoirs and of the Manyame level. Three alternative rainfall sequences were used.

The second type of forecast is the long-range one, which is a kind of statistical forecast. No forecasted meteorological data are entered. For the forecasted period, the model instead uses rainfall data for the corresponding days of previous years. A hydrograph is computed for each of the available rainfall series. Note that all the hydrographs will start from the same model state, i.e. that of the last day before the forecast. An example of a long-range forecast, based on 13 years of rainfall series, is given in Figure 4.5. If the rainfall series can be assumed to represent a reasonable probability distribution of input data, the corresponding hydrographs will give a probability distribution of runoff. The daily runoff can be accumulated to give the forecasted volume inflow to reservoirs, in this case the Chivero and the Manyame (Figure 4.6). As for the short-range forecast, the runoff can also be converted to reservoir levels (Figure 4.7).

The long-range forecast is normally used for periods between one and six months, and should of course be based on as many years as possible of rainfall series. It differs from a statistical forecast based on runoff data, in the respect that consideration is taken to the catchment conditions on the day before the forecast. A forecast starting from dry conditions will differ from one starting from wet conditions (see further Chapter 6). It is also common to have longer records of rainfall than of runoff.

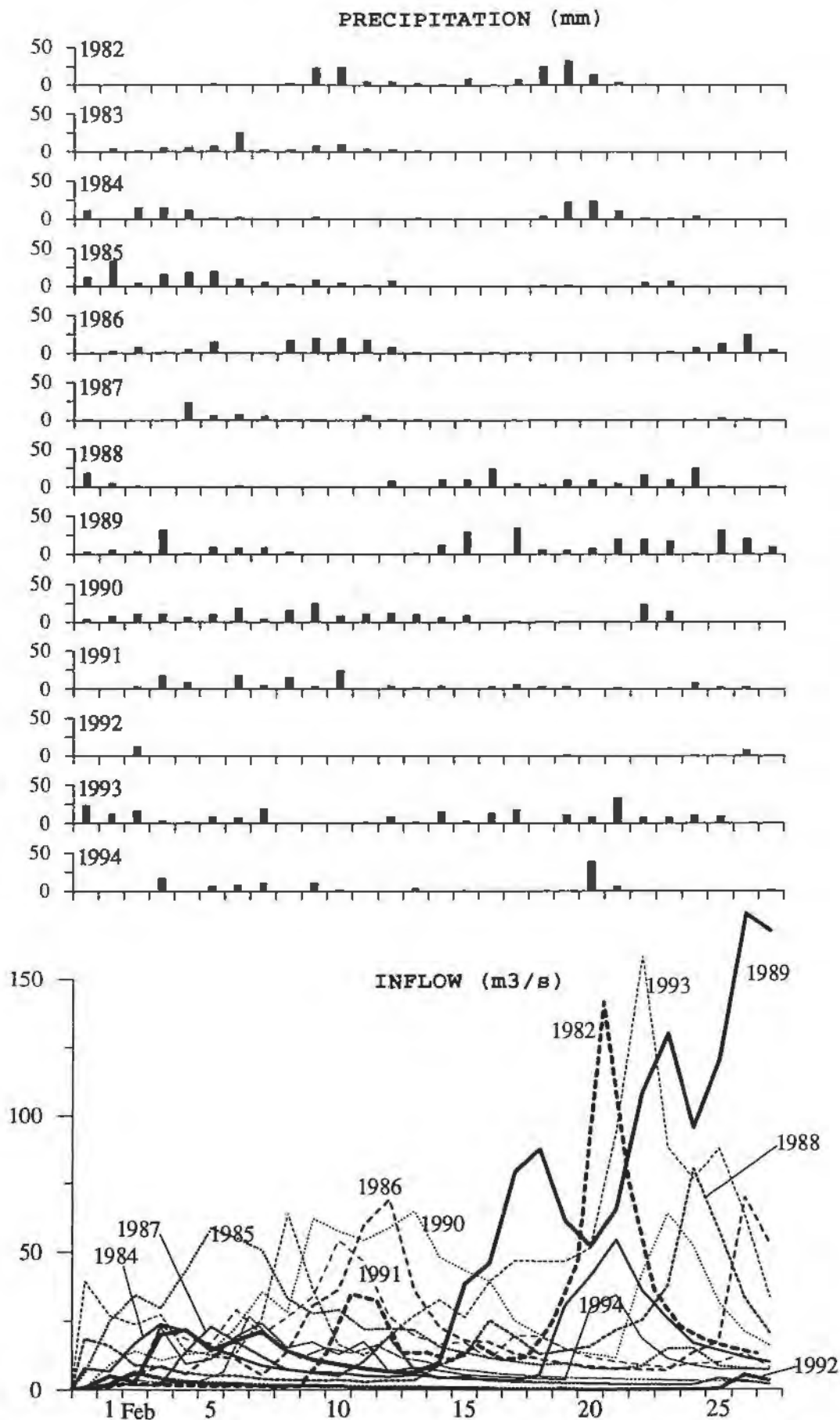


Figure 4.5. Illustration of a long-range forecast of the inflow to the Chivero and Manyame reservoirs for February 1995. The forecast is based on rainfall records from 1982 to 1994.

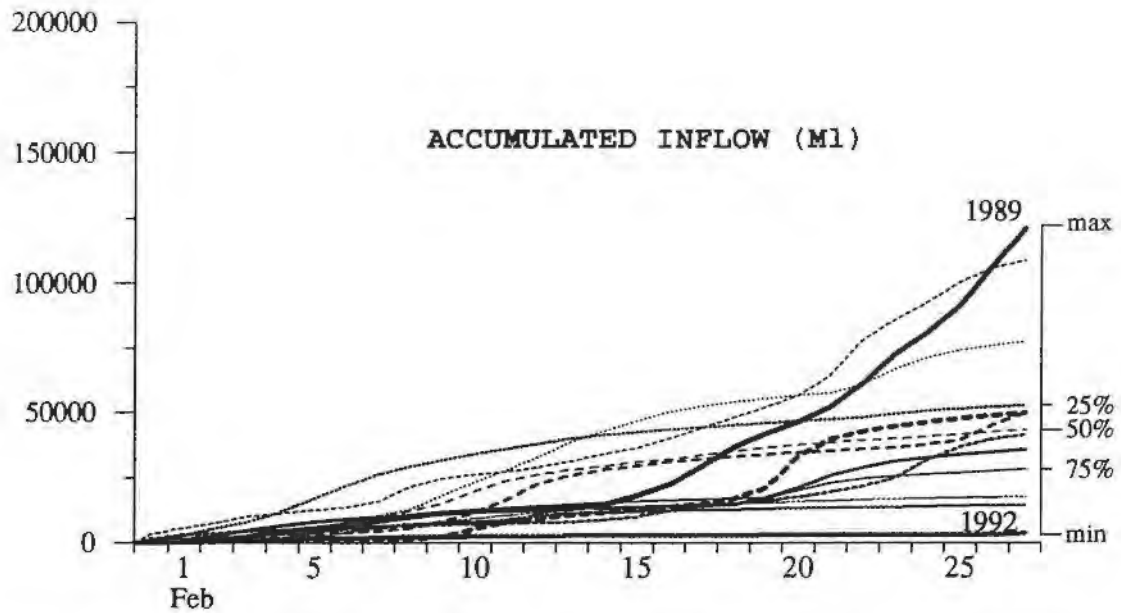


Figure 4.6. Long-range forecast of the inflow to the Chivero and Manyame reservoirs for February 1995. The daily values of the hydrographs in Figure 4.5 have been accumulated to give the inflow volume.

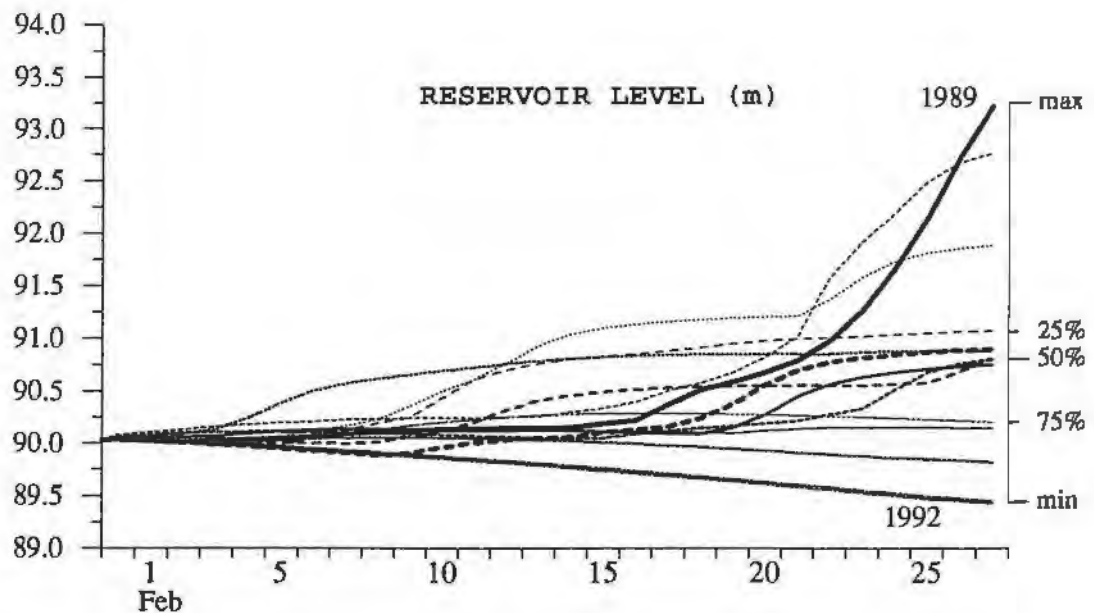


Figure 4.7. A long-range forecast of reservoir levels in the Manyame for February 1995. The hydrographs of Figure 4.5 have been converted to reservoir levels, assuming an abstraction of $1.1 \text{ m}^3/\text{s}$ from the Chivero, $3 \text{ m}^3/\text{s}$ from the Manyame and a release of $1 \text{ m}^3/\text{s}$ from the Manyame.

5. CALIBRATION

5.1. Basin subdivision

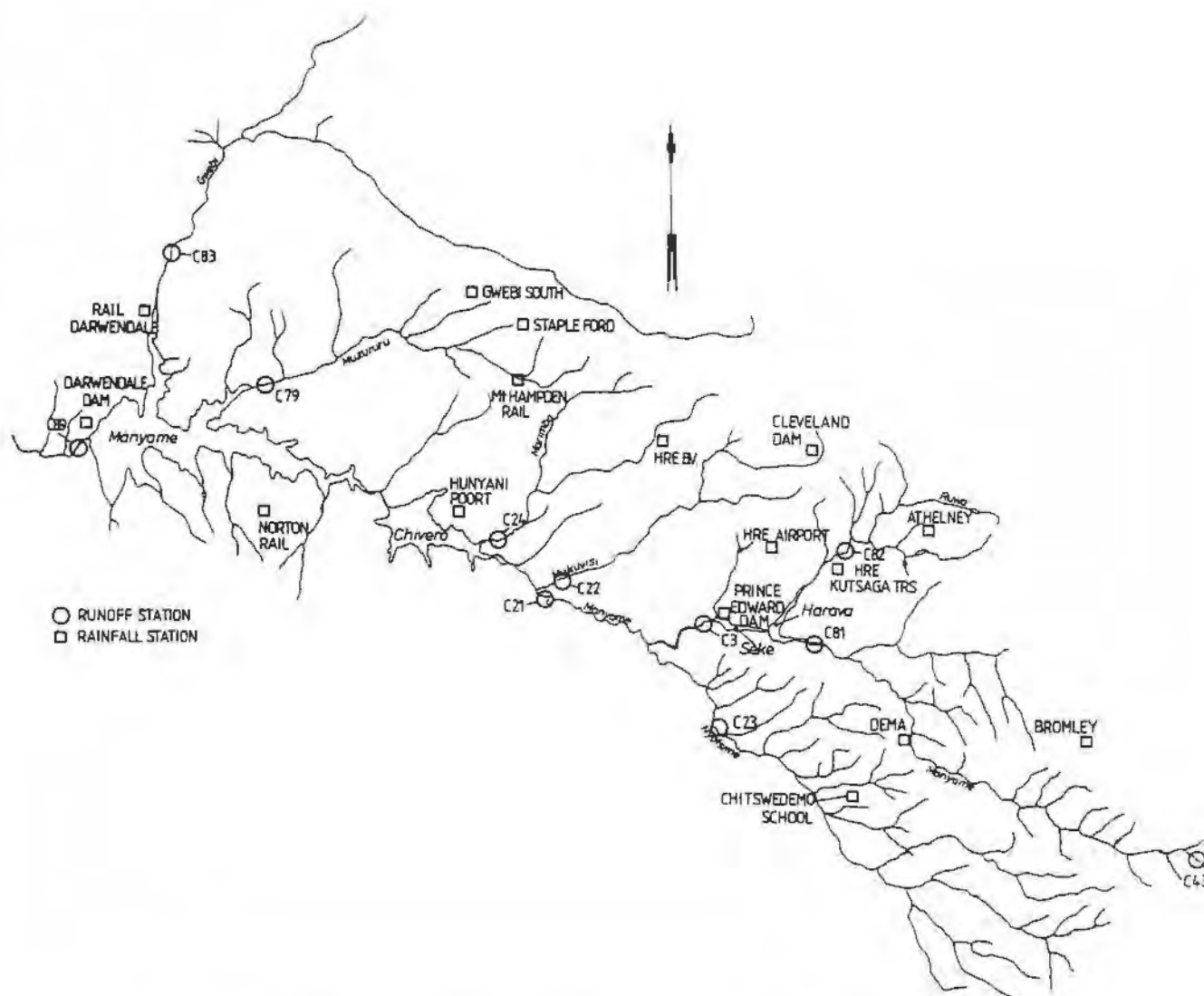


Figure 5.1. Runoff and rainfall stations used for the HBV model simulations.

The Manyame catchment was divided into a number of subbasins. The selection of subbasins was mainly based on the location of the runoff stations (Figure 5.1). The model was calibrated for each station, which means that to a certain extent, consideration was taken to the different characteristics in different parts of the catchment. In catchments containing urban areas (C22, C24), an extra subbasin was created with parameters that makes the model respond very quickly to rainfall. A subdivision was also made downstream of each large reservoir (Harava, Seke, Chivero, Manyame). Potential evapotranspiration from land was estimated to 0.7 times observed pan evaporation, and lake evaporation to 0.85 times pan evaporation.

The catchments with large reservoirs presented a special problem. The model could not be calibrated against the observed outflow, as that flow depends on the operation of the reservoirs. Instead a naturalized flow was computed as

$$Q = Q_{obs} + \Delta S \quad \text{where}$$

Q_{obs} = observed outflow
 ΔS = change in reservoir storage

Note that ΔS can represent storage in several consecutive reservoirs.

The abstraction of water from each subbasin was estimated from the lists of water rights. A mean abstraction rate, varying with the time of the year, was computed from the allocated volumes. It was assumed that this was more representative than the abstraction rate given in the water rights, as abstraction is not continuous. For the abstraction from the Chivero and Manyame reservoirs, figures were available for 1993, but an estimate had to be made for the 1970s and 1980s.

5.2. Results

For most stations, calibration was carried out for a period before 1987, and the years thereafter were used for verification. At some stations this was not possible due to lack of data.

In general the model performed satisfactorily, especially when looking at the runoff volumes. Single runoff peaks were sometimes more difficult to simulate accurately, mainly due to the uneven distribution of rainfall. For a single rainstorm, the available rainfall stations may not have been representative for the catchment as a whole. The model performed equally well during wet and dry years (Figure 5.2). The importance of the soil moisture conditions is clear, if the end of March 1981 is compared with the end of March 1984. Approximately the same amount of rainfall gives a considerable peak in 1981, but no runoff at all in 1984. This is because there had been a drought for two years prior to 1984 and, hence, the soil was very dry. Most of the rainfall therefore went to feeding the soil moisture.

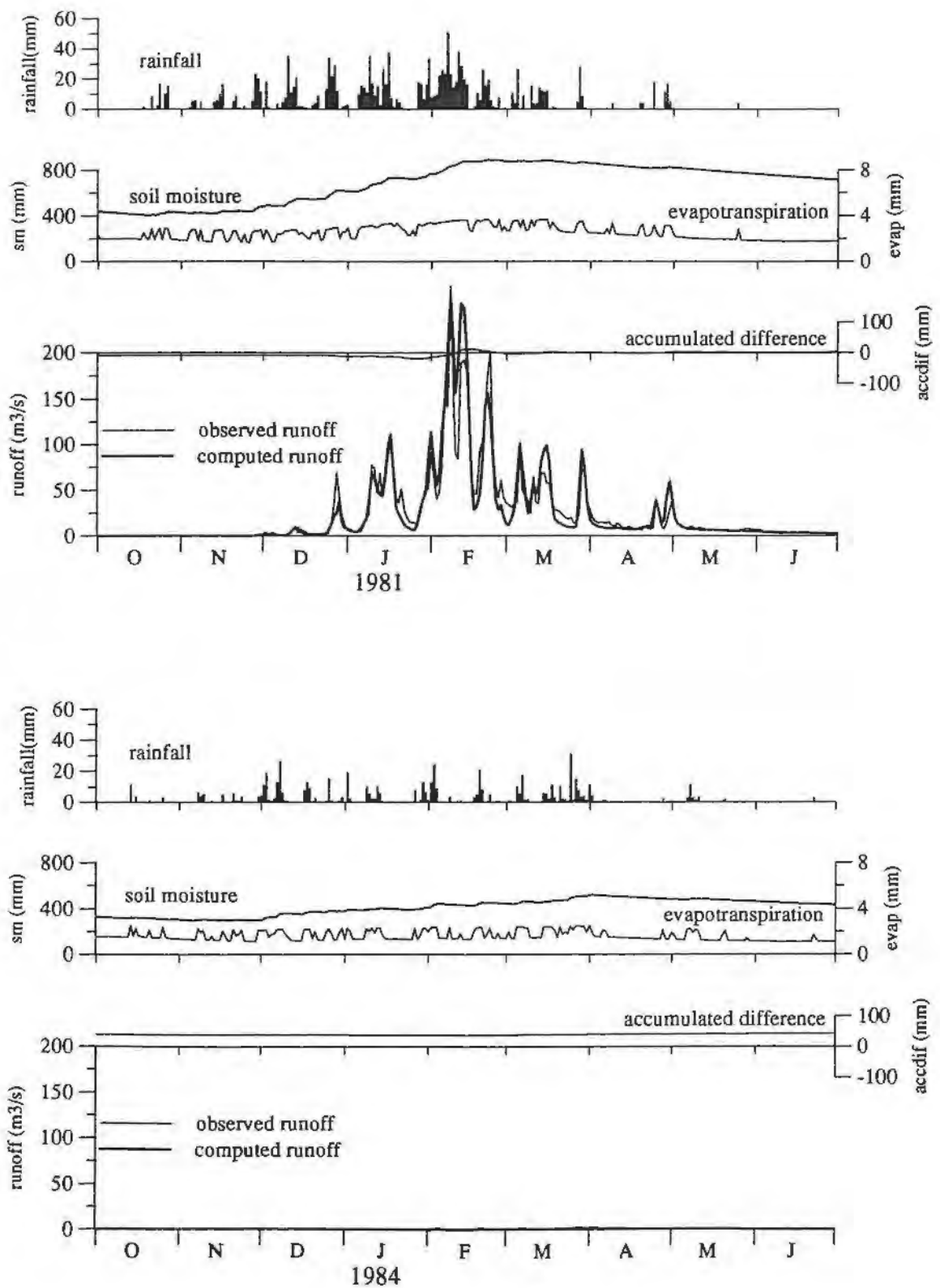


Figure 5.2. Simulated and observed runoff for the very wet 1980/81 and the very dry 1983/84 at C21.

For most stations, the simulated runoff volume over a 10-year period, differed by about 10% from the observed one (Table 5.1). Generally the simulated volume was slightly higher than the observed. One reason for this could be that the abstraction was underestimated. Another reason might be that during the calibration process, greater importance was given to the high flows. In order to get the simulated values high enough during such periods, medium and low flows may have been overestimated.

Catchment	area	rainfall	simulated runoff		observed runoff		difference
	(km ²)	(mm)	(mm)	(m ³ /s)	(mm)	(m ³ /s)	
C81 (Manyame)	488	6200	870	1.7	820	1.6	6.5
C82 (Ruwa)	189	7500	1470	1.1	1270	0.97	16.2
C3 (Manyame)	793	6600	780	2.5	850	2.7	-8.2
C23 (Nyatsime)	500	6100	680	1.4	670	1.4	1.9
C21 (Manyame)	1510	6300	720	4.4	640	3.9	12.9
C22 (Mukuvisi)	232	5600	1040	0.99	1090	1.0	-4.1
C24 (Marimba)	189	5800	900	0.69	820	0.63	10.0
C89 (Manyame)	3792	5900	310	4.8	280	4.3	11.5

Table 5.1. Total estimated rainfall, simulated and observed runoff for the period 1/10/79-30/9/89. Data missing for the following periods: 19/11/79-14/3/80, 26/2-31/3/81, 1/10/83-28/2/84, 25/3-30/4/85, 15/1-31/3/86, 1/7-30/9/86.

In Table 5.1 it is also seen that the total mean runoff from C21, C22 and C24 is 5.6 m³/s, while the total inflow to the Chivero and Manyame reservoirs is only 4.3 m³/s. This in spite of the increase in catchment area by almost 100%. There are consequently great losses of water along this stretch of the Manyame. In the model simulations, the mean abstraction from the Chivero and Manyame reservoirs was estimated to 3.2 m³/s. The evaporation from the reservoirs corresponded to a runoff of 2.3 m³/s. (The abstraction from the river and smaller reservoirs in the whole catchment was estimated to 1.2 m³/s.)

One of the aims of setting up the model for a catchment is to be able to extend the recorded time series and to fill in gaps. It is obvious that the further back you go in time, the less reliable are the simulated runoff values. There are fewer rainfall stations and their quality is more difficult to check. However, for C3 (among others) runoff data were available from the 1950s, and as is shown by Figure 5.3, the accuracy is quite acceptable. The Harava dam was of course excluded from the model when simulating the 1950s, and the abstraction from the Seke was neglected.

This was one of the first opportunities to set up the HBV model for catchments in Southern Africa. The model parameter values were mainly in the same range as in other parts of the world, with one exception. The FC parameter, describing the maximum soil moisture variation, was unusually high. One reason for this could be the long memory in the system - from one rainy season to the next and even over several rainy seasons.

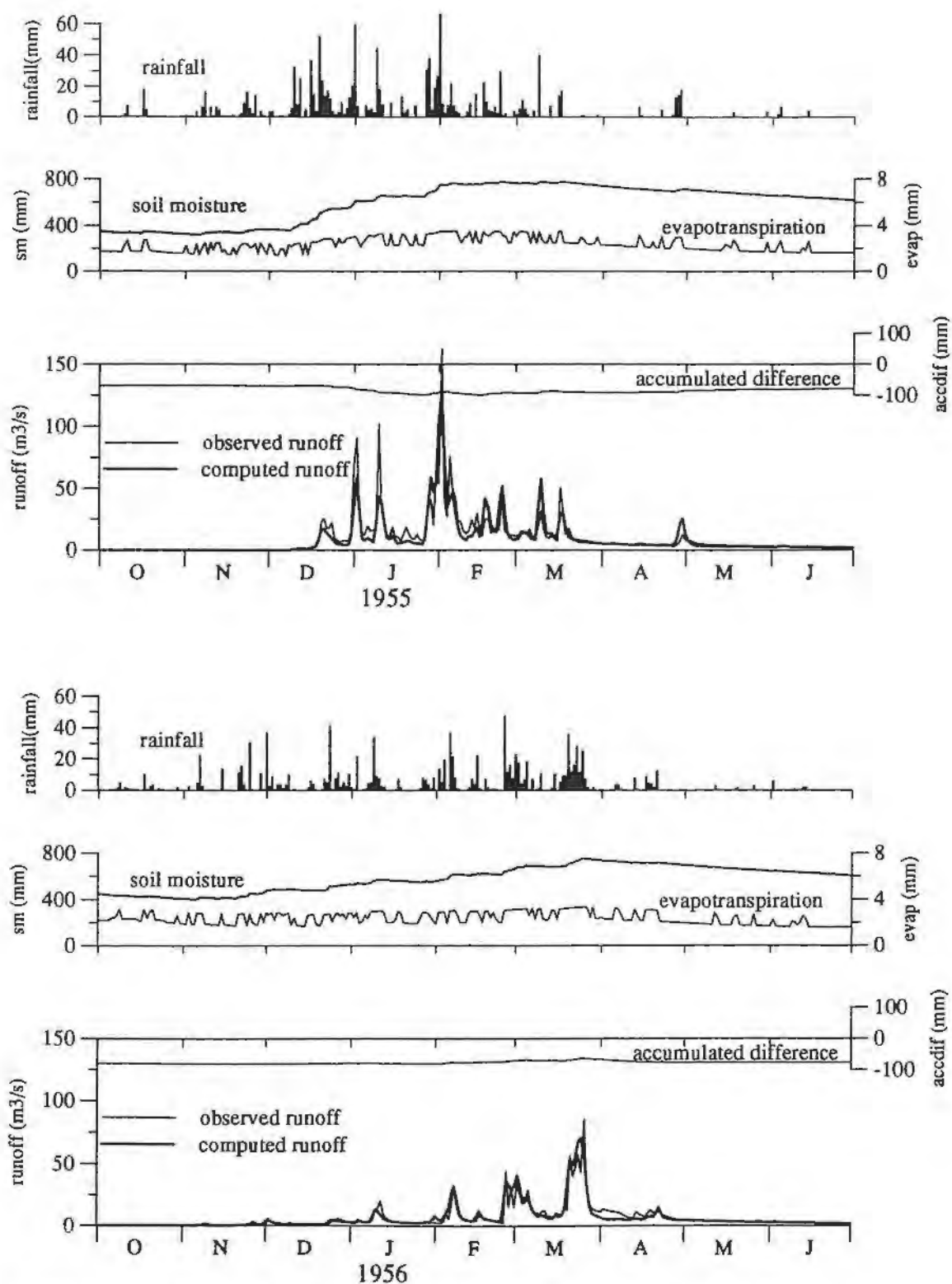


Figure 5.3. Simulated and observed runoff for 1954/55 and 1955/56 at C3.

A more detailed description of each station is given in Appendix 3. The stations that had been calibrated at the completion of this report were C81, C82, C23, C3, C21, C22, C24, C79, C83 and C89.

6. FORECASTING

The forecasting effort at the end of the project was concentrated on the Manyame and Chivero reservoirs. Total inflow and reservoir levels were forecasted, but of course it will take some time before the benefit of the forecasts can be assessed. It is both a question of to what extent the forecasts can be trusted and a question of for what purpose they could be used.

The short-range forecast is rather straight forward (see Fig. 3.4), and it was suggested that a weekly forecast of the reservoir levels should be issued together with the weekly report on the state of Zimbabwe's major dams.

For the long-range forecast, there are some aspects that are of interest to discuss. Figure 6.1 shows a long-range volume forecast for February 1995, based on rainfall records from 1982 to 1994. If the runoff series for February for the same years are used to estimate possible inflow volumes, one gets the results shown in Figure 6.2. One can see that, as no consideration is taken to the initial state, the range of values in Figure 6.2 is much larger. Because of this, a statistical forecast based only on runoff records is probably of less value than a model forecast. The number of runoff series is also fewer than the rainfall series, as runoff data are missing for 1984, 1986 and 1989. Rainfall data may be missing too, but they can often be replaced by data from other stations.

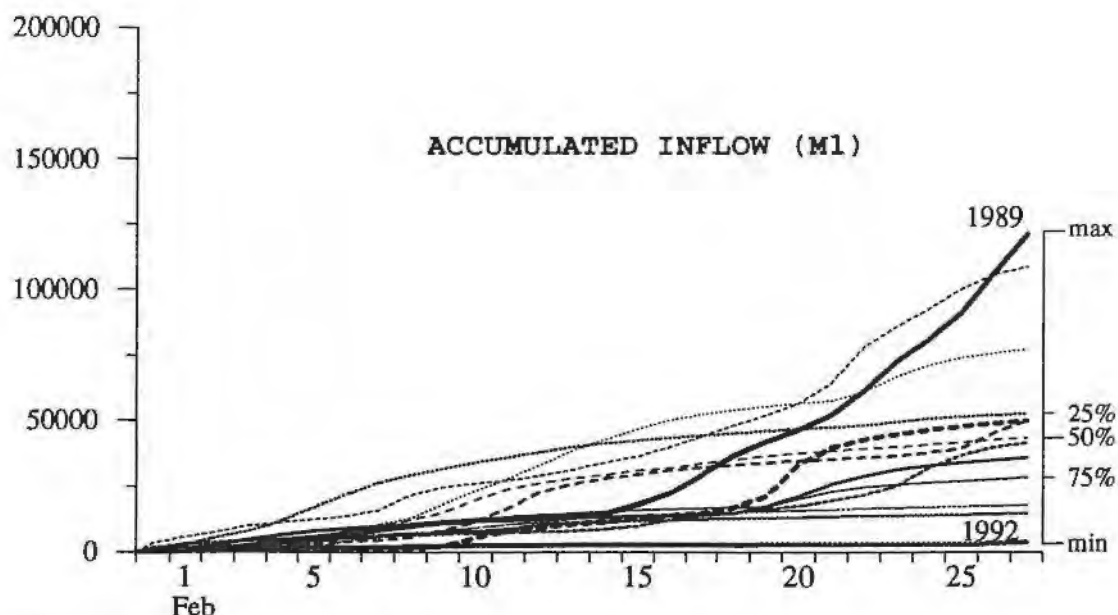


Figure 6.1. Forecasted inflow to the Chivero and Manyame reservoirs for February 1995. The forecast is based on rainfall series from 1982 to 1994.

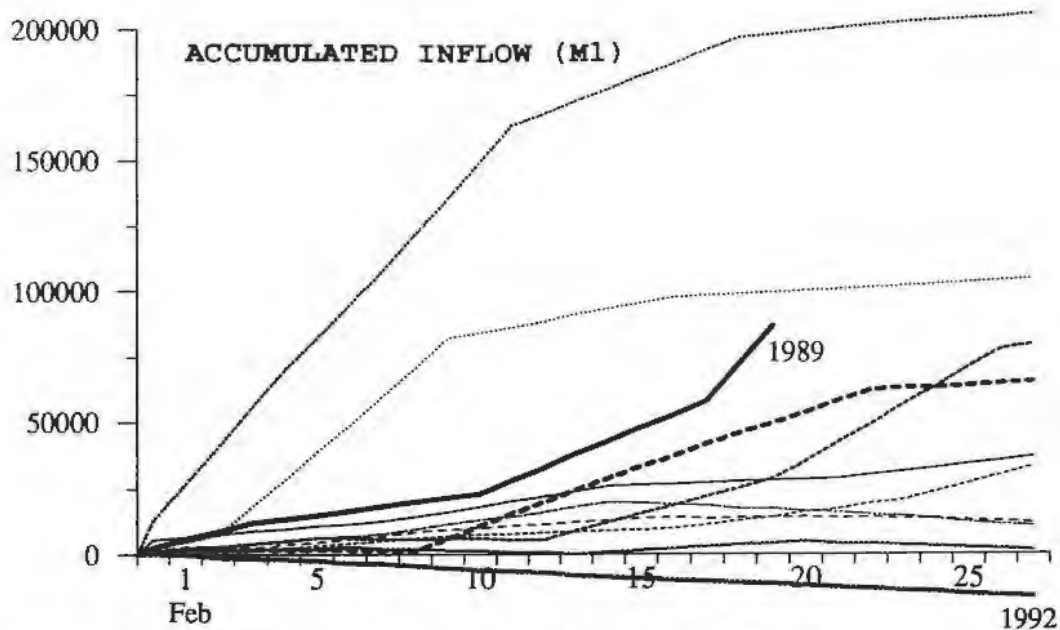


Figure 6.2. Accumulated inflow to the Chivero and Manyame reservoirs during February for the years 1982 to 1994 (data missing for 1984, 1986 and 1989).

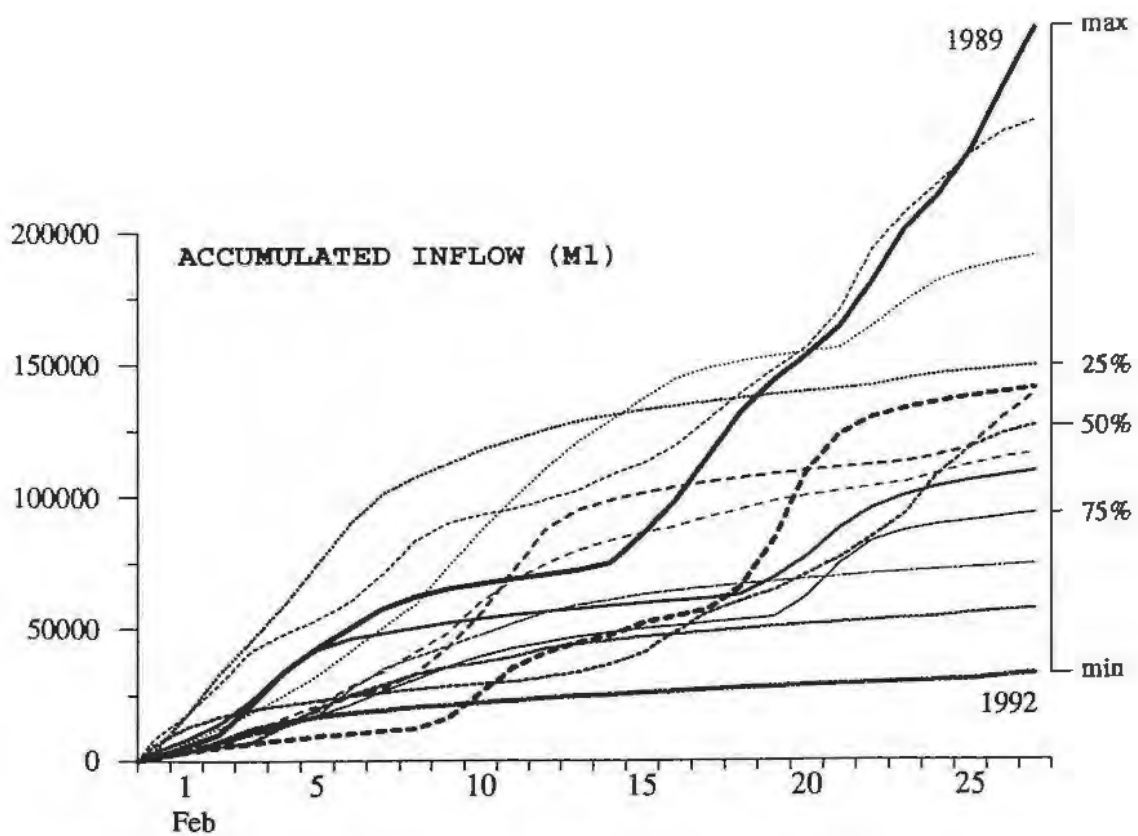


Figure 6.3. Forecasted inflow to the Manyame and Chivero reservoirs for February, using the initial state from the last of January 1981. The forecast is based on rainfall series from 1982 to 1994

. The importance of the initial state is illustrated by Figure 6.3. This is a long-range forecast for February, using the same rainfall series as the one for February 1995, but it starts with the initial conditions of the 31st of January 1981, which was a very wet year. The probability to exceed an inflow of 50000 Ml in February 1995 is less than 25%, while with the initial state of 1981 the probability would be well above 75%.

The forecasts shown so far have been based on only 13 rainfall series, as that is more easy to illustrate. However, for the statistics to be of any real value, the number of rainfall series should be higher. In Figure 6.4, 50 years of rainfall data have been used. Actually this changes very little the values of the inflow volume to be exceeded by the 75% and 50% probabilities, but the probability for higher inflow volumes increases. It is interesting to see that it is a very skew distribution. The distance between the 50% probability and the maximum is about 6 times the distance between the 50% probability and the minimum.

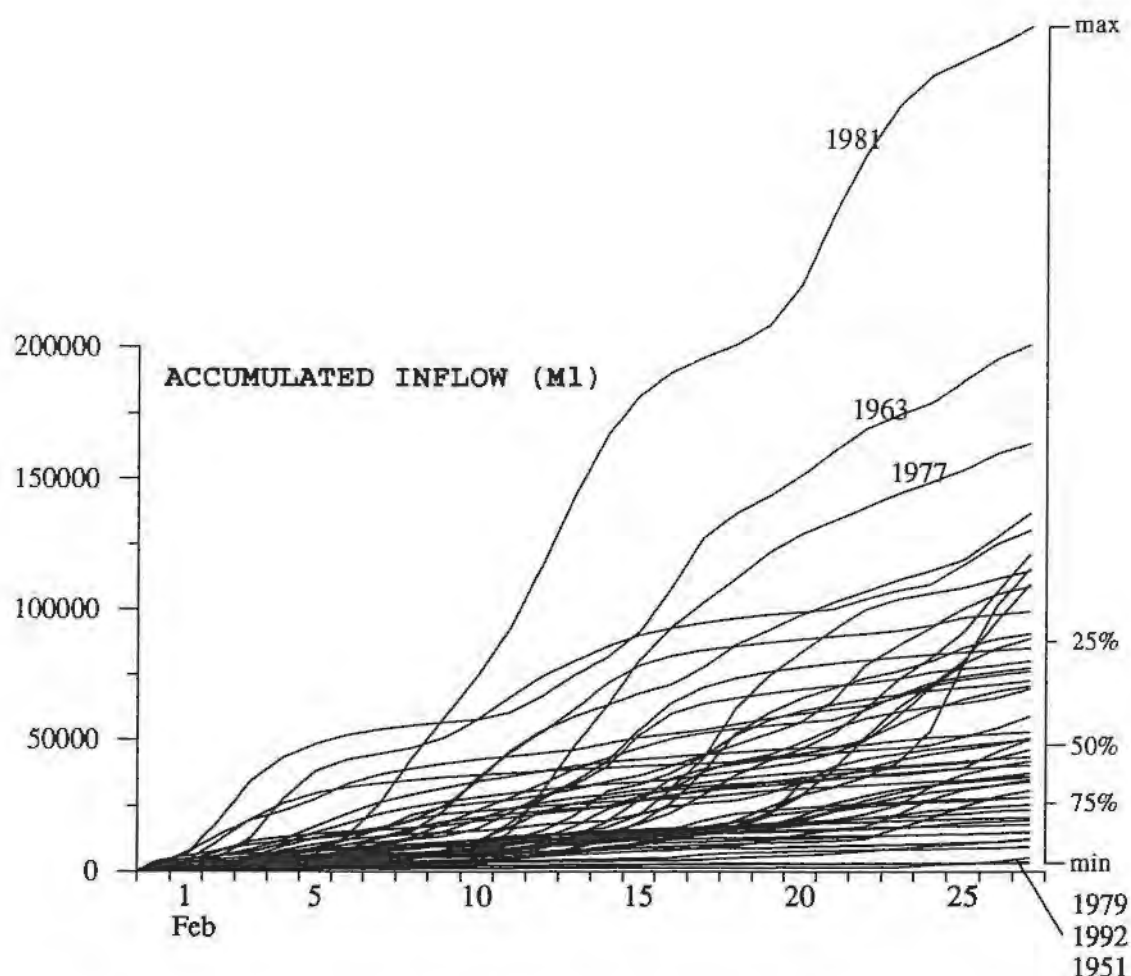


Figure 6.4. Forecasted inflow to the Chivero and Manyame reservoirs for February 1995. The forecast is based on rainfall series from 1945 to 1994.

Table 6.1 further illustrates the range of values. It gives the forecasted total inflow to the Chivero and the Manyame and the reservoir levels in the Manyame, starting the forecast on the last of January 1995 and ending on the last of April. The computation of the reservoir levels is based on the assumptions that the abstraction from the Chivero is $1.1 \text{ m}^3/\text{s}$, that the abstraction from the Manyame is $3.0 \text{ m}^3/\text{s}$ and that the release of water is $1.0 \text{ m}^3/\text{s}$.

Date	max		25%		50%		75%		min	
	vol. (MI)	w (m)	vol. (MI)	w (m)	vol. (MI)	w (m)	vol. (MI)	w (m)	vol. (MI)	w (m)
28/2/95	327000	97.8	90000	92.1	51000	90.9	27000	90.2	3000	89.4
31/3/95	501000	100.0	168000	94.2	112000	92.3	52000	90.4	6000	88.8
30/4/95	560000	100.0	199000	94.5	136000	92.6	68000	90.4	7000	87.9

Table 6.1. Forecasted inflow to the Chivero and Manyame reservoirs, and forecasted levels in the Manyame. The values to be exceeded with a 25%, 50% and 75% probability are given. The forecast starts on the last of January 1995, and is based on rainfall series from 1945 to 1994.

A detailed description of the forecasting procedure is given in Appendix 4.

7. CONCLUSIONS

The current meter gaugings carried out within the project indicated that such gaugings are useful and indeed necessary to improve the rating of the stations. They are most important for flows above the notch capacity, but at some stations checking of the rating curves is also required at low flows.

During the calibration of the HBV model it was found that, in general, the quality of the runoff data was quite high. There were exceptions for single years and single stations, but there were enough reliable data to make a calibration possible for most stations. Obvious errors in the runoff data were easy to locate when running the model, for instance time shifts and large peaks when there was no rainfall.

The calibration results were satisfactory. For the catchments where the model has been calibrated, it can now be used to forecast the runoff, to fill in gaps in the data and to extend time series. The model performed especially well when simulating runoff volumes, which is important when forecasting reservoir inflow. Due to the high spatial variation in rainfall, peak values connected to a single rain storm were obviously difficult to model accurately. However the range of flows was reflected well by the model, and for the largest peaks, the ones occurring during years with high rainfall, there was a good agreement between the observed and simulated values. For the highest peaks one must yet remember that the accuracy of the discharge observations may be low.

The calibration of the HBV model for the Manyame was a pilot project. The results are encouraging and indicate that the model is one valuable tool in the task of assessing the water resources of Zimbabwe.

Recommendations

The project time was limited and on the completion of the project there were still tasks that had not been performed and ideas that had not been tested. Some of them are listed below.

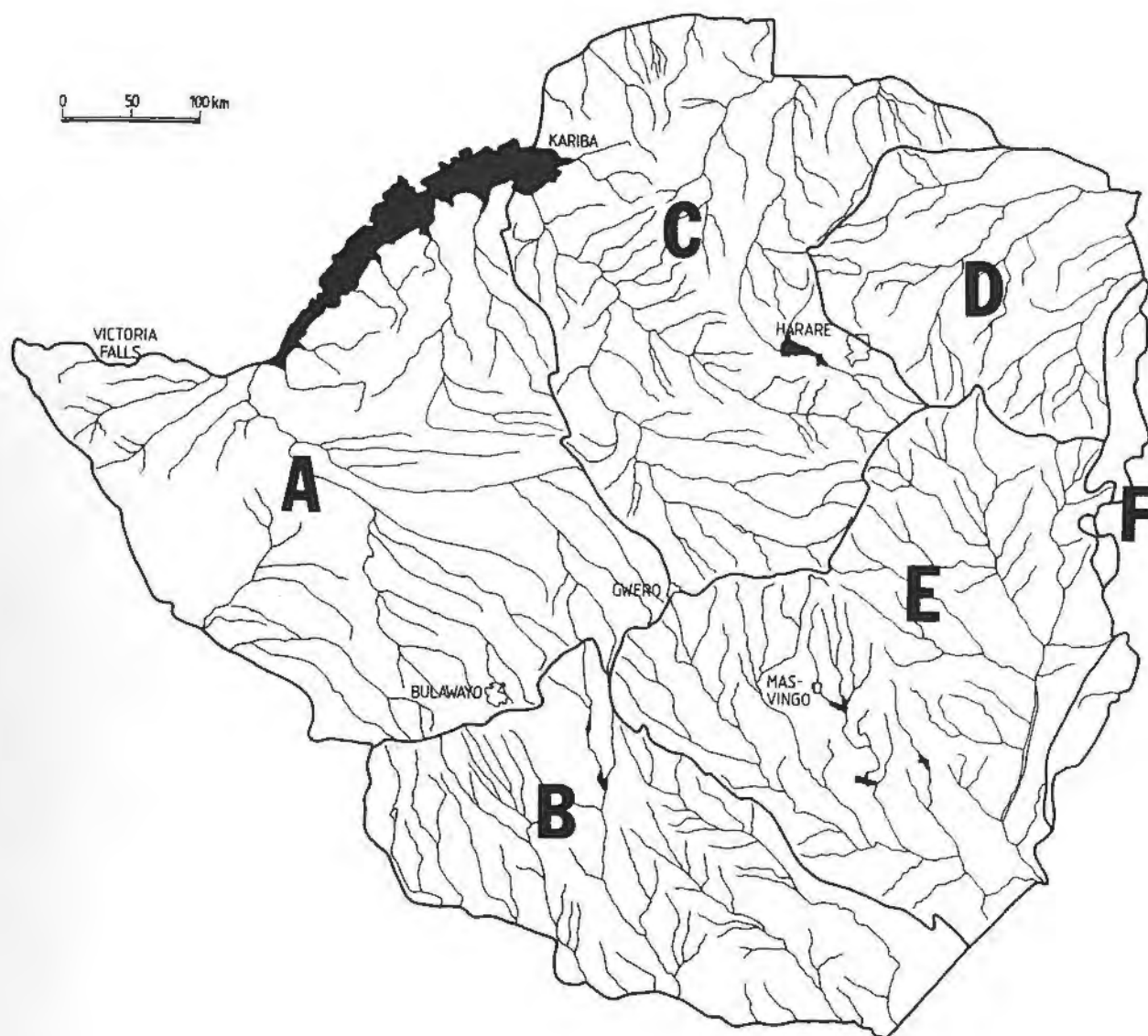
- Due to the rather low flows during the project period, very few current meter gaugings were carried out above the notch capacity of the stations. This must be done during the coming rainy seasons. Further gaugings below notch capacity are also required at most stations. At some stations the river banks need to be cleared of trees and bushes that may cause turbulence at high flows.
- One of the aims of calibrating the model for a catchment is to be able to extend the time series backwards, to create statistics on runoff. Going backwards in time, fewer rainfall stations were operating, and this naturally affects the accuracy of the model simulations. In order to see to which extent, the model should be run for some years with runoff data, using only the rainfall stations with long records. (This can be done rather easily, by creating a PTQW-file with only the stations with long records.)

- For water assessment purposes, the HBV model can be used to estimate the runoff from ungauged catchments. In this case, some kind of regional model parameters must be used, i.e. a set of parameters that gives acceptable runoff values for several catchments in the same region. Before using the model for ungauged catchments, one should determine these regional model parameters and verify them in catchments with runoff observations.
- For an outsider it appears that long-range forecasts for one to six months of the inflow to the Chivero and Manyame reservoirs should be valuable. However, a discussion between the interested parties on if and how to use the forecasts is needed.
- Within the project there was not enough time to collect all the data required. For instance, we only had data on the abstraction from the Chivero and Manyame for 1993, no data on the abstraction from the Seke and Harava dams, no data on their levels before 1988 and no data on the release of water through the sewage works. We did make educated guesses, but it would improve the model simulations if the correct data were entered. For the catchments of C79 and C83, hardly any rainfall stations within the catchments had been punched. Work on this is on its way, and such stations should be included to improve the simulations for C89.
- The catchments of C79 and C83 could not be calibrated separately, as there were problems with the rating of the stations. C79 is closed, but for C83 a new rating table will be constructed, and a proper calibration should then be made.

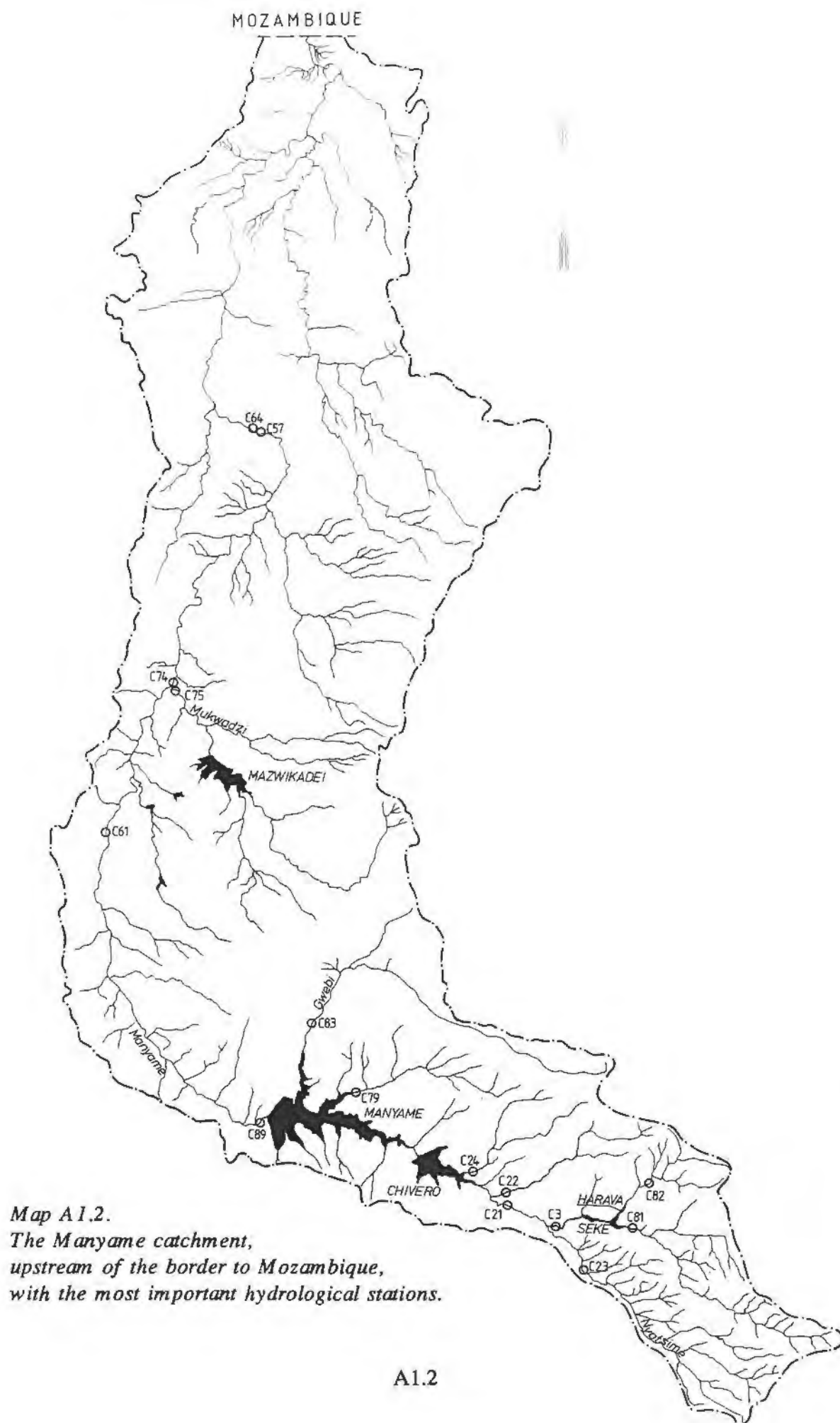
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APPENDIX 1. MAPS

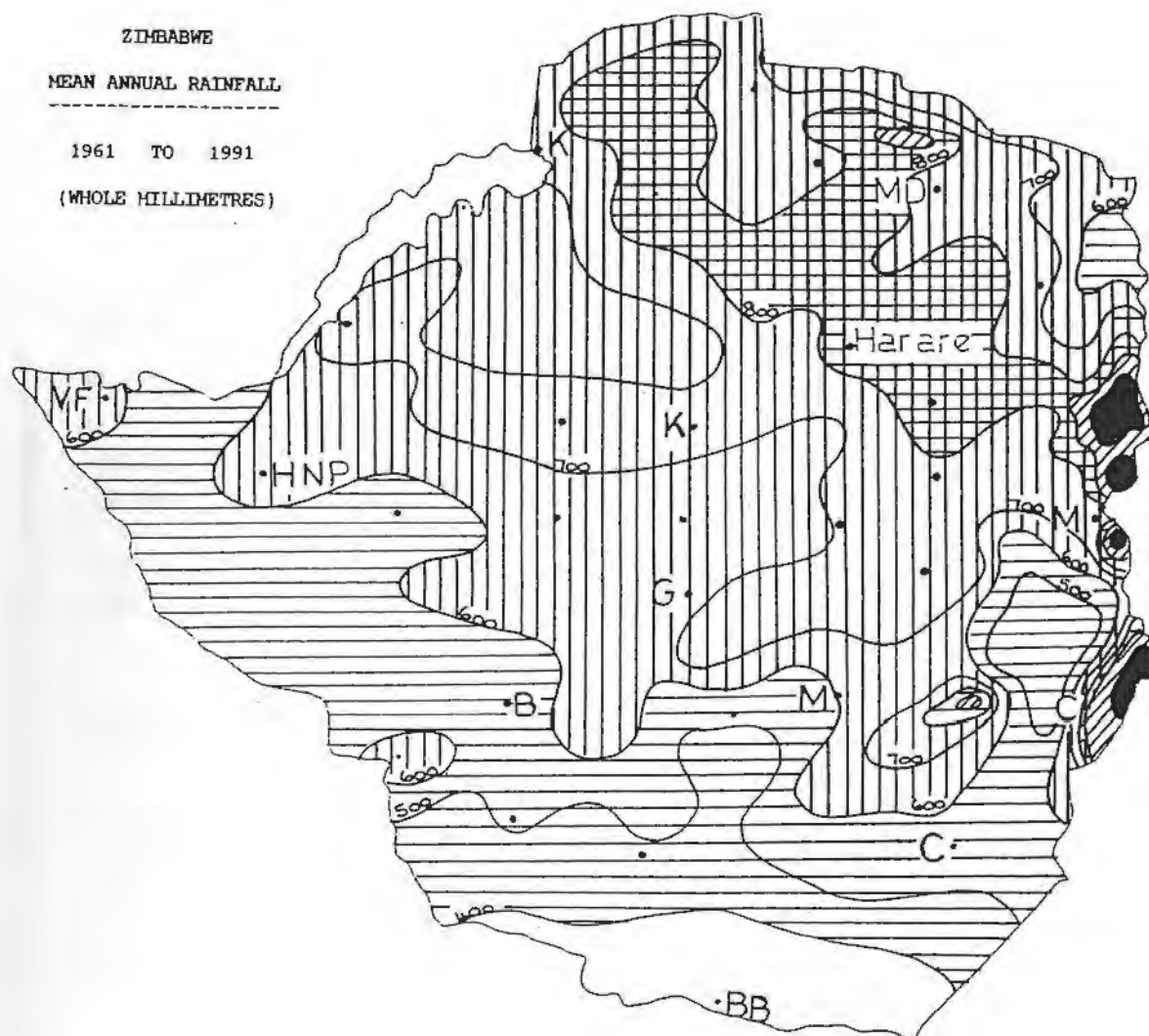


Map A1.1. The Hydrological Zones of Zimbabwe.



ZIMBABWE
 MEAN ANNUAL RAINFALL

 1961 TO 1991
 (WHOLE MILLIMETRES)



Map A1.3. Mean annual rainfall. Prepared by the Rainfall Section, Zimbabwe Meteorological Department.

APPENDIX 2. CURRENT METER GAUGINGS.

One of the tasks of the Manyame project was verification of station rating tables through current meter gaugings. To make this possible, cable ways were installed at C81, C23, C75, C74 and C57/64 (Map A1.2, Appendix 1). Two portable winches were kept at the Hydrological branch and transported to the stations when current meter gaugings took place. Due to unfavourable flow conditions, only a limited number of gaugings were carried out within the project. They are described below.

A1.1 C81

Location: Harava dam u/s River: Manyame Area: 488 km²
R/T Code no: 3081 01 Notch capacity: 78.7 m³/s

Performed current meter gaugings

Date	Stage	Flow	Deviation from R/T	
			absolute	%
25/1/94	0.727 m	10.26 m ³ /s	-0.14 m ³ /s	-1.3%
27/1/94	0.610 m	5.6 m ³ /s	-0.77 m ³ /s	-2.6%

The two performed current meter flow gaugings fit almost perfectly to the existing rating table.

Action needed

- Below notch capacity, at least two more gaugings should be made, preferably at higher levels than already checked. If these fit the existing rating table with the same precision, there is no need for any further measurements at this station, except for a check gauging every second year.
- Above notch capacity, it has so far not been possible to perform any current meter gaugings. To establish an extrapolation with acceptable accuracy, at least three, but preferably five, gaugings are needed.

A1.2 C23

Location: Edinburgh Farm
R/T Code no: 3023 11

River: Nyatsime
Notch capacity: 21.8 m³/s

Area: 500 km²

Performed current meter gaugings

Date	Stage	Flow	Deviation from R/T	
			absolute	%
26/1/94	0.351 m	4.08 m ³ /s	+0.49 m ³ /s	+13%
27/1/94	0.520 m	10.50 m ³ /s	+1.73 m ³ /s	+20%
28/1/94	0.590 m	13.72 m ³ /s	+1.42 m ³ /s	+10%

All three current meter gaugings give higher flow values than the existing rating table. There is thus a systematical difference between measured values and the rating table. A check of the levels of the weir crests indicated that most levels differed from the ones on which the rating table was based. A rating table based on the new levels might give an even greater deviation from the current meter gaugings.

Action needed

- Below notch capacity, two more current meter gaugings should be made to verify the deviation from the existing rating table. From five gaugings, it should then be possible to construct a new more accurate rating.
- Above notch capacity, it has so far not been possible to perform any current meter gaugings. To establish an extrapolation with acceptable accuracy, at least three, but preferably five, gaugings are needed.

Other comments

The cableway installation is about 2 km upstream of the weir, and there is at least one tributary (Nyamafufu) with a significant inflow between the cableway and the weir. Measurement of the flow of the tributary must be done parallel to the measurement of the main flow. Here normally a wading technique is applicable.

There is also a certain risk of delay in the change of water level between the gauging site and the weir. During fast raising and falling levels, flow measurements at the cableway site may not be quite representative for the flow at the weir. To compensate for this, an adjustment in time for a gauged flow could be based on the difference between the peak passage at the cableway and the weir. The gauging team should, during measurements, check the change in levels, both at the weir and at the cableway. This would be made easier if a gauge plate was installed at the cableway.

A1.3 C75

Location: Buwi Farm, River: Mukwadzi Area: 1730 km²
R/T Code no: 3075 02 Notch capacity: 35.0 m³/s

This station is situated downstream of the Mazwikadei dam, and during the project period no measurable flows occurred.

Action needed

- Below notch capacity, three to five gaugings at different levels are required to verify the existing rating table.
- Above notch capacity, three to five gaugings at different levels are required to establish a rating table with acceptable accuracy.

Other comments

The cableway is placed some 500 m downstream of the weir. The measuring section is cleared, but there is abundant vegetation both upstream and downstream. The bushes along the banks will cause a lot of turbulence at high flows, and they should be removed.

A1.4 C74

Location: Buwi Farm River: Manyame Area: 6107 km²
R/T Code no: 3074 02 Notch capacity: 49.8 m³/s

Performed current meter gaugings

Date	Stage	Flow	Deviation from R/T	
			absolute	%
6/3/94	0.460 m	0.95 m ³ /s	-0.48 m ³ /s	-44%
21/1/95	0.745 m	11.94 m ³ /s	-1.74 m ³ /s	-17%

The current meter gaugings have so far been of very little value for checking the rating table. The rather low flows in conjunction with the wide measuring section give low flow velocities and thus a high inaccuracy in the flow measurements.

Action needed

- Below notch capacity, at least three, and preferably five more current meter gaugings should be made to verify the existing rating table. They must be spread across the whole range of levels.
- Above notch capacity, it has so far not been possible for perform any current meter gaugings. To establish an extrapolation with acceptable accuracy, at least three, but preferably five, gaugings are needed.

Other comments

The cableway installation is about 500 m upstream of the weir and their could be a minor delay in flow between the cableway and the weir, when there are fast changes in water levels. The gauging team must thus, during measurements, check the change in levels, both at the weir and at the cableway. This should be made easier if a gauge plate was installed at the cableway.

There are a lot of vegetation, trees and bushes along the river bank. Some of it should be cleared away as, at high flows, it may cause both a lot of turbulence and get the current meter stuck.

A1.5 C57/C64

Location: Nyakapupu
R/T Code no: 3064 01

River: Manyame
Notch capacity: 19.2 m³/s

Area: 9744 km²

Performed current meter gaugings

Date	Stage	Flow	Deviation from R/T	
			absolute	%
22/1/94	0.476 m	1.60 m ³ /s	-1.01 m ³ /s	-39%
4/3/94	1.470 m	30.57 m ³ /s	+0.77 m ³ /s	+2.6%
5/3/94	0.800 m	10.25 m ³ /s	+2.05 m ³ /s	+25%
22/1/95	1.250 m	22.92 m ³ /s	+2.12 m ³ /s	+10%
12/2/95	0.710 m	6.20 m ³ /s	-0.04 m ³ /s	0

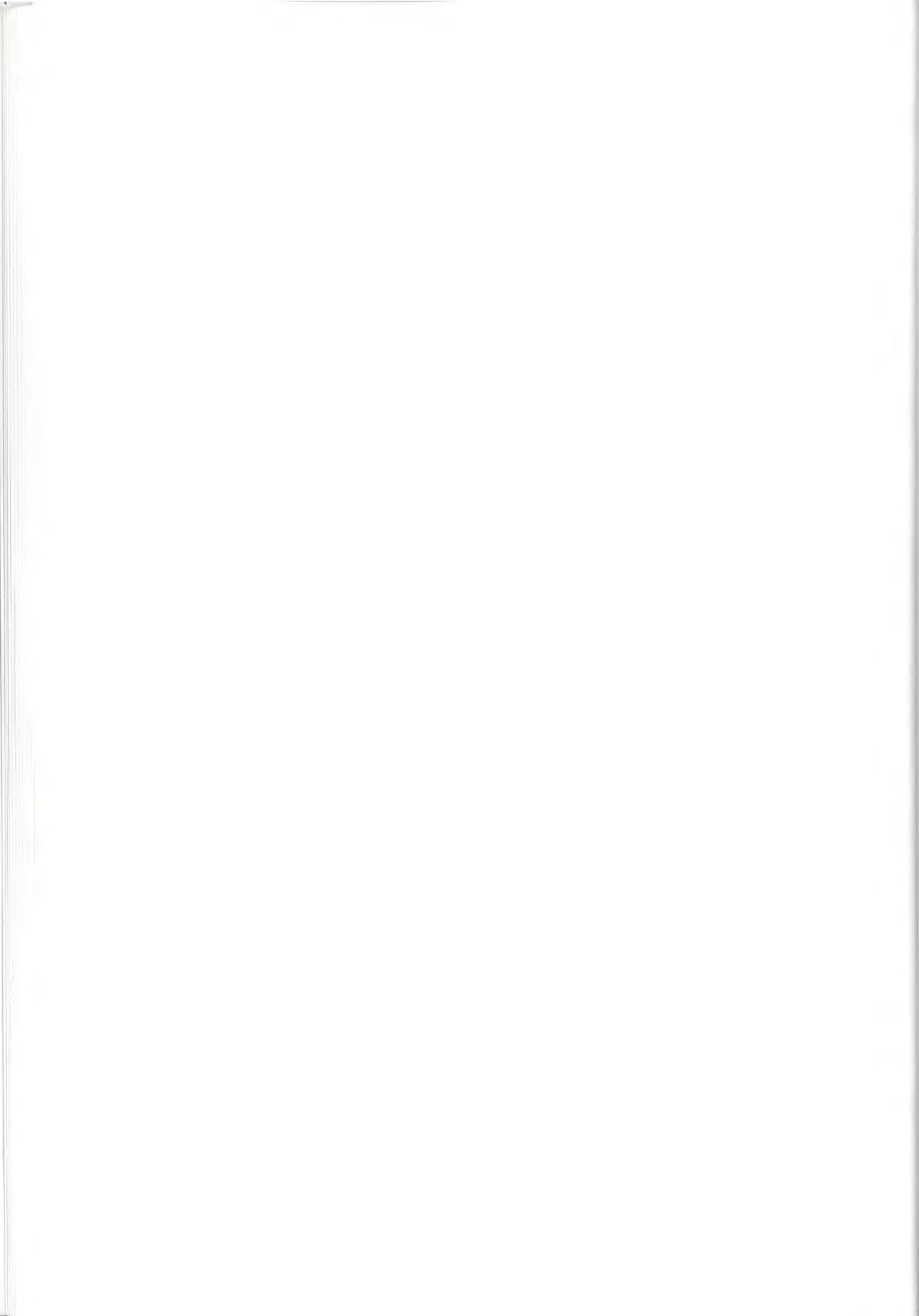
The five current meter gaugings are spread in an appropriate way over the range of levels, but they fit irregularly to the existing rating table. More gaugings are needed, before it is possible to establish a new rating.

There is a suspicion of upstream flow in the area near to the left bank. The gauging 12/2/95 was made with special attention to this, but no such flow was then indicated. This was certified by observing the direction of the current meter tail. Due to the very turbid water, this could only be done just when lifted up from the water, thus in fact

representing only the near surface water conditions. However, if there was such a flow at the earlier gaugings, the gauged values are of course an overestimation. The problem is to verify the flow direction in this normally very turbid water.

Action needed

- Both below and above notch capacity more gaugings are needed to establish a new rating curve. Special attention must be given to the backwater effect mentioned above.



APPENDIX 3.

CALIBRATION DESCRIPTION.

The calibration procedure was made starting far upstream in the catchment and continuing downstream. For most stations, calibration was carried out for a period before 1987, and the years thereafter were used for verification. (See Map A1.4, Appendix 1 for the location of the stations.)

General figures of abstraction losses according to existing water rights have been applied in the modelling work.

Pan evaporation values have been multiplied with 0.7 to obtain potential evapotranspiration.

1.1 Upper Manyame.

1.1.1 Station C43.

The runoff station situated most far upstream in the Manyame catchment is **C43**, with a drainage area of only 3.5 km². Discharge data are available since 1956, with interruptions in 1958, 1986, 1987 and 1990. No calibration was made for this station, as the area is very small and of minor importance for the river as a whole, as well as for the modelling of the Seke and Harava reservoirs. The station was modelled as a subcatchment of C81, using its own station weights and the same model parameters as C81.

Precipitation stations used:

<u>Name</u>	<u>Weight</u>
Bromley	1.0 until 30/6/76
Marondera	1.0 after 1/7/76

For periods with missing data at these stations, the stations Prince Edward Dam and Athelney are used as substitutes.

Evaporation station: Marondera.

1.1.2. Station C81.

The first station to be calibrated was **C81** in the northern branch of upper Manyame, with a drainage area of 488 km² (including C43). Period with discharge records: Since 1/10/75, with shorter interruptions in 1979/80, 1983, 1985, 1987 and 1988.

Precipitation stations used:

<u>Name</u>	<u>Weight</u>
Athelney	0.2
Dema	0.4
Bromley	0.4

For periods with missing data at these stations, the stations Harare Airport, Harare Kutsaga, Prince Edward Dam and Marondera are used as substitutes.

Evaporation stations: The mean between Harare Kutsaga and Marondera.

Summary of model parameters:

PCORR:	1.0
FC:	1000
LP:	1.0
BETA:	2.8
K0:	0.4
UZL0:	5.0
K1:	0.1
K4:	0.02
PERC:	0.8
MAXBAS:	2.0
ICFI:	1.0

An example of the calibration result for the years 1981 and 1988 is shown in Figure A3.1. The R² value for the period 1980-89, with some short periods with interruptions at the station, is 0.79, and the accumulated difference between recorded and simulated discharge volume is -60 mm (5%), the simulated being lower than the recorded.

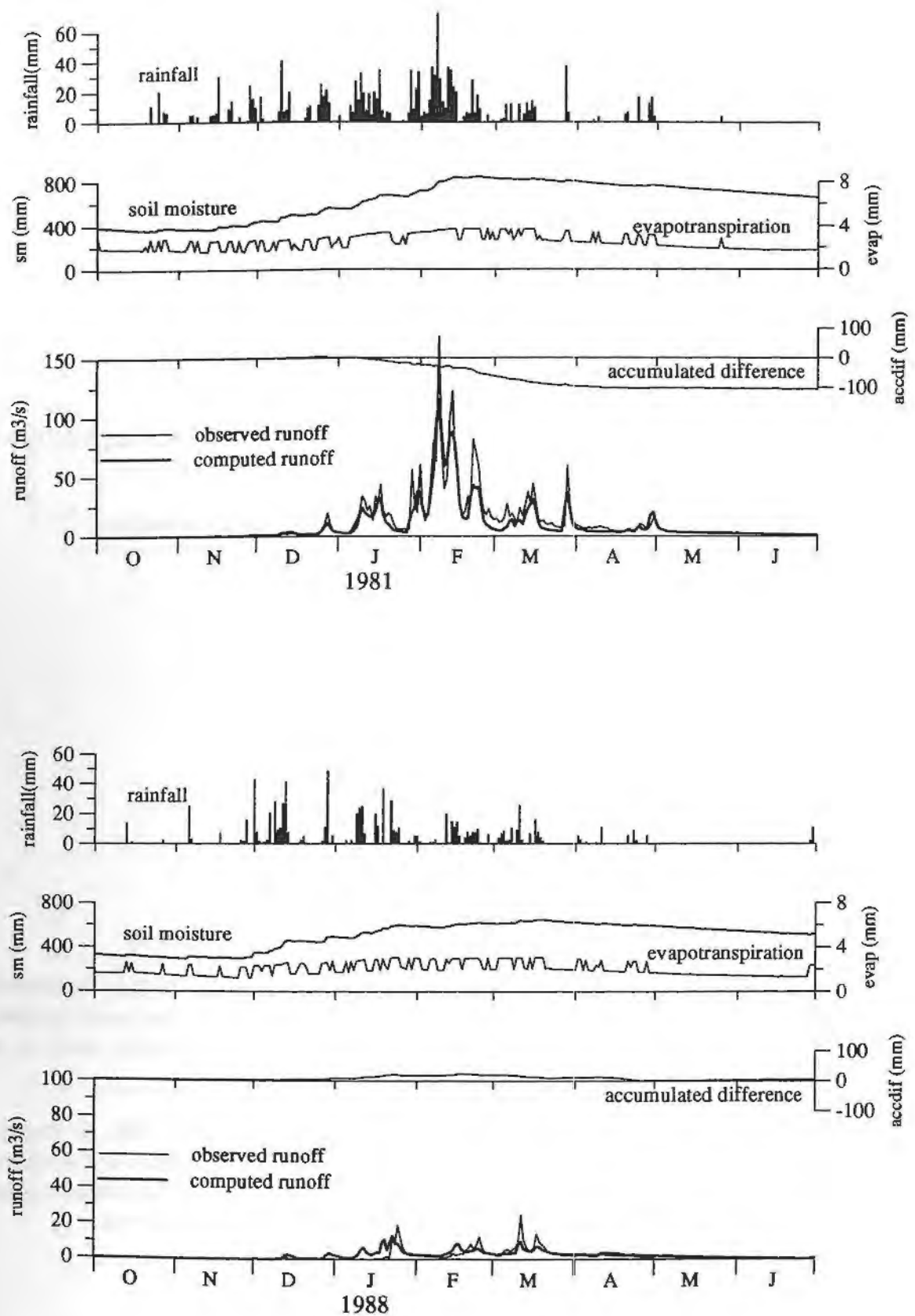


Figure A3.1. Model simulation for C81, 1981 and 1988.

1.1.3. Station C82.

The station **C82**, in the Ruwa river, is the northern tributary to the Harava reservoir, and the area of this subcatchment is 189 km². Recorded discharge values are available since 1/10/73, with a period of interruption in 1983.

Precipitation stations used:

<u>Name</u>	<u>Weight</u>
Athelney	0.7
Harare Kutsaga	0.3 (until 30/6/77)
Harare Airport	0.3 (after 30/6/77)

For periods with missing data at these stations, the stations Prince Edward Dam and Bromley are used as substitutes.

Evaporation stations: The mean between Harare Kutsaga and Marondera.

Summary of model parameters:

PCORR:	1.2
FC:	1000
LP:	1.0
BETA:	3.2
K0:	0.65
UZL0:	7.0
K1:	0.1
K4:	0.01
PERC:	1.0
MAXBAS:	3.0
ICFI:	1.0

For satisfying results of simulations of the high flood peaks in this catchment, a correction factor of 1.2 for the precipitation was used. Obviously the actual catchment precipitation is higher than the precipitation recorded at the stations used, as only Athelney is situated within the basin.

An example of the calibration result for the years 1981 and 1988 is shown in Figure A3.2. The R² value for the period 1980-89, with an interruption at the station in 1983, is 0.66, and the accumulated difference between recorded and simulated discharge volume is 186 mm (10 %), the simulated being higher than the recorded.

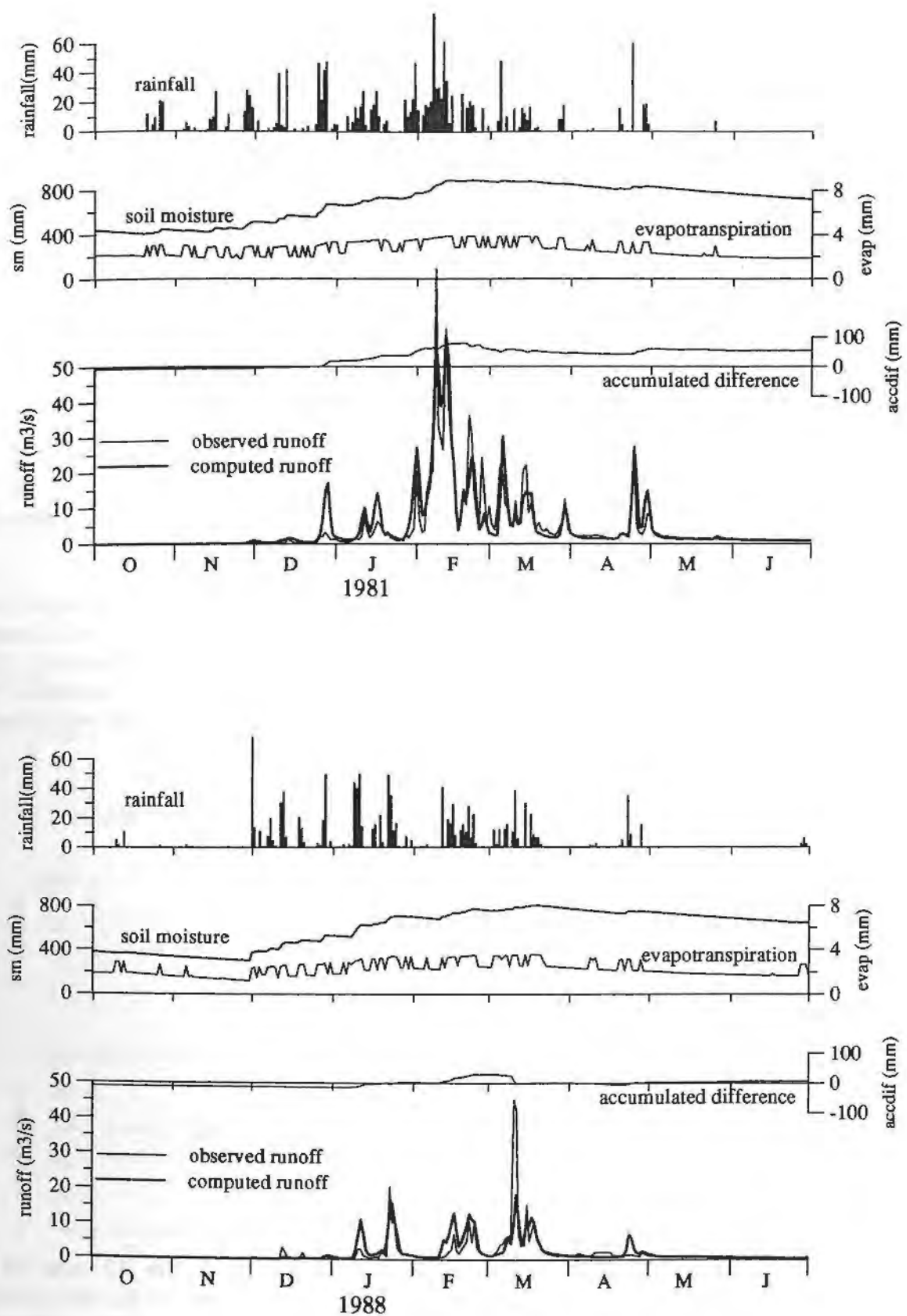


Figure A3.2. Model simulation for C82, 1981 and 1988.

1.1.4. Station C23.

The Nyatsime river is the southern main branch of the upper Manyame river. The confluence is a few kilometres downstream the Seke dam. The runoff station C23 is situated about 15 km upstream of the confluence, and has a drainage area of 500 km². The station started to operate in 1956. Data are missing between 1/10/64 and 30/9/72 and between 1/12/74 and 3/7/75, and there are shorter periods with interruptions also after 1975.

Precipitation stations used:

<u>Name</u>	<u>Weight</u>
Dema	0.15
Chitsvedemo School	0.15
Marondera	0.5
Prince Edward dam	0.2

For periods with missing data the stations substitute each other and Bromley is also used as a substitute station.

None of these stations is situated in the southern part of the basin, which implies that they are not well representative for the total catchment. In spite of this, the calibration results were acceptable, see Figure A3.3. After completing the calibration work, however, data from one precipitation station, Mahusekwa, have become available. This station is situated south of the catchment, close to the water divide, and will probably imply better calibration results.

Evaporation stations: The mean between Harare Kutsaga and Marondera.

Summary of model parameters:

PCORR:	1.0
FC:	1200
LP:	1.0
BETA:	3.2
K0:	0.65
UZL0:	4.0
K1:	0.06
K4:	0.01
PERC:	0.4
MAXBAS:	3.0
ICFI:	1.0

The calibration results for 1981 and 1988 is shown in fig A3.3. The R² value for the period 1980-89 was 0.70 and the accumulated difference 30 mm, (3 %), the simulated being higher than the recorded. The two recorded peaks in the beginning of February 1988 are probably erroneous, as they are not visible in the downstream station C21. See Figure A3.3b.

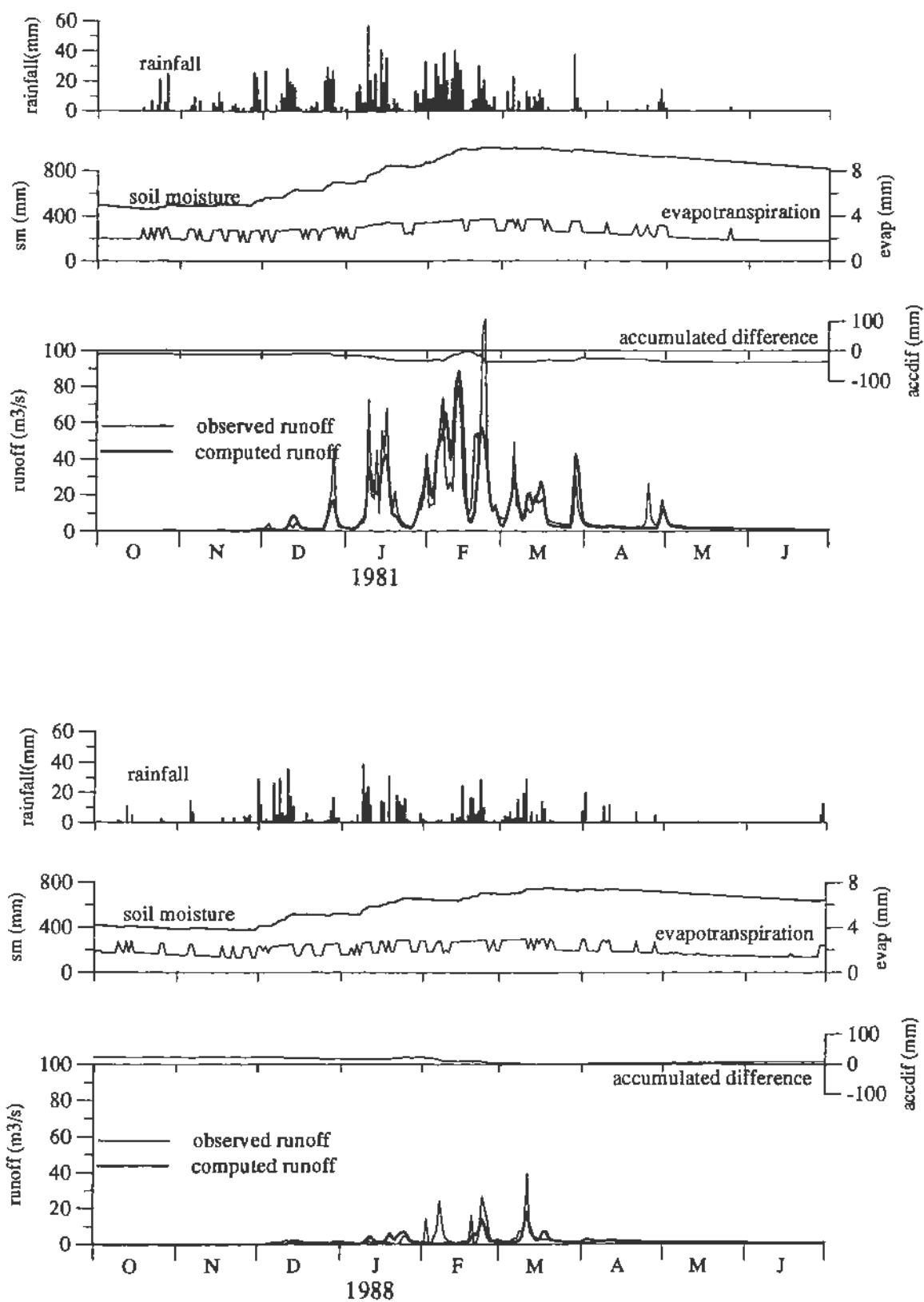


Figure A3.3. Model simulation for C23, 1981 and 1988.

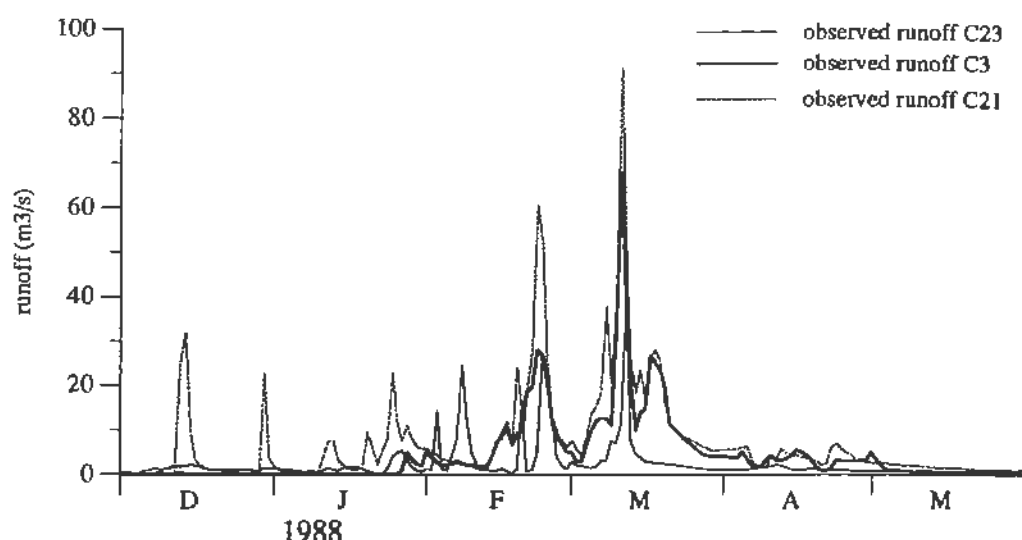


Figure A3.3b. Comparison of recorded discharge at C3, C23 and C21 1988.

1.2. Seke and Harava reservoirs.

The two reservoirs Seke (former Prince Edward), C3, and Harava, C2, are situated in the northern branch of the upper Manyame river. The Seke dam has an average surface area of 1 km², and the upstream reservoir, Harava, is of the same size. The total catchment area for the Seke reservoir is 793 km², giving 116 km² for the local area downstream of C81 and C82, and 16 km² for the area downstream of the Harava dam. Discharge data are available for C3 for the period 1/10/51 to 30/9/56 and since October 1962, with shorter periods of interruptions. C2 started operating in 1940 and ceased in 1972, when it was flooded by the construction of the Harava reservoir.

Water is abstracted from the reservoirs, mainly for agricultural purposes. The main regulation strategy is to keep the water stage in Harava as high as possible. When required, water is released from the Seke dam for supplying the downstream reservoirs Chiver oand Manyame. These occasions seem to be rather rare. An average value of 0.9 m³/s for the total abstractions from the reservoirs is used in the model applications.

Precipitation stations used for the area downstream of C81 and C82:

<u>Name</u>	<u>Weight</u>
Harare Kutsaga	0.6 (until 30/6/84)
Harare Airport	0.6 (from 1/7/84)
Prince Edward dam	0.4

For periods with missing data the stations are substituting each others, and Bromley and Athelney are also used as substitute stations.

Evaporation stations: The mean between Harare Kutsaga and Marondera.

The parameters from C82 were used as model parameters for the small local subcatchments of C2 and C3.

Discharge data for C2 are only available until 1972, i.e. before the construction of Harava, and consequently simulations have been made for the total inflow to the two reservoirs C2 and C3. Recorded inflow is obtained using the outflow recorded at C3 plus the change (positive or negative) in water level between the current day and the previous day. However, recorded water stages in the reservoirs were only available after 18/3/88, making too short a period for calibration of inflow. Another limitation is that water stage is only available on weekly basis, and linear interpolations had to be made to create daily values. This implies that small variations within a week are not reflected in the recorded levels.

(An example of the modelled total *inflow* to the reservoirs in 1989 is shown in Figure A3.4.)

Results of modelled total *outflow* at C3 1981 and 1988 are shown in Figure A3.5. Simulation have been made modelling also the upstream subcatchments of C81 and C82. R2 value for the period 1980-1989, with some periods with missing data from C3, was 0.79 and the accumulated difference -250mm, (17 %), the simulated being lower than the recorded. The results were improving when the recorded discharge values at C81 and C82 were used as input and only the areas downstream were simulated. However, the latter require periods with discharge data at all the three stations C81, C82 and C3, which makes it difficult to simulate a long period.

A comparison between the stations C3, C23 and C21 implies that one of the stations is recording erroneously, as the monthly means of the recorded discharge 1976-1990 from C3 and C23 for January, February and April are exceeding the recorded discharge for C21. See Table A3.1.

Mean values 1976-1990	C3 (m ³ /s)	C23 (m ³ /s)	C21 (m ³ /s)	C3+C23 (m ³ /s)	C3 (mm)	C23 (mm)	C21 (mm)
Feb	18.6	6.8	24.8	25.4	56.7	32.9	39.7
Mar	12.8	3.9	18.1	16.7	43.2	20.9	32.1
Apr	5.3	1.8	7.0	7.1	17.3	9.3	12
May	1.5	0.7	2.4	2.2	5.1	3.7	4.3
Jun	0.6	0.3	1.1	0.9	2.0	1.6	1.9
Jul	0.4	0.2	0.6	0.6	1.4	1.1	1.1
Aug	0.1	0.1	0.2	0.2	0.3	0.5	0.4
Sep	0.1	0.1	0.1	0.2	0.3	0.5	0.2
Oct	0.1	0.1	0.1	0.2	0.3	0.5	0.2
Nov	0.1	0.2	0.2	0.3	0.3	1.0	0.3
Dec	1	1.4	3	2.4	3.4	7.5	5.3
Year	4.1	1.6	5.8	5.7	158.8	102.1	118.3

Table A3.1. Comparisons of recorded discharge values at the stations C21, C23 and C3.

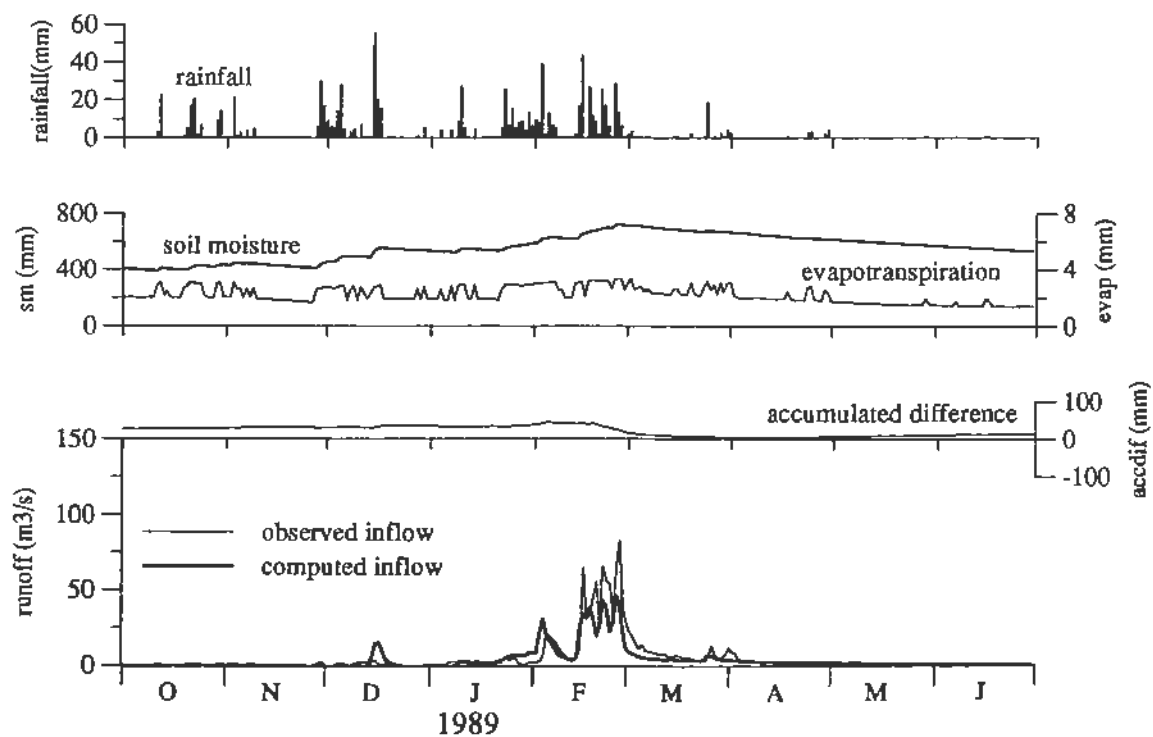


Fig A3.4. Model simulation of the inflow to the Harava and Seke dams, 1989.

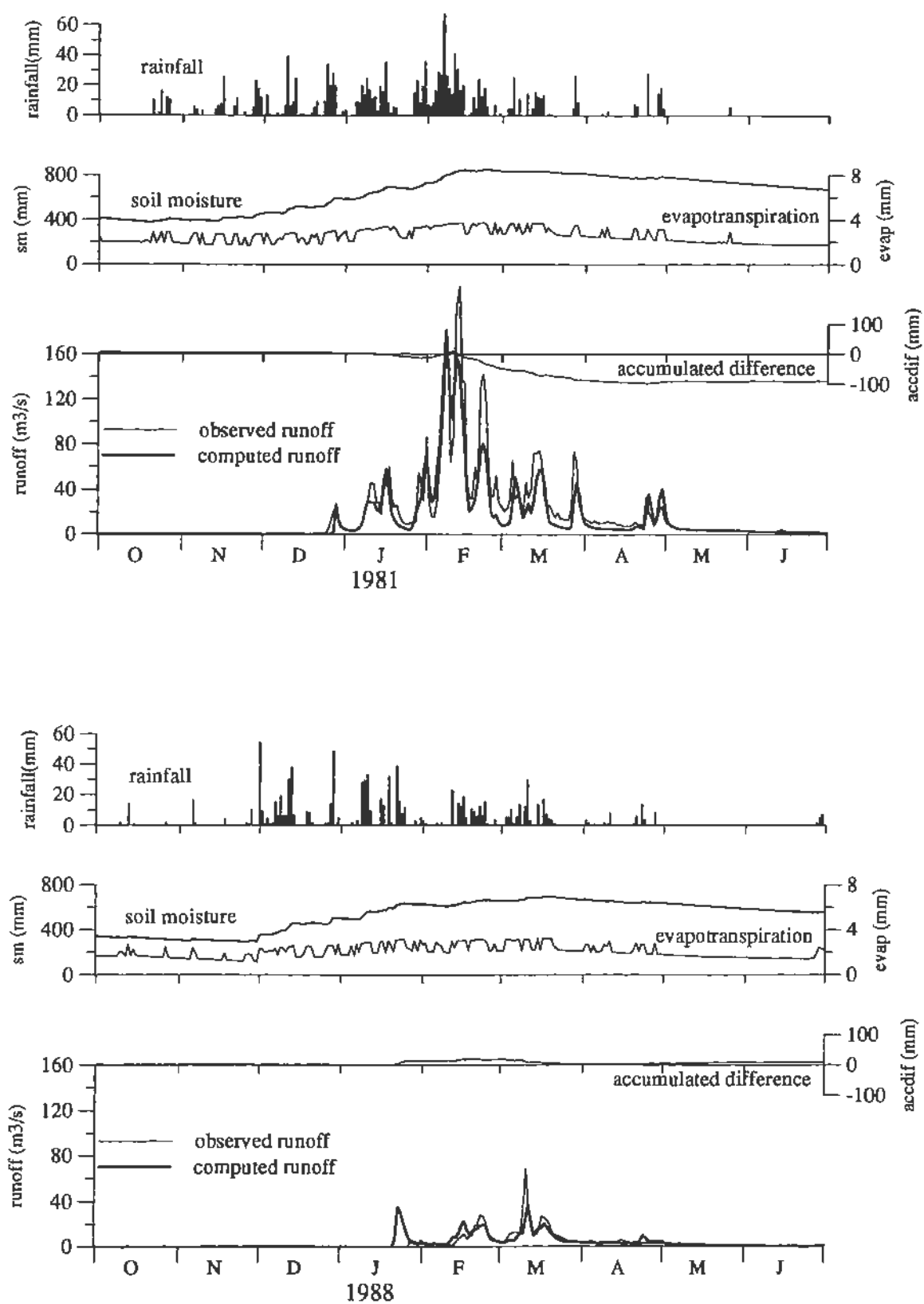


Figure A3.5. Model simulation for C3 (the outflow from Seke), 1981 and 1988.

1.3. C21.

The station **C21** is situated in the main river, about 10 km downstream of the confluence between the Manyame and the Nyatsime rivers. The total catchment area of the station is 1510 km², whereas the local area downstream of C3 and C23 is 217 km². Discharge data are available for the periods 1/10/59-30/9/62, 1/10/64-30/9/70, 1/10/72-30/9/73 and after 1/10/74.

Precipitation stations used for the area downstream of C3 and C23:

<u>Name</u>	<u>Weight</u>
Harare Kutsaga	0.5 (until 30/6/84)
Harare Airport	0.5 (from 1/7/84)
Prince Edward dam	0.5

For periods with missing data the stations substitute each other.

Evaporation stations: The mean between Harare Kutsaga and Marondera.

Summary of model parameters:

PCORR:	1.0
FC:	1000
LP:	1.0
BETA:	2.8
K0:	0.4
UZLO:	5.0
K1:	0.1
K4:	0.02
PERC:	0.8
MAXBAS:	2.0
ICFI:	1.0

An example of the model results for 1981 and 1988 is shown in Figure A3.6. The R² value for the period 1980-1989 was 0.83 and the accumulated difference 85 mm, (8 %), the simulated volume being higher than the recorded. An obvious time lag of recorded discharge data in 1989 has been corrected.

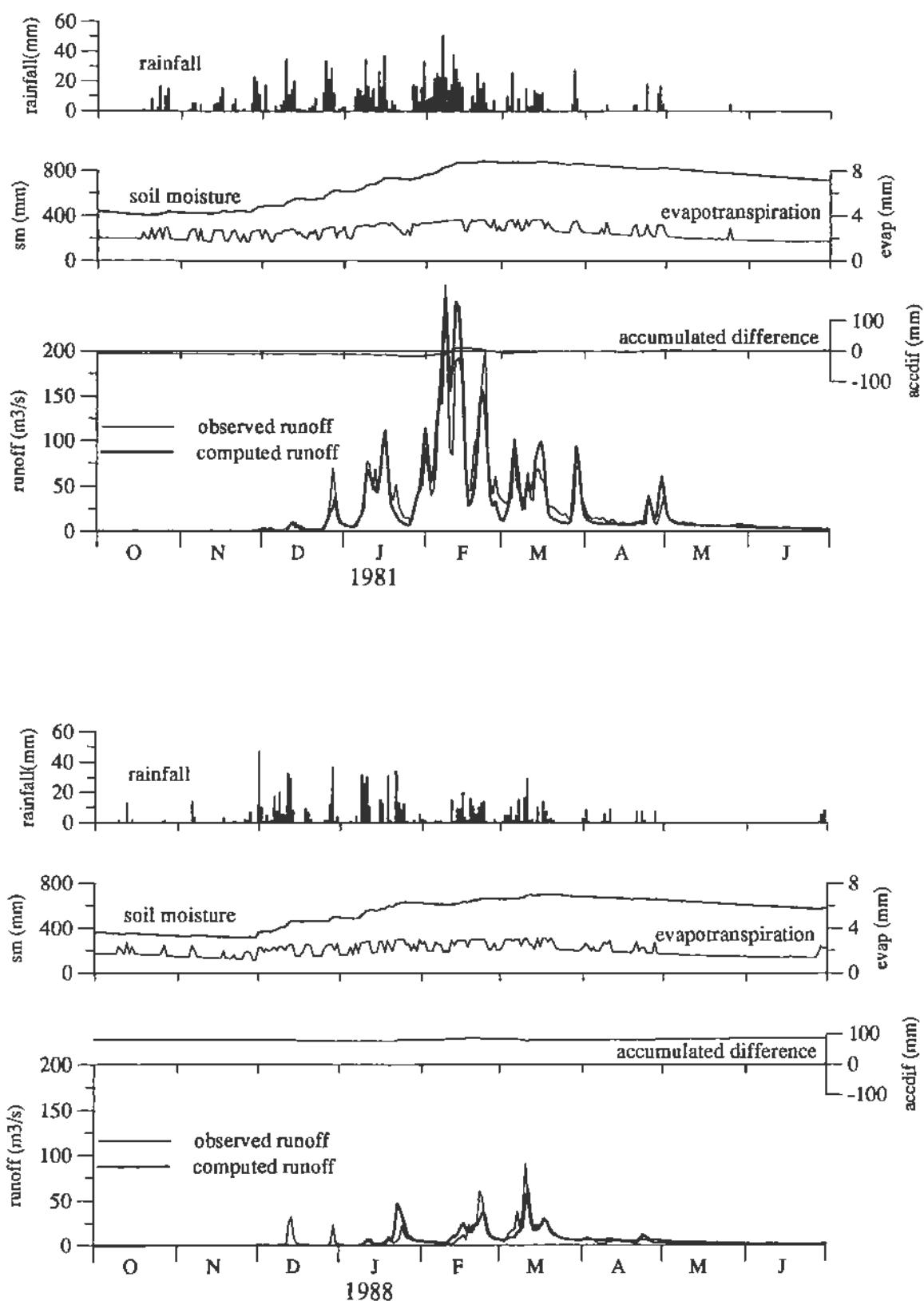


Figure A3.6. Model simulation for C21, 1981 and 1988.

1.4. C22, C24.

Mukuvisi and Marimba are the two northern tributaries to the Chivero (former McIlwaine) reservoir. **C22** on the Mukuvisi drains an area of 232 km² and **C24**, on the Marimba, 189 km². Discharge data for C22 are available since 1/10/53 with short periods of interruptions in 1954 and 1955. C24 has data for the periods 2/11/53-30/9/58 and since 1/10/60, with short periods missing in 1961.

The treated sewage water from Harare is released into the rivers, mainly to the Mukuvisi, and hence recycled in the Manyame catchment. The amount of water added to the stations in this artificial way was in the model application put at 0.2 m³/s to C24. The additions to C22 were assumed to have been 0.2 m³/s until 30/9/84, 0.3 m³/s between 1/10/84 and 30/9/87, and 0.5 m³/s from 1/10/87 onwards. These values were assumed to be mean values, valid for the whole year, and were applied as negative abstractions.

The calibrations were made using a small subcatchment representing the urban areas of Harare for each of the stations C22 and C24. In these subcatchments the model parameters are somewhat different from the main catchment of the station, illustrating low infiltration and a rapid runoff from the paved areas and house roofs in the city. The areas for these urban subcatchments were set to 30 km² for the subcatchment for C22 (Harare Urban) and 10 km² for the one for C24 (Harare Urban2).

Precipitation stations used for Harare Urban and Harare Urban2:

<u>Name</u>	<u>Weight</u>
Harare Belvedere	1.0

Cleveland Dam is used as the substitution station.

Evaporation station: Harare Kutsaga.

Precipitation stations used for C22:

<u>Name</u>	<u>Weight</u>
Harare Kutsaga	0.4 (until 30/6/84)
Harare Airport	0.4 (from 1/7/84)
Cleveland Dam	0.2
Prince Edward dam	0.2
Harare Belvedere	0.2

For periods with missing data the stations substitute each other.

Evaporation station: Harare Kutsaga.

Summary of model parameters Harare Urban and Harare Urban2:

PCORR:	1.0
FC:	100
LP:	1.0
BETA:	1.0
K0:	1.0
UZL0:	0
K1:	0
K4:	0
PERC:	0
MAXBAS:	1.0
ICFI:	0.5

Summary of model parameters C22:

PCORR:	1.0
FC:	1200
LP:	1.0
BETA:	3.0
K0:	0.3
UZL0:	5.0
K1:	0.1
K4:	0.05
PERC:	0.8
MAXBAS:	2.0
ICFI:	1.5

An example of the model results for 1981 and 1988 is shown in Figure A3.7. The R² value for the period 1980-1989 was 0.74 and the accumulated difference -60mm, (4 %), the simulated volume being lower than the recorded. The small rapid peaks from the urban areas of Harare are well simulated by the model.

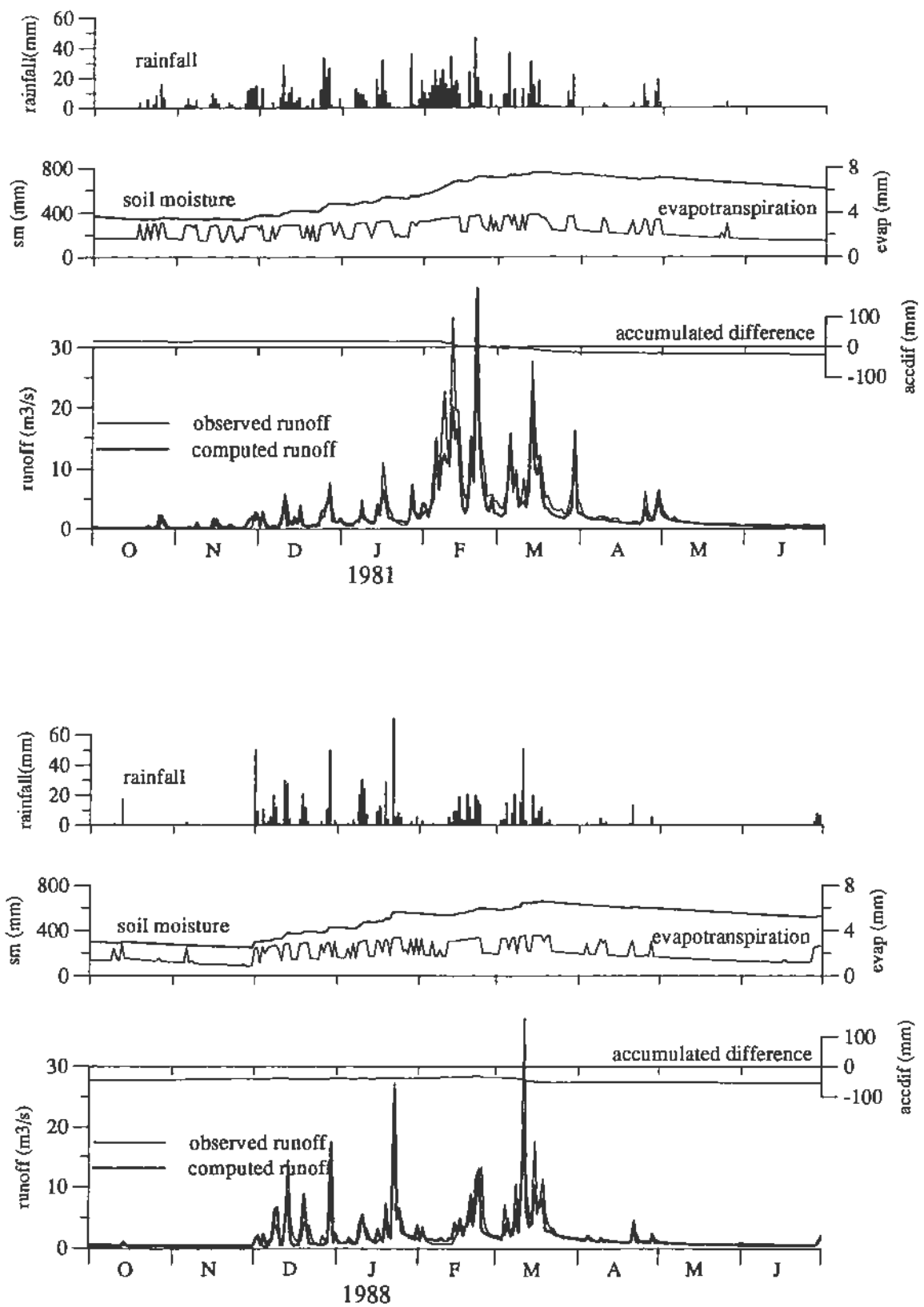


Figure A3.7. Model simulation for C22, 1981 and 1989.

Precipitation stations used for C24:

<u>Name</u>	<u>Weight</u>
Mount Hampden Rail	0.3
Hunyani Farm	0.2
Harare Belvedere	0.5

For periods with missing data Cleveland Dam, Stapleford and Marimba are used as substitution stations.

Evaporation station: Harare Kutsaga

Summary of model parameters C24:

PCORR:	1.0
FC:	1200
LP:	1.0
BETA:	3.0
K0:	0.6
UZL0:	1.5
K1:	0.2
K4:	0.01
PERC:	0.2
MAXBAS:	2.0
ICFI:	1.5

An example of the model results for 1981 and 1988 is shown in Figure A3.8. The R² value for the period 1980-1989 was 0.67 and the accumulated difference -23mm, (2 %), the simulated volume being lower than the recorded. The small peaks from the urban areas of Harare are seen here just like at C22. The baseflow at C24 is lower than at C22, where the main part of the water from the Harare sewage plant is released.

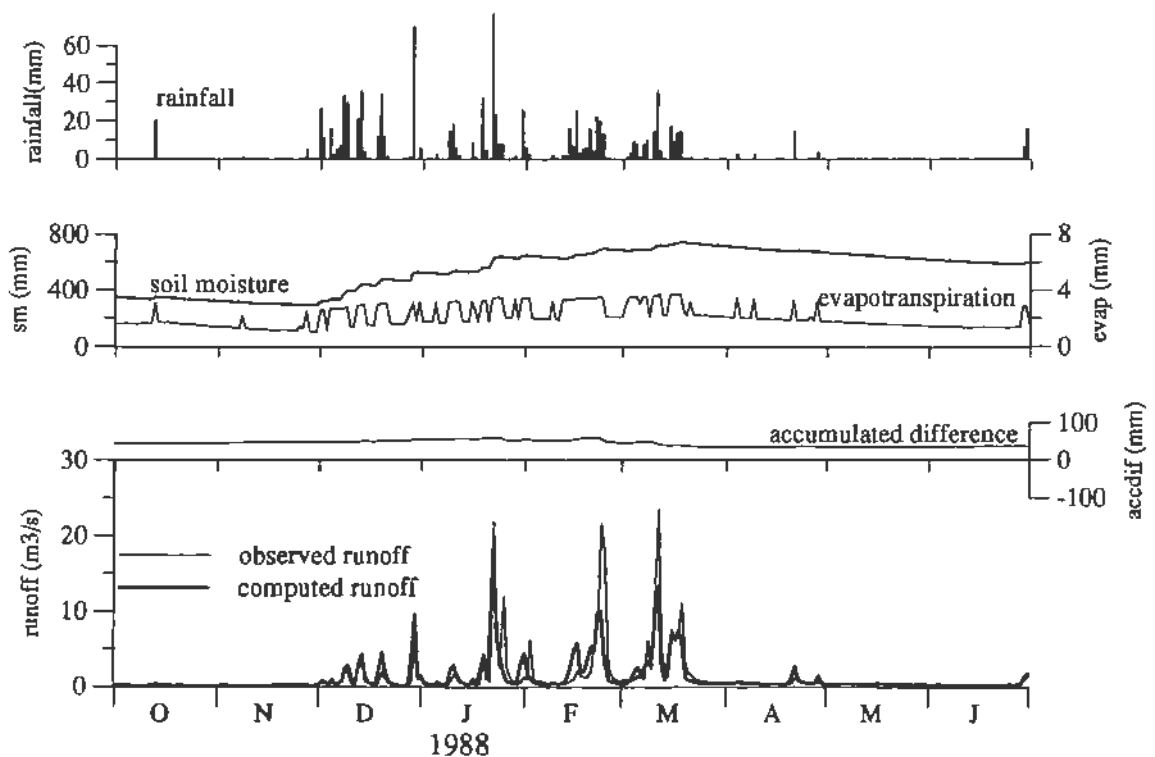
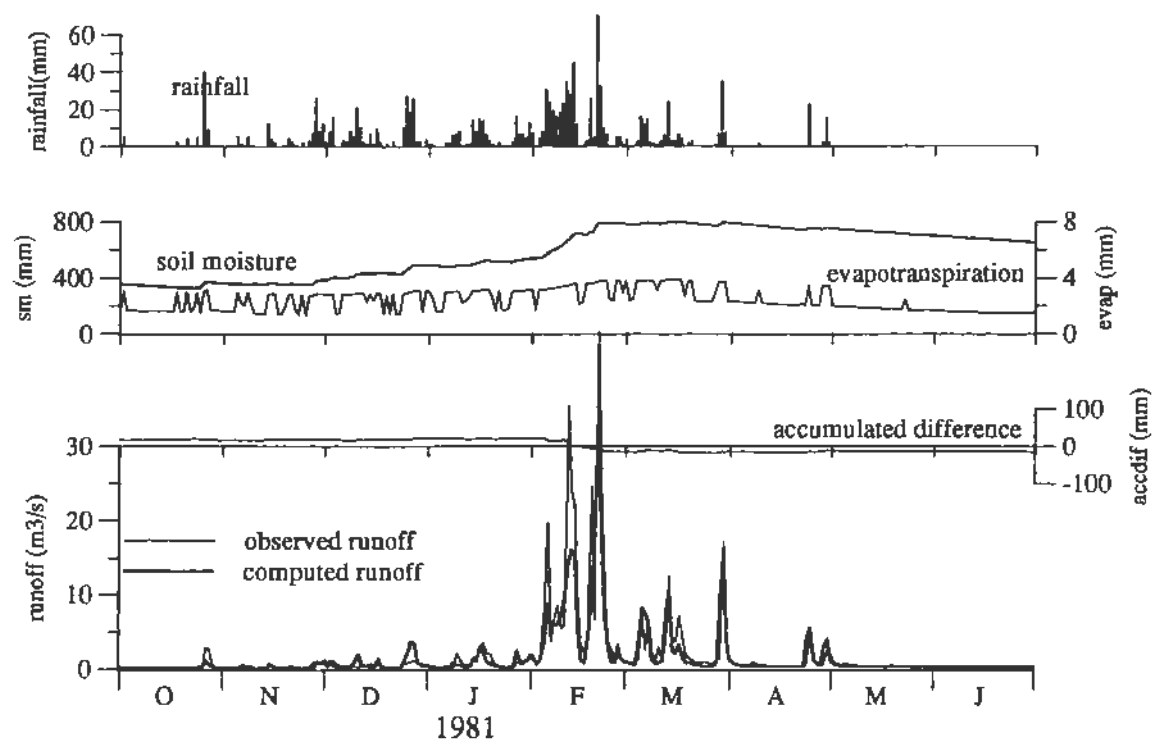


Figure A3.8. Model simulation for C24, 1981 and 1988.

1.5. C79, C83.

The two rivers Muzururu and Gwebi are the northern tributaries of the Manyame (former Darwendale) reservoir. The station **C79** on the Muzururu river has an area of 221 km², and **C83** on the Gwebi river drains an area of 362 km². The stations started operating on 1/10/74.

The calibration procedures for these two stations were giving some problems. One reason has been the lack of data punched for the rainfall stations, implying that there have not been enough precipitation stations available. The other reason is that the rating tables for both stations are in the process of being corrected, making the discharge values for C83 not fully correct and the values for C79 not yet at all corrected at the time for this report. This implied that it was not possible to use the discharge data for these stations for accurate calibrations. At the present moment the calibrated parameters for C89 were used also for C83 and C79. Preliminary calibration runs for the period 1980-89 resulted in an accumulated difference of -134 mm and an R²-value of 0.50 for C79, and - 1240 mm accumulated difference and R²= 0.43 for C83. It is recommended to complete the calibrations with correct discharge data available and with more precipitations stations. This would improve the model results for the inflow to the Manyame reservoir.

The following precipitation stations were used for C83:

<u>Name</u>	<u>Weight</u>
Darwendale Rail	0.3
Stapleford Farm	0.7

For periods with missing data Stapleford substitutes Darwendale Rail. Gwebi South, Mount Hampden Rail and Harare Belvedere are also used as substituting stations.

Evaporation station: Henderson.

C79 was simulated using the following precipitation stations:

<u>Name</u>	<u>Weight</u>
Mount Hampden Rail	0.65
Gwebi South	0.35

For periods with missing data Gwebi South substitutes Mount Hampden Rail and Harare Belvedere and Stapleford Farm are also used as substituting stations.

Evaporation stations: Mean between Henderson and Banket.

1.6. Manyame and Chivero reservoirs.

The outflow from the Manyame reservoir is recorded by the station **C89**, having a total catchment area of 3972 km². The local catchment area of Chivero, **C17**, i.e. downstream of C21, C22 and C24, is 290 km²; 24 km² of these being the mean area of the reservoir. The local catchment area of Manyame, downstream of C17, C79 and C83, is 795 km²; 87 km² of these being the mean area of the reservoir. Discharge data are available for C89 since 1/10/76, with periods with shorter interruptions. Water stage data for the reservoirs have been available on weekly basis for the period since 1/10/79.

These reservoirs are the main source for Harare's water supply, and water is also released from the Manyame dam for agricultural use further downstream. At the present moment, for water quality reasons, normally 75% of the water for the Harare water supply is taken from Manyame and 25% from Chivero. During periods with low water stages in Manyame, however, a higher amount has to be taken from Chivero. These variations are not possible to describe in the model application, and therefore the relation 75-25 has been used throughout the calibration. This implies that the modelled water levels in the reservoirs will be overestimated and underestimated, respectively, during periods with low water stages in Manyame. The total inflow to the two reservoirs is however not influenced by this.

The inflow to Chivero (C17) was not calibrated separately, although this is possible if necessary. The calibration was made for Manyame (C89), allowing the upstream Chivero to fill up and to spill the inflow when water stage 100 was reached. Values for the total abstractions from the two reservoirs for 1994 were received from the City Council, being as an average 4.1 m³/s, and values for previous years were assumed and applied in the model application. The assumptions made were that the abstractions were 2 m³/s until 1971 and then increasing linearly up to 4.1 m³/s in 1988. It was, as mentioned above, assumed that 75% of these abstractions were taken from Manyame and 25% from Chivero.

The calibration was made for the area downstream of the stations C21, C22 and C24. For reasons mentioned in Section A1.5 the discharge values for C79 and C83 were not reliable. Because of this the inflow to the reservoirs had to be calibrated modelling also these subcatchments in the same run. The normal procedure in this project has been to calibrate specific parameters for each subbasin, to achieve a more detailed description of the catchment. This implies that the model parameters should be regarded as temporary. Despite this, the calibration results for C89 were acceptable.

Precipitation stations used for C17 downstream of C21, C22 and C24:

<u>Name</u>	<u>Weight</u>
Mount Hampden Rail	0.5
Marimba	0.35
Norton Rail	0.15

For periods with missing data the stations substitute each other, and Gwebi South is also used as a substituting station.

Evaporation stations: Mean between Harare Kutsaga and Henderson.

Precipitation stations used for C89 downstream of C17, C79 and C83:

<u>Name</u>	<u>Weight</u>
Mount Hampden Rail	0.4
Darwendale Rail	0.45
Norton Rail	0.15

For periods with missing data the stations substitute each other, and Darwendale dam, Stapleford Farm or Harare Belvedere are also used as substituting stations.

Evaporation stations: Mean between Banket and Henderson.

Summary of preliminary model parameters:

PCORR:	1.0
FC:	1000
LP:	1.0
BETA:	3.0
K0:	0.3
UZL0:	4.0
K1:	0.1
K4:	0.05
PERC:	0.4
MAXBAS:	2.0
ICFI:	1.5

An example of the results of modelling the total inflow to the Manyame and Chivero reservoirs 1981 and 1989 is shown in Figure A3.9. Recorded inflow is obtained using the outflow from the dam recorded at C89 plus the change (positive or negative) in water level between the current and the previous day. Inflow values will be negative during long periods of the dry season due to the high evaporation from the large dam in comparison with the inflow during this season. As for the Seke and Harava dams, reservoir levels were only available on weekly basis, and daily values have been created using linear interpolation between weekly values.

The R2 value for the period 1980-1989, with several periods of interruptions in the recorded data, was 0.60, and the accumulated difference between the simulated and the recorded inflow volumes for the period was 165 mm. The model calibration could still be improved when discharge data for C79 and C83 as well as more precipitation stations are provided.

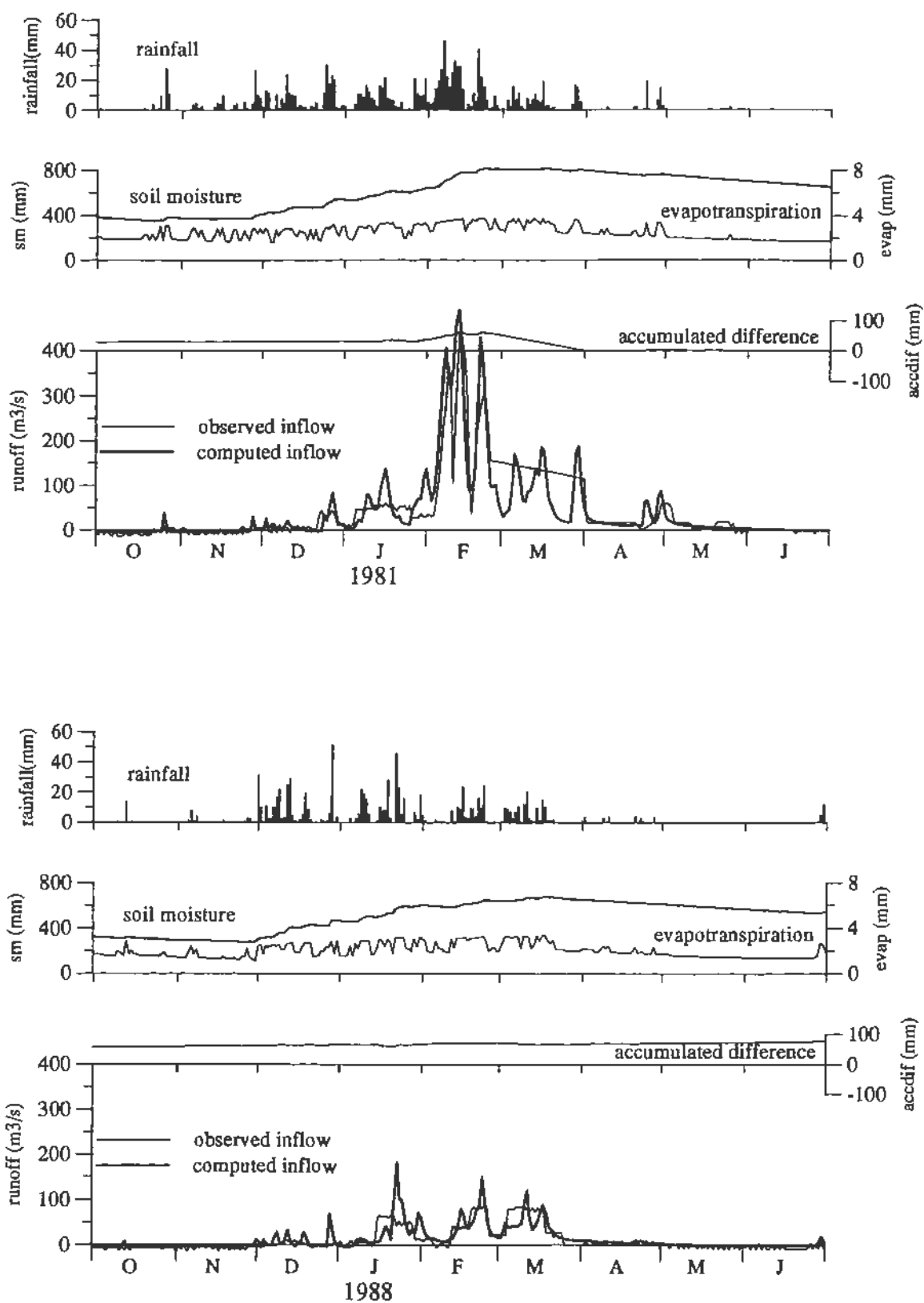


Figure A3.9. Model simulation of the inflow to the Chivero and Manyame reservoirs, 1981 and 1988.

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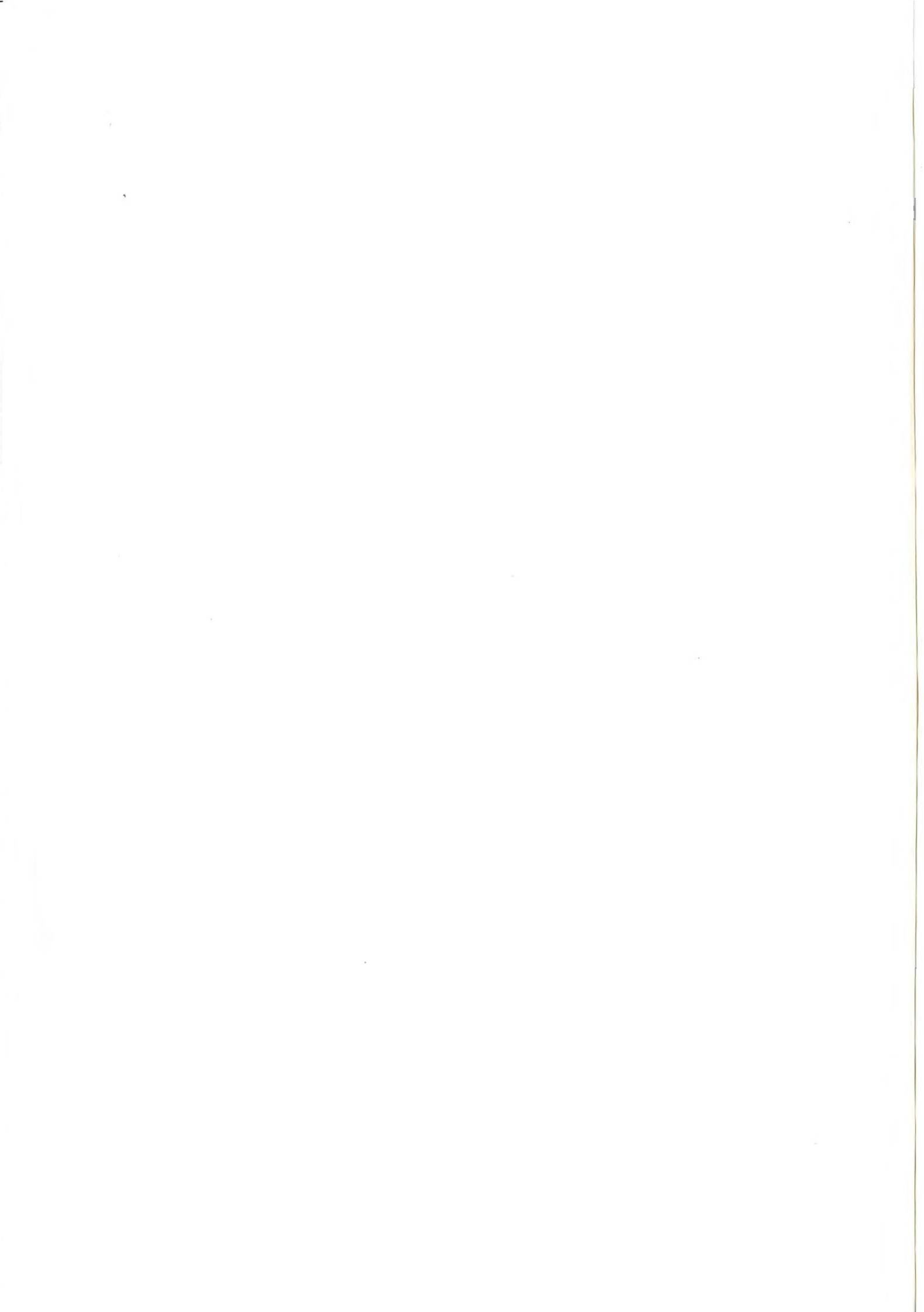
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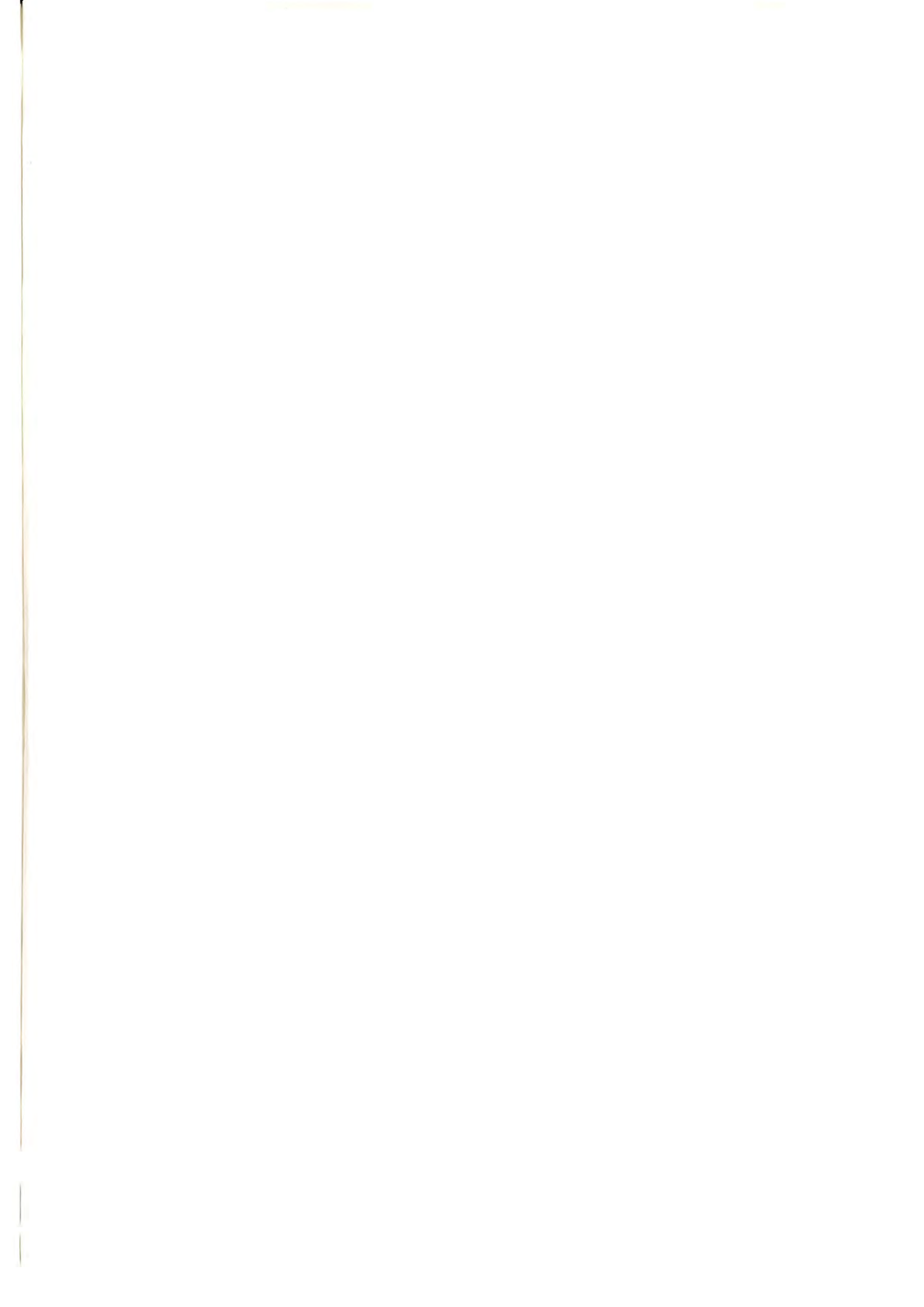
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