OVERSEAS DEVELOPMENT ADMINISTRATION
MINISTRY OF AGRICULTURE, GOVERNMENT OF SOMALIA

HYDROMETRY PROJECT - SOMALIA

Flow Forecasting Models
Jubba and Shebelli Rivers

Sir M MacDonald & Partners Limited
Demeter House, Station Road, Cambridge CB1 2RS
United Kingdom

in association with

Institute of Hydrology
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1. INTRODUCTION

This report describes a flow forecasting model for the rivers Jubba and Shebelli. The model was developed during the Somalia Hydrometry Project, which was instituted and supported by the Overseas Development Administration (ODA) as part of the British Government's programme of Technical Cooperation with developing countries. Staff from Sir M.MacDonald and Partners (now part of Mott MacDonald International Ltd.) and the Institute of Hydrology provided technical assistance and training to the Hydrology Section of the Department of Irrigation and Land Use (DILU) in the Ministry of Agriculture, Mogadishu. This support was on an intermittent basis from late 1983 to mid 1986 and full time from 1988 to 1990. A preliminary version of the forecasting model was installed in Mogadishu in 1986 (ref. 1) and later versions were installed in 1989 and 1990. The final version is currently installed on the IBM PS2 Series 50 computer operated by the DILU.

The model is designed to predict river levels and flows at the main gauging stations in Somalia. Forecasts of up to about one week ahead can be obtained. Forecasts are normally based on radio transmissions of levels at the border stations of Beled Weyn and Lugh Ganana, and at Bardheere on the Jubba. The radio data can also be supplemented by observations made during field trips. In the calculations, precedence is always given to data for the nearest station upstream. It is hoped that, in future, it will be possible to greatly increase the lead time of forecasts by using estimates of the flow at Beled Weyn and Lugh Ganana obtained from satellite images of cloud cover within the Ethiopian portion of the catchments. The required satellite receiving equipment is already installed in Mogadishu but, at the time of writing, was not yet fully operational.

The software is based around the HYDATA hydrological database system used by the DILU. This database is used to store all level, flow and water quality data for the rivers Jubba and Shebelli and is updated on a daily basis. The model bases its forecasts on values of daily mean flow read directly from the database. Simple regression equations are used to describe the relationship between flows at neighbouring stations. The calculated flows are then converted to levels using the current rating equations for each station. A fixed time lag is assumed for each reach. Earlier studies (ref. 2) have shown that, in most circumstances, this approach gives excellent results. It also has the advantage of making the model simple enough to be operated by in-experienced staff, which was a major consideration in the design of the software.

To improve the accuracy of the model, a facility is provided to adjust the forecast to blend with any observed data that are available. For the Shebelli, the forecast can also, if required, include estimates of the flows into and out of Jowhar Offstream Storage reservoir obtained from a water balance model. This model can also be used to study the historical performance of the reservoir, and to investigate the likely effects of changing the operating rules used at the reservoir. Another option provided for forecasts on the Shebelli is to use a flow routing model for the reach between Beled Weyn and Bulo Burti. This option is made available when flows on the Shebelli are high and significant overbank storage is likely to be occurring. Also, to allow for future expansion of the model, a facility is provided to specify lateral inflows and/or outflows in any reach on either river. Some typical uses of this option might be to model inflows from local runoff or outflows due to irrigation abstractions or the operation of flood relief canals.

The model has been used intermittently throughout the period 1986 to 1990. Within the Hydrology Section, it has proved useful in helping to plan field trips, for example by indicating whether river levels will be low enough to allow scheduled maintenance to be carried out, or whether the flow will be at a value which merits a check gauging measurement. Uses outside the section have included radioing estimated levels to irrigation schemes on the lower Jubba during periods of high flow, and to a construction team working on a river intake on the mid Jubba. One possible future use of the model - as yet untried - would be to assist in planning operations at Jowhar Offstream Storage reservoir and, possibly, at other irrigation and flood relief schemes on the two rivers.

This report gives all of the information required to install and operate the forecasting model. It also presents an evaluation of the performance of the model during 1988, 1989 and 1990, and gives some discussion of the performance of the Jowhar Offstream Storage reservoir since it was commissioned in 1980. The theory is presented in Section 2 and the evaluation of performance is given in Section 3. Section 4 gives some general conclusions on this work and recommendations for future developments (including some discussion on the use of satellite data for flow forecasting). Full operating instructions, together with guidelines on using the model, are given in Appendix A.

2. THEORY

This section presents the theoretical background to the forecasting model. Section 2.1 discusses the calculation methods used for the main channel of each river and Section 2.2 discusses the sub-model which was developed for the Jowhar Offstream Storage reservoir.

2.1 Forecasts for the main river channel

2.1.1 Basic model

To derive an appropriate form for the forecasting model, it is helpful to consider briefly the hydrology of the rivers Jubba and Shebelli. Tables 1 and 2 summarise the main characteristics of each river within Somalia and the locations of the main gauging stations are shown in Figure 1. A full description of the hydrology can be found in other reports issued by the Hydrometry Project (refs. 2 and 3).

Some typical hydrographs for the main gauging stations in Somalia are shown in Figure 2. A number of features can be noted from these hydrographs. Firstly, both rivers have two main flood seasons, which correspond to the northwards and southwards passage of the Inter-Tropical Convergence Zone over the Ethiopian highlands. The rivers also have slow response times, with significant changes in flow occurring over days, rather than hours. At the lowermost stations, the flows reach a sustained peak during both flood seasons. This occurs because, in the lower reaches, the river banks generally lie above the level of the surrounding land, so that any spillages are lost permanently from the river, and no return flow occurs. The sustained peaks correspond to periods when the river is flowing at its bank-full capacity. At other times, there is a strong correlation between flows at neighbouring stations with a roughly constant time lag in flows. For the year shown there is little evidence that any local runoff occurred on either river. For both rivers, some evidence can be seen of flow reductions due to irrigation abstractions between the lowermost stations; in particular, weekly releases between Mahaddey Weyn and Afgoi caused a regular cycle in the flows in the lower Shebelli during the dry season. Operations at Jowhar Offstream Storage reservoir also affected flows on the lower Shebelli for part of the year.

The flow hydrographs shown in Figure 2 are broadly typical of most years since reliable records first began in 1963. On the basis of these records, it was decided that a simple correlation model, with a fixed time lag between stations, would be suitable for the forecasting model. The general form assumed for the correlations was:

$$Q_t^n = aQ_{t-T}^{n-1} + b, \qquad Q_{t-T}^{n-1} \le Q_{\text{lim}} \qquad (1)$$

where Q is flow, a and b are constants, t is time, and T is the lag time for the n'th reach. Q_{lim} is the upper flow limit for which the segment of the correlation is valid. Each correlation can consist of up to three

Station	Altitude (m. amsl)	APPROXIMATE BANK-FULL VALUES Max. width (m)	Max. depth (m)	Max. flow (cumecs)
JUBBA				
Lugh Ganana	142.6	140	9	
Bardheere	89.5	100	8	
Mareere	13	85		590
Kamsuma	8.6	85	8	507
Jamamme	1	65	8	480
SHEBELLI				
Beled Weyn	176.1	44	7	
Bulo Burti	134.4	48	6	
Mahaddey Weyn	104.6	46	5	166
Afgoi	77.4	40	5	97
Audegle	70.1	38	5	94

(Note : Altitude is height of gauge zero above mean sea level)

TABLE 1 Characteristics of the main gauging stations on the rivers Jubba and Shebelli (from ref. 2). The maximum width, depth and flow are approximate values when the river is at bank-full level

Reach	Length (km) Straight line	Along bed	Average slope	Average lag (days)	Average wavespeed (m/s)
JUBBA					
LG - BA	165	234	0.00023	2.3	1.2
BA - MA	217	412	0.00019	4.1	1.2
MA - KM	20	39	0.00011	0.4	1.1
KM - JA	28	53	0.00014	0.6	1.0
SHEBELLI					
BW - BB	107	171	0.00024	2.0	1.0
BB - MW	98	188	0.00016	2.4	0.9
MW - AF	111	199	0.00014	2.9	0.8
AF - AU	35	66	0.00011	1.2	0.6

LG = Lugh Ganana
BA = Bardheere
MA = Mareere
KM = Kamsuma
JA = Jamamme

BW = Beled Weyn
BB = Bulo Burti
MW = Mahaddey Weyn
AF = Afgoi
AU = Audegle

TABLE 2 **Hydraulic characteristics of selected reaches on the rivers Jubba and Shebelli (from ref. 2)**

segments, each with the general form shown in equation (1). To cope with the problem of spillage occuring in the lower reaches, a maximum bank full flow was specified for each of the stations affected. The values used in the model were averages for the period 1988 to 1990.

During the second phase of the Hydrometry project, a preliminary model was developed (ref. 1) in which the lag times were constrained to be equal to a whole number of days. Later studies (ref. 2) suggested that better results could be obtained if lag times were allowed to be equal to fractional parts of a day, with the required flows estimated by linear interpolation between observed values. The lag times used in the current version of the model (see Table 2) were based on estimates obtained from observed values of river level during the period 1963 to 1989. A wide variety of specific events was identified, such as peaks or sudden drops in river level, and the time taken for each event to move between stations was estimated. A main conclusion from this work was that the observed lag times and wave speeds showed little discernible variation with flow, and were effectively constant provided that the flow remained in-bank.

Using the estimated lag times, correlations were developed between neighbouring gauging stations on each of the rivers. For the Shebelli, the stations chosen were Beled Weyn, Bulo Burti, Mahaddey Weyn, Afgoi and Audegle. A station at Kurten Warey, which was established in 1988, was excluded since very little data has yet been collected. However, this station could be incorporated into the model in future, if required. The stations chosen for the Jubba were Lugh Ganana, Bardheere, Mareere and Jamamme. As on the Shebelli, a further station - Kamsuma - was not included since there were not yet sufficient recent data to develop reliable correlations.

The correlations were based mainly on the flow data for 1988, 1989 and 1990. These years were chosen since, for the purposes of flow forecasting, it was considered desirable to base the model only on recent, reliable data. The Hydrometry project was operating throughout this period, so the data were known to be of good quality. In some cases, however, data for 1990 were excluded since the values had not yet been fully checked. For the correlation between Afgoi and Mahaddey Weyn, it was necessary to exclude all periods in which the canals to Jowhar Offstream Storage reservoir were operating. However, this left so few values that the correlation period was extended to 1985 to 1989. In all cases, the correlations were calculated using a computer program called **RIVERI** which was developed earlier in the Hydrometry Project (see ref. 2). The final equations are shown in Table 3, and plots of the data are shown in Figure 3.

When operating the forecasting model, forecasts are calculated automatically for each station from every other station upstream for which data are available. For example, for Afgoi on the Shebelli, individual forecasts are calculated from the observed data (if any) for Beled Weyn, Bulo Burti and Mahaddey Weyn. From these individual forecasts, a 'combined' forecast is produced which, for each day, takes the forecast from the nearest possible station upstream. This gives precedence to forecasts from nearby stations, which are more likely to be reliable than forecasts from distant stations. Using the above example, forecasts from Mahaddey Weyn would be used in preference to forecasts from Bulo Burti, and forecasts from Bulo Burti would be used in preference to forecasts from Beled Weyn. The 'combined' forecast is the main output from the model and should normally be used in preference to forecasts from individual stations.

	Segment	Lag (days)	Slope	Intercept (cumecs)	Max. flow (cumecs)	No. of points
JUBBA						
BA - LG	1	2.3	1.118	7.935		869
MA - BA	1	4.1	0.925	-8.102		544
JA - MA	1	1.0	1.001	1.651		198
SHEBELLI						
BB - BW	1	2.0	1.052	-3.842	60	320
	2	2.0	0.846	8.526	250	232
MW - BB	1	2.4	1.099	3.701		416
AF - MW	1	2.9	0.694	-0.045	40	441
	2	2.9	0.651	1.677		404
AU - AF	1	1.2	1.158	-2.416		491

(Example : the correlation between Afgoi and Mahaddey Weyn is

$$Q_{AF} = 0.694\ Q_{MW} - 0.045 \quad \text{for } Q_{MW} <= 40 \text{ cumecs}$$

$$Q_{AF} = 0.651\ Q_{MW} + 1.677 \quad \text{for } Q_{MW} > 40 \text{ cumecs}$$

where Q is the flow in cumecs and Q_{MW} is lagged by 2.9 days)

TABLE 3 Correlations used in the forecasting model. The table also shows the number of data points used when calculating the correlations. The abbreviations of station names are defined in Table 2.

The model has a number of features which can improve the accuracy of the forecasts. To cope with periods of missing data (a common occurrence), an option is provided to infill up to 3 daily values for any station using logarithmic interpolation. To allow for discrepancies between forecasts and observations, the model includes an option to adjust forecasts to match with any observed data. Two types of adjustment can be performed, called 'shift' and 'join' adjustments. The shift option adds or subtracts an amount equal to the difference between the observed and forecast values on the last day for which an observed value was available. The join option distributes the difference over a period specified by the user. Figure 4 shows an example of each type of adjustment.

The output from the model consists of screen tabulations and plots of the forecasts for each station on each river. Some typical examples of the graphical output are shown in Figure 5. Guidelines on using the model and full operating instructions are given in Appendix A. A detailed examination of the performance of the model is given in Section 3.

Experience gained with early versions of the model suggested that its main deficiencies were that it did not allow for inflows and outflows in a reach (except permanent spillage), and that, for the reach between Beled Weyn and Bulo Burti on the Shebelli, the model could not represent the significant overbank storage which occurs during flood events. The following sections describe how the model was extended to allow for these effects.

2.1.2 Flow routing model

The assumption of a fixed lag time generally gives good results on both the rivers Jubba and Shebelli. The only situation where a fixed lag seems inappropriate is during periods of high flow in the reach between Beled Weyn and Bulo Burti on the Shebelli, when a considerable increase in lag time can occur. On the Jubba, a similar but much less pronounced increase appears to occur between Bardheere and Kaitoi, but was not felt to be worth modelling since the change is only small. Instead, a warning message appears if the flow at Lugh Ganana exceeds a pre-set limit (currently set at 1000 cumecs).

Figure 6 shows the main flood events which have been recorded on the Beled Weyn-Bulo Burti reach since 1963. It can be seen that the lag time for the reach first begins to increase when the flow at Beled Weyn exceeds about 250 cumecs. The lag time can exceed one week during exceptional events, which compares with the average value of 2 days when flows are in-bank. Observations during the 1981 flood (ref. 4) - the highest on record - show why this occurs. During this flood, considerable spillage occurred upstream of Beled Weyn, and a parallel flow developed along the flood plain. A slow moving sheet of water, up to 1.5m deep, was observed to travel along the valley, and much of the town of Beled Weyn was flooded. Downstream of Beled Weyn, the passage of the flood was impeded by natural controls at Giglei and El Geibo. This had the effect of further delaying the time taken for flows passing Beled Weyn to reach Bulo Burti.

In the lower Shebelli, the river valley widens and spilled flows are normally lost permanently from the river.

Thus, for the lower stations, the main effect of a parallel flow upstream of Bulo Burti is to delay the time at which the river starts to drop below its bank-full level. In general, the values of the bank full flows themselves appear not to be greatly affected by the magnitude of the flow at Beled Weyn. This is because there is a limit to the maximum flow at each station, which is determined by the level of the river banks immediately upstream. Generally, the majority of the permanent spillage from the Shebelli occurs a short way upstream of Mahaddey Weyn. Spillage downstream from Jowhar is relatively rare, and can be controlled by timely operation of the Duduble flood relief canal and the supply canal to the Jowhar Offstream Storage reservoir.

For the purposes of the flow forecasting model, it would be desirable to reproduce the apparent increase in the lag between Beled Weyn and Bulo Burti when the flows at Beled Weyn are high. This would then give a better representation of flows in the lower Shebelli whilst the flood is subsiding. The best way to model this effect would be to use a full flow routing model, based either on the Saint Venant equations or a reasonable approximation to them, such as the Muskingum-Cunge method. Some preliminary simulations of the 1981 flood were made using a variable parameter Muskingum Cunge (VPMC) model (ref 2), the results of which are shown in Figure 7. Whilst excellent results were obtained, there are two main objections to using such a model for forecasting on the Shebelli. Firstly, models of this type require information on the hydraulic characteristics of the flood plain, but very little other than qualitative data are currently available. Secondly, there is great uncertainty in the accuracy of the rating equations for Beled Weyn and Bulo Burti at high flows. For example, the peak flow at Beled Weyn during the 1981 flood was estimated to be over 1400 cumecs (ref.4), but the rating equation indicated a peak of only 500 cumecs. Such uncertainties make it difficult to be sure that the model parameters will remain valid if applied to other flood events. For these reasons, a compromise approach was used which proved simple to implement and complemented the correlation method already used by the model. During periods of high flow, the flow at Bulo Burti was assumed to be given by the expression:

$$Q_t^n = p_t Q_{t-1}^{n-1} + (1-p_t)\,Q_{t-1}^n, \qquad Q_{t=0}^1 \geq Q_{lim} \tag{2}$$

where Q is flow, t is time and the reach is divided into n sections. The parameter p is a time and flow dependent variable analagous to a scaled wavespeed. It controls the apparent lag time and attenuation for the reach and must be determined by trial and error. It can be shown (ref. 5) that equation (2) is a reasonable approximation to the kinematic wave equation and is a special case of the Muskingum Cunge equation. However here it can be regarded simply as a form of correlation which gives the required hydrograph response.

To calibrate the model, all that is required is to define the form of the parameter p. The calibrations were performed using data for the 1981 Gu and Der floods on the Shebelli. Several functional forms were evaluated, all based on the flow at Bulo Burti at the previous time step. The form finally adopted is shown in Figure 8, and was chosen because it seemed to give an excellent representation of the decline in flows which occurs after the main flood peak passes Beled Weyn. Figure 9 shows the results obtained for the calibration period using this function, together with some sample results for other periods. It can be seen that the model generally gives a good representation of the timing of events, but is less good at predicting flow peaks (whose magnitude is, in any case, uncertain). However, as pointed out above, this will not change the forecasts for the lower stations on the river since, during flood events, the river will generally be flowing at bank full level at these stations.

Within the forecasting model, the routing option is made available if the flow at Beled Weyn exceeds a preset limit (currently set at 250 cumecs). If this option is selected, the simulation is then repeated but using equation (2) from the day on which the flow at Beled Weyn first exceeds this limit (although the standard correlation model is still used up until this day). The flows at the lower stations on the Shebelli are then based on the flows at Bulo Burti calculated using the routing method. The final forecasts can still be adjusted, plotted and printed in the usual way.

2.1.3 Lateral flows

The main causes of inflows and outflows on the Jubba and Shebelli are a) spillage and flood plain flows, b) irrigation abstractions, c) flows into flood relief canals and d) local runoff due to rainfall within Somalia. Ref. 2 gives several examples of the effects of these inflows and outflows on river flows further downstream. In the model, the only explicit representation of these flows was for the Jowhar Offstream Storage reservoir (see Section 2.2). However, a facility was provided to allow any arbitrary inflow or outflow in a reach to be specified by the user. This should allow the model to be expanded to include sub-models of, for example, specific irrigation schemes, or rainfall runoff models for the Somali sections of the river catchments.

Figure 10 shows an example of how this facility might be used to include a local runoff event in a forecast for the Shebelli. A hypothetical local runoff event has been specified to occur in the reach between Beled Weyn and Bulo Burti and has been included in the forecasting calculations. As expected, this event appears in the forecast for Afgoi obtained using data from Beled Weyn. The event does not appear in the forecast from Bulo Burti, of course, since the measured data for Bulo Burti do not allow for the imagined runoff event.

2.2 Jowhar Offstream Storage reservoir model

The Jowhar Offstream Storage reservoir is situated in the reach between Mahaddey Weyn and Afgoi on the river Shebelli. The reservoir was designed to collect surplus river flows during the Der season for subsequent release for irrigation during the following dry season (i.e. November to March approx.). The supply canal can also be used as a flood relief canal. Since the reservoir was commissioned in 1980, it has had a major impact on flows in the lower Shebelli. The forecasting model includes a simple water balance model of the reservoir which allows the flows in the supply and outlet canals to be estimated for inclusion in forecasts for the Shebelli. This model can also be used in a 'historic' mode, in which an entire year of operations can be simulated. This allows the model to be used to study the effects of proposed changes in the operating rules, and to examine the historical performance of the reservoir system. The historical mode can also assist in infilling periods of missing or doubtful data.

Figure 11 shows the layout of the Jowhar scheme. The reservoir lies in a shallow depression to the east of the town of Jowhar and its outlet canal joins the Shebelli approximately 40 km downstream of the intake to the supply canal. The maximum capacity of the reservoir is 205 million cubic metres and the design capacities of the supply and outlet canals are 50 and 25 cumecs respectively. Due to siltation, the current capacities of these canals are estimated to be about 25 and 10 cumecs respectively. The maximum flow ever passed down the supply canal was about 35-40 cumecs (in 1981).

The operating rules at the reservoir have been evolved over the past 10 years. From discussions with staff at the reservoir, it seems that the current rules are as follows. A few days after the onset of the Gu flood, the supply canal gates are opened slightly to admit a small flow which serves to wet and stabilise the bed of the canal. The time delay is required to allow the high sediment load and salinity levels associated with the start of the flood to subside. Once the bed is fully wetted, the flow is increased to its maximum value. The gates to the canal are closed either when the reservoir fills, or when the Gu flood ends. Note that no attempt is made to keep the reservoir 'topped up' once it has filled; this is for the benefit of users further downstream who require river levels to be maintained to feed gravity supply canals. After the end of the Gu flood, the reservoir level declines due to evaporation and seepage losses until, at the onset of the Der season, the supply canal gates are again opened. The aim now is for the reservoir to be full before the end of the Der season. Once the reservoir has filled (or the Der season ends) the canal gates are again closed and are not re-opened until the following Gu season. The outlet canal is brought into operation after the end of the Der season. Throughout most of the year, this canal - which has no outfall structure - is isolated from the river by an earth bank. This bank is removed as soon as the flow in the main channel of the Shebelli drops below about 40-45 cumecs. The canal gates are operated so as to maintain this flow in the Shebelli for as long as there is sufficient water available in the reservoir. The canal is left 'open' until warning of the next Gu flood is received, when it is then blocked off again by a new earthbank.

The forecasting model can perform two types of simulation of the reservoir. In the first type (Type 1), the volume of the reservoir is calculated using the measured flows in the supply and outlet canals (if available).

Any differences between the measured and estimated volume are then due either to errors in the measured canal flows, or to inaccuracies in the losses estimated by the model. The results from these calculations are useful for calibrating the model. The second type of simulation (Type 2) produces estimates of the canal flows for inclusion in flow forecasts for the Shebelli. In this case, all flows and volumes in the reservoir system are estimated from the flow at Mahaddey Weyn, which may itself have been estimated from levels at Beled Weyn. A model of the current operating rules is used to estimate when the canal gates are likely to be opened or closed. Note that this model is required because, in practice, it is unusual for current, real time data for the reservoir to be available.

In both types of simulation, the volume of the reservoir is estimated using a simple water balance model. This model will only be described briefly here but is discussed in more detail in ref. 6, together with the equations used. Net losses from the reservoir are assumed to be equal to the sum of the evaporation and seepage (infiltration) losses, less any contribution from rainfall. Individual losses are based on the current volume, and hence surface area, of the reservoir. The program assumes the volume-area relationship shown in Figure 12, which is based on the design level-volume and level-area curves given in ref.7. The model provides default values for the contributions from evaporation and rainfall which are set equal to the long term monthly averages for the town of Jowhar. These defaults are shown in Section A.5. The default value for infiltration losses is set at 5 mm/day and is based on the studies described in ref. 6. To allow for the increased infiltration which occurs when filling the reservoir from empty, an additional parameter (user defined) is built into the model which provides a time lag between the supply canal first being opened, and the reservoir beginning to fill. In the model, the apparent losses due to the 'lost' supply canal flows are lumped into the infiltration losses. The default value for the time lag was based on the data for 1981 to 1989 and is set at 10 days.

A number of parameters must be supplied by the user in order to operate the model. These include the maximum allowed flows in the supply and outlet canals, and the maximum capacity of the reservoir. Default values are provided for use if no other values are available. As with all the other default values in the model, these can be changed by the user if required. Estimated values are also required for the monthly average abstractions/losses in the reach of the Shebelli between the inlet and outlet canals (the Jowhar reach). These values are required to estimate the flows in the main channel of the Shebelli downstream of the outlet canal. In the model, the default values provided are taken from ref. 7. Defaults are also provided for the monthly flow requirements in the Shebelli downstream of the outlet canal. However, these values are only used in the graphical output from the model (see, for example, Figure 14) and have no effect on the results of the simulations. An option is also provided to specify inflows to the reservoir from the neighbouring SNAI sugar estate. For the present, these flows should normally be set to zero, since the required drainage pumps are not yet installed.

In the Type 2 simulations, some additional parameters are required which define the assumed operating rules. Figure 13 shows schematically how the rules are modelled. The hydrograph at Mahaddey Weyn is assumed to have the typical form shown in the figure, with flow peaks during the Gu and Der seasons. The hydrograph is assumed to be divided into 7 periods, which are defined by the 6 key points identified. These periods are:

1 - Before the start of the Gu flood
2 - Between the start of the Gu flood and the day on which the flow at Mahaddey Weyn reaches its bank full value
3 - During the Gu period of bank full flow at Mahaddey Weyn
4 - Before the start of the Der flood
5 - Between the start of the Der flood and the day when the flow at Mahaddey Weyn next reaches its bank full value
6 - During the Der period of bank full flow at Mahaddey Weyn
7 - After the end of the Der flood

For years in which the bank full flow is not reached, periods 2 and 3, and 5 and 6, are assumed to be merged. An algorithm in the model estimates the dates defining each period for the year being simulated; alternatively, the user may define these dates explicitly. The operating rules are then defined by reference to these dates. The supply canal is assumed to be opened a fixed time (T_1) after the start of the Gu flood. Initially, a small 'trickle' flow is admitted (Q_1) for a fixed period (T_2) before admitting the full flow. By default, the supply canal is closed either when the reservoir fills or when the Gu flood ends. A similar algorithm is used during the Der Season. The supply canal is assumed to be opened a fixed time (T_3) after the start of the Der flood and the 'trickle' flow (Q_1) is again maintained for a fixed period (T_2) before admitting the full flow. The supply canal is again closed either when the reservoir fills or when the Der flood ends. The outlet canal is only permitted to open after the end of the Der season and remains open either until the reservoir empties or the Gu flood starts. Some further parameters can over-ride these rules. Flows in the supply canal are only allowed if the flow at Mahaddey Weyn exceeds a value Q_2 and flows in the outlet canal are only allowed when the flow at Mahaddey Weyn drops below a value Q_3. In both cases, the canal flows are set equal to the difference between these thresholds and the flow in the Shebelli (up to the maximum canal capacities). For the supply canal, an additional parameter determines whether the canal is to be closed when the reservoir fills, or whether a trickle flow is to be maintained to keep the reservoir 'topped up'. The default is to close the canal on filling.

The six parameters T_1 to T_3, and Q_1 to Q_3, together with the dates defining the periods, define how the reservoir is operated in any one year. This provides great flexibility in using the model to examine the performance of the reservoir and to study the effects of any proposed changes to the operating rules. As will be explained in Section 3.2, these parameters are set to default values suitable for use in the forecasting mode of operation, so the user should not normally need to change these values when using the model in forecasting mode.

In both the forecasting and historic modes of operation, the simulations are started from the first day of the year under study. Unless specified otherwise, the reservoir volume is assumed to equal the measured volume on the last day of the previous year. In the forecasting mode, precedence is given to measured values of volume and flow so, if these are available, the simulation is re-started from the last day for which measured values are available. Some limited infilling is done automatically by the model using logarthmic interpolation. In practice, the only measurements likely to be available in real time are spot measurements of the reservoir level (and hence volume) made during field trips. Should these be available, the model automatically restarts the simulation from the last measured value.

The output from the model consists of plots and statistical summaries describing the performance of the reservoir. Several examples of this output are shown in Figure 14. Examples of the types of plot which can be obtained include comparisons of predicted and estimated reservoir volumes, comparisons of flows in the Shebelli with required flows, and plots of the flows in the supply and outlet canals. Appendix A gives some guidelines on using the model together with full operating instructions.

3. EVALUATION OF THE MODEL

This section evaluates the performance of the forecasting model over recent years. It also gives some discussion of the performance of the Jowhar Offstream Storage reservoir since it was commissioned in 1980.

3.1 Forecasts for the main river channel

The most usual use of the forecasting model is to estimate flows in the Jubba and Shebelli from river level data transmitted by radio from Lugh Ganana, Beled Weyn and Bardheere. Although data for other stations are occasionally available (from field trips, or visits to Mogadishu by observers), this cannot be relied upon. The most useful test of the forecasting model was therefore felt to be to calculate forecasts solely from data for Lugh Ganana and Beled Weyn. Using the model, forecasts were calculated retrospectively for each station on each river throughout 1988 and 1989. Forecasts were also made for 1990 up until October, which was the last month for which data were available at the time the calculations were performed. For all stations, forecasts were made for the longest possible lead time. Figures 15 show that there was generally excellent agreement between the forecast flows and the flows which were subsequently observed. This confirms that the model is working as expected and has been calibrated correctly. Unfortunately, it was not possible to make a realistic test of the routing option for the Shebelli since the flows at Beled Weyn were never high enough to cause any significant over-bank storage in the period 1988 to 1990.

These were of course some differences between the forecast and observed flows. It is likely that many of these differences were due to errors in the measured flows - either the values at Beled Weyn and Lugh Ganana used for the forecasts, or the values subsequently observed at stations further downstream. Errors of this type are particularly likely for 1990 since, due to the security situation, little fieldwork could be done to check the accuracy of the measurements. Some systematic errors also occurred due to deficiencies in the model. On the Shebelli, the main differences were at Afgoi and Audegle. During the dry seasons of 1988 and 1989, the model could not predict an irrigation abstraction which occurred between Mahaddey Weyn and Afgoi. This caused the flow at Afgoi and Audegle to rise and fall by about 10 cumecs on a weekly cycle. It is not known where this abstraction occurred, or what operating rules were used. If more information was available, the effects of this abstraction could be included in the model by using the lateral flow option. Errors also occurred in the forecasts for Afgoi and Audegle due to omitting the flows into and out of Jowhar Offstream Storage reservoir. It can be seen from Figures 15 that the model over-estimates the flow when the supply canal is operating and under-estimates the flow when the outlet canal is operating. These errors could, of course, be corrected by running the reservoir model, and so incorporating the canal flows into the forecasts for the main river channel. Note that the differences between the observed flows at Mahaddey Weyn and Afgoi are not exactly equal to the flows in the supply canal due to inaccuracies in the rating equations for the three stations, and losses and abstractions in the reach.

On the Jubba, the main cause of errors in the forecasts was local runoff in the reach between Lugh Ganana and Bardheere. Some typical events can be seen in the forecasts for April 1988 and March 1989, in which the model under-estimated the observed flows at Bardheere and stations downstream. Currently, the only way of allowing for runoff is to base forecasts for the lower Jubba on the daily transmissions of river levels at Bardheere. Provided that these are entered onto the DILU's database, the model will use these data in preference to data for Lugh Ganana whenever possible. The only other period of major errors was for the lower Jubba in late 1989. However, a comparison with data for Lugh Ganana and Bardheere suggests that the observed values for Mareere and Jamamme may have been in error, rather than the values predicted by the forecasting model.

3.2 Jowhar Offstream Storage reservoir model

Calibration

The main method used to evaluate the reservoir model was to compare the observed values of reservoir volume with values predicted by the model. As mentioned earlier, two types of simulation could be performed by the model. In the Type 1 simulations, the measured canal flows are used whilst, in the Type 2 simulations, estimates of the canal flows are used.

The initial calibrations of the model were performed using the results of the Type 1 simulations. Some typical results are shown in Figure 16. The best check on the accuracy of the model's estimates of losses is to compare the predicted and observed volumes whilst both the supply and outlet canals are closed. Generally, the volumes were in good agreement during these periods, which suggests that the model is providing good estimates of the losses. The agreement between predicted and observed volumes is also good for periods when the reservoir is filling, which suggests that the measured flows in the supply canal are reliable. Note that, in most years since 1982, the peak recorded flows have been about 25 cumecs, which is much less than the design value of 50 cumecs.

The only periods when the Type 1 simulations gave poor results were when the outlet canal was open. Given that the estimated losses were reasonable in all other periods, it seems likely that the main cause of these errors is that the measured flows in the canal overestimate the actual flows due to errors in the rating equation for the canal. To estimate the likely true value of these flows, some Type 2 simulations were performed using a range of estimates for the maximum flow in the outlet canal, and assuming a peak supply canal flow of 25 cumecs. The maximum flow in the outlet canal was varied until a good fit was obtained between the estimated and measured rates of decrease in reservoir volume. It was found that a value of 10 cumecs gave reasonable agreement between observed and predicted volumes throughout the period 1981 to 1989. In these simulations, the parameters defining the operating rules were set so that the canals were opened and closed by the model on the same dates on which the canals were actually opened and closed.

The main use of the Type 2 simulations is, of course, to estimate the canal flows for use in forecasts for the main channel of the Shebelli. To do this, it is necessary to set the 6 parameters T_1 to T_3 and Q_1 to Q_3 which define the operating rules at the reservoir, together with the 6 key dates defined in Figure 13. It is anticipated that, in most circumstances, the dates will be estimated automatically by the model. As a test on the algorithm which estimates these dates, the model was applied to the flow data for Mahaddey Weyn for each year from 1963 to 1989 and compared with the dates estimated by eye from the flow hydrographs. Figure 17 summarises the results which were obtained. There was reasonable agreement with the values estimated by eye; the only difficulties occurred in years like 1979 and 1986 where the Gu and Der seasons were not clearly defined.

To estimate the 6 parameters which define the rules, a process of trial and error was used. The method used to judge the suitability of the parameters was to compare the predicted dates for the opening and closing of the canals with the actual dates which were observed. After much experimentation, it was found that the following values gave reasonable results throughout the period 1981 to 1989:

T_1 = 15 days $\qquad$ Q_1 = 10 cumecs

T_2 = 7 days $\qquad$ Q_2 = 25 cumecs

T_3 = 25 days $\qquad$ Q_3 = 45 cumecs

These values imply the following operating rules. In the Gu season, the supply canal is first opened 15 days after the Shebelli starts to rise at Mahaddey Weyn, provided that by then the flow at Mahaddey Weyn exceeds 25 cumecs. A trickle flow of 10 cumecs is maintained for one week (7 days) before fully opening the canal. The canal is closed either at the end of the Gu season, or when the reservoir fills. In the Der season, the same trickle flow and time is used but there is a delay of 25 days after the onset of the Der flood before first opening the supply canal. The supply canal is again closed at the end of the season, or when the reservoir fills. After the end of the Der flood, the outlet canal is opened once the flow at Mahaddey Weyn drops below 45 cumecs. Peak flows in the supply and outlet canals are assumed to be 25 and 10 cumecs respectively.

Figure 18 shows the results of some Type 2 simulations for 1987, 1988 and 1989 when applying these assumed operating rules. For 1987 and 1988, the agreement between the predicted and observed volumes was generally very good, as was the agreement between the observed and predicted canal flows (although note that there were few observations available for the outlet canal). For 1989, the agreement was less good but still satisfactory; the differences here may have been due to the lack of a well defined Der flood season in this year, with a corresponding modification of the operating rules used at the reservoir.

Applications

The reservoir model was designed with two aims in mind; flow forecasting and historical (operational) studies. In the forecasting mode, the model is used to predict the canal flows for the next few days based on the flow forecasts for Mahaddey Weyn. These estimated canal flows are then allowed for in the flow forecast for the main river channel. In the historical mode of operation, the model is operated for a full year in each simulation. Some possible applications of this mode are infilling missing data for the reservoir system and studying the operating rules for the reservoir.

A full evaluation of the reservoir's performance falls outside the terms of reference of the Hydrometry project and in any case could not be performed without consideration of the needs of other water users on the river. Consequently most of the operational studies were confined to calibrating the model to represent the current rules used at the reservoir. The studies described above suggest that the calibrated model gives a reasonable representation of the reservoir system, and can be used with confidence in conjunction with the flow forecasting model. Figure 19 shows an example of a forecast obtained when using the reservoir model in conjunction with the forecasting model. The forecast is for Afgoi on the river Shebelli during a period when the reservoir supply canal was known to be operating.

As an indication of the types of operational studies which could be performed, some trial simulations were performed using the data for 1988. The simulations described earlier (see Figure 18) were repeated assuming two changes. Firstly, the maximum flows allowed in the supply and outlet canals were raised to values of 40 and 25 cumecs respectively, which are believed to have been the maximum capacities of each canal when the reservoir was first commissioned. The second change made - via an option in the model - was to specify that, on filling the reservoir, the supply canal is left open so as to keep the reservoir topped up. The results of this simulation are shown in Figure 20. Two interesting points can be noted from these results, namely a) the higher flow in the outlet canal causes the reservoir to empty about 1 month earlier than before and b) the reservoir volume is little different at the end of the Der season. It could be argued that, although the reservoir is operating closer to design, the effect on flows in the Shebelli is less beneficial than before i.e. the flow from the outlet canal is stopped earlier in the dry season, and more flows are abstracted from the Shebelli but with little increase in the reservoir storage at the critical time of the onset of the dry season. Obviously, further studies of this type, perhaps in conjunction with a detailed water use model of the Shebelli, are required to determine the optimum operating rules for the reservoir.

The only other simulations performed using the historical mode of operation were to run the model for each year since the reservoir was commissioned in 1981. These simulations were done primarily as a check on the output from the model. However, the output from these simulations may be useful for future studies of operations at the reservoir, and so is presented in Appendix B. Note that, in these simulations, the parameters for the Type 2 simulations were set at the default values provided for use in the forecasting mode of operation.

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

In its current form, the forecasting model appears to give reasonably accurate forecasts of flows and levels for the main gauging stations on the Jubba and Shebelli for lead times of up to about one week. For the Shebelli, options are also provided to represent the overbank storage which occurs during periods of high flow in the reach between Beled Weyn and Bulo Burti, and the abstractions and releases at Jowhar Offstream Storage reservoir. The reservoir model can also be used for operational studies and for infilling periods of missing flow data.

The forecasting model has been calibrated using data for recent years and so should remain valid for the next few years. However, if possible, the model should be recalibrated at regular intervals (say annually) as new data become available. Users should be aware that the model only provides approximate estimates of flows and levels, and so should only be used as a guide to future flow behaviour. In particular, the model cannot predict the location or magnitude of spillages from the rivers. In situations where estimates of levels are important (e.g. for assessing the likelihood of flooding), it is vital to make regular (say hourly) observations of levels at all sites where major spillages are expected, or where the consequences of a spillage could be serious. To make sensible estimates of spillages would require much more detailed information on the river geometry and bank elevations than is currently available.

At present, the major impediment to further development of the model is the lack of real time data for the two rivers. One possibility for improving the model would be to expand it to include some representation of the major irrigation and flood relief schemes on each river. Sub-models could be developed along the lines of that developed for the Jowhar Offstream Storage reservoir. However, this would require a much better understanding of the operating rules, and current state of repair, of all the major schemes on each river. Also, much better communications would be required to obtain data sufficiently early for use in flow forecasting. A proposal for a more comprehensive model has been made for the Shebelli (ref. 8) but is unlikely to be implemented in the near future.

For the immediate future, the most exciting possibility for improving the model is to make use of real time satellite images of cloud cover over the Ethiopian part of the catchments. During the course of the Hydrometry project, a Meteosat satellite receiving station was installed in the Food Early Warning System (FEWS) department in the Ministry of Agriculture in Mogadishu. The installation was funded by the British Government's Overseas Development Administration. Amongst the many intended applications of this system was the facility to estimate rainfall over the Ethiopian highlands from measurements of so-called Cold Cloud Duration (CCD), which is based on the observed temperatures of the tops of rain bearing (mainly cumulus) clouds. Research by the TAMSAT group at Reading University in the UK has shown that, in tropical regions, there is a strong correlation between CCD observations and measurements of rainfall at ground level. Given areal rainfall estimates from CCD data, estimates of the flow in the Jubba and Shebelli could be obtained using a suitable rainfall runoff model. It is believed that, using these estimates, the maximum lead time for flow forecasts could be increased to about 1 month for the lower stations on both rivers.

By the end of the Hydrometry project, the satellite receiving equipment had been installed in Mogadishu but was not yet fully operational. Consequently, the CCD data could not be used in the forecasting model. However, some work by the TAMSAT group indicates how this information might be used in future. During March, April and May 1990, daily values of CCD were computed for both the Jubba and Shebelli catchments. Figure 21 shows a comparison of these measurements with the flows observed at Beled Weyn and Lugh Ganana during the same period. These results show that there is a reasonable correlation between CCD and flow, and that there is a time lag of around 20-30 days between periods of high rainfall in the Ethiopian highlands and periods of high flow at the two stations. A crude first step towards a rainfall runoff model would be to derive a direct correlation between observations of CCD and the corresponding flows. However, as more CCD data becomes available, it should be possible to develop more sophisticated models which take account of the hydrological characteristics of the river catchments within Ethiopia.

In its current form, the forecasting model could make direct use of any CCD derived estimates of flows at Beled Weyn and Lugh Ganana. All that is required is to enter the estimated values onto the DILU's HYDATA database. The model will then read these values and use them in calculating the forecasts for stations further along the river. The estimated values on the database could of course be over-written by observed values as these became available.

5. REFERENCES

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APPENDIX A - OPERATING INSTRUCTIONS

This Appendix gives full operating instructions for the forecasting model RIVERF. Section A.1 describes how forecasts are made for the main river channel, Section A.2 describes the lateral flow option and Section A.3 describes the Jowhar reservoir model. Section A.4 gives general advice on using the model and Section A.5 describes the layout of the setup files which define the parameters used in the model. The installation of the software is described briefly in Section A.6.

A.1 Forecasts for the main river channel

Before using the forecasting model, all available level data for each river should be loaded onto the HYDATA database and converted to flows. For the longest possible lead times, values should ideally be entered up to the current day (if available). Rating equations for each station must also be defined up to the current day.

The forecasting calculations are started by typing the command **RF** from within the \HYDATA directory. The screen will then clear and a menu will appear requesting the river for which the forecast is required:

```
          Menu A1 - Main Menu

     [1 ]  Quit
     [2 ]  River Shebelli
     [3 ]  River Jubba
```

Option [2] selects a forecast for the river Shebelli and Option [3] for the river Jubba. On choosing the required option, a second menu is displayed. For the Shebelli, this appears as follows:

```
          Menu F1S - Control Menu

     [1 ]  Quit
     [2 ]  Setup file       [RFSHEB.DAT      ]
     [3 ]  Date             [1990 Oct  7]
     [4 ]  Forecast type    [0  ]
     [5 ]  Days to infill   [1  ]
     [6 ]  Jowhar OSR
     [7 ]  Lateral flows
     [8 ]  Continue
```

The control menu for the Jubba is similar, but does not have an option for the Jowhar reservoir model.

For both rivers, the entries in these control menus are set to defaults which are suitable for obtaining a forecast for the current day. Normally, these defaults should not need to be changed so, to obtain a current forecast, all that is required is to select the 'Continue' option. A message:

```
[3 ]  *INFO* Please wait....reading data from database
```

then appears. Once the forecast has been calculated, the screen clears and the main forecast output menu is displayed. The entries in this menu are described in Section A.1.2; users who require a quick description of the model should skip straight to this section. The following description is for the benefit of users who wish to modify the default options in the control menus:

A.1.1 The Control Menus

Menus F1S (Shebelli) and Menu F1J (Jubba) control the period and type of forecast obtained, and the equations used in the calculations.

The first option, Option [2], defines the name of the 'setup' file for the river. The setup file is an ASCII (i.e. normal text) datafile which contains the names of the stations on the river and the correlations between the flows at these stations. The layout of this file is described in Section A.5. The default filenames shown in the control menus are RFSHEB.DAT for the Shebelli and RFJUBB.DAT for the Jubba. Currently, these files contain the correlations given in Table 3 (Section 2.1) of this report. Normally, these default setup files should be used and Option [2] should be left unchanged. However, two additional files are provided for use in evaluating the historical performance of the model. These files - RFSHEB1.DAT and RFJUBB1.DAT - contain correlations based on all the available data for the period 1963 to 1989 inclusive.

The forecasting date, defined by Option [3], is by default set to the current date. This date should only be changed if it is required to examine the historical performance of the model. Any date between 1963 and the current date can be selected. However, the year specified must lie within the range specified in the setup file; for the default setup files, this means that the year must be between 1988 and 1992. For the additional files RFSHEB1.DAT and RFJUBB1.DAT, any date between 1963 and 1992 is acceptable.

Option [4], 'Forecast type', should normally be set to zero. In this case, the model reads data from the database up to, but not beyond, the forecasting date. The value for this entry may also be set to 1, in which case all available data are read by the model. This facility was provided for use when satellite based forecasts of the flows at Beled Weyn and Lugh Ganana become available. It should then be possible to enter the satellite based values into the database for a considerable period beyond the forecasting date, greatly increasing the lead time of forecasts for the lower stations on both rivers.

Option [5], 'Days to infill', specifies the maximum number of days for which missing values are to be infilled before calculating the forecast. This number can be set in the range 0 to 3 days, and by default is set to 1 day. If a value greater than 0 is entered, the model will infill all periods of missing data shorter than the period specified. The infilling is done using logarithmic interpolation and produces the same values as would be obtained by using the INT option in HYDATA. The infilled values are held in memory, and are shown as estimated values in all of the output from the model. The values are not written to the database. The advantage of infilling short periods of missing data is that the lead time and accuracy of the forecast is improved, particularly when the missing values are close to the forecasting date. For missing periods longer than about 3 days, it is debatable whether any meaningful forecast can be obtained from the station, given that the maximum lead time currently available on either river is only 7 days. To infill longer periods, the infilling program **RIVERI** should be used (ref. 2).

The remaining options in the control menus, concerning the lateral flow and Jowhar reservoir models, are described in Sections A.2 and A.3. The remainder of this section discusses how the forecast for the main river channel may be displayed and adjusted to blend with the observed data.

A.1.2 Output

The output from the forecasting model is controlled by Menu F2. This menu is displayed as soon as the forecast has been calculated:

```
            Menu F2 - Output

      [1 ]  Quit
      [2 ]  Parameter        [River flows        ]
      [3 ]  Accuracy         [0  ]
      [4 ]  Display all
      [5 ]  Plot all
      [6 ]  Write all
      [7 ]  Plot station
      [8 ]  Write station
      [9 ]  Adjust forecast
```

During periods of high flow, the following message may also appear if the flow at the uppermost station exceeds a pre-set limit defined in the setup file:

```
*** WARNING ***

Flows at uppermost station exceed
limit specified in setup file

Forecast may be inaccurate
```

The limits used are discussed in Section 2.1. For forecasts on the Jubba, the forecast should be carefully examined if this message appears, and compared with previous flood events on the river to see if it reasonable. For forecasts on the Shebelli, an additional option is provided to re-calculate the forecast using the routing model described in Section 2.2. In addition to the above message, the following prompt appears:

Use routing model (Y or N) >

If the answer given is N, then Menu F2 will be displayed as normal. If the answer is Y, there will be a pause whilst the forecast is re-calculated and then a plot of the forecast for Bulo Burti will appear. This compares the forecast obtained with the routing model with the forecast from the correlation model. Menu F2 can then be displayed by exiting from the plot and the associated Plot Menu. However, initially, many of the options in Menu F2 will be found to be unavailable; this is because at first the model only stores the results from the routing calculations temporarily in memory. This encourages the user to take a definite decision as to whether the results from the routing model are satisfactory. If they are not, the forecast should be aborted and re-started using only the correlation option. To accept the results of the routing calculations, the 'Reset flows' option in the Adjust Flows menu, Menu F3 (see below), should be selected. Once this option has been selected, all of the options in Menu F2 will become available as normal.

The options in Menu F2 are described below:

Option [2], 'Parameter', determines whether the forecast is to be presented in terms of levels or flows. This option acts as a'toggle' switch, and the required parameter can be selected simply by pressing the **[ENTER]** key twice.

Option [3], 'Accuracy', defines the number of decimal places to be shown in all tabulated output. For flows, the permitted values are 0 or 1 decimal places; for levels the permitted values are 1 or 2 decimal places. The default values are 0 and 1 respectively.

Option [4], 'Display all', allows the forecast for the entire river to be displayed on the screen. When Menu F2 first appears, the cursor is placed on this option. The display initially shows the forecast for the next 7 days. A typical display for the Shebelli is shown below:

Station	2/10	3/10	4/10	5/10	6/10	7/10	8/10	9/10
Beled Weyn	80	m	m	m	m	m	m	m
Bulo Burti	64	63	76	m	m	m	m	m
Mahaddey Weyn	87	81	76	73	82	m	m	m
Afgoi	60	64	64	57	54	50	50	m
Audegle	61	67	71	72	64	61	56	55.

(All flows in cumecs)

The m symbols signify that no forecast could be obtained for the day. For the current day alone, if an observed value is available for the station, the entry (for 2/10 in the above example) shows this value, rather than the forecast value. Also, if the forecast for a station has been adjusted (see below), the adjusted values are shown in the display rather than the unadjusted values.

The display can be cleared by pressing the [ENTER] key twice.

Option [5], 'Plot all', allows the forecast for each station to be plotted on the screen or on a HP7475A plotter. Figure 5(a) shows a typical example of the type of plot produced. When this option is selected, the following menu is displayed:

```
          Menu P1 - Plot all

[1 ]  Quit
[2 ]  Max Y            [500.0    ]
[3 ]  Min Y            [0.0      ]
[4 ]  Y intervals      [5  ]
[5 ]  No. days         [10 ]
[6 ]  Colour           [1  ]
[7 ]  Key position     [1  ]
[8 ]  Plot original    [1  ]
[9 ]  Plot Type
[10]  Paper plot
[11]  Screen plot
```

Options [2] to [7] control the appearance of the plot. Options [2] and [3] define the maximum and minimum values on the Y-axis. Suitable defaults are suggested according to the river and the parameter (flows or levels) being displayed. Option [4] controls the number of intervals on the Y-axis. Option [5] defines the number of days to be shown on the X-axis before and after the forecasting date. Values in the range 10 to 30 days may be entered; however, the number chosen should be a multiple of 5. Option [6] defines whether the plot is to appear in monochrome (0) or colour (1). Option [7] defines whether the key to the graph is to appear in the top left (0) or top right (1) of the plot.

Option [8] determines whether the plot is to show the forecast values alone (0) or whether precedence is to be given to any observed and estimated values read from the database (1). In the former case, only forecast values will be shown before the forecast date, even if observed values are available. In the latter case, any observed and estimated values are indicated by symbols, and the forecasts are drawn through these values. Normally, this option should be set to 1 since precedence should be given to observed data. Figure 5(a) shows an example of a plot produced with the 'Plot Original' value set to 1. Note that, for both types of plot, if the forecast has been adjusted (see below), the adjusted values are shown on the plot, rather than the original, unadjusted values.

Option [9] determines which forecasts are to appear on the plot. When this option is selected, a further menu is displayed, an example of which is shown below:

```
Menu P2 - Define curves

[1 ]  Quit
[2 ]  Beled Weyn      [1 ]
[3 ]  Bulo Burti      [1 ]
[4 ]  Mahaddey Weyn   [1 ]
[5 ]  Afgoi           [1 ]
[6 ]  Audegle         [1 ]
```

A value 1 signifies that the forecast for the station is to be plotted; a value 0 that it is to be omitted.

Options [10] and [11] initiate the plot. If a 'Paper plot' is selected, a message appears requesting that the plotter be checked; if all is ready, the **[ENTER]** key should be pressed to produce the plot. Alternatively, the F2 key can be pressed to abort the plot.

Option [6], 'Write all', produces a hard copy of the screen display produced by the 'Display all' option. When this option is selected, a further menu appears prompting for the name of the file to which the values are to be written:

```
Menu F4 - Write all

[1 ]  Quit
[2 ]  Filename      [                 ]
[3 ]  Continue
```

If the characters PRN are entered for the filename, the output is sent directly to the printer attached to the computer. The output is started on selecting Option [3], 'Continue'. Values are written for a period of about 10 days before and after the forecasting date. The output below shows an example of a forecast for the river Shebelli:

```
RIVER SHEBELLI

FORECASTING DATE  : 1989 Oct  2

Station      10 =  Beled Weyn
Station      11 =  Bulo Burti
Station      12 =  Mahaddey Weyn
Station      14 =  Afgoi
Station      15 =  Audegle

(All flows in cumecs)

Date                    10     11     12     14     15

1989 Sep 23             76     89    110     70     89
1989 Sep 24             74     78    104     72     89
```

1989 Sep 25	75	73	97	75	89
1989 Sep 26	77	71	89	74	88
1989 Sep 27	86	72	84	67	84
1989 Sep 28	74	74	83	64	78
1989 Sep 29	67	81	83	58	73
1989 Sep 30	65	71	85	56	69
1989 Oct 1	64	65	88	56	67

1989 Oct 2	80	64	86	60	67
1989 Oct 3	m	63	81	64	67
1989 Oct 4	m	76	76	64	71
1989 Oct 5	m	m	73	57	72
1989 Oct 6	m	m	82	54	64
1989 Oct 7	m	m	m	50	61
1989 Oct 8	m	m	m	50	56
1989 Oct 9	m	m	m	m	55
1989 Oct 10	m	m	m	m	m

Option [7], 'Plot station', allows the forecast for each station to be examined in detail on a screen or paper plot:

```
                 Menu P3 - Station Plot

         [1 ]  Quit
         [2 ]  HYDATA station  [15       ]
         [3 ]  Max Y           [500.0    ]
         [4 ]  Min Y           [0.0      ]
         [5 ]  Y intervals     [5  ]
         [6 ]  No. days        [10 ]
         [7 ]  Colour          [1  ]
         [8 ]  Key position    [1  ]
         [9 ]  Plot Type       [1  ]
         [10]  Paper plot
         [11]  Screen plot
```

Option [2] defines the number of the HYDATA station for which plots are to be produced. Options [3] to [8] define the appearance of the plot and have the same meanings as the corresponding options in Menu P1 (see above). Options [10] and [11] also operate in the same way as with Menu P1.

Option [9], 'Plot Type', defines which curves are to be plotted. Three types of plot are available:

```
1  The combined forecast together with any observed values
2  As 1, but with the adjusted forecast as well
3  The individual (unadjusted) forecasts from each of the
   stations upstream for which data were available
```

Figures 4(a) and 5(b) show examples of the output produced using Plot Types 2 and 3. As mentioned in Section 2.1, the 'combined' forecast is the initial best estimate of the flows and levels at a station, obtained by combining the individual forecasts from each upstream station so that precedence is always given to the nearest station from which a forecast is available. Thus, on the Jubba, a forecast for Mareere would use forecast values from Bardheere - where available - in preference to values from Lugh Ganana. When the forecast for a station is adjusted, the adjustments are made to the combined forecast, rather than the individual forecasts. Thus Plot Type 1 plots only the combined forecast whereas Plot Type 2 allows both the combined and adjusted forecasts to be compared. A typical use of Plot Type 2 is to examine whether the adjustments made to a forecast appear reasonable.

Plot Type 3 allows the separate forecasts from each of the upstream stations to be plotted. Note that it is always the unadjusted values which are shown, even if some adjustments have been made to the combined forecast for the station. One use for this type of plot is when the observed data for a station are suspect. For example, if the forecasts from two or more stations disagree with the forecast from the suspect station, this might suggest that the data for the station should be corrected or deleted from the database and the forecast then re-calculated. Another use is for examining the historical performance of the model. For real time use, it is unlikely that current data will ever be available for more than one or two stations. However, for forecasts in previous years, it is probable that data will have been obtained or estimated for all stations on the river up to the specified forecasting date. A plot produced using Plot Type 3 can therefore give an indication of the forecast which would have been obtained had some of the data been missing for the lower stations on the rivers.

Option [8], 'Write station', allows the forecasts for a given station to be written to file. The output includes the combined and adjusted forecasts, any observed values, and the individual forecasts from each of the upstream stations. When this option is selected, a further menu appears, requesting the number of the HYDATA station for which the output is required, and the file to which the output is to be written:

```
          Menu F5 - Write station

[1 ]  Quit
[2 ]  HYDATA Stn.  [15        ]
[3 ]  Filename     [                 ]
[4 ]  Continue
```

If the characters PRN are entered for the filename, the output is sent directly to the printer attached to the computer. The output is produced on selecting Option [4], 'Continue'. Values are written for the month prior to the forecasting date, and for about ten days after the forecasting date. The example below shows the first few lines of the output for a forecast for Audegle on the river Shebelli:

RIVER SHEBELLI

FORECAST FOR : Audegle

Forecasting date : 1989 Oct 2

Station 10 = Beled Weyn
Station 11 = Bulo Burti
Station 12 = Mahaddey Weyn
Station 14 = Afgoi

(All flows in cumecs)

DATE	Observed flow	Combined pred.	Adjusted pred.	Forecasts from individual stations 10	11	12	14
1989 Sep 2	42	30	30	m	m	m	30
1989 Sep 3	44	42	42	m	m	m	42
1989 Sep 4	44	45	45	m	m	47	45
1989 Sep 5	44	44	44	m	m	48	44
1989 Sep 6	44	44	44	m	m	46	44
1989 Sep 7	44	44	44	m	49	45	44
1989 Sep 8	45	44	44	m	48	46	44
1989 Sep 9	46	45	45	m	47	46	45
1989 Sep 10	49e	47	47	48	49	47	47
1989 Sep 11	55e	54	54	52	54	53	54
1989 Sep 12	59	62	62	60	62	59	62
1989 Sep 13	66	67	67	65	68	65	67

The flag 'e' indicates an estimated value, and can be either an estimated value read from the database, or a value which has been infilled by the model (see Section A.1.1). Some missing values, shown by the flag 'm', always occur at the start of the file, since the observed flows are all read from the same starting date, so that forecasts from distant stations do not become available until several days after this date.

Option [9], 'Adjust forecast', allows the forecasts calculated by the model to be adjusted to blend smoothly with the observed flows. The adjustments take place from the last date for which an observed value is available. If there are no observed values for the station, no adjustments are made. Note that the adjustments only affect the combined forecast for individual stations and the forecasts for stations further downstream are **not** re-calculated using the adjusted values.

When this option is selected, a further menu appears:

```
        Menu F3 - Adjust

[1 ]    Quit
[2 ]    HYDATA Station   [0        ]
[3 ]    Number of days   [3    ]
[4 ]    Shift
[5 ]    Join
[6 ]    Reset flows
```

Two types of adjustment are available - Shift and Join. The Shift option adds or subtracts an amount equal to the difference between the observed and forecast values on the last day for which an observed value was available. The Join option distributes the difference over the number of days specified in Option [3]. Figures 4(a) and 4(b) show examples of each type of adjustment. Note that Option [3] affects only the Join type of adjustment.

Experience gained with the model during 1989 and 1990 suggests that, for most (but not all) cases, a shift adjustment usually gives satisfactory results. It is therefore recommended that the shift option is selected before trying the join option. To facilitate the shift adjustments, a value 0 may be entered for Option [2], 'HYDATA Station'; the adjustments are then performed for all stations on the river (if possible). In addition, shift adjustments are made for any periods of missing data prior to the last observed value. Whilst this does not affect the forecast, it can considerably improve the appearance of plots of the forecast, since the forecast will blend smoothly with the observed values throughout the plot. Note that if 'shift' adjustments are made to individual stations, the adjustments are only made for values beyond the forecasting date.

The adjusted forecasts should always be plotted on the screen (using the 'Plot station' option, with Plot Type 2) before finally accepting the forecast. If the adjustments are not satisfactory, Option [6], 'Reset flows', can be used to reset the adjusted flows to their original values.

A.2 The lateral flow model

The lateral flow model allows any user defined inflow or outflow to be added to the flow in a reach. Some possible uses of the model are described in Section 2.1.3.

To use the model, the lateral flows must be specified as a continuous sequence of daily average values. Inflows should be given as positive values; outflows as negative values. All flows must be in cubic metres per second. The flows should be entered in an ASCII (i.e. normal text) data file with one value per line. The forecasting model will then read the contents of this file into memory and, when the forecast is calculated, the lateral flows will be added to the corresponding flows at the upper station in the specified reach. The flow at the lower station in the reach is then calculated by applying the correlation for the reach. Note that it is the responsibility of the user to check that the specified flows are reasonable; no checks are made in the program on their magnitude.

The file RFLATF.DAT is provided as an example of a lateral flow input file; these flows represent the weekly irrigation abstractions in the reach between Mahaddey Weyn and Afgoi on the Shebelli. If this file is used, the 'Start Date' (see below) should be timed to start 2-3 days before a day in the cycle when the abstraction was zero. This date must be within the previous three months.

The lateral flow model is invoked by selecting the 'Lateral flows' option from the control menu (Menu F1S or Menu F1J). This option can only be selected if a forecast has already been obtained with the Lateral Flow model **OFF**. This encourages the user to check that the lateral flows to be specified really might have occurred, and can justifiably be included in the forecast. Note that, for the Shebelli, it is permissible to select this option in conjunction the Jowhar reservoir model.

When the lateral flow option is selected, the screen clears and a menu is displayed showing each of the reaches on the river. For the Shebelli, using the default setup file RFSHEB.DAT, this menu appears as follows:

```
          Menu LF1 - Lateral flows

[1 ]  Quit
[2 ]  Beled Weyn - Bulo Burti
[3 ]  Bulo Burti - Mahaddey Weyn
[4 ]  Mahaddey Weyn - Afgoi
[5 ]  Afgoi - Audegle
```

The required reach, or reaches, should be selected in turn. Each time a reach is chosen, a second menu will be displayed:

```
          Menu LF2 - Input

[1 ]  Quit
[2 ]  Filename     [                  ]
[3 ]  Start Date   [1990 Oct  2]
[4 ]  Read flows
```

Option [2] in this menu defines the name of the ASCII datafile which contains the daily values of lateral flow for the reach. Option [3] defines the date of the first value in the file. Any date can be specified, provided that there are sufficient values in the datafile to extend to within a few days of the forecasting date. By default, the Start Date is set to the current forecasting date. Dates after the forecasting date are also permitted.

The lateral flow file is read on selecting Option [4]. If this is the first time this option has been selected, the screen display will indicate that the lateral flow model is now **ON**. This means that the lateral flows are stored in memory, and will be included in the forecast when it is re-calculated. An error message will appear if the specified file cannot be found or does not contain enough values to extend to the forecasting date.

Once all of the required flows have been entered, Option [1], 'Quit', should be selected from Menu LF1, and the 'Continue' option again selected from the main control menu. The revised forecast will then include the lateral flows. Also, the 'Display all', and 'Write all' options in Menu F2 will now include a listing of the flows which have been entered. These flows will be listed under the headings 'Lateral flow 1', 'Lateral flow 2', 'Lateral flow 3', and so on, where the number identifies the reach. Reach 1 is the reach between the first and second stations on the river (e.g. Beled Weyn-Bulo Burti), Reach 2 is the reach between the second and third stations, and so on. Note that these listings show the lateral flows as specified; these will generally be slightly different from the inflow or outflow to the reach that the model calculates. This is because the specified flows are added to the flow at the upper station **before** applying the correlations.

A.3 The Jowhar Offstream Storage reservoir model

The background to the reservoir model is given in Sections 2.2 and 3.2. As discussed, the model has two modes of operation and, in both cases, the simulations are started from the first day of the year under study. In the forecasting mode, precedence is given to measured values of volume and flow so, if these are available, the simulation is re-started from the last day for which measured values are available. Obviously, all such values should be entered on the HYDATA database before using the model. In the historic mode, it is important to note that the model can only operate if the database has a reasonably complete flow record for Mahaddey Weyn for the year being simulated. This is because, in the Type 2 simulations, the opening and closing of canals is controlled solely by the flow at Mahaddey Weyn. Since the simulations start from the first day of the year, the reservoir volume, which is a cumulative parameter, cannot be estimated if there are any missing values. Although some limited infilling is done automatically by the model (using the same infilling procedure described in Section A.1.1), the model will not operate if periods of more than 3 days are missing. This restriction is relaxed in the forecasting mode and values are only required from the last day for which the reservoir level is entered on the HYDATA database. Also, forecasts of the flows at Mahaddey Weyn are available in the month up to the forecasting date should there be no observed values.

In cases where there are insufficient flow values available for Mahaddey Weyn, it is recommended that the missing values are infilled using the infilling model **RIVERI**. This program was also developed during the Somalia Hydrometry Project and is described in ref. 2.

A.3.1 Data input

The reservoir model is accessed by selecting Option [6], 'Jowhar OSR', from Menu F1S. When this option is selected, the screen will clear and the following menu will be displayed:

```
            Menu JR1 - Jowhar

      [1 ]  Quit
      [2 ]  Forecast type    [0  ]
      [3 ]  Start volume     [195.1      ]
      [4 ]  Season           [1  ]
      [5 ]  Define losses
      [6 ]  Define system
      [7 ]  Define rules
      [8 ]  Define seasons
      [9 ]  Continue
```

This menu defines the initial state of the reservoir, the parameters defining the reservoir system, the losses from the reservoir, and the model of the current operating rules. Note that the default values in this menu, and all others for the reservoir model, are read from the file RFJOSR.DAT. The layout of this file is described in Section A.5.

Option [2], 'Forecast type', defines whether the forecasting (0) or historic mode (1) of operation is to be used. In the forecasting mode, the forecast date is assumed to be the same as specified in the main control menu, Menu F1S. In the historic mode, the simulation will be made for the year in which this date occurs and the month and day entries will be ignored. For example, if the date 1983 Jul 2 was entered in the control menu, in mode 0 a forecast would be made for this date, and in mode 1 a simulation would be performed for the whole of 1983. It is suggested that the date Jan 1 is entered when using the historic mode.

The forecasting mode can only be selected if a forecast has previously been obtained in the current session for the main channel of the Shebelli. This encourages the user to first compare the flow forecasts and observed data for Afgoi and stations further downstream, and so to determine whether the supply and outlet canals are likely to be operated in the period covered by the forecast. For example, if the forecast for Afgoi is very close to the most recent observed values, it is unlikely that either of the canals is currently open, and it should be carefully considered whether the canals are likely to be opened in the next few days. If they are not likely to be opened, the reservoir model should not be used. Note that, if a forecast has already been obtained for the main channel, the mode is by default set to 0 and the cursor is positioned in the entry for Option [4], 'Season' (see below).

Option [3], 'Start volume', defines the volume of the reservoir at the start of the simulation. By default, this is set to the volume of the reservoir on the last day of the previous year. This default value can be changed if required. If no value is available, the start volume is set to zero.

Option [4], 'Season', applies only to the forecasting mode of operation and, in the historic mode, can be set to zero. In the forecasting mode, this parameter should be set to a value in the range 1 to 7. The appropriate value can be determined by reference to Figure 13 and the discussion in Section 2.2. If the forecasting model is used regularly, it should be a simple matter to decide on the appropriate period. Note that, in the event that the bank full level is not reached during the Gu season, value 3 should not be used; similarly, value 6 should not be used if the bank full level is not reached during the Der season.

Option [5], 'Define losses', allows the losses from the reservoir to be defined, and the minor gains from rainfall. When this option is selected, the following menu is displayed:

```
            Menu JP1 - Define losses

    [1 ]    Quit
    [2 ]    Infiltration   [5.0       ]
    [3 ]    Evaporation
    [4 ]    Rainfall
```

The default values for each parameter are obtained from the file RFJOSR.DAT.

Option [2] defines the infiltration in mm/day, Option [3] allows the mean daily evaporation in each month (mm/day) to be defined and Option [4] allows the mean total rainfall in each month (mm/month) to be defined. When Options [3] or [4] are selected, a further menu is displayed requesting the monthly mean values. For example, for the evaporation data, this menu appears as follows:

```
            Menu JP2 - Monthly values

    [1 ]    January     [5.0     ]
    [2 ]    February    [5.8     ]
    [3 ]    March       [5.8     ]
    [4 ]    April       [4.9     ]
    [5 ]    May         [4.3     ]
    [6 ]    June        [3.8     ]
    [7 ]    July        [3.7     ]
    [8 ]    August      [4.1     ]
    [9 ]    September   [4.6     ]
    [10]    October     [4.6     ]
    [11]    November    [4.5     ]
    [12]    December    [4.7     ]
```

The default values can be changed as required.

Option [6], 'Define system', allows the system capacities and flow requirements to be defined. When this option is selected, the following menu appears:

```
          Menu JP3 - Define system

[1 ]  Quit
[2 ]  Max. supply flow   [25.0    ]
[3 ]  Max. outlet flow   [15.0    ]
[4 ]  Max. volume        [205.0   ]
[5 ]  Refill lag         [10      ]
[6 ]  Flows Jowhar reach
[7 ]  Flows d.s. outlet
[8 ]  Flows from SNAI
```

The menu entries show the default values read from file RFJOSR.DAT. Option [2] defines the maximum permitted flow in the supply canal (in cumecs), Option [3] defines the maximum permitted flow in the outlet canal (in cumecs) and Option [4] defines the maximum volume of the reservoir (in million cubic metres). Option [5] defines the time delay which is applied by the model when the reservoir starts to re-fill from empty during the simulation.

Options [6], [7] and [8] define the monthly average flows at three key locations in the system. Section 2.1 describes how these parameters are used in the simulations. Option [6] defines the estimated irrigation abstractions in the reach between the Sabuun barrage and the outlet canal, Option [7] defines the minimum flow requirements for the Shebelli downstream of the outlet canal and Option [8] defines the drainage flows into the reservoir from the SNAI sugar estate (currently always zero). Whenever one of these options is selected, a monthly data input menu appears, identical to Menu JP2 which was described above. The entries in this menu can be changed as required.

Option [7], 'Define rules', defines the estimated operating rules which the forecasting model uses when no measured data are available for the reservoir canals. When this option is selected, the following menu appears:

```
          Menu JP4 - Estimated rules

[1 ]  Quit
[2 ]  Supply threshold  [25.0    ]
[3 ]  Outlet threshold  [45.0    ]
[4 ]  Trickle flow      [10.0    ]
[5 ]  Trckle time       [7       ]
[6 ]  Start Gu lag      [15      ]
[7 ]  Start Der lag     [25      ]
```

The menu entries show the default values read from file RFJOSR.DAT. Option [2] defines the flow at Mahaddey Weyn (in cumecs) above which the supply canal may be opened (Q_2), Option [3] defines the flow at Mahaddey Weyn (in cumecs) below which the outlet canal may be opened (Q_3), Option [4] defines the trickle flow to be used (in cumecs) when the supply canal is first opened (Q_1) and Option [5] defines the number of days for which this flow is to last before the canal is fully opened (T_2). Option [6] defines the time delay to be applied between the start of the Gu flood and the first opening of the supply canal (T_1) and Option [7] defines the corresponding delay at the start of the Der flood (T_3).

Option [8], 'Define seasons', allows the dates indicated in Figure 13 to be defined by the user. When this option is selected, the following menu is displayed:

```
            Menu JP5 - Seasons

      [1 ]  Quit
      [2 ]  Mode              [0   ]
      [3 ]  Start Gu          [1983 Jan 1]
      [4 ]  Start main Gu     [1983 Jan 1]
      [5 ]  End main Gu       [1983 Jan 1]
      [6 ]  Start Der         [1983 Jan 1]
      [7 ]  Start main Der    [1983 Jan 1]
      [8 ]  End main Der      [1983 Jan 1]
```

By default, the dates are initially set to the first day of the year for which the simulation is being performed.

Option [2], 'Mode', determines whether these dates are to be estimated by the program (0) or entered explicitly by the user (1). By default, the mode is set to 0. In most instances, the program will make sensible estimates of the dates of the seasons, so mode 0 should be used. However, the program does assume that the annual hydrograph at Mahaddey Weyn is roughly of the form shown in Figure 13. In years when this hydrograph departs drastically from this shape, it may be necessary to define the dates manually, in which case mode 1 should be used. Obviously, if the dates are defined manually, they should all apply to the forecasting year, and should be in increasing chronological order. Note that, in the forecasting mode of operation, dates need only be entered up until the start of the current season (as defined in Option [4] of Menu JR1). The program then automatically sets the date of the end of this season to 10 days after the forecasting date, and the remaining dates are set to Dec 31 of the forecasting year.

Option [9], 'Continue', initiates the calculations for the reservoir. Initially, a message appears indicating that data are being read from the database, and then a counter appears indicating the percentage of the calculations which has been completed.

Once the calculations have finished, the main output menu is displayed. The entries in this menu are described in the following section:

A3.2 Output of results

Menu JR3, 'Output', is displayed on completion of the simulations:

```
        Menu JR3 - Output

[1 ]    Quit
[2 ]    Plot results
[3 ]    Write summary
[4 ]    Write results
[5 ]    Write forecast
[6 ]    Save forecast
```

This menu allows the results of the simulation to be plotted or written to file, or saved in memory.

Option [2], 'Plot', allows the forecast for each station to be plotted on the screen or on a HP7475A plotter. Figure 14 shows some typical examples of the type of plot produced. When this option is selected, the following menu is displayed:

```
        Menu PL1 - Plot

[1 ]    Quit
[2 ]    Max Y             [300.0    ]
[3 ]    Min Y             [0.0      ]
[4 ]    Start Date        [1983 Jan  1]
[5 ]    End Date          [1983 Dec 31]
[6 ]    Y intervals       [5  ]
[7 ]    Colour            [1  ]
[8 ]    Key position      [1  ]
[9 ]    Define type
[10]    Define curves
[11]    Paper plot
[12]    Screen plot
```

Options [2] to [8] control the appearance of the plot. Options [2] and [3] define the maximum and minimum values on the Y-axis. Options [4] and [5] control the start and end dates to appear on the X axis. Option [6] controls the number of intervals on the Y-axis and Option [7] defines whether the plot is to appear in monochrome (0) or colour (1). Option [8] defines whether the key to the graph is to appear in the top left (0) or top right (1) of the plot. Note that the start and end dates specified must be at least one month apart.

Options [11] and [12] initiate the plot. If a 'Paper plot' is selected, a message appears requesting that the plotter be checked; if all is ready, the [ENTER] key should be pressed to produce the plot. Alternatively, the F2 key can be pressed to abort the plot.

The curves which appear on the plot are selected using Options [9] and [10] together. A maximum of 6 curves can be displayed on any one plot. When Option [9] is selected, the following menu is displayed:

```
            Menu PL2 - Define data type

      [1 ]  Quit
      [2 ]  Estimated (Type 1)  [1 ]
      [3 ]  Estimated (Type 2)  [1 ]
      [4 ]  Measured            [1 ]
```

This menu defines which types of estimate are to be plotted. A value 1 signifies that the results are to be plotted; a value 0 that the results are to be omitted. Option [2] selects the Type 1 estimates, Option [3] selects the Type 2 estimates, and Option [4] selects any measured data.

To select the parameters to be plotted, Option [10], 'Define curves', should be selected from Menu PL1. The following menu is then displayed:

```
            Menu PL3 - Define curves

      [1 ]  Quit
      [2 ]  Reservoir volume           [1  ]
      [3 ]  Mahaddey Weyn              [0  ]
      [4 ]  Supply canal               [0  ]
      [5 ]  Outlet canal               [0  ]
      [6 ]  Shebelli ds Sabuun         [0  ]
      [7 ]  Shebelli ds Sabuun (req)   [0  ]
      [8 ]  Shebelli ds outlet         [0  ]
      [9 ]  Shebelli ds outlet (req)   [0  ]
      [10]  Jowhar reach               [0  ]
      [11]  Jowhar reach (req)         [0  ]
```

A value 1 signifies that the curve is to be plotted; a value 0 that it is to be omitted. The parameters appearing in the menu have the following meanings:

```
Reservoir volume - the reservoir volume (in million cubic metres)
Mahaddey Weyn    - the measured or forecast flow at Mahaddey Weyn
Supply canal     - the estimated or measured flow in the supply canal
Outlet canal     - the estimated or measured flow in the outlet canal
Shebelli ds Sabuun - the estimated or measured flow passing Sabuun
                     barrage (i.e. HYDATA Station 102). The 'req' flow
                     is the required flow calculated as the sum of the Jowhar
                     reach and Shebelli ds outlet 'req' flows as specified in
                     the setup file RFJOSR.DAT (and possibly modified from
                     Menu JP3)
```

```
Shebelli ds outlet - the estimated or measured flow passing the
                     junction of the outlet canal with the Shebelli
                     (i.e. HYDATA Station 105).  The 'req' flow
                     is the required flow as specified in the setup file
                     RFJOSR.DAT (and possibly modified from Menu JP3)
Jowhar reach - the estimated flow in the reach between Sabuun and the
               junction of the outlet canal with the Shebelli.  The 'req'
               flow is the required flow as specified in the setup file
               RFJOSR.DAT (and possibly modified from Menu JP3)
```

All flows are plotted in units of cumecs. Note that Options [6] and [7], [8] and [9], and [10] and [11], when used in pairs, allow the estimated or measured flows to be compared with the minimum flow requirements for the reach.

Option [3], 'Write Summary', allows a statistical summary to be written to file for an entire year of reservoir operations. This option can only be selected in the historical mode of operation. When this option is selected, the following menu is displayed:

```
        Menu JR4 - Write file

[1 ]    Quit
[2 ]    Filename  [              ]
[3 ]    Continue
```

If the characters PRN are entered for the filename, the output is sent directly to the printer attached to the computer. The output is started on selecting Option [3], 'Continue'.

Tables B.1 to B.9 show some examples of the output produced using this option. The output gives some simple statistics for each of the types of simulation (Types 1 and 2) and for the measured data (if available). Values are only shown if the parameter was available or computed for the entire year, otherwise a missing symbol (m) is shown. The entries for the 'Jowhar reach irrigation requirements' and 'Shebelli downstream of outlet canal' relate to the minimum flow requirements specified in the setup file RFJOSR.DAT (and possibly modified from Menu JP3). The station numbers refer to the HYDATA station numbers defined on the HYDATA database. The estimated Gu/Der seasons give the six key dates as defined in Figure 13. By default, these dates are estimated by the program but can be entered manually using Menu JP5.

Option [4], 'Write results', allows the computed daily flows and volumes to be written to file for inspection or further analysis. A complete listing appears for each of the two types of estimate, and for the measured data. When this option is selected, the following menu is displayed:

```
            Menu JR4 - Write file

      [1 ]  Quit
      [2 ]  Filename  [                ]
      [3 ]  Continue
```

If the characters PRN are entered for the filename, the output is sent directly to the printer attached to the computer. The output is started on selecting Option [3], 'Continue'.

The following example shows the first few lines of a file produced using this option:

JOWHAR OFF STREAM RESERVOIR - ESTIMATED FLOWS AND VOLUMES

Start Date : 1988 Jan 1
End Date : 1988 Dec 31

Type 1; Results based on measured flows at MW and in canals

DATE	V101m	V101e	Q12m	Q102m	Q102e	Q105m	Q105e	QSNAI	Q103m	Q103e	Q104m
1988 Jan 1	134.1	132.4	8.7		8.1		21.3		0.6		23.4
1988 Jan 2	132.2	129.5	8.7		8.1		21.3		0.6		23.4
1988 Jan 3	130.8	126.6	8.7		8.1		21.2		0.6		23.4
1988 Jan 4	129.4	123.7	8.6		8.0		21.2		0.6		23.4
1988 Jan 5	128.4	120.8	8.5		7.9		21.0		0.6		23.4

The column headings have the following meanings:

V101m - the measured reservoir volume
V101e - the estimated reservoir volume
Q12m - the measured flow at Mahaddey Weyn
Q102m - the measured flow passing Sabuun barrage
Q102e - the estimated flow passing Sabuun barrage
Q105m - the measured flow passing the junction of the outlet canal and the Shebelli
Q105e - the estimated flow passing the junction of the outlet canal and the Shebelli
QSNAI - the estimated inflow from the SNAI sugar estate
Q103m - the measured flow in the supply canal
Q103e - the estimated flow in the supply canal

Q104m - the measured flow in the outlet canal
Q104e - the estimated flow in the outlet canal

The numbers in the titles refer to the HYDATA station numbers on the HYDATA database. In the listings, all volumes are in million cubic metres and all flows are in cumecs. A blank appears where a parameter value is either missing or not applicable.

Option [5], 'Write results', allows the Type 2 estimates of the reservoir volume, and of the flows in the supply and outlet canals, to be written to file. The files are written in ASCII text format and are suitable for input directly into HYDATA using HYDATA's 'Read file' (F4 key) facility. All values are flagged as estimated. The intended use of this option is to allow estimates of the reservoir flows and volumes to be entered onto HYDATA for years when no measured data are available.

When this option is selected, three files are written into the current directory:

J101.DAT The daily values of volume (in million cubic metres)
J103.DAT The daily flows in the supply canal (in cumecs)
J104.DAT The daily flows in the outlet canal (in cumecs)

There will be a short pause whilst the files are being created. To read the files into HYDATA, the appropriate editor should be entered, the F4 key pressed and the filename entered. The contents of the file will then be read into memory and can be plotted, edited and saved to disc in the usual way. Note that the first value in each file is for January 1st of the forecasting year.

Option [6], 'Save forecast', allows the Type 2 forecasts of the canal flows to be saved in memory. These flows will then be available for inclusion in any further forecasts for the main channel of the Shebelli made within the current session. Note that this option can only be selected when the reservoir model is being used in the forecasting mode of operation. It is permissible to select this option in conjunction the lateral flow option.

When Option [6] is selected, there will be a short pause whilst the flows are saved in memory. A message will appear when the operation is completed. Also, the indicator for the Jowhar reservoir model will be set to ON. The forecast for the main channel should then be repeated by returning to the main control menu for the Shebelli, Menu F1S, and selecting the 'Continue' option. The forecast flows for Afgoi and Audegle will then be modified according to the flows in the canals. Also, the 'Display all', and 'Write all' options in Menu F2 will now include a listing of the estimated canal flows. Note that the apparent inflow or outflow due to the canals will appear slightly different to that specified. This is because the specified flows are added to the flow at the Mahaddey Weyn **before** applying the correlations. Note also that it is assumed that the lag between Mahaddey Weyn and the junction with the outlet canal is small compared with the lag between Mahaddey Weyn and Afgoi, so the outlet canal flows are added directly to the Mahaddey Weyn flows for the same day.

An important point to note is that if the flows for Mahaddey Weyn were adjusted before running the reservoir model, the adjusted flows will have been used in the reservoir simulations. However, on recalculating the forecast, the adjusted flows for all stations will be reset to their original values. The adjusted values can be recovered by repeating the original adjustments for each station.

A.4 Guidelines on use

This section gives some recommendations on how the forecasting model should be used operationally. Table A.1 lists the options which should be selected for the most usual types of forecast. The first point to note is that the model has been designed so that a preliminary forecast can be obtained with very little effort. Normally, the user can accept all the default values provided by the model, and only a few key strokes are required before a forecast is obtained. Forecasts are calculated for every station on the river in a single operation. The forecasts - in terms of levels or flows - can then be tabulated or plotted on the screen, or written to a file or a printer.

To improve the accuracy of the forecasts, it is recommended that the forecast for each station is adjusted to blend with any observed data. An option is provided in Menu F3 to globally 'shift' the forecasts for all stations in a single operation. However, if time permits, it is preferable to first plot the observed and forecast values for each station in order to determine the appropriate type of adjustment for each station. Also, comparisons of this type may reveal errors in the observed data, which should ideally be corrected before continuing with the forecasting analysis.

In some cases, a comparison of the observed and forecast values may indicate that significant inflows or outflows are entering a reach. In this case, consideration should be given to specifying these flows (if known) using the lateral flow option. For example, this option might be used during the dry season to model the weekly abstractions upstream of Afgoi, or to include estimates of local runoff obtained from observations during a field trip. For the lower Shebelli, discrepancies between the forecast and observations are most likely to be caused by operation of the supply and outlet canals at Jowhar Offstream Storage reservoir. In this case, an estimate of these flows can be obtained by running the reservoir model in forecasting mode. The forecast can then be repeated so that these flows are included in the calculations.

It should be noted that the model has mainly been calibrated using data from 1988 and 1989. In future years, it may prove necessary to modify some of the default values provided by the model. For the main channel model, the correlations may change in time due to changes in the bed profile, and hence the ratings, at individual stations. The correlations should therefore be re-evaluated at regular intervals (say annually) using the infilling model provided (ref. 2). For the reservoir model, the parameters most likely to need changing are the maximum permitted flows in the supply and outlet canals. The values supplied were estimated from the data for 1987 to 1989. In future years, these maxima may change due either to sedimentation, or due to the canals being dredged. An estimate of the maxima could be obtained either by

1. **Forecast for the main river channel**

   - Load all available levels onto HYDATA database and convert to flows
   - Exit from HYDATA
   - Type **RF**
   - Enter password
   - Select river
   - Check date is correct and alter if not
   - Select 'Continue' option from Control Menu
   - Choose display type (flows or levels) and accuracy (optional)
   - Select 'Display All' to examine forecast
   - Use 'Plot All' and 'Plot Station' options to examine any adjustments needed to individual forecasts. Make the required adjustments
   - Print or plot the final forecast

2. **Forecast incorporating canal flows for Jowhar Offstream Storage reservoir**

   - Load all available reservoir data onto HYDATA
   - Perform the operations in (1) above until a satisfactory forecast is obtained
   - Select 'Quit' option from Menu F2
   - Select 'Jowhar OSR' option
   - Enter the current 'Season' after referring to Figure 13
   - Select the 'Continue' option
   - Plot the Type 2 forecasts for the volume and the canal flows
   - If satisfactory, select 'Save forecast' option and then press F2 key repeatedly to return to the Control Menu, Menu F1S
   - Select the 'Continue' option to repeat the forecast incorporating the canal flows. Display and plot the forecasts as before

3. **Forecast incorporating lateral flows**

   - Create a datafile containing the lateral flow estimates
   - Perform the operations in (1) above until a satisfactory forecast is obtained
   - Select 'Quit' option from Menu F2
   - Select 'Lateral flows' option
   - Select the required reach from Menu LF1
   - Enter the name of the file containing the lateral flows and the date of the first value in the file. Select the 'Read flows' option
   - Press the F2 key repeatedly to return to the Control Menu
   - Select the 'Continue' option to repeat the forecast incorporating the lateral flows. Display and plot the forecasts as before

4. **Historic simulations for Jowhar Offstream Storage reservoir**

   - Type **RF**
   - Enter password
   - Select river Shebelli
   - Enter required year for simulation; month and day are not important
   - Select 'Jowhar OSR' option from Control Menu
   - Select 'Continue' option from Menu JR1
   - Plot and display the results as required

TABLE A.1 Summary of procedures for operating the forecasting model assuming default settings are used throughout

comparing the flows at Mahaddey Weyn and Afgoi for recent months, or by recalibrating the reservoir model using the methods outlined in Section 3.2. Other parameters which might need modifying are those controlling the estimated (Type 2) operating rules. The reservoir forecasting model can be run as many times as necessary to obtain a good match between the estimated volume and any available observations of the actual volume. If required, the new parameter values can be entered into the file RFJOSR.DAT so that they appear as default values in any future analyses.

To evaluate the performance of the forecasting model, it may be desirable to run it for dates before the current day. It should be noted that, for the main channel, the 'combined' forecasts will generally be slightly better than they would have been if the model had been run in real time. This is because, for previous years (particularly pre 1990) there will be few, if any missing data values on the database, and all periods of doubtful data will have been corrected. Consequently, the model will make full use of the data from neighbouring stations, rather than relying on intermittent data from only one or two stations, as it does in real time. To obtain a truer idea of the accuracy of the forecasts, it is recommended that the forecasts from individual stations are examined, rather than the 'combined' forecast.

A.5 Layout of the setup files

Files for the main river channel

The setup files define the names and numbers of the HYDATA stations on the river, the order of the stations (starting from the uppermost), and the correlations between the stations. The files should be in ASCII text format and are best created using a word processor in unformatted mode. Four prepared files are provided with the forecasting model:

RFSHEB.DAT *Default setup file for the river Shebelli*
RFJUBB.DAT *Default setup file for the river Jubba*
RFSHEB1.DAT *Setup file for the river Shebelli, containing correlations based on data for the period 1963 to 1989 inclusive*
RFJUBB1.DAT *Setup file for the river Jubba, containing correlations based on data for the period 1963 to 1989 inclusive*

The files should only need to be modified if the correlations are revised, or if it is required to add new stations into the forecast.

The general layout of the setup files should be exactly as shown below.

```
River name                                                   (A80)
Comment line                                                 (A80)
Number of stations on river, start year, end year            (3I5)
First HYDATA station, station name                       (I6,A14)
Second HYDATA station, station name                      (I6,A14)
......and so on for remaining stations
```

```
Comment line                                              (A80)
Number of correlations                                     (I5)
Uppermost stn. no., Lowermost stn. no., No. segments      (3I5)
Lag time, unallocated, max. flow, unallocated          (4F10.3)
Max. flow 1, intercept, slope, unallocated             (4F10.3)
Max. flow 2 ..... and so on for all segments           (4F10.3)
<
```

Here, underlined boldface type (e.g. A80) shows the FORTRAN format specifier for each line; these specifiers define the spacing and types of variables required. Further information on FORTRAN format statements can be found in any introductory textbook on the FORTRAN programming language.

The start year and end year listed in the file define the range of years which the model will accept as input. The years specified must be in the range 1963 to 1992 inclusive. Up to 6 HYDATA station names and numbers can be specified on either river. HYDATA stations must be listed in the same order as they occur on the river, starting from the upstream end. In each of the entries for the correlations, the first line lists the numbers of the HYDATA stations to which the correlation equation applies, and the number of parts (segments) to the correlation. The second lists the lag time between the stations and the maximum flow allowed at the lowermost station. The unallocated numbers are for use in future versions of the model and can be entered as 0.0 here (Note, however, that, in the Shebelli default file RFSHEB.DAT, these entries are used by the routing model and MUST NOT be changed by the user). The remaining lines list the equation for each segment (i.e. slope and intercept) and the range of flows (at the uppermost station) over which it is valid. Each correlation can have up to three segments. The Max. flow here defines the upper limit of the segment.

The < symbol indicates that the file must be terminated with an end of file character (CTRL-Z or ASCII character 26 decimal). Most word processors will insert this character automatically. The comment lines can contain any text specified by the user provided that it does not exceed 80 characters (including spaces).

The following example shows the default setup file RFJUBB.DAT for use on the river Jubba. Four stations are defined (HYDATA Stations 1, 2, 5 and 3), and the range of valid years is 1988 to 1992 inclusive.

```
RIVER JUBBA
File for forecasting 1988-1992
    4 1963 1992
1      Lugh Ganana
2      Bardheere
5      Mareere
3      Jamamme
a) CORRELATIONS - Downstream on upstream
3
2    1    1
2.30      0.0       9999.0    0.0
1000.0    7.935     1.118     0.0
```

```
5       2       1
4.10        0.0         590.0       0.0
1000.0      -8.102      0.925       0.0
3       5       1
1.00        0.0         480.0       0.0
9999.0      1.651       1.001       0.0
```

Taking just one regression as an example, the lag between stations 1 and 2 is defined to be 2.3 days, and the regression equation is:

Bardheere flow = 1.118 Lugh Ganana flow + 7.935

where the flows are in cumecs. In this example, if the flow at Lugh Ganana exceeds 1000 cumecs, a warning message appears (as described in Section A.1.1).

Files for Jowhar reservoir model

The setup file for the Jowhar reservoir model must have the name RFJOSR.DAT. This file contains the default values which appear in the data input menus for the model. The current defaults were obtained from a study of the reservoir data for the period 1987 to 1989. Any or all of these values can be changed if required.

The layout of the file is shown below. The comment lines must be included but the text for the comments can be changed if required. The comments must not exceed 80 characters in length:

```
Default data values for use by Jowhar Offstream Storage reservoir model
Mean daily infiltration (mm/day)
5.0
Average daily evaporation Jan-Dec (mm/day)
5.0 5.8 5.8 4.9 4.3 3.8 3.7 4.1 4.6 4.6 4.5 4.7
Average total monthly rainfall Jan-Dec (mm/month)
4.8 1.2 21.3 94.0 88.2 25.4 25.8 15.7 10.9 105.9 75.9 21.4
Mean irrigation requirements in Jowhar reach Jan-Dec (cumecs)
10.2 9.4 10.2 6.7 6.7 8.1 7.5 8.4 10.0 6.9 7.8 9.4
Mean irrigation requirements d.s. of outlet canal Jan-Dec (cumecs)
11.7 7.8 7.8 5.3 14.5 24.3 22.7 8.0 12.4 25.6 30.0 24.7
Mean inflow from SNAI sugar estate Jan-Dec (cumecs)
0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
Entries for Menu JP3 - Max. flows (cumecs) Max vol (MCM) Refill lag (days)
25.0 10.0 205.0 10
Entries for Menu JP4 - Flows (cumecs), Lags (days)
25.0 45.0 10.0 7 15 25
<
```

Each line of data can be entered in free format (i.e. any number of decimal places); the only restriction is that the correct number of values must appear, and each value must be separated by a blank space. As with the main setup files, the < symbol indicates that the file must be terminated with an end of file character (CTRL-Z or ASCII character 26 decimal). Most word processors will insert this character automatically.

A.6 Installation

The forecasting model is currently loaded on the IBM PS2 Series 50 computer in the Department of Irrigation and Land Use (Ministry of Agriculture, Mogadishu). To use the model, the following programs and datafiles are required:

RIVERF.EXE	*The main forecasting program*
RFSHEB.DAT	*Setup file for the river Shebelli*
RFJUBB.DAT	*Setup file for the river Jubba*
RFJOSR.DAT	*Definition datafile for Jowhar Offstream Storage reservoir*
RF.BAT	*Batch file to run the forecasting program*

These files must be loaded in the same directory as the HYDATA database (currently this is directory \HYDATA) and the model must be operated from this directory.

The model uses a similar menuing system to the HYDATA program and users of HYDATA should have little difficulty in operating the menus. As with HYDATA, menu entries can be selected either by entering the number of the required option, or by using the arrow keys to highlight the required option, and then pressing the **[ENTER]** key. As with HYDATA, the program is password protected; the passwords used are those defined in the HYDATA installation file.

Hard copy output can be obtained of all plots and listings produced by the model. Currently, the model is only configured to produce A4 plots on the HP7475A plotter used by the Department of Irrigation and Land Use.

WARNING

RIVERF uses the same system for screen graphics and printer control as Versions 3.00 and 3.01 of HYDATA, and should operate correctly provided that the installation instructions for HYDATA have been followed correctly. However, problems be encountered if later versions of HYDATA are installed, or additional software is installed using large amounts of resident memory.

APPENDIX B - Statistical summaries (JOSR 1981 - 1989)

This Appendix presents statistical summaries for each year of operations at Jowhar Offstream Storage reservoir between 1981 and 1989. The summaries were obtained by running the reservoir model in historical mode, using the default settings shown in Section A.5 for file RFJOSR.DAT.

JOWHAR OFFSTREAM STORAGE RESERVOIR - FLOW AND VOLUME STATISTICS

Start Date : 1981 Jan 1
End Date : 1981 Dec 31

		DATA TYPE		
		Type 1	Type 2	Measured
No. days in calculations		365	365	365
VOLUMES				
Average volume	(MCM)	93.2	89.1	78.3
Reservoir empty	(% of time)	0.0	0.0	0.0
Reservoir full	(% of time)	0.0	0.0	0.0
> 75 % full	(% of time)	17.5	20.0	5.8
> 50 % full	(% of time)	64.1	55.9	41.9
> 25 % full	(% of time)	68.5	64.4	69.3
FLOWS				
Total passing Mahaddey Weyn	(MCM)	2560.3	2560.3	2560.3
passing Sabuun barrage	(MCM)	2203.4	2211.5	2241.4
through supply canal	(MCM)	356.9	348.9	356.9
through outlet canal	(MCM)	38.1	33.7	38.1
downstream of outlet canal	(MCM)	2037.9	2041.5	m
Supply canal flowing	(No. of days)	145	190	145
Outlet canal flowing	(No. of days)	45	39	45
LOSSES/MINOR INFLOWS				
Infiltration losses	(MCM)	121.6	116.2	114.0
Evaporation losses	(MCM)	104.9	100.4	98.7
Rainfall	(MCM)	39.1	36.3	37.5
Drainage from SNAI sugar estate	(MCM)	0.0	0.0	0.0
Total net losses	(MCM)	187.3	180.4	175.2
JOWHAR REACH IRRIGATION REQUIREMENTS				
Flow > 100 % requirements	(% of time)	78.4	78.4	m
> 75 % requirements	(% of time)	78.4	78.4	m
> 50 % requirements	(% of time)	78.4	78.4	m
> 25 % requirements	(% of time)	80.5	80.5	m
Required volume	(MCM)	266.1	266.1	266.1
Volume delivered	(MCM)	203.6	203.6	m
SHEBELLI DOWNSTREAM OF OUTLET CANAL				
Flow > 100 % requirements	(% of time)	67.4	62.2	m
> 75 % requirements	(% of time)	76.4	74.0	m
> 50 % requirements	(% of time)	78.4	78.4	m
> 25 % requirements	(% of time)	78.4	78.4	m
Required volume	(MCM)	513.5	513.5	513.5
Volume delivered	(MCM)	2037.9	2041.5	m

MISSING DATA

Station 101. Number of values missing = 0
Station 102. Number of values missing = 0
Station 103. Number of values missing = 0
Station 104. Number of values missing = 0
Station 105. Number of values missing = 81
Station 12. Number of values missing = 0

ESTIMATED GU/DER SEASONS

Year	GU SEASON Start	Start main	End main	DER SEASON Start	Start Main	End main
1981	Mar 21	Mar 24	Jun 9	Jul 24	Aug 13	Nov 4

Definition of data types

Type 1 - Based on measured flows at Mahaddey Weyn and in the supply and outlet canals
Type 2 - Estimated operating rules

TABLE B.1 Statistical summary for simulation of Jowhar Offstream Storage Reservoir 1981 (Default settings)

JOWHAR OFFSTREAM STORAGE RESERVOIR - FLOW AND VOLUME STATISTICS

Start Date : 1982 Jan 1
End Date : 1982 Dec 31

		DATA TYPE Type 1	Type 2	Measured
No. days in calculations		365	365	365
VOLUMES				
Average volume	(MCM)	52.4	108.7	82.7
Reservoir empty	(% of time)	0.0	0.0	0.0
Reservoir full	(% of time)	0.0	0.0	0.0
> 75 % full	(% of time)	0.0	28.2	13.2
> 50 % full	(% of time)	16.2	59.5	25.2
> 25 % full	(% of time)	46.6	76.4	75.9
FLOWS				
Total passing Mahaddey Weyn	(MCM)	2505.5	2505.5	2505.5
passing Sabuun barrage	(MCM)	2269.5	2181.1	2538.3
through supply canal	(MCM)	236.0	324.4	236.0
through outlet canal	(MCM)	86.2	60.5	86.2
downstream of outlet canal	(MCM)	2095.8	1981.7	m
Supply canal flowing	(No. of days)	168	162	168
Outlet canal flowing	(No. of days)	106	70	106
LOSSES/MINOR INFLOWS				
Infiltration losses	(MCM)	105.6	148.3	134.0
Evaporation losses	(MCM)	96.6	134.4	124.0
Rainfall	(MCM)	24.4	39.1	32.8
Drainage from SNAI sugar estate	(MCM)	0.0	0.0	0.0
Total net losses	(MCM)	177.9	243.6	225.3
JOWHAR REACH IRRIGATION REQUIREMENTS				
Flow > 100 % requirements	(% of time)	87.7	87.7	m
> 75 % requirements	(% of time)	97.3	97.3	m
> 50 % requirements	(% of time)	100.0	100.0	m
> 25 % requirements	(% of time)	100.0	100.0	m
Required volume	(MCM)	266.1	266.1	266.1
Volume delivered	(MCM)	259.9	259.9	m
SHEBELLI DOWNSTREAM OF OUTLET CANAL				
Flow > 100 % requirements	(% of time)	99.2	84.7	m
> 75 % requirements	(% of time)	100.0	91.5	m
> 50 % requirements	(% of time)	100.0	94.5	m
> 25 % requirements	(% of time)	100.0	96.4	m
Required volume	(MCM)	513.5	513.5	513.5
Volume delivered	(MCM)	2095.8	1981.7	m

MISSING DATA

Station 101. Number of values missing = 0
Station 102. Number of values missing = 0
Station 103. Number of values missing = 0
Station 104. Number of values missing = 0
Station 105. Number of values missing = 97
Station 12. Number of values missing = 0

ESTIMATED GU/DER SEASONS

Year	GU SEASON Start	Start main	End main	DER SEASON Start	Start Main	End main
1982	Mar 12	Apr 22	Jun 16	Jul 13	Aug 13	Dec 31

Definition of data types

Type 1 - Based on measured flows at Mahaddey Weyn and in the supply and outlet canals
Type 2 - Estimated operating rules

TABLE B.2 Statistical summary for simulation of Jowhar Offstream Storage Reservoir 1982 (Default settings)

JOWHAR OFFSTREAM STORAGE RESERVOIR - FLOW AND VOLUME STATISTICS

Start Date : 1983 Jan 1
End Date : 1983 Dec 31

		DATA TYPE		
		Type 1	Type 2	Measured
No. days in calculations		365	365	365
VOLUMES				
Average volume	(MCM)	72.2	119.8	104.3
Reservoir empty	(% of time)	0.0	0.0	0.0
Reservoir full	(% of time)	0.0	0.0	0.0
> 75 % full	(% of time)	14.8	33.2	29.0
> 50 % full	(% of time)	32.6	65.5	46.3
> 25 % full	(% of time)	51.0	82.7	78.6
FLOWS				
Total passing Mahaddey Weyn	(MCM)	2868.3	2868.3	2868.3
passing Sabuun barrage	(MCM)	2594.5	2560.3	2940.8
through supply canal	(MCM)	273.8	308.0	273.8
through outlet canal	(MCM)	242.3	89.9	242.3
downstream of outlet canal	(MCM)	2570.8	2384.1	m
Supply canal flowing	(No. of days)	183	151	183
Outlet canal flowing	(No. of days)	138	104	138
LOSSES/MINOR INFLOWS				
Infiltration losses	(MCM)	114.6	159.1	150.9
Evaporation losses	(MCM)	107.4	147.4	141.5
Rainfall	(MCM)	26.4	39.6	38.7
Drainage from SNAI sugar estate	(MCM)	0.0	0.0	0.0
Total net losses	(MCM)	195.6	266.9	253.7
JOWHAR REACH IRRIGATION REQUIREMENTS				
Flow > 100 % requirements	(% of time)	100.0	100.0	m
> 75 % requirements	(% of time)	100.0	100.0	m
> 50 % requirements	(% of time)	100.0	100.0	m
> 25 % requirements	(% of time)	100.0	100.0	m
Required volume	(MCM)	266.1	266.1	266.1
Volume delivered	(MCM)	266.1	266.1	m
SHEBELLI DOWNSTREAM OF OUTLET CANAL				
Flow > 100 % requirements	(% of time)	100.0	99.5	m
> 75 % requirements	(% of time)	100.0	100.0	m
> 50 % requirements	(% of time)	100.0	100.0	m
> 25 % requirements	(% of time)	100.0	100.0	m
Required volume	(MCM)	513.5	513.5	513.5
Volume delivered	(MCM)	2570.8	2384.1	m

MISSING DATA

Station 101.	Number of values missing =	0
Station 102.	Number of values missing =	0
Station 103.	Number of values missing =	0
Station 104.	Number of values missing =	0
Station 105.	Number of values missing =	53
Station 12.	Number of values missing =	0

ESTIMATED GU/DER SEASONS

Year	GU SEASON Start	Start main	End main	DER SEASON Start	Start Main	End main
1983	Apr 19	May 1	Jul 11	Jul 29	Aug 2	Nov 30

Definition of data types

Type 1 - Based on measured flows at Mahaddey Weyn and in the supply and outlet canals
Type 2 - Estimated operating rules

TABLE B.3 Statistical summary for simulation of Jowhar Offstream Storage Reservoir 1983 (Default settings)

JOWHAR OFFSTREAM STORAGE RESERVOIR - FLOW AND VOLUME STATISTICS

Start Date : 1984 Jan 1
End Date : 1984 Dec 31

		DATA TYPE Type 1	Type 2	Measured
No. days in calculations		366	366	366
VOLUMES				
Average volume	(MCM)	28.8	70.0	45.6
Reservoir empty	(% of time)	0.0	0.0	0.0
Reservoir full	(% of time)	0.0	0.0	0.0
> 75 % full	(% of time)	0.3	3.8	1.6
> 50 % full	(% of time)	5.5	30.6	14.5
> 25 % full	(% of time)	23.2	56.6	41.3
FLOWS				
Total passing Mahaddey Weyn	(MCM)	1552.0	1552.0	1552.0
passing Sabuun barrage	(MCM)	1426.3	1296.5	1539.9
through supply canal	(MCM)	125.8	255.5	125.8
through outlet canal	(MCM)	276.5	142.3	276.5
downstream of outlet canal	(MCM)	1436.2	1172.3	m
Supply canal flowing	(No. of days)	118	130	118
Outlet canal flowing	(No. of days)	207	165	207
LOSSES/MINOR INFLOWS				
Infiltration losses	(MCM)	63.5	117.3	89.8
Evaporation losses	(MCM)	61.2	109.7	89.6
Rainfall	(MCM)	15.2	26.5	22.4
Drainage from SNAI sugar estate	(MCM)	0.0	0.0	0.0
Total net losses	(MCM)	109.4	200.4	156.9
JOWHAR REACH IRRIGATION REQUIREMENTS				
Flow > 100 % requirements	(% of time)	98.1	98.1	m
> 75 % requirements	(% of time)	100.0	100.0	m
> 50 % requirements	(% of time)	100.0	100.0	m
> 25 % requirements	(% of time)	100.0	100.0	m
Required volume	(MCM)	266.9	266.9	266.9
Volume delivered	(MCM)	266.5	266.5	m
SHEBELLI DOWNSTREAM OF OUTLET CANAL				
Flow > 100 % requirements	(% of time)	85.0	73.8	m
> 75 % requirements	(% of time)	89.6	84.7	m
> 50 % requirements	(% of time)	93.7	94.5	m
> 25 % requirements	(% of time)	100.0	100.0	m
Required volume	(MCM)	514.2	514.2	514.2
Volume delivered	(MCM)	1436.2	1172.3	m

MISSING DATA

Station 101. Number of values missing = 0
Station 102. Number of values missing = 0
Station 103. Number of values missing = 0
Station 104. Number of values missing = 0
Station 105. Number of values missing = 28
Station 12. Number of values missing = 0

ESTIMATED GU/DER SEASONS

Year	GU SEASON Start	Start main	End main	DER SEASON Start	Start Main	End main
1984	Apr 19	May 26	May 29	Jul 2	Aug 3	Oct 22

Definition of data types

Type 1 - Based on measured flows at Mahaddey Weyn and in the supply and outlet canals
Type 2 - Estimated operating rules

TABLE B.4 Statistical summary for simulation of Jowhar Offstream Storage Reservoir 1984 (Default settings)

JOWHAR OFFSTREAM STORAGE RESERVOIR - FLOW AND VOLUME STATISTICS

Start Date : 1985 Jan 1
End Date : 1985 Dec 31

		DATA TYPE		
		Type 1	Type 2	Measured
No. days in calculations		319	365	365
VOLUMES				
Average volume	(MCM)	m	78.8	67.4
Reservoir empty	(% of time)	m	0.0	0.0
Reservoir full	(% of time)	m	0.0	0.0
> 75 % full	(% of time)	m	12.6	0.0
> 50 % full	(% of time)	m	46.0	28.8
> 25 % full	(% of time)	m	60.5	61.4
FLOWS				
Total passing Mahaddey Weyn	(MCM)	m	2078.7	2078.7
passing Sabuun barrage	(MCM)	m	1781.5	1952.7
through supply canal	(MCM)	m	297.3	277.2
through outlet canal	(MCM)	m	84.5	m
downstream of outlet canal	(MCM)	m	1634.5	m
Supply canal flowing	(No. of days)	m	151	191
Outlet canal flowing	(No. of days)	m	98	m
LOSSES/MINOR INFLOWS				
Infiltration losses	(MCM)	m	114.3	114.7
Evaporation losses	(MCM)	m	99.5	102.0
Rainfall	(MCM)	m	32.0	30.9
Drainage from SNAI sugar estate	(MCM)	m	0.0	0.0
Total net losses	(MCM)	m	181.7	185.8
JOWHAR REACH IRRIGATION REQUIREMENTS				
Flow > 100 % requirements	(% of time)	m	74.2	m
> 75 % requirements	(% of time)	m	78.9	m
> 50 % requirements	(% of time)	m	90.7	m
> 25 % requirements	(% of time)	m	100.0	m
Required volume	(MCM)	m	266.1	266.1
Volume delivered	(MCM)	m	231.5	m
SHEBELLI DOWNSTREAM OF OUTLET CANAL				
Flow > 100 % requirements	(% of time)	m	55.9	m
> 75 % requirements	(% of time)	m	79.7	m
> 50 % requirements	(% of time)	m	84.9	m
> 25 % requirements	(% of time)	m	84.9	m
Required volume	(MCM)	m	513.5	513.5
Volume delivered	(MCM)	m	1634.5	m

MISSING DATA

Station 101. Number of values missing = 0
Station 102. Number of values missing = 0
Station 103. Number of values missing = 0
Station 104. Number of values missing = 46
Station 105. Number of values missing = 109
Station 12. Number of values missing = 0

ESTIMATED GU/DER SEASONS

Year	GU SEASON Start	Start main	End main	DER SEASON Start	Start Main	End main
1985	Apr 5	Apr 20	Jun 17	Jul 22	Aug 6	Oct 11

Definition of data types

Type 1 - Based on measured flows at Mahaddey Weyn and in the supply and outlet canals
Type 2 - Estimated operating rules

TABLE B.5 Statistical summary for simulation of Jowhar Offstream Storage Reservoir 1985 (Default settings)

JOWHAR OFFSTREAM STORAGE RESERVOIR - FLOW AND VOLUME STATISTICS

Start Date : 1986 Jan 1
End Date : 1986 Dec 31

		DATA TYPE		
		Type 1	Type 2	Measured
No. days in calculations		0	365	365
VOLUMES				
Average volume	(MCM)	m	92.0	101.0
Reservoir empty	(% of time)	m	0.0	0.0
Reservoir full	(% of time)	m	0.0	0.0
> 75 % full	(% of time)	m	26.8	25.2
> 50 % full	(% of time)	m	45.5	47.4
> 25 % full	(% of time)	m	64.4	74.5
FLOWS				
Total passing Mahaddey Weyn	(MCM)	m	2161.7	2161.7
passing Sabuun barrage	(MCM)	m	1846.8	1944.5
through supply canal	(MCM)	m	314.9	227.0
through outlet canal	(MCM)	m	104.3	m
downstream of outlet canal	(MCM)	m	1697.2	m
Supply canal flowing	(No. of days)	m	150	183
Outlet canal flowing	(No. of days)	m	121	m
LOSSES/MINOR INFLOWS				
Infiltration losses	(MCM)	m	124.3	148.0
Evaporation losses	(MCM)	m	111.5	135.6
Rainfall	(MCM)	m	30.1	38.5
Drainage from SNAI sugar estate	(MCM)	m	0.0	0.0
Total net losses	(MCM)	m	205.7	245.1
JOWHAR REACH IRRIGATION REQUIREMENTS				
Flow > 100 % requirements	(% of time)	m	84.4	m
> 75 % requirements	(% of time)	m	90.7	m
> 50 % requirements	(% of time)	m	100.0	m
> 25 % requirements	(% of time)	m	100.0	m
Required volume	(MCM)	m	266.1	266.1
Volume delivered	(MCM)	m	253.8	m
SHEBELLI DOWNSTREAM OF OUTLET CANAL				
Flow > 100 % requirements	(% of time)	m	77.5	m
> 75 % requirements	(% of time)	m	79.5	m
> 50 % requirements	(% of time)	m	83.8	m
> 25 % requirements	(% of time)	m	89.6	m
Required volume	(MCM)	m	513.5	513.5
Volume delivered	(MCM)	m	1697.2	m

MISSING DATA

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Station 102. Number of values missing = 0
Station 103. Number of values missing = 0
Station 104. Number of values missing = 322
Station 105. Number of values missing = 149
Station 12. Number of values missing = 0

ESTIMATED GU/DER SEASONS

Year	GU SEASON Start	Start main	End main	DER SEASON Start	Start Main	End main
1986	Apr 21	Apr 22	Oct 17	Oct 26	Oct 29	Oct 29

Definition of data types

Type 1 - Based on measured flows at Mahaddey Weyn and in the supply and outlet canals
Type 2 - Estimated operating rules

TABLE B.6 Statistical summary for simulation of Jowhar Offstream Storage Reservoir 1986 (Default settings)

JOWHAR OFFSTREAM STORAGE RESERVOIR - FLOW AND VOLUME STATISTICS

Start Date : 1987 Jan 1
End Date : 1987 Dec 31

		DATA TYPE Type 1	Type 2	Measured
No. days in calculations		0	365	365
VOLUMES				
Average volume	(MCM)	m	106.7	110.1
Reservoir empty	(% of time)	m	0.0	0.0
Reservoir full	(% of time)	m	0.0	0.0
> 75 % full	(% of time)	m	34.0	41.4
> 50 % full	(% of time)	m	56.2	55.9
> 25 % full	(% of time)	m	73.4	70.7
FLOWS				
Total passing Mahaddey Weyn	(MCM)	m	1910.9	1910.9
passing Sabuun barrage	(MCM)	m	1561.7	m
through supply canal	(MCM)	m	349.1	258.3
through outlet canal	(MCM)	m	110.6	m
downstream of outlet canal	(MCM)	m	1438.3	m
Supply canal flowing	(No. of days)	m	179	124
Outlet canal flowing	(No. of days)	m	128	m
LOSSES/MINOR INFLOWS				
Infiltration losses	(MCM)	m	141.7	146.7
Evaporation losses	(MCM)	m	127.6	133.8
Rainfall	(MCM)	m	35.3	35.5
Drainage from SNAI sugar estate	(MCM)	m	0.0	0.0
Total net losses	(MCM)	m	234.0	245.0
JOWHAR REACH IRRIGATION REQUIREMENTS				
Flow > 100 % requirements	(% of time)	m	74.8	m
> 75 % requirements	(% of time)	m	78.9	m
> 50 % requirements	(% of time)	m	90.7	m
> 25 % requirements	(% of time)	m	100.0	m
Required volume	(MCM)	m	266.1	266.1
Volume delivered	(MCM)	m	234.0	m
SHEBELLI DOWNSTREAM OF OUTLET CANAL				
Flow > 100 % requirements	(% of time)	m	77.5	m
> 75 % requirements	(% of time)	m	90.1	m
> 50 % requirements	(% of time)	m	94.5	m
> 25 % requirements	(% of time)	m	98.1	m
Required volume	(MCM)	m	513.5	513.5
Volume delivered	(MCM)	m	1438.3	m

MISSING DATA

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Station 102. Number of values missing = 11
Station 103. Number of values missing = 0
Station 104. Number of values missing = 334
Station 105. Number of values missing = 74
Station 12. Number of values missing = 0

ESTIMATED GU/DER SEASONS

Year	GU SEASON Start	Start main	End main	DER SEASON Start	Start Main	End main
1987	Apr 1	Apr 18	Jul 5	Aug 29	Sep 27	Nov 12

Definition of data types

Type 1 - Based on measured flows at Mahaddey Weyn and in the supply and outlet canals
Type 2 - Estimated operating rules

TABLE B.7 Statistical summary for simulation of Jowhar Offstream Storage Reservoir 1987 (Default settings)

JOWHAR OFFSTREAM STORAGE RESERVOIR - FLOW AND VOLUME STATISTICS

Start Date : 1988 Jan 1
End Date : 1988 Dec 31

		DATA TYPE		
		Type 1	Type 2	Measured
No. days in calculations		48	366	366
VOLUMES				
Average volume	(MCM)	m	74.8	67.4
Reservoir empty	(% of time)	m	0.0	0.0
Reservoir full	(% of time)	m	0.0	0.0
> 75 % full	(% of time)	m	15.3	16.7
> 50 % full	(% of time)	m	34.7	29.8
> 25 % full	(% of time)	m	52.7	44.3
FLOWS				
Total passing Mahaddey Weyn	(MCM)	m	2032.9	2032.9
passing Sabuun barrage	(MCM)	m	1730.8	m
through supply canal	(MCM)	m	302.1	247.5
through outlet canal	(MCM)	m	105.6	m
downstream of outlet canal	(MCM)	m	1616.5	m
Supply canal flowing	(No. of days)	m	162	173
Outlet canal flowing	(No. of days)	m	123	m
LOSSES/MINOR INFLOWS				
Infiltration losses	(MCM)	m	117.4	112.6
Evaporation losses	(MCM)	m	109.0	105.8
Rainfall	(MCM)	m	28.9	29.8
Drainage from SNAI sugar estate	(MCM)	m	0.0	0.0
Total net losses	(MCM)	m	197.5	188.6
JOWHAR REACH IRRIGATION REQUIREMENTS				
Flow > 100 % requirements	(% of time)	m	71.3	m
> 75 % requirements	(% of time)	m	74.3	m
> 50 % requirements	(% of time)	m	82.2	m
> 25 % requirements	(% of time)	m	94.8	m
Required volume	(MCM)	m	266.9	266.9
Volume delivered	(MCM)	m	219.9	m
SHEBELLI DOWNSTREAM OF OUTLET CANAL				
Flow > 100 % requirements	(% of time)	m	66.4	m
> 75 % requirements	(% of time)	m	83.1	m
> 50 % requirements	(% of time)	m	92.6	m
> 25 % requirements	(% of time)	m	95.9	m
Required volume	(MCM)	m	514.2	514.2
Volume delivered	(MCM)	m	1616.5	m

MISSING DATA

Station 101. Number of values missing = 0
Station 102. Number of values missing = 366
Station 103. Number of values missing = 0
Station 104. Number of values missing = 318
Station 105. Number of values missing = 366
Station 12. Number of values missing = 0

ESTIMATED GU/DER SEASONS

Year	GU SEASON Start	Start main	End main	DER SEASON Start	Start Main	End main
1988	Apr 15	Apr 26	May 13	Jun 20	Aug 13	Nov 15

Definition of data types

Type 1 - Based on measured flows at Mahaddey Weyn and in the supply and outlet canals
Type 2 - Estimated operating rules

TABLE B.8 Statistical summary for simulation of Jowhar Offstream Storage Reservoir 1988 (Default settings)

JOWHAR OFFSTREAM STORAGE RESERVOIR - FLOW AND VOLUME STATISTICS

Start Date : 1989 Jan 1
End Date : 1989 Dec 31

		DATA TYPE		
		Type 1	Type 2	Measured
No. days in calculations		0	365	365
VOLUMES				
Average volume	(MCM)	m	118.1	145.0
Reservoir empty	(% of time)	m	0.0	0.0
Reservoir full	(% of time)	m	0.0	13.2
> 75 % full	(% of time)	m	26.0	46.3
> 50 % full	(% of time)	m	66.6	77.8
> 25 % full	(% of time)	m	83.8	100.0
FLOWS				
Total passing Mahaddey Weyn	(MCM)	m	2236.6	2236.6
passing Sabuun barrage	(MCM)	m	1918.5	m
through supply canal	(MCM)	m	318.0	259.2
through outlet canal	(MCM)	m	102.0	m
downstream of outlet canal	(MCM)	m	1754.4	2043.0
Supply canal flowing	(No. of days)	m	166	208
Outlet canal flowing	(No. of days)	m	118	m
LOSSES/MINOR INFLOWS				
Infiltration losses	(MCM)	m	158.9	175.6
Evaporation losses	(MCM)	m	145.9	162.5
Rainfall	(MCM)	m	40.8	46.1
Drainage from SNAI sugar estate	(MCM)	m	0.0	0.0
Total net losses	(MCM)	m	264.0	292.0
JOWHAR REACH IRRIGATION REQUIREMENTS				
Flow > 100 % requirements	(% of time)	m	100.0	m
> 75 % requirements	(% of time)	m	100.0	m
> 50 % requirements	(% of time)	m	100.0	m
> 25 % requirements	(% of time)	m	100.0	m
Required volume	(MCM)	m	266.1	266.1
Volume delivered	(MCM)	m	266.1	m
SHEBELLI DOWNSTREAM OF OUTLET CANAL				
Flow > 100 % requirements	(% of time)	m	89.9	100.0
> 75 % requirements	(% of time)	m	96.7	100.0
> 50 % requirements	(% of time)	m	100.0	100.0
> 25 % requirements	(% of time)	m	100.0	100.0
Required volume	(MCM)	m	513.5	513.5
Volume delivered	(MCM)	m	1754.4	2043.0

MISSING DATA

Station 101.	Number of values missing =	0
Station 102.	Number of values missing =	184
Station 103.	Number of values missing =	0
Station 104.	Number of values missing =	365
Station 105.	Number of values missing =	0
Station 12.	Number of values missing =	0

ESTIMATED GU/DER SEASONS

Year	GU SEASON Start	Start main	End main	DER SEASON Start	Start Main	End main
1989	Apr 2	Apr 7	Jun 5	Jul 22	Sep 11	Nov 6

Definition of data types

Type 1 - Based on measured flows at Mahaddey Weyn and in the supply and outlet canals
Type 2 - Estimated operating rules

TABLE B.9 Statistical summary for simulation of Jowhar Offstream Storage Reservoir 1989 (Default settings)

Map showing the gauging stations represented in the forecasting model

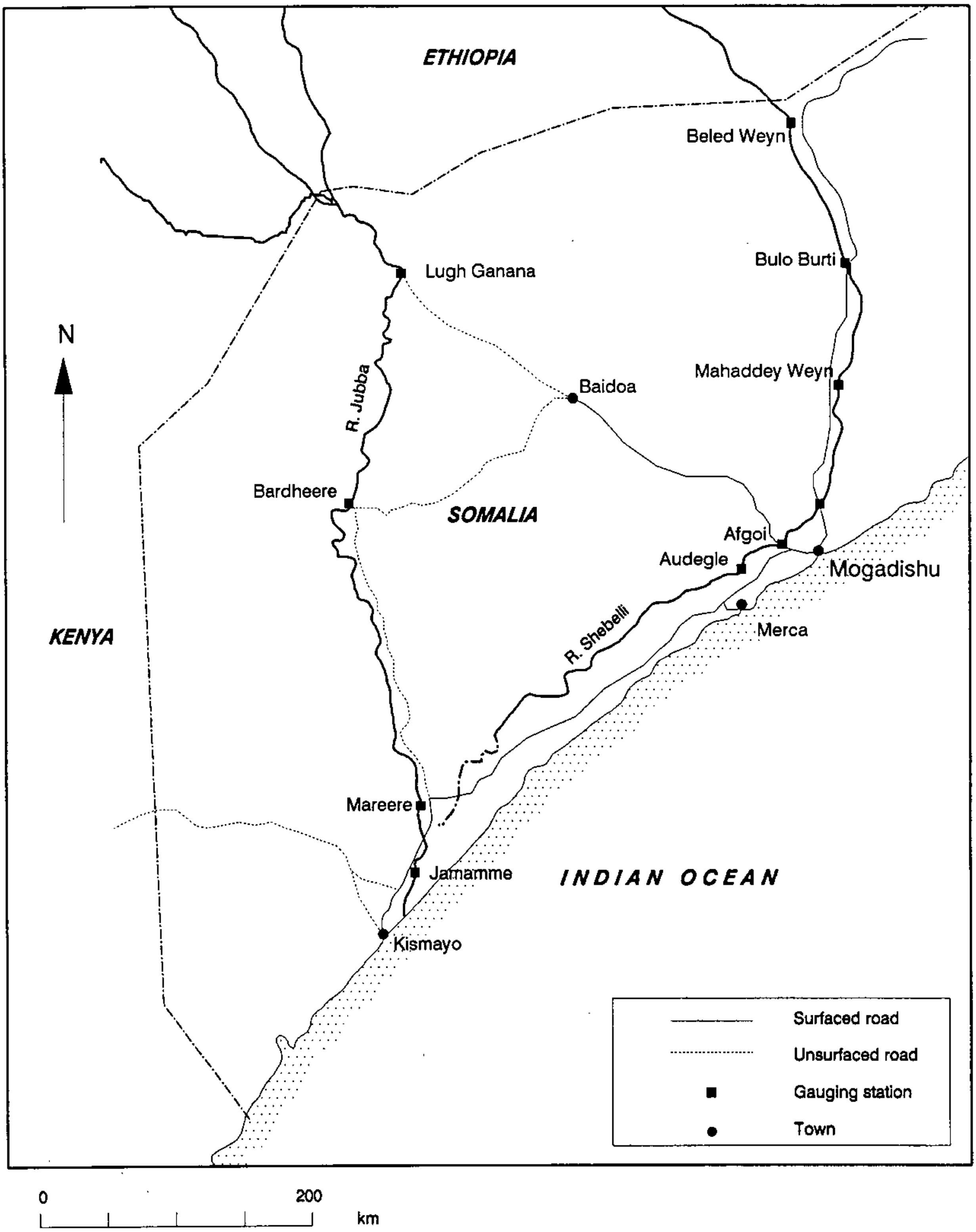
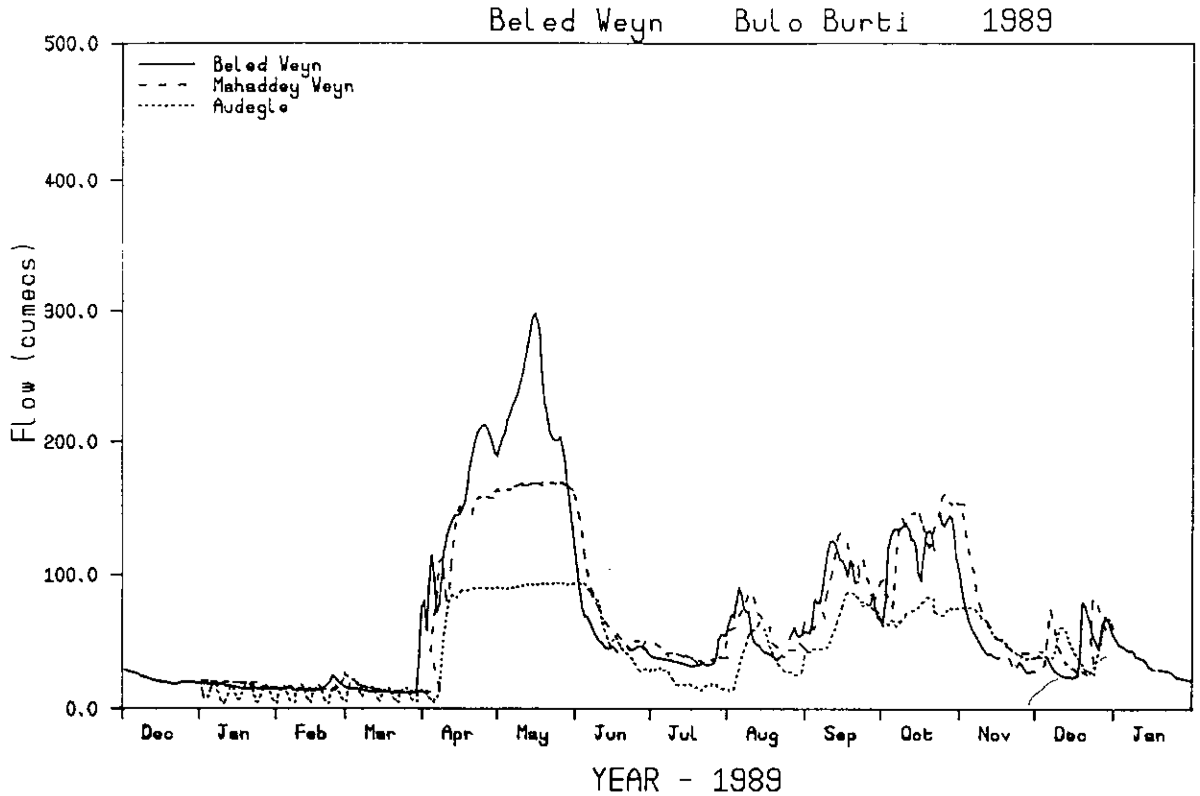


Figure 1

Typical flow hydrographs for 1989

(a) River Shebelli



(b) River Jubba

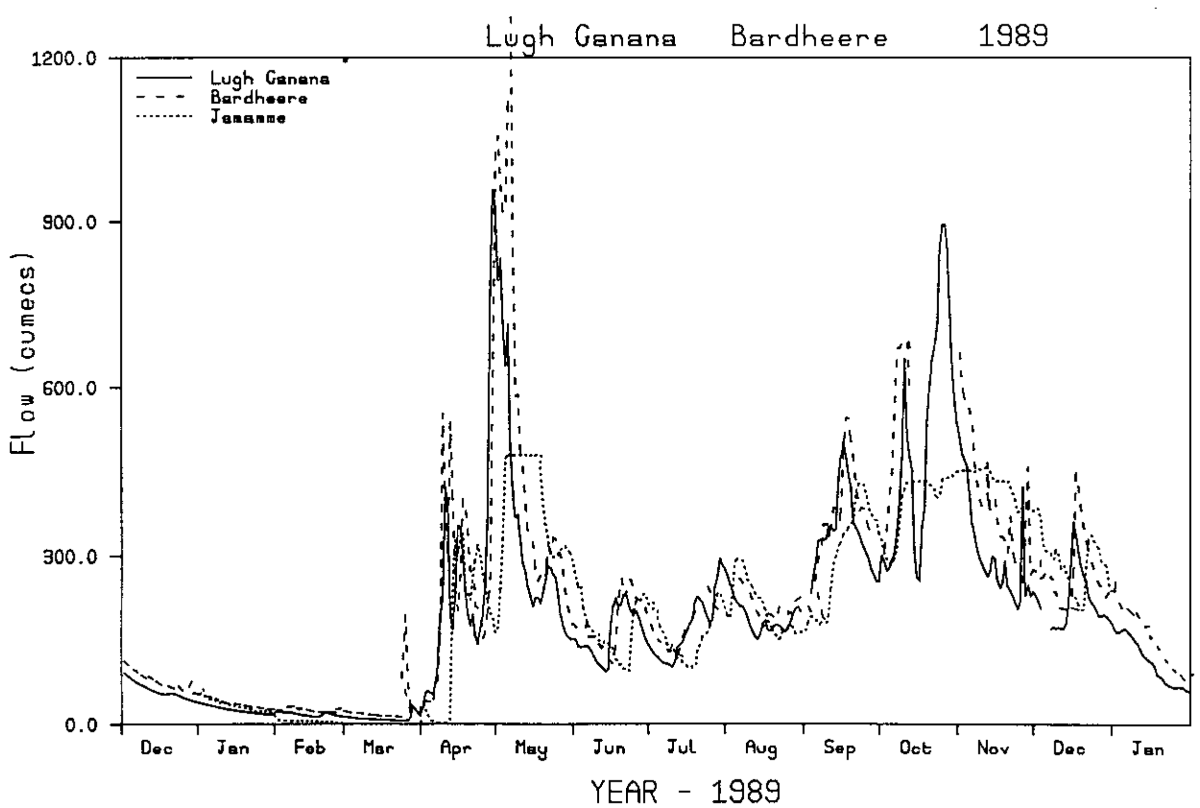
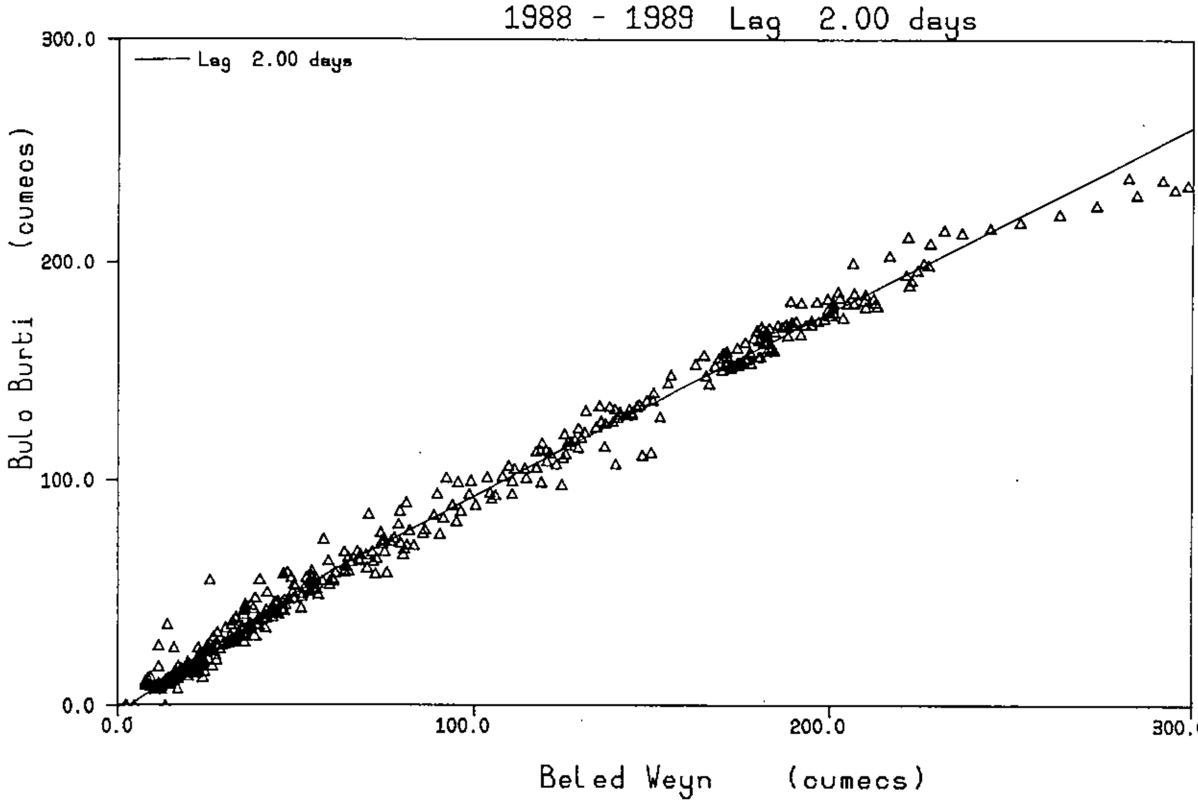


Figure 2

Correlation plots used in deriving correlations for forecasting model

(a) River Shebelli



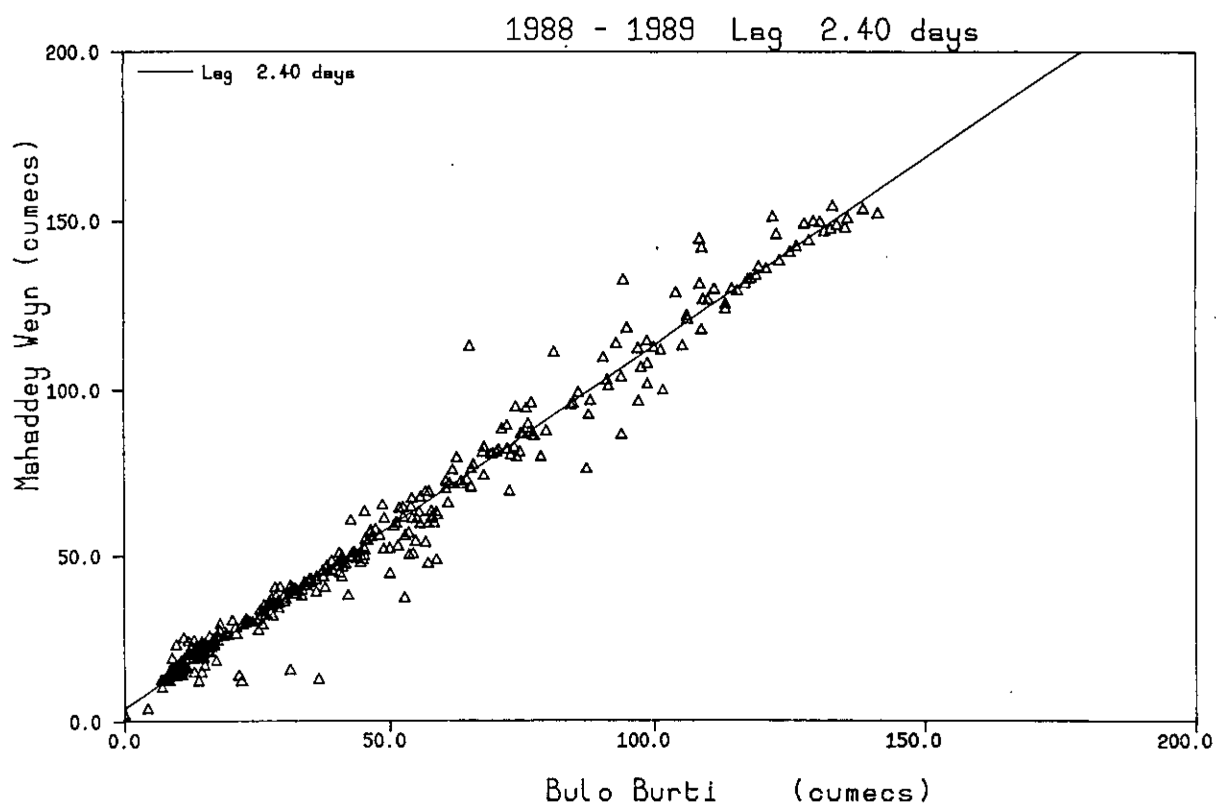
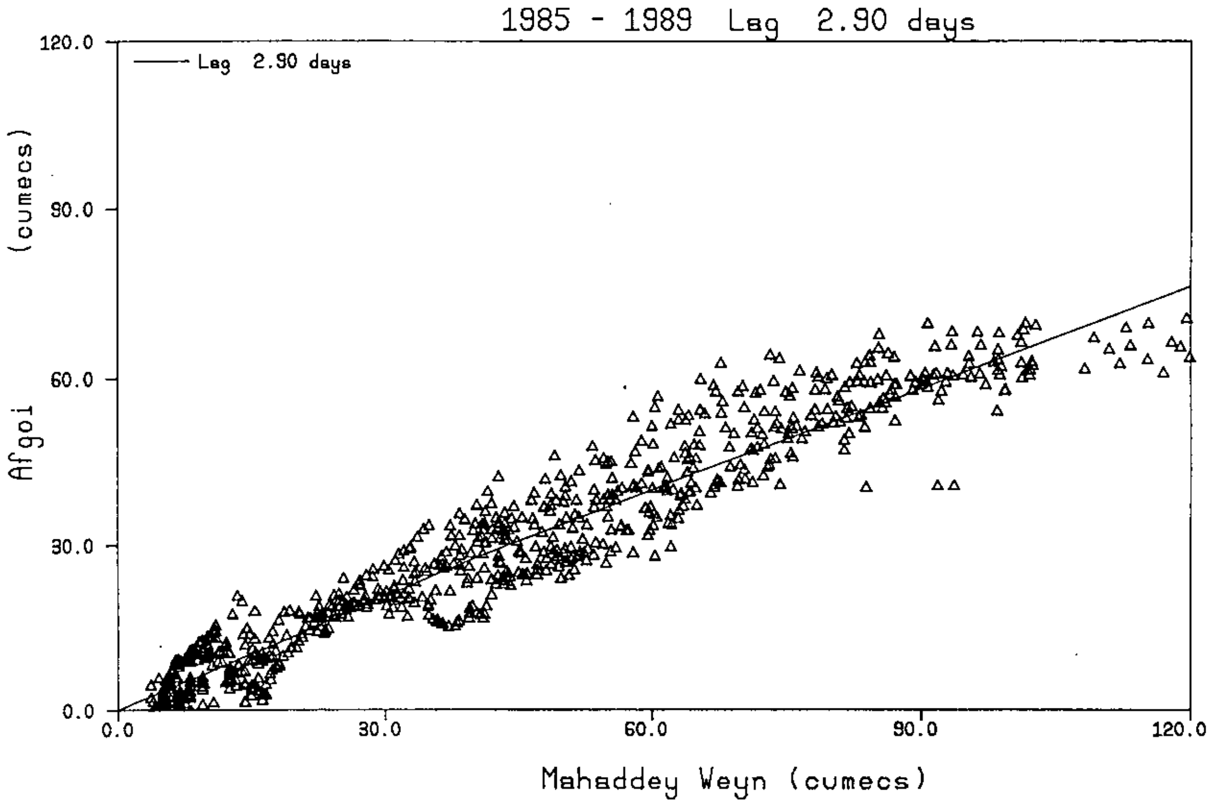


Figure 3

Correlation plots used in deriving correlations for forecasting model

(a) River Shebelli



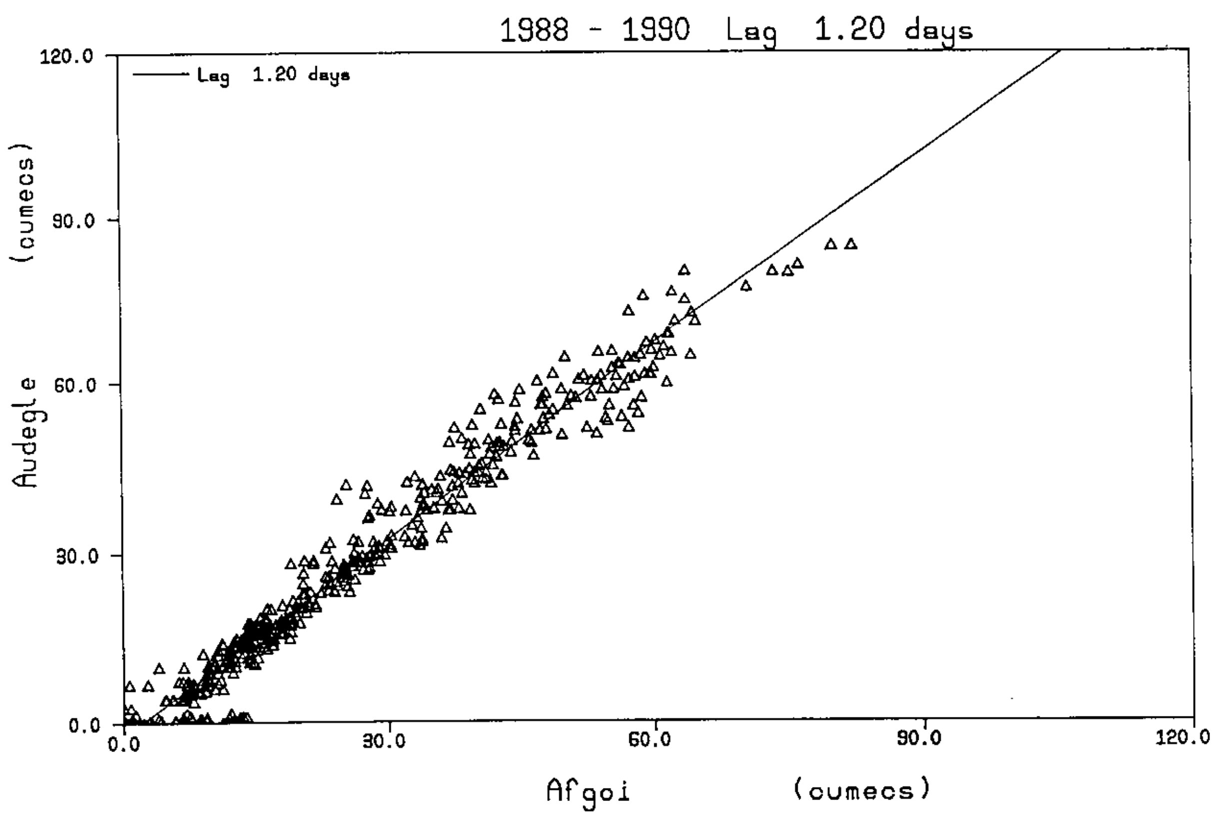
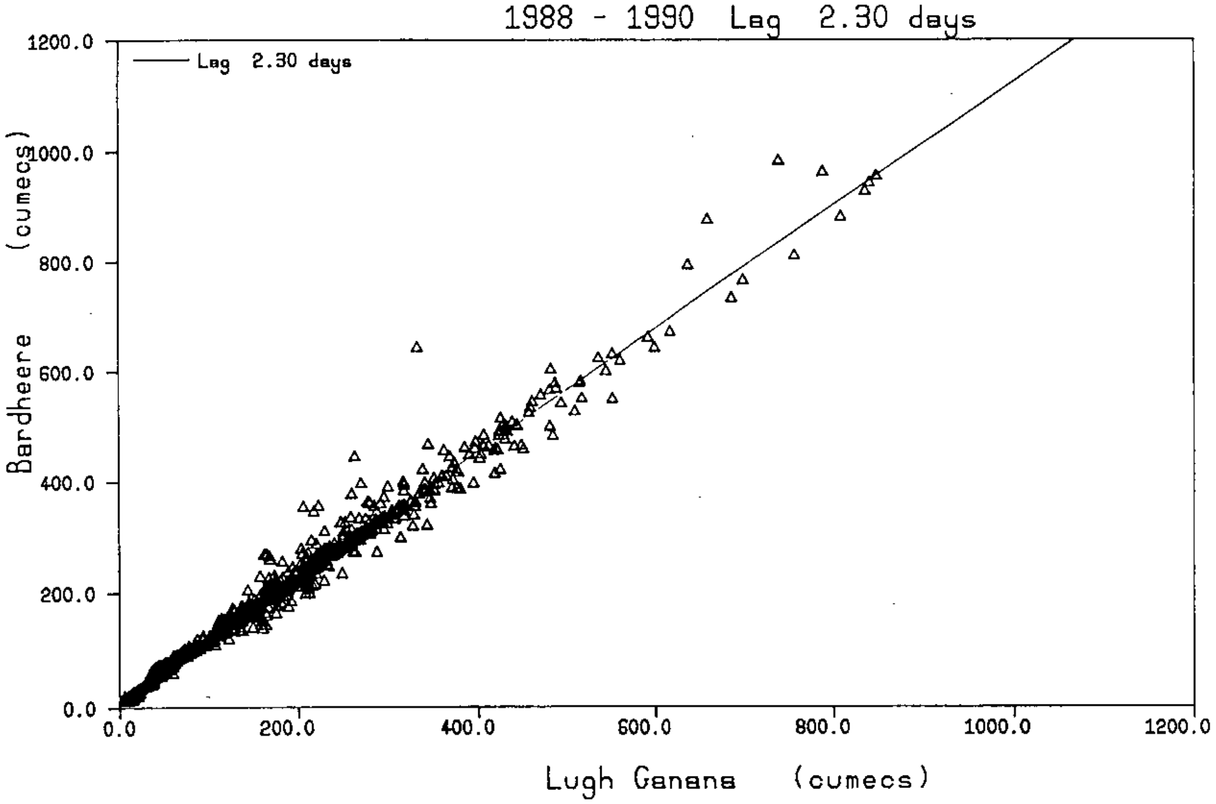


Figure 3 (cont.)

Correlation plots used in deriving correlations for forecasting model

(b) River Jubba



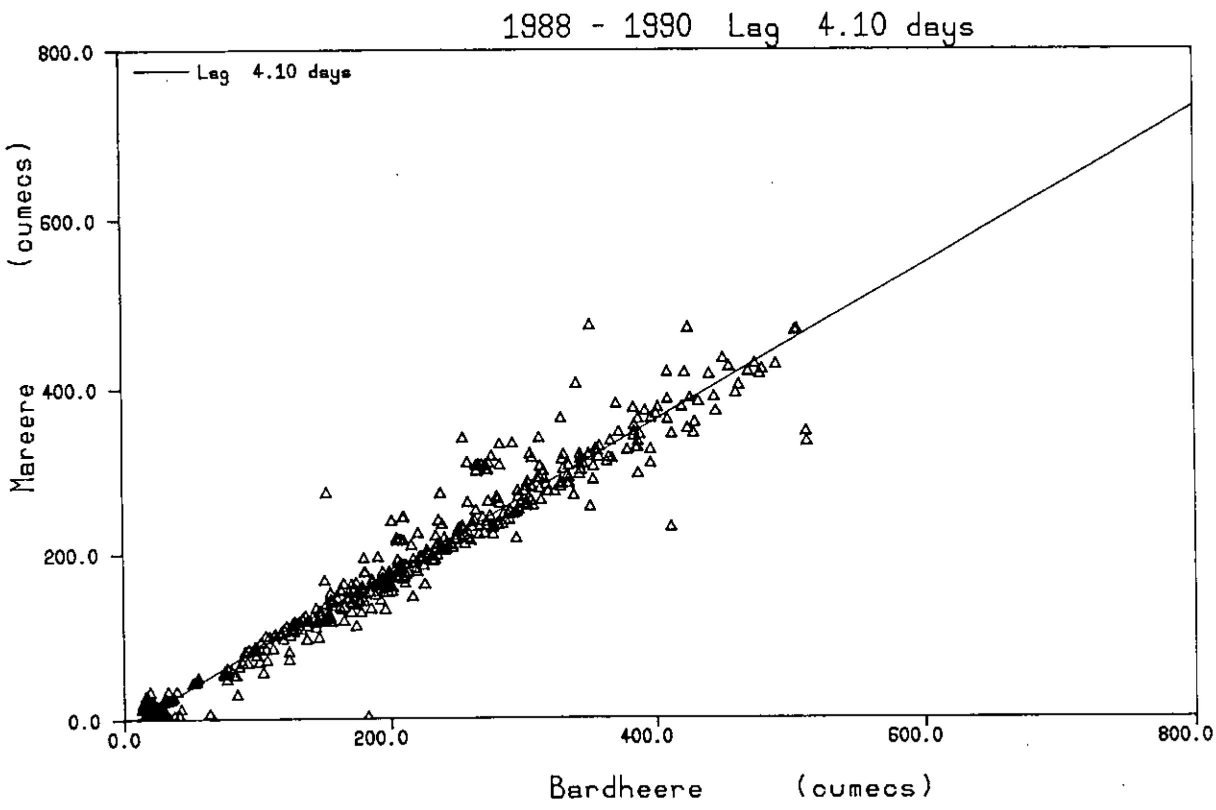


Figure 3 (cont.)

Correlation plots used in deriving correlations for forecasting model

(b) River Jubba

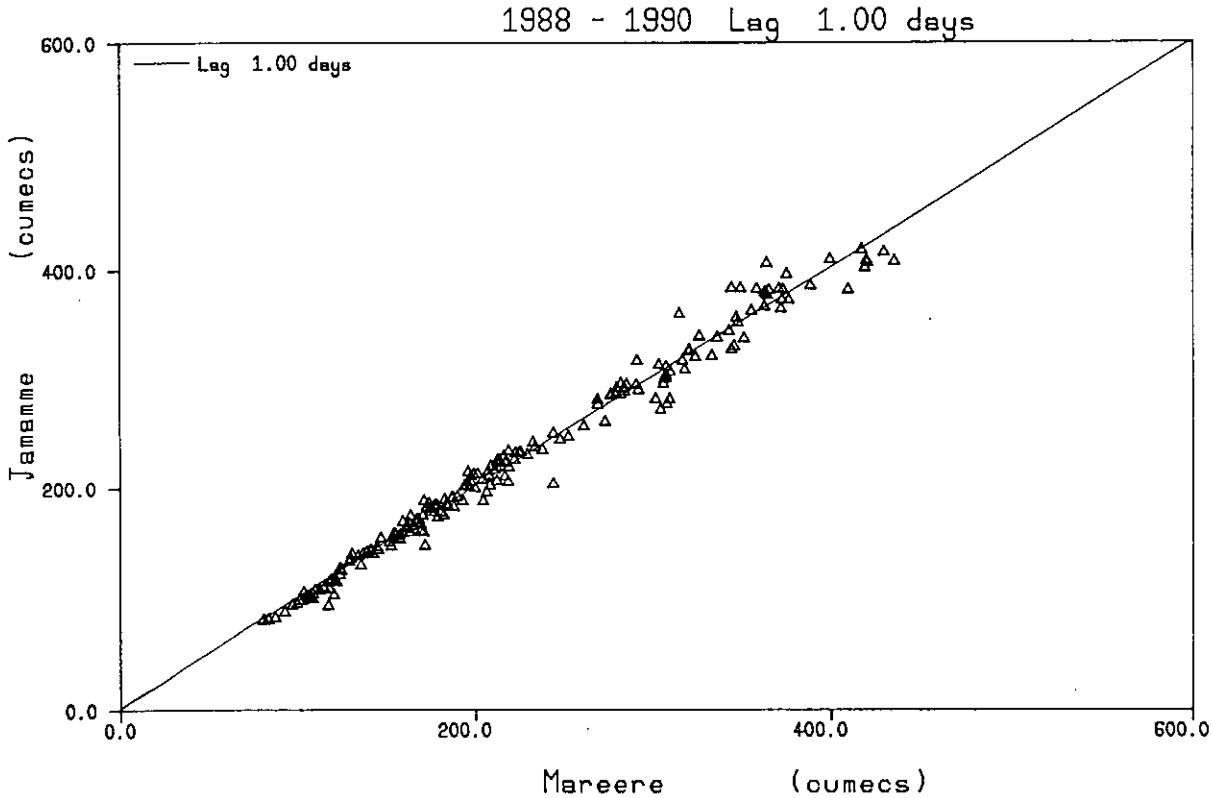
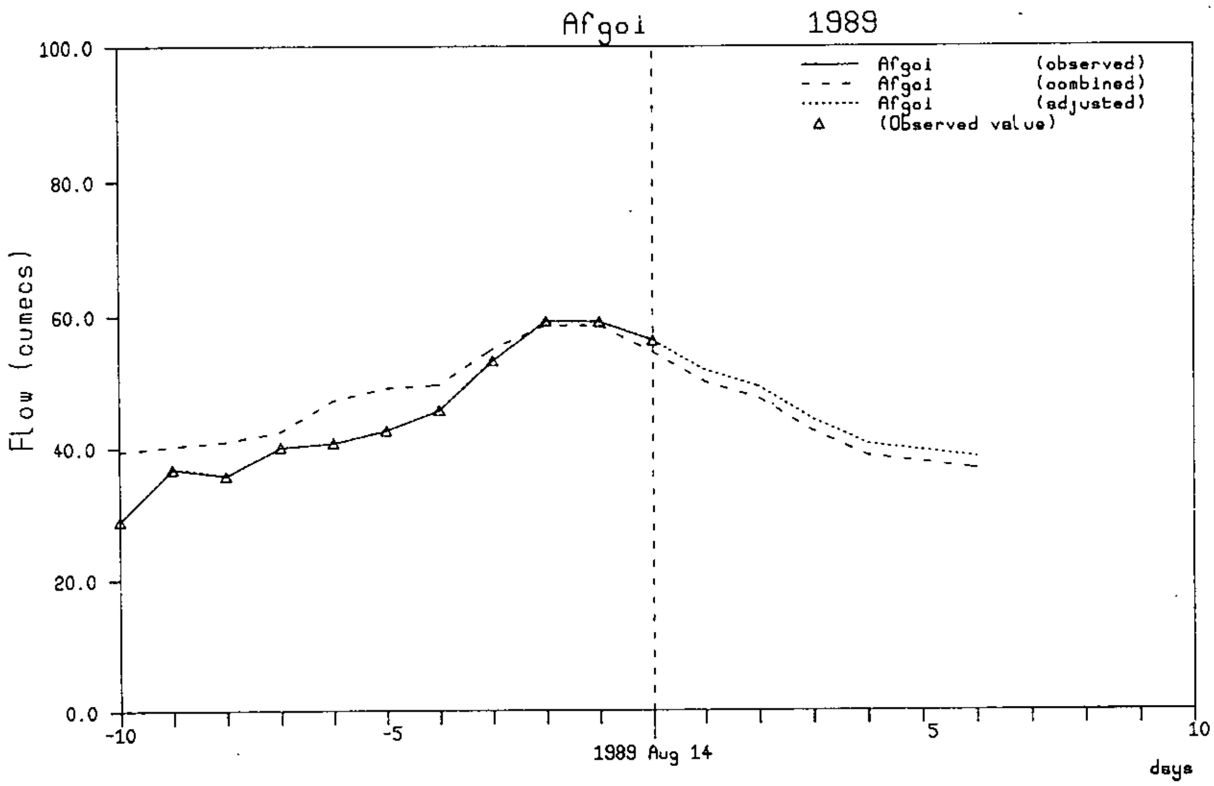


Figure 3 (cont.)

Examples of adjustments which can be made using the forecasting model
(the forecasts are for Afgoi on the River Shebelli 14 Aug 1989)

(a) Shift adjustment



(b) Join adjustment

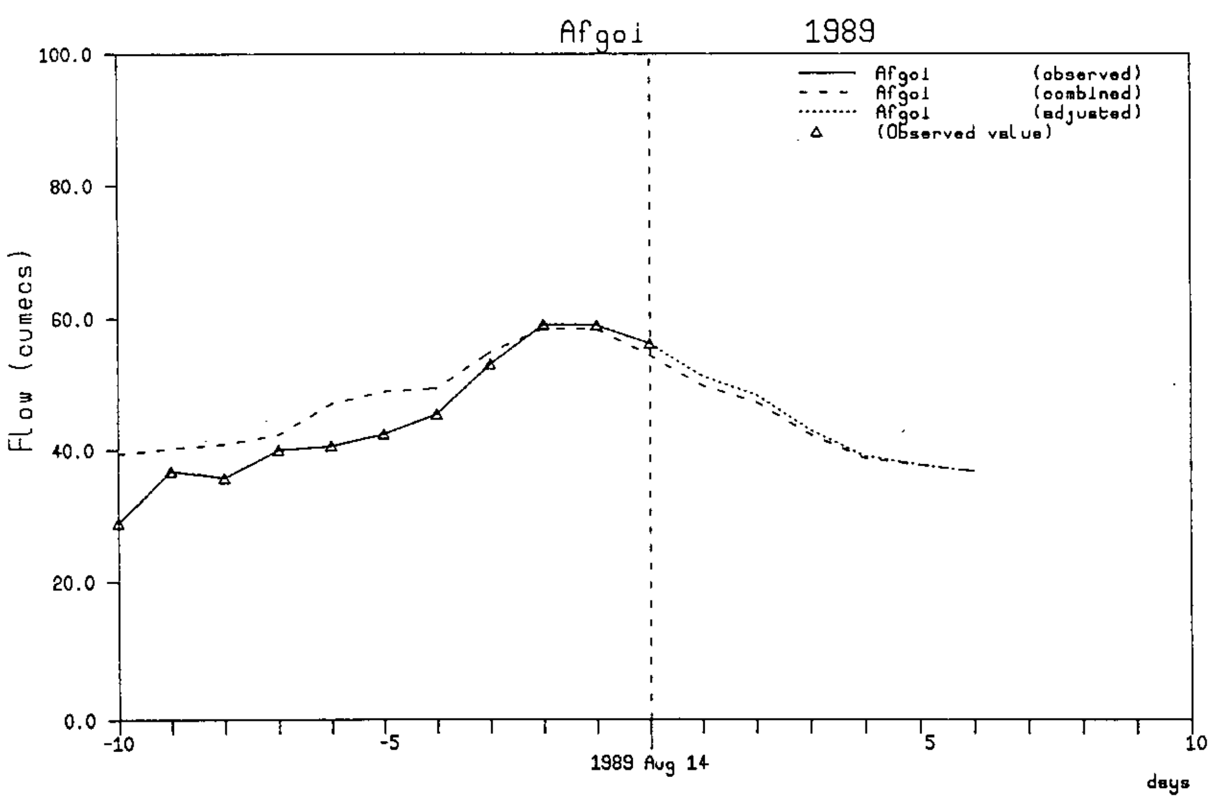
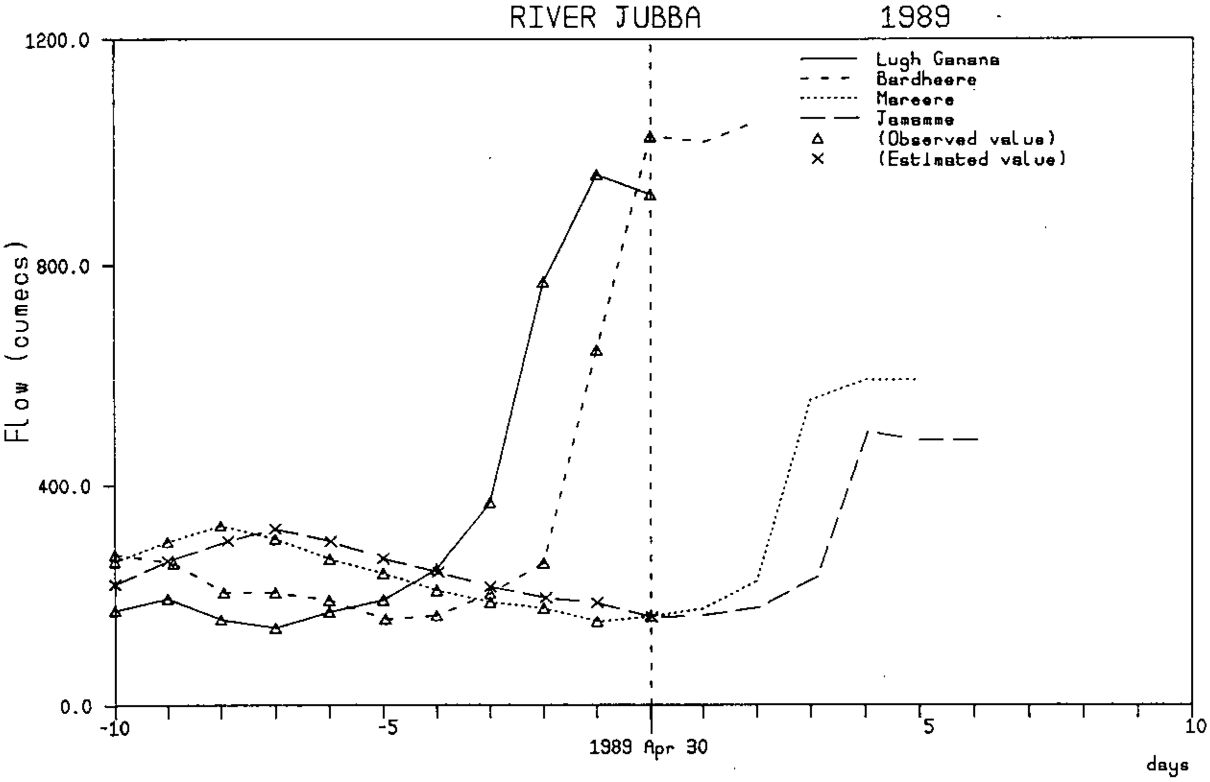


Figure 4

Examples of graphical output from the forecasting model

(a) Combined forecasts for the River Jubba 30 Apr 1989



(b) Individual forecasts for Afgoi on the River Shebelli 14 Aug 1989
from each upstream station

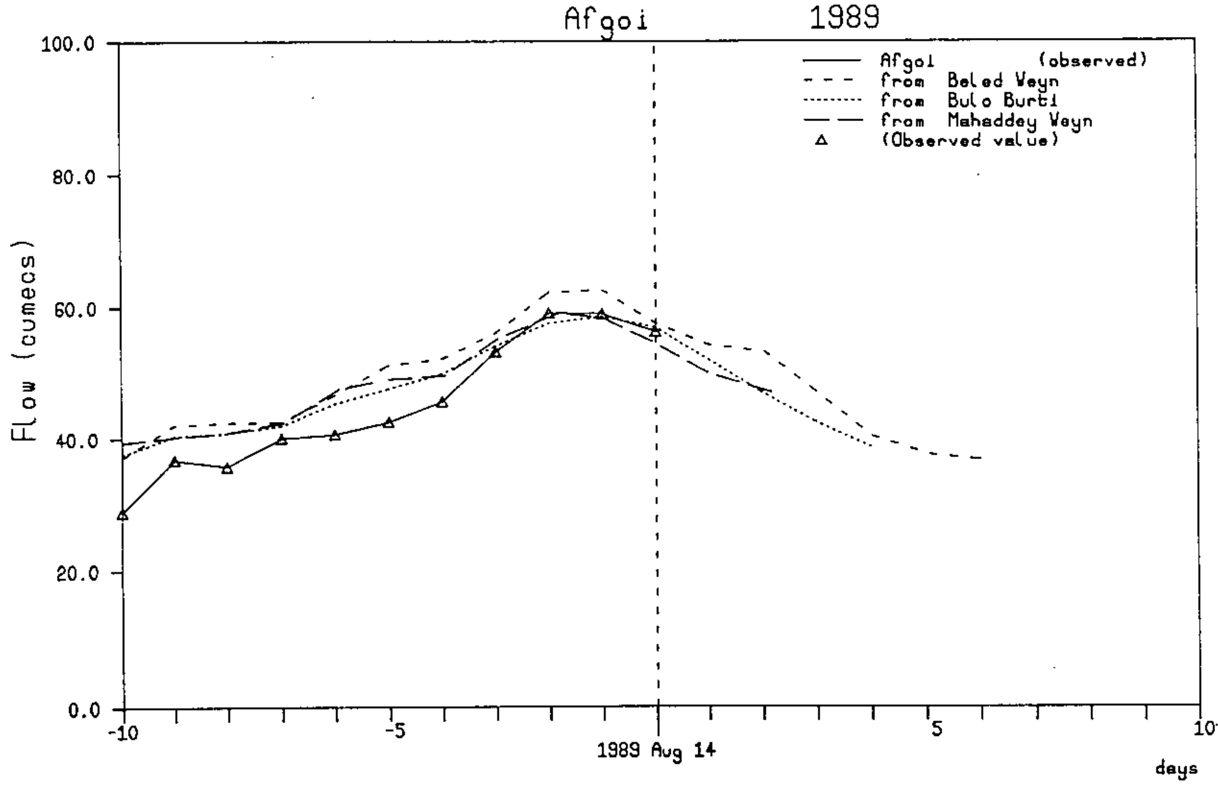


Figure 5

Catalogue of the main flood events on the River Shebelli 1963-89

(Beled Weyn to Bulo Burti reach)

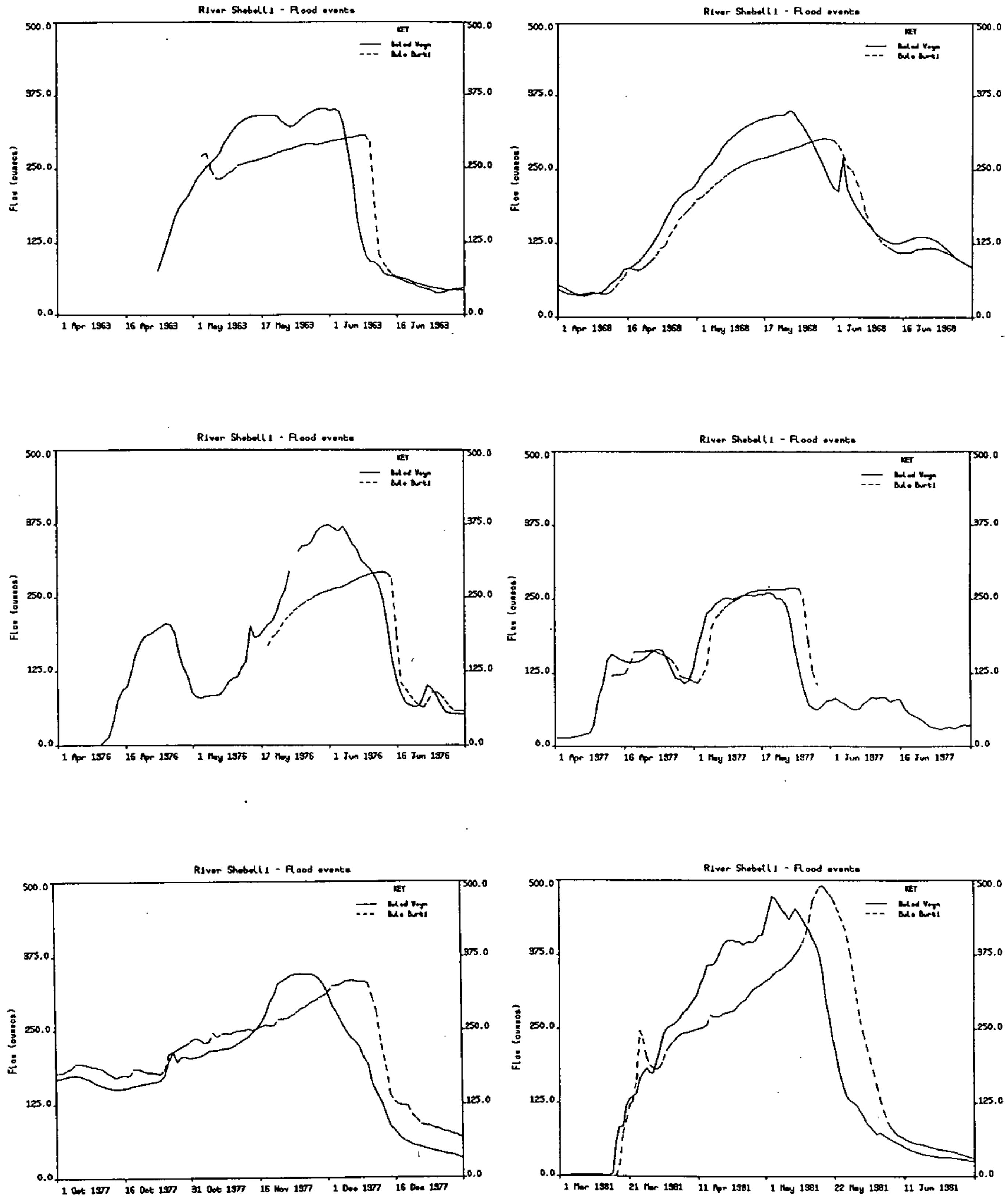


Figure 6

Catalogue of the main flood events on the River Shebelli 1963-89
(Beled Weyn to Bulo Burti)

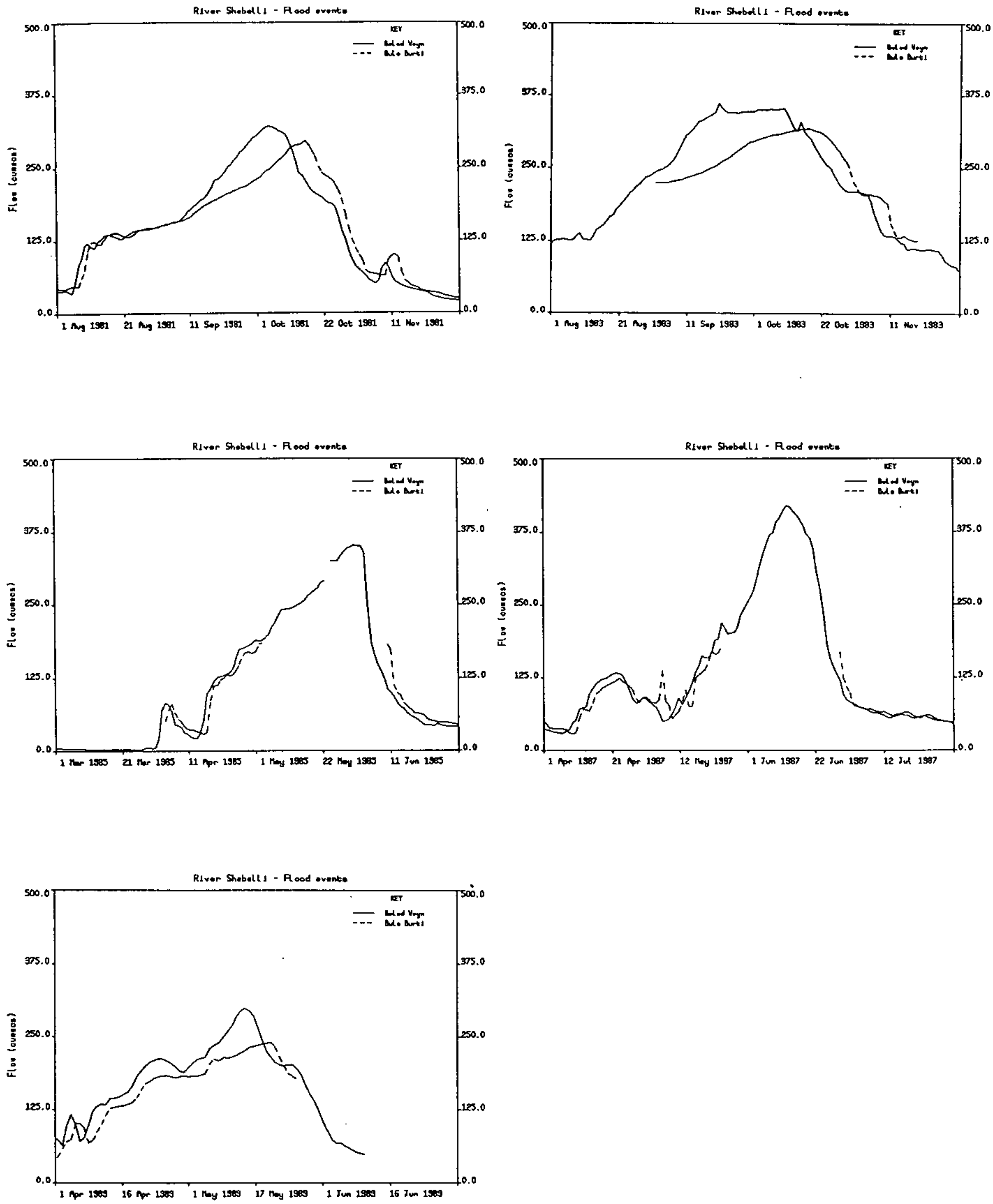


Figure 6 (cont.)

Example of the output from a VPMC model
when applied to the reach between Beled Weyn and Bulo Burti for 1981

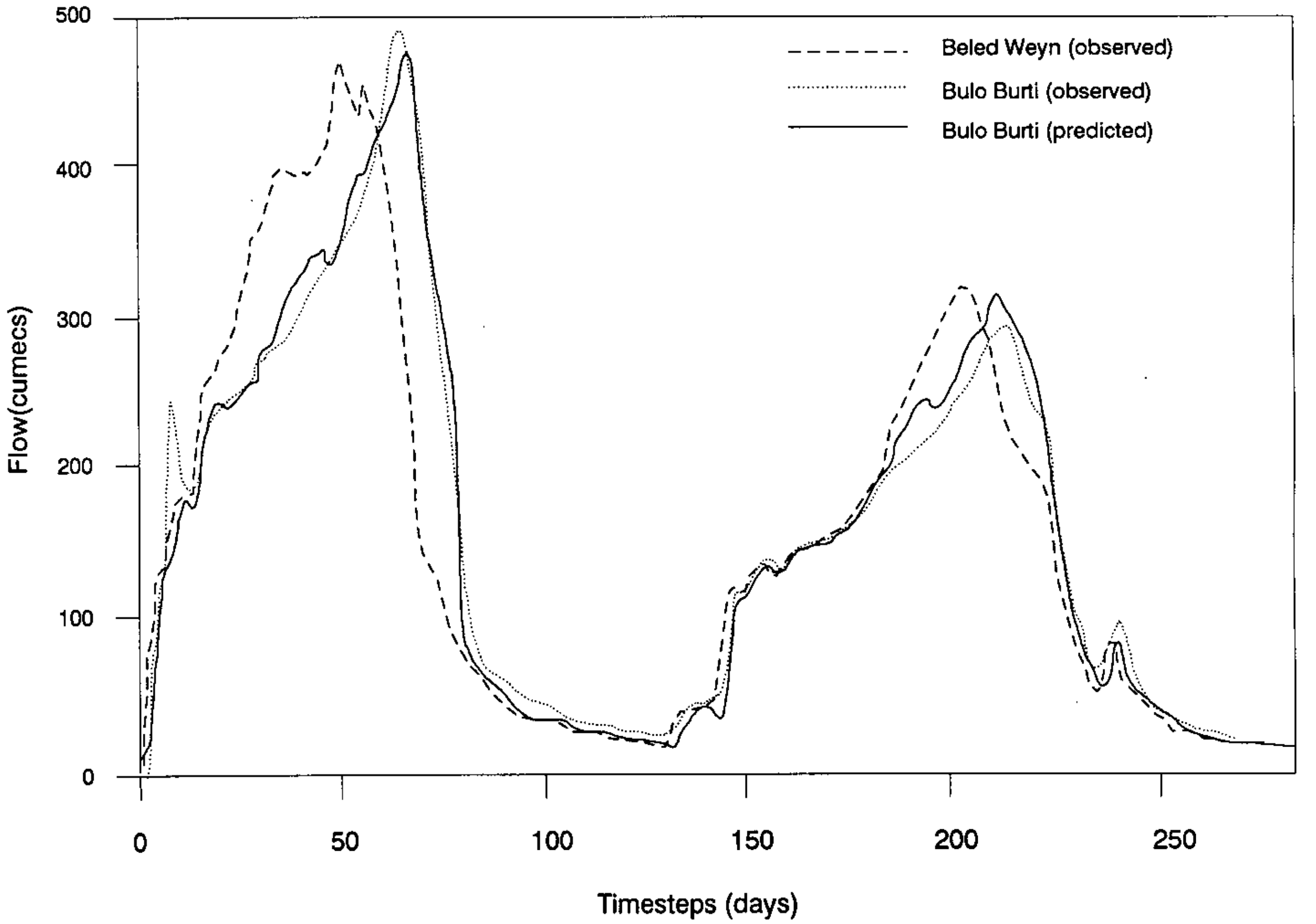


Figure 7

Assumed variation of the parameter p in equation (2) with flow

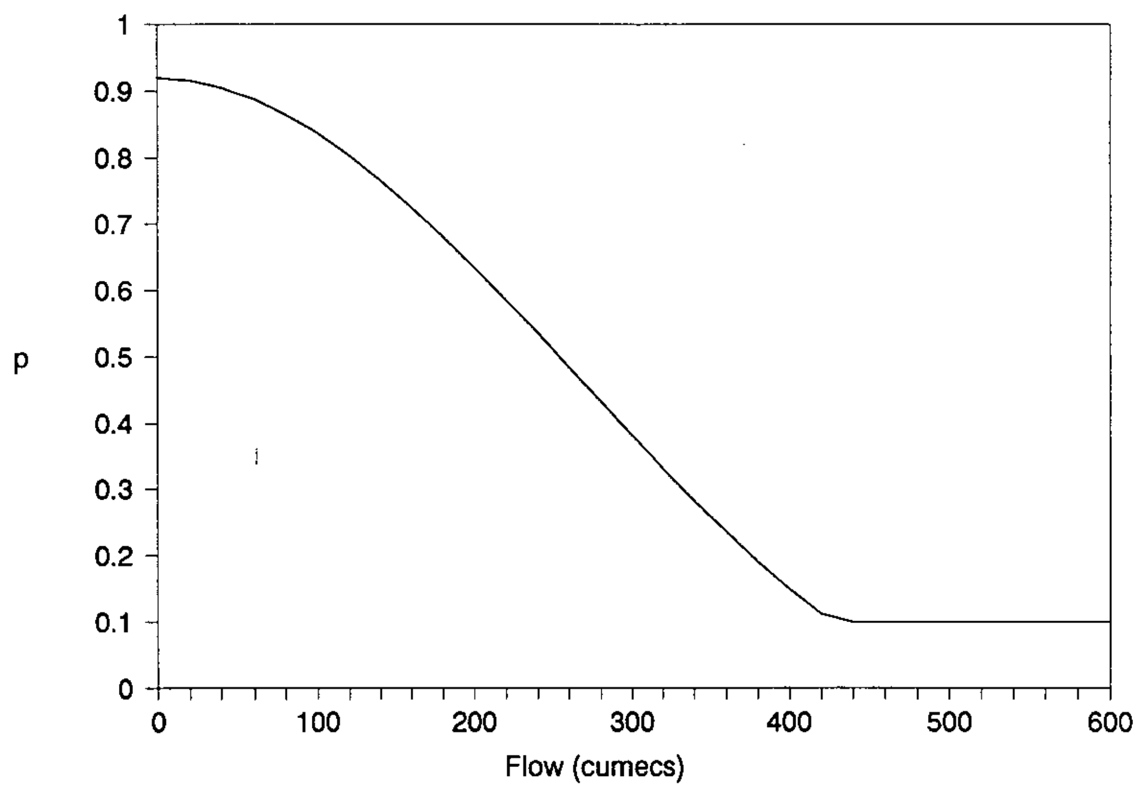
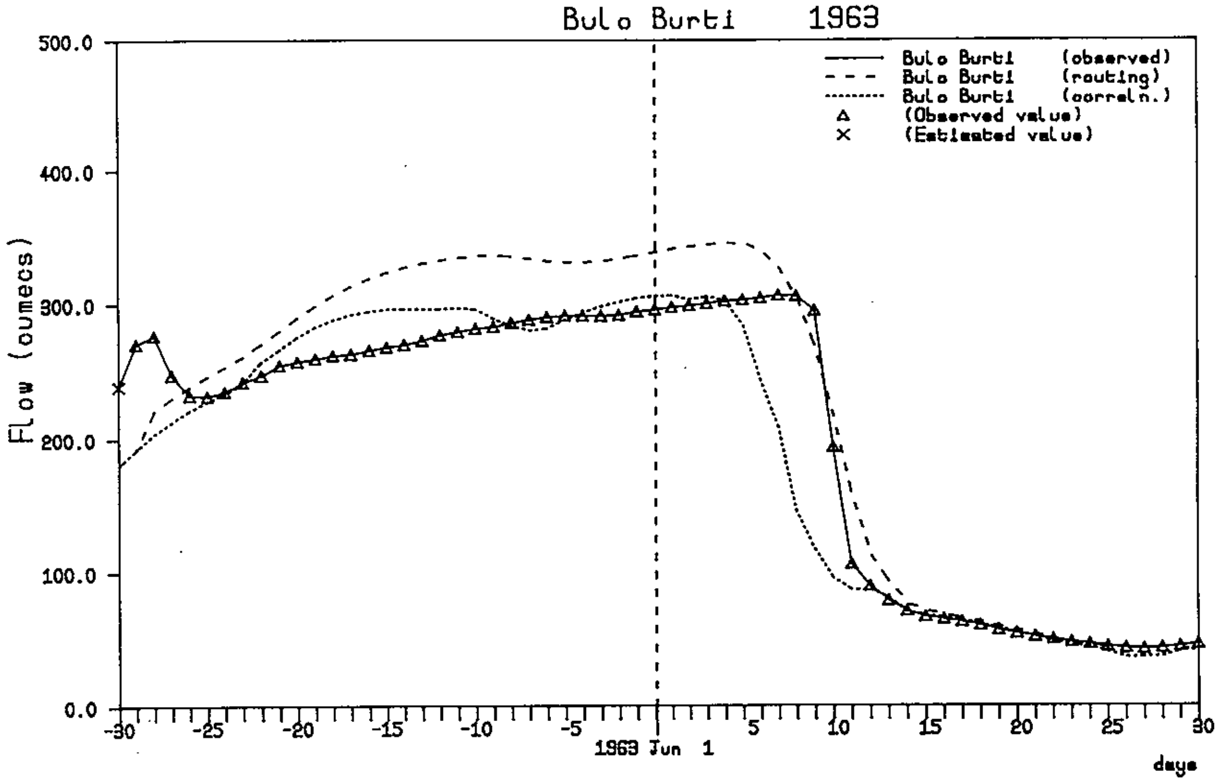


Figure 8

Examples of output from the flow routing model for the River Shebelli

(Beled Weyn to Bulo Burti reach)



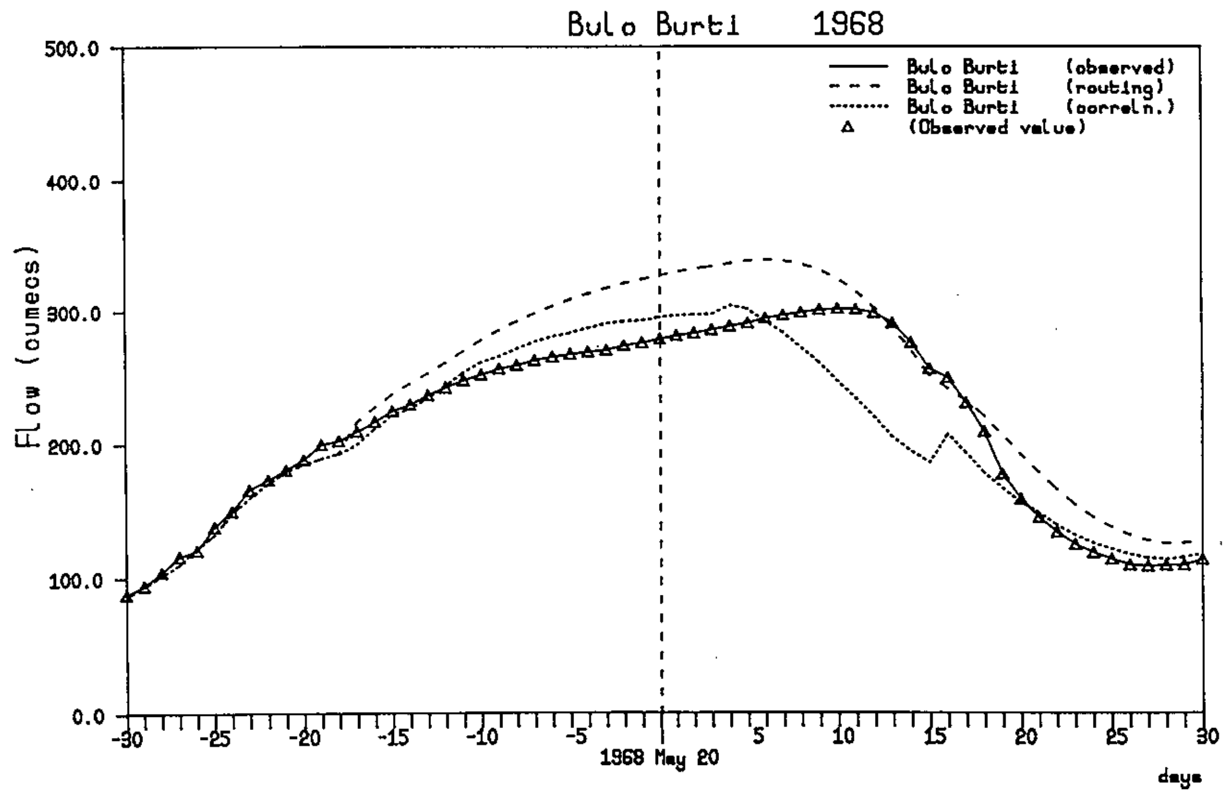


Figure 9

Examples of output from the flow routing model for the River Shebelli

(Beled Weyn to Bulo Burti reach)

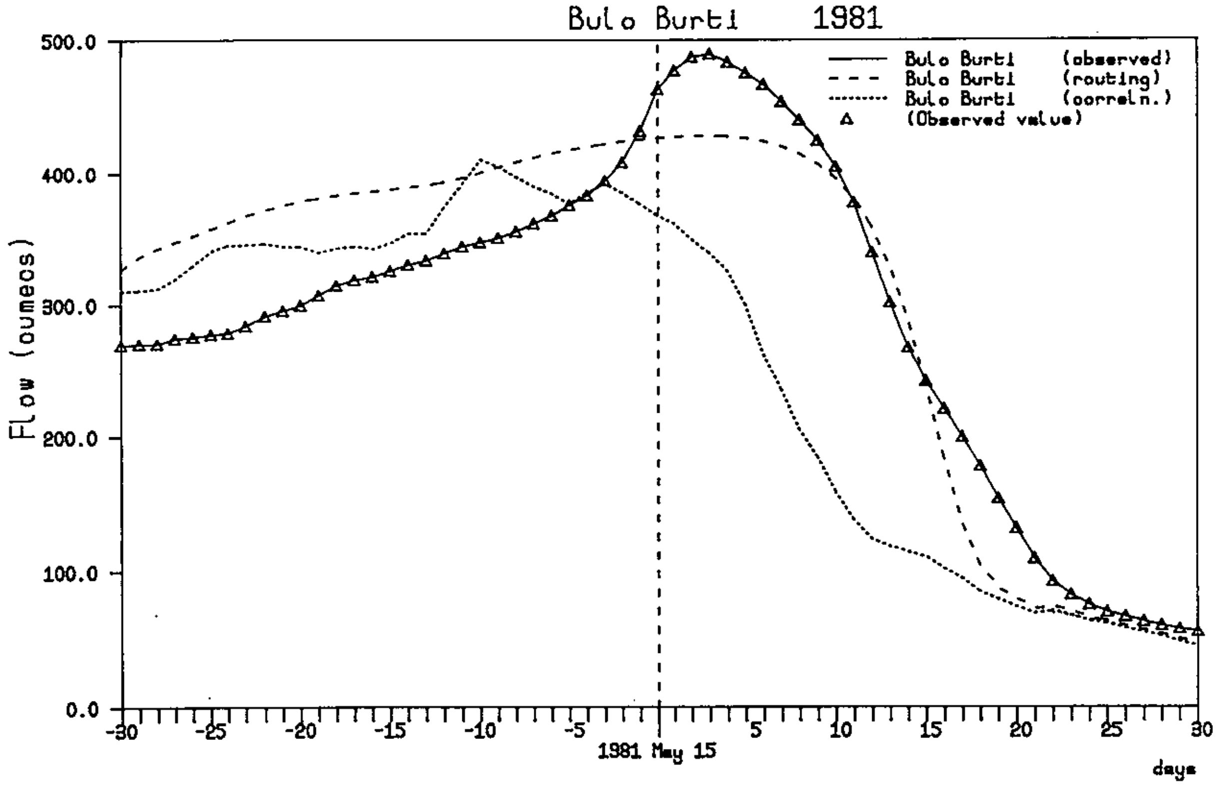
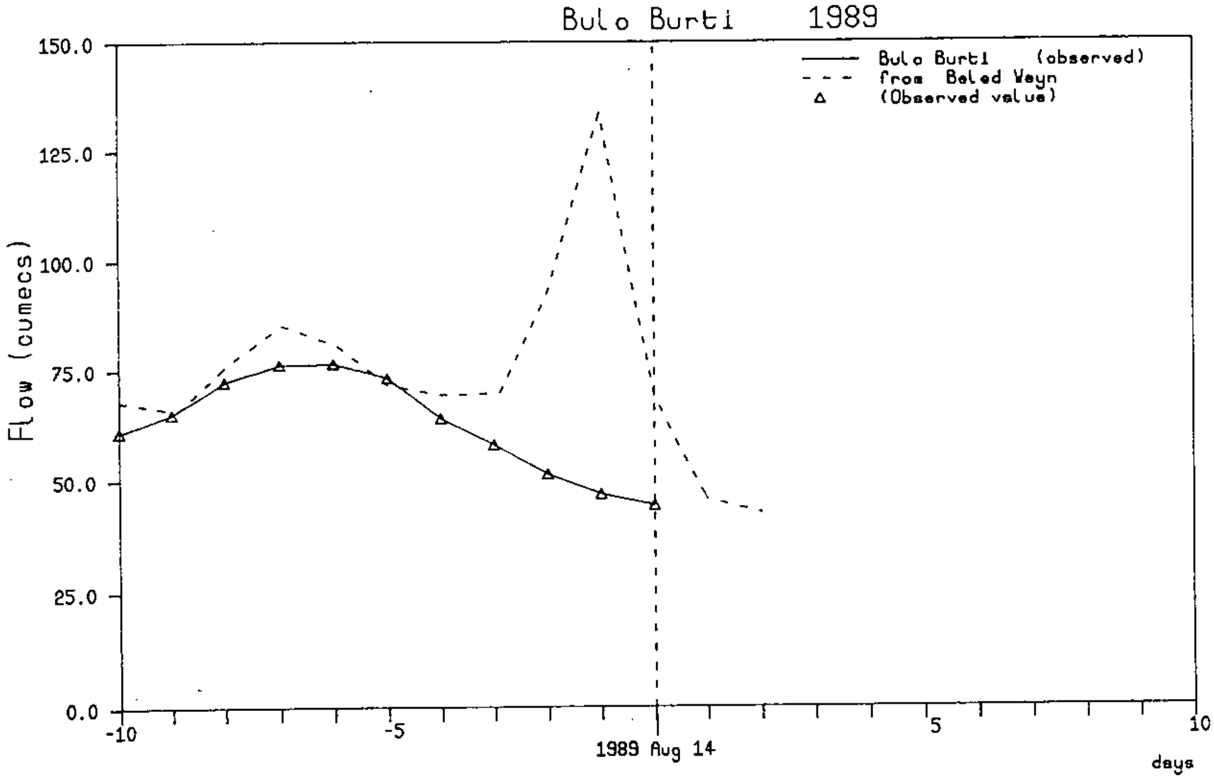


Figure 9 (cont.)

Example of use of lateral flow option to simulate a local runoff event

(a) Simulated event



(b) Predicted downstream hydrograph

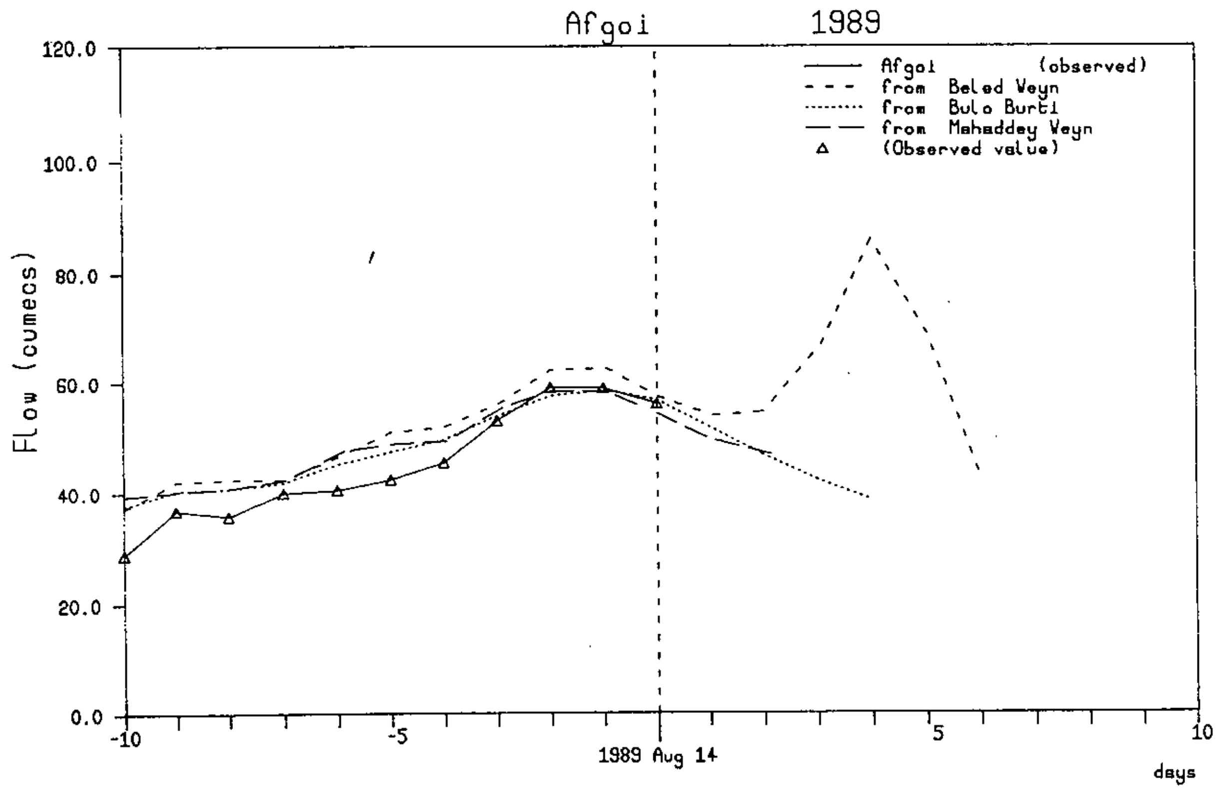


Figure 10

Schematic map of the reservoir system

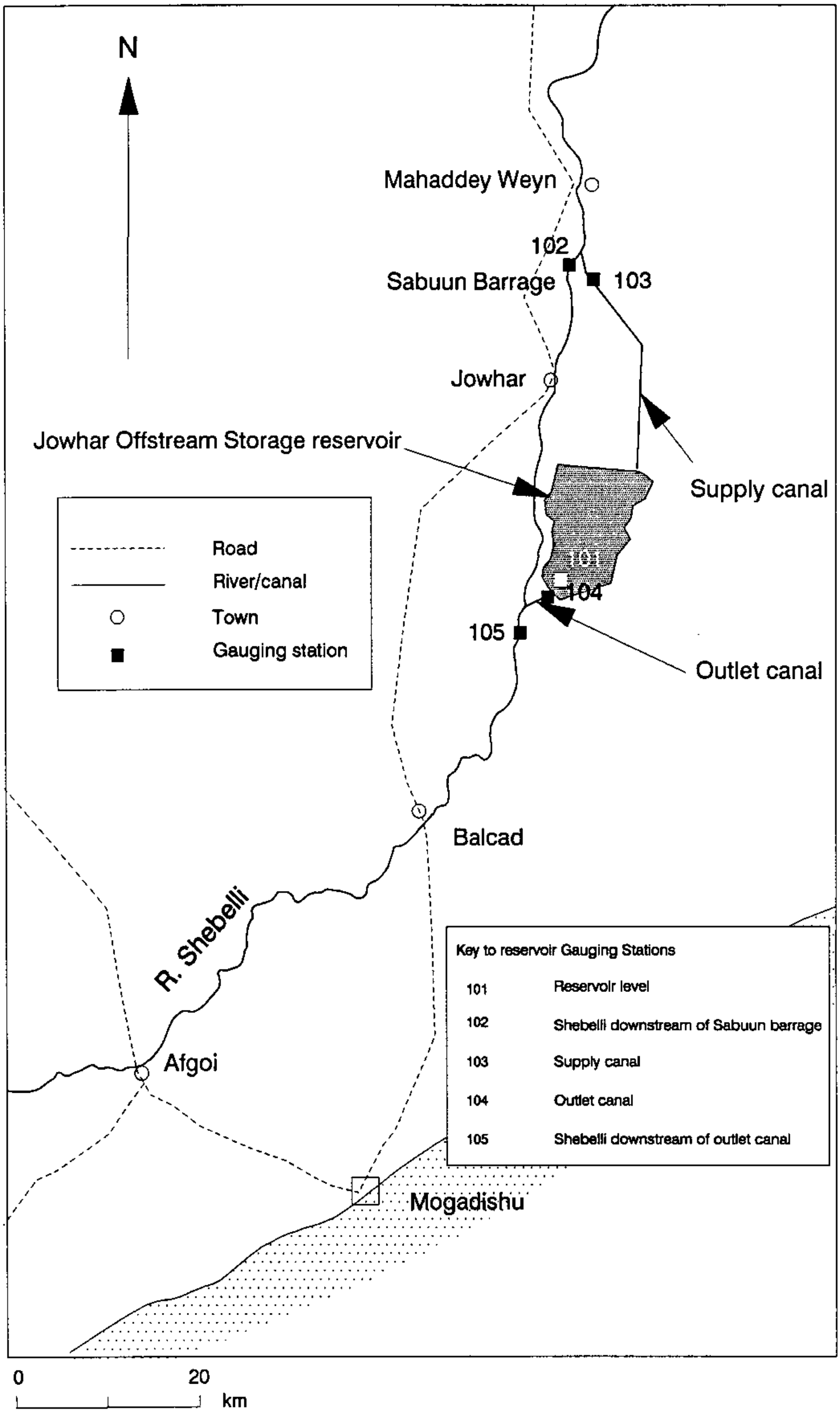


Figure 11

Assumed area/volume curve for the Jowhar Offstream Storage reservoir

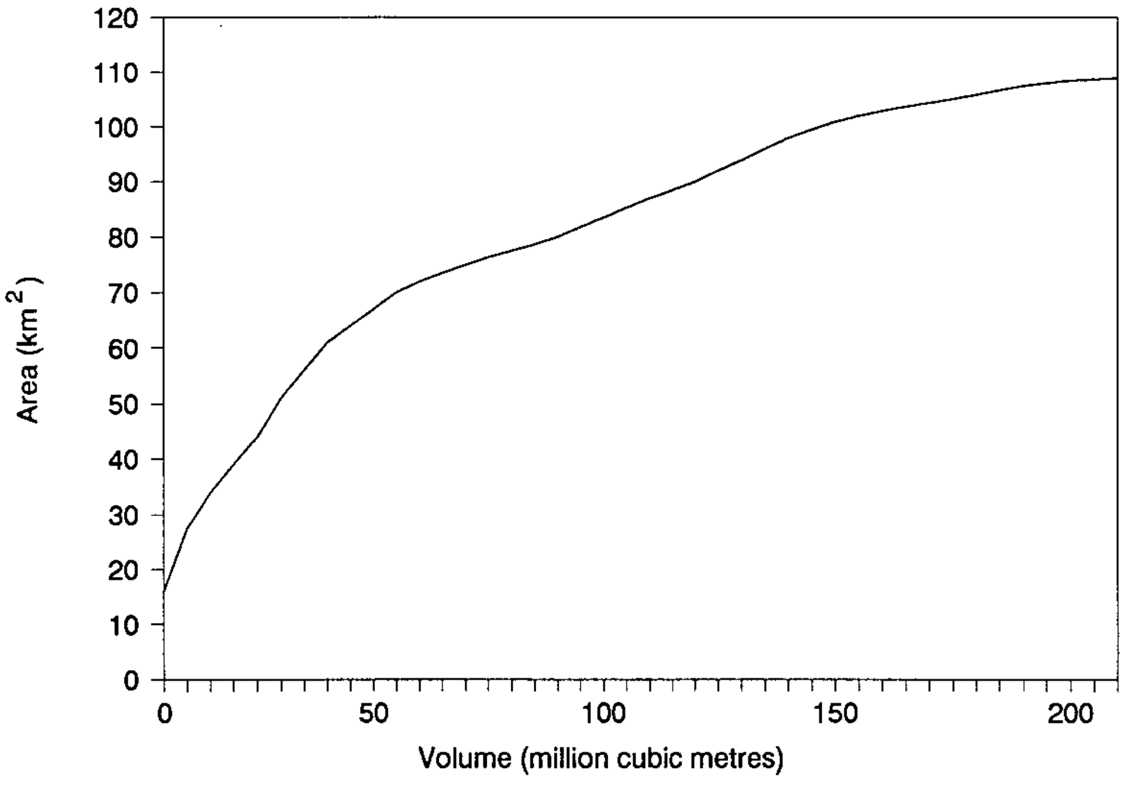


Figure 12

Sketch showing the parameters defining the assumed operating rules for the Type 2 reservoir simulations

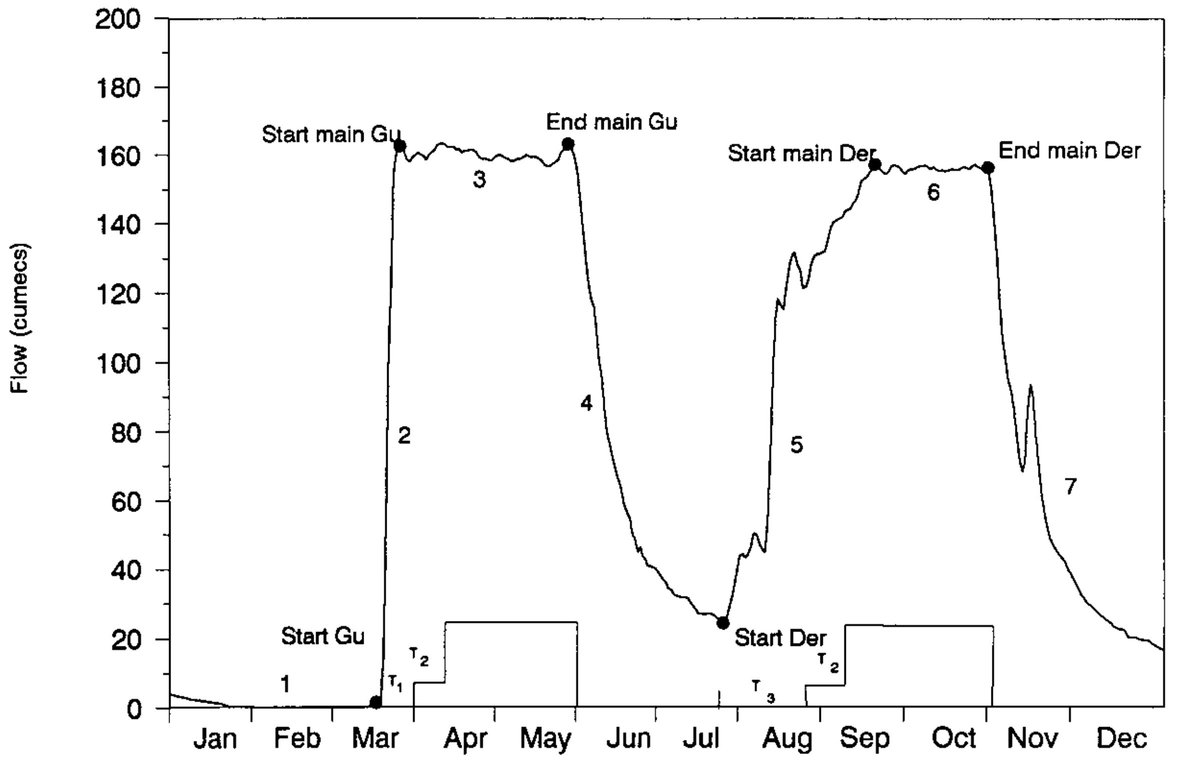
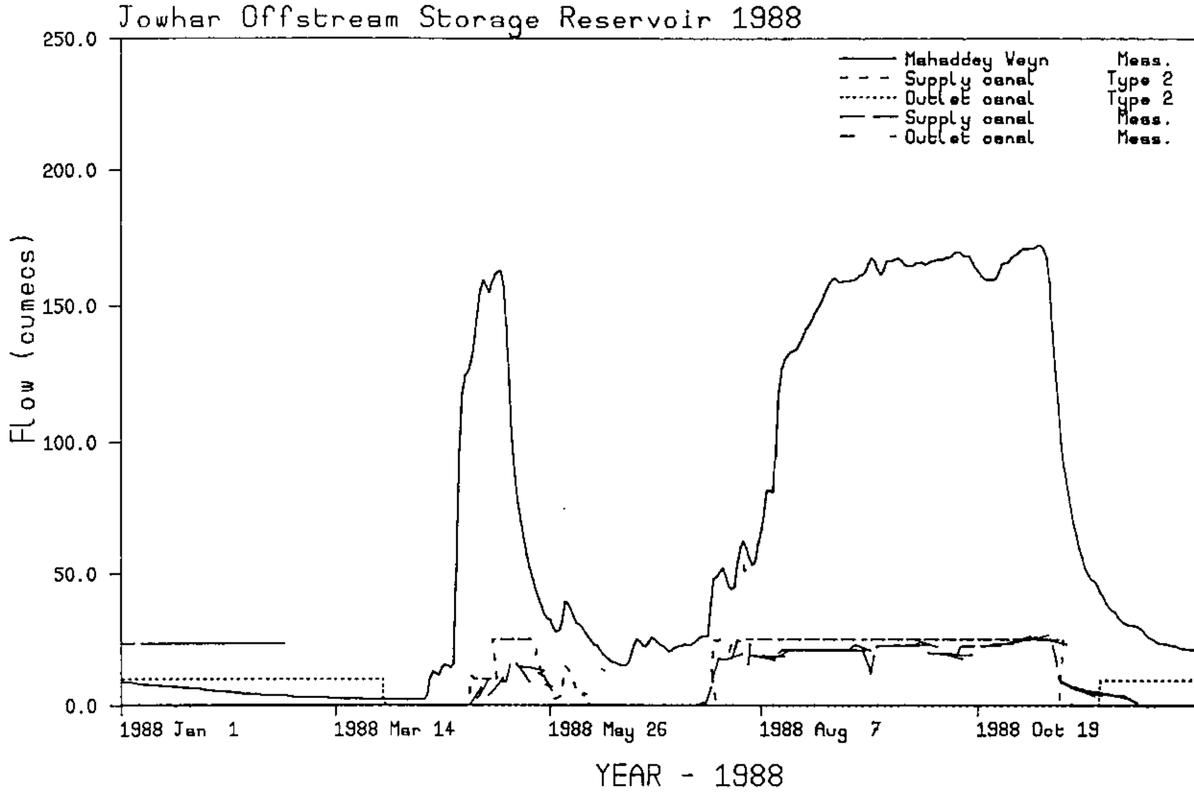


Figure 13

Examples of output from the reservoir model

(a) Predicted canal operations (forecasting mode)



(b) Comparison of predicted and observed volumes

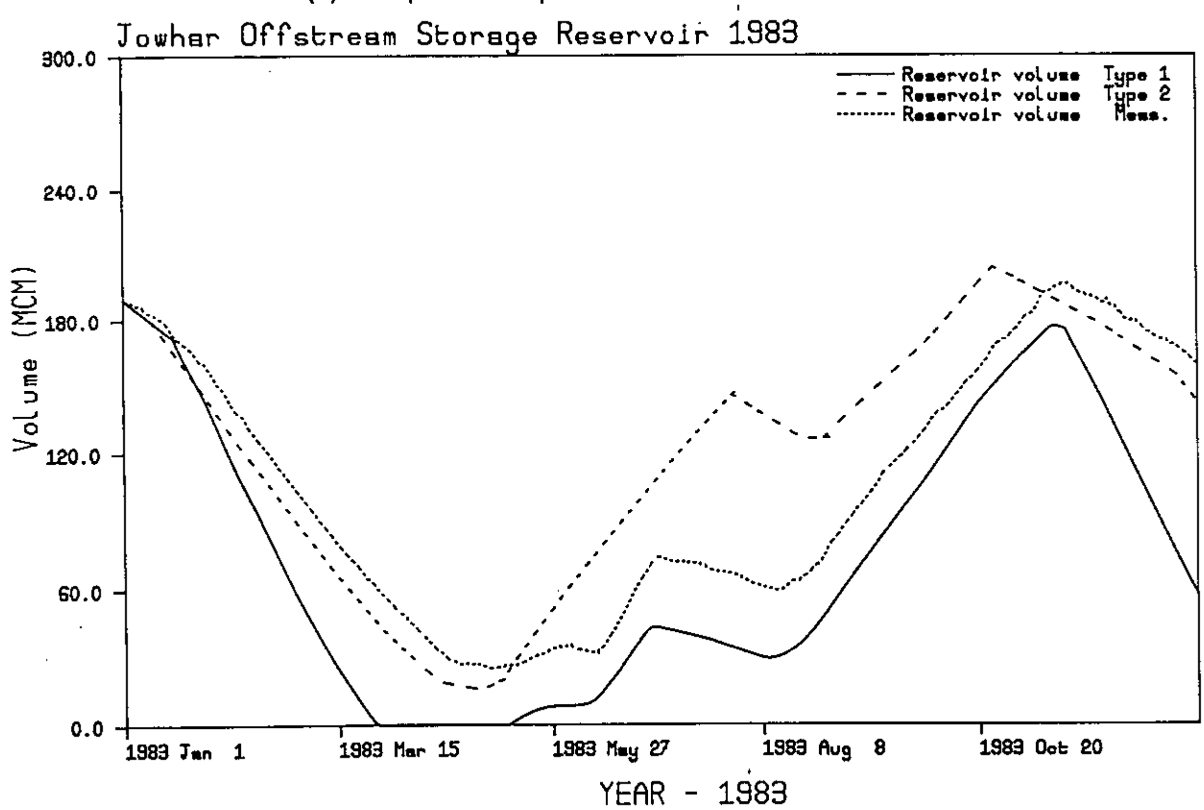


Figure 14

Examples of output from the reservoir model

(c) Comparison of predicted flow in Shebelli with estimated flow requirements

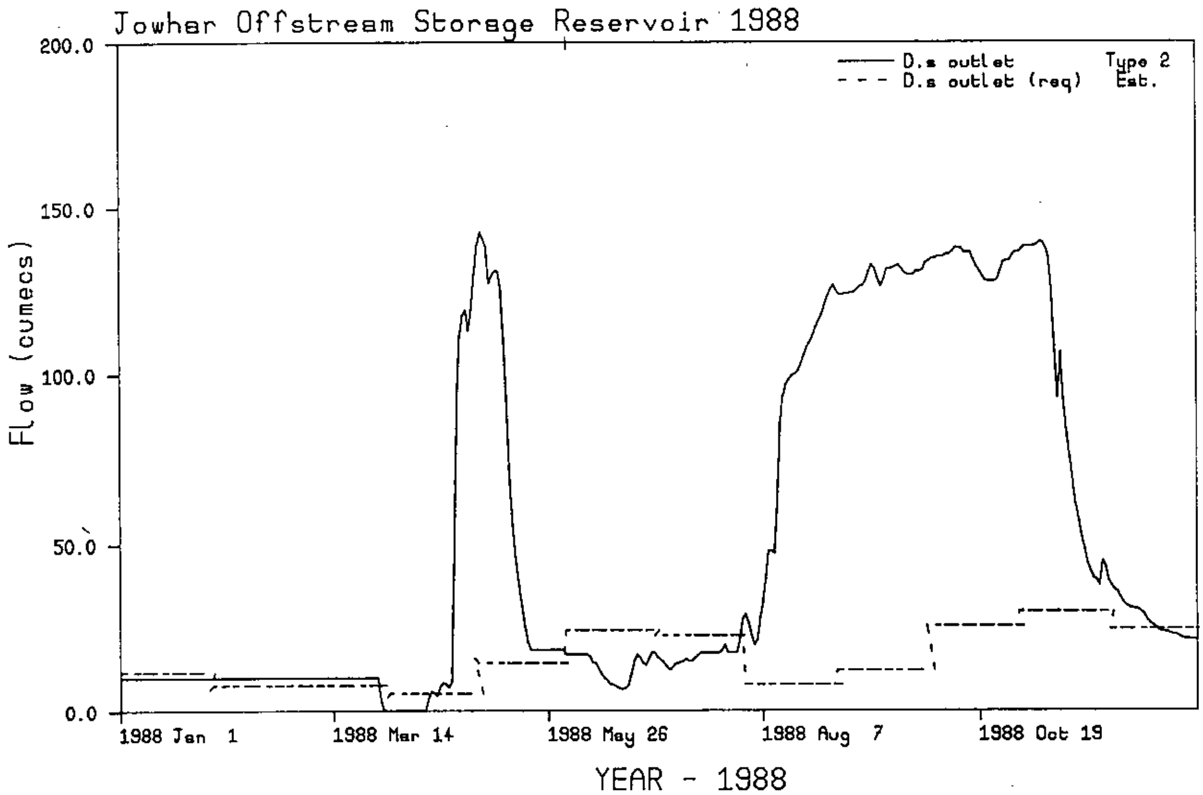


Figure 14 (cont.)

Comparison of forecasts with observed flows for the main gauging stations on the River Shebelli during 1988, 1989 and 1990

(a) Bulo Burti - 2 day forecast

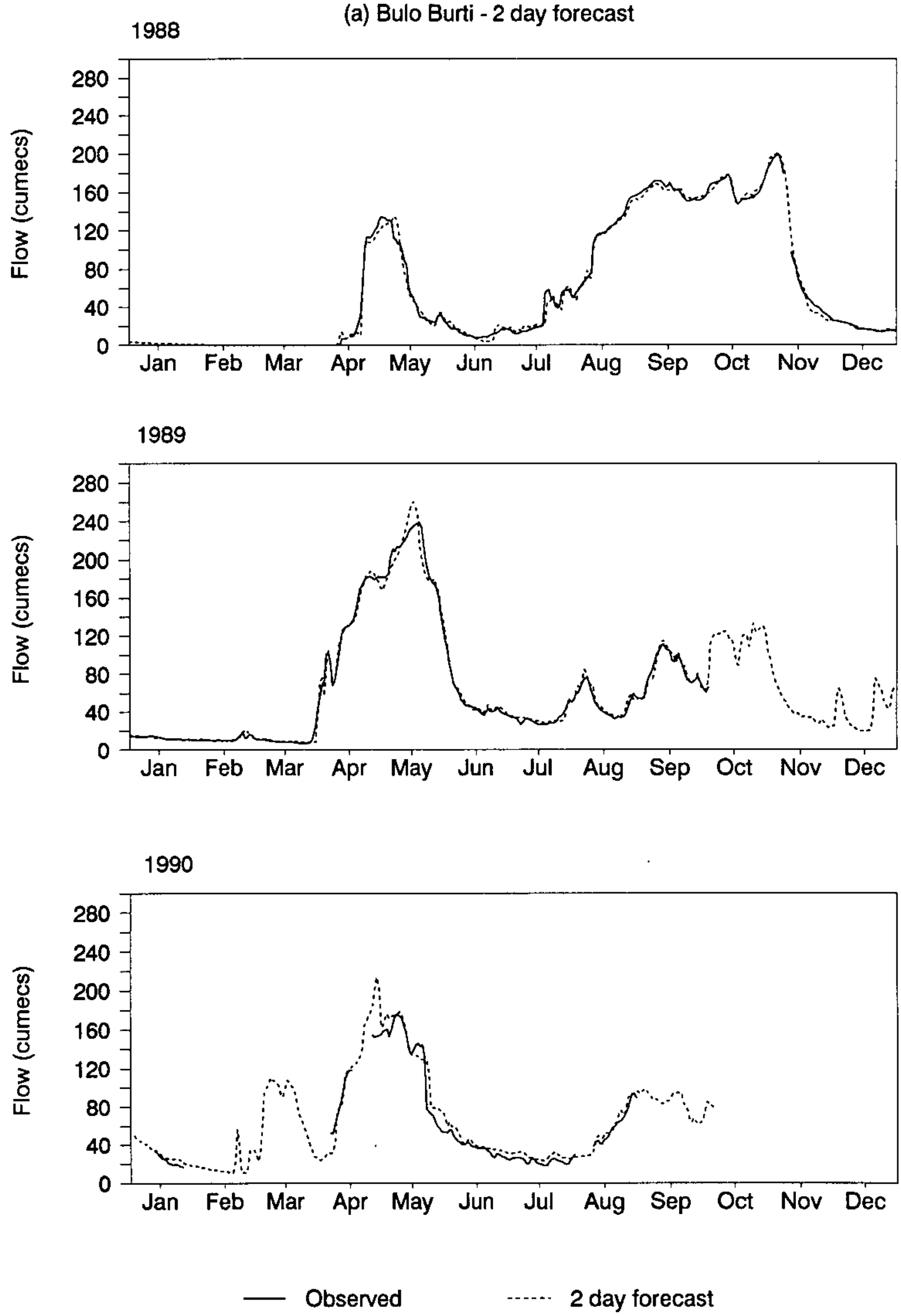


Figure 15a

Comparison of forecasts with observed flows for the main gauging stations on the River Shebelli during 1988, 1989 and 1990

(b) Mahaddey Weyn - 4 day forecast

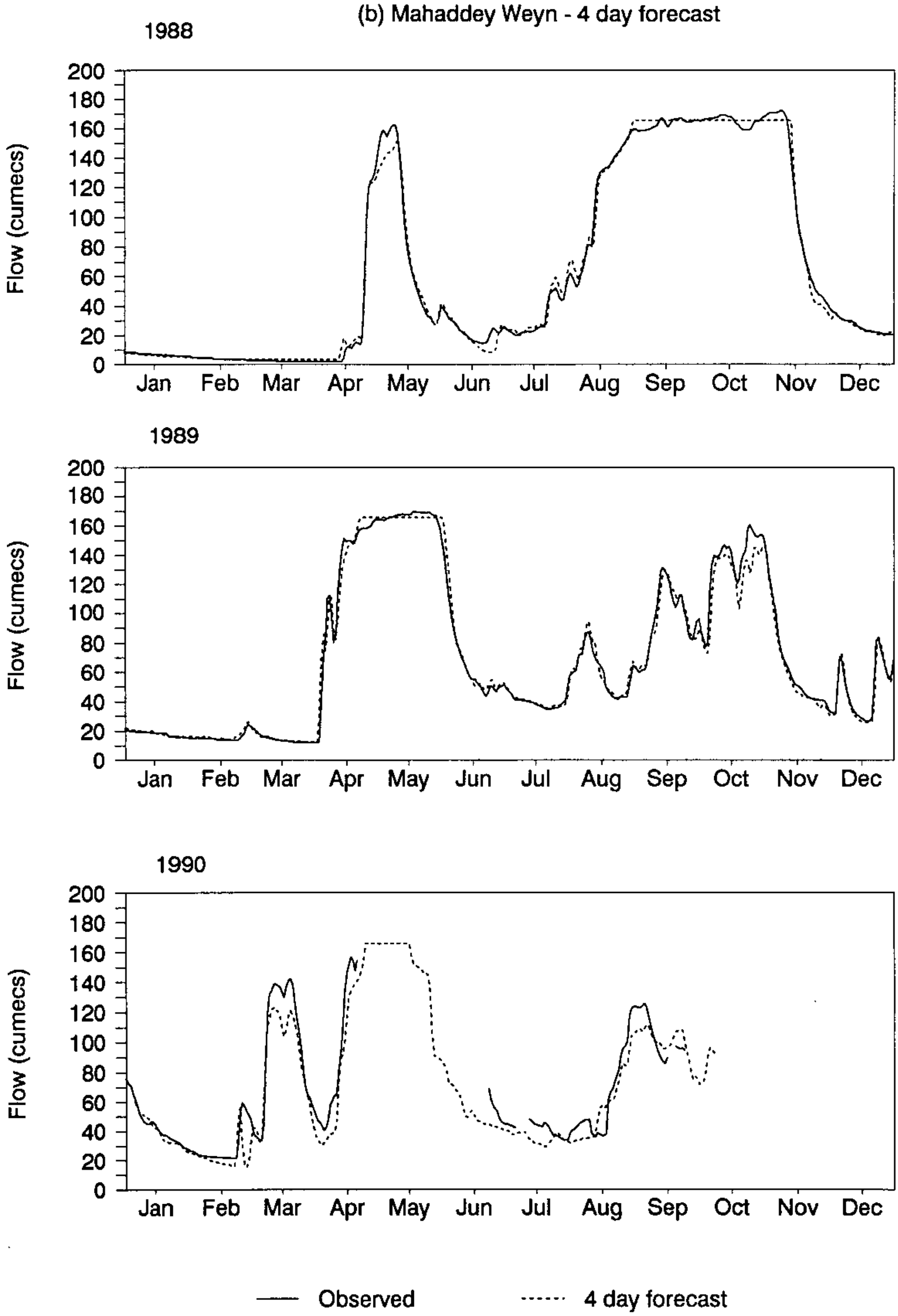


Figure 15b

Comparison of forecasts with observed flows for the main gauging stations on the River Shebelli during 1988, 1989 and 1990

(c) Afgoi - 6 day forecast

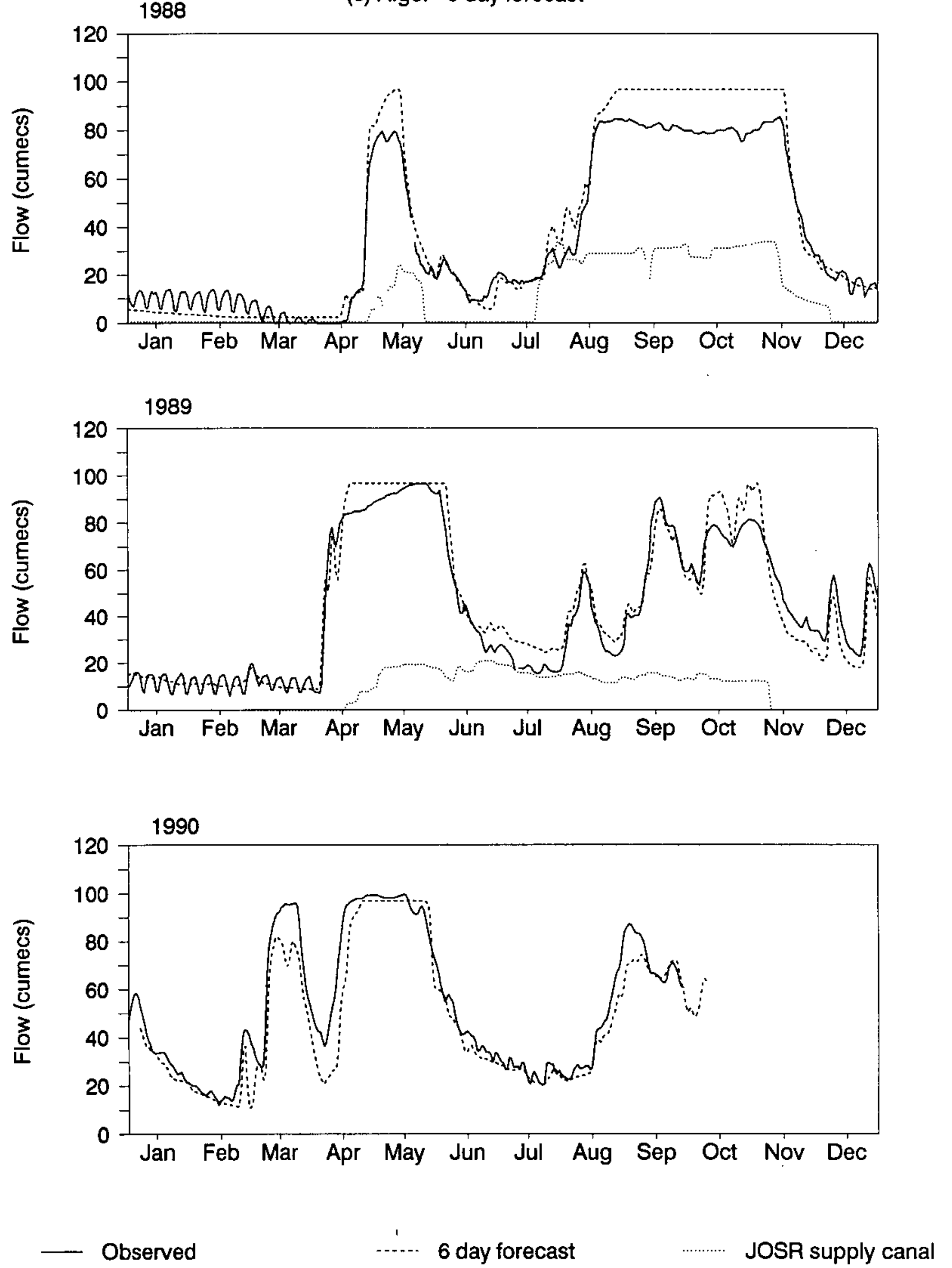


Figure 15c

Comparison of forecasts with observed flows for the main gauging stations on the River Shebelli during 1988, 1989 and 1990

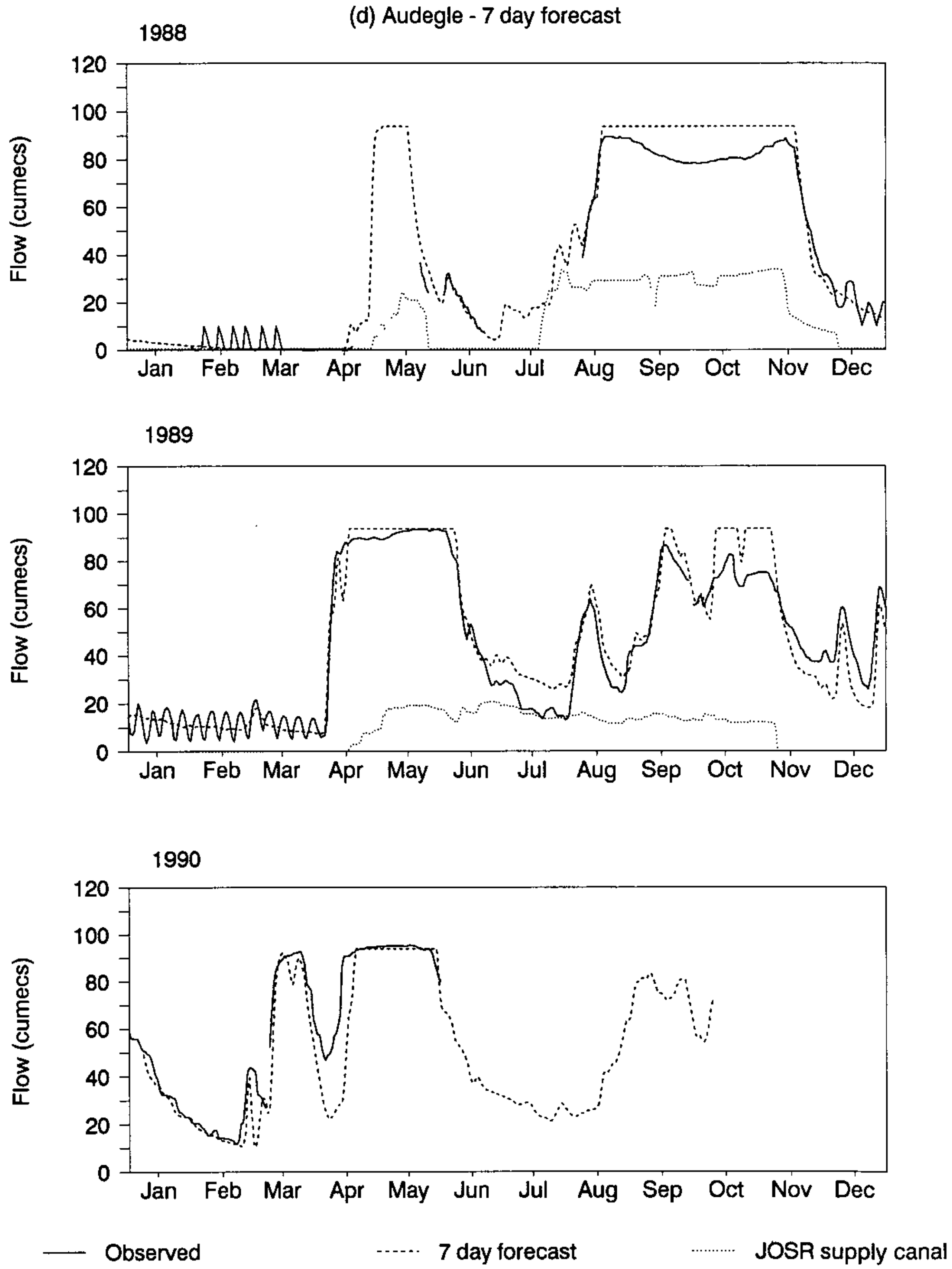


Figure 15d

Comparison of forecasts with observed flows for the main gauging stations on the River Jubba during 1988, 1989 and 1990

(e) Bardheere - 2 day forecast

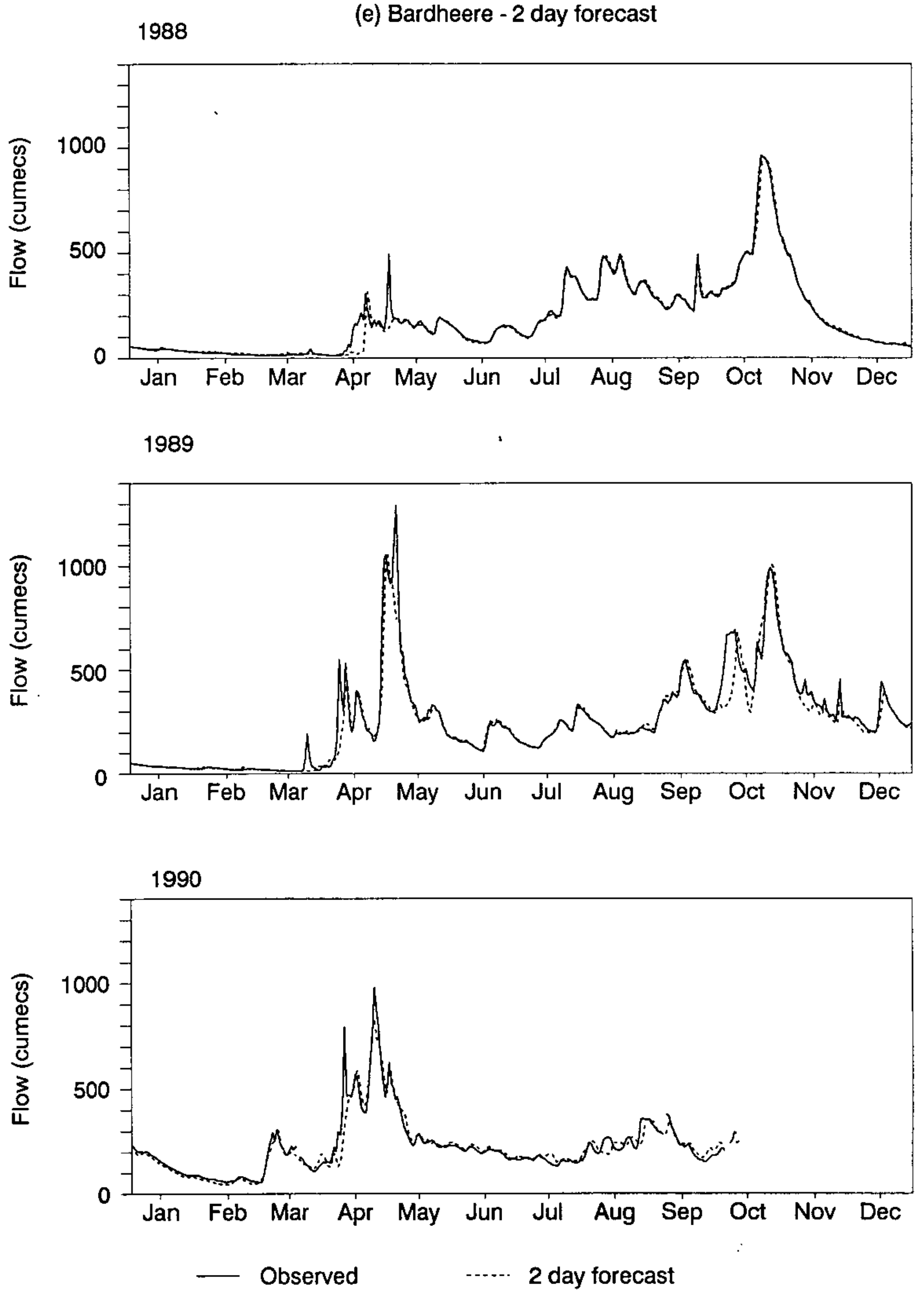


Figure 15e

Comparison of forecasts with observed flows for the main gauging stations on the River Jubba during 1988 and 1989

(f) Mareere - 6 day forecast

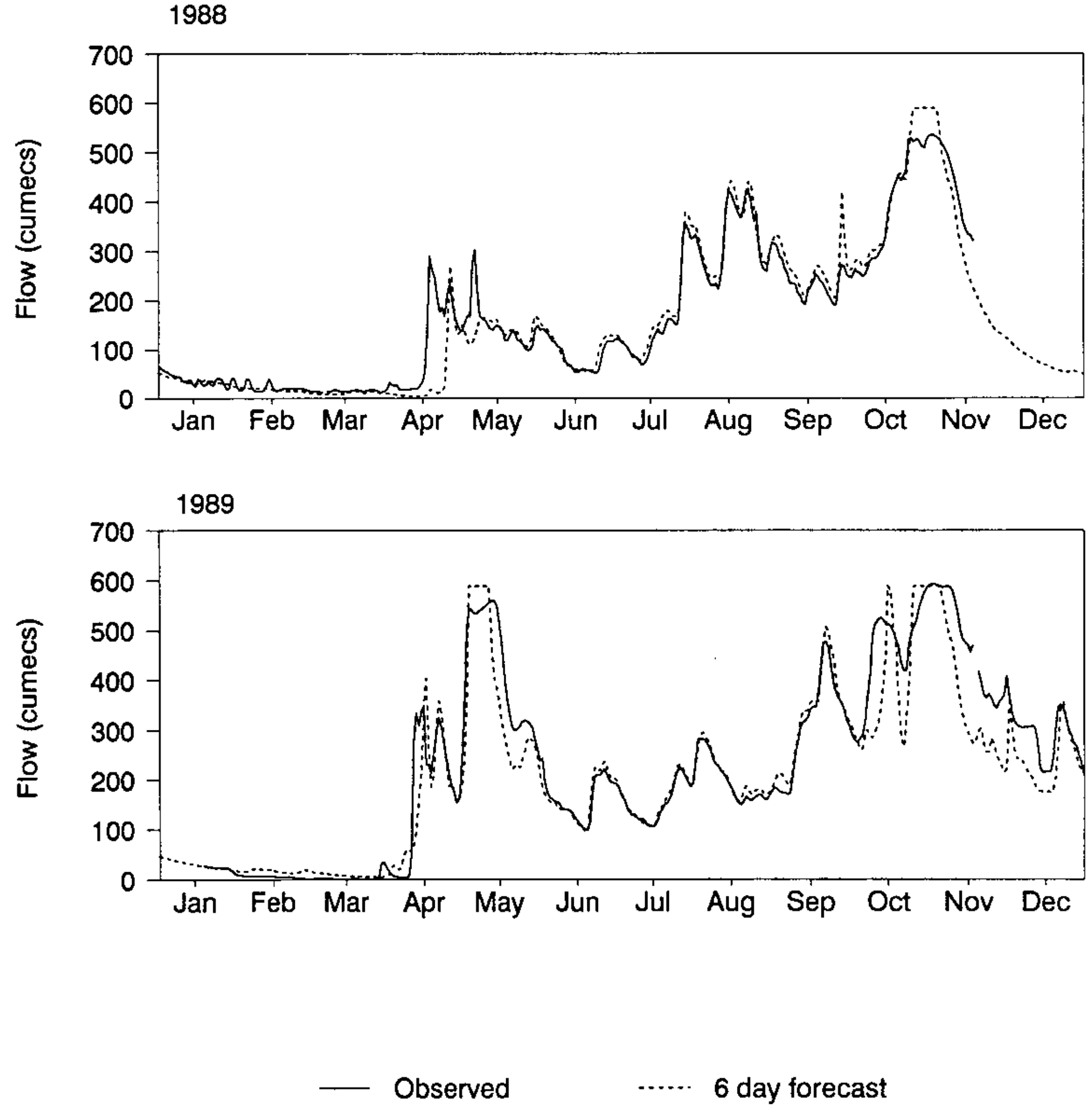
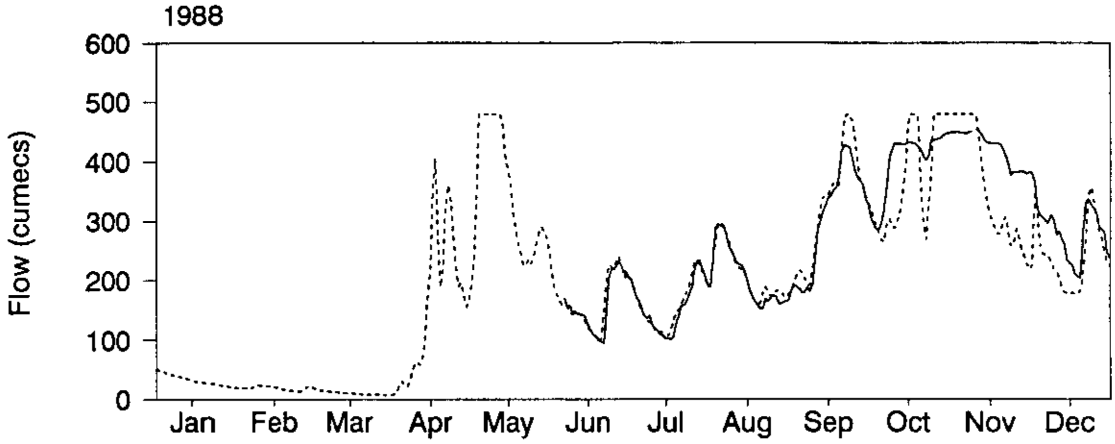


Figure 15f

Comparison of forecasts with observed flows for the main gauging stations on the River Jubba during 1989 and 1990

(g) Jamamme - 7 day forecast



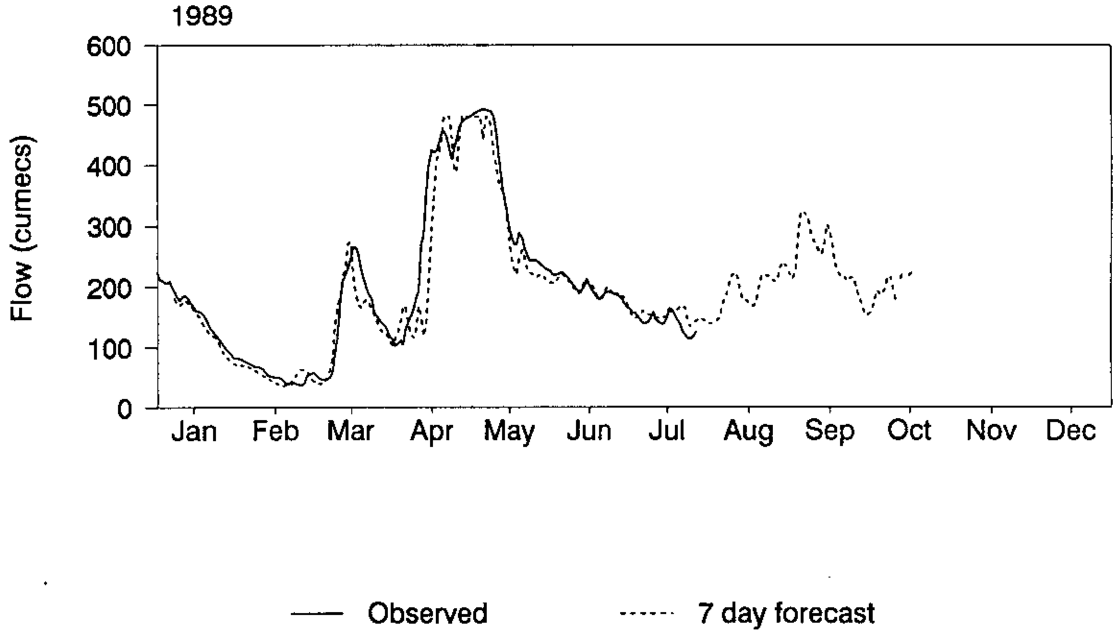


Figure 15g

Comparisons of measured reservoir volumes with the predictions from the Type 1 simulations

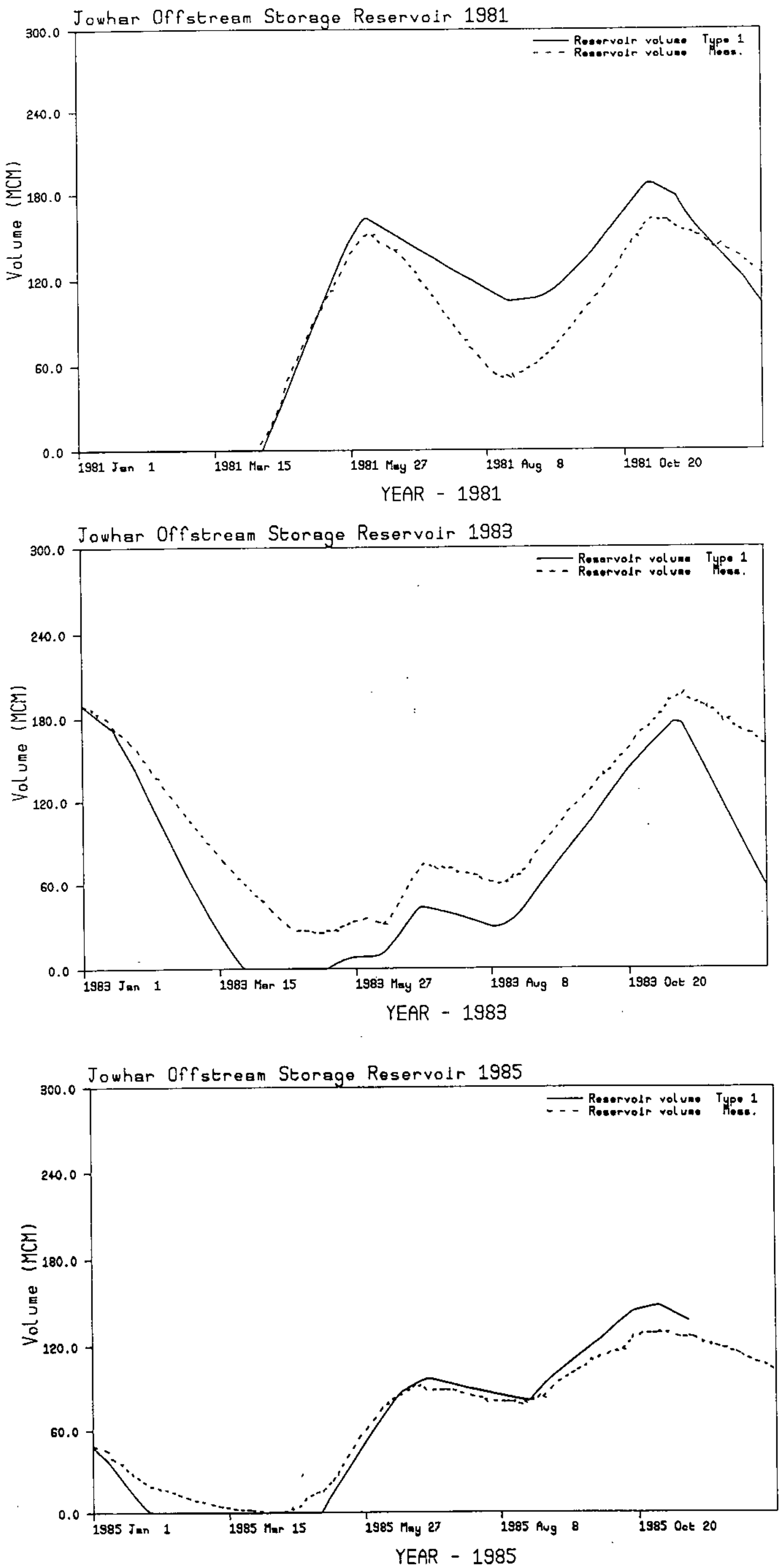


Figure 16

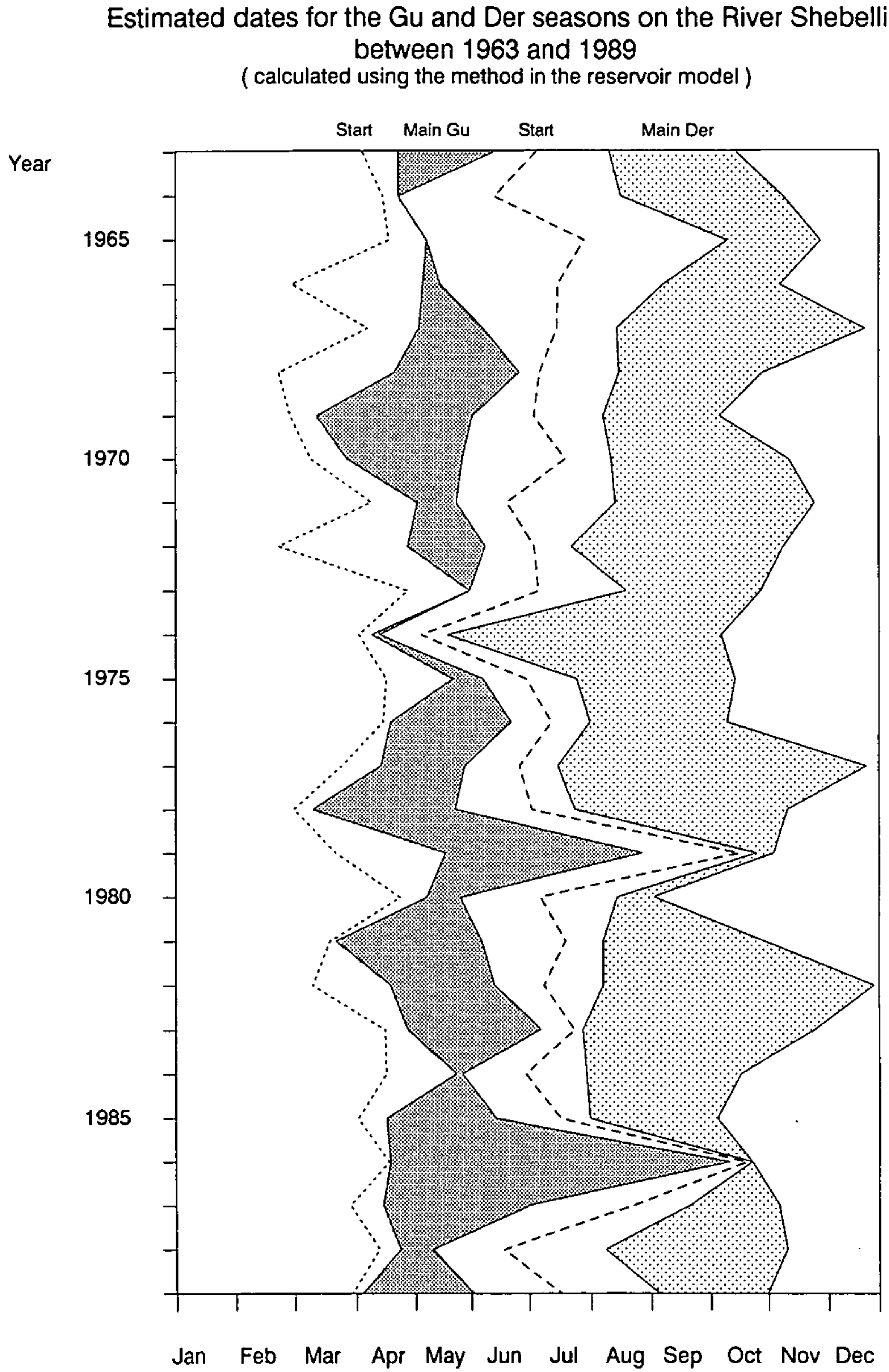

Estimated dates for the Gu and Der seasons on the River Shebelli
between 1963 and 1989
(calculated using the method in the reservoir model)
Start
Main Gu
Start
Main Der
Year
1965
1970
1975
1980
1985
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Figure 17

Predictions of reservoir volumes made for 1987, 1988 and 1989 using the default parameter values supplied with the reservoir model

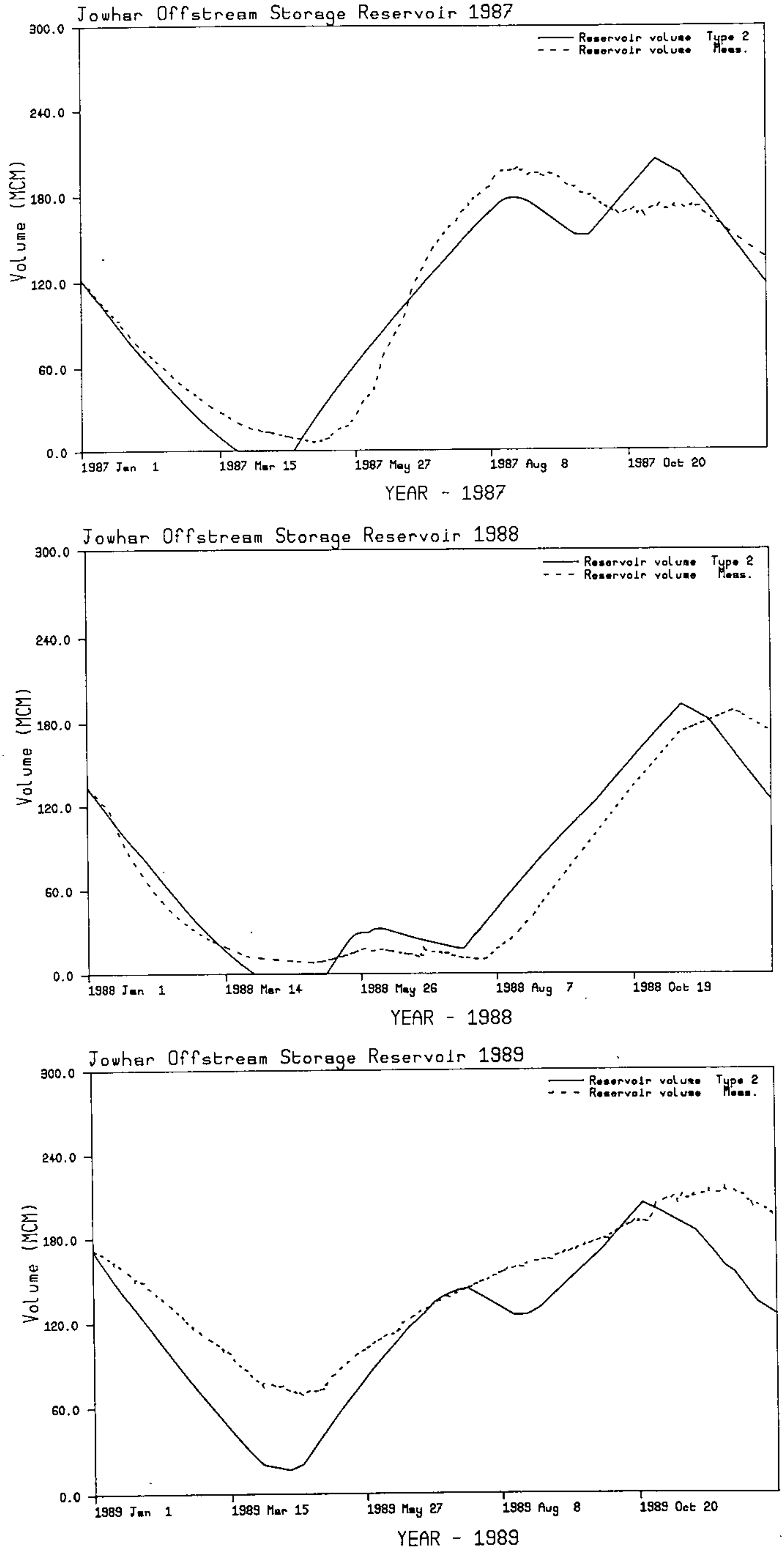
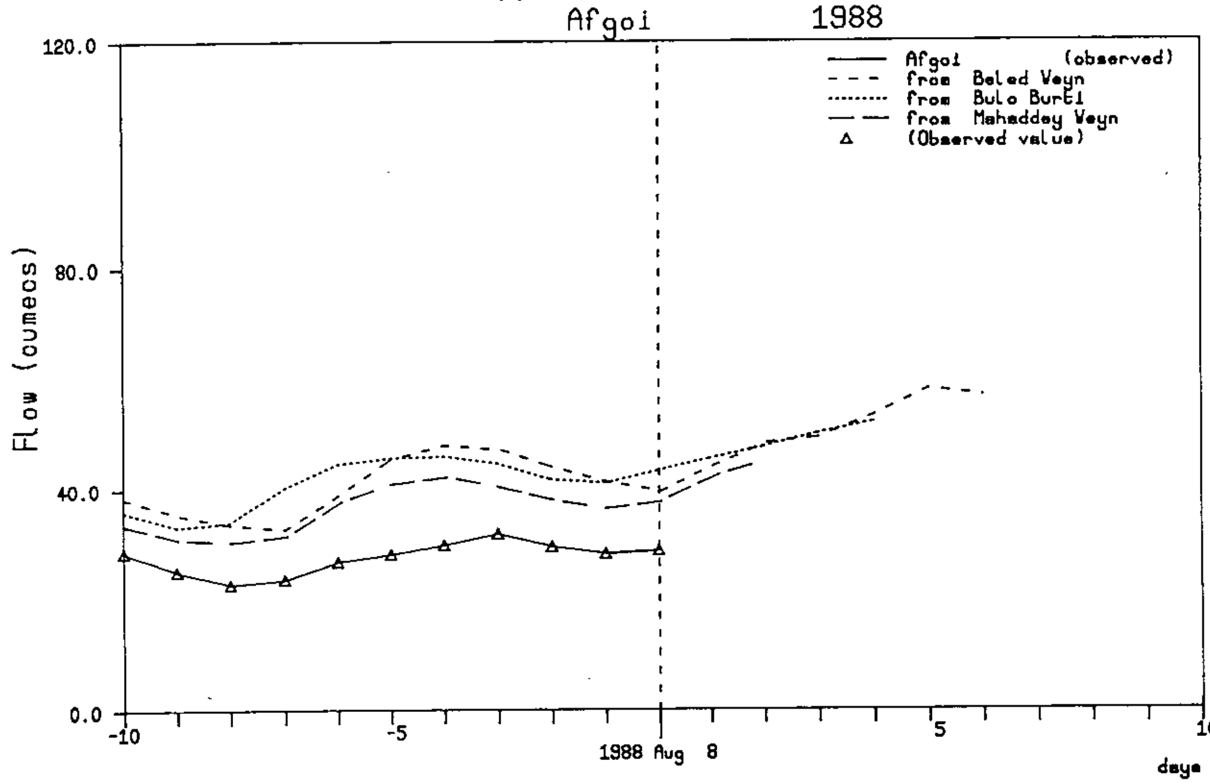


Figure 18

Example of a forecast for the Shebelli in 1989
incorporating the estimated flows in the reservoir canals

(a) Flows omitted



(b) Flows included

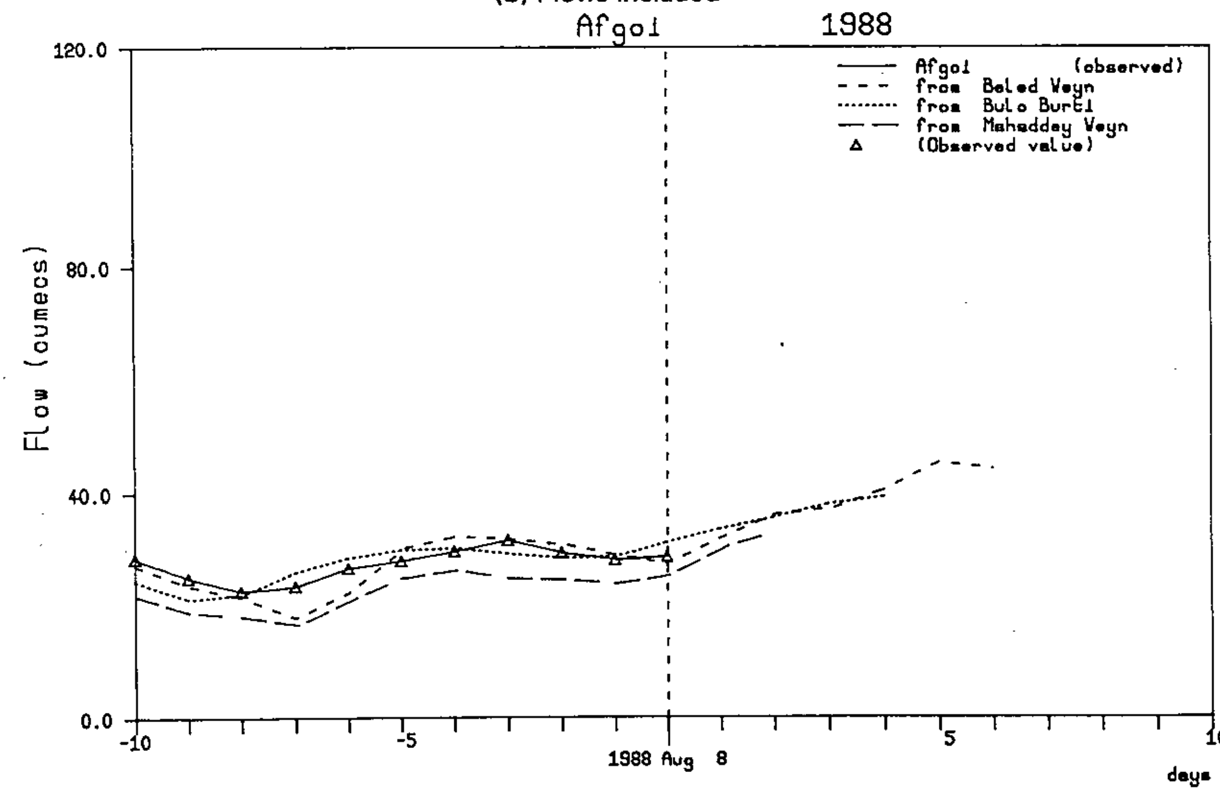


Figure 19

Comparison of observed and predicted reservoir volumes for 1988 assuming the revised operating rules described in the text

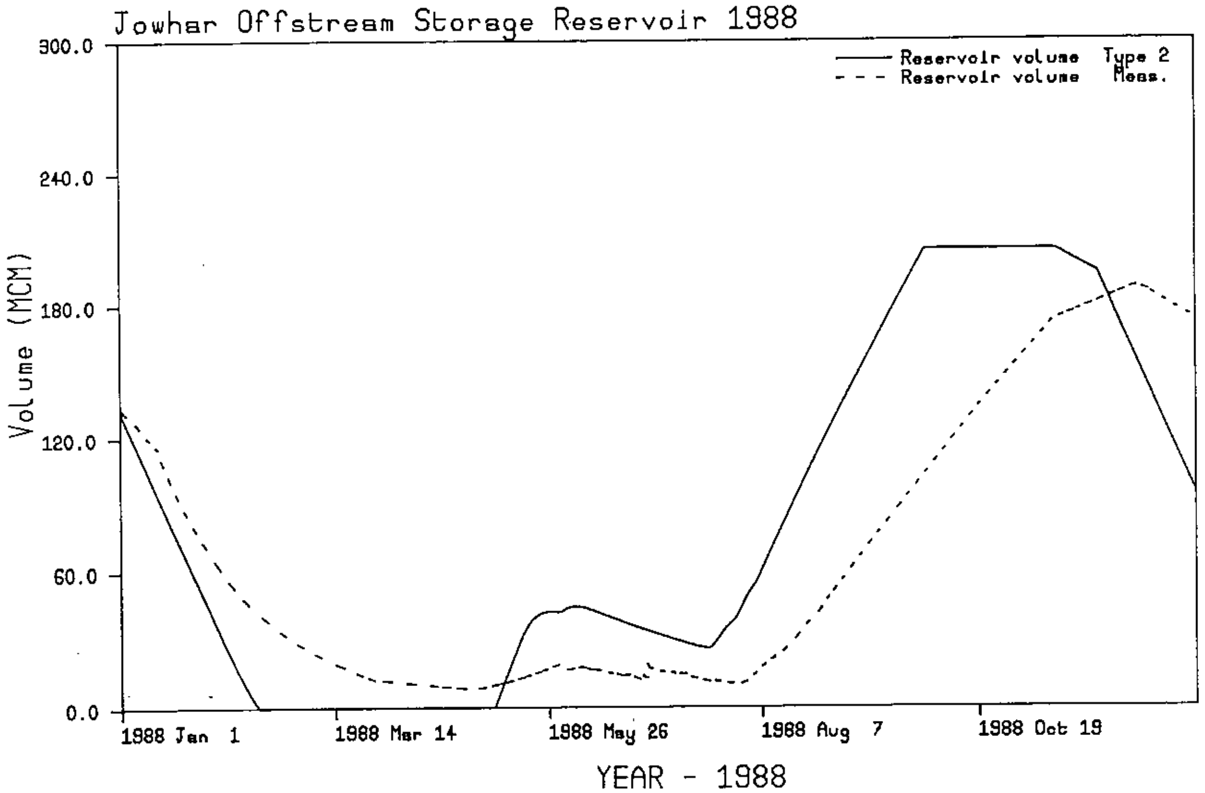
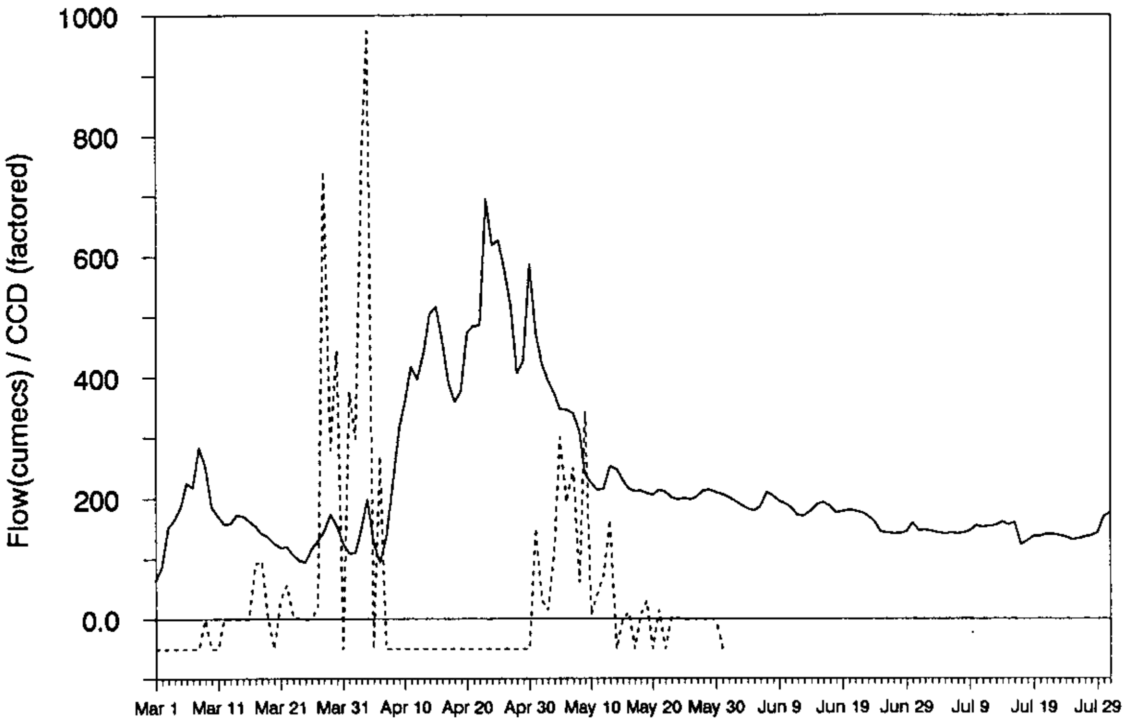


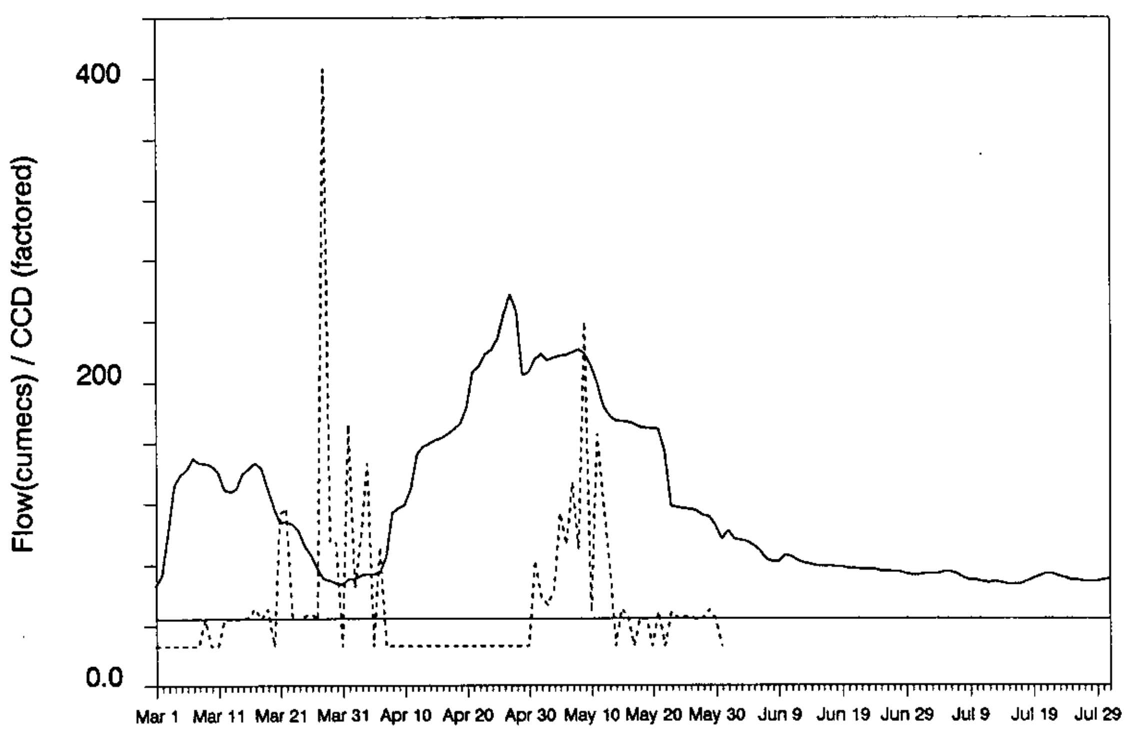
Figure 20

Comparison of measured CCD values with observed daily flows in Somalia during 1990

(a) Lugh Ganana



(b) Beled Weyn



——— Flow ---------- CCD values(factored)

Figure 21