OVERSEAS DEVELOPMENT ADMINISTRATION
MINISTRY OF AGRICULURE, GOVERNMENT OF SOMALIA

HYDROMETRY PROJECT-SOMALIA

Fourth Progress Report
Phase 3
October 1989-April 1990

ARCHIVE

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

in association with

Institute of Hydrology
Wallingford, Oxon OX10 8BB

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SOMALIA HYDROMETRY PROJECT - FOURTH PROGRESS REPORT

SUMMARY

This report describes work on the Somalia Hydrometry Project between October 1989 and April 1990. Office work continued satisfactorily during this period, but fieldwork was very severely restricted by the general situation prevailing in Somalia. The Project Land Rover could only be used for trips to the closest stations on the river Shebelli.

Daily water level data has been received regularly from most of the gauging stations; this has been processed manually and also entered onto the database. A bulletin about the river flows has been produced every ten days and published in cooperation with the Food Early Warning Project. Data from the automatic water level recorder at Bardheere was collected in February, but no visit was possible to Lugh Ganana where the recorder's memory store will now be full.

The main progress on fieldwork was the instituting of regular (weekly) water sampling from the Shebelli at Afgoi, with subsequent analysis for sediment concentration in Mogadishu. The resulting data is presented in this report. The number of discharge measurements was much lower than previously because of the travel restrictions.

The checking of historic river level and flow data for both the Jubba and Shebelli was completed and the Hydrometric Data Book prepared. This contains all available flow data between 1951 and 1989 and is intended to become the definitive record of river flows in Somalia.

Development work continued on the flow forecasting models for the two rivers, and interim versions have been installed on the computer. These have already been helpful for providing interested parties with flood warnings.

Numerous requests for data have been received by the Hydrology Section and appropriate advice and information has been given to various local and international organisations. Close cooperation has been maintained with the National Water Centre and the FEWS Project. The latter link has been expanded by the installation of equipment to receive satellite images from which rainfall estimates may be derived. Quantitative use of the satellite data will be possible when special low power receiving units are installed shortly; this should assist in the provision of flow forecasts.

Throughout the period specific items of work have been treated as training exercises for the counterpart staff. Opportunities for training in fieldwork have necessarily been restricted, but the staff have made good progress with sediment sampling and analysis, and have continued with all relevant office work. One of the staff members attended a UNESCO course for Hydrology Technicians in Zimbabwe early in 1990, but regrettably he had not returned to work in the Hydrology Section by the end of the period. Another is due to be doing postgraduate training in the UK in 1990/91.

The Project will be continuing until the end of 1990, with the Final Report being produced shortly thereafter. The main emphasis in the remaining period will be on continuing the training of the local staff to carry out the regular office work of the Section and whatever fieldwork is possible. The flow forecasting models will be completed and rainfall estimates from the satellite data will be analysed when they are available.

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1. INTRODUCTION

This Progress Report describes work on the Somalia Hydrometry Project during the period from October 1989 to April 1990. In order that it can be read without the need for immediate reference to the previous reports, much of the Introduction and some other general sections and points from the previous Progress Reports have been repeated here. The report comprises a brief summary of progress during the period together with a set of appendices giving some additional details. This report is an addition to the original schedule of reports because it was agreed that funds left over from the existing Project budget could be used to support a continuation of the Project from the planned finish in March 1990 until the end of the year. The Final Report will be produced at the beginning of 1991 when work in Somalia has been completed. The other major publication arising from the Project is the Hydrometric Data Book which has just been published. The Data Book covers flow data to the end of 1989; the Final Report will include a supplement covering available data for 1990.

The project aims to assist the Government of Somalia in the day-to-day management of the Jubba and Shebelli rivers, and to improve the reliability of the hydrometric database for both current and historic data. The locations of the gauging stations are shown in Figure 1. The work is the responsibility of the Hydrology Section of the Directorate of Irrigation and Land Use in the Ministry of Agriculture (MOA). Phase 3 of the Project from March 1988 to December 1990 follows work by the Consultants over a period of about two and a half years between 1983 and 1986.

Appendix A describes the state of the rivers during 1989, together with hydrographs, and Appendix B contains details of the fieldwork during the period. Appendix C covers the work of the Programmer/hydrologist, Dr K J Sene, on the computer models of the Jubba and Shebelli rivers and the data infilling carried out prior to the publication of the Data Book.

2. STAFFING

2.1 Expatriate Staff

Five expatriate staff members (three Sir M MacDonald & Partners and two from the Institute of Hydrology) were scheduled to work on the project in Somalia; three of them have made inputs during this period. One staff member, the Programmer/ hydrologist, has also worked on the project in the UK during this period, and there has been intermittent Head Office backup when required.

2.2 Staff Movements

The Field Hydrologist (Mr P F Ede, MMP) was resident throughout the period except for a period of leave from March 18th to April 22nd; this coincided with Ramadan when there are some restrictions on work in Somalia. The Programmer/hydrologist (Dr K J Sene, IH) worked in Somalia from January 1st until March 4th. Mr P H W Bray, Project Coordinator (MMP), visited Somalia in November and worked briefly on the project.

2.3 Local Staff

The main members of the local staff have been as follows:

Ali Yusuf Wayrax	(on a course in Zimbabwe from January)
Ibrahim Abdullahi Sheikh Ahmed	
Zakia Abdissalam Alim	
Ahmed Nur Garash	(driver)

The driver has been employed by the Project; the remaining staff are employed by the Ministry of Agriculture to work in the Hydrology Section. The work of the Section comes under the overall direction of Omar Haji Dualeh, the Director of Irrigation and Land Use.

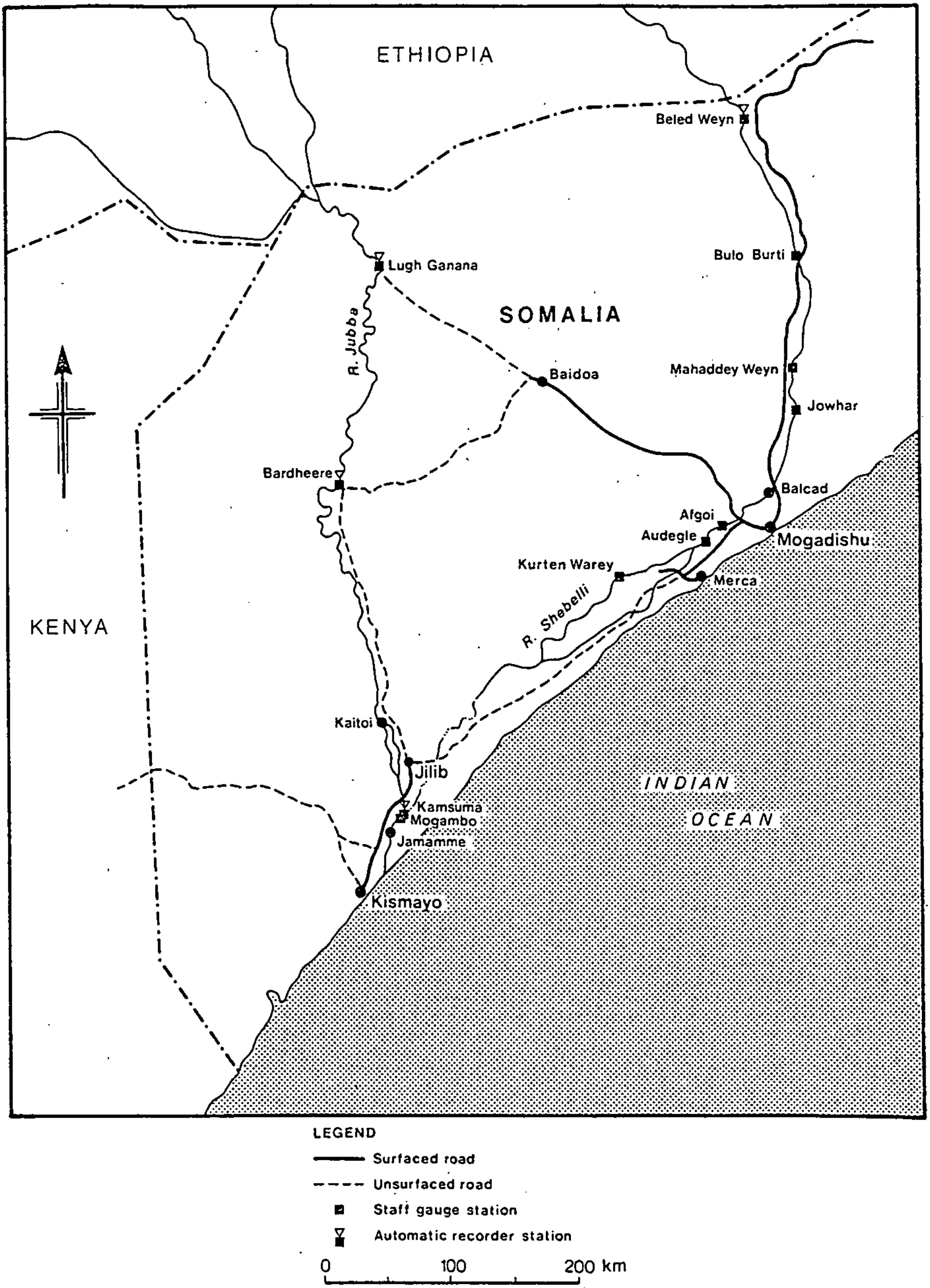
It is regrettable that a previous member of the Section who went to the USA for training in mid-1989 did not return; furthermore, although Ali is reported to have returned from the Hydrology Technicians Course in Zimbabwe he had not returned to work in the Section by the end of April. The absence of staff on training courses has at times slightly restricted the work of the Section; this would be of no consequence if the staff return with improved skills, but if staff do not return then the prospects for the future operation of the Section will be adversely affected.

In connection with the project one Technical Cooperation (TC) award is available from British Council funds to enable one of the local staff to receive postgraduate training at a UK university. Ibrahim is due to be attending a Diploma course in Water Resources for Developing Countries at Birmingham University from September 1990 (preceded by additional English training); this means that he will be away from Somalia at the conclusion of the Project, but if he returns in 1991 the experience he gains should be of great benefit to the Hydrology Section. With his absence in mind, the Director has arranged for an additional graduate to be appointed to the Section.

2.4 Supervision

The British Development Division in East Africa (BDDEA) has maintained a close interest in the progress of the project. Mr B Jackson, Engineering Advisor, visited Somalia in March to discuss the progress of this and other projects, and in particular the arrangements for maximum dissemination of the results of the Project, primarily via the Hydrometric Data Book. The British Embassy in Mogadishu has continued to provide support and communication with BDDEA in Nairobi.

Figure 1
Location Map



3. WORK UNDERTAKEN

3.1 General

The regular office work of the Hydrology Section continued throughout the period, but the programme of fieldwork was very restricted compared to that up until July 1989. The uncertain security situation reported in the last Progress Report continued throughout the period, and possibly became worse by March. The Director of Irrigation and Land Use would not permit the Land Rover to be taken beyond Mahaddey Weyn on the Shebelli or to any station on the Jubba; in general there was less concern about safety of personnel and the Hydrologist did undertake two trips to the Jubba with staff of other projects who were allowed to use their vehicles. The first of these was to the lower Jubba in November and the second to Bardheere in February. Conditions in the lower Jubba area seem to be satisfactory now and it is possible that further trips may be possible, but an incident involving another expatriate on the Bardheere road in March means that a repeat journey there is unlikely.

3.2 Fieldwork

3.2.1 Introduction

As indicated above, the fieldwork programme has been very severely curtailed by the prevailing situation in Somalia. However, some valuable work has been carried out, particularly the introduction of sediment sampling and analysis. Besides occasional trips to sites in the middle and lower Shebelli a weekly programme of visits to Afgoi was started in November for water sampling, with subsequent analysis in the office. This has proved to be an important development of the Section's programme. Appendix B contains more details of the field trips which were undertaken.

3.2.2 Data Collection

The return of observer data to Mogadishu has generally been good, although more sporadic than in the past in the absence of regular field visits. A number of the observers have brought data to the office on visits to Mogadishu; this is rarely the case with stations in the lower Jubba area, but fortunately assistance from other projects allowed data to be collected on three occasions during the period. Infrequent receipt of data makes the task of quality control more difficult and if there has been a problem such as a faulty bridge dipper there may be a gap in the data. For flood warning purposes adequate data is being received from the upstream stations at Lugh Ganana and Beled Weyn, but more frequent returns of data from other stations would be helpful in case of errors in observation or data transmission.

The automatic water level recorder at Bardheere on the Jubba operated well, with data being collected in February; however, the other recorders have now been unattended for more than nine months which is the limit of the memory store. If a future visit is possible it may be possible to retrieve data for the first nine months after the last visit, but it must be feared that this data will not become available. The staff gauge records will therefore continue to be essential.

The new observer at Jamamme has proved to be reliable and good quality records have been obtained for this station which is the most downstream on the Jubba. Unfortunately, the travel restrictions meant that the reintroduction of staff gauges could not be considered, so the record is derived from bridge dip readings. Results have been less satisfactory from Kamsuma where the replacement observer appointed in November appears to be in need of extensive training which the Section is unable to provide.

3.2.3 Discharge Measurements

The regular measurement of river discharge at each station is important in order to check the validity of the existing rating curve, and if necessary to derive a new equation. Unfortunately, regular measurements have only been possible at Afgoi; the measurements made during the period are listed in Table 1.

TABLE 1

Discharge Measurements Carried Out During the Period

Date	Station	Gauge height* (m)	Velocity (m/s)	Area (m^2)	Discharges Measured (m^3/s)	Discharges Equation (m^3/s)	% error
25/11/89	Afgoi	2.77	0.54	56.3	30.7	32.2	-5
30/12/89	Afgoi	3.715	0.52	88.5	46.4	52.9	-12
6/1/90	Afgoi	3.885	0.55	94.8	51.8	56.8	-9
10/2/90	Afgoi	2.025	0.51	35.8	17.3	17.4	0

Note: * Mean gauge height during measurement period.

SEDIMENT MEASUREMENTS AT AFGOI

(NOVEMBER 1989 – APRIL 1990)

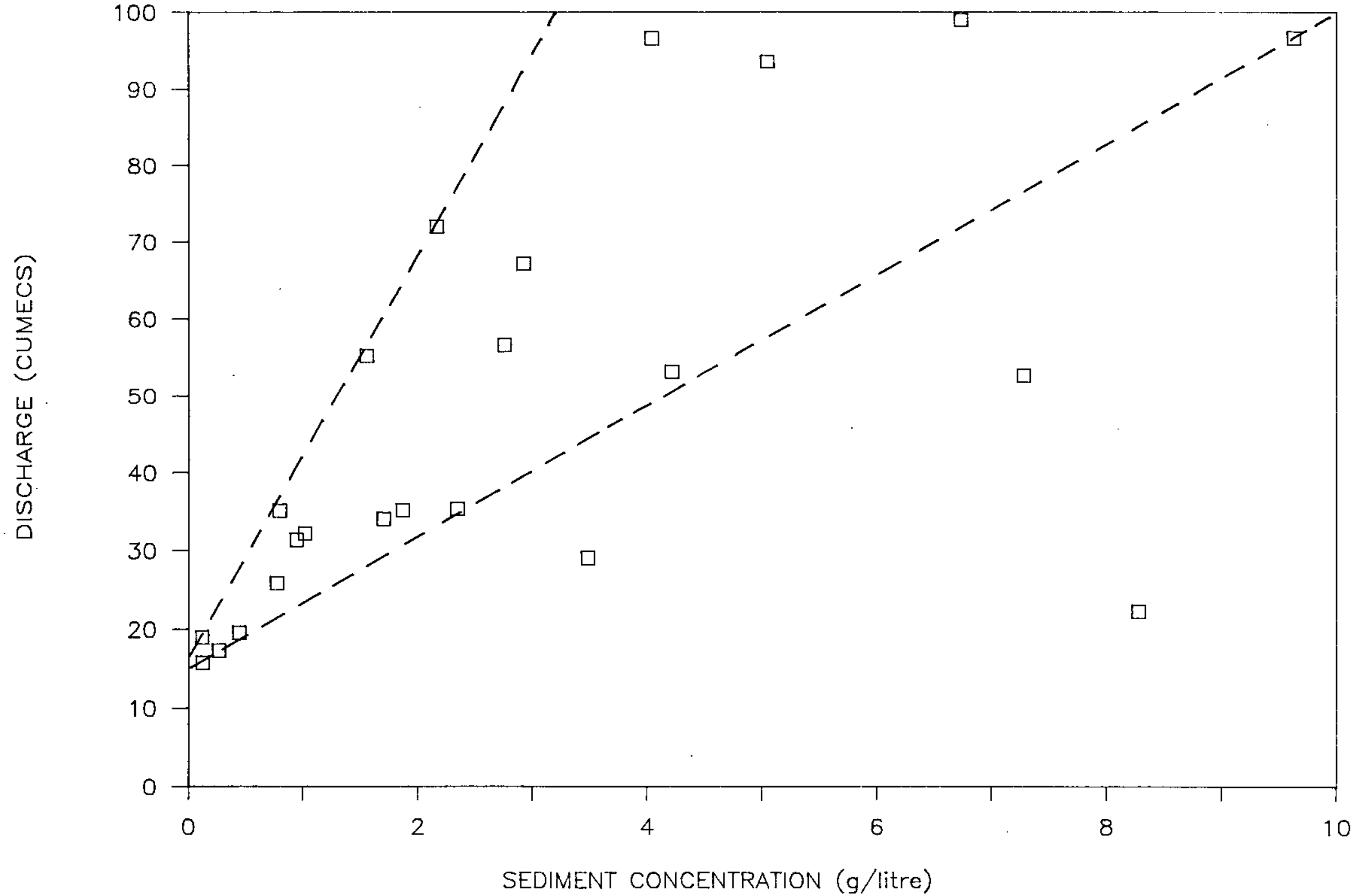


Figure 2.

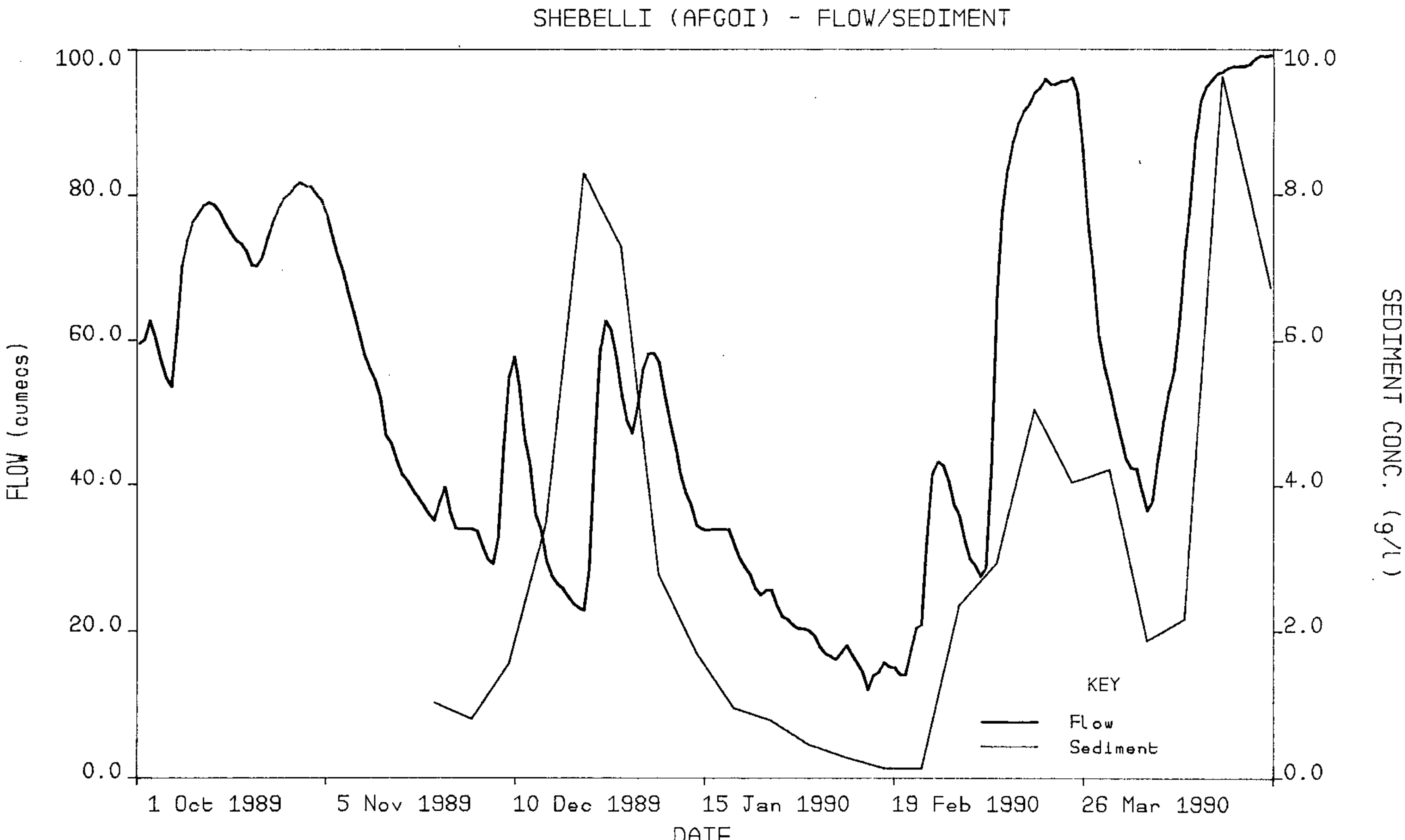


Figure 3

Department of Hydrology, Ministry of Agriculture

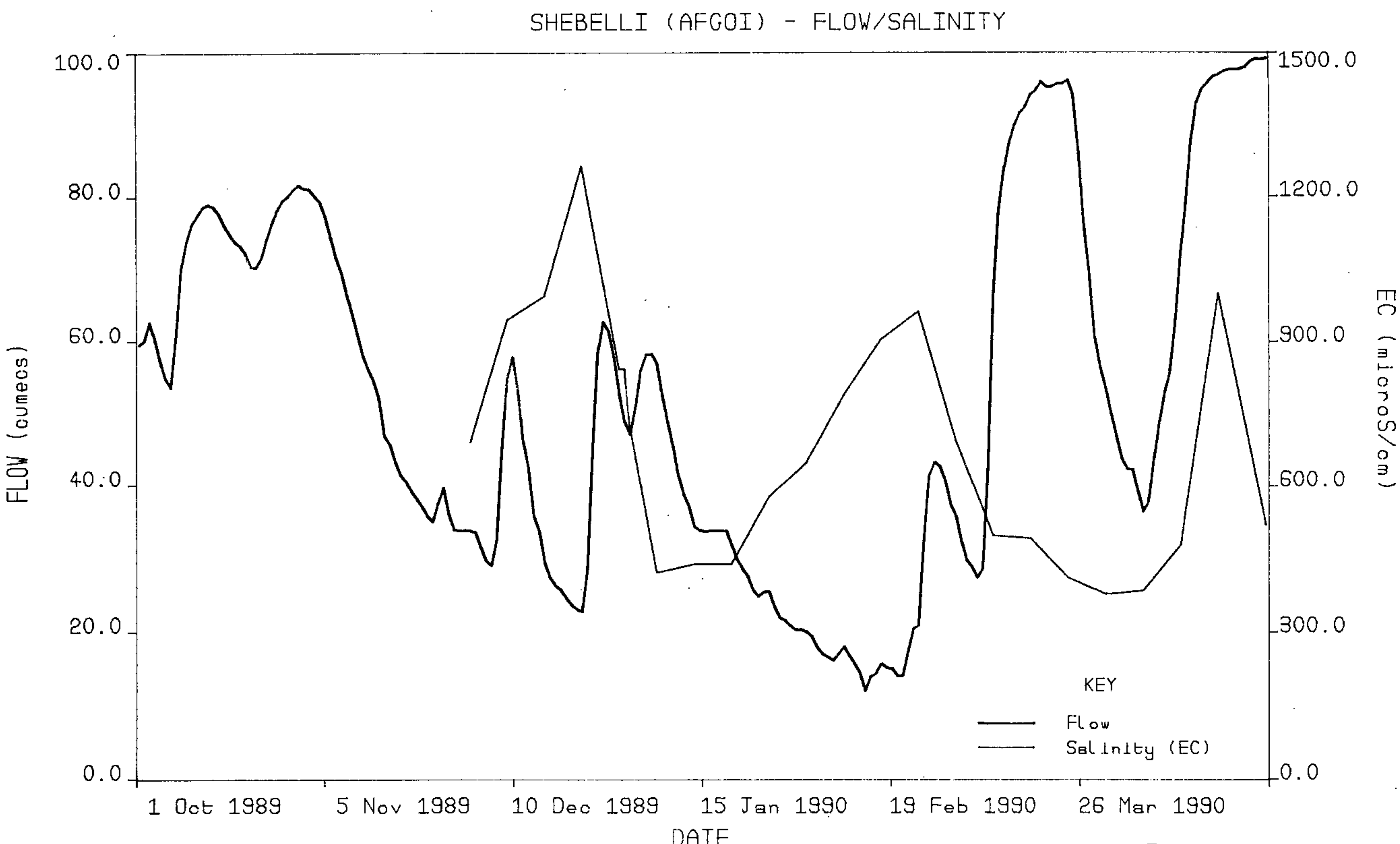


Figure 4

Department of Hydrology, Ministry of Agriculture

3.2.4 Water Quality Measurement

Water quality measurements have provided the major success of fieldwork during this period. It was decided that a weekly sampling programme at one site (the nearest one, Afgoi, being selected) would provide the most useful information over the remainder of the Project. If possible samples will be taken at other sites later. Because of the very limited facilities available to the Section for analysis of samples, the Director of Irrigation and Land Use arranged with a research scientist, Dr Bashir, for additional samples to be taken and used for chemical analyses to supplement the determination of sediment concentration and electrical conductivity (EC) carried out by the Section. Dr Bashir has collected the samples in most weeks and it is hoped that his results will be made available for incorporation in the Final Report. The sediment and EC results are shown in Table 2 and also in Figures 2, 3 and 4.

TABLE 2

Results of Sediment Sample Analysis
(Samples from River Shebelli at Afgoi)

Date	River Level (m)	Rated Discharge (m^3/s)	Sediment Concentration (g/litre)	Electrical Conductivity (microS/cm)
25/11/89	2.77	32	1.0	
2/12/89	2.91	35	0.8	690
9/12/89	3.82	55	1.6	945
16/12/89	2.62	29	3.5	690
23/12/89	2.28	22	8.3	1 263
30/12/89	3.71	53	7.3	841
6/1/90	3.88	57	2.8	421
13/1/90	2.86	34	1.7	439
20/1/90	2.73	31	0.9	439
27/1/90	2.46	26	0.8	576
3/2/90	2.14	20	0.4	648
10/2/90	2.02	17	0.3	788
17/2/90	1.94	16	0.1	904
24/2/90	2.11	19	0.1	963
3/3/90	2.92	35	2.3	693
10/3/90	4.33	67	2.9	496
17/3/90	5.40	94	5.1	490
24/3/90	5.52	97	4.0	410
31/3/90	3.73	53	4.2	376
7/4/90	2.91	35	1.9	384
14/4/90	4.53	72	2.2	478
21/4/90	5.52	97	9.6	1 000
30/4/90	5.61	99	6.7	518

Figure 2 shows the sediment concentration plotted against river level; as is usual with sediment measurements there is considerable scatter, though the three worst outliers were all in December and those measurements made since January fit within a reasonable envelope (as shown with dotted lines). Figure 3 shows the weekly sediment measurements (joined by straight lines), together with the daily discharge hydrograph. These curves show a generally similar pattern. The river water in February was very clean - presumably because the natural river flow was being augmented by releases from the Jowhar Offstream Reservoir which were relatively free of sediment (it having been deposited in the reservoir). The pattern of salinity readings (EC), shown in Figure 4, is somewhat less clear. However, two points may be made: firstly, salinity tends to rise when the river is very low; secondly, no appreciable rise was noted at the onset of the Gu flood. It is general practice in Somalia not to irrigate with the first part of the flood because of the high salinity. The lack of such a peak may be due to the fact that the river flow remained relatively high during the early months of 1990.

3.2.5 Field Trip Reports

Because of the very limited nature of the fieldwork undertaken, the previous policy of producing monthly field trip reports was considered to be inappropriate. However, the trips which were made are described in detail in Appendix B.

3.3 Office Work

Office work has been centred on the computer, primarily the use of the HYDATA package for the entry and checking of data. Training has also been given in the use of Lotus spreadsheets, mainly for the calculation of discharges and sediment concentrations from field observations and for producing the river flow bulletins.

All the data entered to the computer throughout the Project has been carefully checked against original record cards/sheets (where available), and critically examined. During Phase 1 a number of periods of data were rejected because of obvious data fabrication by the observers; some further such periods have been identified during the checking process. In a few cases some additional original data sheets have come to light, thus making the record more complete than had been previously thought.

The work previously done on the Shebelli records was completed and a similar thorough check was carried out for the Jubba using the models developed by the Programmer/hydrologist. Periods of particularly doubtful data were deleted and the models were used to infill these from records at other stations. The work is described in detail in Appendix C. For the Shebelli it was possible to make estimates for all missing periods since the start of 1963, but for the Jubba there was a period of approximately two years in 1967-69 when no records are available for any station; the data for that period therefore remains as 'missing'.

The completed daily and monthly flow records are presented in the Hydrometric Data Book. This is being widely circulated to Ministries, International Agencies and other organisations in Mogadishu so that as far as possible all interested parties will be aware of the existence of up-to-date and validated data sets.

3.4 Liaison With Other Organisations

The close links established with the Food Early Warning System (FEWS) project and the National Water Centre (NWC) have been maintained. Data received via the MOA radio network set up by FEWS has been made available to the Hydrology Section, and in return summary tables and analysis are produced every ten days for the regular bulletin on rainfall, river flows and crop conditions. The NWC computer contains a complete back-up system for HYDATA and the Hydrology Section's database; periodically the revised database has been copied to the NWC computer so that they can use up-to-date data.

The link with FEWS has been furthered by the direct involvement of ODA in that Project; ODA has provided the equipment for receiving satellite data from which rainfall estimates may be made. This should be of great value to the Hydrology Section because the information received covers neighbouring countries as well as Somalia; estimates of rainfall over the Jubba and Shebelli catchments in Ethiopia should help to provide advance warning of floods on the two rivers in Somalia. The equipment was installed in January, but the problems concerning power supply mean that to date it has been of qualitative rather than quantitative interest. To obtain reasonable rainfall estimates requires data on cloud cover throughout the day and night (information is transmitted by the satellite every half an hour), but the extremely limited availability of electricity means that data is only received during the morning - typically 6 to 8 of the 48 half-hourly 'pictures'. This problem should be resolved in June or July when a specially developed low-power unit is available; this will allow the receiving equipment to operate continuously using solar power.

Many requests have been received for data regarding one or both rivers; advice has been given as freely as possible because the provision of validated data sets is one of the major objectives of the project. Information has been given to a number of local organisations and to Consultants and other international organisations studying particular projects related to either of the rivers. There was major flooding on the Jubba during the Der season and appropriate warnings were made available to interested parties.

4. FUTURE PROSPECTS

The Project will be continuing for a further six months until the end of 1990; the Resident Hydrologist is expected to be in Somalia until mid-November and the Final Report will be completed shortly thereafter in the Consultant's Head Office. The Programmer/hydrologist will be making his final visit to Somalia in September and October.

Regrettably, it is considered unlikely that there will be any significant improvement in the overall situation in Somalia and therefore it is expected that fieldwork will continue to be severely restricted. The Project team will, however, be ready to expand the fieldwork programme if conditions permit. The main fieldwork will continue to be the sediment sampling and analysis; by the end of the Project regular data will have been collected for a complete year on the Shebelli. Occasional discharge measurements will also be made.

In the office the major work will be the further development of the forecasting models for the two rivers, and the analysis of data from the FEWS satellite equipment as soon as significant amounts of data become available. Time series analysis of the validated and infilled flow data sets will also be carried out.

The last Progress Report stressed the importance of ensuring continuity to the proposed Shebelli Water Management Project due to be supported by the United States Agency for International Development (USAID). Since that time USAID has removed that project from its planned programme of work in Somalia. It is understood that the European Community (EEC) is considering the possibility of funding part of the work proposed for the Shebelli project; however, even if this materialises it is almost inevitable that there would be some gap between the end of the Hydrometry Project and the start of EEC support. The training of local staff will therefore continue to be of the utmost importance as the handover at the end of the Project approaches. This applies to the general office work of processing and presenting data, and to the fieldwork.

APPENDIX A

RIVER LEVEL FLOW DATA FOR 1989

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APPENDIX A

RIVER LEVEL AND FLOW DATA FOR 1989

A1 INTRODUCTION

This appendix presents the discharge hydrographs for 1989 for the primary gauging stations operated by the Hydrology Section. The pattern of river flows during the year is described in general terms and specific comments are made on the data for individual stations.

A2 STATE OF RIVER FLOWS IN 1989

A2.1 River Jubba

A2.1.1 General

The overall mean flow during the year was significantly above the long-term mean - by 20 to 30% at most stations. Based on the period of reliable records (1963 to date), 1989 represents approximately a 1-in-5 year return period. There were substantial floods in both the Gu and Der seasons, and attendant flooding problems, particularly in the lower Jubba where the main Jilib - Kismayu road was breached in early November.

A2.1.2 Lugh Ganana

The flows at Lugh (Figure A1) have been derived from the automatic water level recorder up until July 6th and thereafter from the staff gauge record. The recorder functioned well, but no visit was possible after July so that the data could not be collected. The observer's data generally appears to be reliable, though there were some doubtful values in the second half of the year when the recorder data would have been useful for clarification. Discharge measurements were made on each visit by Project staff. In March the low flow was measured by wading while other measurements were made from the bridge. At the beginning of May the flow was gauged twice when the river was close to its flood peak. The higher of these measurements was 874 m^3/s which is the highest flow measured by the Hydrometry Project, though still below that measured in the 1977 and 1981 floods.

Measurements since the 1981 flood indicated that a slight adjustment to the rating curve would be appropriate. The available measurements were analysed and the revised rating was applied from the beginning of 1982.

A2.1.3 Bardheere

The flows for Bardheere (Figure A2) have been derived from the automatic water level recorder for the entire year except for the first three days in January when the data was accidentally erased. The observer's staff gauge data seems to be reliable, though the availability of the recorder data for virtually the whole year did help to confirm a number of unusual divergences from the flow pattern at Lugh. These were primarily caused by local runoff from the substantial rains in the Jubba valley within Somalia. The overall mean flow for the year is significantly greater than at Lugh because of the local runoff and also possibly because of a shift in the river bed level which means that the rating equation probably requires a slight adjustment. Unfortunately the only measurement made in the year was by wading in March when the flow was around 10 m^3/s; this was well below the rating curve, but is insufficient justification for a change in the rating.

A2.1.4 Mareere

Mareere river level records are not the responsibility of the Hydrology Section, but as the records maintained by the Jubba Sugar Project since 1977 have generally been very reliable it is treated here as a primary station. For some periods in the early 1980s the Mareere data provided the only record on the whole river. The hydrograph in Figure A3 shows substantial flood peaks in both seasons, with that in the Der being preceded and followed by significant subsidiary peaks.

A2.1.5 Kamsuma

Reliable data was recorded at Kamsuma until September when the observer left the area, apparently because of the local security situation. A replacement was appointed in November, but the subsequent returns indicated that training of the observer is required - currently this is not possible because of the travel restrictions. The hydrograph appears as Figure A4.

A2.1.6 Jamamme

Jamamme was one of the original primary stations on the river Jubba (established in 1963), but the station had always been somewhat problematic and the quality of data generally much lower than at other stations. However, as reported in the last Progress Report, it was decided to rehabilitate the station. An observer living near the bridge was appointed in June and he returned bridge dip data for the rest of the year. This appears to be reliable, and in view of the subsequent problems at Kamsuma (see above), Jamamme should be retained in the network.

The main feature of the hydrograph (Figure A5) is the extended Der flood and the relatively slow recession from it. The flows at Lugh Ganana and Bardheere dropped much more rapidly, but in the lower Jubba flows were augmented by return flood flows.

A2.2 River Shebelli

A2.2.1 General

The average flow during 1989 was very close to the long-term average, though the seasonal pattern was far from typical. Flows in the low flow season (Jilaal) from January to March were somewhat higher than normal and the Gu flood was much larger than normal, both in the peak flow magnitude and in the duration of high flows. There was very severe flooding in the lower Shebelli. The Der flood, by contrast, was later and smaller than usual, with no period of sustained high flows. Finally, the usual recession in November and December was interrupted by some significant flood peaks; the year-end flow was the second or third highest in the 27 years of reliable records.

A2.2.2 Beled Weyn

The hydrograph (Figure A6) shows the pattern described above, with the Gu flood peaking at virtually 300 m^3/s. This was well above average, though as it only ranks 9th out of 27 in the list of peak annual floods it was not a particularly rare flood event.

The rating curve for the whole period of the station's operation was reviewed and it was clear that a multi segment curve fitted the available discharge measurements much better than the existing single part equation. The change at low and medium levels (up to about 140 m^3/s) is very small, but at higher levels the flow values are considerably reduced. The fit of the new equation is much better than the old, but it should be noted that the flow characteristics change substantially when the river starts to flow out of bank. The new equation shows a peak flow (in 1981) of less than 500 m^3/s, but at that time the total flow - including that in the flood plain - was estimated to be nearer to 1 000 m^3/s.

A problem was reported with the staff gauge and at low levels bridge dip data had to be used. The relatively high levels during the jilaal season prevented replacement of the gauge, so dip data will continue to be important.

A2.2.3 Bulo Burti

A new 5 to 7m staff gauge was installed in April just before the arrival of the Gu flood. This led to improved data quality at high levels. However, there was a marked deterioration in data quality in October, with conflicting staff gauge and bridge dip values being recorded by the observer, and poor correlation with data from upstream and downstream stations. The lack of regular visits to supervise and encourage the observer must have contributed to this situation. In the absence of reliable data the flow values for the latter part of the year (see Figure A7) have been estimated using the computer model.

A2.2.4 Mahaddey Weyn

The river level data continues to be of good quality, but doubts remain about the rating equation. The discharge measurements during the 1980s have shown substantial scatter and it is therefore difficult to make a reliable adjustment to the equation, though it is most probable that the rating produces slightly high flow values.

The hydrograph (Figure A8) shows that the river was high for an extended period during the Gu season, but that it hardly reached that level in the Der. This is the exact reverse of the flood seasons in 1988.

A2.2.5 Afgoi

The data quality at Afgoi remains good thanks in part to the frequency of check visits by the Hydrology Section staff. The discharge measurements were reviewed and a slight revision to the rating was applied with effect from 1985.

The hydrograph (Figure A9) shows the pattern of weekly fluctuations in level during the jilaal season which was noted in the review of 1988 flows. In 1989, however, the base level was maintained throughout the first three months up to the Gu flood (rather than dropping off in March) because of the generally higher flows in the river and the plentiful supplies available from the Jowhar Offstream Reservoir.

A2.2.6 Audegle

The river level data at Audegle in 1989 was of a higher standard than in the previous year thanks to increased interest shown by the observer. The flow values remain somewhat uncertain because of the effects of the old bridge which collapsed further during the year. The data for Afgoi and Audegle over recent years was analysed to estimate the date when the debris at the bridge started to significantly affect the river level, and hence the date from which a revised rating would be appropriate. This appeared to be in 1985, and in order to avoid a sudden change in flow values 1 March 1985 was chosen because the river was completely dry at that time. The change to the equation involved a shift in the zero flow level, and the size of the shift was determined empirically by comparison with Afgoi flow data, and by reference to the discharge measurement made in March 1989. This adjustment means that flow data from 1985 is now more realistic than with the old rating, but the change must be seen as an interim measure only. The resulting hydrograph (Figure A10) fairly closely follows that for Afgoi.

The top 1 m of the staff gauge was washed away in the Der flood. River levels have not yet allowed access to replace this, but the bridge dip data provides an adequate substitute.

Jubba at Lugh Ganana

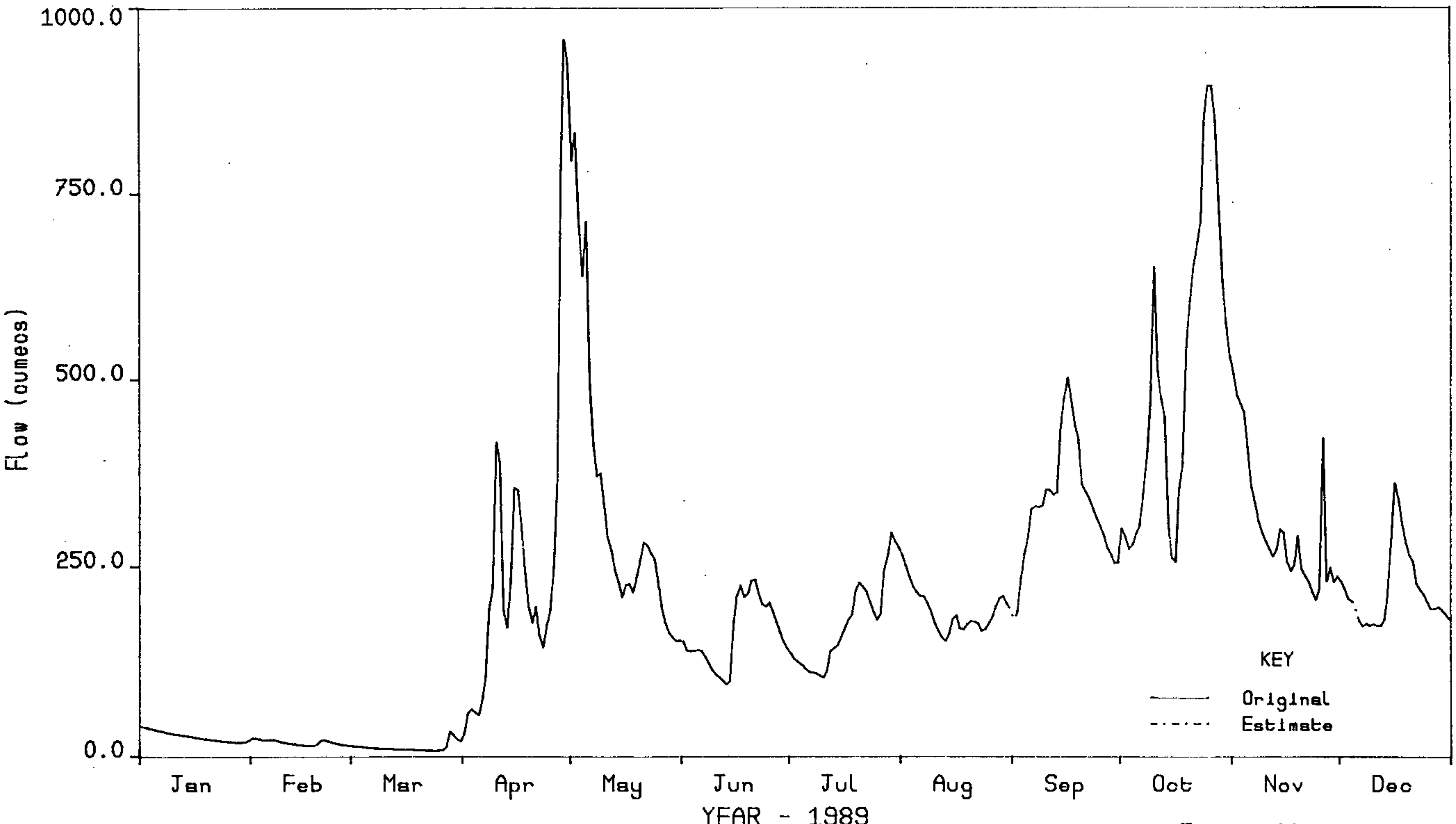


Figure A1

Department of Hydrology, Ministry of Agriculture

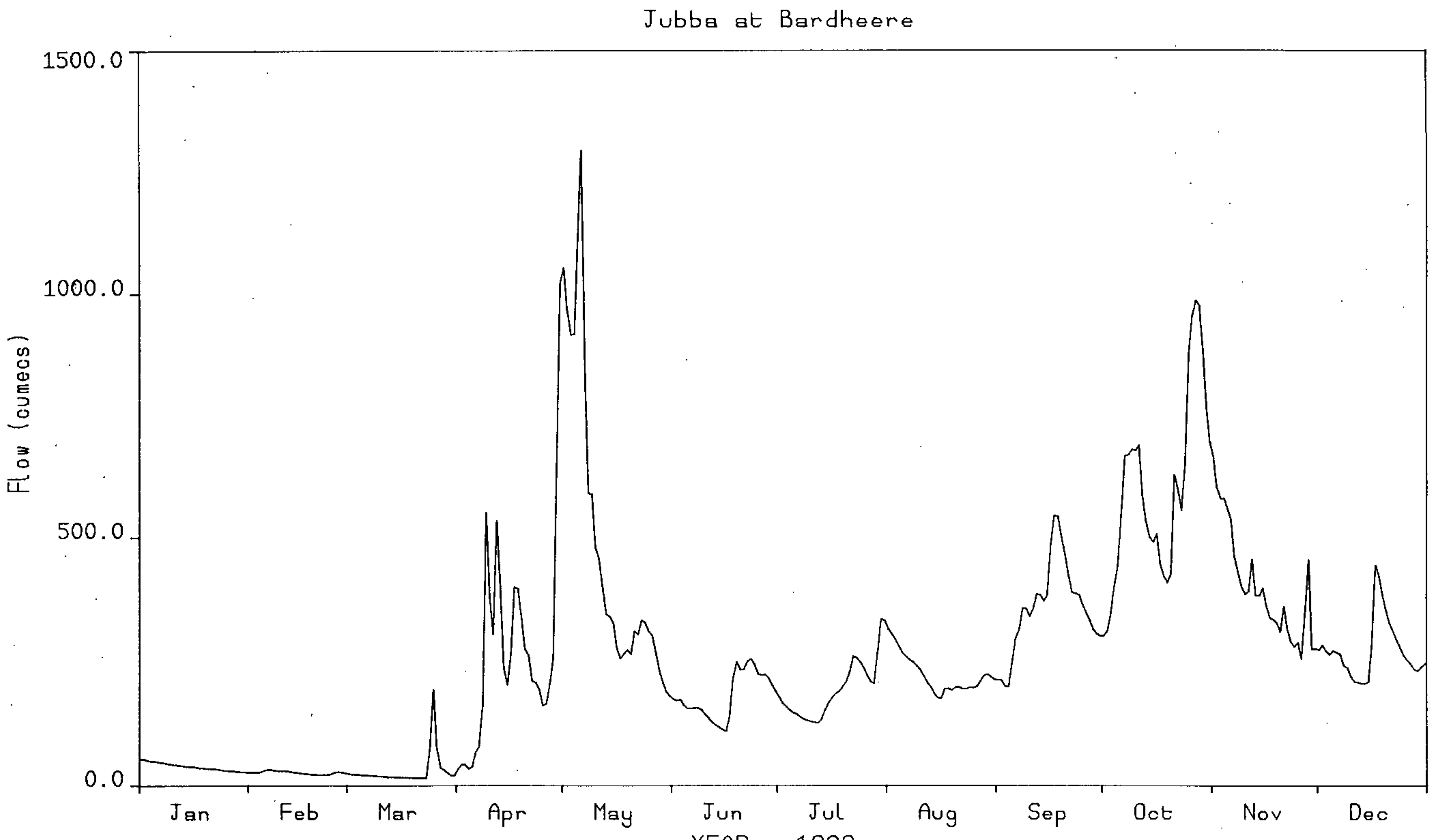


Figure A2

Department of Hydrology, Ministry of Agriculture

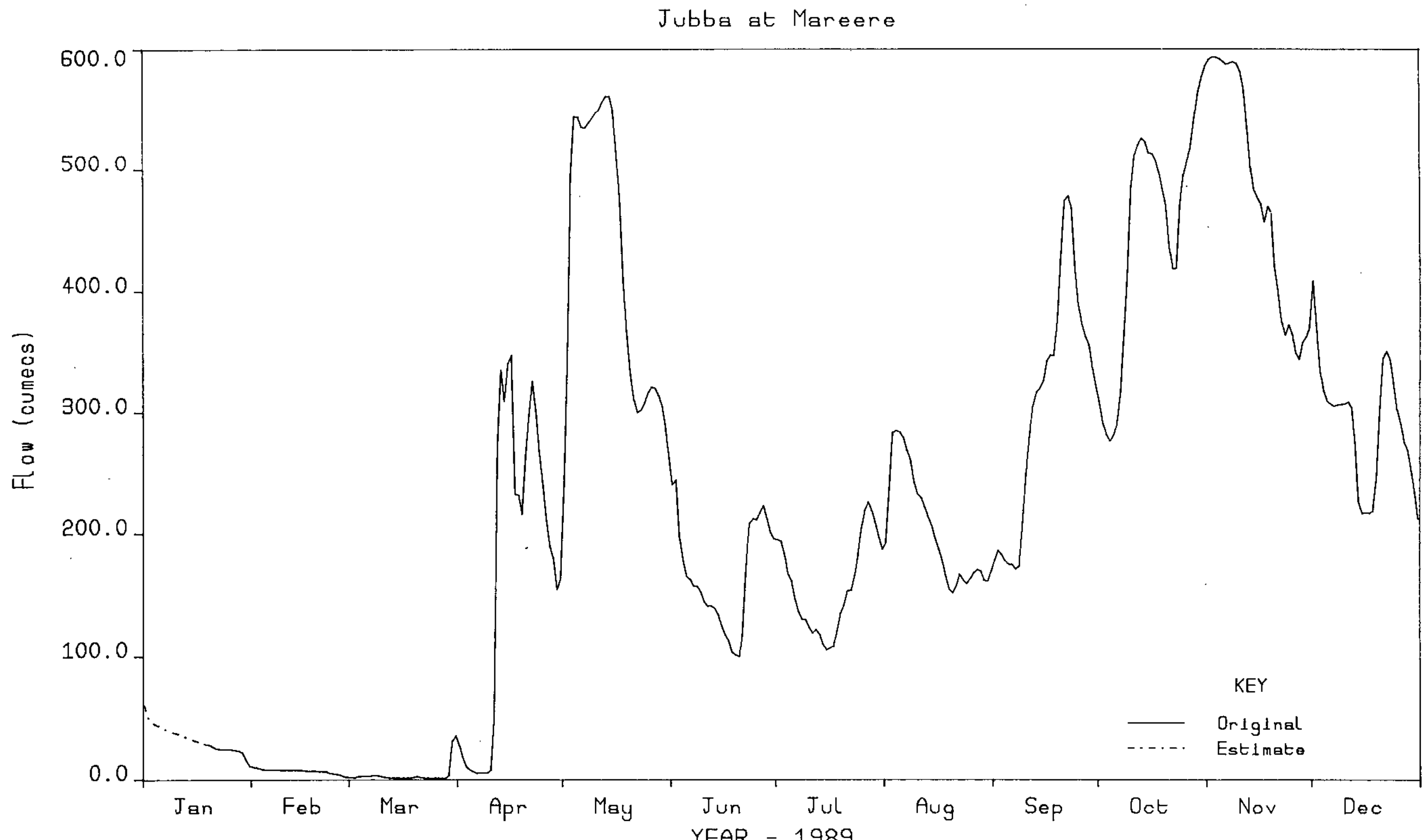
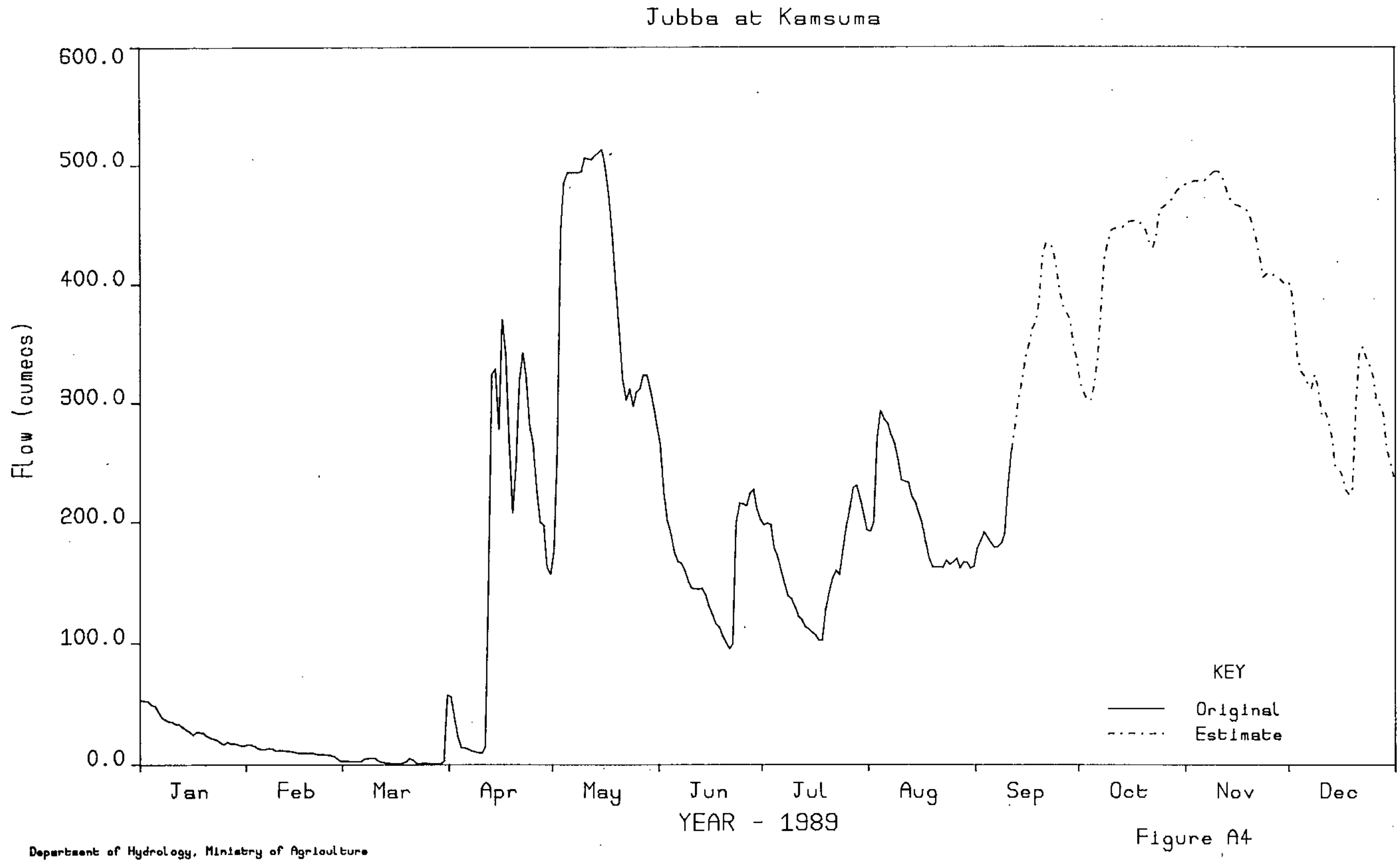


Figure A3

Department of Hydrology, Ministry of Agriculture


Jubba at Kamsuma
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Flow (cumecs)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
YEAR - 1989
KEY
Original
Estimate
Department of Hydrology, Ministry of Agriculture
Figure A4

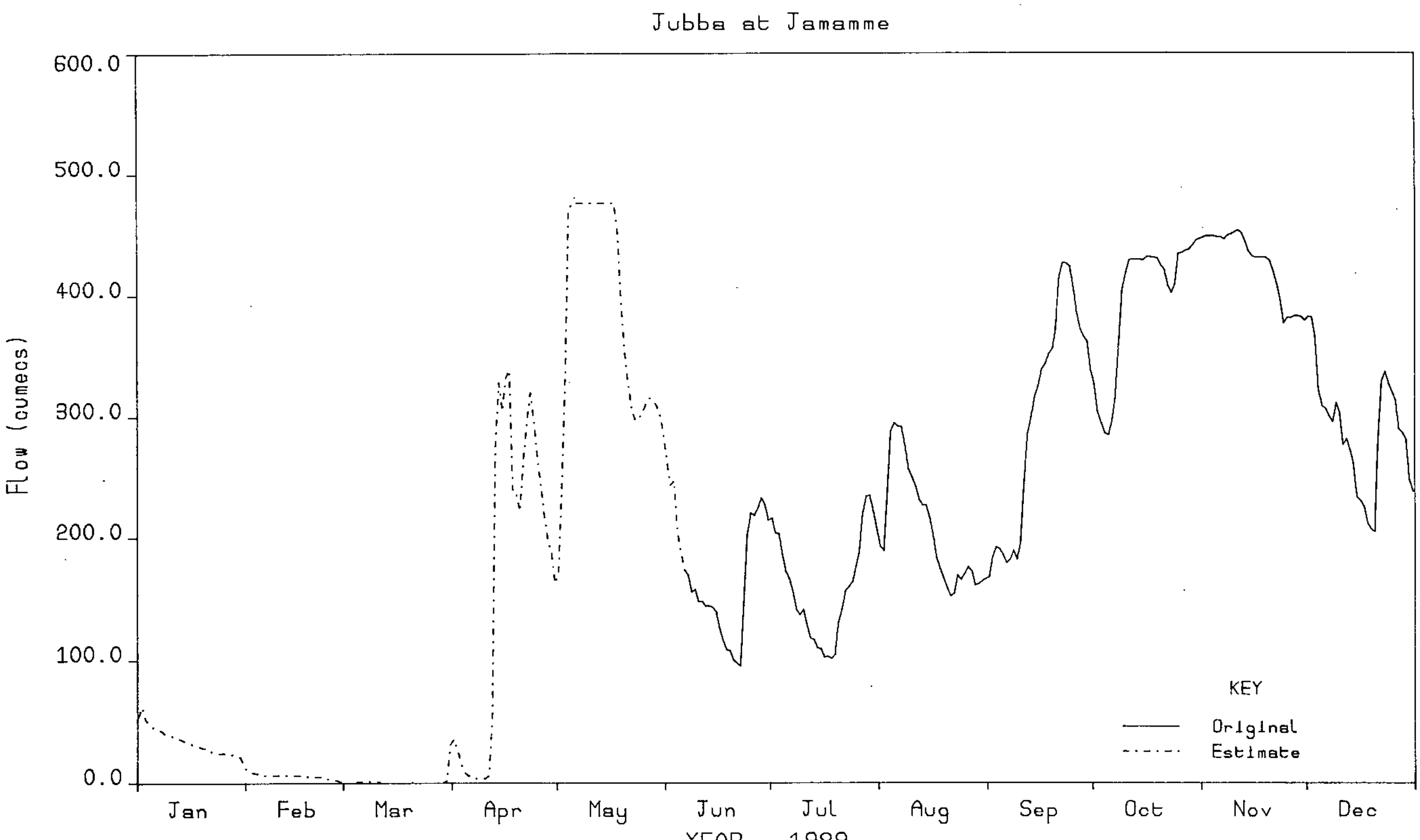


Figure A5

Department of Hydrology, Ministry of Agriculture

Shebelli at Beled Weyn

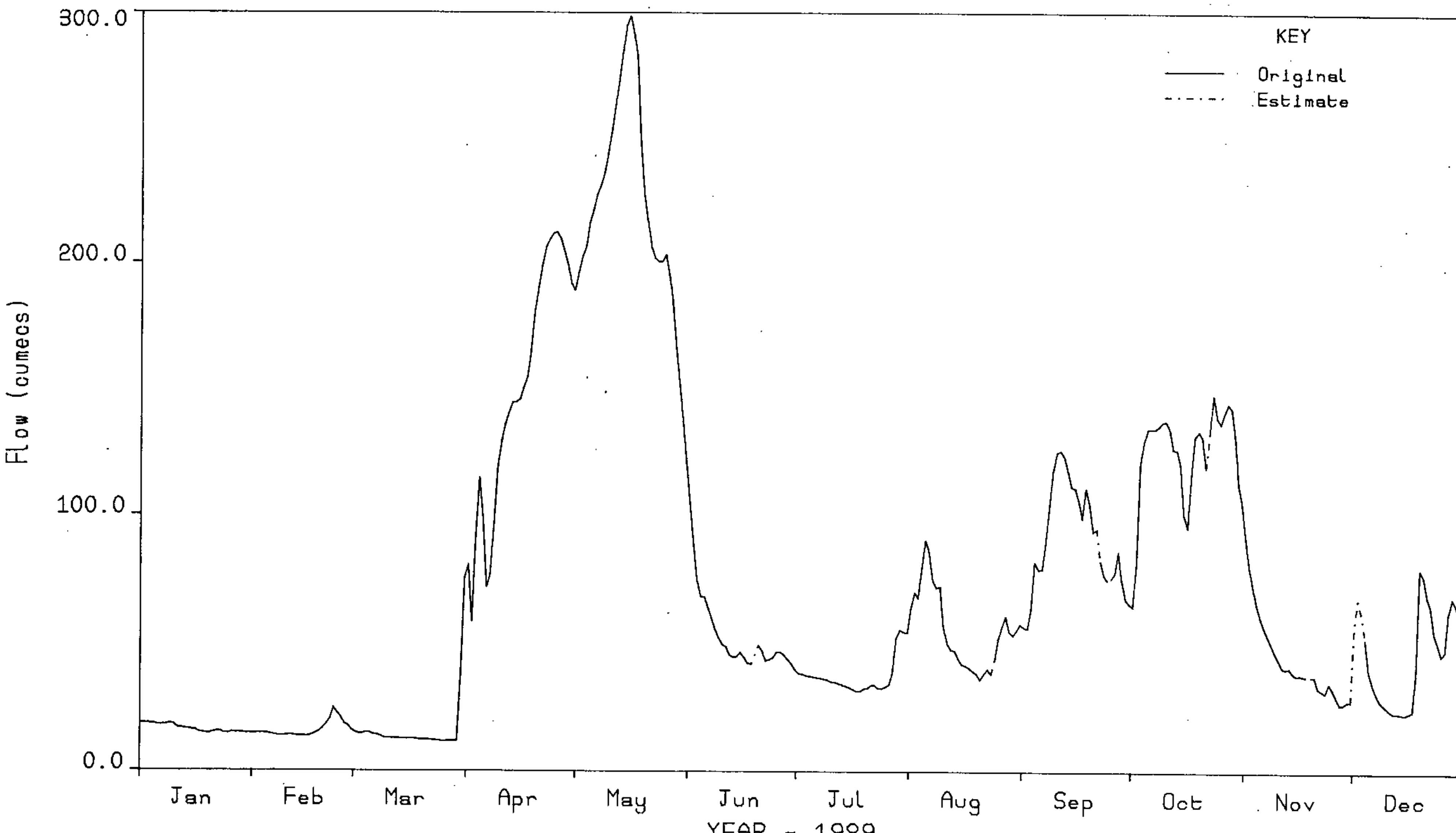


Figure A6

Department of Hydrology, Ministry of Agriculture

Shebelli at Bulo Burti

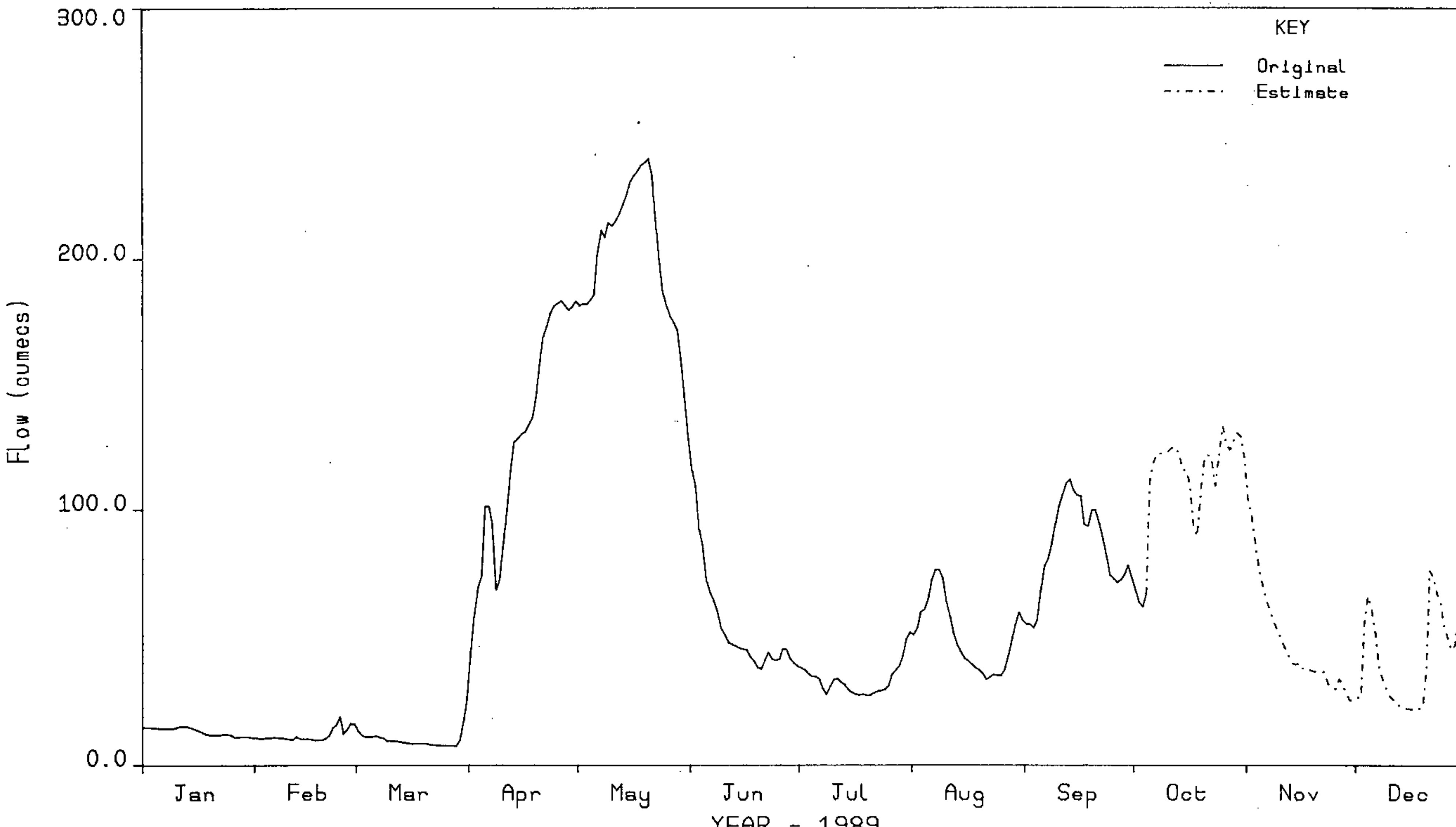


Figure A7

Department of Hydrology, Ministry of Agriculture

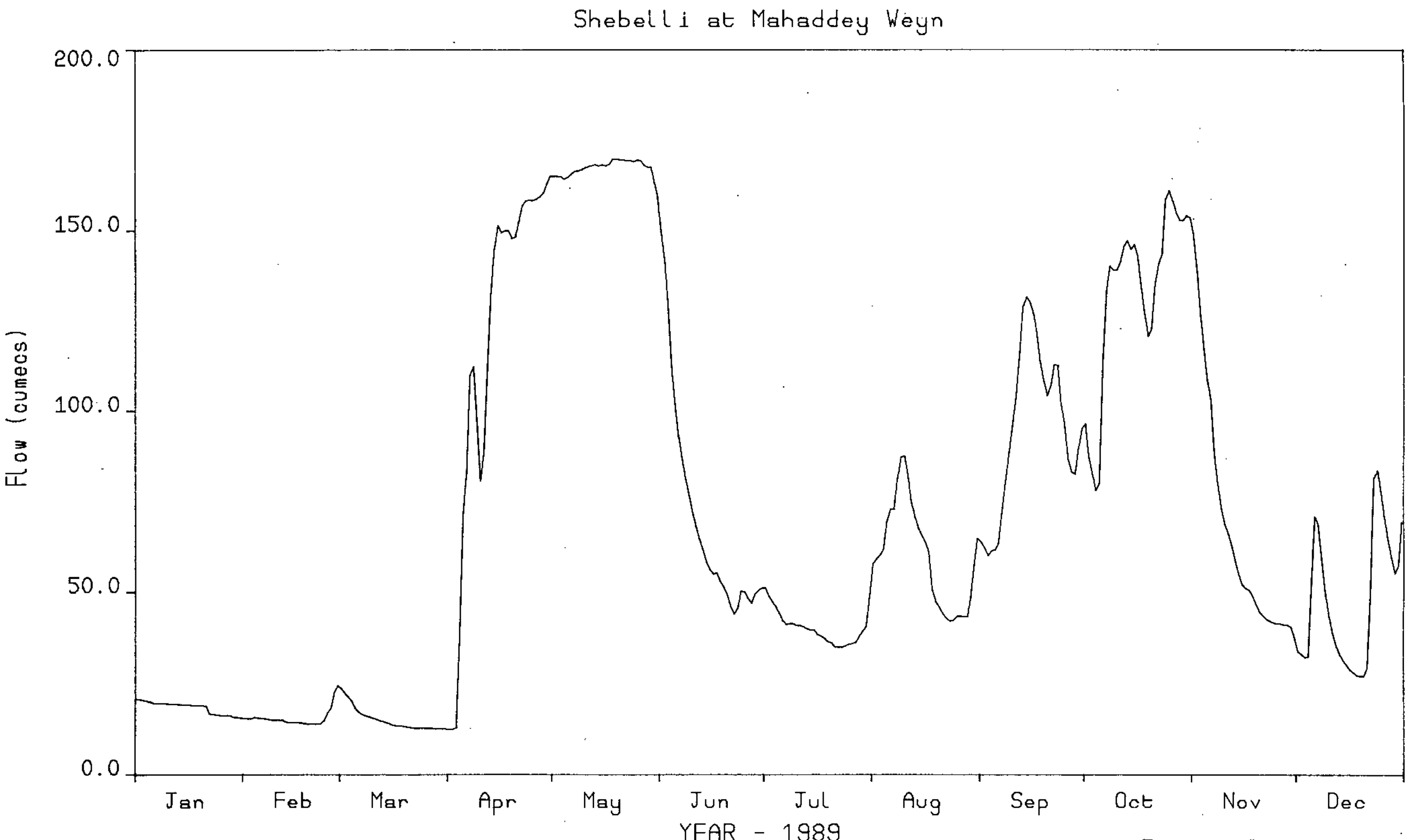


Figure A8

Department of Hydrology, Ministry of Agriculture

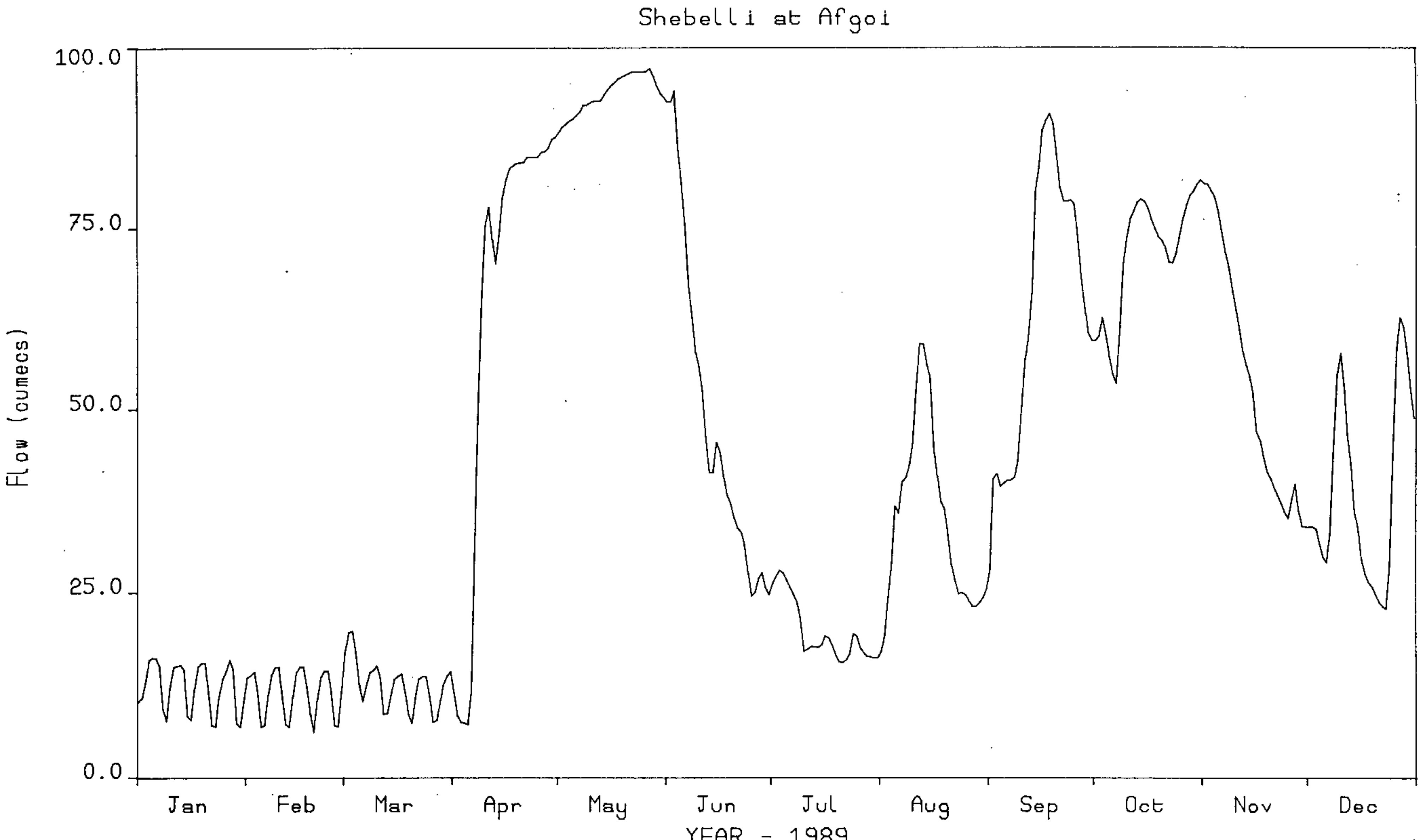


Figure A9

Department of Hydrology, Ministry of Agriculture

Shebelli at Audegle

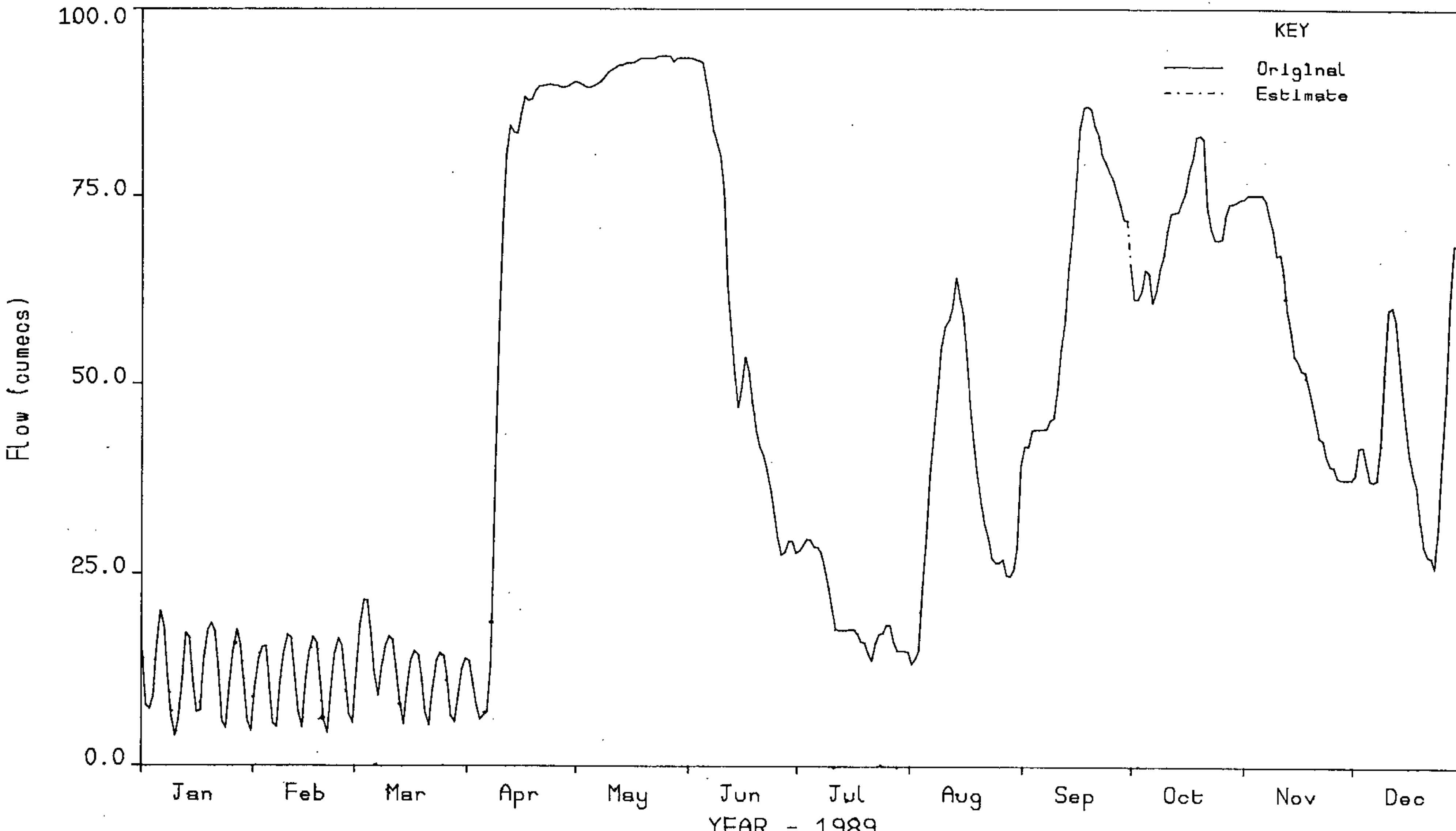


Figure A10

Department of Hydrology, Ministry of Agriculture

APPENDIX B

REPORTS ON FIELDWORK

CONTENTS

		Page Nr
SECTION B1	FIELD TRIP TO LOWER JUBBA 8 - 10 NOVEMBER 1989	B1
SECTION B2	DISCHARGE MEASUREMENTS	B2
SECTION B3	SEDIMENT MEASUREMENTS	B3
SECTION B4	FIELD TRIP TO BARDHEERE 22 - 24 FEBRUARY 1990	B3
SECTION B5	DISCHARGE MEASUREMENTS UNDERTAKEN DURING THE PERIOD	B5

SOMALIA HYDROMETRY PROJECT

REPORTS ON FIELDWORK

B1 Field Trip to Lower Jubba 8 - 10 November 1989

The Director of Irrigation and Land Use confirmed that he was unwilling to support the use of the Project Land Rover for travel to the Jubba valley, even though the journey would have been in convoy with one or more vehicles from the Mogambo Irrigation Project (MIP). The Field Hydrologist and the project driver therefore accompanied the MIP Irrigation Engineer in the latter's project car, but it was not possible for the counterpart staff to participate in the trip.

Jilib 8 November 1989

At 1445 the actual SG reading was 5.62 m, almost 30 cm higher than observed during this year's Gu flood. After the gauge zero correction this should correspond to an observer reading of 5.94 m. Unfortunately the office had already closed and it was not possible to collect any data - and the return journey was on Friday so that the office was again closed.

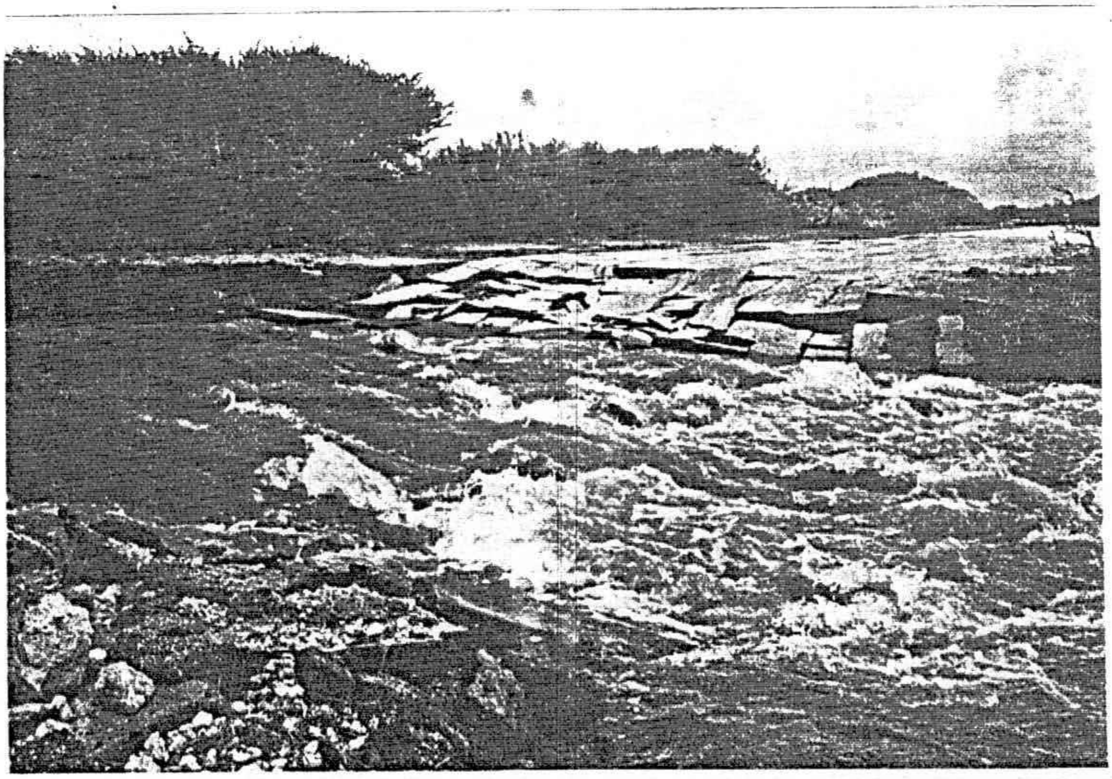
Mogambo

The SG reading was 12.54 m at 1615 on 8 November and 12.55 m at 0920 on 9 November. This represents the peak of the Der season flood to date, though in contrast to Jilib it is slightly lower than the Gu peak in May. Data was collected from mid-August to date, though there were some gaps in late August and early September when many MIP staff were forced to leave the area because of the security situation. At present a level reading is being made each morning but there must be a significant risk that data records will again be interrupted in the future.

Kamsuma 9 November 1989

At 1015 the bridge dip was 3.75 m (EGH = 6.21 m) - 9 cm down on the Gu peak. The observer had fled from the area in September and is unlikely to return; data until then was collected from a member of his family and appropriate payment was made (apparently no allowance had been received from the Jamamme Co-ordinator). Mahamed Abdulahi of MIP offered to try to find a suitable replacement observer.

Jileb - Kismayu Road near Kamsuma
9th November 1989



We travelled about 3 km north of Kamsuma to see the breach in the main road from Jilib. There was a break in the embankment of 8 to 10 m width and water was pouring through from the west side. Consequently, a very large area of land was underwater on the east side of the road; the extent of flooding on the west side (which occurred prior to the breach of the road) could not be easily observed because of the trees. Close to the breach two culverts under the road were discharging at full capacity; this together with the flow through the breach was conservatively estimated to be at least 10 m^3/s. Photocopies of the photographs taken are attached.

Jamamme 9 November 1989

At 1615 the dip was 4.42 m - again significantly lower than in the Gu flood. Data was collected from the observer and an allowance was paid because money promised by the Co-ordinator had not materialized. Later examination of the data indicated that the observer appears to be good and the decision to restart measurements at Jamamme has been justified.

Mareere 9 November 1989

Dr Glyn James, the new Agricultural Manager at JSP, kindly provided copies of the original observation sheets for Mareere for the period since our last visit, together with certain earlier data which had not previously been collected.

Audegle, River Shebelli 10 November 1989

At about 1500 the dip was 2.25 m and the SG reading 4.92 m. The 5 to 6 m staff gauge has been lost in the floods, but the stand appeared to be secure so fixing a replacement should be reasonably straightforward. The road from Audegle to Afgoi on the left bank proved to be almost impassable and that on the right bank should be preferred until repairs have been made.

B2 Discharge Measurements

Four discharge measurements were undertaken during this period, all at Afgoi. The calculation sheets are appended to this report and the results summarised in Table 1 in the main report.

B3 Sediment Measurements

Water samples were taken weekly at Afgoi from November onwards for analysis in Mogadishu. In the absence of laboratory facilities the analysis has had to be performed in the office. This has proved to be adequate for the determination of total sediment concentration and salinity, but more detailed work was not possible. The results are presented in Table 2 in the main report, and a sample calculation sheet is attached to this report.

Because of the very limited electricity supplies it has been necessary to limit drying times in the oven to 4 to 5 hours instead of the more usual 24 hours. However, it is thought that any inaccuracy resulting from this will be insignificant.

B4 Field Trip to Bardheere 22 - 24 February 1990

Travel to the Jubba by means of the Project Land Rover was not possible, but the Hydrologist took the opportunity of a lift with Mr Jim Bradley, Sir Alexander Gibb and Partners' Resident Engineer on the Bardheere Agricultural Experimental Station. Return transport was kindly provided by Murri Freres, the Contractor on that project.

The purpose of this visit was to collect data from the automatic recorder which had last been visited in early July 1989. This was successfully carried out. The period of data collected (nearly 8 months) is only slightly less than the maximum memory of the recorder. The battery voltage was rather low, and there appeared to be a problem when the recorder was demonstrated to Mr Bradley. The battery was therefore replaced by a recently charged battery brought from Mogadishu. This will probably only last for a few months, so if possible there should be a repeat visit to install a new 'permanent' battery.

The recorder seems to have functioned well over this extended period, though there had been slight slippage by the end; the level shown on the recorder was corrected on 23 February after the data was copied to the retriever. The observed levels were as follows:

Date	22nd	23rd	24th
Time	1600	0830	0800
Recorder	1.029	1.014	0.891
Bridge Dip	7.03	7.05	7.10
Equivalent SG	0.96	0.94	0.89

The staff gauge was somewhat obscured by debris and hence very difficult to read.

B5 Discharge Measurements Undertaken During the Period

The folowing pages contain the calculation sheets for the discharge measurements carried out during the period by the project team. Because of the travel restrictions these were only done on the river Shebelli at Afgoi, on the following dates:

25 November 1989
30 December 1989
6 January 1990
10 February 1990

DISCHARGE MEASUREMENT BY CURRENT METER

Station:	Shebelli at Afgoi		Start	Finish
Date:	25th November 1989			
Method:	Suspension from bridge (d/s face) with 10kg weight	Ti	1030	1115
Origin:	Left bank	Sta	2.77	2.77
Observers:	Peter/Ali/Ibrahim/Ahmed			
Meter:	Braystoke BFM 001 No. 75-306 Impellor No. 8011-503			

Calculations made by method of mean velocity over section between two verticals.
Two measurements at each vertical.

Vertical number	Distance (m)	Depth (m)	Depth of observation	Time (s)	Revs	Velocity Point	Velocity Mean (m/s)	Section	Mean dept (m)	Width (m)	Area (sq.m)	Discharge (cumecs)
1	0.0	0.0	-	50	0	0.000	0.000					
				50				0.349	0.25	2.0	0.50	0.175
2	2.0	0.5	.6d	50	130	0.701	0.699					
			.6d	50	129	0.696		0.723	0.75	2.0	1.50	1.084
3	4.0	1.0	.6d	50	136	0.733	0.747					
			.6d	50	141	0.760		0.731	1.25	2.0	2.50	1.827
4	6.0	1.5	.8d	50	110	0.595	0.715					
			.2d	50	155	0.835		0.716	1.60	2.0	3.20	2.291
5	8.0	1.7	.8d	50	117	0.632	0.717					
			.2d	50	149	0.803		0.701	1.80	2.0	3.60	2.525
6	10.0	1.9	.8d	50	118	0.637	0.685					
			.2d	50	136	0.733		0.593	2.05	2.0	4.10	2.433
7	12.0	2.2	.8d	50	99	0.536	0.501					
			.2d	50	86	0.467		0.572	2.35	2.0	4.70	2.689
8	14.0	2.5	.8d	50	122	0.659	0.643					
			.2d	50	116	0.627		0.695	2.45	2.0	4.90	3.404
9	16.0	2.4	.8d	50	119	0.643	0.747					
			.2d	50	158	0.851		0.675	2.45	2.0	4.90	3.306
10	18.0	2.5	.8d	50	84	0.456	0.603					
			.2d	50	139	0.749		0.540	2.45	2.0	4.90	2.646
11	20.0	2.4	.8d	50	74	0.403	0.477					
			.2d	50	102	0.552		0.356	2.25	2.0	4.50	1.602
12	22.0	2.1	.8d	50	51	0.280	0.235					
			.2d	50	34	0.189		0.309	2.15	2.0	4.30	1.330
13	24.0	2.2	.8d	50	89	0.483	0.384					
			.2d	50	52	0.285		0.461	2.15	2.0	4.30	1.984
14	26.0	2.1	.8d	50	82	0.445	0.539					
			.2d	50	117	0.632		0.504	2.10	2.5	5.25	2.646
15	28.5	2.1	.8d	50	72	0.392	0.469					
			.2d	50	101	0.547		0.235	1.05	3.0	3.15	0.739
16	31.5	0.0	-	50	0	0.000	0.000					

Total Area (sq.m) = 56.30 Total discharge (cumecs) 30.68 Mean Velocity (m/s) 0.54

DISCHARGE MEASUREMENT BY CURRENT METER

Station:	Shebelli at Afgoi		Start	Finish
Date:	30th December 1989			
Method:	Suspension from bridge (d/s face) with 10kg weight	Ti	0955	1100
Origin:	Left Bank	Sta	3.72	3.71
Observers:	Peter/Ibrahim/Zakia/Ali/Ahmed			
Meter:	Braystoke BFM 001 No. 75-306 Impellor No. 8011-503			

Calculations made by method of mean velocity over section between two verticals.
Two measurements at each vertical.

Vertical number	Distance (m)	Depth (m)	Depth of observation	Time (s)	Revs	Velocity Point	Velocity Mean (m/s)	Section	Mean (m)	Width (m)	Area (sq.m)	Discharge (cumecs)
1	1.6	0.0	-	50	0	0.000	0.000					
				50				0.177	0.60	2.4	1.44	0.255
2	4.0	1.2	.8d	50	59	0.323	0.355					
			.2d	50	71	0.387		0.405	1.35	2.0	2.70	1.095
3	6.0	1.5	.8d	50	91	0.493	0.456					
			.2d	50	77	0.419		0.501	1.75	2.0	3.50	1.755
4	8.0	2.0	.8d	50	109	0.589	0.547					
			.2d	50	93	0.504		0.588	2.25	2.0	4.50	2.646
5	10.0	2.5	.8d	50	119	0.643	0.629					
			.2d	50	114	0.616		0.599	2.65	2.0	5.30	3.173
6	12.0	2.8	.8d	50	59	0.323	0.568					
			.2d	50	151	0.813		0.564	2.85	2.0	5.70	3.215
7	14.0	2.9	.8d	50	79	0.429	0.560					
			.2d	50	128	0.691		0.632	3.10	2.0	6.20	3.919
8	16.0	3.3	.8d	50	122	0.659	0.704					
			.2d	50	139	0.749		0.732	3.30	2.0	6.60	4.832
9	18.0	3.3	.8d	50	121	0.653	0.760					
			.2d	50	161	0.867		0.756	3.30	2.0	6.60	4.990
10	20.0	3.3	.8d	50	128	0.691	0.752					
			.2d	50	151	0.813		0.679	3.40	2.0	6.80	4.616
11	22.0	3.5	.8d	50	85	0.461	0.605					
			.2d	50	139	0.749		0.457	3.50	2.0	7.00	3.202
12	24.0	3.5	.8d	50	45	0.248	0.309					
			.2d	50	68	0.371		0.299	3.20	2.0	6.40	1.912
13	26.0	2.9	.8d	50	69	0.376	0.288					
			.2d	50	36	0.200		0.369	3.00	2.0	6.00	2.216
14	28.0	3.1	.8d	50	94	0.509	0.451					
			.2d	50	72	0.392		0.459	3.05	2.0	6.10	2.798
15	30.0	3.0	.8d	50	71	0.387	0.467					
			.2d	50	101	0.547		0.512	3.10	2.0	6.20	3.175
16	32.0	3.2	.8d	50	92	0.499	0.557					
			.2d	50	114	0.616		0.173	2.60	2.0	5.20	0.901

(Cont.)

(Cont.)

Shebelli at Afgoi 30th December 1989

Vertical number	Distance (m)	Depth (m)	Depth of observation	Time (s)	Revs	Velocity Point	Velocity Mean (m/s)	Section	Mean (m)	Width (m)	Area (sq.m)	Discharge (cumecs)
17	34.0	2.0	.8d	50	55	0.301	0.309					
			.2d	50	58	0.317		0.155	1.00	2.3	2.30	0.356
18	36.3	0.0	-	50	0	0.000	0.000					

Total Area (sq.m) = 88.54 Total discharge (cumecs) 45.06 Mean Velocity (m/s) 0.51

DISCHARGE MEASUREMENT BY CURRENT METER

Station:	Shebelli at Afgoi		Start	Finish
Date:	6th January 1990			
Method:	Suspension from bridge (d/s face) with 10kg weight	Ti	0945	1040
Origin:	Left Bank	Sta	3.89	3.88
Observers:	Peter Ede/Kevin Sene/Ibrahim/Ahmed			
Meter:	Braystoke BFM 001 No. 75-880 Impellor No. 8011-1247			

Calculations made by method of mean velocity over section between two verticals. Two measurements at each vertical.

Vertical number	Distance (m)	Depth (m)	Depth of observation	Time (s)	Revs	Velocity Point	Velocity Mean (m/s)	Section	Mean (m)	Width (m)	Area (sq.m)	Discharge (cumecs)
1	1.1	0.0	-	50	0	0.568	0.568					
								0.464	0.45	1.9	0.86	0.397
2	3.0	0.9	.6d	50	65	0.355	0.360					
			.6d	50	67	0.365		0.404	1.25	2.0	2.50	1.010
3	5.0	1.6	.8d	50	83	0.451	0.448					
			.2d	50	82	0.445		0.491	1.75	2.0	3.50	1.718
4	7.0	1.9	.8d	50	112	0.605	0.533					
			.2d	50	85	0.461		0.589	2.15	2.0	4.30	2.534
5	9.0	2.4	.8d	50	119	0.643	0.645					
			.2d	50	120	0.648		0.685	2.70	2.0	5.40	3.701
6	11.0	3.0	.8d	50	118	0.637	0.725					
			.2d	50	151	0.813		0.739	3.00	2.0	6.00	4.433
7	13.0	3.0	.8d	50	119	0.643	0.752					
			.2d	50	160	0.861		0.667	3.10	2.0	6.20	4.134
8	15.0	3.2	.8d	50	97	0.525	0.581					
			.2d	50	118	0.637		0.683	3.30	2.0	6.60	4.506
9	17.0	3.4	.8d	50	129	0.696	0.784					
			.2d	50	162	0.872		0.796	3.40	2.0	6.80	5.413
10	19.0	3.4	.8d	50	131	0.707	0.808					
			.2d	50	169	0.909		0.659	3.45	2.0	6.90	4.545
11	21.0	3.5	.8d	50	105	0.568	0.509					
			.2d	50	83	0.451		0.523	3.60	2.0	7.20	3.764
12	23.0	3.7	.8d	50	69	0.376	0.536					
			.2d	50	129	0.696		0.389	3.50	2.0	7.00	2.726
13	25.0	3.3	.8d	50	50	0.275	0.243					
			.2d	50	38	0.211		0.291	3.25	2.0	6.50	1.890
14	27.0	3.2	.8d	50	83	0.451	0.339					
			.2d	50	41	0.227		0.396	3.25	2.0	6.50	2.574
15	29.0	3.3	.8d	50	79	0.429	0.453					
			.2d	50	88	0.477		0.497	3.30	2.0	6.60	3.283
16	31.0	3.3	.8d	50	72	0.392	0.541					
			.2d	50	128	0.691		0.207	3.15	2.0	6.30	1.304

(Cont.)

(Cont.)

Shebelli at Afgoi 6th January 1990

Vertical number	Distance (m)	Depth (m)	Depth of observation	Time (s)	Revs	Velocity Point	Velocity Mean (m/s)	Section	Mean (m)	Width (m)	Area (sq.m)	Discharge (cumecs)
17	33.0	3.0	.8d	50	85	0.461	0.493					
			.2d	50	97	0.525		0.383	2.25	2.0	4.50	1.722
18	35.0	1.5	.8d	50	44	0.243	0.272					
			.2d	50	55	0.301		0.136	0.75	1.5	1.13	0.153
19	36.5	0.0	-	50	0	0.000	0.000					

Total Area (sq.m) = 94.78 Total discharge (cumecs) 49.81 Mean Velocity (m/s) 0.53

DISCHARGE MEASUREMENT BY CURRENT METER

Station:	Shebelli at Afgoi			Start	Finish
Date:	10th February 1990				
Method:	Suspension from bridge (d/s face) with 10kg weight		Ti	0945	1020
Origin:	Left Bank		Sta	2.03	2.02
Observers:	Peter Ede/Kevin Sene/Ibrahim/Ahmed				
Meter:	Braystoke BFM 001 No. 75-880 Impellor No. 8011-1247				

Calculations made by method of mean velocity over section between two verticals.
Two measurements at each vertical.

Vertical number	Distance (m)	Depth (m)	Depth of observation	Time (s)	Revs	Velocity Point	Velocity Mean (m/s)	Section	Mean (m)	Width (m)	Area (sq.m)	Discharge (cumecs)
1	2.1	0.0	-	50	0	0.000	0.000					
				50				0.145	0.35	2.9	1.02	0.148
2	5.0	0.7	.6d	50	56	0.307	0.291					
			.6d	50	50	0.275		0.401	0.85	2.0	1.70	0.682
3	7.0	1.0	.6d	50	92	0.499	0.512					
			.6d	50	97	0.525		0.604	1.10	2.0	2.20	1.329
4	9.0	1.2	.8d	50	111	0.600	0.696					
			.2d	50	147	0.792		0.577	1.35	2.0	2.70	1.559
5	11.0	1.5	.8d	50	81	0.440	0.459					
			.2d	50	88	0.477		0.576	1.65	2.0	3.30	1.901
6	13.0	1.8	.8d	50	111	0.600	0.693					
			.2d	50	146	0.787		0.732	1.80	2.0	3.60	2.636
7	15.0	1.8	.8d	50	125	0.675	0.771					
			.2d	50	161	0.867		0.669	1.80	2.0	3.60	2.410
8	17.0	1.8	.8d	50	78	0.424	0.568					
			.2d	50	132	0.712		0.473	1.75	2.0	3.50	1.657
9	19.0	1.7	.8d	50	56	0.307	0.379					
			.2d	50	83	0.451		0.340	1.20	2.0	2.40	0.816
10	21.0	0.7	.6d	50	55	0.301	0.301					
			.6d	50	55	0.301		0.343	1.05	2.0	2.10	0.720
11	23.0	1.4	.8d	50	76	0.413	0.384					
			.2d	50	65	0.355		0.460	1.40	2.0	2.80	1.288
12	25.0	1.4	.8d	50	70	0.381	0.536					
			.2d	50	128	0.691		0.555	1.45	2.0	2.90	1.609
13	27.0	1.5	.8d	50	84	0.456	0.573					
			.2d	50	128	0.691		0.287	0.75	2.7	2.02	0.581
14	29.7	0.0	-	50	0	0.000	0.000					

Total Area (sq.m) = 33.84 Total discharge (cumecs) 17.33 Mean Velocity (m/s) 0.51

APPENDIX C

DATA CHECKING AND INFILLING

This appendix was compiled by the Programmer/Hydrologist, Dr KJ Sene, following his visit to Somalia between January and March 1990. It represents a final report on the modelling work for validating flow data for the Jubba and Shebelli rivers, and for infilling missing or doubtful values. The models were used extensively by both the Programmer and the Resident Hydrologist for the checking and infilling of the historic data which was completed in March 1990. The models will continue to be of value for the same purposes for data recorded in 1990 and thereafter.

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1. INTRODUCTION

River levels have been recorded on Somalia's two main rivers - the Jubba and Shebelli - since 1951. These records from a valuable database for use in the evaluation and design of irrigation and flood relief schemes. At most stations, levels are measured two or three times a day by observers using either staff gauges or bridge dip meters. The handwritten records are then sent to Mogadishu for checking, conversion to flows and archiving on a computer database. Currently, the Department of Irrigation and Land Use (DILU) in the Ministry of Agriculture has responsibility for this data processing work, and for the operation and maintenance of the stations.

Since 1983, the work of the DILU has been supported by the Somalia Hydrometry Project. One of the main aims of this project was to check and computerise all of the available river level data for the rivers Jubba and Shebelli and, wherever possible, to infill periods of missing data using estimates from computer models. The development of the computer models was started during the second phase of the project (1985-1986) and, for the Shebelli, a simple correlation model was found to give promising results. This model was completed during the final phase of the project (1988-1990), and a similar model was developed for use on the Jubba. These models were used for the majority of the data checking and infilling work. As a result of this work, a national hydrometric databook was issued in mid-1990.

This report describes the development of the computer models and outlines how they were used during preparation of the hydrometric databook. The report also gives an introduction to the hydrology of the Jubba and the Shebelli and, in particular, the main features which should be included in any computer model of the rivers. The description of the hydrology is given in Section 2 and the development and application of the models is described in Section 3. Appendix A gives full operating instructions for the software. Further information on the work of the Somalia Hydrometry Project can be found in the final report (**Ref: Somalia Hydrometry Project - Final Report, Ministry of Agriculture (Somalia), Overseas Development Administration (UK) 1990).**

2. HYDROLOGY

2.1 General

The flows in the Jubba and Shebelli rivers originate in the Ethiopian highlands to the south and east of Addis Ababa. Figure 1 shows the catchment boundaries and the isohyets of total annual rainfall, and Figure 2 shows the general geology and topography of the catchments. The Jubba is formed from the confluence of three tributaries near to the Somali border whilst the main channel of the Shebelli traverses almost the entire catchment. Flows are seasonal and are dependent on the rainfall which falls in Ethiopia during the northwards and southwards movement of the Inter-Tropical Convergence Zone. The main flood seasons are the Gu, which typically lasts between April and June (in Somalia), and the Der, which typically lasts between September and November. In the dry period preceeding the Gu season, the flow into Somalia has virtually ceased on several occasions since records began in 1951. Between the Gu and Der seasons, flows are normally more sustained although, in some years, near zero levels have been reached, particularly on the Shebelli. At the border stations, the average total annual flows are about 6000 million cubic metres on the Jubba and 2000 million cubic metres on the Shebelli. Flood flows, sufficient to cause serious damage to crops and infrastructure, occur every few years. On the Jubba, the peak flow recorded since 1963 (within Somalia) is about 1800 cumecs. Peak flows on the Shebelli are harder to quantify since the river is more prone to flooding in its upper reaches; in one of the worst floods on record (1981) the peak flow along the flood plain was estimated to be about 1400 cumecs.

Within Somalia, the hydrological characteristics of the rivers are broadly similar. In their upper reaches, both rivers pass through low lying hills and have a narrow flood plain. Substantial local runoff can occasionally occur from flash floods flowing in the normally dry tributaries in these hills. Annual average rainfall in this region is 200-300mm. Within these upper reaches, any flood spillages are contained on the flood plain and can return to the main channel at a later date. This effect is more noticeable on the Shebelli, with the result that the main flood may not reach lower stations until several weeks after its arrival at the Somali border. Further downstream, both rivers traverse flat, featureless alluvial plains. In many places, the tops of the river banks lie above the surrounding countryside, so any flood spillages are lost permanently from the river. During the flood seasons, this gives rise to characteristic flat-topped hydrographs at the lower stations, when the river flows at its bank-full capacity for several weeks at a time. On the Jubba, any remaining flows discharge into the Indian Ocean near Kismayu; on the Shebelli, flows are absorbed in a swamp region which finishes close to the lower part of the Jubba basin. During flood events, flows from the lower Shebelli basin can sometimes enter the lower Jubba basin, although it seems likely that these flows originate from local runoff rather than being residual flows arriving from the Ethiopian catchment of the Shebelli. Also, during flood events, flows spilling from the Jubba have been observed to enter the lower Shebelli basin.

Within Somalia, abstractions from the rivers are used mainly for irrigation. Most irrigation schemes lie on the lower sections of the rivers. Use is also made of land flooded by controlled and uncontrolled spillages during the flood seasons. Currently, irrigation schemes on the Jubba support about 20,000 ha of farmed land (AHG 1988). No accurate figures are available for the Shebelli but the existing irrigation infrastructure could potentially support more than 100,000 ha (USAID 1987). Irrigation efficiencies are generally very low. On the Jubba, the major engineering schemes are the Jubba Sugar Project (near Mareere), the Fanoole project (near Jilib) and the Mogambo rice farm and flood relief canal (between Kamsuma and Jamamme). On the Shebelli, the largest irrigation scheme is the SNAI sugar farm at Jowhar. Irrigation supply to these schemes is primarily by gravity fed canals. The Shebelli also has a flood relief canal (at Duduble) and an offstream storage reservoir (at Jowhar). There are also numerous smaller pump and canal irrigation schemes in the lower reaches of the rivers, primarily for fruit and cereal production.

The national hydrometric network currently consists of 5 gauging stations on the Shebelli and 5 gauging stations on the Jubba:

Jubba	*Lugh Ganana*	*Shebelli*	*Beled Weyn*
	Bardheere		*Bulo Burti*
	Mareere		*Mahaddey Weyn*
	Kamsuma		*Afgoi*
	Jamamme		*Audegle*

Two more stations, at Kaitoi on the Jubba, and Balcad on the Shebelli, are no longer operational. A further station on the Shebelli - Kurten Warey - was established in 1988 but is not yet fully operational. Levels have been recorded at Lugh Ganana and Beled Weyn since 1951, and at most of the other stations since 1963. At all stations, readings are taken either by staff gauge or bridge dip meter. The stations at Lugh Ganana and Bardheere are also equipped with automatic level recorders, which have been operated intermittently since 1986. Most of the discussion in the remainder of this report is in terms of the reaches between these primary gauging stations.

2.2 The Jubba

The Jubba is formed from three tributaries - the Gestro, Genale Doria and Dawa Parma - which join near to the border town of Dolo. It is estimated that, of the 140,000 km^2 drainage area in Ethiopia, the Dawa Parma and Genale Doria each drain 40% of the area and the Gestro drains 20%. The average annual rainfall over the catchments varies from about 200 mm per year near the Somali border to more than 1500 mm per year in the Ethiopian highlands. Within Ethiopia, the catchment average rainfall is about 550 mm. Within the Somali portion of the catchment, the average annual rainfall reaches a maximum of over 600 mm in the area of Jilib near to the coast (all figures from Kammer 1989).

The first major town within Somalia is Lugh Ganana. Between Dolo and Lugh, the Jubba traverses alluvial soils with only a narrow meander belt. Downstream of Lugh, it enters a region of steeply sloping hills which it leaves about 20 km north of Bardheere. Within this reach, local runoff from tributaries can cause large increases in the flow reaching Bardheere. These tributaries, which are normally dry, can flow for several days following local rainfall. An idea of the flows reached in these tributaries can be gained by comparing the hydrographs for Lugh Ganana with those for stations further downstream. Figure 3 shows a typical example of a local runoff event ; starting from May 17, the flows at Kamsuma and Jamamme rose from 100 cumecs to a peak of over 400 cumecs, with no corresponding change in the flow at Lugh Ganana. The increased runoff lasted about 6 days.

Downstream from Bardheere, the flood plain of the Jubba widens but is still confined by low hills until Saakow. By Kaitoi, the river's meander belt is about 5 km wide. This meander belt contains many natural depressions (called desheks) which are often filled during flood events and are used for farming. Between Kaitoi and Jamamme, the flood plain reaches a maximum width of about 10km, and then narrows again before cutting through stabilised sand dunes to the Jubba's outlet near Kismayu. There are several old river channels in this reach, particularly to the west of Jilib, in the 'Far Shebelli' network of channels. These drain into the large Deshek Wamo depression to the west of the Jubba.

The main characteristics of the Jubba at each of the main gauging stations are summarised in Table 1. The maximum width and depth are approximate values, corresponding to the maximum in-bank flow at each station. Table 2 summarises the average slope, lag time and wavespeeds along the Jubba between each of the main gauging stations. The lag times and wavespeeds were estimated from a combination of two methods. Firstly, using the river level records from 1963 to 1989, a wide variety of specific events was identified, such as peaks or sudden drops in level, and the time taken for each event to move down the river was estimated. Estimates were made to the nearest hour. Table 3 summarises the results of this work and Figure 4 shows the observed lag times for each of the reaches. It is interesting to note that, provided the flow remains in-bank, there appears to be little dependence of lag time on flow ; this observation is discussed further in Section 3.1.

The second method of estimating lag times was to produce correlation plots between neighbouring pairs of stations for all available daily mean flow values in the period 1963 to 1989. For each pair of stations, the correlation plots were produced for a range of assumed lag times, and best fit straight lines were fitted to the data for each assumed time. Figure 5 shows an example of a correlation plot; in this case, between the stations of Balcad and Afgoi on the Shebelli. The figure also shows how the error of fit varied with the assumed lag time for this pair of stations. Plots like these were produced for all pairs of stations and the assumed lag time giving the lowest error of fit was then taken as a measure of the average lag time between the stations. The resulting estimates of lag time are compared with those from actual events in Table 4. The agreement is generally very good, except perhaps for the reach Kaitoi - Mareere, in which the lag time estimated from actual events appears to be too low. Table 4 also shows some estimates of lag time derived in other studies. The estimates by Gemmel (Gemmel 1982) were to the nearest day. The estimates by Agrar and Hydrotechnik (AHG 1984) were optimum values derived during calibration of a flood routing model. Again, there is good agreement between the various estimates. For the purposes of flow modelling, the values shown in Table 2 are recommended. In general, these are based on the values estimated from actual events; however, where these estimates appeared too low, they were adjusted assuming a constant wavespeed for the reach and the two adjoining reaches.

Engineering works

Most of the irrigation schemes on the Jubba are concentrated between Kaitoi and the coast. Upstream of Kaitoi, there are a few small pumped irrigation schemes. The only major structure on the Jubba is the Fanoole barrage which is a short distance downstream from Kaitoi. This barrage was constructed between 1977 and 1982 and is designed to pass a flood of about 800 cumecs. Bunds on the right bank upstream of the barrage are designed to fail above this threshold, allowing water into the Far Shebelli network of channels (Gemmel 1981). The barrage feeds the supply canal to the farms of the Fanoole project, which is situated on the left bank upstream of Jilib. The canal is 56km long and has a design capacity of 20.7 cumecs. Currently, an area of about 1000 ha is supplied by this canal (AHG 1988). Since 1981, backwater effects from the Fanoole barrage have affected the gauging station at Kaitoi such that measurements at this station have been of little use for estimating discharges in the Jubba.

Much of the reach between Fanoole and Jamamme is protected by bunds. There are many small pumped irrigation schemes in this reach, including several banana plantations. The only major irrigation schemes are the Jubba sugar project at Mareere and the rice farm at Mogambo. Both schemes are pump fed. The Jubba sugar project currently supports an irrigated area of about 7000 ha and the Mogambo rice farm an area of 1600 ha. Design pumping capacities at the two farms are 13.6 cumecs at the Jubba sugar project and 3.7 cumecs at Mogambo (all figures AHG 1988). At Mogambo, there is also a flood relief canal which discharges water to a low lying area to the west of the farm. The capacity of this canal is about 50 cumecs.

The total water requirements of the main irrigation schemes are small compared with the total flow in the Jubba, so that their effects are normally only apparent at low flows. Figure 6 shows the most obvious example which could be found of the effects of irrigation abstractions. It can be seen that, during January and February 1988, flows at Mareere and Mogambo varied on a weekly cycle, possible due to abstractions at the Fanoole barrage. The peak to peak variation in the flow was about 30 cumecs.

Flood flows

Flooding is common on the Jubba downstream from Barheere, but is normally confined to the meander belt and causes little damage. Indeed, breaches are often made deliberately in the river banks to allow the desheks adjacent to the river to be farmed. Because of spillages, both natural and man-made, the flows at Kaitoi and downstream often reach constant bank-full levels which are sustained for weeks at a time. Figure 7 shows a typical example of the hydrographs for the lower stations on the Jubba and Figure 8 summarises the bank-full flows reached in the period 1963-1989 at Kaitoi and all stations downstream. Where no value is plotted for a year, either no data were available or the bank-full level was not reached. There is little evidence of any change in time of bank-full flows. Variations from year to year occur because of changes in the location of breaches, improvements to flood protection bunds and, possibly, backwater effects from regions downstream. Table 5 summarises the average, maximum and minimum values of bank-full flow for the period 1963 to 1989. As expected, the average value decreases progressively in the downstream direction, reaching a value of about 480 cumecs by Jamamme.

Major concerns arise when flows at Lugh Ganana and Bardheere exceed about 1000 cumecs. Flood waters then not only inundate the meander belt but may also cause widespread damage to surrounding areas. Rather than just filling depressions, a parallel flow can develop along the meander belt, cutting across roads and flooding farmland and villages. Major floods occurred in 1956, 1961, 1977 and 1981. The 1981 flood was particularly well documented (Gemmel 1981 and MMP 1981). Little damage was caused upstream of Fanoole, although part of the town of Bardheere was flooded. As planned, the bunds upstream of Fanoole breached and a flow of 350-400 cumecs developed in the Far Shebelli network of channels. Much of this flow drained into the Deshek Wamo depression, but part of it eventually rejoined the Jubba near Kamsuma. There was also some flooding of the Jubba sugar project from its west side. Breaches downstream of Fanoole also caused flooding in the region between the Jubba river and the Fanoole irrigation canal, and cut the main Jilib-Kismayu road in several places. A portion of these flows eventually collected in the swamps of the lower Shebelli valley.

2.3 The Shebelli

The river Shebelli has a catchment area of about 300,000 km^2, of which approximately two thirds lies upstream of Beled Weyn. The total length of the Shebelli is about 1800 km, of which about 900 km lies in Somalia. In its upper reaches, the Shebelli passes through steep sided gorges, reaching its maximum total annual flow after about 500 km. Thereafter, the terrain becomes flatter, the river slope decreases and the flow remains roughly constant until shortly before the Somali border, where major spillages can occur into an area of permanent swamp. These swamps, and the surrounding flood plain, reduce and attenuate the flood flows reaching Somalia. A major tributary, the Fanfan, joins the Shebelli just upstream of the swamps but flows from this tributary do not reach the Shebelli in all years. Average annual rainfall over the Ethiopian part of the catchment varies from 1200 mm in the upper reaches to 200-300 mm near the Somali border. The catchment average rainfall in Ethiopia is about 475mm (Kammer 1989).

The first major town in Somalia is Beled Weyn, which lies in a shallow valley a few kilometres wide. This valley continues between low lying escarpments as far as Bulo Burti. In this reach, flood flows run parallel to the river along the valley floor, eventually returning to the river as the flow subsides. A few natural depressions retain some of the flood water, and are used for farming after inundation. Several tributaries join the Shebelli in this reach; these are normally dry but can contribute considerable runoff following local rainfall. Figure 9 shows an example of a local runoff event ; the event started in mid April when the flow at Bulo Burti jumped from 40 to 90 cumecs, whilst the flow at Beled Weyn was decreasing. The flow peak - slightly attenuated - was later observed at several locations downstream. During the 1981 floods, which were some of the worst on record, several smaller tributaries were observed to flow, with estimated flows of over 400 cumecs (Gemmel 1982). A widely quoted estimate, that these tributaries contribute a total of about 10

% of the average annual flow in the Shebelli, appears to have been obtained from an analysis of the 1968 flood on the Shebelli (MMP 1969).

The first non-returnable spillages occur downstream of Jalalagsie. Here, the Shebelli valley widens out into flat, featureless terrain and the tops of the river banks are generally above the surrounding land. Spillages occur in most years due either to collapse of the river banks or openings made to allow irrigation of low lying land. Spillages on the left bank sometimes enter an old river channel, and in exceptional years, can reach as far as a large depression to the east of Jowhar. On the right bank, the main spillages occur in the region of Duduble. By Balcad, the major spillages have occurred and the bank-full capacity has decreased to less than 100 cumecs. Beyond Balcad, spillages are usually small. As the Shebelli approaches Mogadishu, it turns parallel to the coast at a point where it meets a range of coastal sand hills. The river continues unchanged until Farkeerow, about 70 km downstream of Audegle, where it begins to branch into a series of swamp and channel systems. The defined channel resumes near Haaway. It is sometimes claimed that, in exceptional years, the flows from the Shebelli reach the Jubba valley but it seems more likely that these flows originate from local runoff from tributaries lying to the north of the the basin.

The main gauging stations on the Shebelli are currently at Beled Weyn, Bulo Burti, Mahaddey Weyn, Afgoi and Audegle. Levels were also recorded daily at Balcad until 1979 when station was closed down following construction of a barrage a short distance downstream. A new station was started at Kurten Warey in 1988 but is not yet fully operational. Table 1 summarises the characteristics of the Shebelli at the main stations, and Table 2 summarises the average slope, lag time and wavespeeds for the reaches between the stations. The lag times and wavespeeds were estimated using the same methods used for the Jubba (see Section 2.2). Table 3 summarises the estimates of lags from actual events and Table 4 compares these lag times with those estimated from correlation plots. Figure 10 shows the variation with flow of the actual lag times. As with the Jubba, provided the flow remains in-bank, there appears to be little dependence of lag time on flow ; this observation is discussed further in Section 3.1.

Engineering works

Despite its lower annual flow, there are many more irrigation and flood protection schemes on the Shebelli than the Jubba. In 1987, it was estimated that the Shebelli supports about 132000 ha of irrigated land (including regular flood inundations), of which about 98,500 ha lies downstream of Afgoi (USAID 1987).

In the upper reaches of the Shebelli, irrigation consists mainly of small scale pumping schemes, or cultivation of flooded desheks. There are flood relief canals at Beled Weyn and Duduble. The canal at Beled Weyn is sited 2 km upstream of the town and has a design capacity of about 20 cumecs. The canal at Duduble routes flows under the main road between Mahaddey Weyn and Bulo Burti into a low lying region. The scheme was completed in 1987. The design capacity of the canal is 40 cumecs although the actual capacity is probably less than this since there is considerable sedimentation in front of the canal's supply gates (a 1989 visit showed them to be almost blocked).

The first structure across the Shebelli is the weir at Sabuun, about 13 km downstream of Mahaddey Weyn. This weir raises water levels for the supply canal to Jowhar Offstream reservoir. This reservoir was completed in 1980 and has had a major impact on the low flow behaviour of the Shebelli in its lower reaches. It lies in a shallow depression to the east of Jowhar town and 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 outlet canal joins the Shebelli approximately 40 km downstream of 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 15 and 10 cumecs respectively. The maximum flow ever passed down the supply canal was about 35-40 cumecs (in 1981).

From discussions with staff at the reservoir, it seems that the current operating 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 after the start of the flood 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. After the end of the flood, the reservoir level declines due to evaporation and seepage losses. At the onset of the Der season, the 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, the canal gates are closed and are not re-opened until the following Gu season. After the end of the Der season, the outlet canal is brought into operation. 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. A more detailed discussion of these operating rules is given in the report on the forecasting model developed for the Somalia Hydrometry Project (see the final report).

Some examples of the effects of the reservoir are shown in Figure 11. Figure 11(a) shows the canal operations for the year 1984 ; during this year, the supply canal was operated from mid-July to early November, and the outlet canal was open from January to mid-May, and from early November onwards. An example of the effects of the supply canal can be seen in Figure 11(b), which compares the flows for Mahaddey Weyn and Afgoi for the period June to September. Until mid-July, the flows at Afgoi are only slightly lower than those at Mahaddey Weyn. However, in mid-July, at the onset of the Der flood, the supply canal was opened, causing an immediate drop in the flows at Afgoi compared with those at Mahaddey Weyn. A similar effect can be seen in Figure 11(c) for the outlet canal; throughout the period January to April, the outlet canal was open, so that the flow at Audegle was consistently about twice that further upstream at Mahaddey Weyn. Note that the difference in flow is not exactly equal to the flow in the outlet canal due to inconsistencies in the rating equations for the various stations, and due to losses and irrigation abstractions in the reach.

The Jowhar reservoir is built alongside the SNAI sugar farm at Jowhar. This farm began production in the early 1920's and has a cultivated area of about 6300 ha (MMP 1969). The farm is supplied by a gravity fed canal at Jowhar, which has a design capacity of 6 cumecs. Levels at the canal inlet are controlled by a weir across the Shebelli. When this weir was constructed in 1919, the river banks between were raised as far back as Mahaddey Weyn to accomodate the raised water levels caused by the weir. A flood relief canal, with a capacity of 14 cumecs, was built 3 km upstream of the weir in 1969.

The main agricultural areas on the Shebelli lie between Balcad and Farkeerow. There are many small fruit (e.g. grapefruit, bananas) and cereal (e.g. maize) farms in this reach, supplied either by pumps or gravity fed irrigation canals. Along the whole river, there are estimated to be about 330 small scale pumped irrigation schemes, the majority of which are below Balcad (USAID 1987). To supply the gravity fed canals, barrages have been constructed at Balcad (1979), Genale (1927), Gayweerow, Qorioley, Farkeerow, Kurten Warey and Hawaay. These barrages are designed to raise river levels sufficiently to allow water into the canals. As on the Jubba, the effects of these schemes are normally apparent only at low flows. Figure 12 shows the most obvious example which could be found of the effects of irrigation abstractions. Since 1987, weekly abstractions in the reach Mahaddey Weyn - Afgoi have produced fluctuations in the flows measured at Afgoi and Audegle. For the year shown, 1989, the peak to peak variation in the flow was about 15 cumecs.

Flood flows

As on the Jubba, flow spillages occur in most years in the river's lower reaches, with the result that the flows at Mahaddey Weyn and downstream often reach constant bank-full levels which are sustained for weeks at a time (e.g. Figure 13). Figure 14 shows the bank-full flows reached in the period 1963-1989 at Mahaddey Weyn and all stations downstream. Again, where no value is plotted for a year, either no data were available or the bank-full level was not reached. For Mahaddey Weyn, a distinct increase in bank-full flows occurred after 1980. This was probably due to bank raising work associated with the construction of Jowhar Offstream reservoir. For the remaining stations, there is little evidence of any change in time of bank-full flows. Table 5 summarises the average, maximum and minimum values of bank-full flow for the period 1963 to 1989. As expected, the average value progressively decreases in the downstream direction, reaching a value of about 82 cumecs by Audegle.

Abnormal flooding occurs when flows at Beled Weyn exceed about 250 cumecs, and is mostly confined to areas north of Balcad. The best documented flood events occurred in 1968 and 1981 (MMP 1969, Gemmel 1981, MMP 1981); these were also two of the largest floods on record. During these floods, it was observed that, between Beled Weyn and Bulo Burti, the flood waters moved along the river valley parallel to the main channel. The flood front normally travels much more slowly than the flow in the main channel, so ample warning is received of its arrival. The passage of the front is impeded by a natural control point at Giglei, some 40km downstream of Beled Weyn, and a second control at El Geibo, further downstream. In the 1981 flood, a sheet of water, up to 1.5m deep was observed to travel along the valley, and much of the town of Beled Weyn was also flooded. Gemmel (1981) estimated the total flow passing Beled Weyn to be about 1400 cumecs. Since 1963, there have been several other major floods in this reach of the Shebelli. The corresponding hydrographs are shown in Figure 15. It can be seen that usually there is a delay of several days, or even weeks, between arrival of the flood peaks at Beled Weyn and at Bulo Burti. Local runoff in the reach can also increase the magnitude of the flood at Bulo Burti.

As mentioned earlier, the first major non-returnable spillages occur between Jalalagsie and Mahaddey Weyn. The location of the spillages varies from year to year, depending on the state of the river banks and whether breaches are made deliberately (for irrigation or to protect areas downstream). In the 1981 flood, the major spillages occurred near Duduble and the water entered a network of old channels of the Shebelli, flowing over 100km and cutting the road between Mogadishu and Baidoa. In the 1968 flood the major spillages occurred from the left bank, flowing approximately 40 km to collect near to the current site of the Jowhar Offstream reservoir. The pattern of flooding in this reach determines whether any significant flooding will occur in the Shebelli downstream of Mahaddey Weyn. Since the construction of the Duduble flood relief canal and the supply canal to the Jowhar Offstream reservoir, the potential for flooding in the lower Shebelli has been greatly reduced.

3. FLOW MODELLING

3.1 Computer models

River flow models can range in complexity from simple correlation models to full solutions of the St-Venant equations. Normally, the simplest model which gives acceptable results is to be preferred. A notable feature of both the Jubba and the Shebelli is that flows at a station are normally closely related to flows at stations further downstream. This is partly because, for most of the time, there are few significant inflows or outflows along each reach. Also, the lag time curves (Figures 4 and 10) show that, whilst the flows remain in-bank, there is little variation of these parameters with the flow. This means that flood waves tend to preserve their shape as they move downstream, and that the arrival times of flow peaks are not strongly dependent on the magnitude of the flow.

These results suggest that, provided the flow remains in-bank, a simple correlation model should provide acceptable results for both rivers. The basis of a correlation model is to assume that the flows at a downstream station are related to those at an upstream station by a fixed straight line relationship, with a fixed time lag between the stations. Models of this type have been used successfully in several previous studies; for example by MMP (1983) on the Jubba, and by AHG (1986) on the Shebelli. A more detailed study (Meigh 1986), during the second phase of the Hydrometry project, again recommended use of correlation models and a preliminary model was developed for the Shebelli. The model was couched in terms of daily mean flows. The lag times used in the model were those which gave the smallest error of fit in the correlations and, as in previous studies, were constrained to be equal to a whole number of days. One or two part equations could be fitted to the data. To cope with the 'flat-topped' hydrographs observed at lower stations on the rivers, a maximum flow was specified for each of these stations, equal to the average bank-full flow for the station in the period 1963 to 1989. For the uppermost stations, a maximum flow was also specified, beyond which the model was no longer thought to be valid. The model had two modes of operation; a forecasting mode and an infilling mode. The forecasting mode allowed forecasts of flow for the lower stations to be obtained from river level information received by radio from Beled Weyn. The infilling mode allowed missing flow data to be infilled in the historic flow records, and included options for adjusting the estimated flows to blend smoothly with the observed flows at all 'joins' in the data. An option was also available for transferring infilled flows directly to the **HYDATA** hydrological database system which the Department of Irrigation and Land Use (DILU) uses to store river level and flow data for the two rivers.

During the final phase of the Hydrometry project, it was decided to use this model for the main data checking and infilling work, and to develop a similar model for use with the Jubba data. Some thought was given to changing the model to work in terms of instantaneous river levels, rather than daily mean flows, but this was not felt to be worthwhile due to the poor accuracy of much of the original data. Much of the development work centred on improving the ease of use of the software, but a major change to the calculation routines was that lag times were no longer constrained to be equal to a whole number of days. Instead, flows at fractional intervals of a day were estimated from the daily mean flows by linear interpolation. Other changes included allowing flows at a station to be calculated from flows at stations further downstream, and the addition of routines to calculate the correlation equations directly (whereas previously, a commercially available statistical package had been used). The final software package which was developed was called **RIVERI**, for which full operating instructions are given in Appendix A. For each river, the model was calibrated using the methods described in Section 3.2. Examples of the results obtained using the model are given in Sections 3.3 and 3.4. **RIVERI** was used for virtually all of the data checking and infilling work performed during preparation of the national hydrometric databook.

Limitations

The main failings of a correlation model are that it does not allow for variations in wavespeed with flow or for inflows or outflows along a reach. For both the Jubba and Shebelli, the assumption of a constant wavespeed seems reasonable, since wavespeeds remain roughly constant provided that the flow remains in-bank. For periods when the flow is out of bank, the only significant change in wavespeed with flow seems to occur on the reach between Beled Weyn and Bulo Burti on the Shebelli. Here, once the flow goes out of bank, a parallel flow develops on the flood plain, which is subject to natural hydraulic controls at Giglei and El Geibo. A full model of this situation would require detailed information on the shape of the flood plain and its hydraulic characteristics but this information is not available at present. An alternative would be to treat the reach as a 'black box' and to use one of the so-called hydrological routing methods, such as the Muskingum-Cunge method. Figure 16 shows the results of some exploratory computations performed using a variable parameter Muskingum-Cunge (VPMC) model. The simulations were for the 1981 Gu flood, and excellent results were obtained. However, less satisfactory results were obtained when applying the model to some of the other flood events shown in Figure 15. It is believed that this was partly due to the poor quality of the data at high flows and, in particular, uncertainty in the accuracy of the ratings at high flows. Indeed, for Beled Weyn, the existing rating equation probably underestimates the actual flow on the flood plain by a large amount. Because of these problems, this model was not considered for use in the infilling work; instead, any flood events for this reach of the Shebelli were infilled manually (see Section 3.4). It is worth noting that the only previous application of a hydrological routing model in Somalia was by Agrar-und Hydrotechnik on the Jubba (AHG 1984). The model was stated to be of the 'linear fictive reservoir cascade' type, but few details or results are given.

The other main failing of a correlation model is that it does not allow for inflows or outflows into a reach. On the Jubba and Shebelli, three main types of inflow or outflow can occur ; local runoff from tributaries, spillage (and return flows), and abstractions (or releases) associated with irrigation and flood relief schemes. The prospects for modelling local runoff are slim since there are no historical flow records for the tributaries and few rain gauges. To adequately monitor local rainfall, an extremely dense network of raingauges would be required due to the characteristics of the rainfall, which typically results from isolated storms a few kilometres across. Another possibility would be to use satellite imagery of the catchments but the problem of calibrating rainfall runoff models to make use of this data would still remain. Fortunately, local runoff events occur only infrequently and, during the infilling (see Section 3.4) there was no need to model them.

To model spillage from the rivers would require detailed information on the location and size of all breaches in the banks. It is unlikely that such information could ever be obtained, since breaches tend to occur in different places from year to year. In the correlation model, spillage is allowed for indirectly by specifying a bank-full flow which can never be exceeded at each station. The other main cause of inflows and outflows - irrigation schemes - could again be modelled only by having a detailed knowledge of the operating rules for each scheme. Again, this information is not currently available but a computer model along these lines has been proposed as part of a USAID funded development project for the Shebelli valley (USAID 1987). In the present study, it was decided that the only scheme which merited detailed consideration was the Jowhar Offstream reservoir, since this has a major effect on low flows in the lower Shebelli. A detailed model of the reservoir was developed, primarily for use in the forecasting models. Consideration was given to including this model in the infilling model for the Shebelli but, as described in Section 3.4, this did not prove to be necessary. Further information on this model is given in the report on forecasting models issued by the Hydrometry project.

3.2 Calibration

Before using **RIVERI** to infill flow data, it was necessary to calibrate the model for use on the Jubba and the Shebelli. This involved specifying the correlations and average lag times between neighbouring stations on each river, and the average bank-full flows at each station. The average lag times were taken to be the values shown in Table 2 and the bank-full flows were taken to be the average values shown in Table 5. Correlations were developed for each neighbouring pair of stations on each river. The required pairs for each river have changed with time, due to the establishment and closure of stations. For the Jubba, 11 correlations were required in the period 1963 - 1989 (see Table 6), and for the Shebelli, 7 correlations were required in the same period. Correlations were developed for both downstream stations on upstream stations, and upstream stations on downstream. The second type, upstream on downstream, might seem questionable, since there is no possibility of including the effects of inflows (e.g. local runoff) or outflows (spillage) in a reach. Correlations of this type were therefore used as little as possible. However, their use was felt to be preferable to leaving gaps in the flow records. Table 8 shows the 'downstream on upstream' correlation equations which were developed and Figures 18 and 19 show the raw data used in these calculations. In most cases, the intercept of the first segment was calculated, rather than forced through the origin. This allowed for discrepancies in rating equations at low flows. For some correlations (e.g. Bulo Burti - Beled Weyn), an upper limit was specified for the final segment to prevent use of the model during flood events (for which it was not designed).

When developing the correlations, as many as possible of the available observed values of daily mean flow were used. However, all doubtful values were excluded in order to improve the accuracy of the correlations. The methods by which doubtful values were found are described in Section 3.3. Also, for the reasons discussed in Section 3.1, it was necessary to exclude all periods for which there was any significant inflow or outflow in the reaches between stations. Figure 17 shows an example of the effects of not excluding flood and local runoff events for just one year of data; the correlation improves dramatically when these events are excluded. Table 7 summarises the main periods which were excluded from the correlations due to these events. For stations with maximum bank-full flows, periods when the flow was at the maximum were also excluded. In the model, this was done by specifying a maximum flow for each year beyond which data for the station was to be ignored. To allow for fluctuations in flow, this maximum was typically set at 5-10 cumecs less than the average bank-full flow for the year. The other cause of outflows - irrigation abstractions - could generally be neglected, since these are usually much less than the flow in the main river channel. The only exception was for the reach Mahaddey Weyn - Afgoi, where the periods in which the supply and outlet canals to Jowhar Offstream reservoir were operating were excluded.

It is important to note that the correlation equations apply only for the rating equations which were in use when the river levels were converted to flows ; if these ratings are changed, the correlations must also be changed. The rating equations applicable to the correlations are listed in Table 9.

3.3 Data checking

Checking the original data proved to be a major task, since errors were found in practically every year of the record for every station. The main method used for checking data was to compare the daily mean flow records at each station with those for the other stations on the same river in the same period. The records for each station were checked for every year for which data were available. These comparisons were performed using the plotting facilities in the computer model. Two types of comparison plot could be produced ; time series plots showing up to 5 stations per plot and correlation plots between pairs of stations. The types of errors looked for included:

- *excessive lag times between stations during events*
- *abrupt increases or decreases in flow*
- *long periods of constant flow*
- *unlikely (e.g. stepwise) variations in flow*
- *flows much higher or lower than at adjacent stations*
- *flows increasing in the downstream direction*

Wherever errors were identified, the original handwritten records were inspected to try and determine the cause of the error. For example, unlikely lag times can occur because the correct levels have been attributed to the wrong dates, and stepwise variations can occur due to readings being taken intermittently and incorrectly interpolated in the missing periods. Table 10 lists the most common causes of errors which were identified during the data checking work.

For both rivers, the data checking was performed bearing in mind the known hydrological characteristics of each reach. For example, the average observed lag times shown in Table 2 were used as a guide to the likely lag times between stations. For the reaches Beled Weyn - Bulo Burti, Bulo Burti - Mahaddey Weyn, and Lugh Ganana - Bardheere, longer lag times were permitted during exceptional flood events. During periods of high flow, checks were made that the bank-full flows at the lower stations reached values comparable with the long term average values given in Table 5. During periods of low flow, checks were made to see whether abrupt changes in flow could have been caused by irrigation abstractions or, on the Shebelli, by operation of Jowhar Offstream reservoir.

A few problems arose with checking data during low flow periods. Normally, some decrease in flows in the downstream direction would be expected due to losses and irrigation abstractions. Often, however, an apparent increase occurred. The cause of this problem was the poor accuracy at low flows in the rating equations used to convert levels to flows. The reasons for this poor accuracy are discussed in the final report of the Hydrometry project. As the fault here was due to the rating equations, rather than the observed levels, levels and flows for these periods were retained. For this reason, the resulting low flow values should not be used for estimating losses or abstractions between stations.

For some periods, additional information was available to assist with the data checking. On the Jubba, from 1983 onwards, river levels were available for a station at the inlet canal to the Mogambo rice farm. These levels were used in checking the flows at the other stations on the Jubba. On the Shebelli, from 1980 onwards, records were available for the flows into and out of the Jowhar Offstream reservoir. These records were used when checking the data for Afgoi and Mahaddey Weyn, and helped to explain several periods of apparently doubtful data for Afgoi, in which abrupt increases or decreases in flow proved to be caused by operation of the reservoir canals. Records were also available from 1980 for Sabuun weir, by the inlet to the supply canal to Jowhar Offstream reservoir. These were of great help in checking the records for Mahaddey Weyn for this period, since the two stations are separated by a distance of only 13 km.

The data checking procedure outlined above was used for all stations from 1963 onwards. However, for the period 1951 - 1962, data were only available for the uppermost station on each river, so these methods could not be used. Instead, the hydrographs for each year were checked visually and only obvious errors removed. For this reason, the data for 1951 - 1962 should be treated as less reliable than that for 1963 onwards. A similar problem also arose for the Jubba for a few years from 1963 onwards. For some periods, data were only available for two stations, so it was difficult to know which of the records was correct. Because of this, some periods of possibly doubtful data had to be accepted.

The outcome from the data checking work was a list of periods of doubtful data for each of the gauging stations (Table 11). This list was used both in calibrating the computer model and in the infilling work.

3.4 Data infilling

The aim of the infilling exercise was to estimate flows for all periods in which original values were missing, and to deal with all the periods of doubtful data identified in the data checking work. Typically, the worst periods of missing data were found to occur in the periods between foreign funded development projects. For the Jubba, the poorest data returns were in the late 1960's and early 1980's and, for the Shebelli, the worst periods were in the mid to late 1970's.

In developing the correlations, all periods of doubtful data were excluded. This still left plenty of data points for use in the calculations and improved confidence in the resulting correlation equations. By contrast, for the infilling work, it was decided to retain as much as possible of the original data, so as to preserve the natural variability (in lags and flows) typical of the rivers. Consequently, before starting the infilling, all periods of doubtful data were re-evaluated and a final decision was taken as to whether data should be retained or deleted from the database. Only those periods which were definitely incorrect were deleted. The infilling exercise was thereby reduced to the task of replacing all missing data values on the database with estimated values.

The model makes flow predictions for a year at a time. For each river, flow values were infilled year by year starting from the earliest year for which data were available. This ensured that the record was continuous between years. All stations for the year were dealt with at the same time ; this helped in building-up a picture of the state of the river for the year and gave more consistent results. For each year, stations were first infilled in the downstream direction, and all previously estimated values (if any) were over-written. Once the lowermost station had been infilled, the infilling was repeated station by station in the opposite direction and any previously estimated values in the database were retained. This procedure ensured that precedence was given to values estimated in the downstream direction. For all stations, great care was taken that the flow values merged smoothly at the start and end of each year. Also, within each year, the estimated flows were adjusted to blend smoothly with the observed flows at the ends of each gap in the original data. Figure 20 gives some examples of the types of adjustments which can be performed using the computer model. Generally, 'shift' type adjustments were made for small gaps and 'join' type adjustments for the larger gaps. It is worth noting that, in most cases, the predicted flows were encouragingly close to the observed flows at the ends of the gaps.

Values were generally infilled only for years in which some original data were available for the station. The only exceptions were for Jamamme on the Jubba and Audegle on the Shebelli, for which a complete record from 1963 to 1989 was generated. For both these stations, there were several years for which original measurements were either not available or were of such doubtful value that they had to be discarded.

As in the data checking work, use was made of data for some stations which do not form part of the national hydrometric network. On the Jubba, data for Mogambo was used to infill some periods for Jamamme from 1983, and, on the Shebelli, data for Sabuun weir was used to infill some periods for Mahaddey Weyn from

1980. In the latter case, the infilling was performed before starting to infill data for Afgoi from data for Mahaddey Weyn ; this was the only case for which infilling in the upstream direction was preferred and was justified here since the stations are such a short distance apart.

Before starting the infilling work, it was thought that there might be several periods when the model would not produce satisfactory results. The chief worry was that flood and local runoff events could not be modelled. Infact, it was found that few, if any, local runoff events required modelling, and that only two flood events could not be satisfactorily modelled. These events were for Bulo Burti in 1977 and 1981. For these events, the missing data values were estimated by eye and entered manually onto the database. The estimates were made by comparison with the other flood events for the same reach, using the catalogue of flood events shown in Figure 15. The only other situation where data were entered manually onto the database was for periods of zero flow. Here, it proved to be simpler to enter the zero values directly rather than to attempt to produce the zero values using the adjustment options in the computer model. Another potential source of problems, the reach including the inlet and outlet to Jowhar Offstream reservoir, proved not to require any special procedures since there was sufficient data available for the infilling to be performed without considering the flows into and out of the reservoir.

The infilling exercise was carried out during January and February 1990. Approximately 30,000 daily mean flow values (about 30 % of the total record) were estimated and transferred to the database. Table 12 summarises the condition of the database immediately before and after the infilling operation. The final database was published in the form of a national hydrometric databook in mid-1990 (**Ref : Hydrometric Databook - Jubba and Shebelli rivers 1951 - 1989, Somalia Hydrometry Project, May 1990**).

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AHG = Agrar-und Hydrotechnik GMBH, West Germany
MMP = Sir M.MacDonald and Partners, United Kingdom

APPENDIX A - OPERATION OF THE MODELS

A.1 Introduction

This Appendix describes the operation of the infilling model **RIVERI**. The model is designed to develop correlations between stations and to use these correlations to infill periods of missing or doubtful daily flow data on a HYDATA database. Sections 2 and 3 of this report give further information on the development and applications of the model.

RIVERI is designed to work with an IBM or compatible personal computer running under DOS. Both text and graphical output can be obtained. Currently, only the Hewlett Packard HP7475A series plotter is supported for hard copies of graphical output. An analysis with **RIVERI** is started by typing the command **RI** from the directory containing the HYDATA database on which data are to be infilled. The program is controlled using a similar menuing system to HYDATA, and it is assumed that the user is already familiar with the operation of these menus ; further information can be found in the HYDATA Operation Manual. As with HYDATA, the program is password protected, and uses the same passwords that are defined on the HYDATA database. Passwords must be entered in uppercase characters; for the benefit of users without colour monitors, the sixth password in the HYDATA installation file (if defined) causes the display to appear in monochrome.

Once the password has been entered, the main menu, menu A1, is displayed :

```
            Menu A1 - Main Menu

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

The required river should be selected, which will then cause menu A2, 'Mode', to be displayed:

```
            Menu A2 - Mode

   [ 1]  Quit
   [ 2]  Infill data
   [ 3]  Correlate
   [ 4]  Find flags
```

This is the main control menu for **RIVERI**. Option [2] allows data to be infilled using existing correlations, Option [3] allows new correlations to be developed, and Option [4] displays the current numbers of original, estimated and missing values on the HYDATA database. These options are discussed in Sections A.2, A.3 and A.4. Section A.5 gives guidelines on how **RIVERI** is used to infill a period of missing data and Section A.6 describes the layout of the setup files used by **RIVERI** to define the main characteristics of each river.

A.2. Infilling mode

The infilling mode of operation allows flows at one station to be predicted from flows at a second station. Normally, at the start and end of every gap in the observed data, the predicted flows will differ slightly from the observed flows. An option is therefore provided to allow the predicted flows to be adjusted to blend smoothly with the observed flows. In **RIVERI**, gaps are defined to occur wherever there is missing data, where there is doubtful data (as specified in the setup file; see Section A.6), and where there is estimated data (if the 'Fill estimated' option is selected ; see Section A.2). Note that the terms predicted and estimated flow are both used to describe the flows calculated by the program.

The infilling mode is selected by choosing Option [2] from menu A2. This causes menu I1, 'Infilling', to appear:

```
                Menu I1 - Infilling

        [ 1]  Quit
        [ 2]  Setup file         [                  ]
        [ 3]  Year               [      ]
        [ 4]  HYDATA Station A   [         ]
        [ 5]  HYDATA Station B   [         ]
        [ 6]  Fill estimated     [   ]
        [ 7]  Continue
```

Option [2] requests the name of the setup file. This file defines the numbers of the HYDATA stations on the river, the periods of rejected data for each station, and the correlations to be used between the flows at pairs of stations. It also defines the maximum flow at each station. The layout of this file is described in Section A.6. The file should be in ASCII text format and is most easily created using a word processor in unformatted mode.

Option [3] defines the year for which data are to be infilled and Options [4] and [5] define, respectively, the HYDATA station for which flows are to be predicted and the HYDATA station from which these flows are to be calculated. The setup file must contain a correlation between the two stations specified. Option [6], 'Fill estimated', determines whether previously estimated values are to be over-written. An entry of 0 means estimated values are to be retained ; a value of 1 means that they are to be over-written. Some uses of this option are given in Section A.5; typically, a value of 1 would be selected when infilling from an upstream station, and a value of 0 selected to infill the remaining missing values from a downstream station.

When all of the entries in menu I1 have been completed, Option [7], 'Continue', should be selected. **RIVERI** will then begin to read the required data from HYDATA and to calculate the required flow estimates for Station A. Once these calculations have been completed, the screen will clear and menu I2, 'Output', will be displayed:

```
        Menu I2 - Output

[ 1]    Quit
[ 2]    Plot flows
[ 3]    Adjust flows
[ 4]    Display gaps
[ 5]    Write gaps
[ 6]    Write flows
[ 7]    Display correlations
[ 8]    Transfer flows
```

This is the main control menu for output of the estimated flows; the options in the menu allow the estimated flows to be displayed, printed, adjusted and/or transferred to the HYDATA database. These options are described in detail below. It should be noted, however, that Options [3], [4], [5] and [8] can only be selected if there are one or more gaps in the data for the selected year.

[2] Plot flows

This option allows the observed flows, estimated flows and adjusted flows to be plotted on the screen or on a HP7475A plotter. The following menu appears when this option is selected:

```
        Menu P2 - Plot

[ 1]    Quit
[ 2]    Max Y            [500.0   ]
[ 3]    Max X            [0.0     ]
[ 4]    Start Month      [Jan 90            ]
[ 5]    End Month        [Dec 90            ]
[ 6]    Y intervals      [5  ]
[ 7]    Show gaps        [1  ]
[ 8]    Colour           [0  ]
[ 9]    Plot estimated   [0  ]
[10]    Plot Type
[11]    Paper Plot
[12]    Screen plot
```

The menu entries show typical default values. Options [2] and [3] define the maximum and minimum flow values (in cumecs) to appear on the Y-axis, and Option [6] defines the number of tick marks to appear on this axis. Options [4] and [5] define the start and end month to appear on the X-axis. These values are displayed in the form **mmm** yy, where **mmm** represents the month and yy represents the year for which flows are being infilled. Thus, if the year entered in menu I1 was 1985, yy would be 85. Entries of Dec of the previous year (e.g. Dec 84) and January of the next year (e.g. Jan 86) are also allowed ; this enables checks to be made that the estimated flows blend smoothly with flows from the preceeding and following years. If only the month is entered, then the year is assumed to be the infilling year. The range of dates entered affects the way in which the X-axis is plotted. If both the start and end month are the same, the axis is annotated with each day of the month (e.g. Figure 3). If the months are different, than annotations appear for each of the months selected (e.g. Figure 7). However, if the months Jan and Dec are selected, then the axis automatically spans the period from December in the previous year to January in the next year.

Option [7], 'Show gaps', can have entries of 0 (no) or 1 (yes). If a 1 is entered, this causes a letter S to appear on the plot at the start of every gap in the record and a letter F to appear at the end of each gap (e.g. Figure 20). This facility is useful for identifying narrow gaps which otherwise would not be easily visible on the plot. Option [8], 'Colour', allows plots to be displayed or plotted in monochrome (0) or colour (1). Option [9], 'Plot estimated', determines whether previously estimated values (i.e. estimated values already saved in the database) are to be plotted. This facility is useful for checking whether the estimated values have themselves been calculated from estimated values. Note that this option only affects the plots for Stations A and B, as defined in menu I1.

Option [10], 'Plot Type', determines which flow values are to appear on the plot. If this option is selected, the following menu is displayed:

```
                Menu P3 - Define curves

[ 1]  Quit
[ 2]  Station A              [1  ]
[ 3]  Predicted (in gaps)    [1  ]
[ 4]  Predicted (all)        [0  ]
[ 5]  Adjusted (in gaps)     [0  ]
[ 6]  Adjusted (symbols)     [0  ]
[ 7]  Station B              [0  ]
[ 8]  Another station        [         ]
[ 9]  Another station        [         ]
[10]  Another station        [         ]
```

For Options [2] to [7], an entry 1 signifies that the stated curve is to be plotted and an entry 0 that the curve is not to be plotted. Option [2] selects the flow data for Station A, Option [3] selects the predicted flows for Station A in the gaps only, Option [4] selects the predicted flows for Station A for the entire year, Option [5] selects the adjusted predictions (see 'Adjust flows' option), plotted as a line, and Option [6] selects the same flows plotted as triangular symbols (useful if there are only one or two daily values missing in the gap). Option [7] selects the flows for Station B. The remaining options, Options [8] to [10], allow any other of the HYDATA stations defined in the setup file to be selected. For these entries, the station number itself must be entered; note, however, that the numbers of Stations A and B cannot be entered here. It can be seen that, by using these options, and Options [2] and [7], up to 5 stations on the river can be plotted on a single graph (e.g. Figure 9).

The maximum number of lines which can be plotted on any one graph is six. If additional lines are selected, these will not appear on the plot. Note that Option [2] effectively selects two lines, one showing valid original data and one showing any periods of rejected data for the station as defined in the setup file. Once the required entries have been made in this menu, Option [1], 'Quit', should be selected which returns control to menu P2. The plot can be then be displayed on the screen by selecting Option [12], 'Screen Plot', or drawn on a HP7475A plotter by selecting Option [11], 'Paper Plot'. If Option [11] is selected, a warning message first appears, asking if the plot is to proceed. To abandon the plot, the F2 key should be pressed, and to continue the plot, the **ENTER** key should be pressed.

[3] Adjust flows

This option allows the estimated flows to be adjusted to blend smoothly with the observed flows at the start and end of each gap in the original data. When this option is selected, the following menu, menu I3, is displayed:

```
            Menu I3 - Adjust

[ 1]   Quit
[ 2]   Gap number        [0   ]
[ 3]   Number of days    [3   ]
[ 4]   Join type         [0   ]
[ 5]   Max. flow         [9999.0 ]
[ 6]   Shift
[ 7]   Join at start
[ 8]   Join at end
[ 9]   Reset flows
```

Some typical default values are shown in the menu entries.

Option [2], 'Gap number', selects the number of the gap for which the adjustments are to be performed. If 0 is entered, the same type of adjustment is performed for all gaps in the year (if possible). Two main types of adjustment are possible, called 'Shift' and 'Join'. 'Shift' bodily moves the predicted flow curve to match the observed flows at the ends of each gap, whilst 'Join' only affects the flows within a specified number of days of the end of each gap. Figure 20 shows examples of the types of adjustment available.

Options [3] and [4] only affect the 'Join' mode of adjustment and can be left unchanged if a 'Shift' is to be performed. Option [3], 'Number of days', requests the number of days over which the join is to be made, and can take any value from 1 to 366. Option [4] selects the type of join required. Three types are available:

0 - Distribute difference at start/end of gap over specified number of days

1 - Join to start/end of gap by a straight line over specified number of days

2 - Set all values in specified number of days to zero

Option [5], 'Max. flow', affects both the 'Shift' and 'Join' type of adjustment. The initial value displayed in this option is the value of maximum flow specified for Station A in the setup file. If a lower maximum is specified, then all predicted flows above the new value will be set to the new value. Alternatively, if a higher maximum is entered, then all predicted flows above the original maximum will be set to the new value. This facility allows predictions of bank full flows to be adjusted to account for annual variations in maximum flow. The adjustments take place as soon as the new maximum is entered. The effects of this option are more predictable if it is selected before using Options [6], [7] or [8].

Options [6], [7] and [8] allow 'Shift' or 'Join' operations to be performed. If selected, and the adjustments have been completed successfully, the message:

[4] Adjustments to flows completed

appears. If the specified adjustment could not be performed, then the message:

[18] Specified adjustment could not be performed for one (or more) gaps

is displayed. The predicted flows are then left unchanged for all the gaps for which the required adjustment was not possible.

The final option in menu I3, Option [9], allows the adjusted flows to be reset to the original predicted values. This option can be used at any time either to recover the predicted flows or to reset the adjusted flows before trying another type of adjustment.

[4] Display gaps

This option allows information on each gap in the data for Station A to be displayed on the screen. Normally, this display should be inspected before starting to plot, adjust or transfer the predicted flows. By default, the cursor is placed on Option [4] when Menu I2 first appears on the screen.

When this option is selected, the screen clears and a display appears. A typical example of this display is shown below:

GAP	NUMBER	DATE	Observed (cumecs)	Predicted (cumecs)	Diff. (cumecs)
START	1	1984 Dec 31	e	12.06	0.00
END	1	1985 Jan 15	8.07	8.19	0.12
START	2	1985 May 14	127.43	129.35	1.92
END	2	1985 Jun 2	165.03	m	m

This example is for a station which has two gaps in its record for 1985. The first missing value is on 1985 Jan 1, so the gap is shown as starting on Dec 31 of the previous year. The 'e' flag indicates that the value for that date was itself estimated, so the difference between the predicted and stored values is of course zero. This gap ends on Jan 15. A second gap starts on May 14 and ends on Jun 2. At the end of this gap, the 'm' flag indicates that a predicted value could not be calculated (because no flow values were available for Station B at the required time).

The 'Display Gaps' option can display information on up to 50 gaps but only 4 gaps are displayed at any one time. To page through the gaps, the **ENTER** key should be pressed repeatedly.

[5] Write gaps

This option allows the information shown by 'Display Gaps' to be written to file. If selected, an extra menu, menu A3, is displayed:

```
            Menu A3 - Write file

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

The name of the file for output should be entered in Option [2] and then Option [3] should be selected. To obtain a hard copy of this file, the DOS **PRINT** command should be used after exiting from **RIVERI**.

[6] Write flows

This option allows the observed, predicted and adjusted flows to be written to file for each day in the year being infilled. If selected, an extra menu, menu A3, is displayed:

```
            Menu A3 - Write file

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

The name of the file for output should be entered in Option [2] and then Option [3] should be selected. To obtain a hard copy of this file, the DOS **PRINT** command should be used after exiting from **RIVERI**. The example below shows the first few lines of a file produced using this option:

PREDICTED FLOWS

Station A : Mahaddey Weyn
Station B : Bulo Burti
Year : 1985

DATE	Station A Observed	Station A Pred.	Station A Adjusted	Diff.	Error (%)
1985 Jan 1	m	13.44	13.44	m	m
1985 Jan 2	m	12.87	12.87	m	m
1985 Jan 3	m	12.45	12.45	m	m
1985 Jan 4	11.10	12.21	m	1.11	10.00
1985 Jan 5	11.09	12.18	m	1.09	9.90

.... (continued)

All flow values are displayed in cumecs. The difference (Diff.) is defined as the difference between the predicted and observed flow, and the error is this difference as a percentage of the observed flow. Adjusted flows are only shown for periods in which original data are missing i.e. in the gaps. In the above example, no adjustments have yet been performed so the adjusted flows are equal to the predicted flows.

[7] Display correlations

This option allows the correlation equation between Stations A and B to be displayed on the screen. The equation is read from the setup file. This facility provides a quick way of checking that the correct equation is being used with the correct lag time.

When this option is selected, the screen clears and a display appears. A typical example of this display is shown below:

SEGMENT 1 : 0.0 to 250.0 cumecs

LAG days	Slope	Intercpt.
2.40	1.034	0.000

For this station, there is a lag time of 2.4 days between Stations A and B, and correlation equation used has a slope of 1.034 and a zero intercept. There is only one part to the correlation, and the equation is valid for flows up to 250 cumecs at Station B (Note that if this flow is exceeded, no predicted flow is calculated).

[8] Transfer flows

This option allows the adjusted flows to be transferred to the HYDATA database. Flows can either be transferred directly or via an intermediate HYDATA macro file. It is important to note that it is the adjusted flows, not the predicted flows, which are transferred. All transferred flows (except missing values) are assigned to HYDATA data flag number 2 ; typically, this flag will be defined as meaning 'estimated' data. Normally, the 'Direct Transfer' option is used in preference to the 'Write HYDATA file' option . Some situations where the 'Write HYDATA file' option might be used are a) to transfer estimated flows to a database in another directory or on another computer and b) when there is a real risk of a power failure occurring during the transfer (this could possibly corrupt the database ; see below).

The following menu is displayed when the 'Transfer flows' option is selected:

```
                 Menu I4 - Transfer

            [ 1]  Quit
            [ 2]  Filename          [SFILL2.REC      ]
            [ 3]  Gap number        [0   ]
            [ 4]  Direct transfer
            [ 5]  Write HYDATA file
```

The menu entries show some typical default values.

Option [2], 'Filename', has different meanings according to whether the 'Direct Transfer' or 'Write HYDATA file' option is to be selected. If the 'Write HYDATA file' option is to be used, the filename required is the name of the file to which the data are to be written. If the 'Direct Transfer' option is to be used, the filename referred to is the name of a file to which information about the transfer is to be written. This type of file is called a 'log' file. The log information is written for every gap for which data are transferred directly, and provides a useful record of the infilling operations which have been performed. The example below shows the first few lines of a 'log' file:

```
RECORD OF INFILLING OPERATIONS

Date         User  River           Station   Start Date       End Date Number

1990 Jan 27    6   RIVER SHEBELLI       12  1985 Jan  1   1985 Apr  5     95
1990 Jan 27    6   RIVER SHEBELLI       12  1985 Apr 13   1985 Apr 19      7
1990 Jan 27    6   RIVER SHEBELLI       12  1985 Jul 27   1985 Jul 31      5
1990 Jan 27    6   RIVER SHEBELLI       12  1985 Nov  1   1985 Nov  1      1
1990 Feb 12    6   RIVER SHEBELLI       12  1985 Jan  1   1985 Apr  5     95
1990 Feb 12    6   RIVER SHEBELLI       12  1985 Apr 13   1985 Apr 19      7
1990 Feb 12    6   RIVER SHEBELLI       12  1985 Jul 27   1985 Jul 31      5
```

The records in this example are all for Station number 12 on the River Shebelli. The infilling operations were performed by HYDATA user number 6. The 'Date' shows the date on which each infilling operation was performed. The 'Start' and 'End' dates show the dates of the first and last values transferred in each gap and the 'Number' shows the number of values transferred in that gap. Note that the number of values also includes days for which predicted values could not be calculated (i.e. missing values).

If required, the log file can be printed using the DOS **PRINT** command after exiting from **RIVERI**. By default, **RIVERI** assumes that the file will be called ssssss.**REC**, where ssssss is the root name of the setup file and must be six characters in length. Thus, for example, if the setup file was called SFILL2.INF, the default name for the log file would be SFILL2.REC and this default would appear in the entry for Option [2]. This name can be changed if required by selecting Option [2]. If the specified log file already exists, the transfer information is added to the end of the file. If the log file is a new file, the file is created before the transfer starts.

Option [3] specifies the gaps for which adjusted flows are to be transferred. A value 0 signifies all gaps in the year. A typical use of this option occurs when there are many gaps in the year ; first, the flows for all gaps in the year are adjusted in a single operation (using, say ,the 'Shift' option) and are transferred. The adjusted flows are then reset and the adjustments and transfers repeated for those gaps for which the 'Shift' adjustment was not suitable.

Options [4] and [5] initiate the transfer. When Option [4] is selected, a message appears which gives an option to quit using the F2 key (if, say, the option was selected accidentally). At the end of the transfer, one of two messages can appear:

[51] Transfer complete. Log file updated

or

[54] Error transferring to HYDATA. Transfer aborted.

Message [51] indicates that the transfer has been completed successfully and message [54] indicates that an error occurred. If message [54] is obtained, the data for the HYDATA station should be checked to find the cause of the error and how much of the adjusted data was transferred before the error occurred. The transfer may also be aborted if the log file becomes too large, in which case the message:

[52] Log file too long. Rename using DOS

appears. The length of the log file is limited to 1000 lines. If this message is obtained, the transfer should be repeated using a different (or new) name for the log file , or the name of the existing log file should be changed using the DOS command **RENAME** after exiting from **RIVERI**. Note that, as the length of the file increases, the time taken to update the file also increases, so it is often desirable to rename the file before its length exceeds 1000 lines.

*** Important Note ***

When using the 'Direct Transfer' option, the same precautions should be taken as during normal operation of HYDATA. Transfers must NEVER be interrupted whilst in progress and backup copies of the database should be taken at regular intervals. Ignoring this advice could lead to losses of large amounts of data.

Option [5], 'Write HYDATA file', initiates transfer of the data into a datafile with the name specified in Option [2]. As the file is being written, HYDATA macro commands are interspersed with the data to allow the datafile to be read at a later stage into HYDATA using HYDATA's 'Read File' facility. From within HYDATA, this file can be read by selecting the 'Data Selection' menu for daily flow, menu C6, then entering the station number, and then using the F4 key to name the file and initiate operation of the macro. Further information on the use of this macro facility can be found on pages 2.19 to 2.23 of the HYDATA Operation Manual.

A.3 Correlation mode

As well as using correlations to predict flows, **RIVERI** allows new correlations to be developed between pairs of stations on the same river. Correlations can be developed between any pair of stations specified in the setup file.

The correlation routines are accessed by selecting Option [3], 'Correlate', from menu A2 of **RIVERI**. This causes menu C1, 'Correlations', to be displayed:

```
              Menu C1 - Correlations

[ 1]   Quit
[ 2]   Setup file          [                ]
[ 3]   Start Year          [    ]
[ 4]   End Year            [    ]
[ 5]   HYDATA Station A    [       ]
[ 6]   HYDATA Station B    [       ]
[ 7]   Find data
```

The setup file defines the HYDATA station numbers and the periods of rejected data for each station. The layout of this file is described in Section A.6. The file should be in ASCII text format and is most easily created using a word processor in unformatted mode.

Options [3] and [4] define the period over which data are to be read for deriving the correlation. The years entered must be between 1963 and 1992 inclusive, with the 'End Year' on or after the 'Start Year'. Options [5] and [6] define the numbers of each of the pair of HYDATA stations. Station A is the station for which the correlation is being developed and Station B is the station with which Station A is being correlated. Both stations must be defined in the setup file. Station B can be upstream or downstream of Station A; the flow direction is deduced from the order in which the stations are defined in this file.

Option [7] causes **RIVERI** to read the flow data for each station from HYDATA. A monitor is displayed showing which year is being read. When this operation is completed, the screen will clear and menu C2, 'Plot', will be displayed:

```
          Menu C2 - Plot

[ 1]  Quit
[ 2]  Plot data
[ 3]  Calculate
```

<u>The 'Plot data' option</u>

Option [2] of this menu allows the flow data for the stations to be plotted before performing any calculations. Figures 18 and 19 show examples of the type of plot produced. This facility is useful for obtaining an idea of the number of parts required for the correlation equation and the approximate lag time between stations. It also assists with the data checking process, allowing correlation plots to be produced solely for the purposes of identifying periods of bad data (as described in Section 3.3). When this option is selected, the following plot menu is displayed:

```
          Menu P1 - Plot

[ 1]  Quit
[ 2]  Max Y          [500.0   ]
[ 3]  Min Y          [0.0     ]
[ 4]  Max X          [500.0   ]
[ 3]  Min X          [0.0     ]
[ 6]  Y intervals    [5  ]
[ 7]  X intervals    [5  ]
[ 8]  Lag            [0.00    ]
[ 9]  Colour         [0  ]
[10]  Paper Plot
[11]  Screen plot
```

The menu entries show typical default values. Options [2] and [3] define the maximum and minimum flow values (in cumecs) to appear on the Y-axis, Options [4] and [5] define the maximum and minimum flow values (in cumecs) to appear on the X-axis, and Options [6] and [7] define the number of tick marks to appear on the Y and X-axes. Option [8] defines the lag time to assume between the stations when plotting the data points. Lags of between 0 and 10.0 days and can be specified with up to 2 decimal places. The lag applies only to the values for Station B ; thus the plot shows the actual values for Station A plotted against the lagged values for Station B. The lag must always be specified as positive since **RIVERI** takes account of the assumed flow direction between the stations.

Option [9], 'Colour', specifies whether plots are to be produced in monochrome (0) or colour (1). Options [10] and [11] initiate the plotting ; the plot can be either displayed on the screen by selecting Option [11], 'Screen Plot', or drawn on a HP7475A plotter by selecting Option [10], 'Paper Plot'. If Option [10] is selected, a warning message first appears, asking if the plot is to proceed. To abandon the plot, the F2 key should be pressed, and to continue it, the **ENTER** key should be pressed.

Once the plot has been displayed, Option [1], 'Quit', can be selected, which returns control to menu C2. The correlation analysis can then be either terminated, by selecting Option [1], 'Quit', or continued by selecting Option [3], 'Calculate', from this menu.

Calculating the correlations

When Option [3] is selected from menu C2, menu C3, 'Parameters', is displayed:

```
          Menu C3 - Parameters

[ 1]   Quit
[ 2]   Number        [1   ]
[ 3]   Max flow 1    [9999.00 ]
[ 4]   Max flow 2    [9999.00 ]
[ 5]   Max flow 3    [9999.00 ]
[ 6]   Origin        [0   ]
[ 7]   Min lag       [0      ]
[ 8]   Max lag       [5      ]
[ 9]   No per day    [1   ]
[10]   Calculate
```

The menu entries show typical default values. This menu allows the form of the correlations to be defined. Option [2], 'Number', defines the number of parts to the correlation equation. Up to 3 segments are permitted. Options [3], [4] and [5] define the upper flow limit of each segment (in cumecs). These limits define the range of flow values to be used in calculating each segment of the correlation, and apply to the flows at Station B. Thus the upper limit for segment 1 is the lower limit for segment 2 and so on i.e.

Segment 1 is calculated using Station B lagged flows $\geq$ 0.0 and < Max. flow 1
Segment 2 is calculated using Station B lagged flows $\geq$ Max. flow 1 and < Max. flow 2
Segment 3 is calculated using Station B lagged flows $\geq$ Max. flow 2 and $\leq$ Max. flow 3

The limits can be left at their default values (9999.00) provided this does not cause any ambiguity in the range of flows for each segment.

The entry for Option [6] determines whether the intercept of the first segment is to be calculated (0) or forced through the origin (1). Options [7], [8] and [9] allow the correlation to be fitted for a range of assumed lag times. Options [7] and [8] specify the limits of the range and Option [9] specifies the number of intervals per day by which the lag is to be incremented. Thus, with the default values shown above, correlations will be fitted assuming lag times of 0, 1, 2, 3, 4 and 5 days. The number of assumed lag times in any one calculation cannot exceed 11. Thus, if 'No per day' was 10, the 'Min lag' and 'Max lag' would have to differ by only one day.

When the entries in menu C3 are as required, Option [10], 'Calculate', should be selected. A calculation monitor will then appear on the message line and, when this reaches 100 %, the screen will clear and a new menu will be displayed:

```
                 Menu C4 - Output

            [ 1]  Quit
            [ 2]  Plot data
            [ 3]  Plot correlations
            [ 4]  Display correlations
            [ 5]  Write correlations
            [ 6]  Write flows
            [ 7]  Plot St. Devs.
```

The entries in this menu are described in the following sections:

[2] Plot data

This option allows the calculated correlation lines to be plotted against the data. The operation of this option is identical to that of Option [2] of menu C2 which was discussed earlier. Menu P1 is again used to setup the plot and is displayed when this option is selected. The correlation line plotted is that for the lag time specified in menu P1. If no line was calculated for that precise time, the line for the nearest assumed lag time is shown.

[3] Plot correlations

This option allows all of the calculated correlation lines to be plotted on a single graph. No data points are shown. Menu P1 is again used to setup the plot and is displayed when this option is selected. If the number of assumed lag times exceeds 6, only the first 6 lines are drawn. Note that, for these plots, the 'Lag' entry, Option [8], in menu P1 is inoperative, and the entry can be left at the default value shown.

[4] Display correlations

This option allows the calculated correlations to be displayed on the screen. When selected, the screen will clear and a tabular display will appear showing the first segment of the correlation equation for each of the assumed lag times. An example is shown below:

LAG (days)	Slope	Intercept	St. Dev.	C.V.	Origin		Number
SEGMENT 1 :	0.0 to 9999.0 cumecs						
1.00	0.841	6.900	5.364	0.064	-8.207	0.000	2198
1.50	0.834	7.239	7.179	0.086	-8.683	0.000	2196
2.00	0.821	8.121	9.713	0.116	-9.896	0.000	2198

For this example, the correlations have been calculated for Station B flows in the range 0.0 to 9999.0 cumecs (i.e. in effect, all available flows) using assumed lag times of 1.0, 1.5 and 2.0 days. The standard deviation and the coefficient of variation (C.V.) are measures of the error of fit. The C.V. is defined as the standard deviation divided by the mean of the Station A flows. Normally, the standard deviation and C.V. change quite noticeably with the assumed lag time, with minimum values occurring close to the average lag time between the stations. In the above example, the best fit is obtained for a lag time of 1 day. The two entries for 'Origin' show, respectively, the intercepts of the line on the Y and X axes. The 'Number' is the number of data points used in calculating the correlation, and excludes **all** missing, estimated and rejected flow values. This number normally varies slightly with the assumed lag time.

If the correlations are specified as having more than one segment, then information on the next segment is displayed on pressing the **ENTER** key. Otherwise, control returns to menu C4.

[5] Write correlations

This options allows a a printed record to be obtained of the information shown by Option [4], 'Display correlations'. If selected, an extra menu, menu A3, is displayed:

```
                    Menu A3 - Write file

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

The name of the file for output should be entered in Option [2] and then Option [3] should be selected. To obtain a hard copy of this file, the DOS **PRINT** command should be used after exiting from **RIVERI**.

[6] Write flows

This option allows the observed flows for Station A to be compared with the interpolated flows for Station B and with the flows predicted by the correlation equations. The comparisons are shown for every day in the period specified in menu C1. If selected, an extra menu, menu C5, is displayed:

```
Menu C5 - Write flows

[ 1]  Quit
[ 2]  Filename      [               ]
[ 3]  Lag           [2.00    ]
[ 4]  Marker type   [0    ]
[ 5]  Tolerance     [10.00    ]
[ 6]  Continue
```

The menu entries show some typical default values. The required name of the file for output should be entered using Option [2].

Option [3], 'Lag', specifies the lag time, and hence the correlation equation, to be used in producing the output. If no equation is available for that precise time, the closest assumed lag time will be used. Options [4] and [5] provide additional information in the output indicating the closeness of fit of the correlation for each day. For every day, the difference is calculated between the observed flows and the flows estimated using the correlation equation for the assumed lag time. The percentage error is then given by the difference divided by the observed flow for the day. Both the difference (Diff.) and the percentage error (Error) appear in the output. As an aid to identifying days with large errors, arrow symbols (<) are shown if the percentage error or the difference exceeds a certain tolerance. Option [4] determines whether these markers are shown for the error (0) or difference (1). One arrow is shown if the quantity exceeds the tolerance, two arrows if it exceeds twice the tolerance, and three arrows if it exceeds three times the tolerance. A maximum of three arrows can be shown in the output. The tolerance (in % or cumecs) is entered using Option [5].

When all of the entries in menu C5 are as required, Option [6], 'Continue', should be selected. The specified file will then be produced. A printed copy of this file can be obtained by exiting from **RIVERI** and using the DOS command **PRINT**.

An example of the type of output obtained is shown below:

CALCULATED FLOWS

```
Station A          :  Bulo Burti
Station B          :  Beled Weyn
Start Year         :  1963
End Year           :  1989
Lag for Station B  :    2.00 days
Tolerance          :    10.0 %
```

DATE	Station A	Station B Interp.	Station A Regr.	Diff.	Error (%)	Segment
....						
....						
1963 Sep 26	161.67	188.61	164.49	2.82	1.7	1
1963 Sep 27	142.02	175.66	153.69	11.67	7.6	1
1963 Sep 28 <	125.80	162.79	142.96	17.16	12.0	1
1963 Sep 29 <	113.76	152.32	134.23	20.47	15.2	1
1963 Sep 30 <	104.15	143.61	126.97	22.81	18.0	1
1963 Oct 1 <	96.34	135.31	120.05	23.70	19.7	1
1963 Oct 2 <<	91.02	128.30	114.21	23.19	20.3	1
1963 Oct 3 <	87.49	119.31	106.71	19.22	18.0	1
....						
....						

All flows are in cumecs. The 'Segment' entry shows the part of the correlation equation used to calculate the 'Station A Regr.' flows.

[7] Plot St. Devs.

This option allows the calculated error of fit (standard deviation) to be plotted as a function of assumed lag time for each of the segments of the correlation. This facility helps in determining the optimum lag time between the pair of stations. Figure 5(b) shows an example of this output.

If this option is selected, the 'Plot Menu', menu P1, is displayed. The operation of this menu is identical to that of Option [2] of menu C2 which was discussed earlier. Note that, for these plots, the 'Lag' entry, Option [8], in menu P1 is inoperative, and can be left at its default value.

A.4 Find flags mode

The 'Find flags' option is designed to assist with keeping track of the progress of infilling operations. It displays the current numbers of original, estimated, missing and rejected values on the database for a specified station in a specified period.

The 'Find flags' routines are accessed by selecting Option [4], 'Find flags', from menu A2 of **RIVERI**. This causes menu S1, 'Flow flags', to be displayed:

```
                Menu S1 - Flow flags

[ 1]  Quit
[ 2]  Setup file      [                 ]
[ 3]  HYDATA Station  [         ]
[ 4]  Data type       [0  ]
[ 5]  Display flags
[ 6]  Print flags
[ 7]  Write flags
```

Option [2] requests the name of the setup file being used for the infilling operations. This file defines the periods (and hence the numbers) of rejected flow values and also supplies the range of years over which the flag information is to be displayed.

Option [3] requests the number of the HYDATA station for which flag information is to be calculated and Option [4] defines whether information on flow data (0) or stage data (1) is required. In the current version of **RIVERI**, there is not sufficient memory available to select the 'Stage' option, and information on stage flags must be obtained using a separate program **GETFLAGS**. This program can be run by exiting from **RIVERI** and typing the command **GETFLAGS**. A series of prompts then appears asking for the information requested by menu S1.

Options [5], [6] and [7] initiate the calculations of the numbers of flags. Option [5] sends the output to the screen, Option [6] sends it to a printer and Option [7] sends it to a file. If Option [7] is selected, an extra menu, menu A3, is displayed:

```
                Menu A3 - Write file

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

The required filename should be entered in Option [2].

An example of some output data on flow flags is shown below:

SUMMARY OF FLOW DATA FLAGS

Station : Bulo Burti

YEAR	*Original*	*Missing*	*Estimated*	*Rejected*
1980	*366*	*0*	*0*	*0*
1981	*365*	*0*	*0*	*0*
1982	*245*	*49*	*71*	*145*
1983	*114*	*0*	*251*	*0*
1984	*289*	*62*	*15*	*0*
1985	*211*	*62*	*92*	*0*
1986	*279*	*29*	*57*	*0*
1987	*217*	*35*	*113*	*95*
1988	*271*	*0*	*95*	*4*
1989	*277*	*88*	*0*	*0*
1990	*3*	*362*	*0*	*0*
TOTALS	*2637*	*687*	*694*	*244*

In this example, the HYDATA station was specified to be Bulo Burti, and the range of years defined in the setup file was from 1980 to 1990 inclusive. The numbers of rejected flow values were read from the setup file and apply only to rejected original data. Thus, if the rejected periods include periods of estimated or missing data, these are not considered when calculating the numbers of rejected values. The totals show the total numbers of data values for each flag in the period. The ultimate aim of the infilling operation is, of course, to finish with zero missing and zero rejected values in the period (if possible).

The output produced by the program **GETFLAGS** is similar to that shown above except that the column on rejected data is replaced by the number of stage readings per day for that year. This is because the concept of rejected data is not applied to stage values, since **RIVERI** works only in terms of daily flows.

A.5 Guidelines on use

To infill data for a station, the following steps are normally required:

a) Identify periods of doubtful data
b) Develop the correlations
c) Decide which periods require infilling
d) Infill the data

The following sections discuss the main points to consider during each stage.

a) Doubtful data

Periods of doubtful data can be identified in several ways. Usually, gross errors can be spotted from a visual inspection of the hydrographs for each year of data. Further inconsistencies can often be identified by comparing the hydrographs for the station with those for other stations on the same river, after taking into account the hydrology of the river (e.g. tributaries, over-bank spillage, engineering schemes). Correlation plots between stations, using an appropriate assumed lag time, may also reveal periods of data which are inconsistent with the bulk of the data.

RIVERI can be used to plot both hydrograph and correlation plots. On hydrograph plots, up to 5 stations on the river can be displayed at one time. For this preliminary work, a dummy setup file may be used, which does not contain any correlations or dates for rejected data (see Section A.6).

b) Correlations

RIVERI calculates the correlations using original data only, and ignores all estimated values. Accordingly, the setup file should specify only those periods for which original data are to be rejected. It is advisable to reject all periods for which the data are uncertain ; in most cases, this will still leave ample data points for calculating the correlations. It may be necessary to exclude other periods of data for which a correlation model is not valid e.g. when over-bank flow occurs between the stations, or when significant local runoff enters the reach between the stations. Normally, for this preliminary checking work, it is simplest to have a separate setup file for each pair of stations.

To calculate the correlations, an assumed lag time is needed. In the absence of other information, the lag time corresponding to the smallest error of fit could be used. However, if possible, an observed lag time should be used, calculated as the average of the observed lags for several individual events (e.g. flow peaks, sudden increases in flow).

Correlation equations can be assumed to be in 1, 2 or 3 parts. One part correlations are to be preferred provided there are no distinct discontinuities visible on the correlation plots. Normally, a computed intercept should be selected, since this is likely to give better flow predictions at low flows. Correlations should be developed for all neighbouring pairs of stations on the river, for both downstream station on upstream and vice versa. Obviously, the lag for the upstream on downstream station should equal the lag used for the downstream on upstream station. If more than one segment is used, the maximum flows for each segment should be consistent in the two directions. If there is any doubt about the validity of the correlation model at high flows, an upper flow limit should be specified for the final segment. Predicted flows will then not be calculated when the flow at Station B exceeds this maximum. The final correlations obtained should be entered in the setup file for the infilling operation.

c) Periods for infilling

When calculating the correlations, it is desirable to disregard any periods of uncertain data. During infilling, however, it is preferable to retain as much as possible of the original data unless there is a good reason for rejecting it. Before starting to infill the data, it is therefore necessary to re-evaluate all of the periods of doubtful data and to consider how much, if any, of the data can legitimately be retained. Any rejected data which still appears incorrect should then either be deleted from the database or corrected. Sometimes, an inspection of the original record sheets may reveal the source of error. Note that, if original data are deleted from the database, both flow and stage records should be removed. This is to avoid the danger of estimated flows being subsequently over-written should the rating equation for the station be revised.

The final list of dates of rejected data should be entered in a setup file. Normally, for infilling, it is simplest to have a single setup file for the entire river.

d) Infilling

Flow data should be infilled year by year starting from the earliest year for which there are data. This ensures that the record is continuous between years. It is usually easiest to infill data for all stations for the year at the same time ; this helps in building-up a picture of the state of the river for the year and leads to more consistent results.

The infilling should normally proceed downstream from the uppermost station on the river. The 'Fill estimated' option should be set to 1 so as to over-write all previously estimated values (if any). Once the lowermost station has been infilled, the infilling can proceed back upstream, with the 'Fill estimated' option set to 0. This ensures that precedence is given to values estimated in the downstream direction. Care should be taken that flow values blend smoothly at the start and end of each year.

For each station, the predicted flows should be adjusted to match the observed flows as closely as possible. The adjusted flows should always be checked on a plot before they are transferred. Any combination of 'Shift' and 'Join' adjustments can be used in each year. Often, it is easiest to begin with a global 'Shift' for all gaps, transferring all values, then to repeat the adjustments and transfers for those gaps for which the 'Shift' option was not suitable. Generally, 'Shift' works best for small gaps and 'Join' works best for large gaps. For large gaps, care should be taken not to shift low flows to unrealistically high or low values. Occasionally, none of the adjustment methods available in **RIVERI** is suitable. In this case, it may be necessary to enter the estimated values manually into HYDATA. Values can be estimated by eye or interpolated between original values. This approach is sometimes necessary for infilling flood events (for which **RIVERI** is not designed) or for infilling zero flows (which can be difficult to set using the adjustments available in **RIVERI**). Flows may also need to be inserted manually for the first few days in the following year when using 'Shift' after infilling an upstream station from a downstream station. Approximate values can be entered and subsequently corrected once the infilling has been attempted for the following year.

It is essential to keep a careful record of all values deleted, and of the periods infilled, to ensure that good data are not deleted accidentally, and that all periods of missing data are infilled. The 'Find flags' option can assist with this 'book-keeping' work, since it provides an up to date summary of the numbers of values missing and estimated values in each year. The ultimate aim of the infilling should, of course, be to finish with no missing and no rejected values. For specific information on the periods infilled to date, reference should be made to the 'log file', which **RIVERI** updates after every data transfer.

A.6 Layout of setup files

The setup files define the numbers of the HYDATA stations on the river, the periods of rejected data for each station and the correlations between the stations. Three main types of setup file are used:

a) Files for data checking
b) Files for developing correlations
c) Files for infilling data

These files have the same general layout, but differ in the amount of information they contain. A file for data checking contains only the station numbers, a file for developing correlations contains in addition the periods of rejected data, and a file for infilling contains in addition the equations of the correlations. In general, the correlation and infilling files will specify slightly different periods of rejected data (see Section A.5).

Setup files should be in ASCII text format and are best created using a word processor in unformatted mode. The layout of these files should be exactly as shown below. 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 following sections describe the layout of each of the three types of setup file.

a) Files for data checking

A file for data checking need contain only the names and numbers of the stations and the range of valid dates for the analysis. The general layout of this type of file is as follows:

```
River name                                                  (A80)
Comment line                                                (A80)
Number of stations on river, start year, end year           (3I5)
First HYDATA station, station name                          (I5,A14)
Second HYDATA station, station name                         (I5,A14)
......and so on for remaining stations
Comment line                                                (A80)
Number of correlations ; downstream on upstream             (I5)
......correlation equations
Comment line                                                (A80)
Number of correlations ; upstream on downstream             (I5)
......correlation equations
Comment line                                                (A80)
First HYDATA station                                        (I5)
First year, max. flow, no. periods rejected data            (I4,F6.0,I3,40I3)
Second year ......and so on for remaining years
Second HYDATA station                                       (I5)
First year, max. flow, no. periods rejected data            (I4,F6.0,I3,40I3)
Second year ......and so on for remaining years
.......and so on for remaining stations
<
```

The start year and end year listed in the file define the range of years which **RIVERI** will accept as input. The years specified must be in the range 1963 to 1992 inclusive. Up to 10 HYDATA station names and numbers can be specified. HYDATA stations must be listed in the same order as they occur on the river, starting from the upstream end. This is because **RIVERI** uses the order to determine the direction of flow when calculating lagged flows. For a data checking file, the number of correlations and the number of periods of rejected data in each year can be set to zero. Maximum flows can be set to the maximum allowable value of 9999.0 to allow all possible flows. 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 a valid data checking setup file for use on the river Shebelli. Three stations are defined (HYDATA Stations 10, 11 and 12), and the range of valid years is 1980 to 1985 inclusive.

```
RIVER SHEBELLI
Example of setup file for data checking. 3 stations, 1980 to 1985 inclusive.
    3 1980 1985
10    Beled Weyn
11    Bulo Burti
12    Mahaddey Weyn
a) CORRELATIONS - Downstream on upstream
0
b) CORRELATIONS - Upstream on downstream
0
```

```
c) DATA TO BE REJECTED
10
1980 9999.  0
1981 9999.  0
1982 9999.  0
1983 9999.  0
1984 9999.  0
1985 9999.  0
11
1980 9999.  0
1981 9999.  0
1982 9999.  0
1983 9999.  0
1984 9999.  0
1985 9999.  0
12
1980 9999.  0
1981 9999.  0
1982 9999.  0
1983 9999.  0
1984 9999.  0
1985 9999.  0
```

<u>b) Files for developing correlations</u>

This type of file contains, in addition to the information shown above, information on the maximum flow for each station for each year, and any periods of rejected data. Flows exceeding these maximum values, or falling within a rejected period, will then not be used in calculating the correlations.

The layout of this type of file is similar to that shown above. The example given above could be turned into a setup file for correlations simply by editing the lines concerning the max. flow and the number of periods of rejected data e.g.

```
RIVER SHEBELLI
Example of setup file for developing correlations
    3 1980 1985
10      Beled Weyn
11      Bulo Burti
12      Mahaddey Weyn
a) CORRELATIONS - Downstream on upstream
0
b) CORRELATIONS - Upstream on downstream
0
c) DATA TO BE REJECTED
10
1980 9999.  0
1981 9999.  0
```

```
1982 9999.  0
1983 9999.  0
1984 9999.  4  1  9  8  9
1985 9999.  0
11
1980 9999.  0
1981 9999.  0
1982 9999.  4  9  8 31 12
1983 9999.  4  1  1  6  1
1984 9999.  0
1985 9999.  0
12
1980 9999.  0
1981  162.  0
1982  158.  0
1983  156.  0
1984 9999.  0
1985  171.  0
```

This file shows that the periods of rejected data are 1/9/84 to 8/9/84 for Beled Weyn and 9/8/82 to 6/1/83 for Bulo Burti. Note how, if the period of rejected data extends over the beginning or end of a year, the period must be split into two parts, one for each of the years. Again, since no correlations are yet available, the number of correlations is set to zero. The maximum flows for Mahaddey Weyn are 162 cumecs in 1981, 158 cumecs in 1982, 156 cumecs in 1983 and 171 cumecs in 1985. The entries of 9999.0 for the remaining years signify that a bank-full flow was not reached in those years.

c) Files for infilling data

This type of file contains, in addition to the information shown above, each of the correlation equations which has been developed between the stations. The layout of the entry for each correlation is as follows:

```
Number of Station A, Number of Station B, Number of 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)
```

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 Station A. Unallocated numbers are for use in future versions of **RIVERI** and can be entered as 0.0 here. The remaining lines list the equation for each segment (i.e. slope and intercept) and the range of Station B flows 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 correlation equations must be grouped into two blocks, the first giving correlations between downstream and upstream stations and the second giving correlations between upstream and downstream stations. The number of correlations in each block must appear at the start of the block. Within blocks, the correlations can be listed in any order and there is no limit to the number specified. However, correlations can only be supplied between stations listed at the top of the setup file.

The following example shows a setup file suitable for infilling data for the stations Beled Weyn, Bulo Burti and Mahaddey Weyn on the river Shebelli:

```
RIVER SHEBELLI
Example of setup file for infilling data
    3 1980 1985
10     Beled Weyn
11     Bulo Burti
12     Mahaddey Weyn
a) REGRESSIONS - Downstream on upstream
2
11   10   2
2.00      0.00      9999.0    0.0
80.0      0.0       0.982     0.0
250.0     13.522    0.813     0.0
12   11   1
2.40      0.0       164.0     0.0
9999.0    0.0       1.034     0.0
b) REGRESSIONS - Upstream on downstream
1
10   11   2
2.00      0.00      9999.0    0.0
70.0      0.0       1.030     0.0
9999.0    -10.580   1.181     0.0
c) DATA TO BE REJECTED
10
1980 9999.  0
1981 9999.  0
1982 9999.  0
1983 9999.  0
1984 9999.  4  1  9  8  9
1985 9999.  0
11
1980 9999.  0
1981 9999.  0
1982 9999.  4  9  8 31 12
1983 9999.  4  1  1  6  1
1984 9999.  0
1985 9999.  0
12
1980 9999.  0
1981  162.  0
```

```
1982   158.  0
1983   156.  0
1984  9999.  0
1985   171.  0
```

In this example, two regressions are defined in the downstream direction and one in the upstream direction. Taking just one regression as an example, the lag between stations 10 and 11 is defined to be 2.00 days, and the regression in the downstream direction is:

Bulo Burti flow = 0.982 Beled Weyn flow for Beled Weyn flow <= 80 cumecs
Bulo Burti flow = 0.813 Beled Weyn flow + 13.522 for Beled Weyn flow > 80 cumecs and < 250 cumecs

In the opposite direction, the regression is:

Beled Weyn flow = 1.030 Bulo Burti flow for Bulo Burti flow <= 70 cumecs
Beled Weyn flow = 1.181 Bulo Burti flow - 10.58 for Bulo Burti flow > 70 cumecs and < 9999 cumecs

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	
Kaitoi	33	82		660
Mareere	13	85		625
Kamsuma	8.6	85	8	507
Jamamme	1	65	8	477
SHEBELLI				
Beled Weyn	176.1	44	7	
Bulo Burti	134.4	48	6	
Mahaddey Weyn	104.6	46	5	164
Balcad				95
Afgoi	77.4	40	5	96
Audegle	70.1	38	5	82

(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 (where known). 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 - KA	175	335	0.00017	3.4	1.1
KA - MA	42	77	0.00026	0.7	1.3
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 - BC	72	128	0.00014	1.8	0.8
BC - AF	39	71	0.00014	1.1	0.7
AF - AU	35	66	0.00011	1.2	0.6

LG = Lugh Ganana
BA = Bardheere
KA = Kaitoi
MA = Mareere
KM = Kamsuma
JA = Jamamme
MO = Mogambo

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

TABLE 2 Hydraulic characteristics of selected reaches on the rivers Jubba and Shebelli (distances from MMP 1969, MMP 1983)

Reach	Av. obs. lag (days)	No. of events	St. Dev. (days)	Av. wavespeed (m/s)	Max. flow (cumecs)
JUBBA					
LG - BA	2.3	69	0.8	1.3	1520
LG - KA	5.9	45	0.9	1.1	592
LG - MA	6.1	40	0.9	1.2	560
LG - KM	6.6	9	0.7	1.2	572
LG - JA	7.4	50	1.0	1.2	564
BW - BB	2.0	41	0.8	1.1	226
BB - MW	2.4	41	0.9	1.1	172
MW - BC	1.9	18	0.7	0.9	139
BC - AF	1.7	16	1.0	0.6	92
MW - AF	2.9	37	0.9	0.9	159
AF - AU	1.2	26	0.5	0.7	84
BW - MW	4.5	29	1.2	0.93	206
BW - AF	7.4	26	1.5	0.88	206
BW - AU	8.8	14	1.5	0.82	112

Av. obs. lag = Average of observed lag times
No. of events = Number of events used in calculating average observed lag
St. Dev. = Standard deviation of sample
Av. wavespeed = Average wavespeed based on average observed lag
Max. flow = Maximum observed flow at upstream station for events in sample

TABLE 3 **Observed lag times for selected reaches on the rivers Jubba and Shebelli. The abbreviations of station names are defined in Table 2.**

<table>
<tr><th>Reach</th><th>Final
(days)</th><th>Events
(days)</th><th>Best corrln.
(days)</th><th>AHG (1984)
(days)</th><th>Gemmel (1982)
(days)</th></tr>
<tr><td>JUBBA</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>LG - BA</td><td>2.3</td><td>2.3</td><td>2.2</td><td>1.9</td><td>3</td></tr>
<tr><td>BA - KA</td><td>3.4</td><td>3.7</td><td>3.5</td><td>3.1</td><td>3 - 4</td></tr>
<tr><td>KA - MA</td><td>0.7</td><td>0.2</td><td>0.8</td><td>0.6</td><td></td></tr>
<tr><td>MA - KM</td><td>0.4</td><td>0.4</td><td rowspan="2">0.6</td><td>0.4</td><td rowspan="3">1</td></tr>
<tr><td>KM - MO</td><td>0.2</td><td rowspan="2">0.8</td><td rowspan="2">0.7</td></tr>
<tr><td>MO - JA</td><td>0.4</td><td>0.4</td></tr>
<tr><td>SHEBELLI</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>BW - BB</td><td>2.0</td><td>2.0</td><td>1.8</td><td></td><td>2</td></tr>
<tr><td>BB - MW</td><td>2.4</td><td>2.4</td><td>2.4</td><td></td><td>2</td></tr>
<tr><td>MW - BC</td><td>1.8</td><td>1.9</td><td>1.7</td><td></td><td rowspan="2">3</td></tr>
<tr><td>BC - AF</td><td>1.1</td><td>1.7</td><td>1.3</td><td></td></tr>
<tr><td>AF - AU</td><td>1.2</td><td>1.2</td><td>1.1</td><td></td><td>1</td></tr>
</table>

Final = Lag times used for developing the correlations for use in the infilling work

Events = Average of lag times from actual events (see Table 3)

Best corrln. = Lag time giving lowest error of fit on a correlation plot

TABLE 4 **Comparison of estimated lag times for the rivers Jubba and Shebelli. The abbreviations of stations names are defined in Table 2.**

	Period	FLOW (CUMECS) Mean	Maximum	Minimum
JUBBA				
Kaitoi	1963-1989	660	790	590
Mareere	1977-1989	625	805	530
Kamsuma	1963-1989	507	520	495
Mogambo	1983-1989	505	530	480
Jamamme	1963-1989	477	525	450
SHEBELLI				
Mahaddey Weyn	1963-1979	140	147	133
	1980-1989	164	156	171
Balcad	1963-1979	95	101	89
Afgoi	1963-1989	96	112	88
Audegle	1963-1989	82	93	70

TABLE 5 Measured bank-full flows for the period 1963 - 1989 on the rivers Jubba and Shebelli

Year	CORRELATIONS REQUIRED FOR YEAR
1963	BA - LG, KA - BA, JA - KA
1964	BA - LG, KA - BA, JA - KA
1965	BA - LG, JA - BA
1966	BA - LG, JA - BA
1967	BA - LG, JA - BA
1968	BA - LG, JA - BA
1969	BA - LG, JA - BA
1970	BA - LG, JA - BA
1971	BA - LG, JA - BA
1972	BA - LG, KA - BA, KM - KA, JA - KM
1973	BA - LG, KA - BA, KM - KA, JA - KM
1974	BA - LG, KA - BA, KM - KA, JA - KM
1975	BA - LG, KA - BA, KM - KA, JA - KM
1976	BA - LG, KA - BA, KM - KA, JA - KM
1977	BA - LG, KA - BA, MA - KA, JA - MA
1978	BA - LG, KA - BA, MA - KA, JA - MA
1979	BA - LG, KA - BA, MA - KA, JA - MA
1980	BA - LG, KA - BA, MA - KA, JA - MA
1981	BA - LG, MA - BA, JA - MA
1982	BA - LG, MA - BA, JA - MA
1983	BA - LG, MA - BA, MO - MA, JA - MA
1984	BA - LG, MA - BA, MO - MA, JA - MA
1985	BA - LG, MA - BA, MO - MA, JA - MA
1986	BA - LG, MA - BA, MO - MA, JA - MA
1987	BA - LG, MA - BA, MO - MA, JA - MA
1988	BA - LG, MA - BA, MO - MA, JA - MA (Also KM - BA)
1989	BA - LG, MA - BA, MO - MA, JA - MA (Also KM - BA)

TABLE 6 Correlations required for infilling data on the river Jubba. Note that, for the years 1988 and 1989, data for Kamsuma were infilled from Bardheere due to lack of a suitable correlation between flows at Kamsuma and Mareere. The abbreviations of station names are defined in Table 2.

Lugh Ganana - Bardheere

1964	22/4 - 24/4	Local runoff in LG - BA reach
1965	16/4 - 20/4	Local runoff in LG - BA reach
1965	6/10 - 7/10	Local runoff in LG - BA reach
1965	11/11 - 21/11	Local runoff in LG - BA reach
1966	7/10	Local runoff in LG - BA reach
1966	29/10 - 31/10	Local runoff in LG - BA reach
1970	10/4 - 12/4	Local runoff in LG - BA reach
1971	28/4 - 1/5	Local runoff in LG - BA reach
1972	8/10 - 13/10	Local runoff in LG - BA reach
1976	19/5 - 23/5	Local runoff in LG - BA reach
1980	11/5 - 13/5	Local runoff in LG - BA reach
1981	15/3 - 31/3	Local runoff in LG - BA reach
1981	6/4 - 30/4	Local runoff in LG - BA reach
1981	1/5 - 13/6	Flood event
1981	22/9 - 28/9	Local runoff in LG - BA reach
1982	23/7 - 5/8	Local runoff in LG - BA reach
1982	2/9 - 4/9	Local runoff in LG - BA reach
1982	9/10 - 31/10	Local runoff in LG - BA reach
1984	19/4 - 20/4	Local runoff in LG - BA reach
1984	9/5 - 24/5	Local runoff in LG - BA reach
1984	30/10 - 1/11	Local runoff in LG - BA reach
1985	29/3	Local runoff in LG - BA reach
1985	10/4 - 12/4	Local runoff in LG - BA reach
1985	24/4	Local runoff in LG - BA reach
1985	28/4	Local runoff in LG - BA reach
1985	1/5 - 2/5	Local runoff in LG - BA reach
1985	10/5 - 14/5	Local runoff in LG - BA reach
1986	12/4 - 15/4	Local runoff in LG - BA reach
1986	22/4 - 24/4	Local runoff in LG - BA reach
1986	19/9 - 5/10	Local runoff in LG - BA reach
1986	22/10 - 24/10	Local runoff in LG - BA reach
1986	30/10 - 13/11	Local runoff in LG - BA reach
1986	25/11	Local runoff in LG - BA reach
1986	21/12 - 24/12	Local runoff in LG - BA reach
1987	21/4 - 22/4	Local runoff in LG - BA reach
1987	30/4 - 1/5	Local runoff in LG - BA reach
1987	14/5 - 13/6	Flood event
1987	29/8 - 31/8	Local runoff in LG - BA reach
1987	2/11 - 3/11	Local runoff in LG - BA reach
1987	5/11 - 19/11	Local runoff in LG - BA reach
1988	11/1 - 19/2	Weekly abstractions in BA - MA reach
1988	1/3 - 3/3	Local runoff in LG - BA reach
1988	25/3 - 27/3	Local runoff in LG - BA reach
1988	11/4 - 3/5	Local runoff in LG - BA reach
1988	21/10 - 22/10	Local runoff in LG - BA reach
1989	23/3 - 12/4	Local runoff in LG - BA reach
1989	30/4 - 14/5	Local runoff in LG - BA reach
1989	13/10 - 31/10	Local runoff in LG - BA reach

Bardheere - Mareere

1977	15/12 - 22/12	Flood event
1978	15/11 - 29/11	Flood event

Mareere - Jamamme

1965	7/12 - 18/12	Flood event

TABLE 7(a) Periods of significant inflow or outflow excluded when developing the correlations for the river Jubba

Beled Weyn - Bulo Burti

1963	3/5 - 11/6	Flood event
1964	22/4 - 26/4	Local runoff in BW - BB reach
1966	17/10 - 22/10	Local runoff in BW - BB reach
1966	27/10 - 31/10	Local runoff in BW - BB reach
1968	23/4 - 14/6	Flood event
1968	29/10 - 30/10	Local runoff in BW - BB reach
1968	15/11 - 16/11	Local runoff in BW - BB reach
1969	8/10 - 10/10	Local runoff in BW - BB reach
1971	4/5 - 8/5	Local runoff in BW - BB reach
1972	24/5	Local runoff in BW - BB reach
1972	1/6 - 4/6	Local runoff in BW - BB reach
1972	29/10 - 29/10	Local runoff in BW - BB reach
1973	5/5 - 10/5	Local runoff in BW - BB reach
1973	6/11	Local runoff in BW - BB reach
1976	18/5 - 15/6	Flood event
1980	9/5 - 10/5	Local runoff in BW - BB reach
1980	27/10 - 28/10	Local runoff in BW - BB reach
1981	21/3 - 6/6	Flood event
1981	9/9 - 2/11	Flood event
1983	1/9 - 19/11	Flood event
1984	12/5 - 14/5	Local runoff in BW - BB reach
1984	17/10 - 22/10	Local runoff in BW - BB reach
1985	10/6 - 12/6	Flood event
1986	5/6 - 6/6	Local runoff in BW - BB reach
1987	6/5 - 8/5	Local runoff in BW - BB reach
1989	18/5 - 20/5	Flood event

Bulo Burti - Mahaddey Weyn

1981	1/6 - 22/6	Flood event
1981	29/10 - 9/11	Flood event

TABLE 7(b) Periods of significant inflow or outflow excluded when developing the correlations for the river Shebelli

	Segment	Lag (days)	Slope	Intercept (cumecs)	Max. flow (cumecs)	No. of points
JUBBA						
BA - LG	1	2.3	0.967	7.886		4038
KA - BA	1	3.4	0.953	8.195	96	421
	2	3.4	1.027	1.180		654
MA - BA	1	4.1	0.910	-5.313		1892
KM - BA	1	4.5	1.122	-5.099	150	277
	2	4.5	0.988	12.342		166
JA - BA	1	5.1	0.972	-6.756	200	1473
	2	5.1	0.968	-5.962		383
MA - KA	1	0.7	0.784	-6.254	125	445
	2	0.7	1.154	-52.470		571
KM - KA	1	1.1	1.187	-2.812	120	605
	2	1.1	0.979	22.147		561
JA - KA	1	1.7	1.018	-8.213		1812
MO - MA	1	0.6	1.003	-0.637		1322
JA - MA	1	1.0	1.066	-2.148	180	611
	2	1.0	0.890	29.541		161
JA - KM	1	0.6	0.875	-1.456	140	614
	2	0.6	1.034	-23.776		534
JA - MO	1	0.4	1.016	-2.951		.152
SHEBELLI						
BB - BW	1	2.0	1.021	-1.633	60	2978
	2	2.0	0.840	9.253	250	2476
MW - BB	1	2.4	1.034	0.000		3987
BC - MW	1	1.8	1.036	-3.874	40	748
	2	1.8	0.739	8.001		510
AF - MW	1	2.9	1.010	-4.559	40	1278
	2	2.9	0.783	4.256		884
AF - BC	1	1.1	1.050	-2.058		2201
AU - AF	1	1.2	0.988	0.896		2468

(Example : the correlation between Afgoi and Mahaddey Weyn is

$$Q_{AF} = 1.010\ Q_{MW} - 4.559 \quad \text{for } Q_{MW} <= 40 \text{ cumecs}$$

$$Q_{AF} = 0.783\ Q_{MW} + 4.256 \quad \text{for } Q_{MW} > 40 \text{ cumecs}$$

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

TABLE 8 Correlations used during the infilling operation (downstream stations on upstream stations only). The table also shows the number of data points used when calculating each segment of each correlation. The abbreviations of station names are defined in Table 2.

	Start date	a	c	b	Max. h
JUBBA					
Lugh Ganana	1/1/63	60.320	-0.660	1.867	7.50
	1/1/82	58.954	-0.752	1.867	7.50
Bardheere	1/1/63	47.204	0.379	1.897	7.00
Kaitoi	1/1/63	35.115	0.290	1.614	7.00
Mareere	1/1/77	17.870	-4.550	1.903	12.00
Kamsuma	1/1/63	45.759	-2.330	1.405	9.00
	13/6/84	35.018	-0.500	1.521	9.00
Mogambo	1/1/83	18.340	-6.300	1.790	13.50
Jamamme	1/1/63	16.840	0.090	1.727	7.50
SHEBELLI					
Beled Weyn	1/1/63	23.130	0.270	1.879	2.22
		39.790	0.270	1.285	7.00
Bulo Burti	1/1/63	12.760	-0.610	1.772	10.00
	1/7/78	21.079	-0.631	1.468	10.00
Mahaddey Weyn	1/1/63	7.900	0.280	1.698	7.00
	1/1/80	4.904	0.073	2.073	6.00
Balcad	1/1/63	10.083	0.100	1.329	8.00
Afgoi	1/1/63	17.606	-0.890	1.175	7.00
	1/3/85	14.894	-0.890	1.220	7.00
Audegle	1/1/63	9.810	-0.590	1.413	6.50
	1/1/76	11.880	-1.140	1.358	6.50
	1/3/85	13.744	-1.640	1.358	6.50

(Note : All rating equations of the form $Q = a(h+c)^b$ where Q is the flow in cumecs and h is the stage in metres)

TABLE 9 Rating equations in use during development of correlations for gauging stations on the rivers Jubba and Shebelli (note that current rating equations may differ slightly from those shown above)

Observer errors

- Mis-reading staff gauge or bridge dip meter
- Correct reading but recorded against wrong date or time
- Correct staff gauge reading attributed to wrong gauge plate
- Erroneous interpolation of missing values
- Level under-estimated when using dip meter in strong winds
- Staff gauge reading incorrectly estimated from dip reading, or vice versa
- Fundamental mistakes by inexperienced deputy during observer's absence

Equipment faults

- Staff gauge plates missing or shifted after impact
- Staff gauge markings worn or corroded
- Staff gauge zero incorrectly levelled or levelled to wrong benchmark
- Water level below bottom or above top of staff gauge
- Staff gauge reading obscured by debris at waterline
- Dip meter tape broken and incorrectly repaired
- Dip meter used at wrong location
- Dip meter audio indicator not working
- Float support wire slipping on pulley of automatic recorder
- Logger unit not working on automatic recorder
- Float mechanism obstructed by sediment or damaged by debris

Office errors

- Data values incorrectly copied from observer's record sheets
- Data values attributed to wrong period or wrong station
- Missing values recorded when river was infact dry
- Estimated data recorded as original data

TABLE 10 Some common causes of data errors found when checking the flow data for the period 1963 - 1989

Lugh Ganana

1963	14/11 - 16/11	Doubtful data (late rise in flow cf BA, KA)
1963	28/12 - 31/12	Doubtful data (flows high cf BA, KA)
1964	8/7 - 21/7	Doubtful data (small peaks not at BA, KA, JA)
1964	14/11 - 22/12	Doubtful data (flow constant but BA, JA, KA varying)
1964	30/12 - 31/12	Doubtful data (high flow cf BA, KA)
1965	1/1 - 13/1	Doubtful data (high flow cf BA, KA)
1967	13/1 - 3/2	Doubtful data (unlikely sudden increase cf BA)
1972	1/1 - 15/4	Doubtful data (frequent periods of constant flow)
1972	30/6 - 7/7	Doubtful data (peak not appearing at BA, JA)
1982	12/4 - 5/7	Doubtful data (unlikely variation cf MA)
1983	16/7 - 30/7	Doubtful data (poor correlation cf MA)
1983	1/8 - 30/9	Doubtful data (poor correlation cf MA)
1984	11/6 - 13/6	Doubtful data (flow constant)
1984	11/11 - 14/11	Doubtful data (flow constant)
1985	31/5 - 8/6	Doubtful data (flows high cf BA, MA)
1986	2/7 - 23/9	Doubtful data (variable lag cf BA, MA)
1986	25/11 - 30/11	Doubtful data (flow constant)

Bardheere

1964	13/4 - 14/4	Doubtful data (peak not appearing at KA, JA)
1966	5/5 - 15/5	Doubtful data (long lag time cf LG)
1966	28/6 - 31/8	Doubtful data (unlikely slow variation cf LG)
1969	4/11 - 5/12	Doubtful data (unlikely variation cf LG)
1970	24/1 - 24/3	Doubtful data (unlikely variation cf LG)
1970	17/8 - 31/8	Doubtful data (flow low cf LG, JA)
1971	29/7 - 31/7	Doubtful data (unlikely dip cf LG)
1971	19/10 - 26/10	Doubtful data (unlikely dip cf LG)
1972	19/4 - 7/5	Doubtful data (poor correlation cf LG, JA)
1972	28/10 - 31/10	Doubtful data (early rise in flow cf LG, JA)
1976	1/8 - 9/8	Doubtful data (poor correlation cf LG, KA)
1977	1/1 - 6/1	Doubtful data (flows low cf LG, KA)
1977	1/2 - 28/2	Doubtful data (flows low cf LG, KA)
1980	11/5 - 13/5	Doubtful data (peak not appearing at KA, MO)
1981	9/10 - 30/11	Doubtful data (poor correlation cf LG, MA, JA)
1982	15/4 - 11/5	Doubtful data (poor correlation cf MA)
1982	23/7 - 5/8	Doubtful data (poor correlation cf LG, MA)
1984	9/5 - 15/5	Doubtful data (large peak not appearing at LG, MA)
1984	10/8 - 20/8	Doubtful data (poor correlation cf LG, MA)
1985	7/11	Doubtful data (small peak not appearing at MA)
1985	16/11	Doubtful data (small peak not appearing at MA)
1988	15/6 - 18/6	Doubtful data (flow constant)
1988	18/11 - 31/12	Doubtful data (flows low cf BA, KM, MO)
1989	21/7 - 22/7	Doubtful data (poor correlation cf LG, MA, JA)
1989	29/7 - 3/8	Doubtful data (poor correlation cf LG, MA, JA)
1989	3/9 - 11/9	Doubtful data (unlikely variation cf MA)
1989	27/9 - 28/9	Doubtful data (unlikely variation cf MA)
1989	13/10 - 31/10	Doubtful data (unlikely variation cf MA)

Kaitoi

1973	8/11 - 8/11	Doubtful data (small peak not appearing at KM, JA)
1975	12/7 - 28/7	Doubtful data (flows low cf KM, JA)
1975	8/8 - 21/8	Doubtful data (long lag cf KM, JA)
1975	2/12 - 31/12	Doubtful data (flows high cf LG, KM, JA)
1976	1/1 - 8/4	Doubtful data (flows high cf LG, KM, JA)
1976	16/5 - 22/5	Doubtful data (large peak at LG not appearing at KA)
1976	30/11 - 31/12	Doubtful data (flows high cf LG, BA)
1977	1/1 - 7/4	Doubtful data (flows high cf LG, BA)
1978	21/3 - 2/4	Doubtful data (flows high, slowly varying cf LG, MA)
1978	5/5 - 13/5	Doubtful data (early rise in flow cf LG, MA)
1978	4/6 - 25/6	Doubtful data (flows high, slowly varying cf LG, MA)
1979	23/4 - 1/5	Doubtful data (poor correlation cf MA)
1980	19/5 - 7/6	Doubtful data (slow decrease in flow cf MA, JA)

TABLE 11(a) **Periods of doubtful data identified for the river Jubba before starting the infilling exercise**

Mareere

1977	24/8 - 1/9	Doubtful data (unlikely dip cf LG, KA)
1978	7/10 - 17/10	Doubtful data (early rise in flow cf LG, KA)
1979	23/4 - 1/5	Doubtful data (poor correlation cf KA)
1982	18/7 - 5/8	Doubtful data (unlikely variation cf LG)
1984	23/9 - 31/10	Doubtful data (poor correlation cf BA, MO, JA)
1985	19/7 - 24/7	Doubtful data (small dip not appearing at BA, MO)
1985	5/8 - 24/8	Doubtful data (poor correlation cf BA, MO)
1985	19/10 - 23/10	Doubtful data (poor correlation cf BA, MO)
1987	29/8 - 31/8	Doubtful data (flow constant)
1988	14/8 - 15/8	Doubtful data (unlikely dip cf BA, MO)
1988	18/11 - 31/12	Doubtful data (flows low cf BA, MO, KM)

Kamsuma

No doubtful data identified

Jamamme

1963	1/7 - 30/11	Doubtful data (poor corrln./negative lag cf BA, KA)
1965	6/1 - 16/1	Doubtful data (slow decline cf LG, BA)
1970	25/4 - 31/10	Doubtful data (poor correlation cf LG, BA)
1974	21/5 - 24/5	Doubtful data (early peak cf KA, KM)
1975	11/8 - 16/8	Doubtful data (flows low cf KA, KM)
1975	11/9 - 13/9	Doubtful data (flows low cf KA, KM)
1975	14/11 - 15/11	Doubtful data (unlikely rise in flow cf KA, KM)
1976	7/11 - 30/12	Doubtful data (flow constant and low for bankfull)
1977	24/4 - 11/5	Doubtful data (poor correlation cf LG, KA)
1977	16/5 - 31/5	Doubtful data (poor correlation cf LG, KA)
1977	1/10 - 31/12	Doubtful data (poor correlation cf KA)
1979	1/7 - 31/7	Doubtful data (poor correlation cf KA, MA)
1980	15/5 - 7/6	Doubtful data (early rise in flow cf KA, MA)
1980	11/8 - 11/8	Doubtful data (small peak not appearing at KA, MA)
1980	3/11 - 7/11	Doubtful data (early rise in flow cf KA, MA)
1981	16/11 - 17/11	Doubtful data (isolated peak only at JA)
1983	1/4 - 21/4	Doubtful data (poor correlation cf MA)
1983	1/7 - 31/12	Doubtful data (variable lags cf MA)
1984	1/1 - 31/1	Doubtful data (flows high cf LG, BA, MA)
1984	13/9 - 18/9	Doubtful data (unlikely dip cf BA, MA)
1984	29/12 - 31/12	Doubtful data (zero flow at JA, non-zero at LG, MA)
1985	1/1 - 21/2	Doubtful data (zero flow at JA, non-zero at LG, MA)
1989	25/11 - 15/12	Doubtful data (unlikely variation cf LG, MA, JM)

TABLE 11 (a) continued

Beled Weyn

1963	26/8 - 30/8	Doubtful data (low flows cf BB, MW)
1984	1/9 - 8/9	Doubtful data (poor corrln./negative lag cf BB, MW)
1986	21/10 - 29/10	Doubtful data (excessive lag for flow peak cf BB, MW)

Bulo Burti

1965	7/10 - 18/10	Doubtful data (poor corrln./negative lag cf BW, MW)
1967	23/11 - 31/12	Doubtful data (excessive lag cf BW)
1976	29/6 - 31/12	Doubtful data (excessive lag cf BW, MW)
1977	13/4 - 30/5	Doubtful data (high flows cf BW, BA, AF)
1977	12/9 - 31/12	Doubtful data/flood event
1978	1/1 - 31/1	Doubtful data (stepwise recession)
1978	1/7 - 29/9	Doubtful data (stepwise increase cf BW)
1979	1/4 - 16/5	Doubtful data (high flows cf BW)
1979	1/9 - 30/9	Doubtful data (uncorrelated with BW, BA)
1982	9/8 - 31/12	Doubtful data (poorly correlated with BW, MW, AF)
1987	1/9 - 31/12	Doubtful data (poorly correlated with BW, MW)
1988	8/11 - 11/11	Doubtful data (lag too small cf BW, large cf MW)

Mahaddey Weyn

1966	12/11 - 5/12	Doubtful data (decrease in recession rate cf BW, AF)
1970	2/3 - 6/5	Doubtful data (poorly correlated cf BW, AF)
1970	28/7 - 28/8	Doubtful data (poorly correlated cf BW, AF)
1971	23/5 - 31/7	Doubtful data (variable lag cf BW, BA)
1975	1/1 - 30/3	Doubtful data (uncorrelated cf BW, AF)
1975	1/5 - 31/5	Doubtful data (uncorrelated cf BW, AF)
1976	23/6 - 24/6	Doubtful data (poorly correlated with BW, BB)
1976	1/7 - 30/11	Doubtful data (change in slope on correlation plots)
1977	20/4 - 31/12	Doubtful data (poorly correlated with BW, AF)
1978	1/2 - 28/2	Doubtful data (poorly correlated with BW, AF)
1978	1/4 - 31/5	Doubtful data (poorly correlated with BW, AF)
1978	1/7 - 31/12	Doubtful data (poorly correlated with BW, AF)
1979	1/1 - 31/8	Doubtful data (poorly correlated with BW, BA, AF)
1986	16/11 - 11/12	Doubtful data (poorly correlated with BB, AF)
1987	31/10 - 31/12	Doubtful data (flows high, excessive lag cf BW)

TABLE 11(b) Periods of doubtful data identified for the river Shebelli before starting the infilling exercise

Balcad

1967	20/7 - 28/8	Doubtful data (excessive lag cf MW, AF)

Afgoi

1977	27/3 - 25/4	Doubtful data (poorly correlated with AU)
1978	1/1 - 28/2	Doubtful data (poorly correlated with BA, AU)
1978	1/4 - 31/12	Doubtful data (poorly correlated with BA, AU)
1979	10/10 - 31/12	Doubtful data (poorly correlated with BW, BA)
1980	5/1 - 4/2	Doubtful data (flow constant for long period)
1982	19/12 - 31/12	Doubtful data (AU/AF comparison unsatisfactory)
1983	21/2 - 23/4	Doubtful data (AU/AF comparison unsatisfactory)
1984	1/1 - 26/5	Doubtful data (AU/AF comparison unsatisfactory)
1985	23/7 - 6/8	Doubtful data (AU/AF comparison unsatisfactory)

Audegle

1966	31/5 - 3/8	Doubtful data (poorly correlated with MW, AF)
1977	27/3 - 25/4	Doubtful data (AU/AF comparison unsatisfactory)
1978	1/1 - 31/1	Doubtful data (poorly correlated with BA, AF)
1978	1/4 - 30/7	Doubtful data (poorly correlated with BA, AF)
1978	1/11 - 31/12	Doubtful data (poorly correlated with BA, AF)
1979	1/1 - 20/2	Doubtful data (poorly correlated with BA, AF)
1980	19/7 - 29/7	Doubtful data (poorly correlated with BA, AF)
1980	24/8 - 30/8	Doubtful data (unlikely local runoff peak)
1980	10/10 - 10/12	Doubtful data (poorly correlated with BA, AF)
1982	19/12 - 31/12	Doubtful data (AU/AF comparison unsatisfactory)
1983	21/2 - 23/4	Doubtful data (AU/AF comparison unsatisfactory)
1984	1/1 - 26/5	Doubtful data (AU/AF comparison unsatisfactory)
1984	13/7 - 4/8	Doubtful data (AU/AF comparison unsatisfactory)
1985	23/7 - 6/8	Doubtful data (AU/AF comparison unsatisfactory)
1986	1/1 - 31/12	Doubtful data (frequent periods with constant flow)
1987	1/1 - 31/12	Doubtful data (frequent periods with constant flow)
1988	1/1 - 1/8	Doubtful data (frequent periods with constant flow)

TABLE 11(b) continued

	BEFORE INFILLING Orig. (%)	Miss. (%)	Est. (%)	Rej. (%)	AFTER INFILLING Orig. (%)	Miss. (%)	Est. (%)	Rej. (%)	Total
JUBBA									
Lugh Ganana	77	23	0	2	75	8	17	0	9862
Bardheere	55	45	0	1	55	7	38	0	9862
Kaitoi	88	12	0	6	84	.6	16	0	4019
Mareere	92	8	0	5	90	0	10	0	4748
Kamsuma	46	54	0	0	47	0	53	0	3653
Jamamme	43	57	0	7	39	8	53	0	9862
SHEBELLI									
Beled Weyn	89	11	0	.2	90	0	10	0	9862
Bulo Burti	73	27	0	8	63	0	37	0	9862
Mahaddey Weyn	78	22	0	13	70	0	30	0	9862
Balcad	64	36	0	.6	63	0	37	0	6209
Afgoi	95	5	0	8	92	0	8	0	9862
Audegle	57	43	0	16	52	0	48	0	9862

Orig. = Percentage of original data
Miss. = Percentage of missing data
Est. = Percentage of estimated data
Rej. = Percentage of original data which was rejected
Total = Total number of original, missing and estimated flow values

TABLE 12 **The status of the database immediately before and after the infilling exercise**

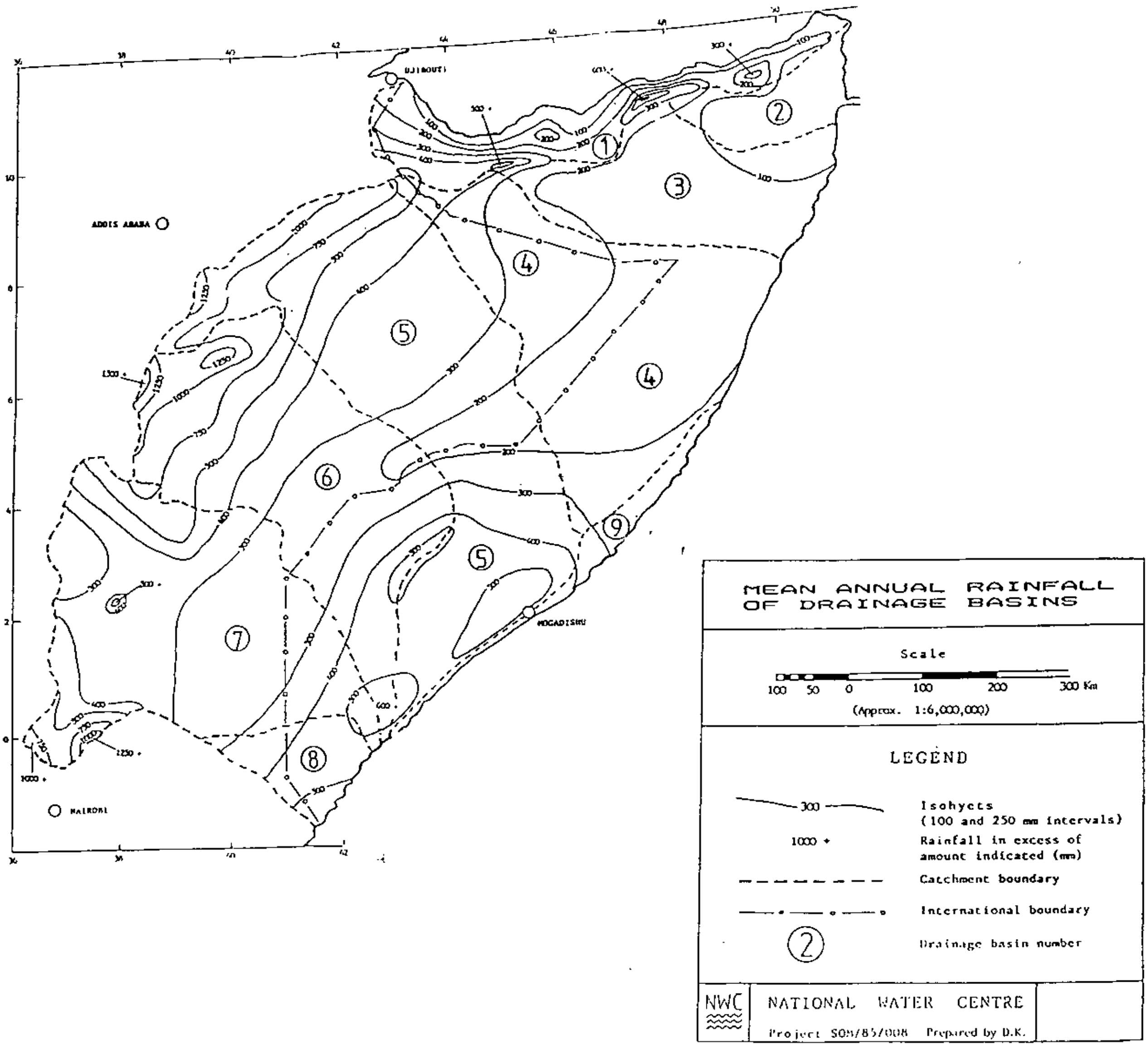


FIGURE 1 Sketch showing catchment boundaries and isohyets of total annual rainfall for all of Somalia (from Kammer 1989). Catchment 5 is the Shebelli catchment and catchment 6 is the Jubba catchment.

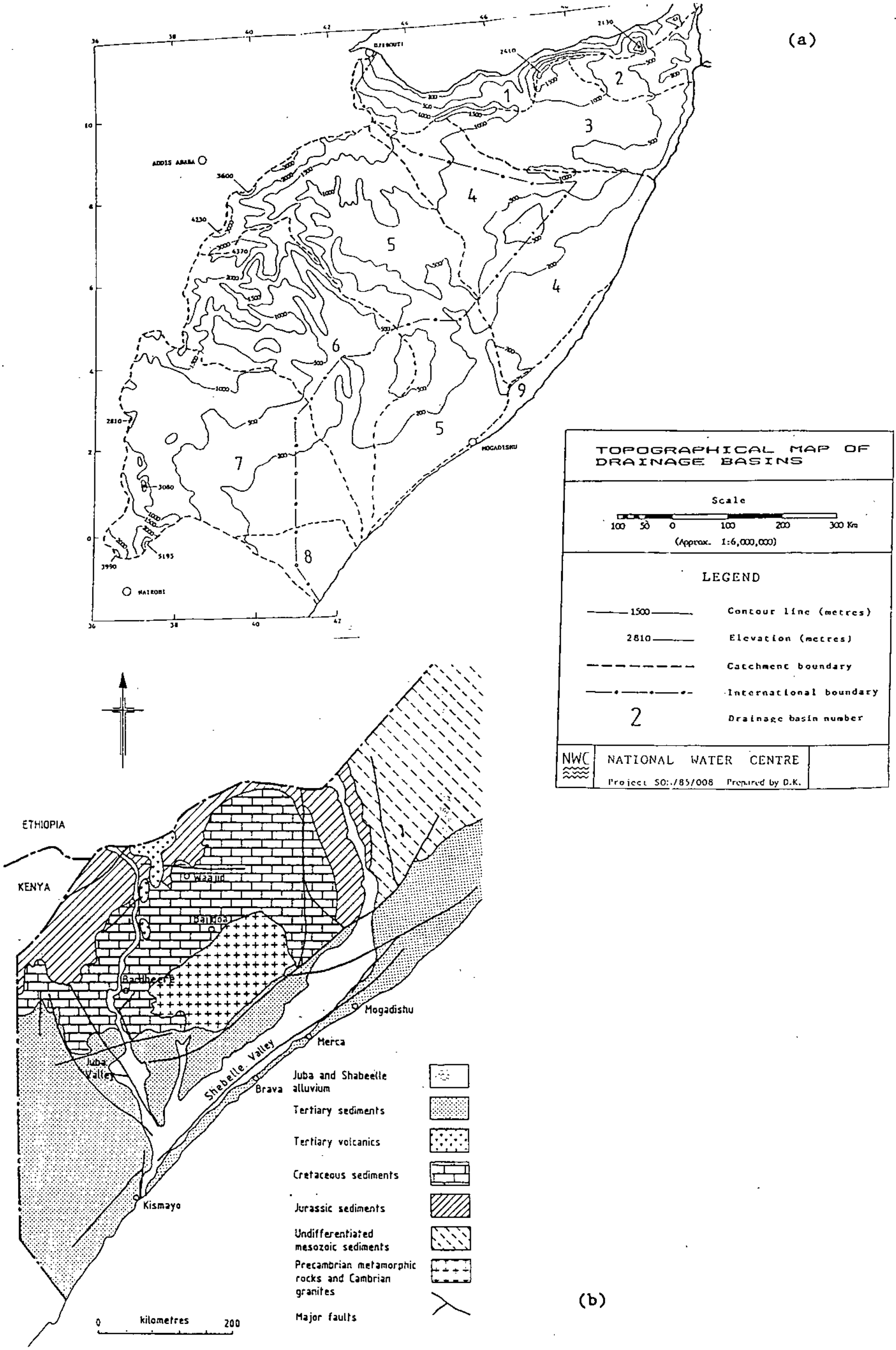


FIGURE 2 Sketch showing topography of the catchments and geology of river basins within Somalia (a) topography (from Kammer 1989), (b) geology (from MMP 1983)

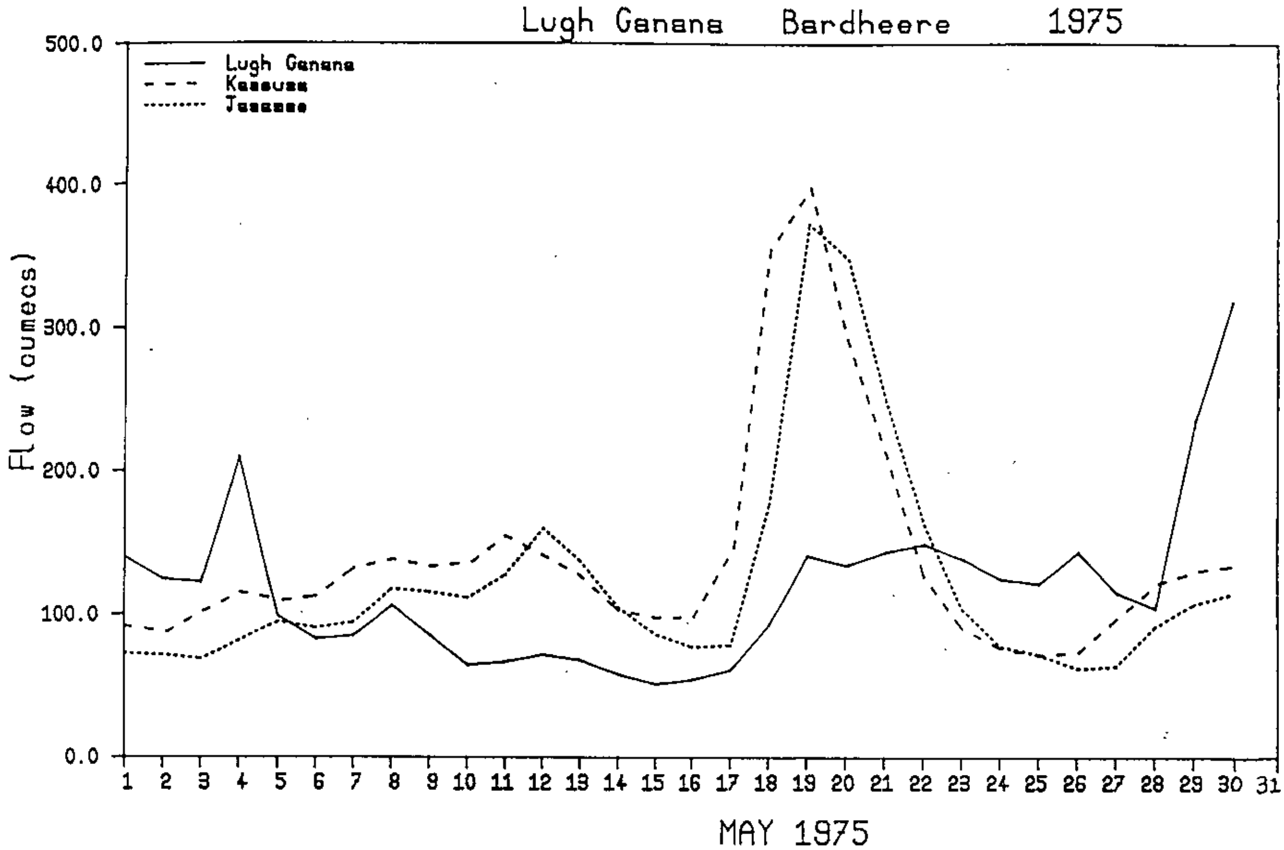


FIGURE 3 Example of a local runoff event on the river Jubba. The flows at Kamsuma and Jamamme reached a peak on May 19 but there was no corresponding change in the flows at Lugh. This was probably due to local runoff in the reach between Lugh and Bardheere.

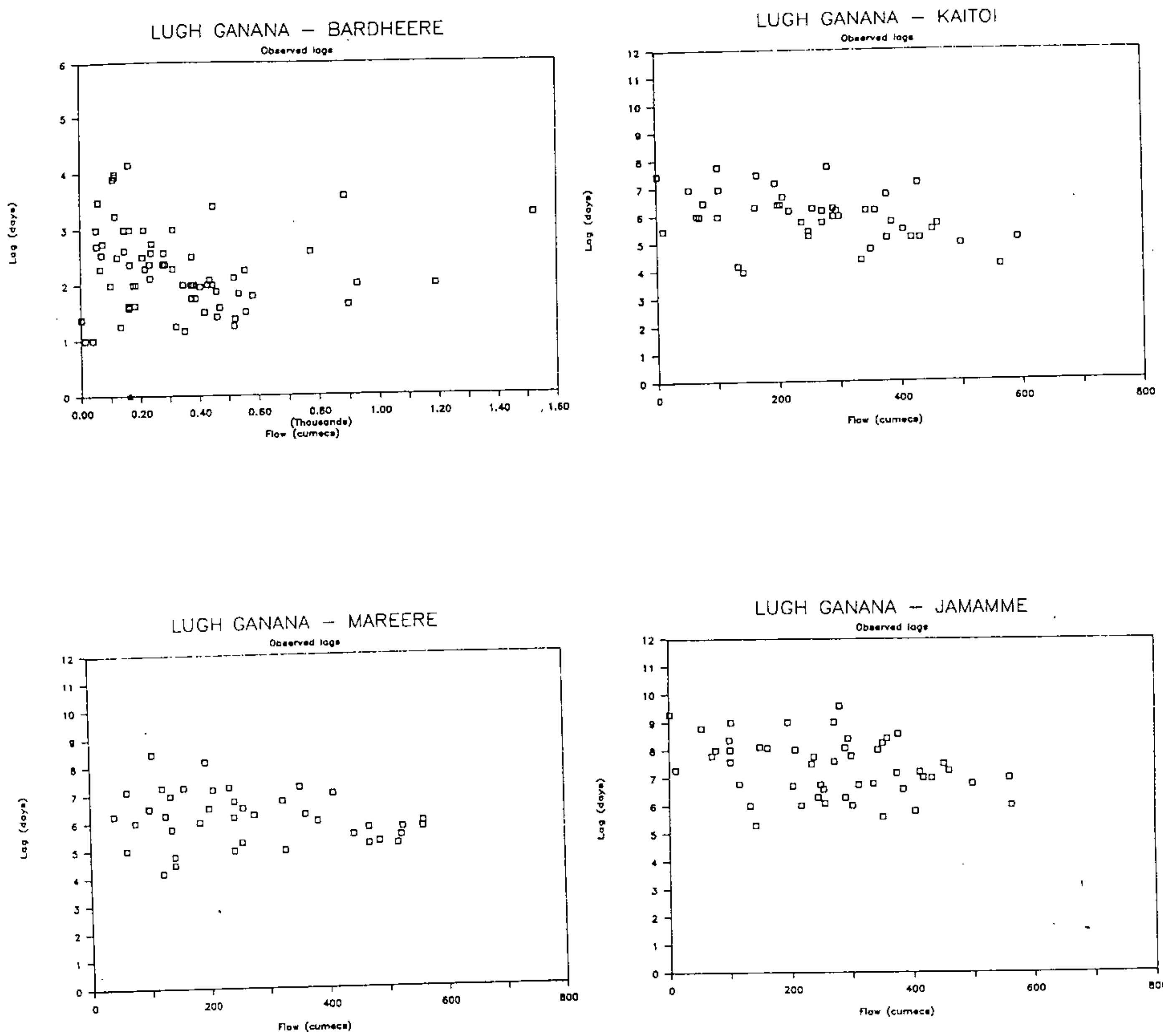
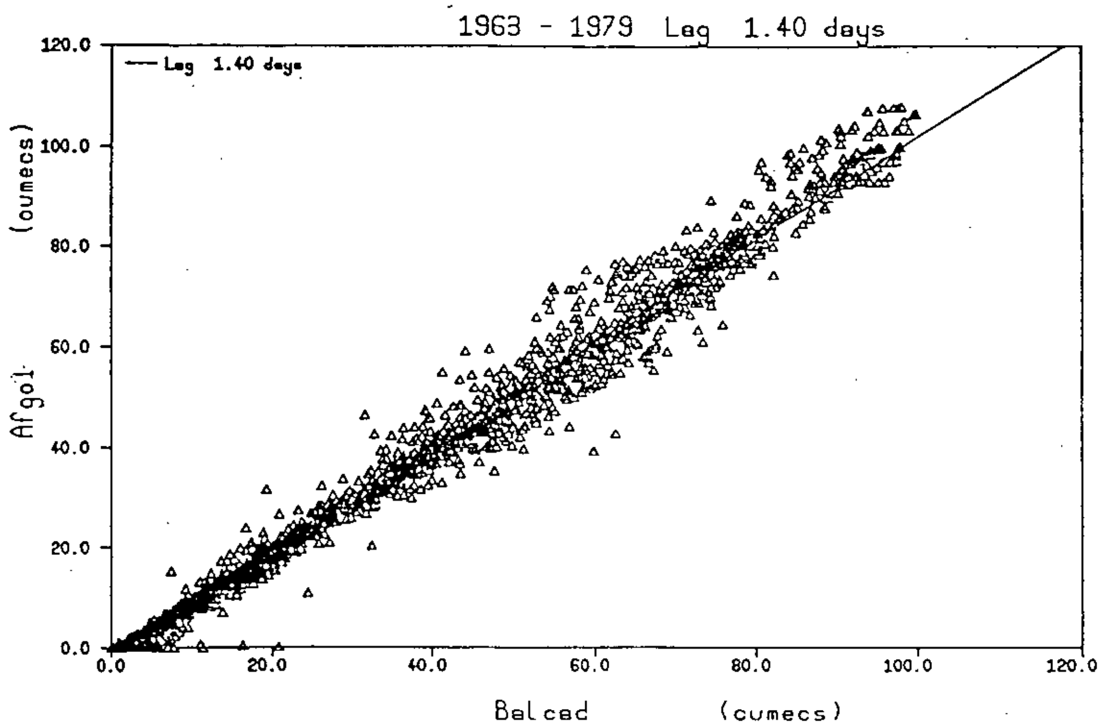
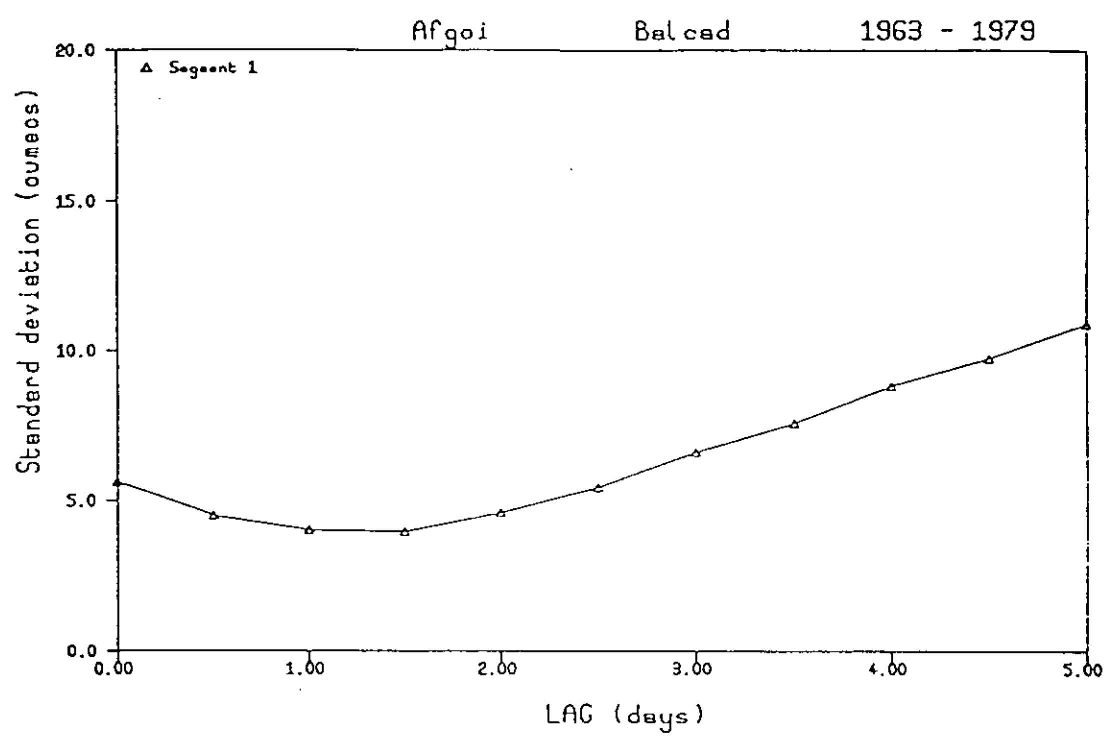


FIGURE 4 Variation with flow of lag times for specific events on the river Jubba, obtained from an analysis of the river level data for the period 1963-1989.



(a)



(b)

FIGURE 5 Example of a correlation plot and the effects of lag time on the error of fit. The data are for Afgoi and Balcad on the river Shebelli (a) Straight line fit assuming a lag of 1.4 days (b) Variation of the error of fit for assumed lags in the range 0 to 5 days.

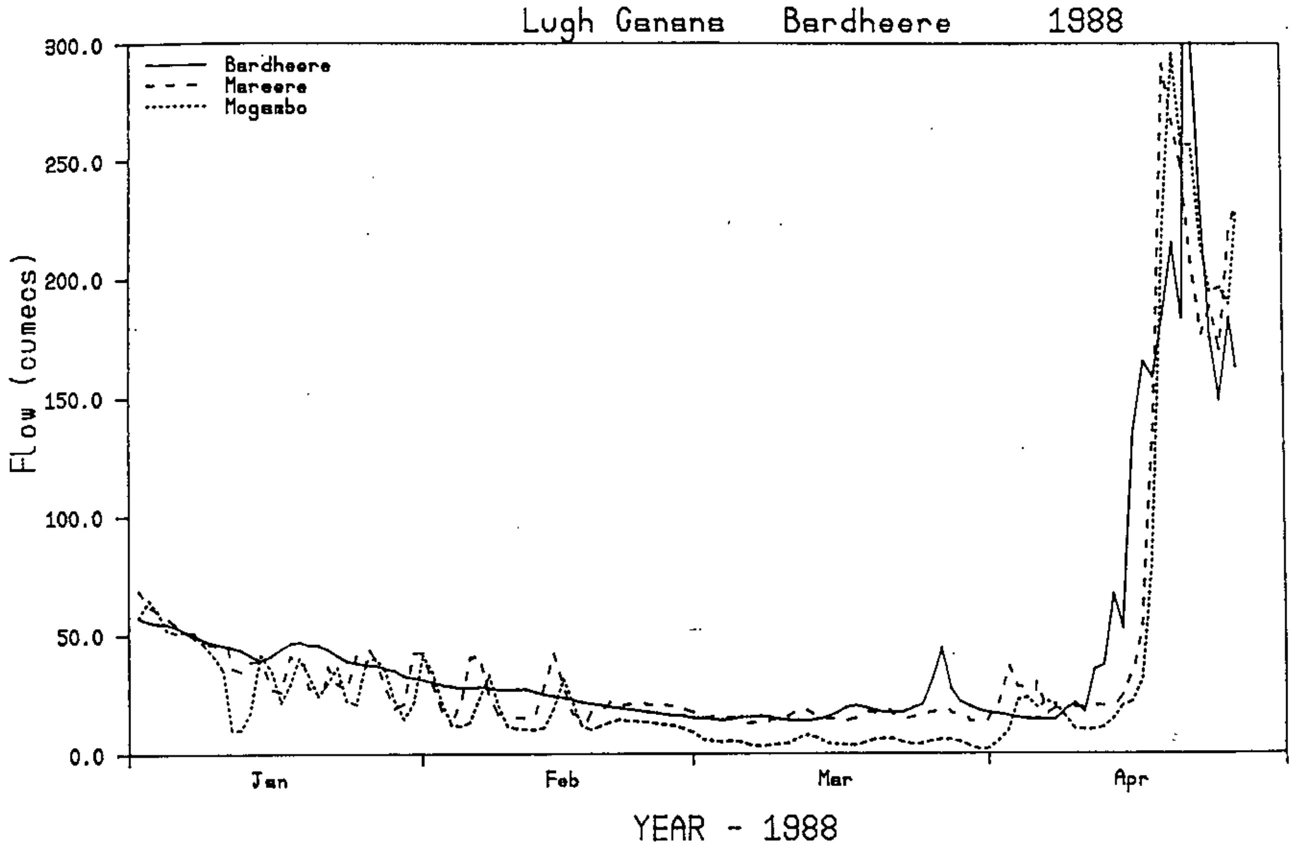


FIGURE 6 Example of the effects of irrigation abstractions on low flows on the Jubba. Abstractions on a weekly basis between Bardheere and Mareere caused a weekly cycle in the flows measured at Mareere and Mogambo.

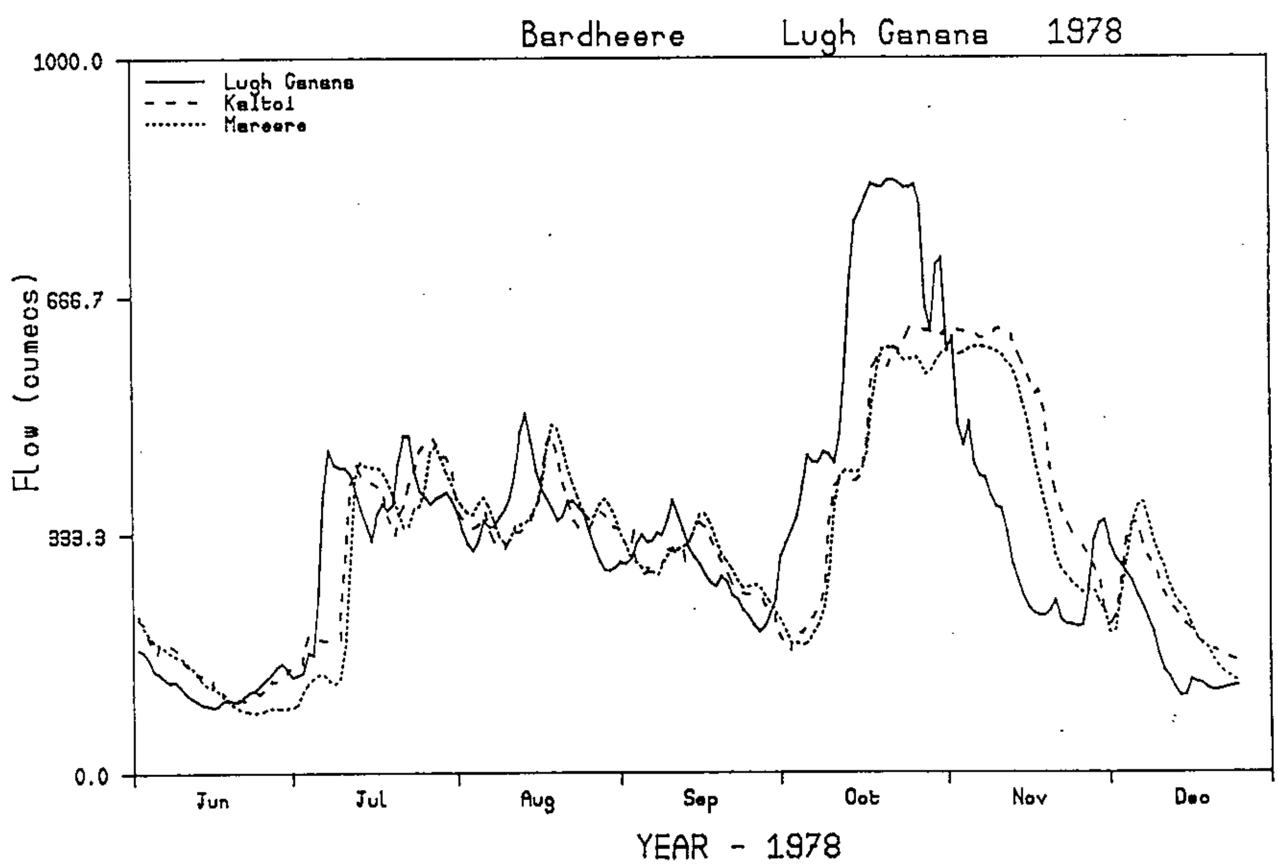


FIGURE 7 Example of the effects of spillage on hydrographs for the lower Jubba. Here, the flows at Kaitoi and Mareere reached a sustained peak which was much lower than the flow at Lugh Ganana.

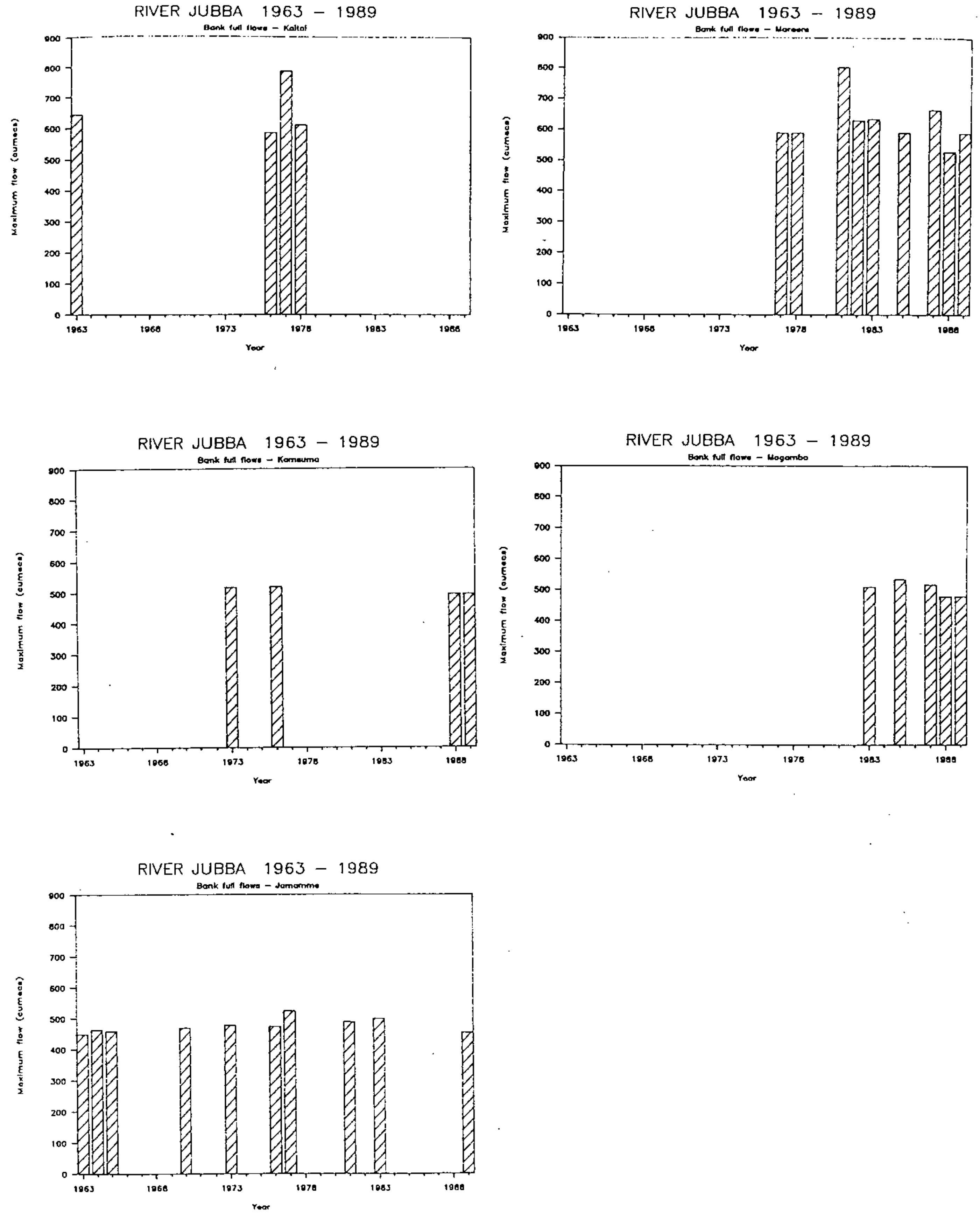


FIGURE 8 Variation with time of bank-full flows for the lower stations on the river Jubba. Missing values occur either when no data were available, or when the bank-full level was not reached in the year.

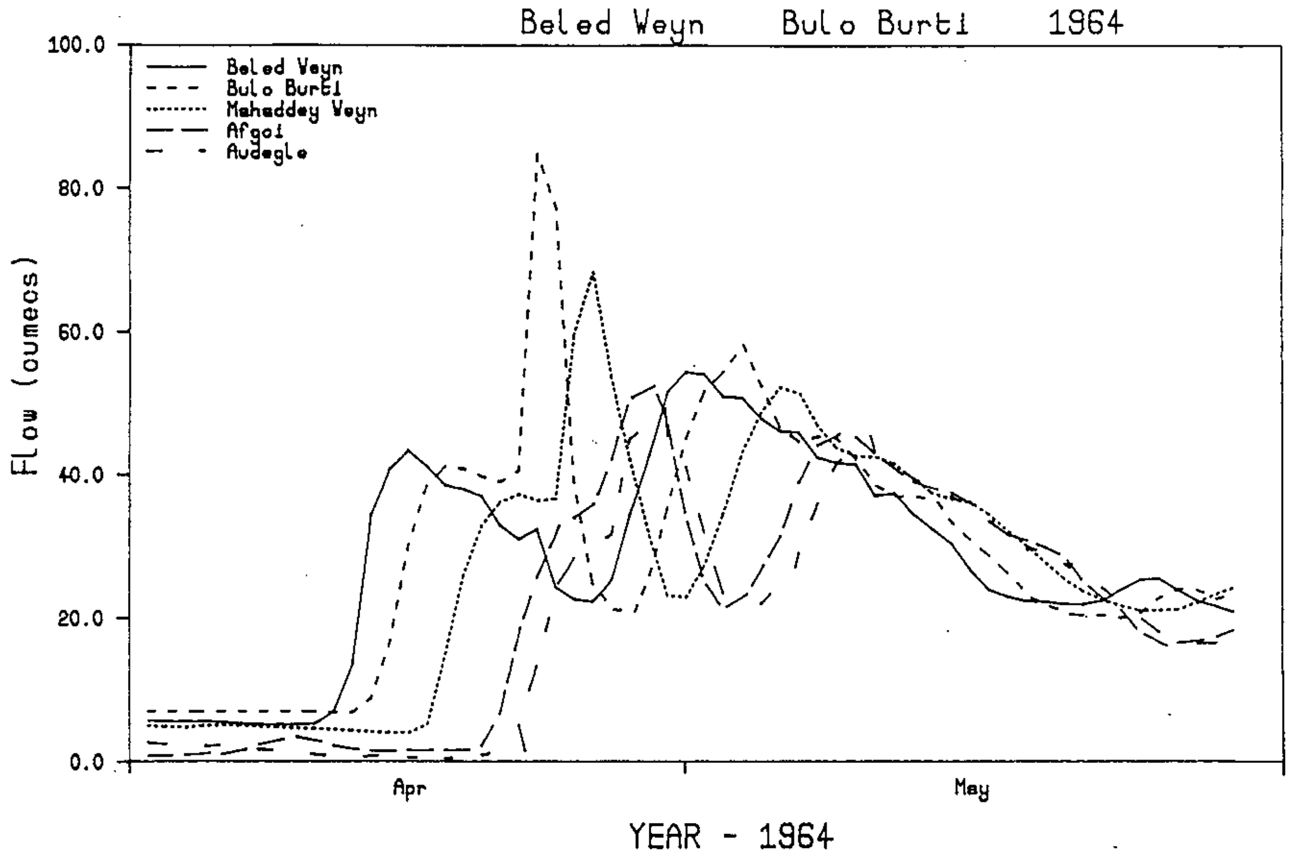


FIGURE 9 Example of a local runoff event on the river Shebelli. The flows at all stations downstream of Beled Weyn rose to a peak in late April but there was no corresponding change in the flows at Beled Weyn. This was probably due to local runoff in the reach between Beled Weyn and Bulo Burti.

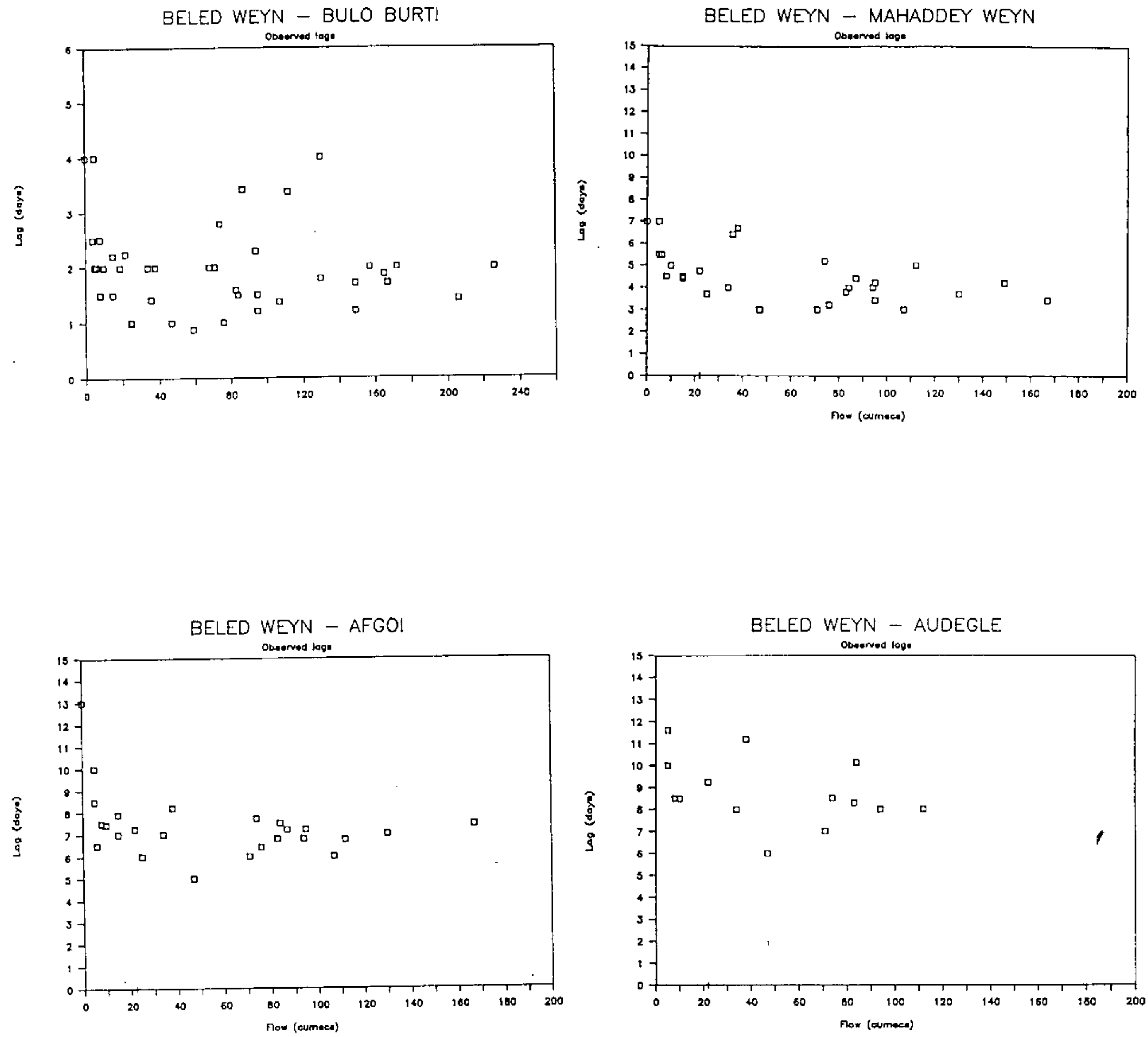
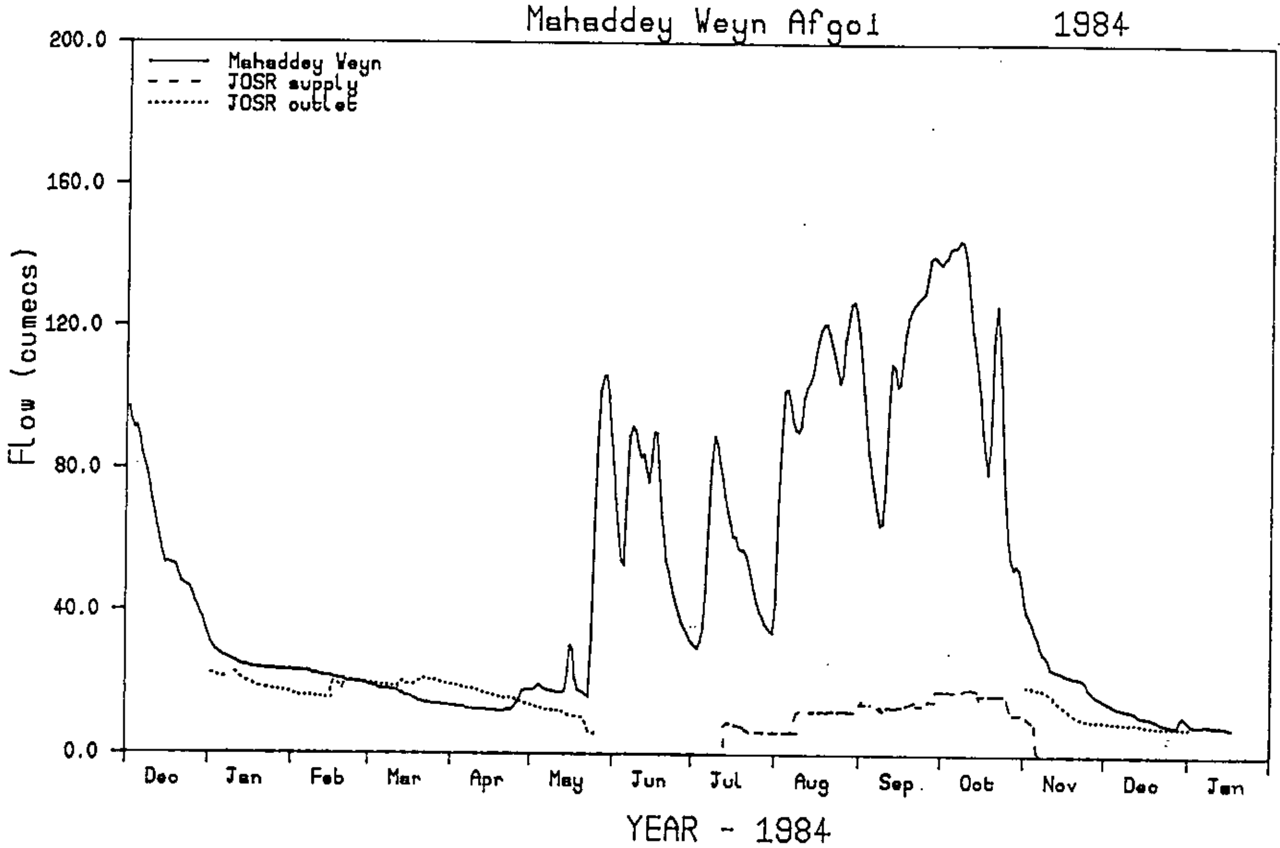
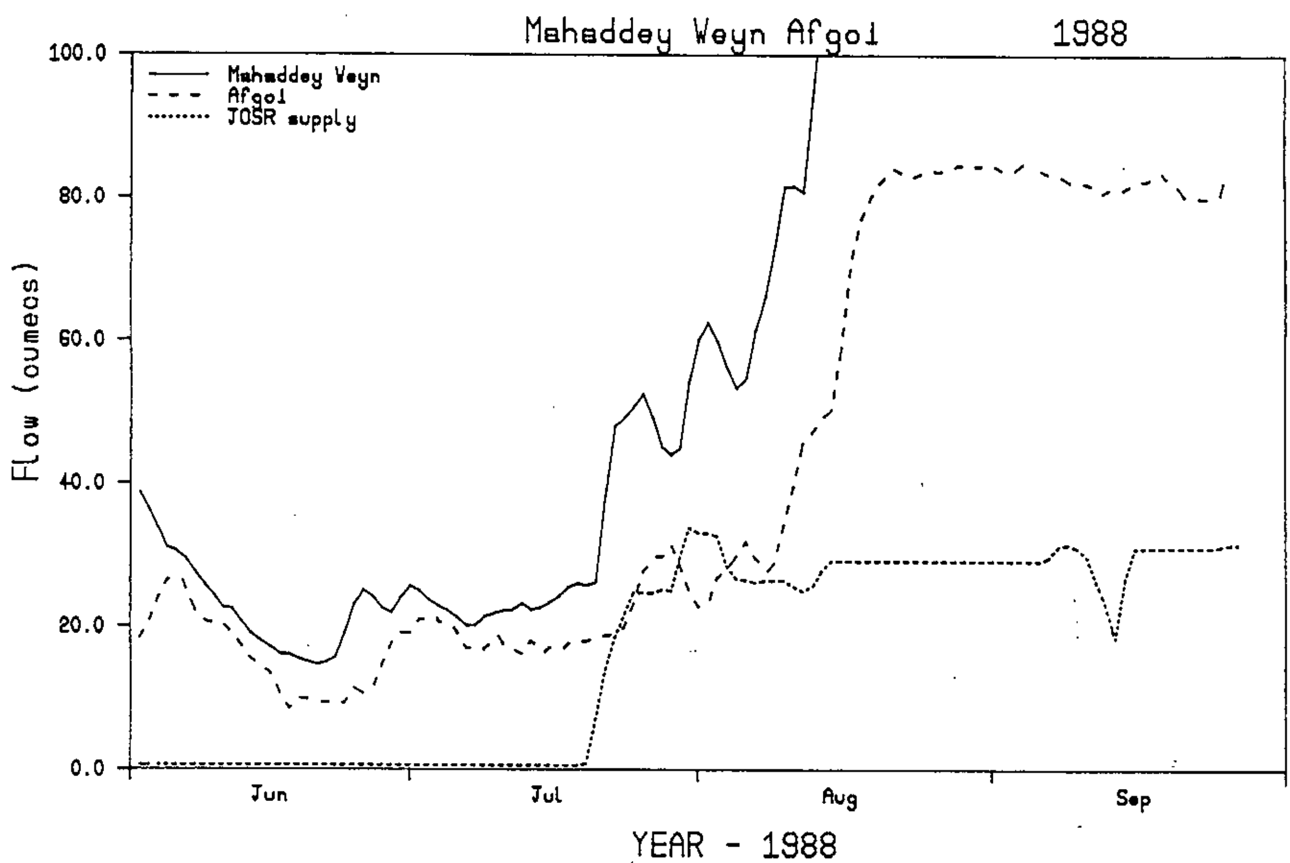


FIGURE 10 Variation with flow of lag times for specific events on the river Shebelli, obtained from an analysis of the river level data for the period 1963-1989.

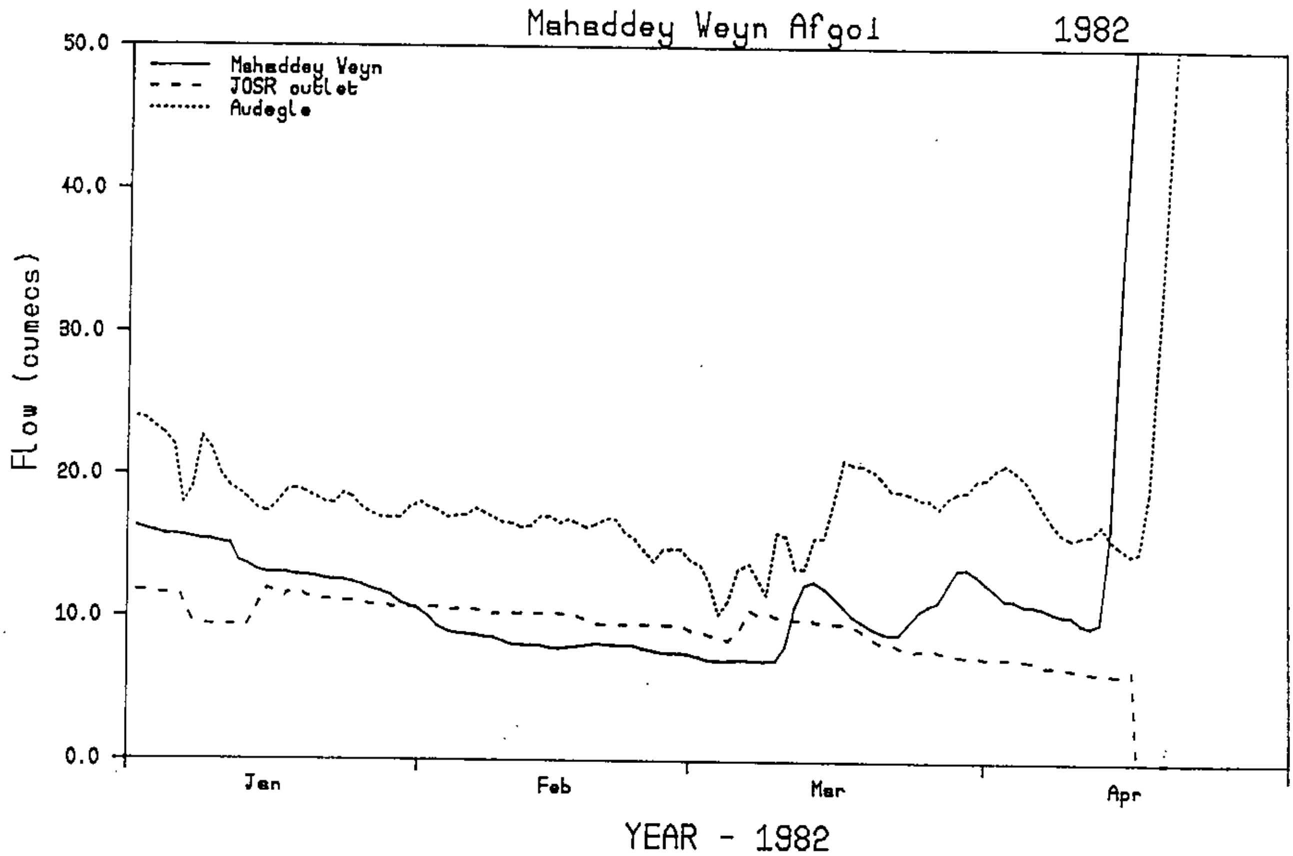


(a)



(b)

FIGURE 11 Examples of the effects of operations at Jowhar Offstream reservoir on flows in the lower Shebelli (a) shows how the supply and outlet canals are operated in response to flows passing Mahaddey Weyn, (b) shows the effects of operating the supply canal on flows at Afgoi and (c) shows the effects of operating the outlet canal on flows at Audegle.



(c)

FIGURE 11 (continued)

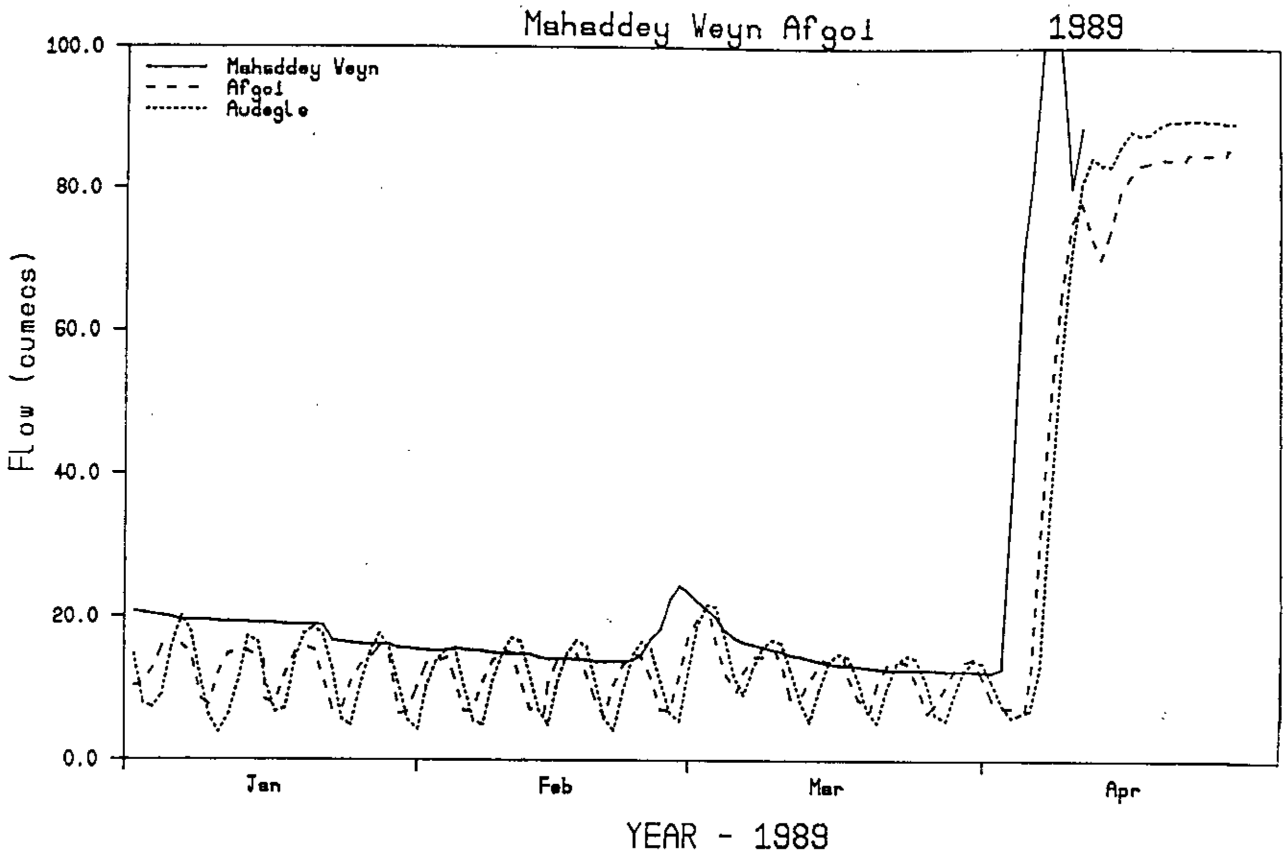


FIGURE 12 Example of the effects of irrigation abstractions on low flows on the Shebelli. Abstractions on a weekly basis between Mahaddey Weyn and Afgoi caused a weekly cycle in the flows measured at Afgoi and Audegle.

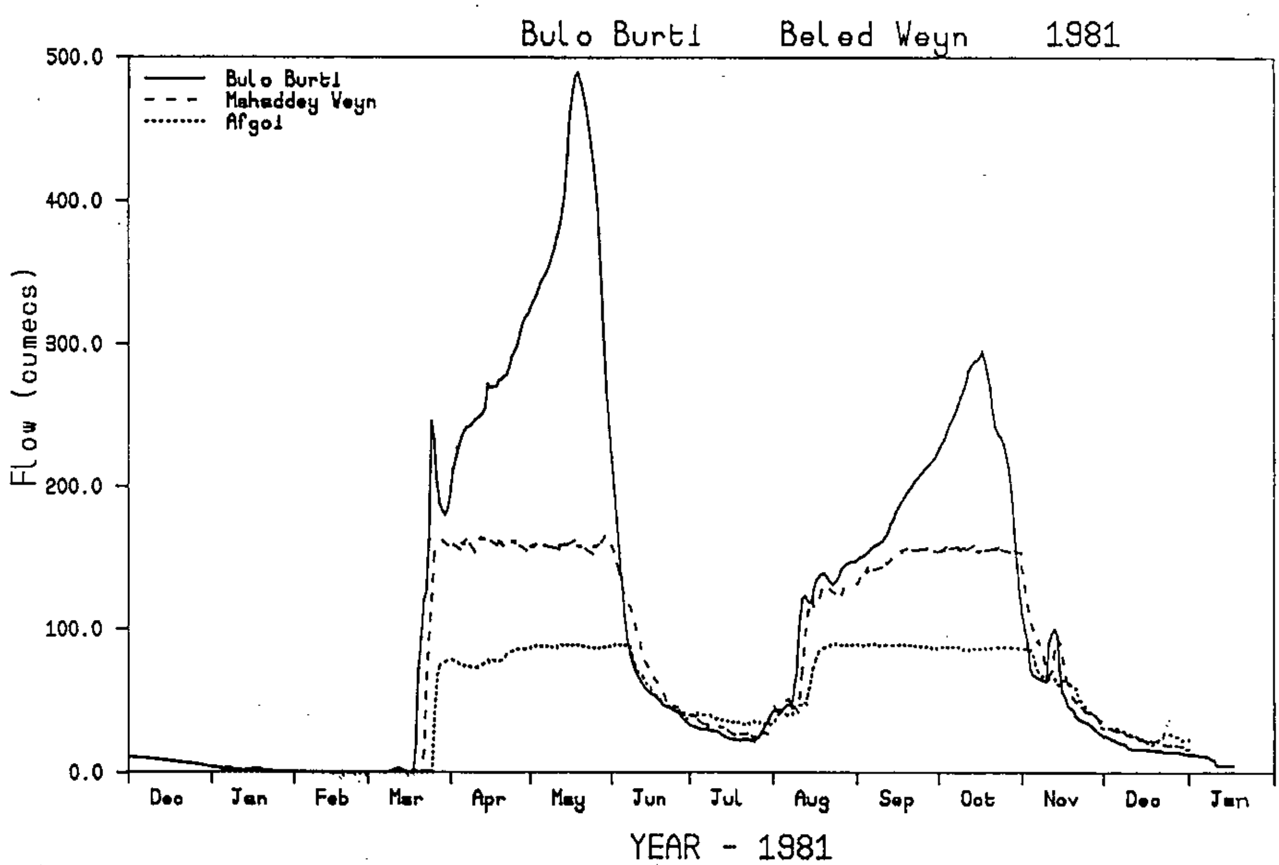


FIGURE 13 Example of the effects of spillage on hydrographs for the lower Shebelli. Here, the flows at Mahaddey Weyn and Afgoi reached a sustained peak which was much lower than the flow at Beled Weyn.

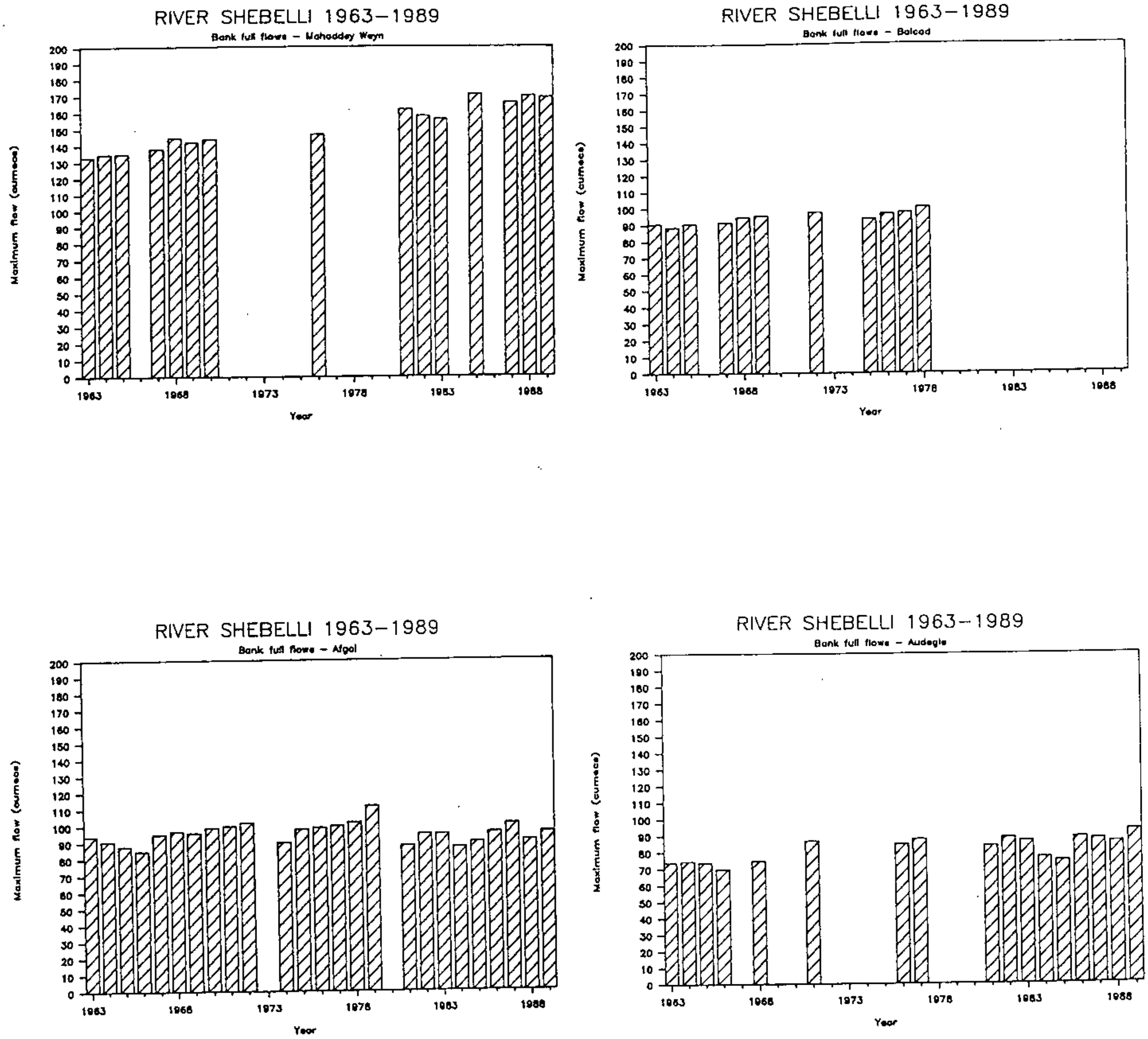


FIGURE 14 Variation with time of bank-full flows for the lower stations on the river Shebelli. Missing values occur either when no data were available, or when the bank-full level was not reached in the year.

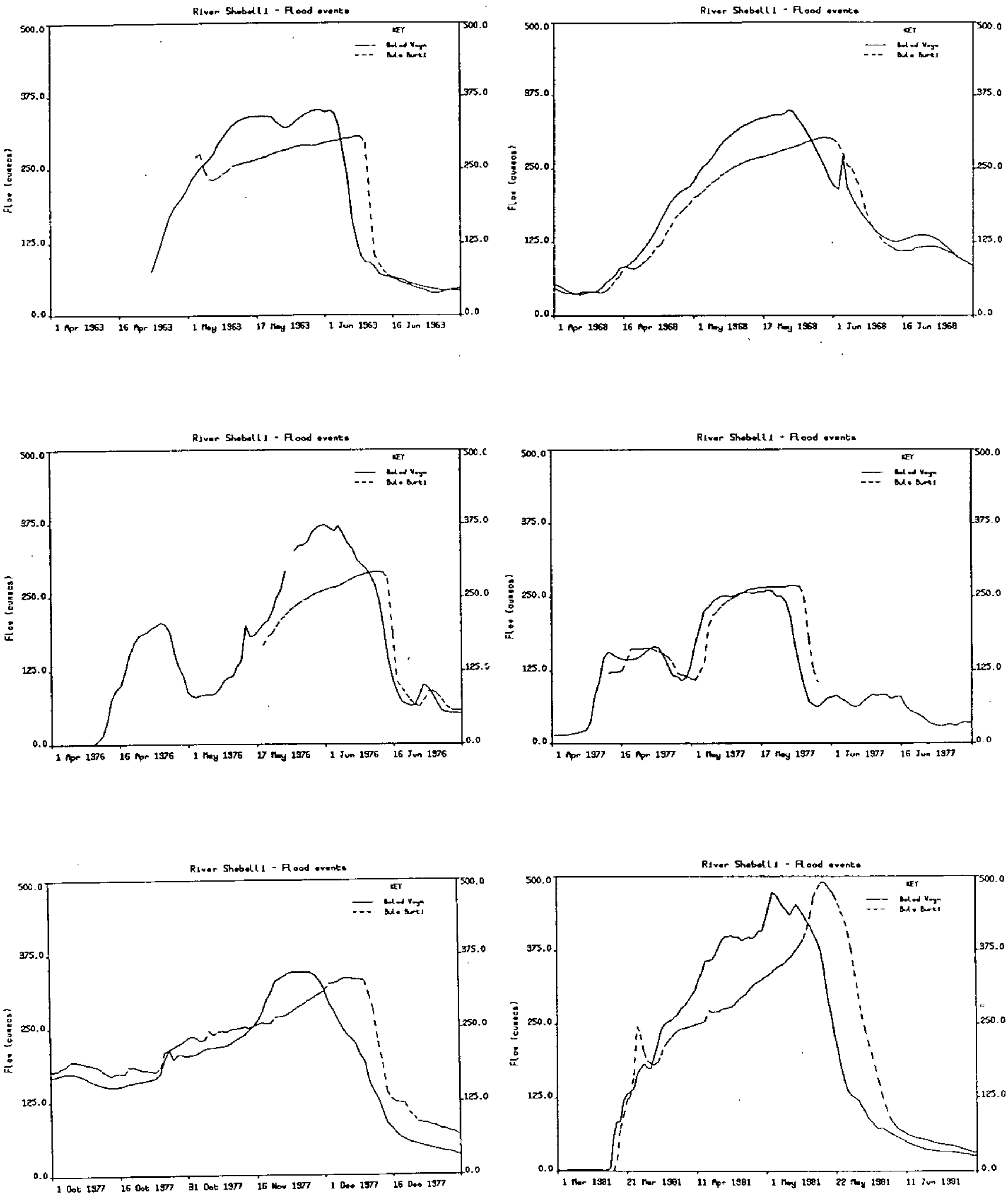


FIGURE 15 Catalogue of the main flood events on the upper Shebelli in the period 1963 - 1989.

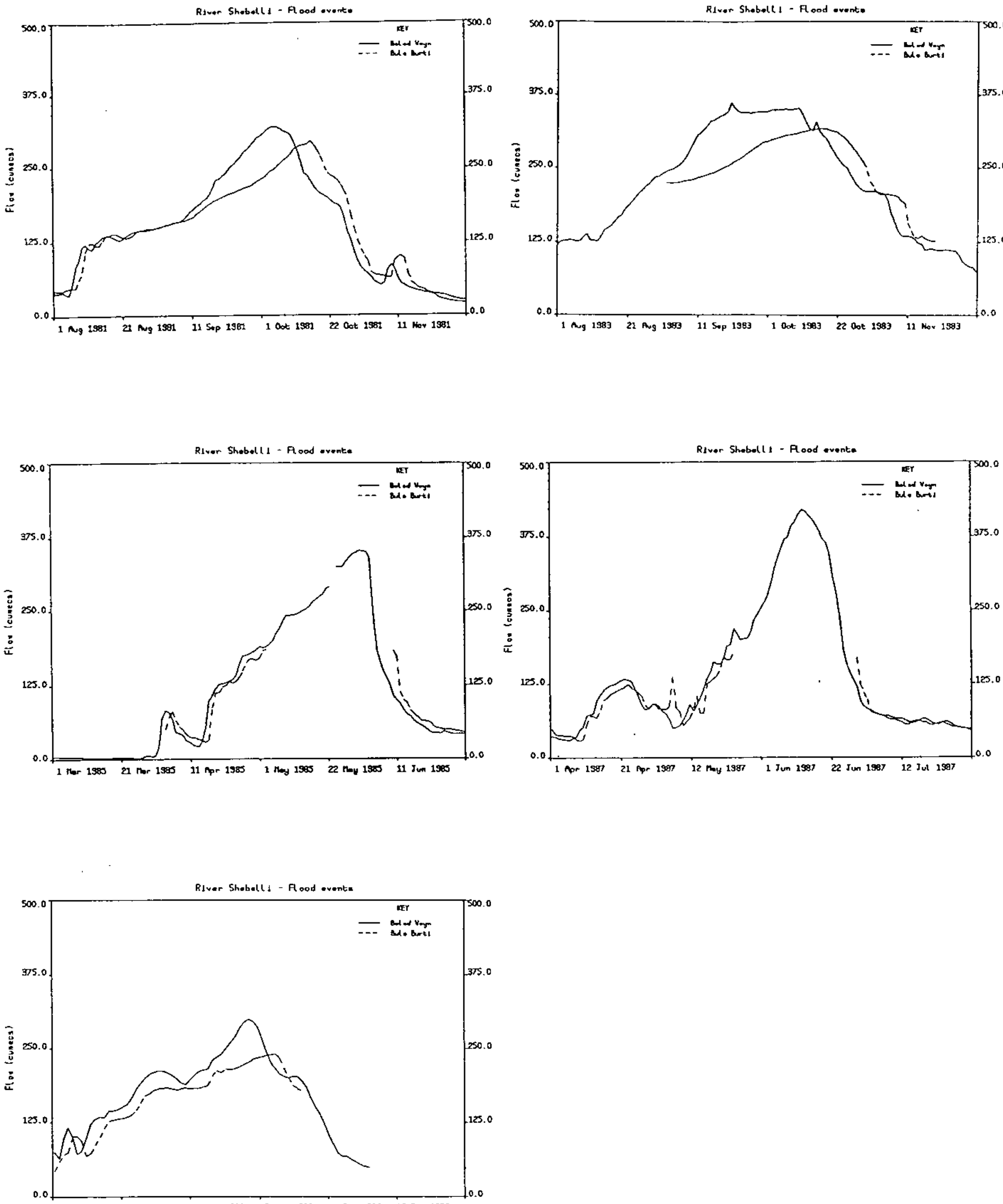


FIGURE 15 (continued)

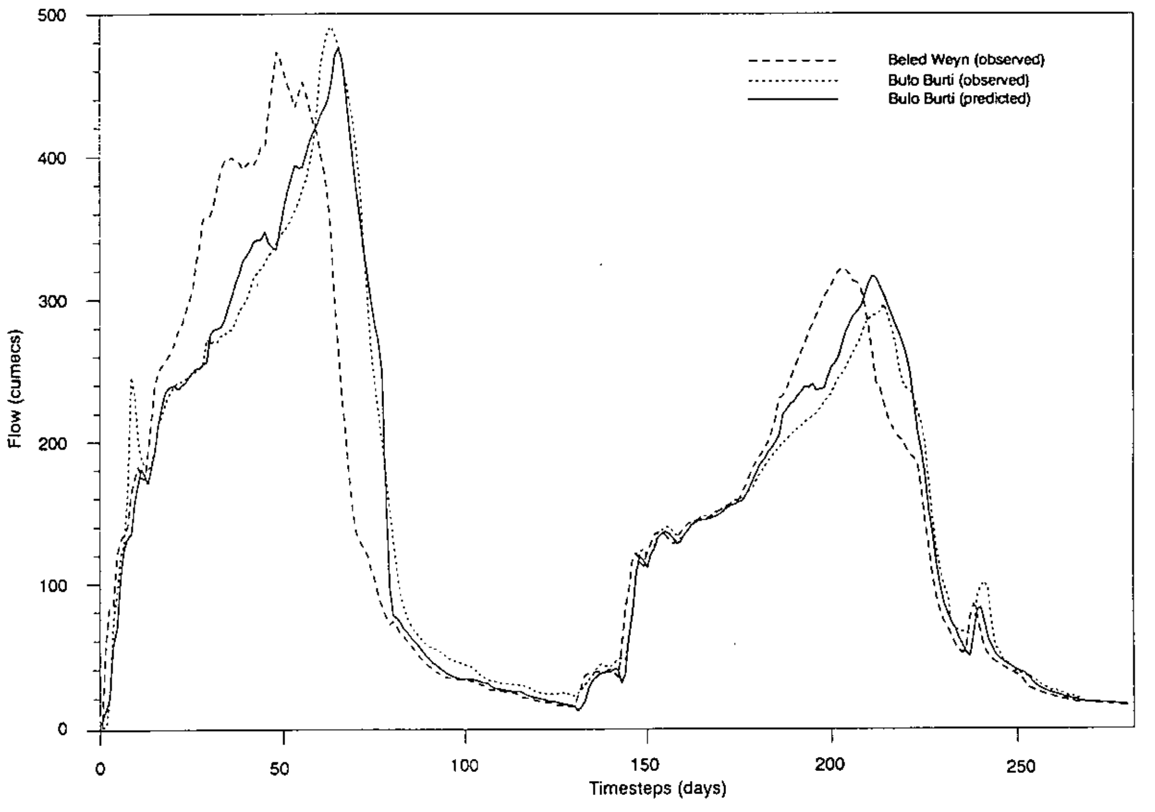
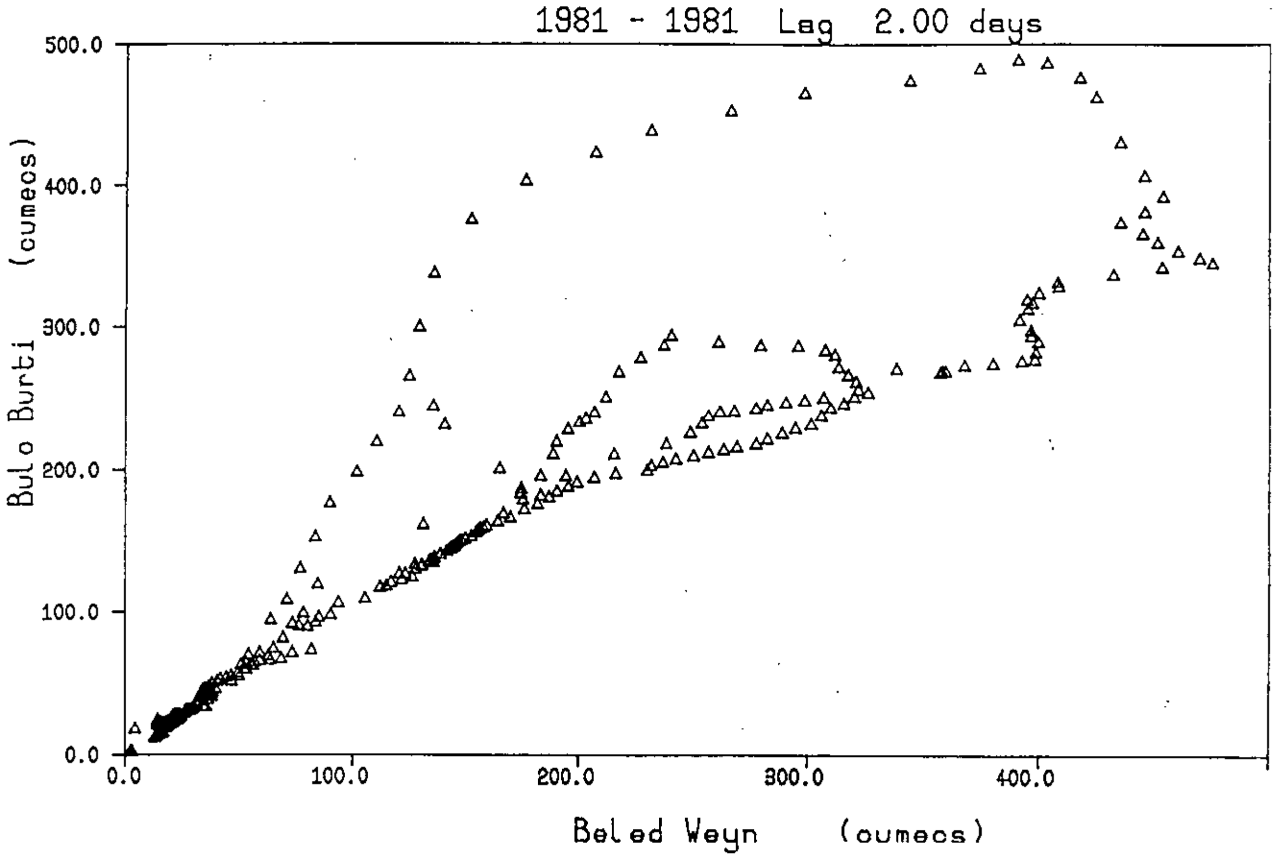
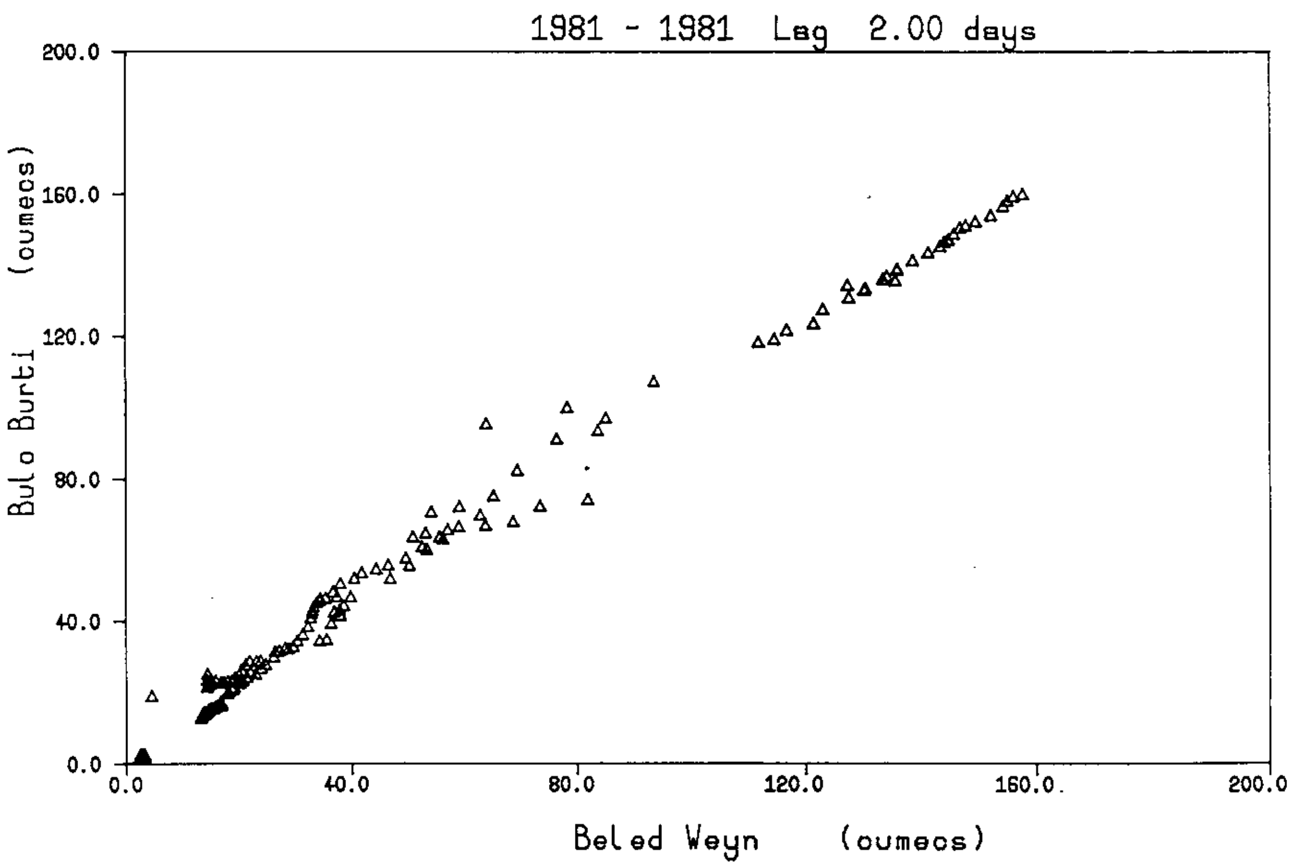


FIGURE 16 Example of the output from a variable parameter Muskingum Cunge routing model. The simulation was of the Gu and Der floods in 1981 for the reach Bulo Burti - Beled Weyn on the river Shebelli. The start date for the simulations was 16 March 1981.

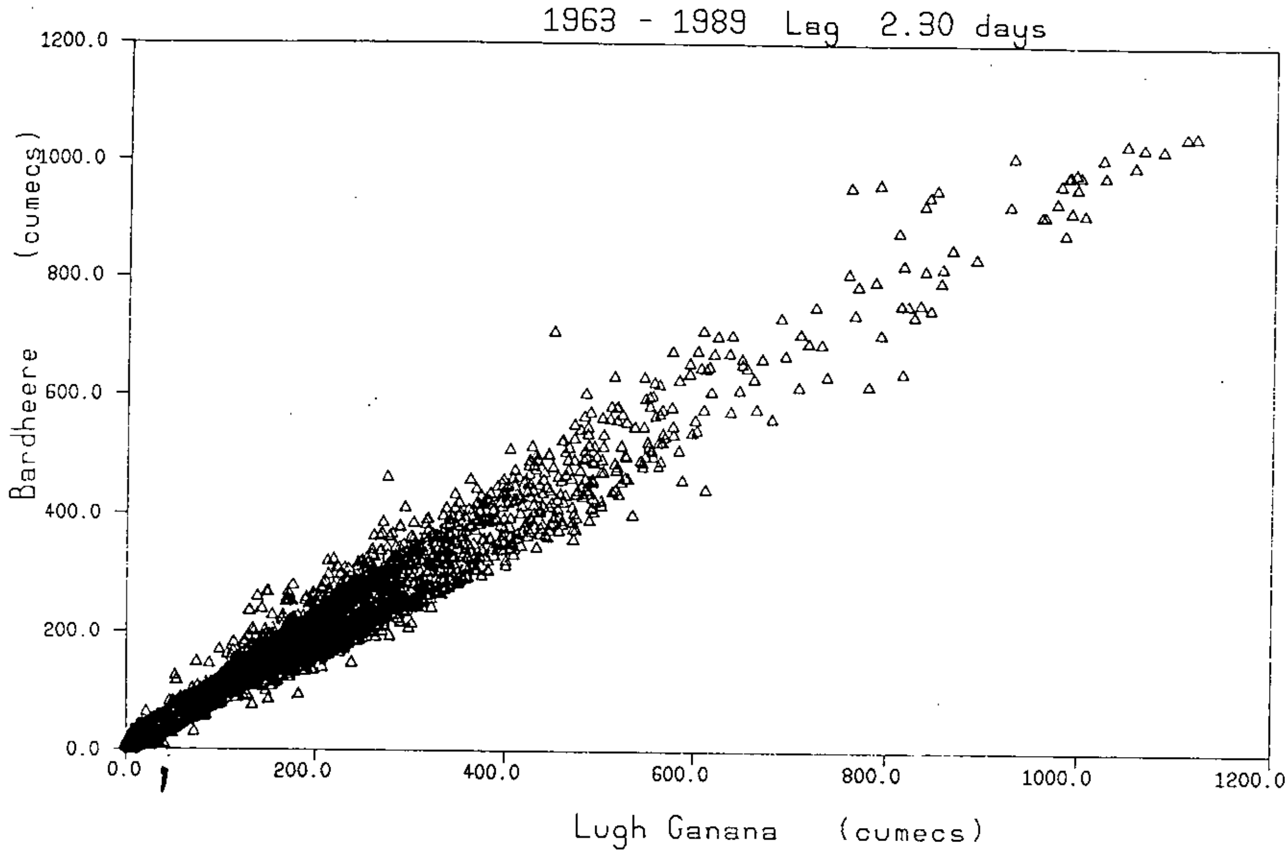


(a)



(b)

FIGURE 17 Example of the effects of excluding periods of doubtful data and inflows/outflows from a correlation plot. The data are for Beled Weyn and Bulo Burti in 1981, the year of one of the largest floods on record (a) all points included (b) flood event excluded



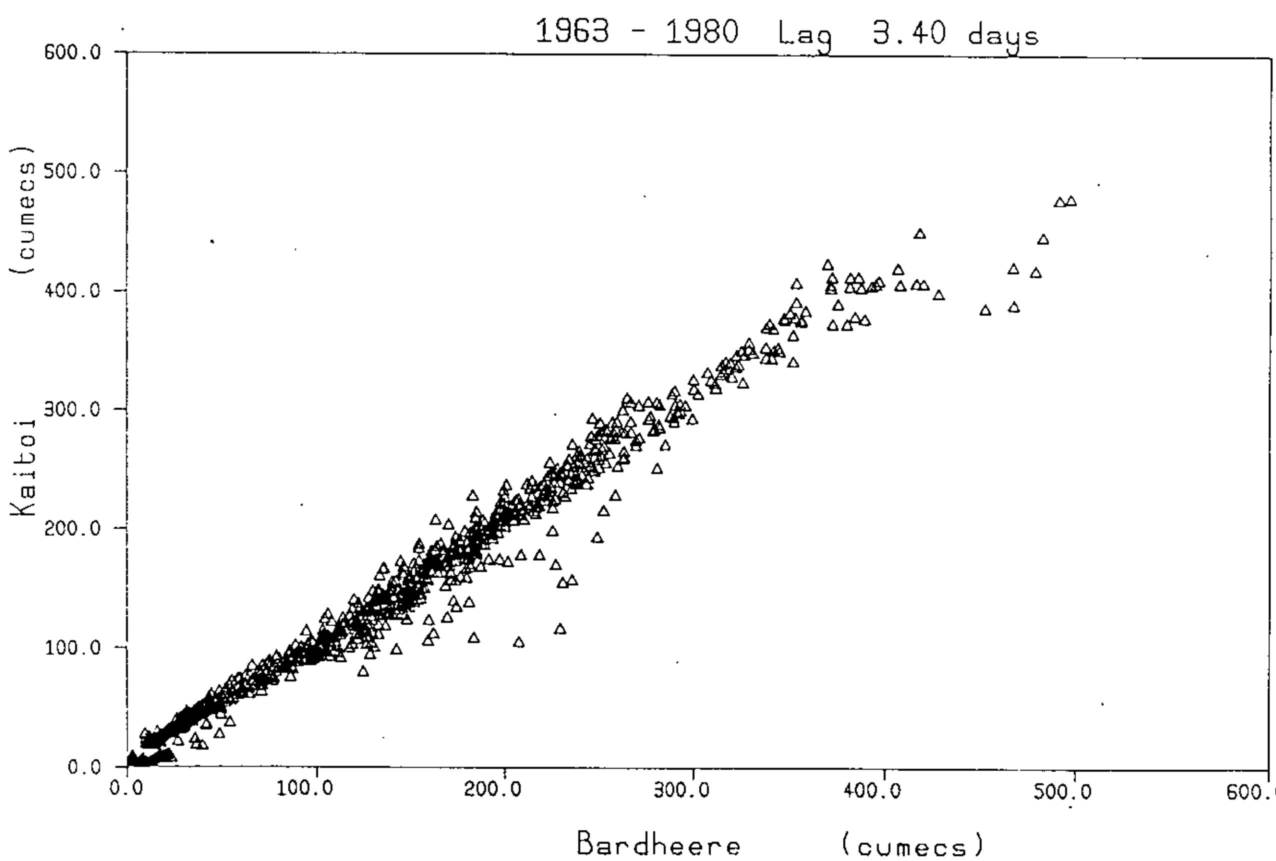
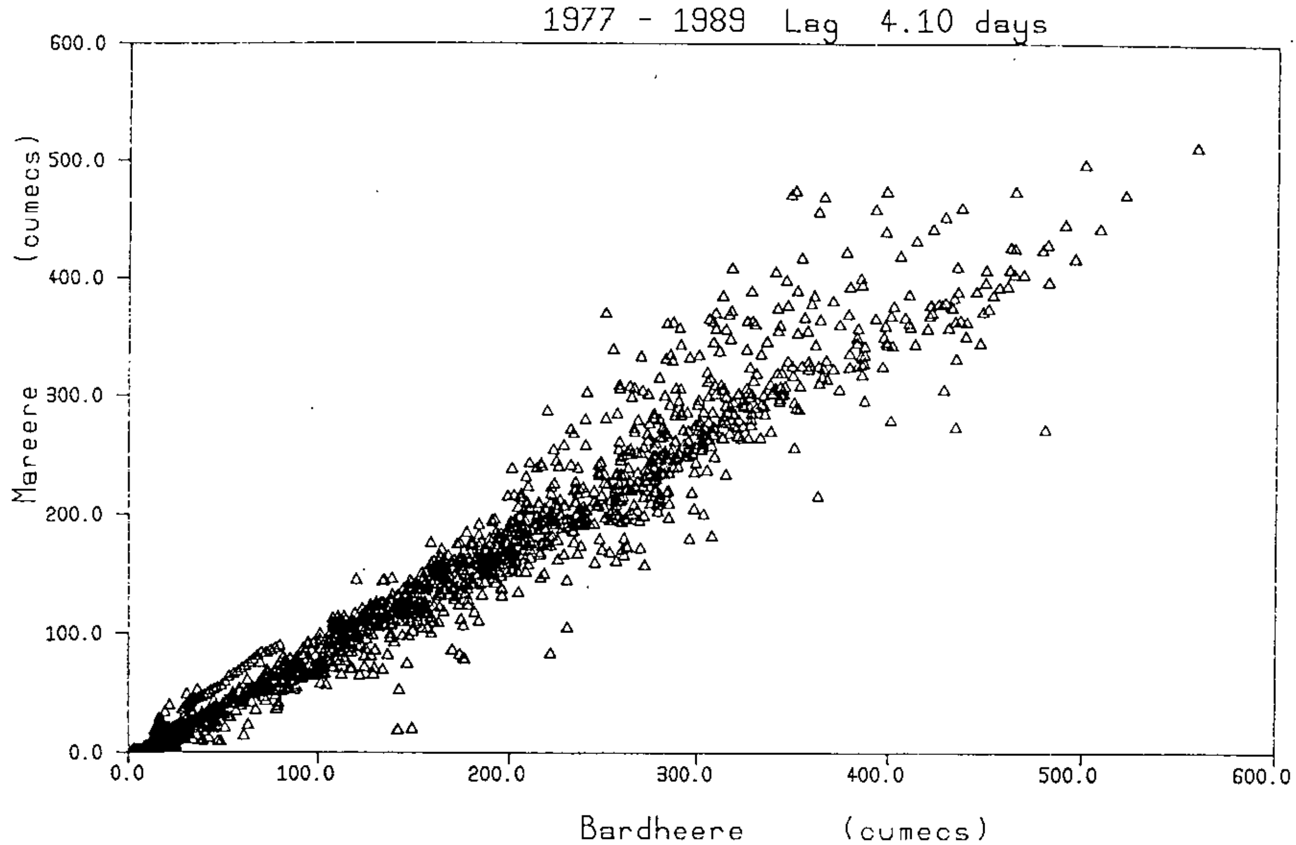


FIGURE 18 Correlation plots for the river Jubba. These were used to derive the equations used in the infilling work.



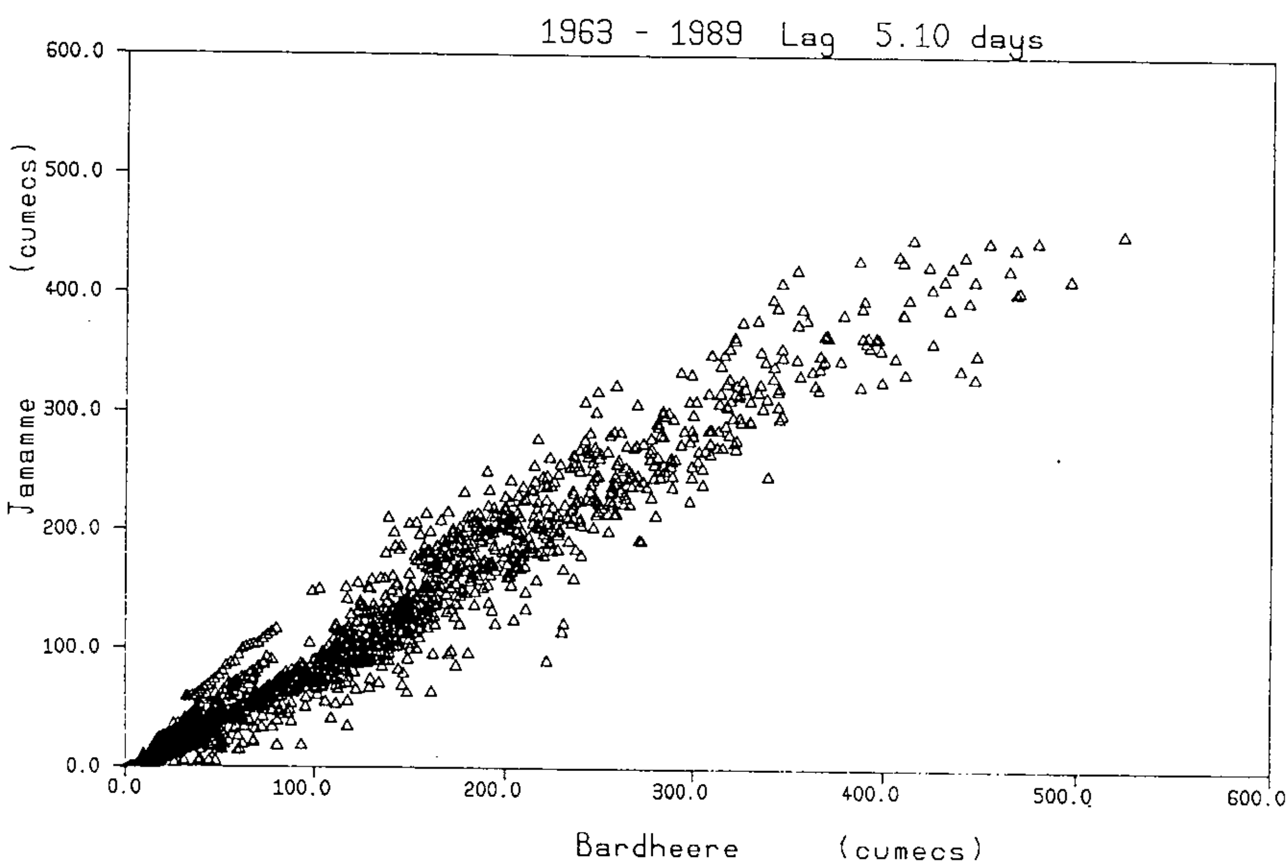
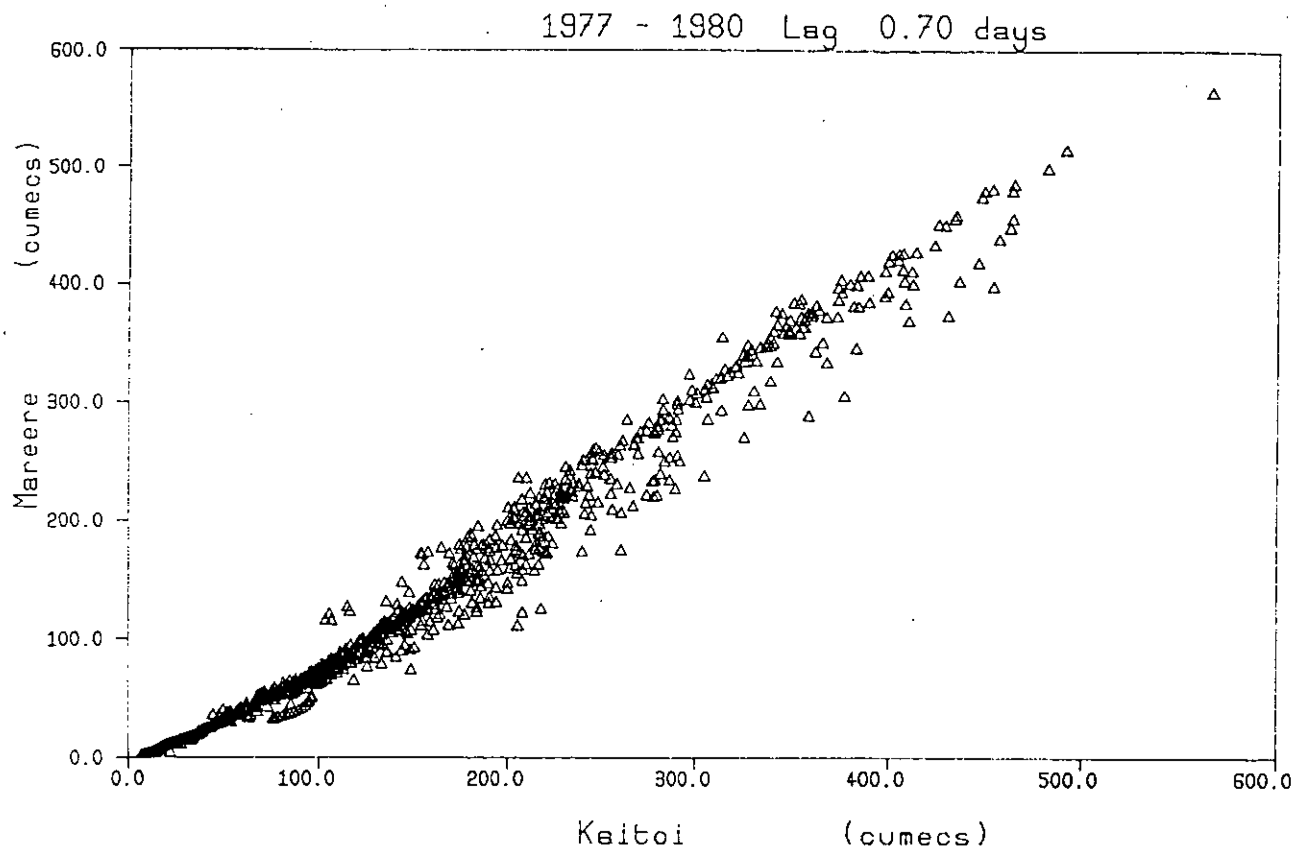


FIGURE 18 (continued)



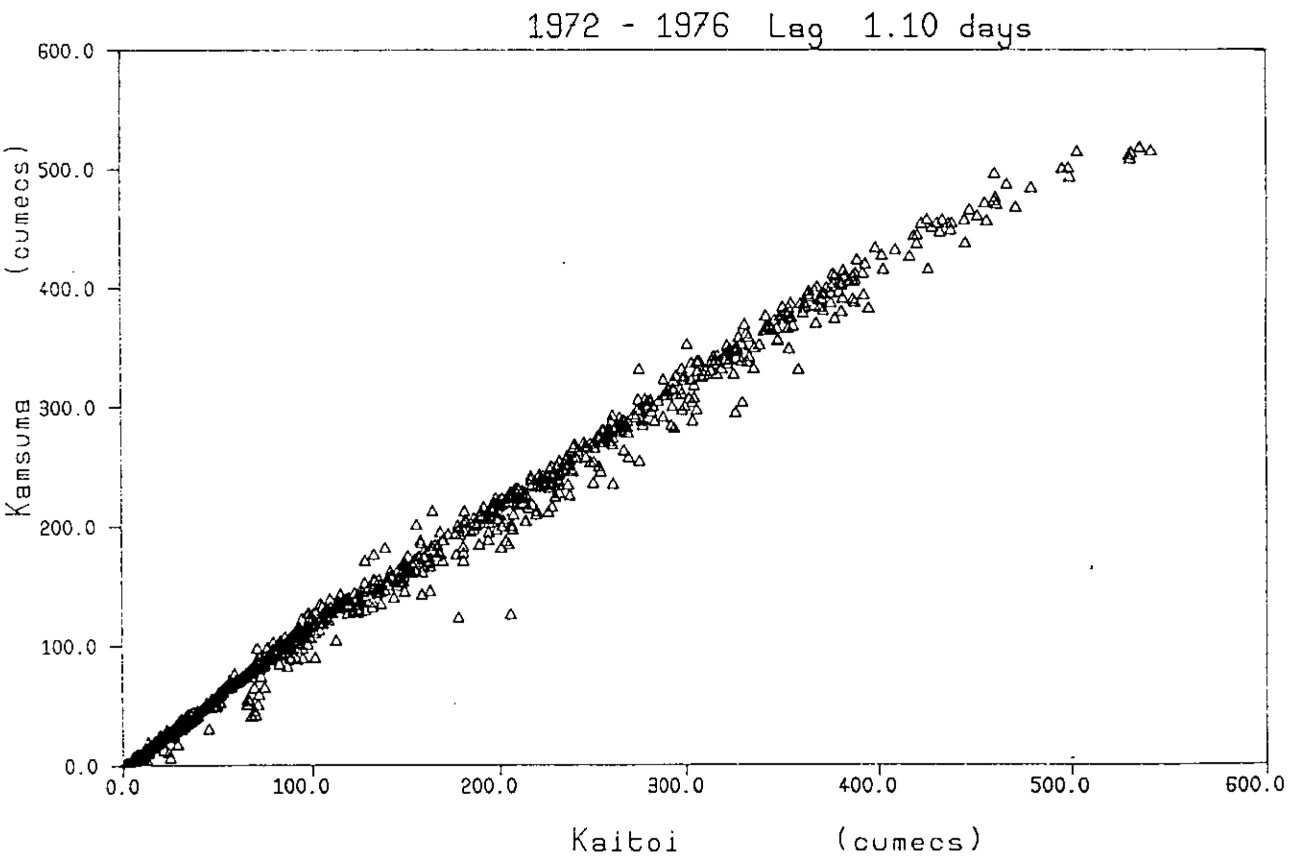
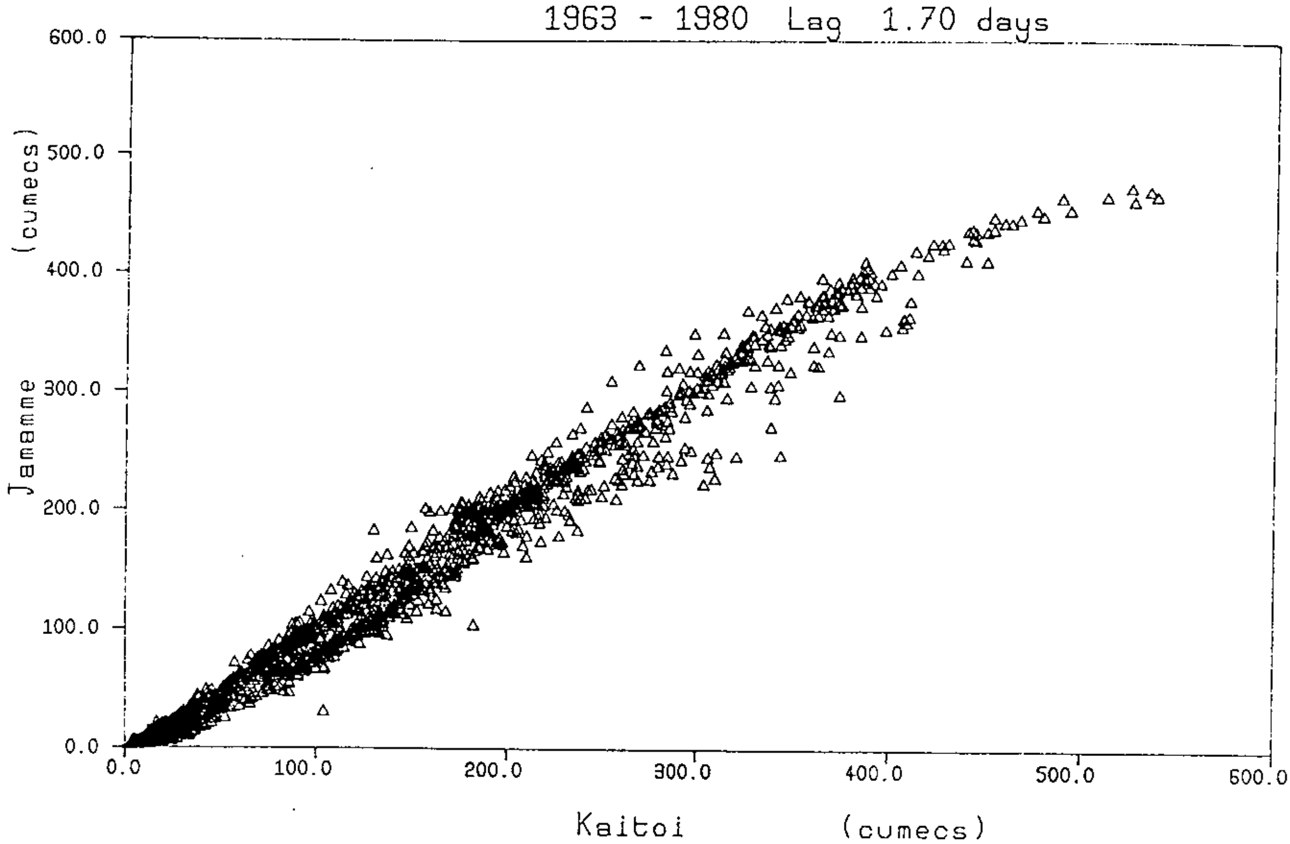


FIGURE 18 (continued)



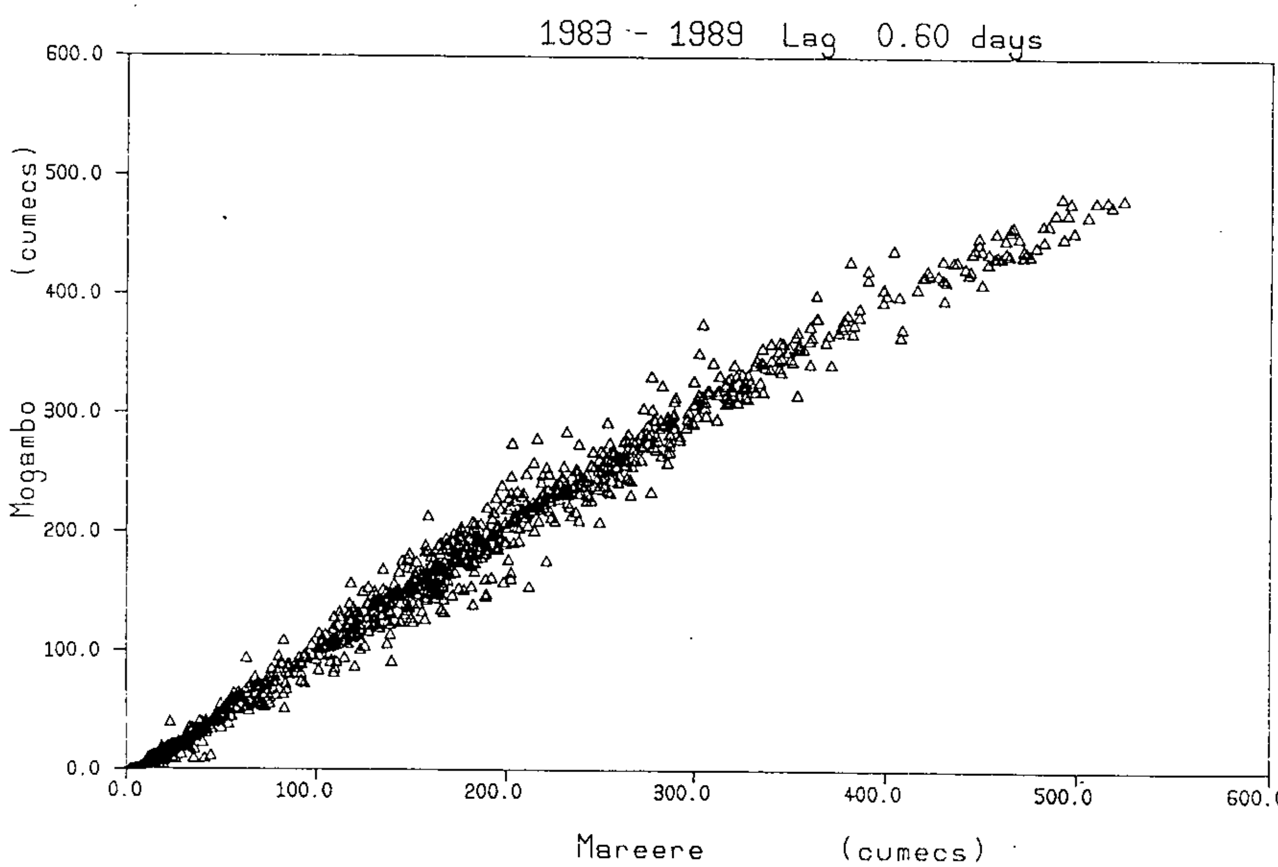
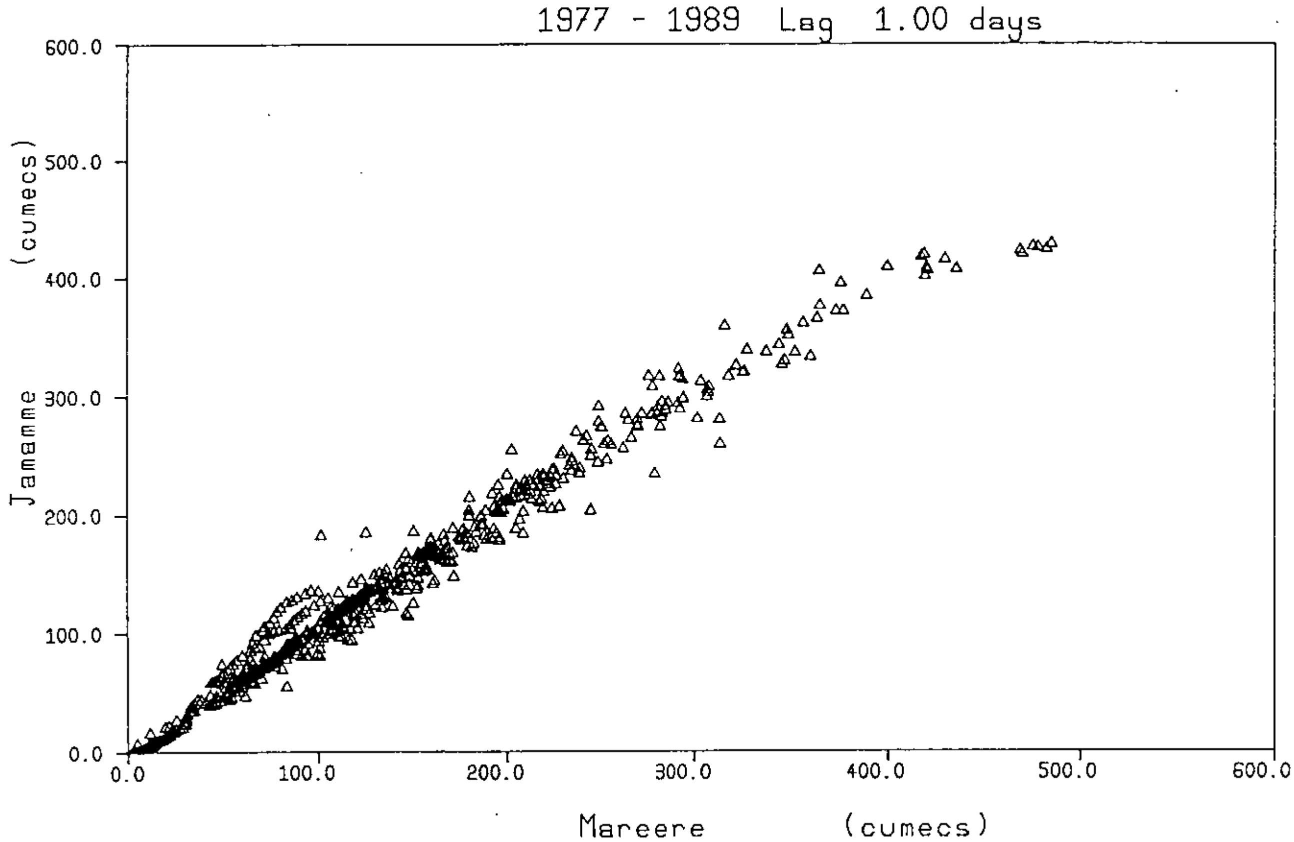


FIGURE 18 (continued)



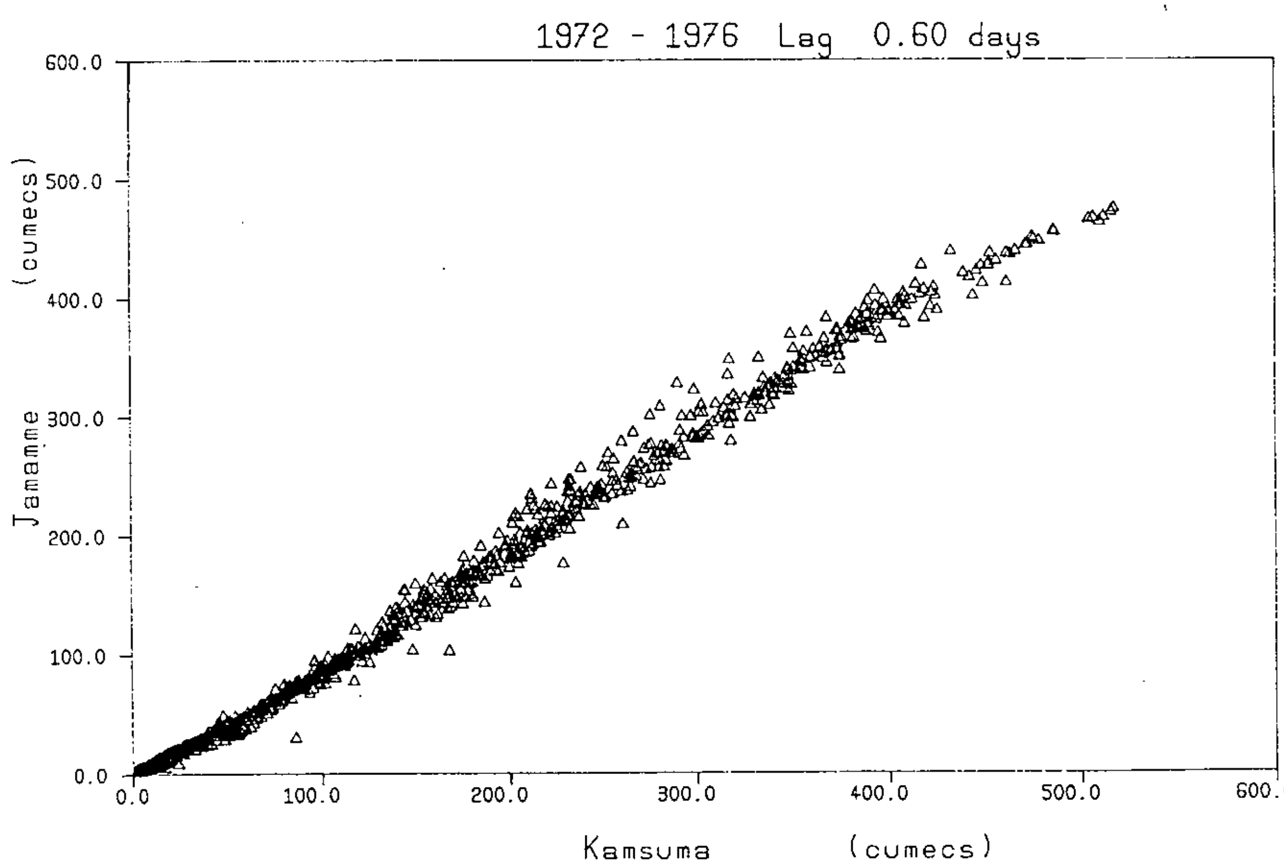
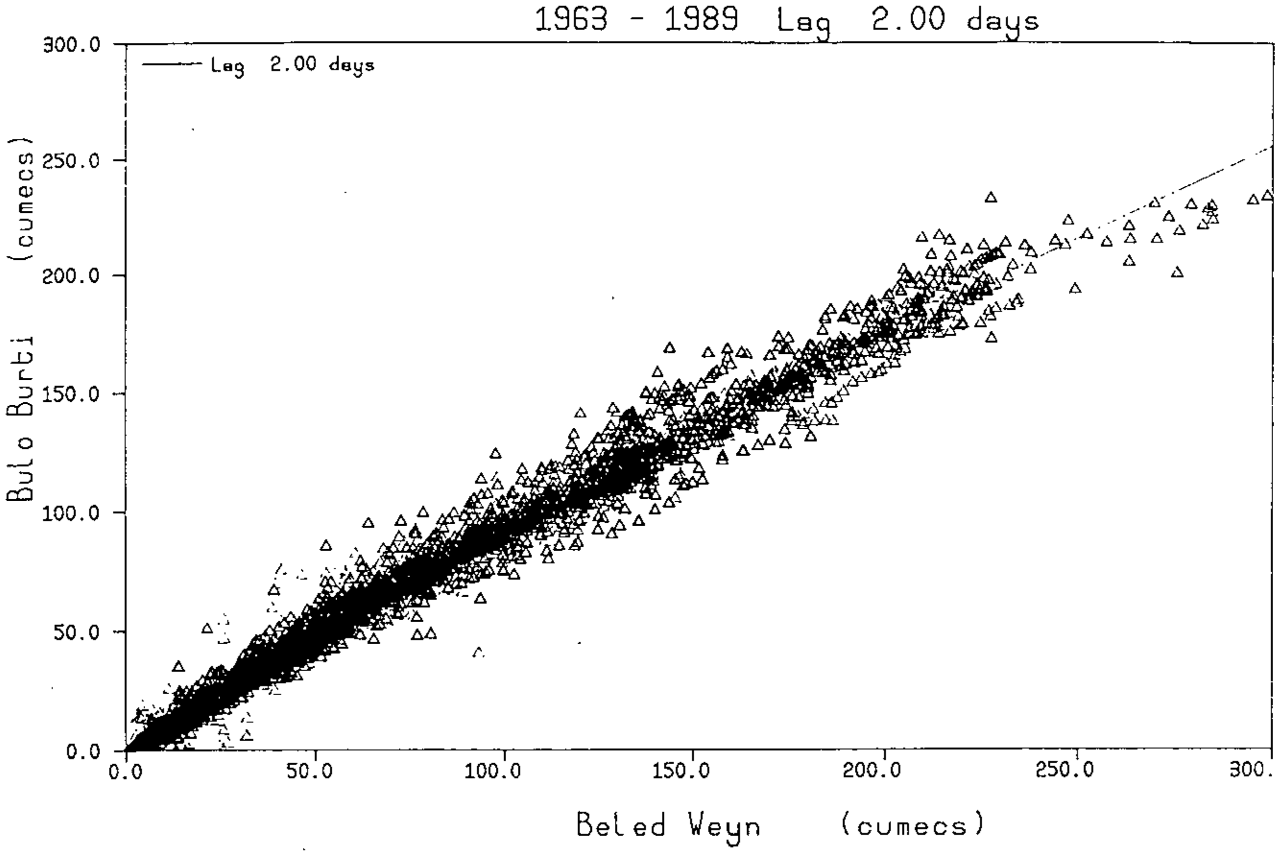


FIGURE 18 (continued)



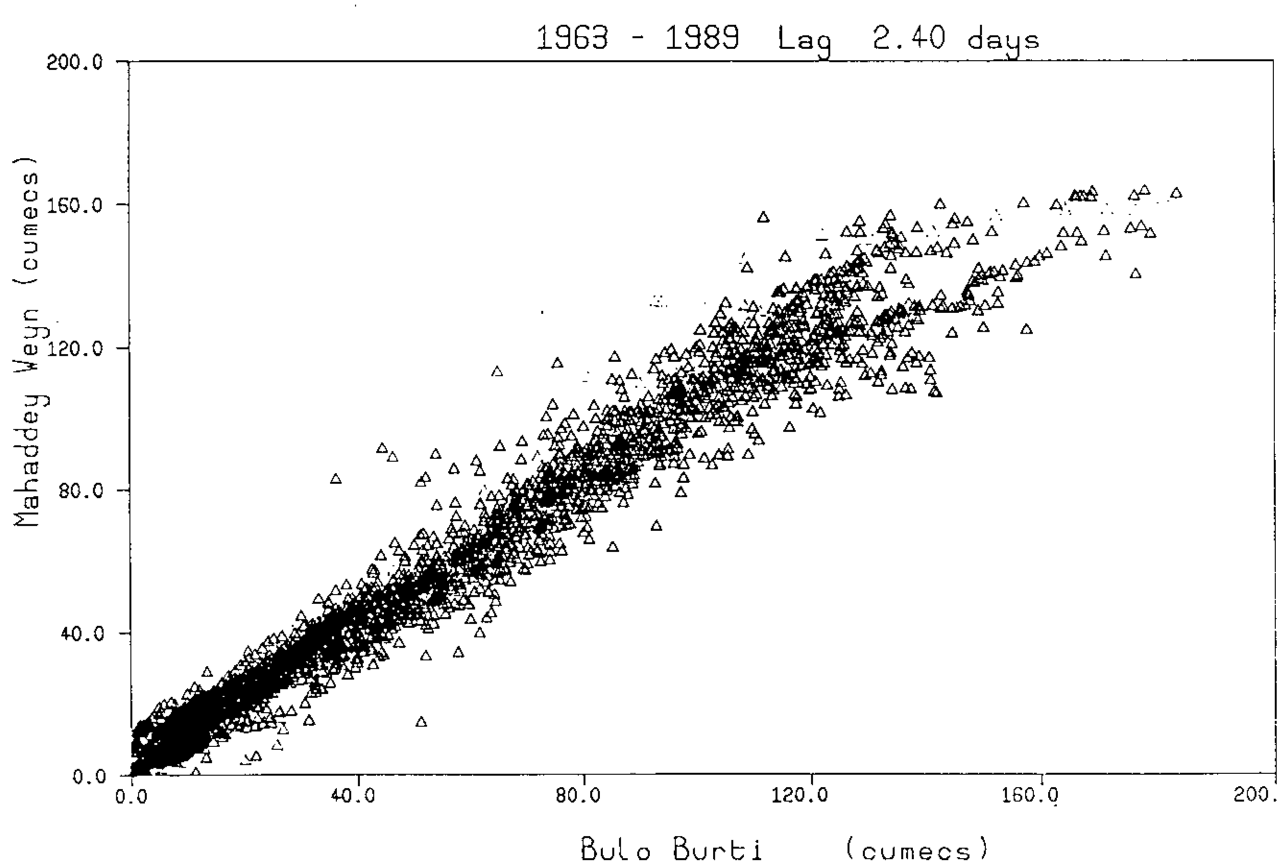
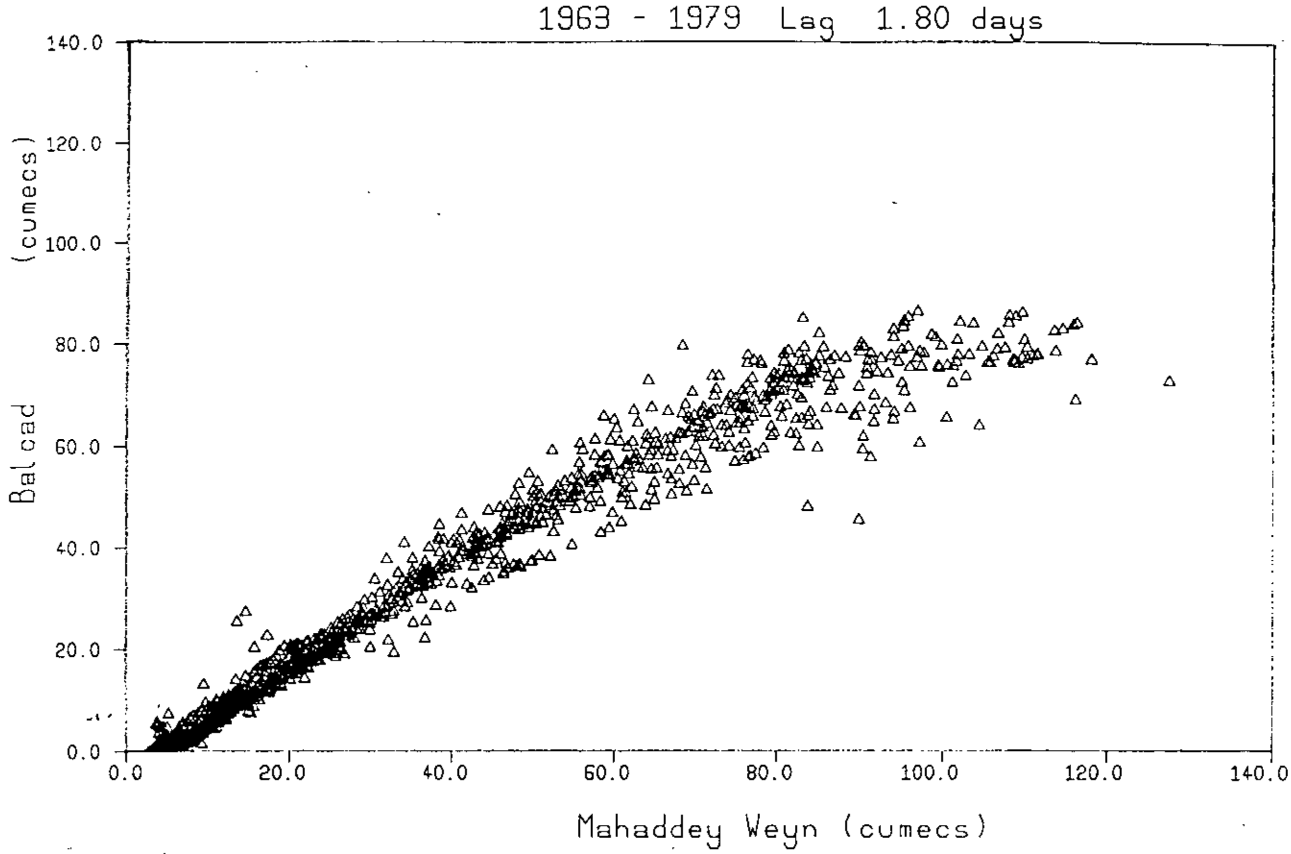


FIGURE 19 **Correlation plots for the river Shebelli. These were used to derive the equations used in the infilling work.**



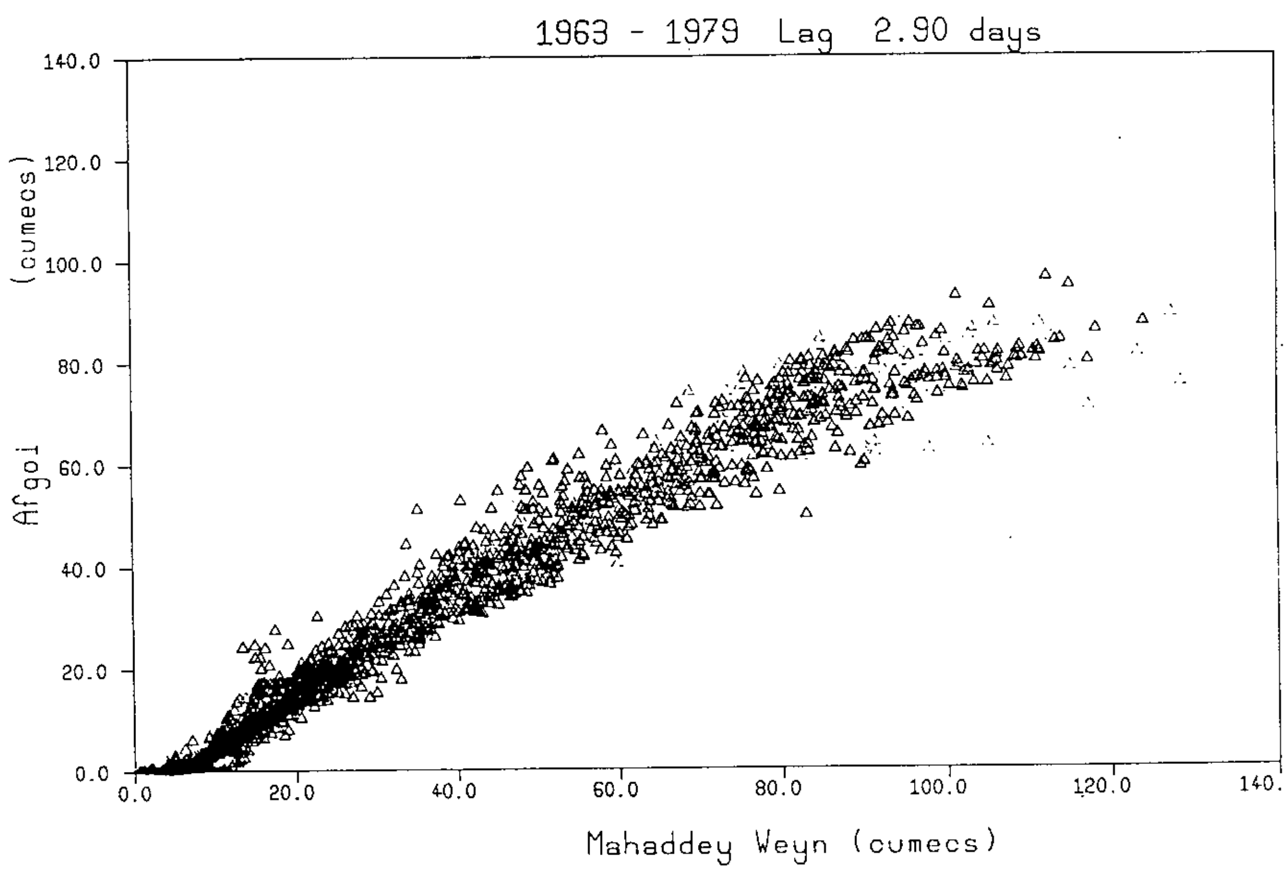
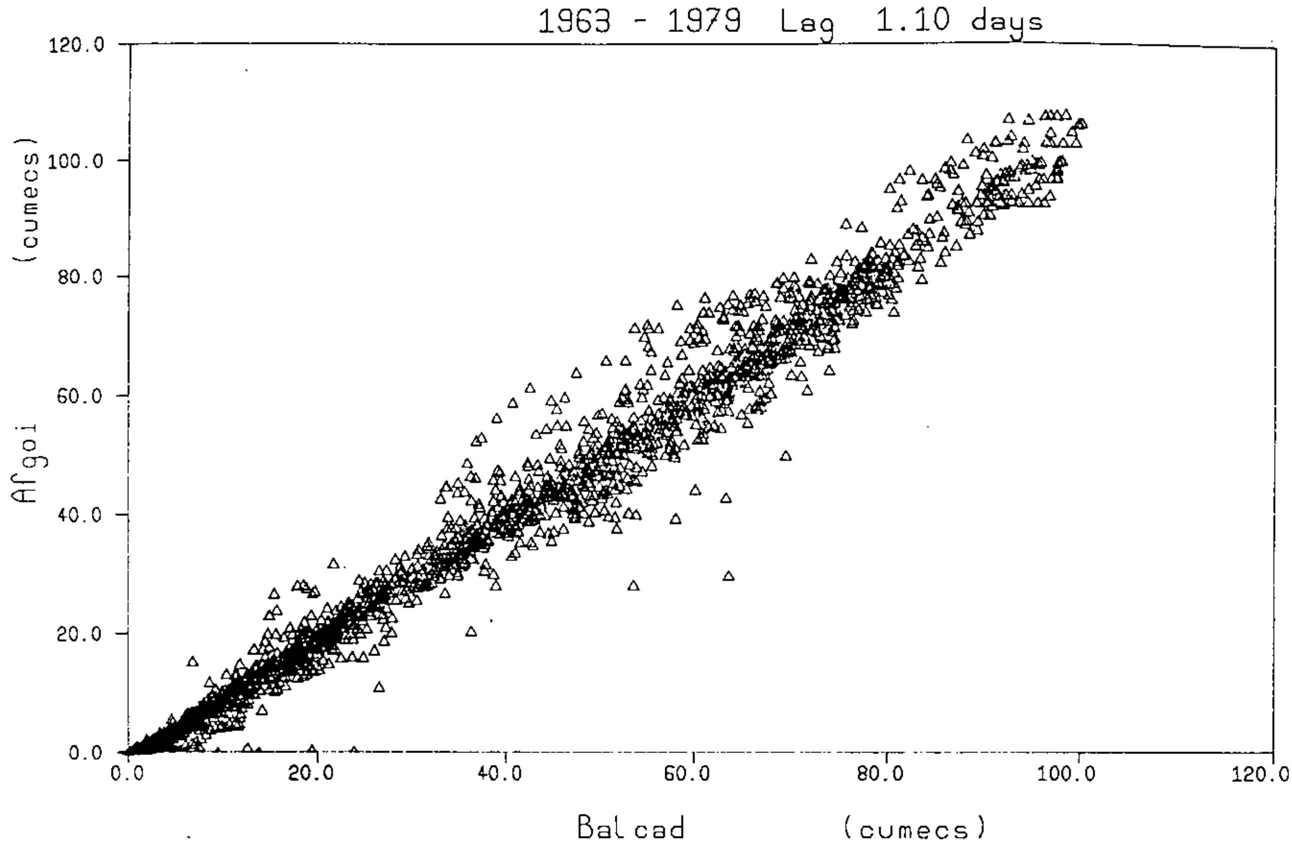


FIGURE 19 (continued)



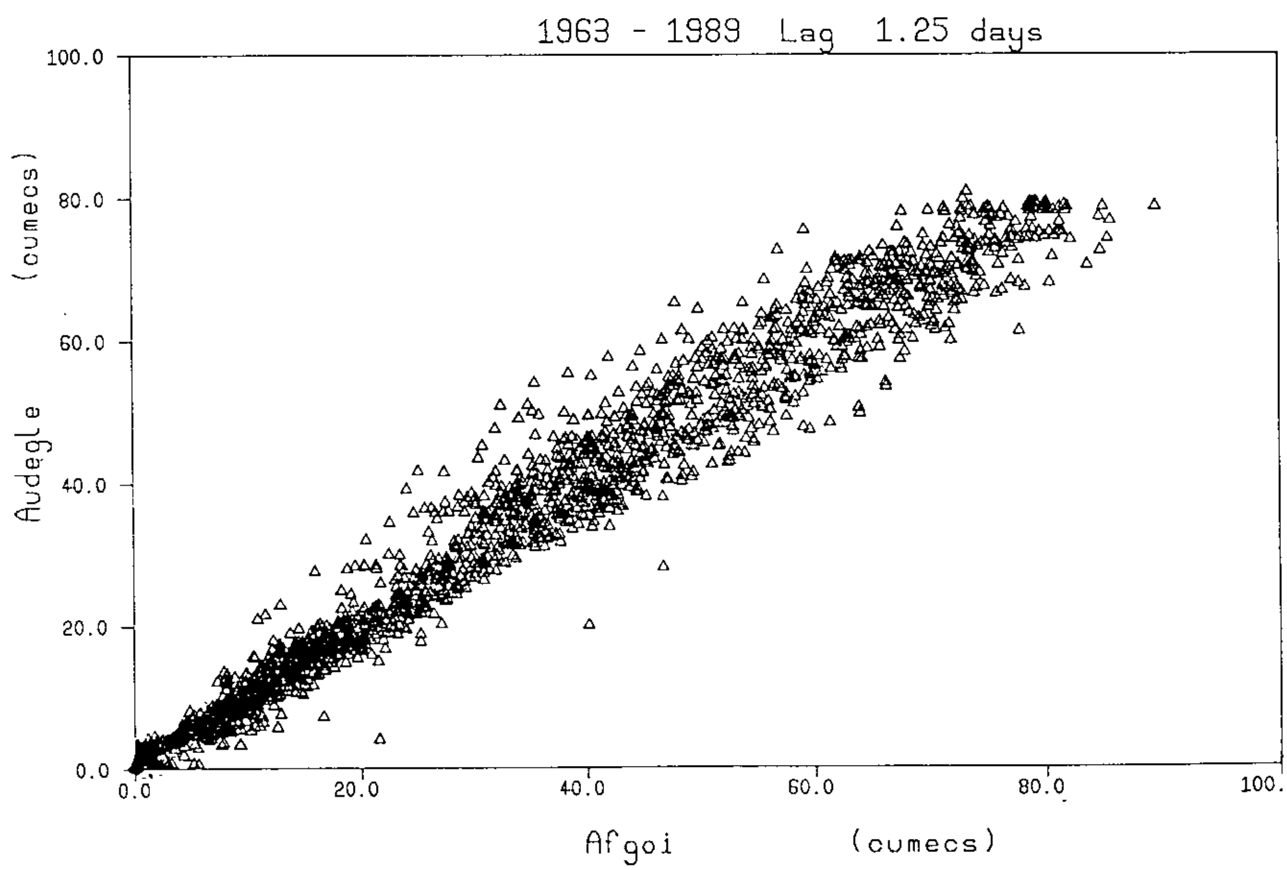
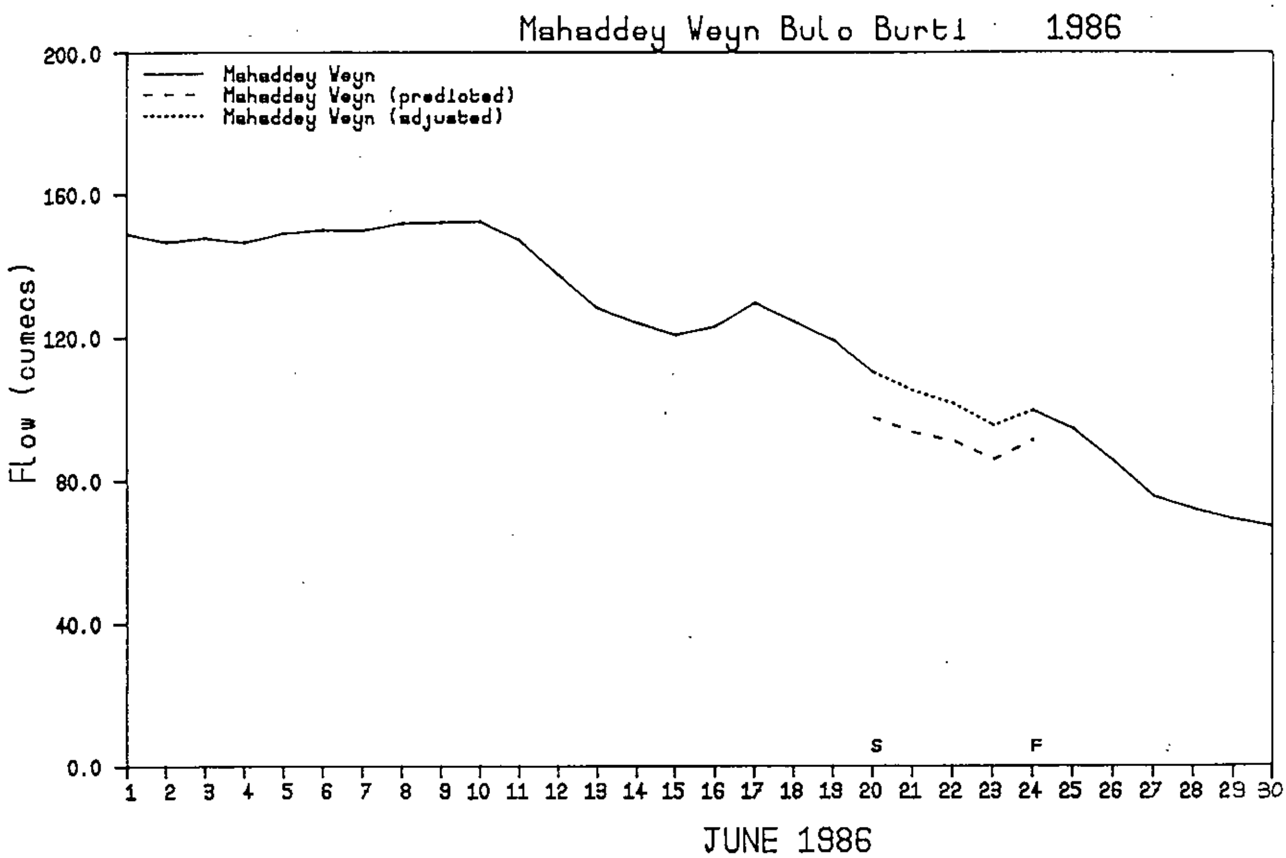
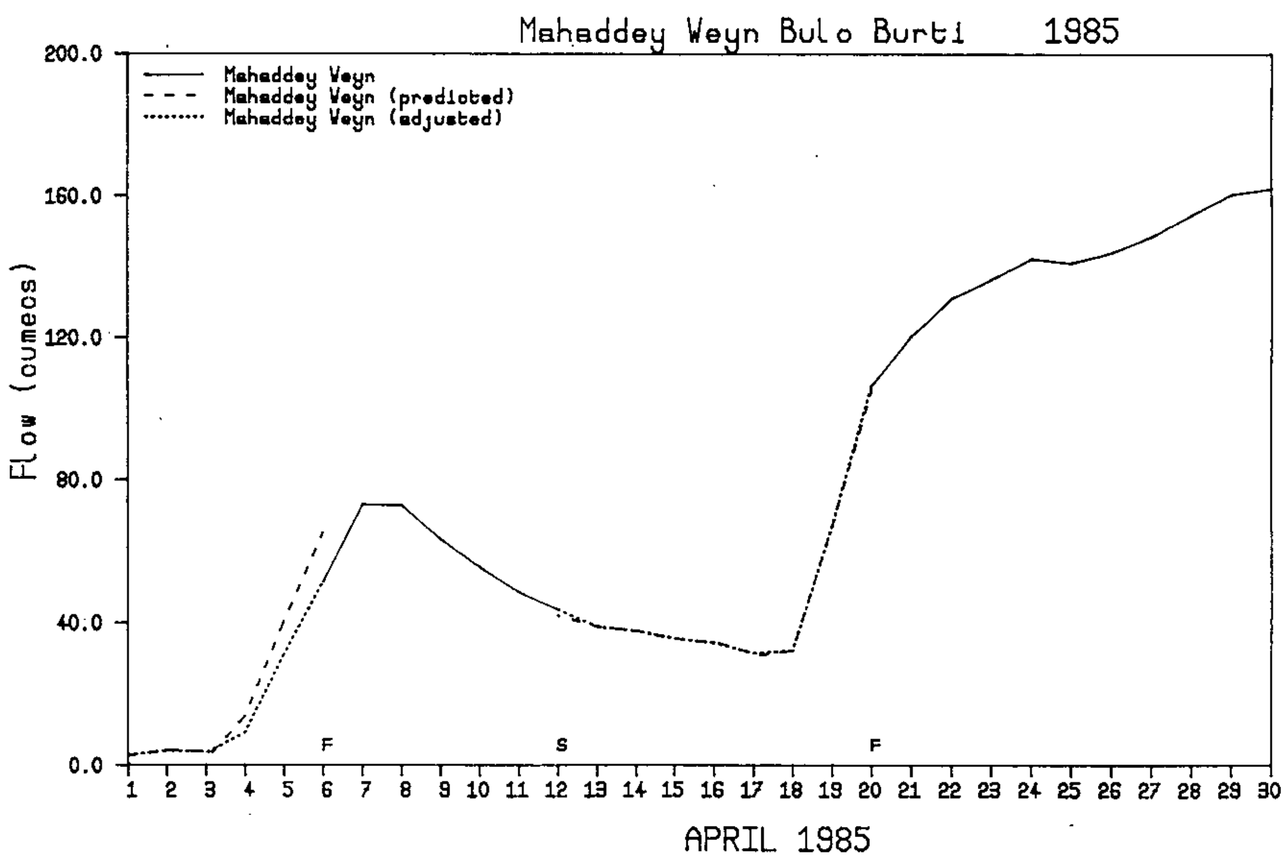


FIGURE 19 (continued)

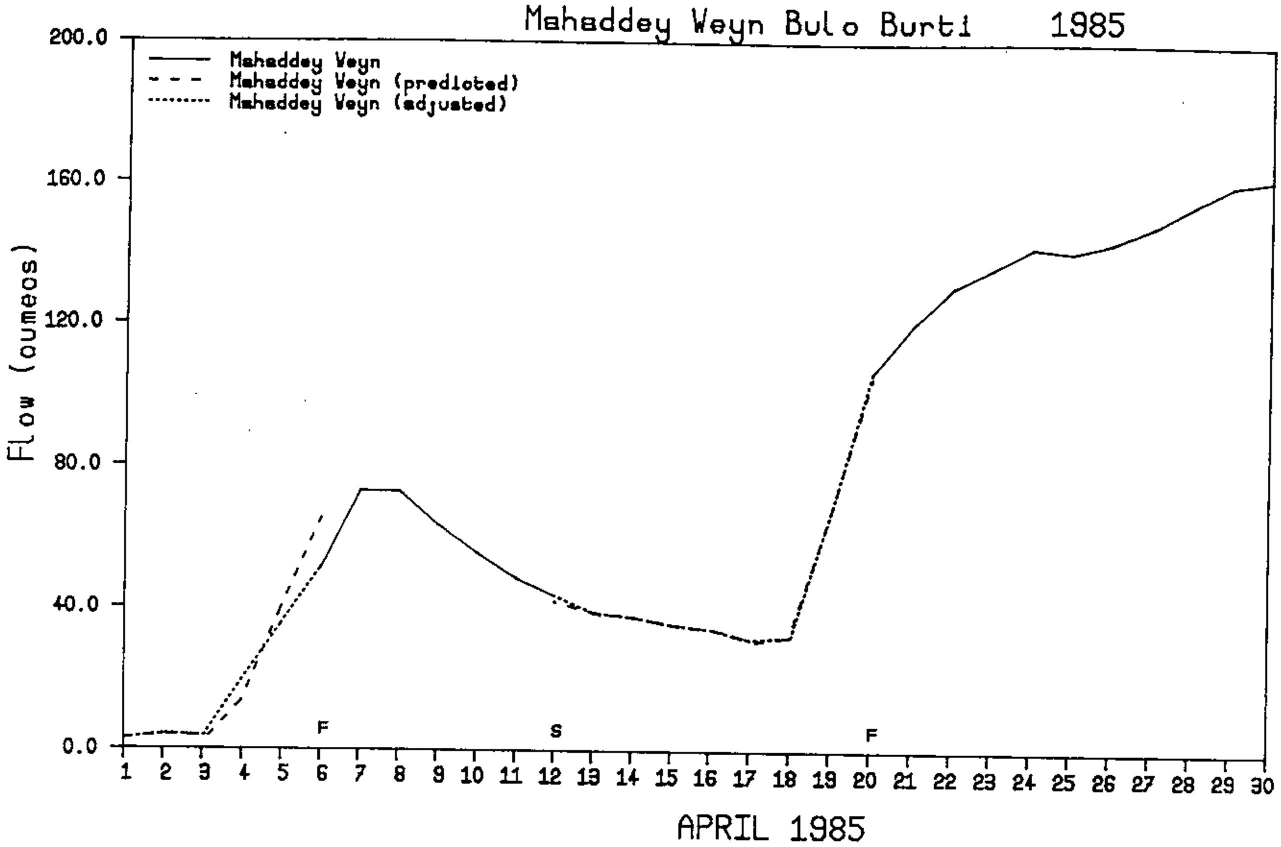


(a)

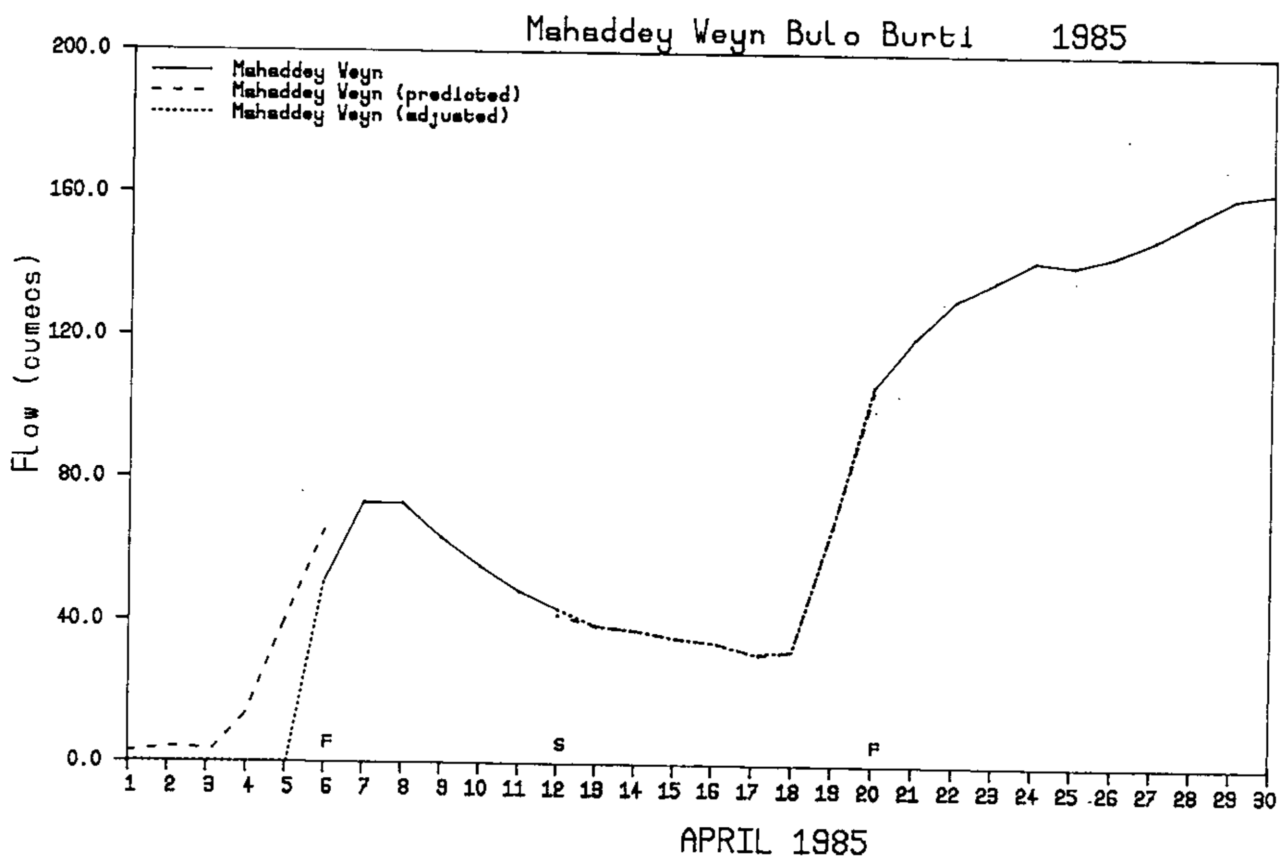


(b)

FIGURE 20 Examples of the types of adjustments which can be performed using the computer model RIVERI (a) Shift (b) Join (distribute) (c) Join (interpolate) (d) Join (set to zero)



(c)



(d)

FIGURE 20 (continued)