INSTITUTE of HYDROLOGY

Review of the water resources of the Rio Sabacuante and San Juancito Mountain catchments supplying Tegucigalpa, Honduras

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Rio Sabacuante and San Juancito Mountain catchments

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January 1987

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1.0 INTRODUCTION

This project was established to evaluate and analyse hydrological data for two proposals concerned with improving the water supply to Tegucigalpa, the capital of Honduras. The study was based in the Plan Maestro Unit of SANAA (Servicio Autonomo Nacional de Acueductos y Alcantarillados). The two proposed projects were :

(1) A replacement of the pipeline between Sabacuante and Miraflores, originally installed in 1950.

(2) Conjunctive use of the existing Las Trojas/San Juan/Las Canas - Lindero pipeline with the development of groundwater extraction along the Rio Chiquito.

The work was divided into four tasks as defined by the terms of reference described below :

(1) Validation of the hydrological and meteorological data available for the Rio Sabacuante catchment and the San Juancito Mountain catchments of Las Trojas, San Juan and Las Canas.

(2) Evaluation of rainfall/run-off characteristics of each of the above catchments to estimate long-term yields of existing and proposed stream offtakes.

(3) Assessment of the existing stream-gauging network and recommendations made to SANAA for its improvement.

(4) The work was to be undertaken and completed in Honduras and the results discussed with Plan Maestro, SANAA.

A subsequent addition to the original terms of reference was the training of Hydrology Unit staff, Plan Maestro, in the use of the Hydrological Database supplied by the Institute of Hydrology.

This project was funded by the Overseas Development Administration (ODA) of the Government of the United Kingdom and carried out in Honduras by two hydrologists from the Institute of Hydrology, Wallingford over the period 9th November to 6th December 1986.

The analysis of the Rio Sabacuante offtake concluded that the capacity of the present pipeline was well designed and that the position of the offtake was also satisfactorily sited. The resulting flow duration curve of the natural river flow at the offtake is presented on Figure 20. The analysis of the Las Trojas, San Juan and Las Canas catchments was impeded by a lack of suitable flow data. However, the long term yields of the catchments could be estimated based on work carried out by R.P. Barahona and E.B. Romero (1977) as shown on Figure 23.

2.0 DESCRIPTION OF PROJECT AREAS

2.1 Project Location

The present study is concerned with the water resources of four small catchments supplying water to Tegucigalpa. These are the Rio Sabacuante, Las Trojas, San Juan and Las Canas streams. The Rio Sabacuante is situated to the south east of Tegucigalpa whereas the Las Trojas, San Juan and Las Canas streams are in a group within the San Juancito mountains to the north east of Tegucigalpa. The catchments form part of the Upper Choluteca basin as shown on Figure 1.

2.2 Climatic conditions in the project area

The climatic conditions experienced in the Upper Choluteca catchment are primarily influenced by low speed prevailing winds called 'alisios' from the north east which pass through Honduras. From May to September the Intertropical Zone of Convergence moves north causing a southerly wind. Convergence of the wind regimes occurs in May resulting in the start of the rainy season, initiating in the southern and central zone of the country and spreading to the whole country. The wet season prevails from May to September, though a drier period called 'veranillo' occurs during July and August. The wettest months are June and September with mean monthly rainfalls of 168mm and 184mm respectively. The average annual rainfall for the region is 885mm but the rainfall increases with altitude and the mean annual total within the San Juancito mountains is 1350mm.

The dry season occurs between November and April, the driest months being February and March. The mean annual temperature is 18 degrees centigrade, but is reduced to 15 degrees in the San Juancito mountains.

The hydrological year adopted in Honduras begins in May.

2.3 Rio Sabacuante Catchment

The Rio Sabacuante catchment, situated to the south east of Tegucigalpa, is shown on Figure 2. A gauging station is sited at a natural river section at El Aguacate where a stilling well and a staff gauge are used to measure stage. The catchment area at this point is 80.3 km^2. A small dam with insignificant storage is positioned 3.9 km upstream from the gauging station. A pipeline from the dam forms part of Tegucigalpa's water supply. The pipeline was installed in 1950 and has an internal diameter of 0.3m (12 inches).

The mean annual rainfall at the catchment is in the order of 875mm. Nearby raingauges are at El Aguacate, El Sauce, El Incienso and at Tegucigalpa's main airport, Toncontin as shown on Figure 2. The mean altitude of the river within the main catchment is approximately 1260m. It has an average slope of 0.03 m/m and the mean annual runoff is approximately 167mm. The mean annual potential evaporation, based on meteorological data from Toncontin, and estimated using the Penman (1963) equation is in the order of 1700mm.

Vegetation within the catchment was once primarily pine forest but this has now been replaced by thin scrubby pasture with occasional stands of scrub oak and, to a lesser extent,

Project location

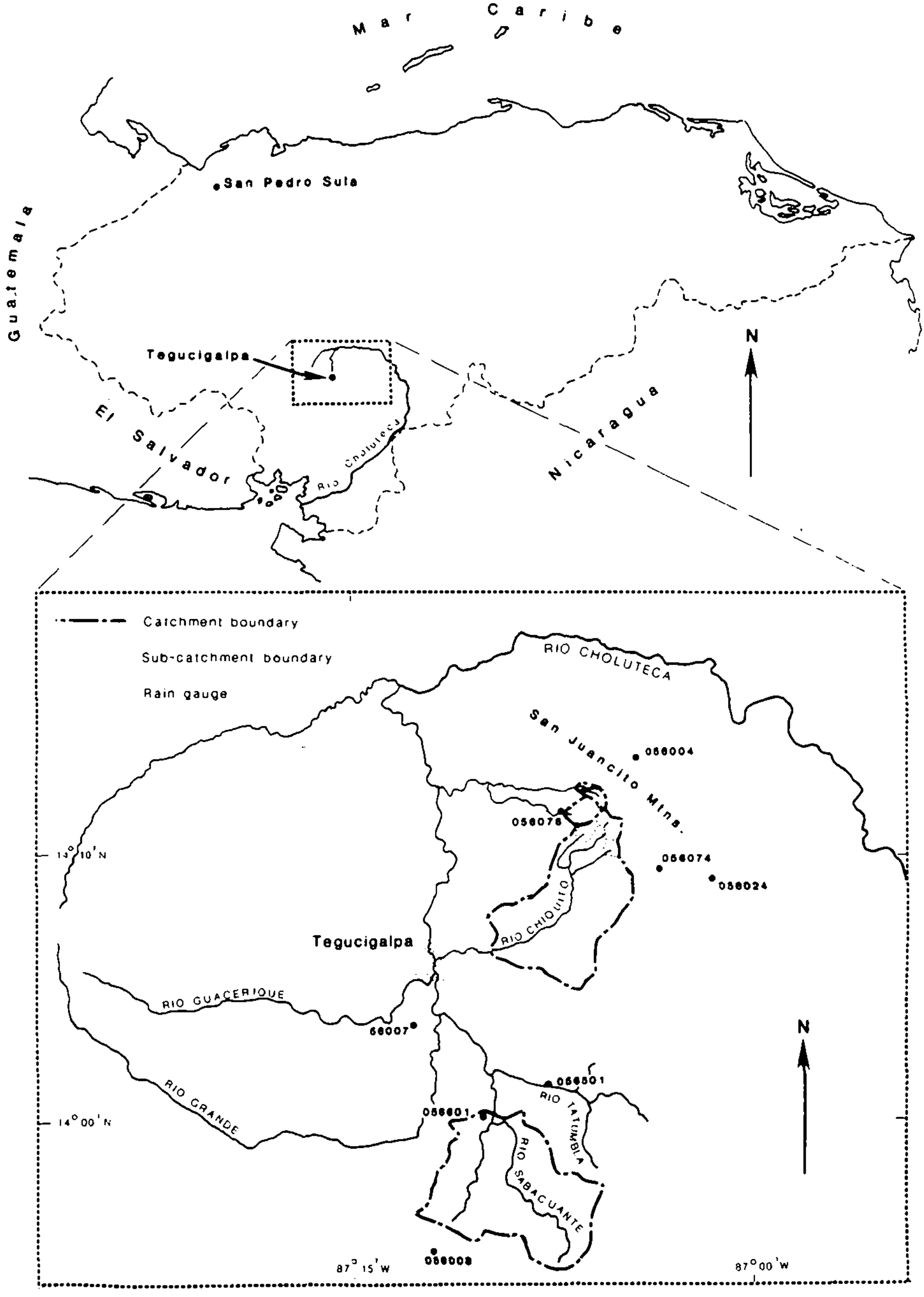


Figure 1

Rio Sabacuante catchment

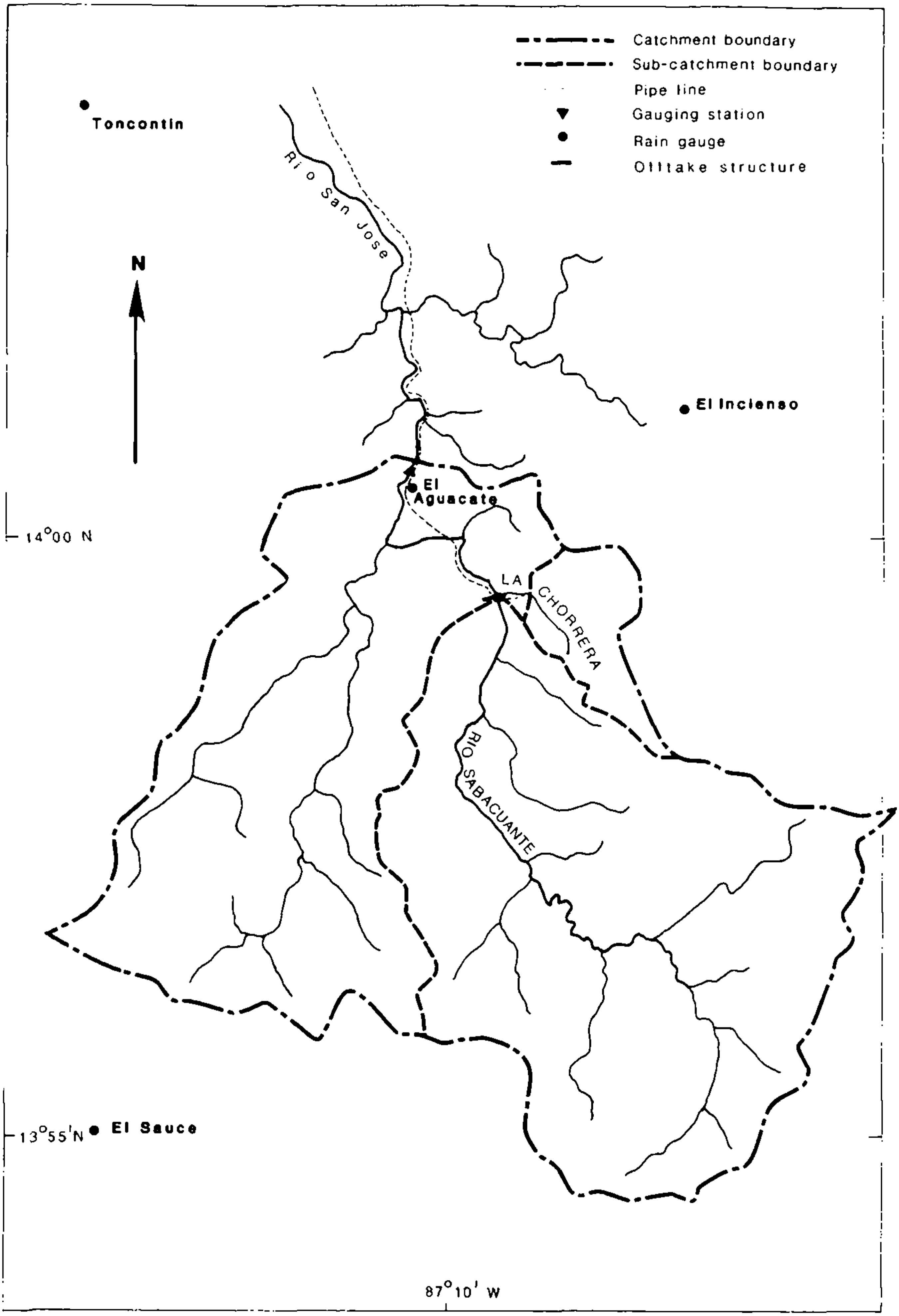


Figure 2

pine.

The geology of the area is composed of volcanic and volcaniclastic rocks of the Padre Miguel group of Miocene age. They comprise acid, rhyolitic, airfall tuffs and ignimbrites, ranging from loosely consolidated to welded. Subsidiary beds include reworked tuffs and minor lacustrine sediments of volcanic origin. The area is structurally simple, comprising flat or gently tilted flat topped hills which have been extensively dissected. There is a well developed conjugate pattern of NW SE and NE - SW faults, apparently of small displacement. This basic sequence is overlain by outliers of olivine basalt lavas which act as sub-planar cappings on various peaks in the eastern and south eastern extremities of the catchment, occupying less than 15% of the total catchment area.

2.4 Las Trojas, San Juan & Las Canas Catchments

The Las Trojas, San Juan and Las Canas streams are tributries of the Rio Chiquito and are situated in the San Juancito Mountains north east of Tegucigalpa, as shown on Figure 3. The rivers are gauged using thin plate V notch weirs which are suitable for measuring low flows. This is acceptable because the pipelines are designed primarily to extract the base flow. The catchment areas of Las Trojas, San Juan and Las Canas at the position of the weirs are 1.19 km^2, 2.115 km^2 and 0.853 km^2 respectively. Each weir is upstream of a pipe offtake which forms part of Tegucigalpa's water supply. The pipe network is shown on Figure 3. The pipeline section between San Juan and Las Trojas was first installed in 1965. It was replaced in 1985 by a pipe whose internal diameter varies from 0.2m (8 inch) to 0.15m (6 inch). The Las Canas to El Chimbo section was first installed in 1948 and was replaced in 1986, again with a 0.2m to 0.15m internal diameter pipe.

The mean annual rainfall at the catchments is in the order of 1518 mm. The closest raingauges are sited at Jutiapa, Carrizal, Nuevo Rosario and Hacienda Las Canadas. The mean altitude of the Las Trojas, San Juan and Las Canas streams are 1720m, 1995m and 1800m with average slopes of 0.24, 0.16 and 0.20 m/m respectively. The mean annual runoff for the Las Trojas, San Juan and Las Canas catchments is approximately 663mm, 865mm and 1098mm respectively. The mean annual potential evaporation, based on meteorological data from Toncontin with a correction made for the change in temperature with altitude, and estimated using the Penman (1963) equation is in the order of 1437mm.

Vegetation within the catchments is primarily cloud forest.

The geology comprises a structurally complex sequence of siltstones and calcerous arkoses of possible Lower Tertiary to Upper Cretaceous age which uncomformably overlie fine grained, cleaved shales and micaceous sandstones of the Lower Jurassic El Plan Formation.

San Juancito mountain catchments

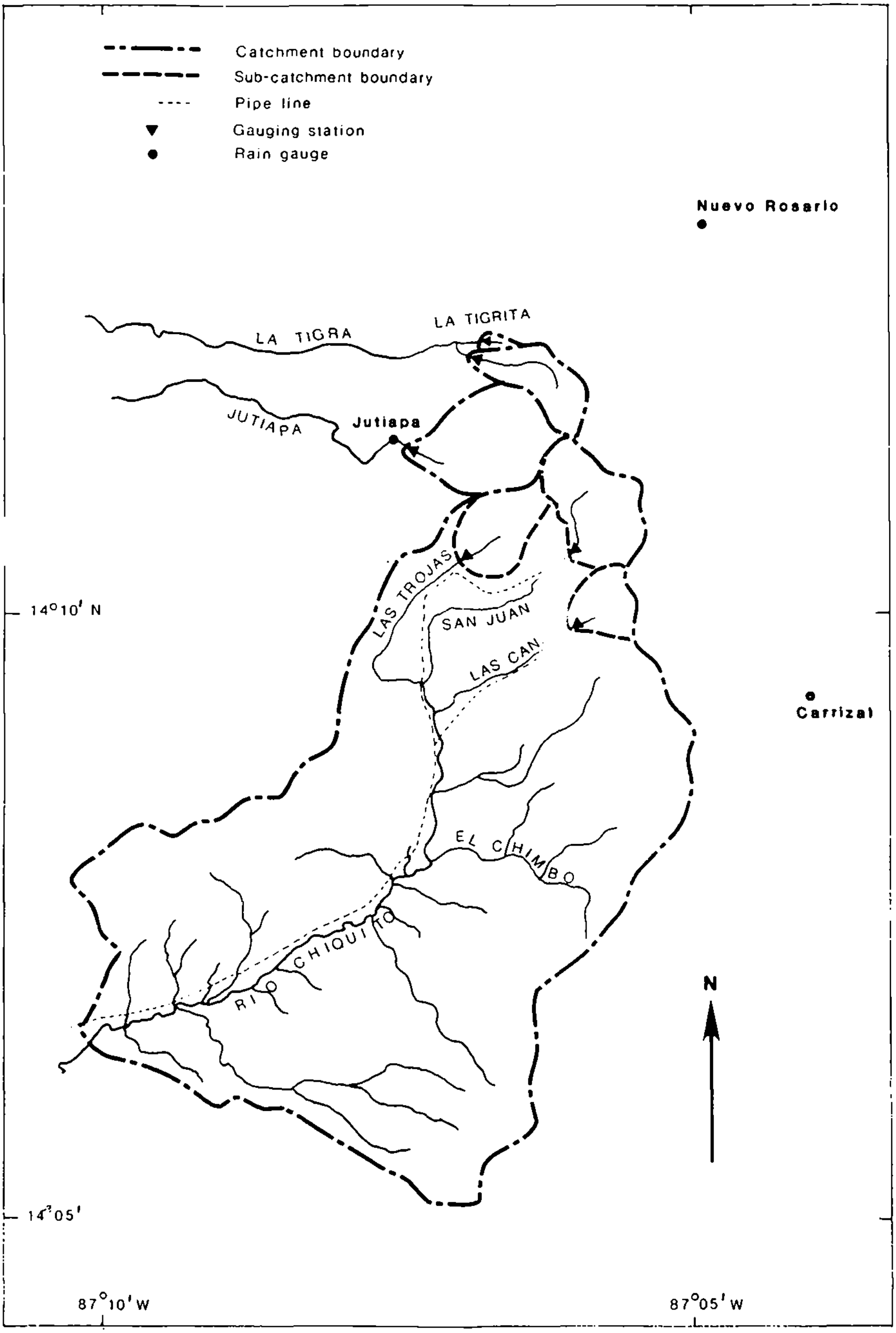


Figure 3

3.0 HYDROLOGICAL DATA

3.1 Collection of data

A summary of the daily data collected and used in the present study, including the source of each record, is shown on Table 1. Daily data rather than monthly data were required for the design of the river offtakes which had no storage. This is because monthly data does not have sufficient time resolution to provide accurate results. These data were entered into a Hydrological Database supplied by the Institute of Hydrology. The Database was capable of storing and checking the validity of the hydrological data as well as providing analysis packages. A full description of the data processing and analysis system may be found in the Operation Manual (Institute of Hydrology, 1986).

3.1.1 Flow data from the Rio Sabacuante catchment

Daily flow data for the Rio Sabacuante measured at El Aguacate, were available for the years 1970-1985 from Plan Maestro, SANAA. These data had been processed by Hydrology Unit staff using stage readings from a chart recorder and a staff gauge read by an observer. The observer recorded stage three times per day at 07:00, 11:00 and 15:00 hours except at weekends when no readings were taken. The chart recorder was removed in 1984 and not replaced. Gauging of the river with a current meter took place once a week and these data were used to develop rating equations for the conversion of stage data to daily flow.

The daily flow data were entered directly onto the Database. Stage data for the years 1980 and 1982 were selected in order to generate daily flow records independently for comparison. Six stage readings per day were input to the Database from the chart recordings, cross referencing them with the observers notes. The gaugings taken over this period were also added to develop independent rating equations.

Daily flow data for the neighbouring catchment of the Rio Tatumbla measured at El Incienso were also available from Plan Maestro. This information was also added to the Database for comparison with the Rio Sabacuante readings.

3.1.2 Flow data from the San Juancito Mountain catchments

The catchments of Las Canas, San Juan, Las Trojas, Jutiapa, La Tigra and La Tigrita each had a 90 degree thin plate triangular V notch weir which were suitable for measuring low flows. The weirs were constructed in 1984 and daily stage readings were available from April 1985 to the present in the form of one reading per day. The stage values were read to an accuracy of 1 centimetre. It should be noted this accuracy was not adequate. Stage readings to the nearest millimetre are required to provide sufficient resolution to determine low flows. The information was available from the Operations & Maintenance Department, SANAA. The theoretical rating equation for the weirs used by the Operations and Maintenance Department was :

$$Q = 1400.H^{2.5}$$

where Q is flow in ls^{-1}.
H is upstream head in metres

This equation was stored in the Database and the stage values converted to flow.

TABLE 1. List of stations and details

Type	Number	Name	Latitude	Longitude	Altitude	Area	Length of record	Source
Stage	560601	Rio Sabacuante at El Aguacate	14: 0: 0 N	87:10: 0 W	1050.0	80.3	1980, 82	PM
Stage	569901	Jutiapa	14:11:18 N	87: 7:30 W	1650.0	2.68	1984,86	O&M
Stage	569902	La Tigra	14:12: 0 N	87: 6:51 W	1920.0	1.173	1984-86	O&M
Stage	569911	San Juan	14:10:25 N	87: 6: 5 W	1900.0	2.115	1984-86	O&M
Stage	569912	Las Trojas	14:10:23 N	87: 7: 0 W	1650.0	1.19	1984-86	O&M
Stage	569913	Las Canas	14: 9:47 N	87: 6: 5 W	1760.0	0.853	1984-86	O&M
Stage	569935	La Tigrita	14:12: 5 N	87: 6:51 W	1920.0	0.113	1984-86	O&M
Rating	560601	Rio Sabacuante at El Aguacate	14: 0: 0 N	87:10: 0 W	1050.0		1980, 82	PM
Rating	569901	Jutiapa	14:11:18 N	87: 7:30 W	1650.0		1984-86	O&M
Rating	569902	La Tigra	14:12: 0 N	87: 6:51 W	1920.0		1984-86	O&M
Rating	569911	San Juan	14:10:25 N	87: 6: 5 W	1900.0		1984-86	O&M
Rating	569912	Las Trojas	14:10:23 N	87: 7: 0 W	1620.0		1984-86	O&M
Rating	569913	Las Canas	14: 9:47 N	87: 6: 5 W	1760.0		1984-86	O&M
Rating	569935	La Tigrita	14:12: 5 N	87: 6:51 W	1920.0		1984-86	O&M
Flow	560501	Rio *Tatumbla* at *El Incienso*	14: 1: 0 N	87: 8: 0 W	1110.0	65.0	1971-85	PM
Flow	560601	Rio Sabacuante at El Aguacate	14: 0: 0 N	87:10: 0 W	1050.0	80.3	1970-85	PM
Flow	560602	Rio Sabacuate above intake (Est.)	13:59:29 N	87: 9:30 W	1120.0	42.7		
Flow	560603	Sabacuante pipe flow (Estimate)	13:59:29 N	87: 9:30 W	1120.0	1.0		
Flow	569901	Jutiapa (Flows in litres/sec)	14:11:18 N	87: 7:30 W	1650.0	2.68	1984-86	O&M
Flow	569902	La Tigra (Flows in litres/sec)	14:12: 0 N	87: 6:51 W	1920.0	1.173	1984-86	O&M
Flow	569905	La Tigrita (Flows in litres/sec)	14:12: 5 N	87: 6:51 W	1920.0	0.113	1984-86	O&M
Flow	569911	San Juan (Flows in litres/sec)	14:10:25 N	87: 6: 5 W	1900.0	2.115	1984-86	O&M
Flow	569912	Las Trojas (Flows in litres/sec)	14:10:23 N	87: 7: 0 W	1620.0	1.19	1984-86	O&M
Flow	569913	Las Canas (Flows in litres/sec)	14: 9:47 N	87: 6: 5 W	1760.0	0.853	1984-86	O&M
General	56007	Evaporation (Pan) - Toncontin	14: 2: 0 N	87:11: 0 W	1007.0		1985-86	SMN
General	56601	Evaporation (Pan) - El Aguacate	14: 0: 0 N	87:10: 0 W	1050.0		1982-86	PM

Type	Number	Name	Latitude	Longitude	Altitude	Area	Length of record	Source
Rainfall	56004	Nuevo Rosario	14:12: 0 N	87: 5: 0 W	1450.0		1953-86	NK
Rainfall	56007	Tegucigalpa - Toncontin	14: 3:31 N	87:13:10 W	1000.0		1950-86	NK
Rainfall	56008	El Sauce	13:55: 0 N	87:13: 0 W	1319.0		1956-86	NK
Rainfall	56024	Hacienda Las Canadas	14: 9: 0 N	87: 3: 0 W	1250.0		1957-86	NK
Rainfall	56501	El Incienso	14: 1: 0 N	87: 8: 0 W	1110.0		1970-86	PM
Rainfall	56601	El Aguacate	14: 0: 0 N	87:10: 0 W	1050.0		1973-86	PM

KEY:

O&M	Operations and Maintenance Department, Sanaa
PM	Plan Maestro, Sanaa
SMN	Servicio Meteorologico Nacional
NK	Nippon Koei

The present flow measurement structures replaced weirs which were destroyed in 1974. No data were therefore available from 1974-1984. Data from the original weirs were recorded from the early 1960's to 1973, the longest record being at Jutiapa. This information was processed by R.P. Barahona & E.B. Romero (1977). Barahona & Romero made corrections to the original data as the weirs were found to be in poor condition due to excessive silting and the calibration found to be inaccurate. A 67 degree V notch weir was installed at Jutiapa, but flows had been calculated using the formula for a 90 degree V notch. Recalibration of the weirs by current meter measurement enabled the data to be revised. Unfortunately this corrected daily data has been lost and only monthly data are available.

3.1.3 Rainfall data

Daily rainfall data for six stations in the vicinity of the two areas of interest were added to the Database.

The stations El Aguacate and El Incienso had records from 1973 and 1970 to the present respectively. Information from these stations was made available by Plan Maestro. Recordings were taken at 07:00 hours except at weekends when no readings were made. A change to the way the rainfall was recorded was introduced by SANAA on 30th August 1983. Prior to this date, each reading represented the daily rainfall for the day in which the reading was made. The readings taken on Mondays' were therefore the cumulative total for three days rainfall. The method of recording the data was changed so that each daily reading of rainfall refered to the previous day. This change in procedure brought the Plan Maestro daily rainfall data in line with the other institutions in Honduras responsible for data collection. The early rainfall data were corrected to conform with the current practice before being added to the Database.

Daily rainfall records for the stations Nuevo Rosario, Toncontin, El Sauce and Hacienda Las Canadas were made available on IBM compatible floppy disk by the Japanese company Nippon Koei attached to ENEE (Empressa Nacional de Energia Electrica). A computer program, JAPRAIN, was written to transfer this information to the Database and is described in Section 7.1. Data were entered for each of the four stations from the years 1953, 1950, 1955 and 1957 respectively. A computer printout of the information was also available from SMN (Servicio Meteorologico Nacional). On examination of the data from both sources, serious discrepancies occured in the Nuevo Rosario readings. Inspection of the original recordings, obtained from Plan Maestro, proved the Nippon Koei data to be valid.

Daily rainfall records for the stations Jutiapa and Carrizal, under the control of Plan Maestro, were not obtainable. At Jutiapa only monthly data were available.

3.2 Site Visits

3.2.1 Rio Sabacuante catchment

A site visit was made to the gauging and climatic stations at El Aguacate. The gauging station was well sited to measure the river flow. A suitable cross section with good control downstream was available to gauge low flows using a current meter. Flood discharge could be gauged within a steep sided gorge using a cableway to traverse the river. Unfotunately the cableway was no longer operative. Stage data were measured using staff gauges read to centimetre accuracy. A stilling well was also present, situated at a good location behind rocks to protect it from river debris. The stilling well was however no longer in use since the chart recorder had been removed.

A number of problems were encountered at the site and are described below :

(1) A cableway suitable for measuring floods was now inoperative.

(2) The chart recorder was removed from the site in 1984 and not replaced.

(3) According to the observer, the stilling well was only flushed clean of silt once a year. It was evident at the time of the site visit that at least one of the two pipe inlets to the stilling well was blocked.

(4) No observations were recorded at weekends.

The climate station also suffered from problems due to lack of maintenance. Only the raingauge and evaporation pan were operating at the time of the visit.

3.2.2 <u>San Juancito Mountain catchments</u>

Site visits were made to the weirs at Las Canas, San Juan, Las Trojas, Jutiapa, La Tigra and La Tigrita as well as to the raingauge station at Jutiapa.

Each of the flow measurement structures had a thin plate 90 degree V notch weir which were well sited, upstream of the pipe offtakes. However a number of problems were encountered which are described below :

(1) There was a lack of supervision and training of observers. Failings include the inability to read staff gauges and rain gauges correctly. It was also suspected that readings were sometimes recorded at incorrect times and data fabricated.

(2) The staff gauges measured only to an accuracy of 1 cm which is insufficient to record the low flows of these small catchments.

(3) The weirs at Jutiapa and La Tigra were held in place by a timber frame which was a very weak construction compared to the concrete structures at Las Canas, San Juan, Las Trojas and La Tigrita. Water was leaking through the timber frame at La Tigra.

(4) Sediment was begining to build up behind all of the weirs and no check calibrations on the standard weir formula had been made.

The raingauge at Jutiapa was also found to be in a state of bad repair with a large hole in the sleeve. The observer was unable to read the measuring cylinder correctly casting doubt on the validity of the rainfall record.

3.3 Quality of data

3.3.1 Flow data from the Rio Sabacuante catchment

An. assessment of the quality of the flow data estimated at El Aguacate was made by first plotting the daily flow records on a logarithmic scale. This procedure clarifies the behaviour of the river at low flows, the most critical design criterion for the present study. An example plot for the year 1982/83 is shown on Figure 4. The plot shows that the floods are being measured adequately but that a problem appears to exist in measuring the low flows as indicated by the horizontal sections of the graph. A normal hydrograph recession would exhibit a smoothly decreasing flow with time. This problem was investigated further. The original stage data for 1982/83 was added to the Database, having manually abstracted six stage readings per day from the chart recordings. A cross reference was made to observers notes to resolve any problems encountered on the chart. Discharge measurements from the river gaugings over the period 1982/83 were first added to the Database to convert the stage readings to flow. The discharge measurements were plotted on a graph and compared to the existing rating equation. Shifts in the rating were observed with the aid of the Database software. The discharge measurements were divided into groups and a rating equation was developed for each group in turn. The form of the rating equation was :

$$Q = a (h + c)^b$$

where Q is flow in m^3s^{-1}
h is stage in metres
a is a multiplier
b is a power exponent
c is a constant representing the stage value equivalent to zero flow.

One such rating is shown on Figure 5. A logarithmic plot of the rating produces a straight line as shown on Figure 6. This plot shows considerable variation in the discharge measurements at low flows. For example, at 0.04m stage, the discharge measurements vary from 0.007 to 0.016 m^3s^{-1}.

The rating equations were used to convert the stage data to daily flow values. The resultant flow record was again plotted on a logarithmic scale and compared to the original data. This comparison is shown on Figure 7. The similarity of the two plots suggests that the flow data has been generated correctly from the stage data by the Hydrology Unit staff, SANAA. The horizontal sections of the plots were caused by the 1 cm accuracy of the staff gauge as well as possible small shifts in datum between ratings and occasional sticking of the float mechanism on the chart recorder. The latter was probably due to the stilling well inlet pipe becoming silted up.

A double mass curve was plotted of the daily flow estimated at El Aguacate versus the daily rainfall measured at Toncontin airport. The double mass curve plots cumulative values of data from two stations. The curve should be a fairly straight line as both variables should increase at a similar rate, for example, a high rainfall at Toncontin results in a corresponding increase of flow at El Aguacate. When plotting flow versus rainfall, however, a 'stepped' curve results due to the dry season between November and April when a base flow is still

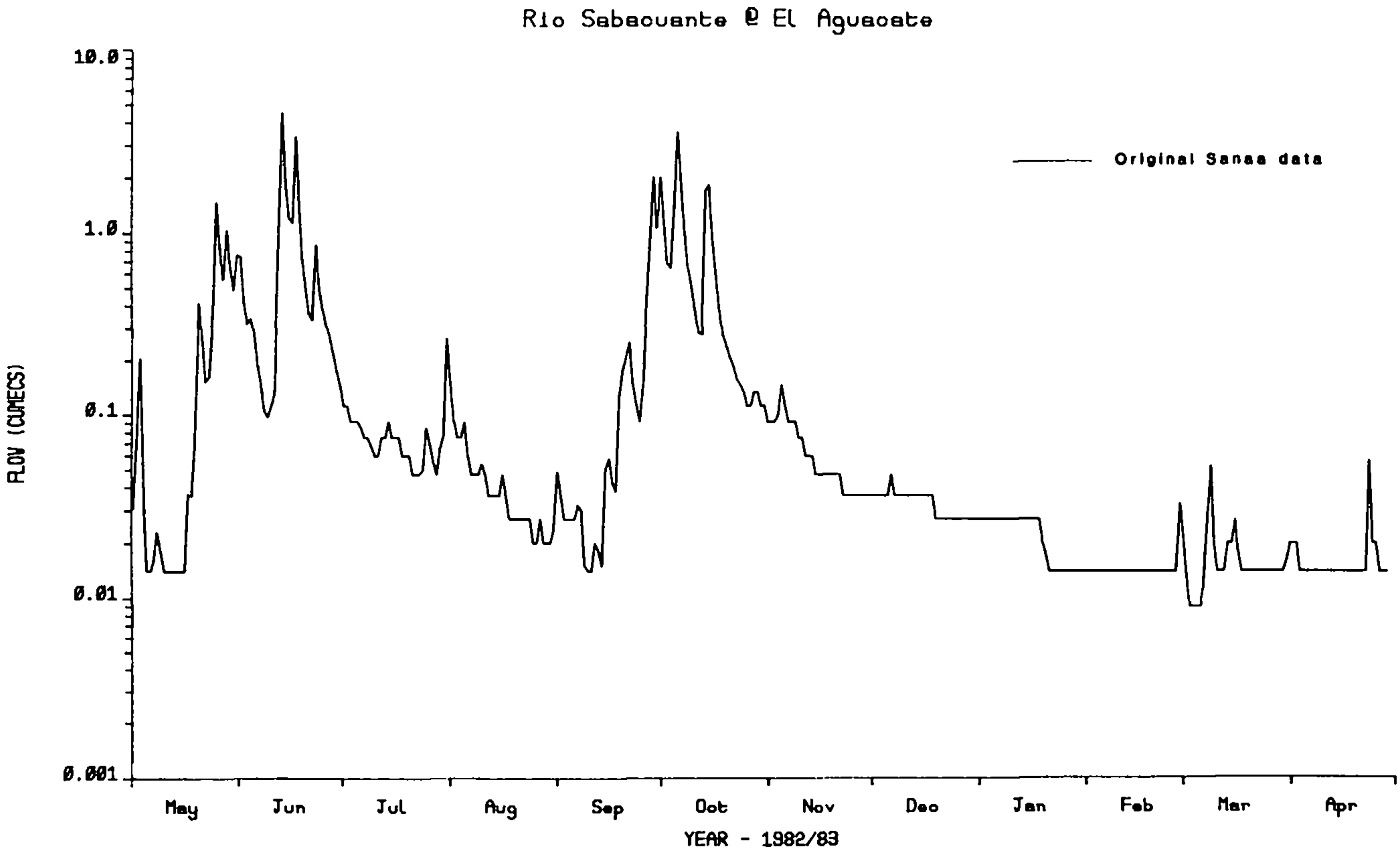

Rio Sabacuante @ El Aguacate
Original Sanaa data
FLOW (CUMECS)
10.0
1.0
0.1
0.01
0.001
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
YEAR - 1982/83

Figure 4

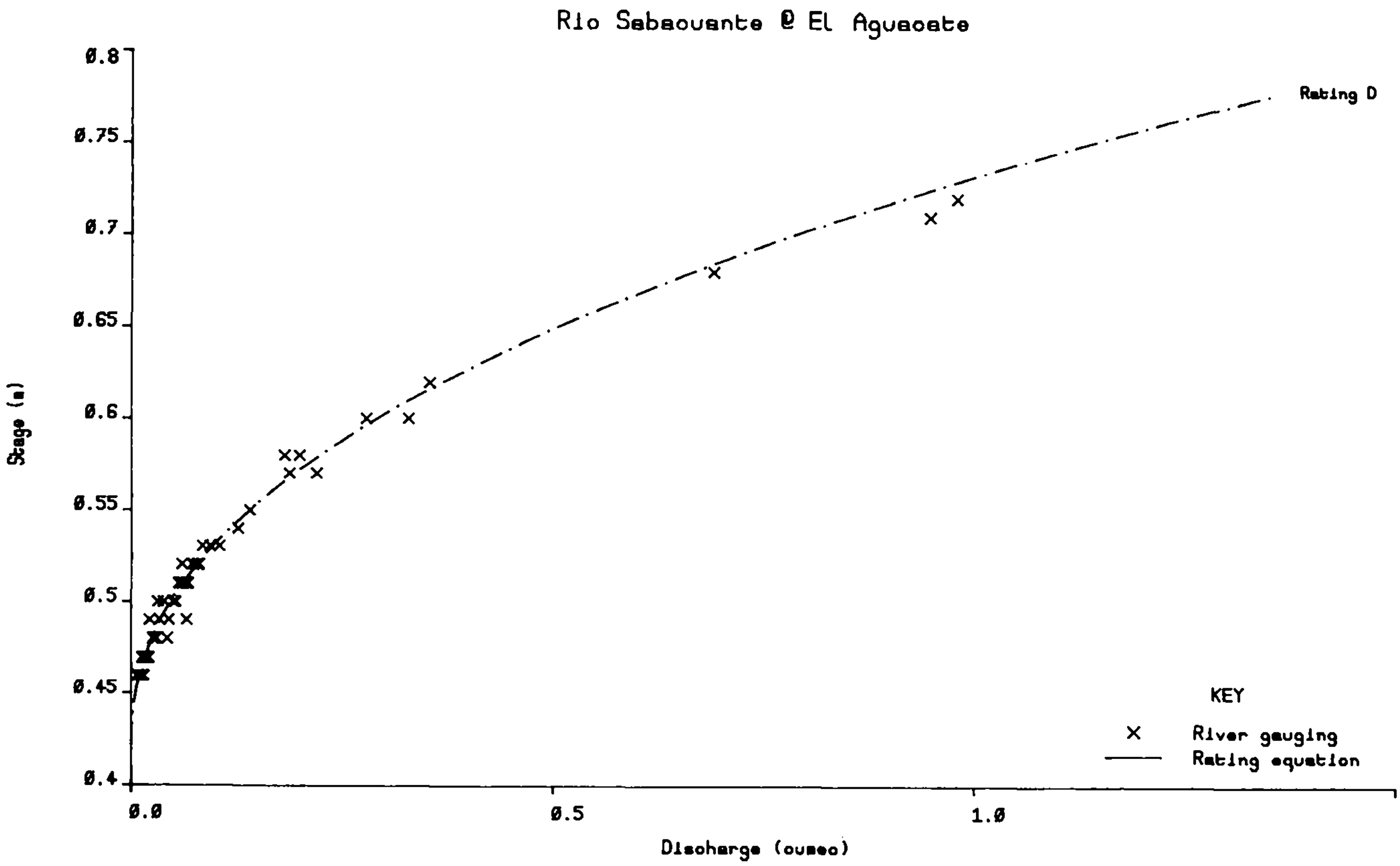
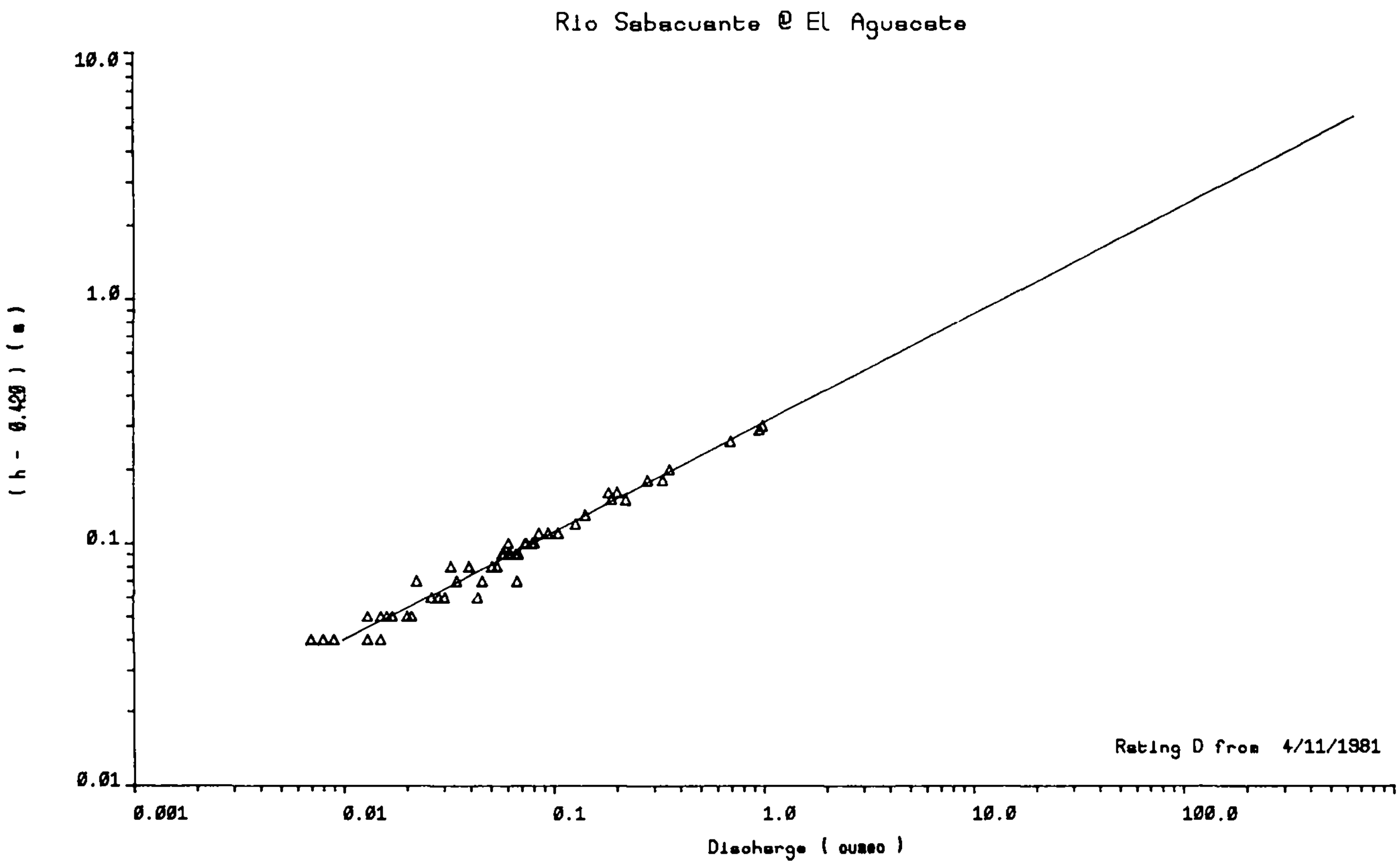
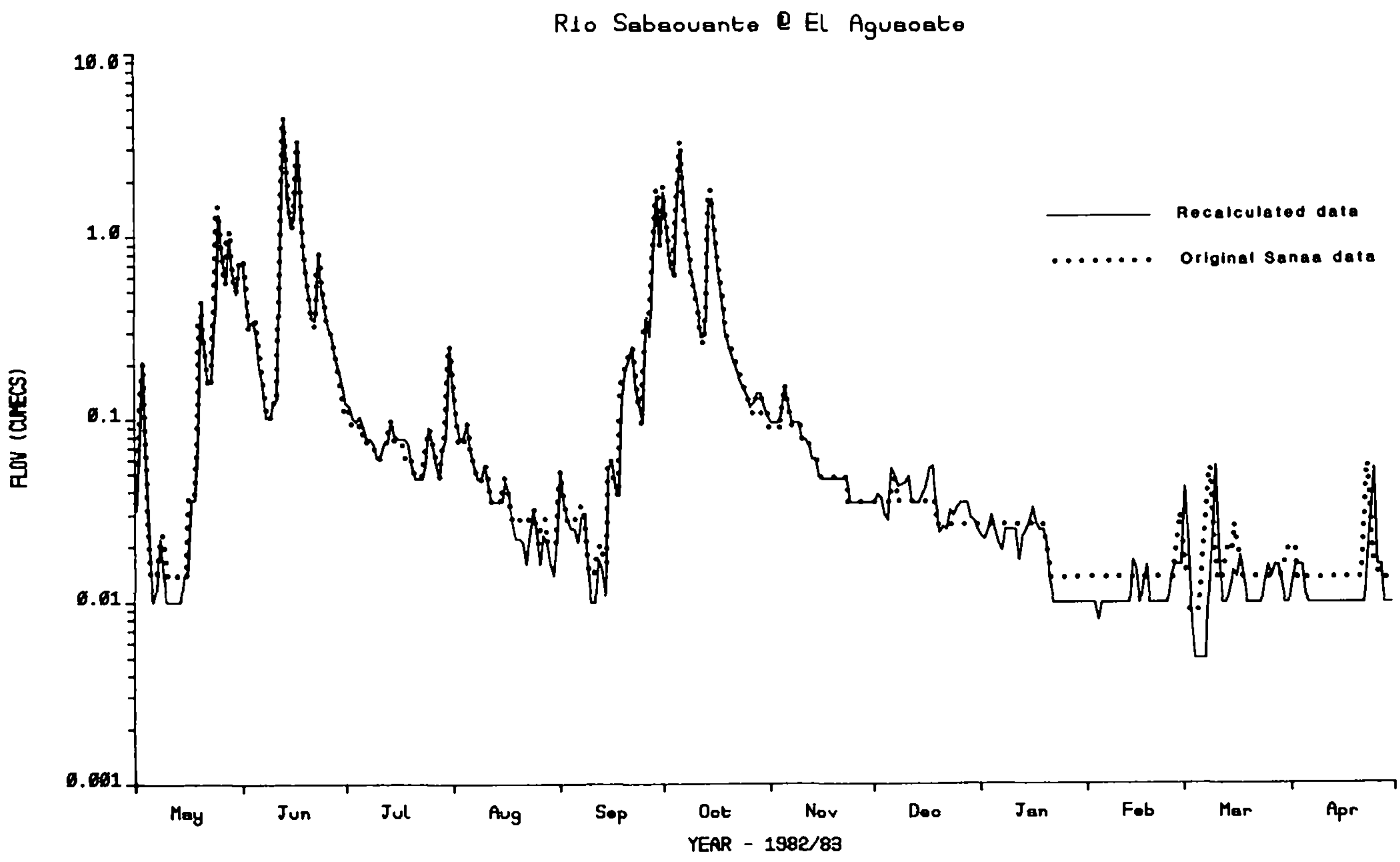

Rio Sabaouante @ EL Aguaoate
Stage (m)
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.0
0.5
1.0
Discharge (cumec)
Rating D
KEY
River gauging
Rating equation

Figure 5



Rio Sabacuante @ El Aguacate
10.0
1.0
0.1
0.01
(h - 0.420) (m)
Rating D from 4/11/1981
0.001
0.01
0.1
1.0
10.0
100.0
Discharge (cumec)

Figure 6



Rio Sabacuante @ El Aguacate
Recalculated data
Original Sanaa data
10.0
1.0
0.1
0.01
0.001
FLOW (CUMECS)
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
YEAR - 1982/83

Figure 7

present at El Aguacate and yet there is little additional rainfall. A distinct departure from the linear relationship indicates a problem with one of the two sets of data. Toncontin was taken as the control because its record was found to be valid when compared by double mass curves to other rainfall stations in the region (Section 3.3). The double mass curve of the flow at El Aguacate versus rainfall at Toncontin is shown on Figure 8. The plot exhibits a distinct change in slope for the water years 1979/80 and 1980/81. A similar plot was derived for the flow data estimated at El Incienso and is shown on Figure 9. The flow data at El Incienso does not show the same distinct departure from a straight line. A closer examination of the El Aguacate data was therefore required over this period. Stage data and discharge measurements for the year 1980/81 were added to the Database and independent rating equations developed to convert the stage data to daily flow data. A comparison of the daily flow values generated with the Plan Maestro flow data is shown on Figure 10. The plot indicates differences in the peak flows which may be primarily attributed to discrepancies in the rating equations. A further double mass curve was developed using the adjusted data for 1980/81 and is shown on Figure 11. The curve now exhibits less distinct changes in slope indicating that the data quality has been improved.

In conclusion, it was considered that the final flow record described by Figure 11 was adequate for use in the present study. However it is recommended that the analysis of the Rio Sabacuante catchment, described in Section 4.0, should be repeated after every year of flow data has been re-analysed. Six stage readings per day should be input to the Database from the chart recordings. Discharge measurements should then be added and rating equations developed. The rating equations can then be used to convert the stage data to daily flow data. The method used by SANAA to calculate the flow during periods of flooding should also be corrected. The flow has been calculated by determining the average stage over the duration of the flood and then using this value to estimate the flow. A more representative approach would be to calculate the flow for each increment of stage and then average the resulting flow values over the duration of the flood. The result has been that the flow was underestimated during periods of flooding, for example, the flow estimated over the period 15 16th September 1981 was underestimated by 17%.

3.3.2 Flow data from the San Juancito Mountain catchments

The quality of the flow data recorded at the present weirs was found to be very poor. An example of the data observed at La Tigra for the water year 1985-1986 is shown on Figure 12. The plot shows that the flow was not being estimated to a sufficient degree of accuracy. The poor resolution of the data is indicated by the 'stepped' appearance of the plot. This was due to the staff gauge above the weirs being read to the nearest centimetre whereas millimetre accuracy is required. Furthermore, it is clear from the horizontal sections of the plot that the peaks of the floods are not being recorded correctly. This is probably caused by observers not reading the staff gauge at the specified times. The recent data were considered to be of insufficient quality and length to allow prediction of long term yields.

In addition no correlation was found between the daily flow data and the daily rainfall record at Neuvo Rosario. Therefore extension of the present record using daily rainfall at Neuvo Rosario was not possible.

3.3.3 Rainfall data

Data from the six rainfall stations in the study area were checked by double mass curves shown on Figures 13 - 17. Toncontin was taken as the control in the analysis because it is the main synoptic station in the region based at the airport and monitored by qualified staff. The plots of Nuevo Rosario, El Incienso, El Sauce & El Aguacate versus Toncontin all exhibit fairly straight lines which indicates that the data are consistent. The plot of Las

Aguacate v Toncontin (original)

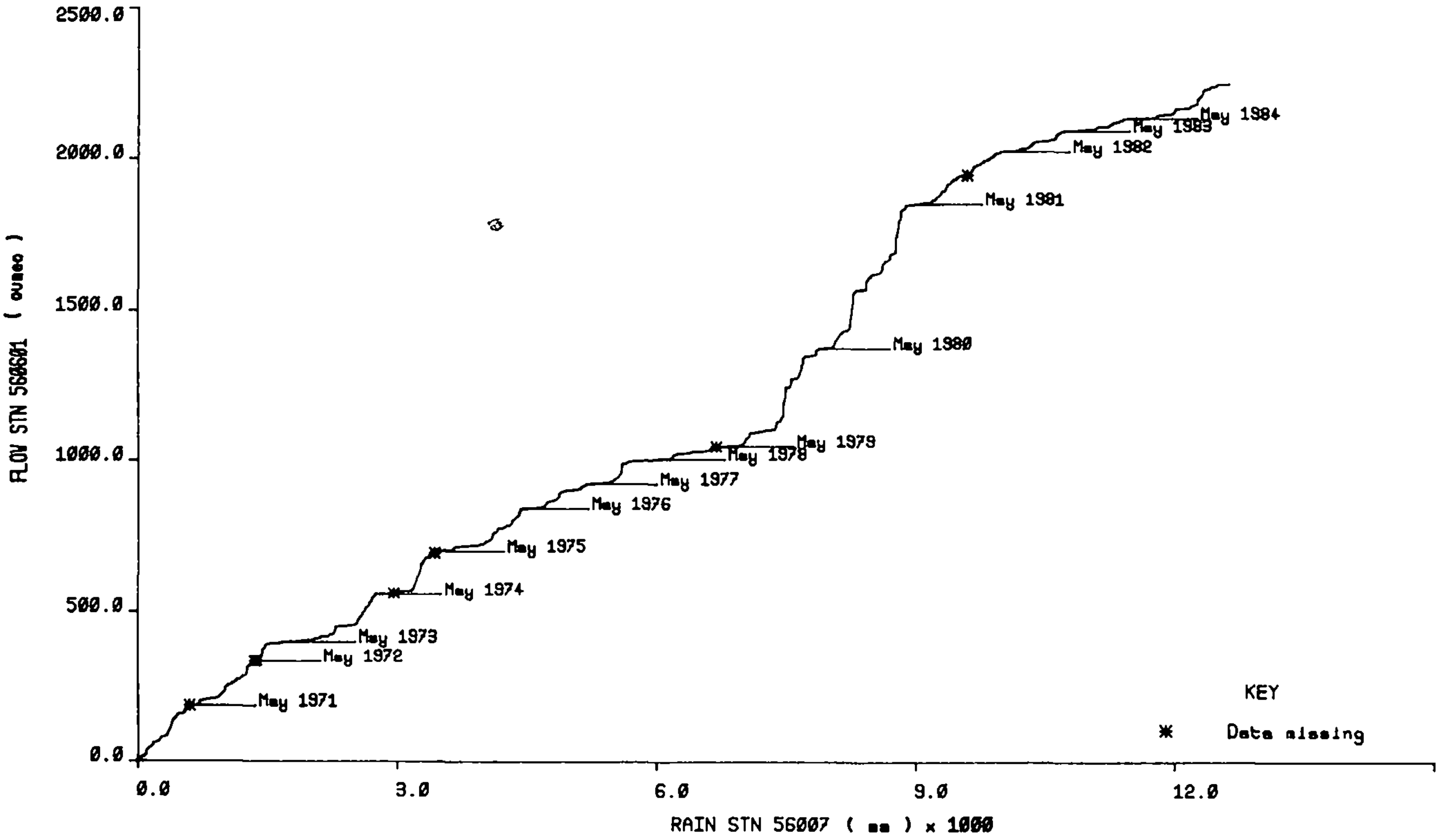
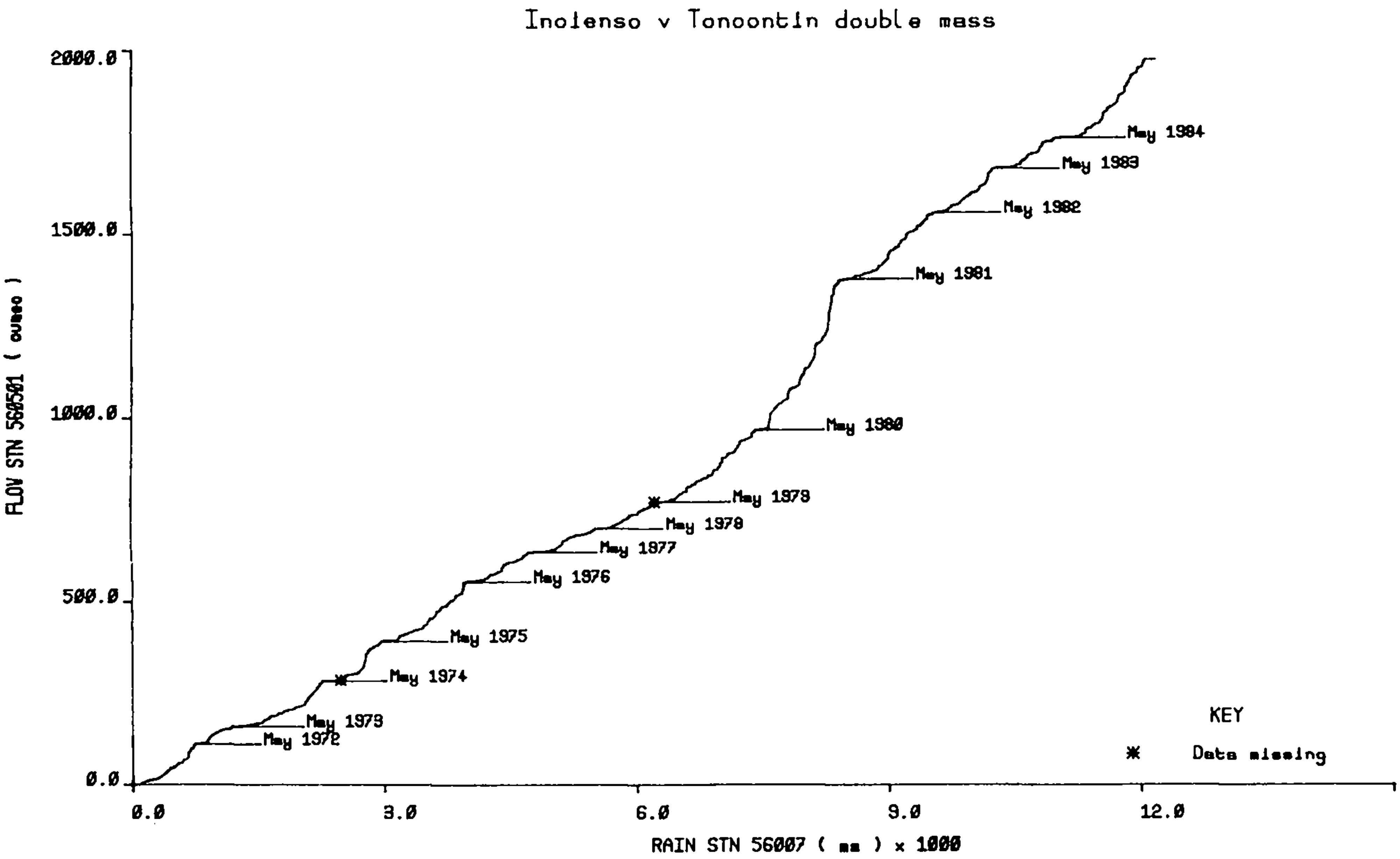


Figure 8



Inolenso v Tonoontin double mass
FLOW STN 560501 (oumeo)
2000.0
1500.0
1000.0
500.0
0.0
RAIN STN 56007 (mm) x 1000
0.0
3.0
6.0
9.0
12.0
May 1972
May 1973
May 1974
May 1975
May 1976
May 1977
May 1978
May 1978
May 1980
May 1981
May 1982
May 1983
May 1984
KEY
* Data missing

Figure 9

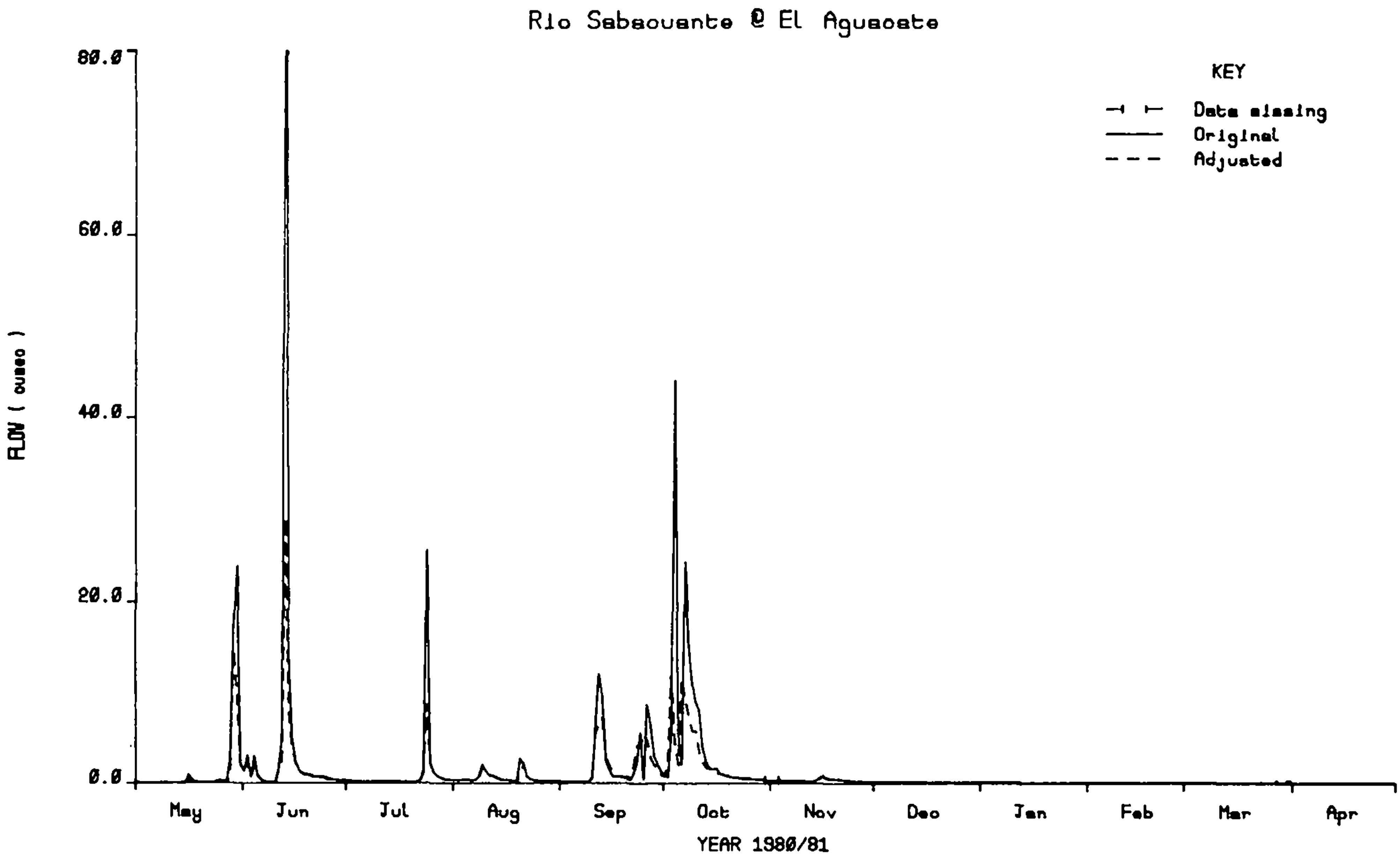

Rio Sabacuante @ El Aguacate
KEY
Data missing
Original
Adjusted
FLOW (cusec)
80.0
60.0
40.0
20.0
0.0
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
YEAR 1980/81

Figure 10

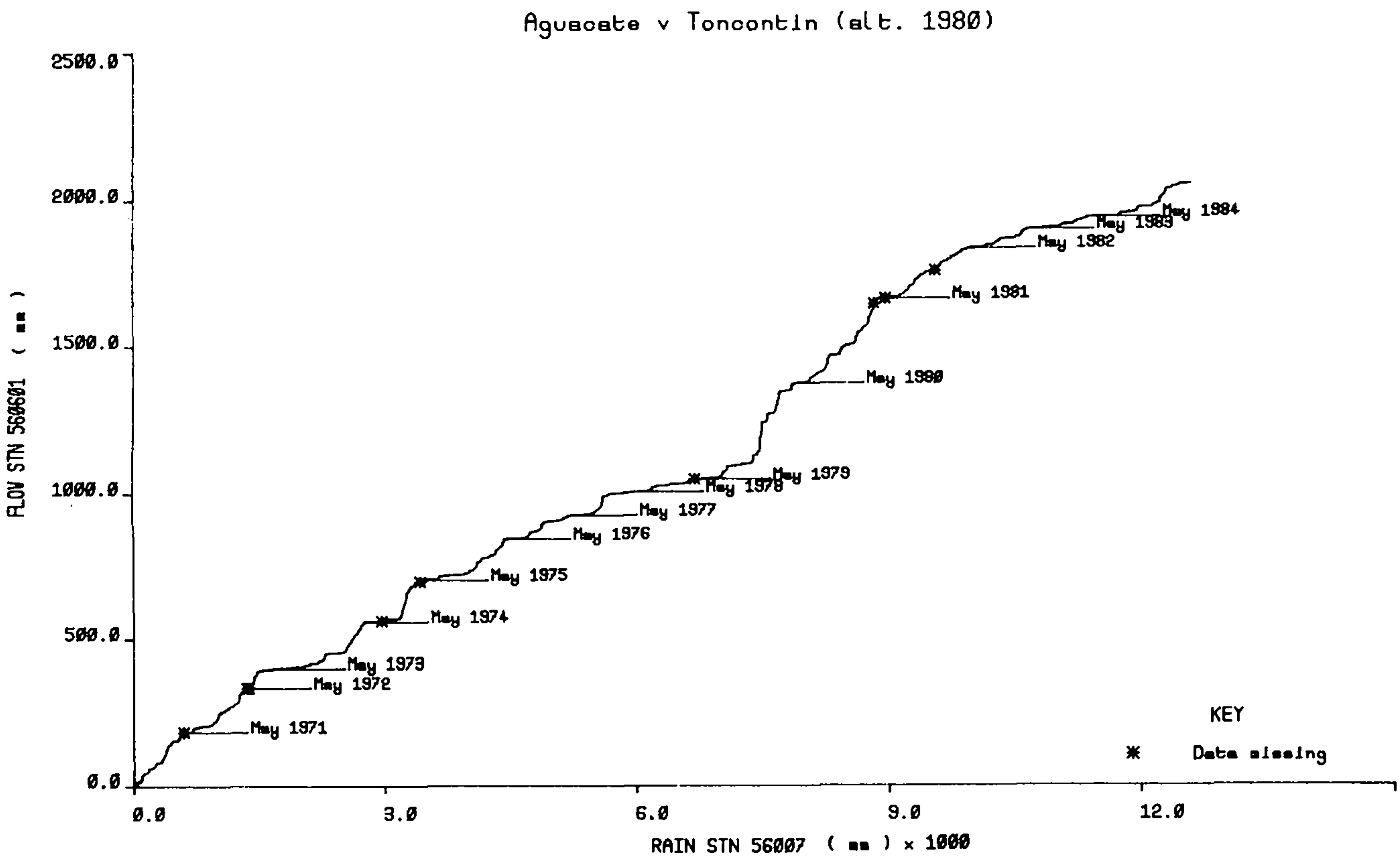
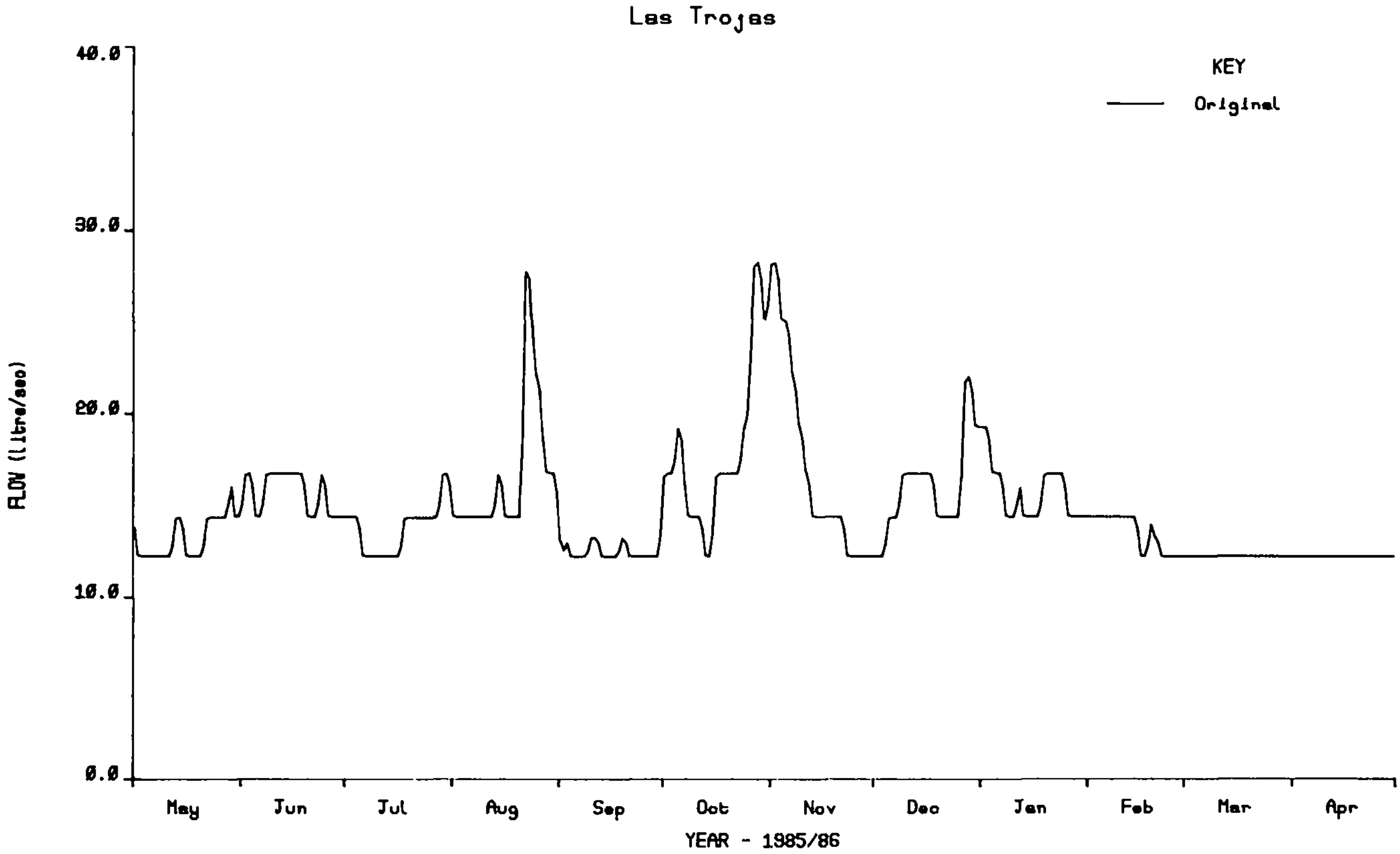

Aguacate v Toncontin (alt. 1980)
FLOW STN 560601 (mm)
RAIN STN 56007 (mm) x 1000
2500.0
2000.0
1500.0
1000.0
500.0
0.0
3.0
6.0
9.0
12.0
May 1971
May 1972
May 1973
May 1974
May 1975
May 1976
May 1977
May 1978
May 1979
May 1980
May 1981
May 1982
May 1983
May 1984
KEY
Data missing

Figure 11



Las Trojas
KEY
Original
40.0
30.0
20.0
10.0
0.0
FLOW (litre/sec)
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
YEAR - 1985/86

Figure 12

Rosario v Tonoontin double mass

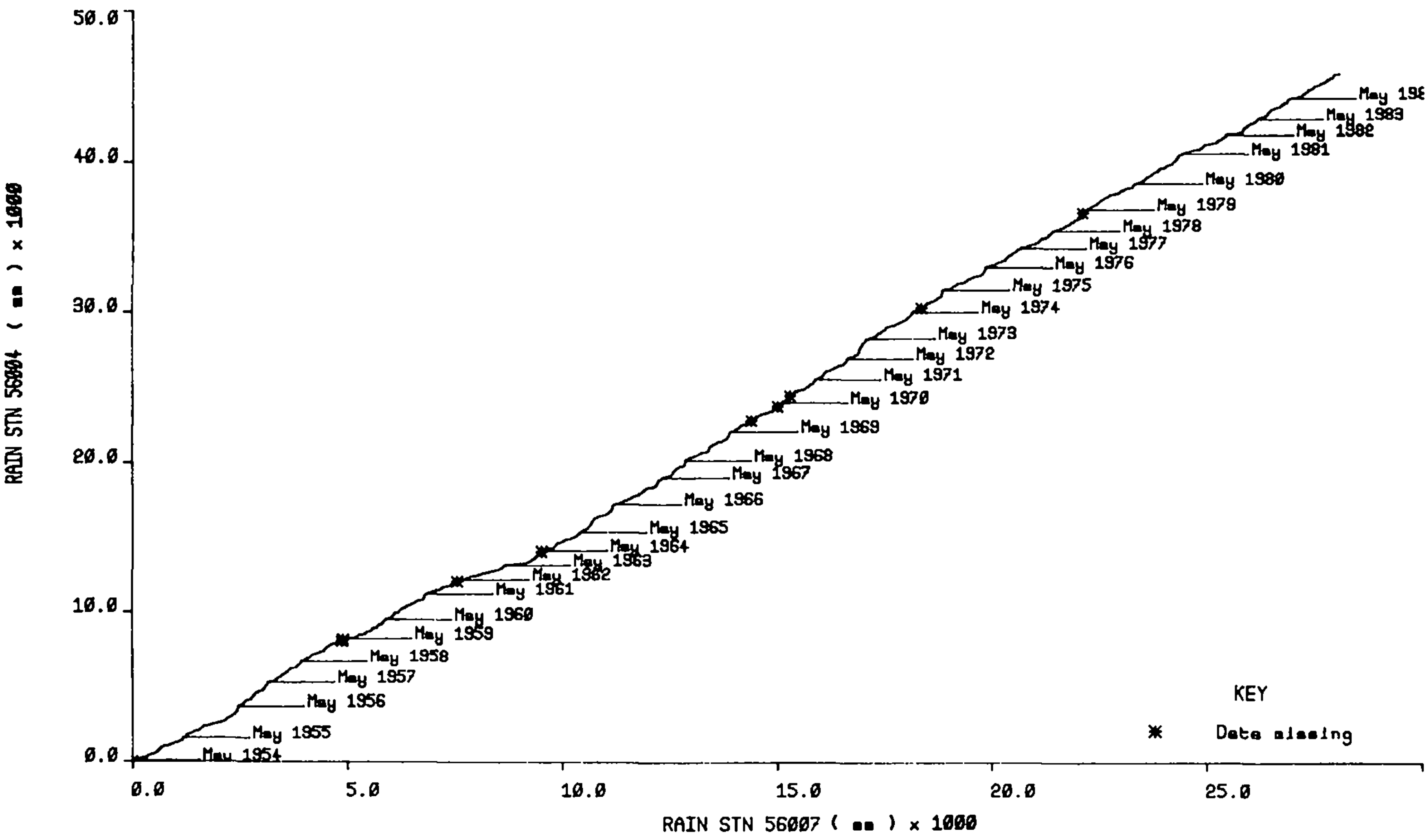


Figure 13

Incienso v Toncontin double mass

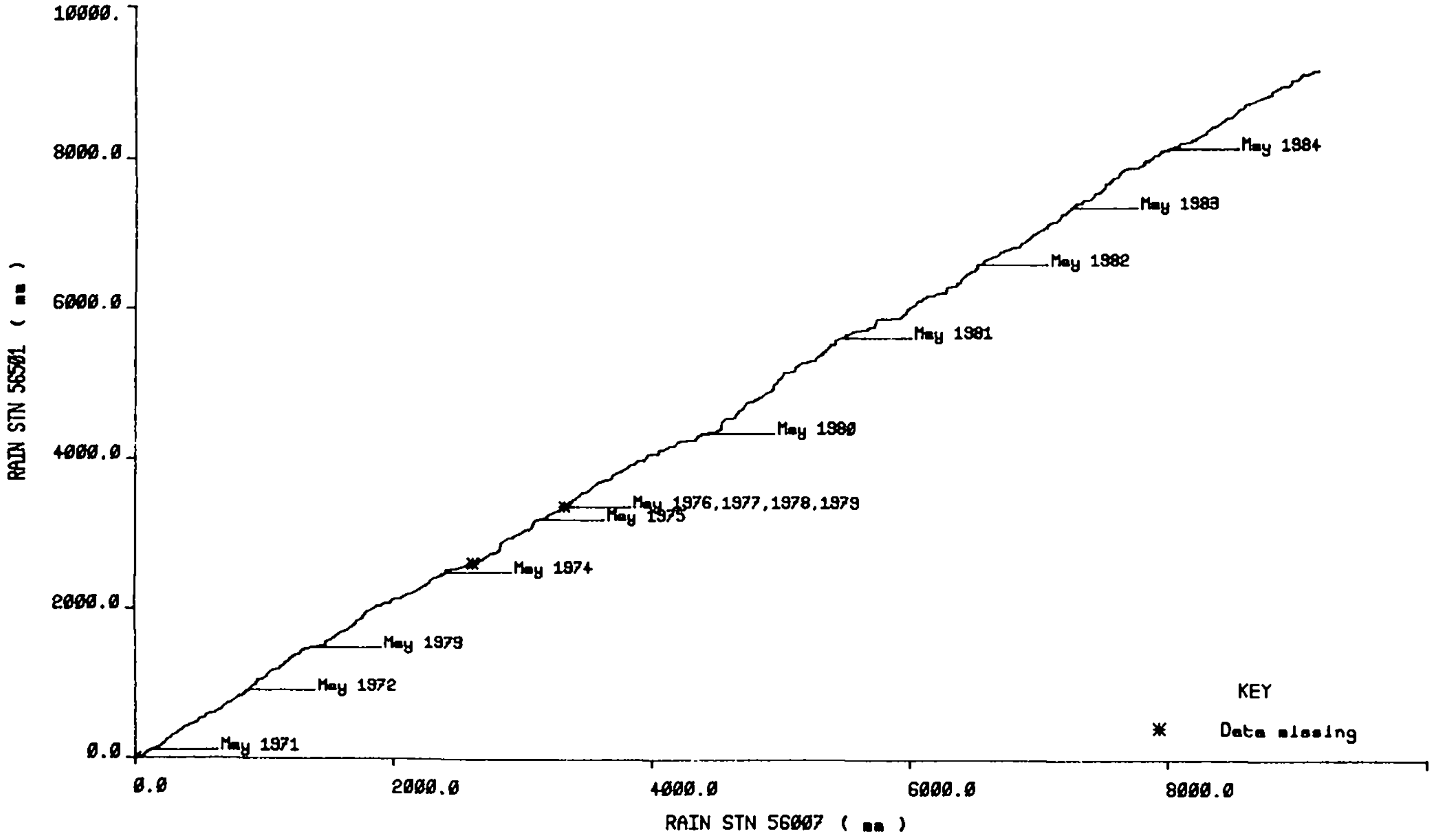


Figure 14

El Sauce v Toncontin double mass

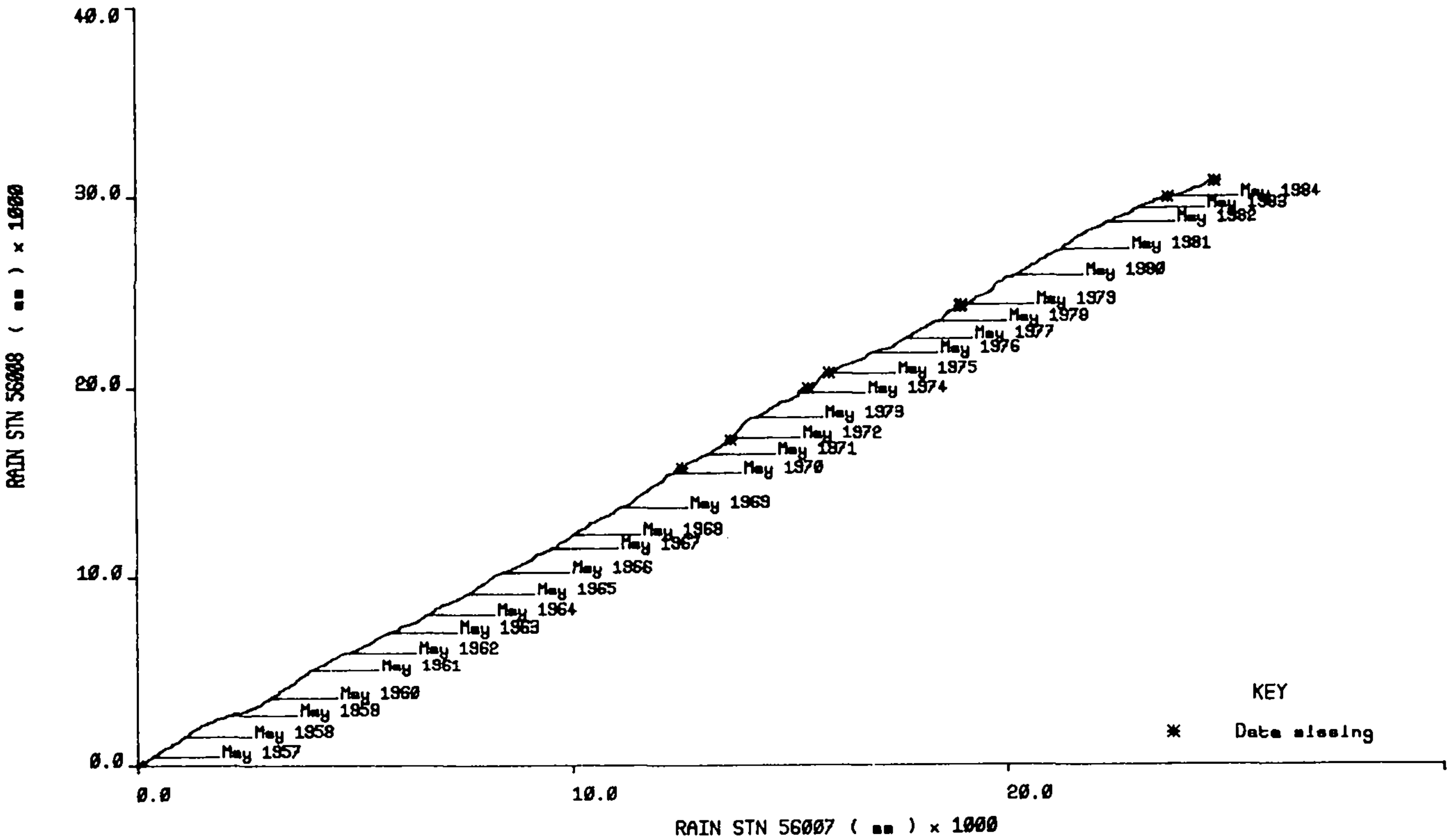


Figure 15

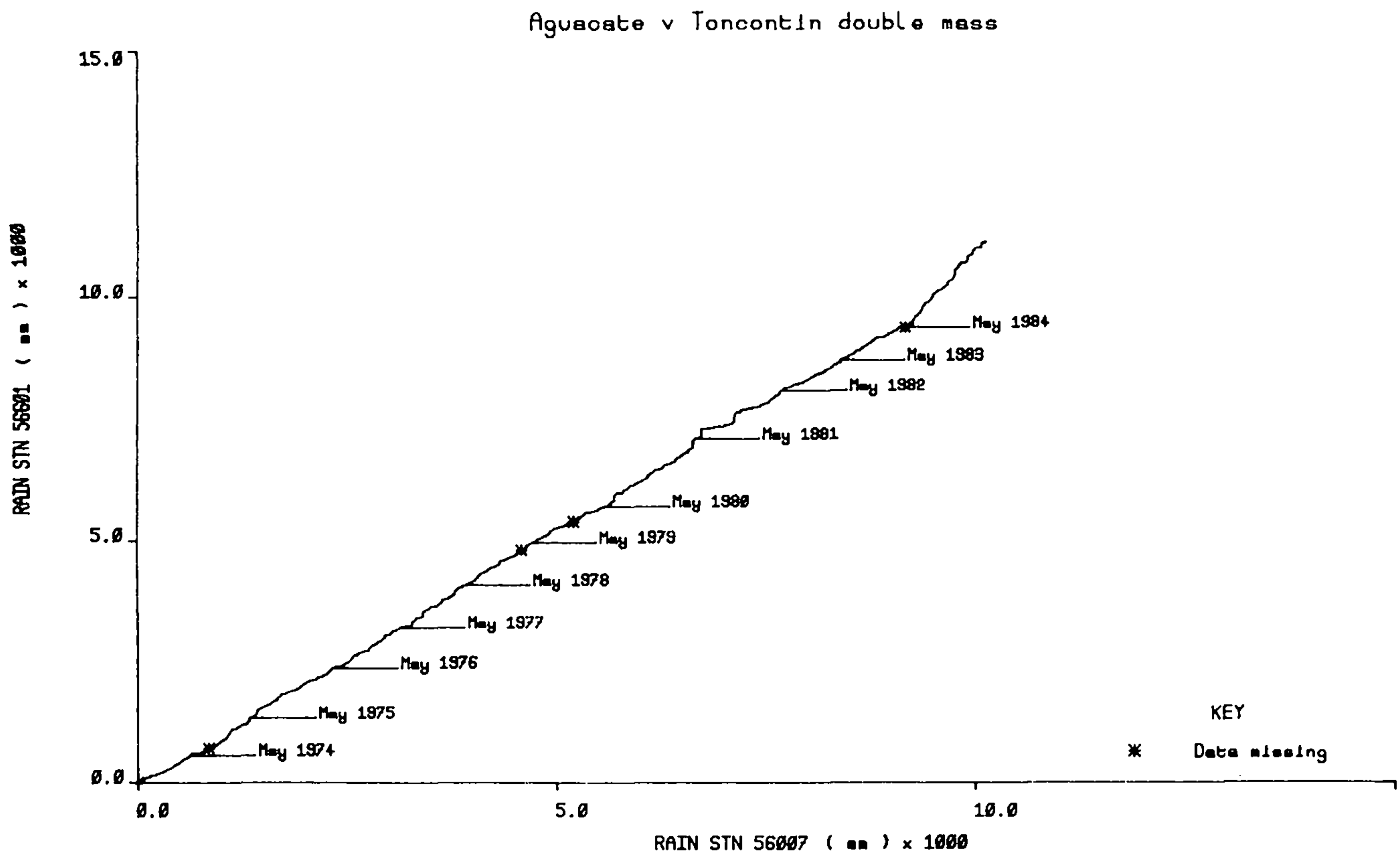

Aguacate v Toncontin double mass
15.0
10.0
5.0
0.0
RAIN STN 56001 (mm) x 1000
0.0
5.0
10.0
RAIN STN 56007 (mm) x 1000
May 1974
May 1975
May 1976
May 1977
May 1978
May 1979
May 1980
May 1981
May 1982
May 1983
May 1984
KEY
* Data missing

Figure 16

Canadas v Tonoontin double mass

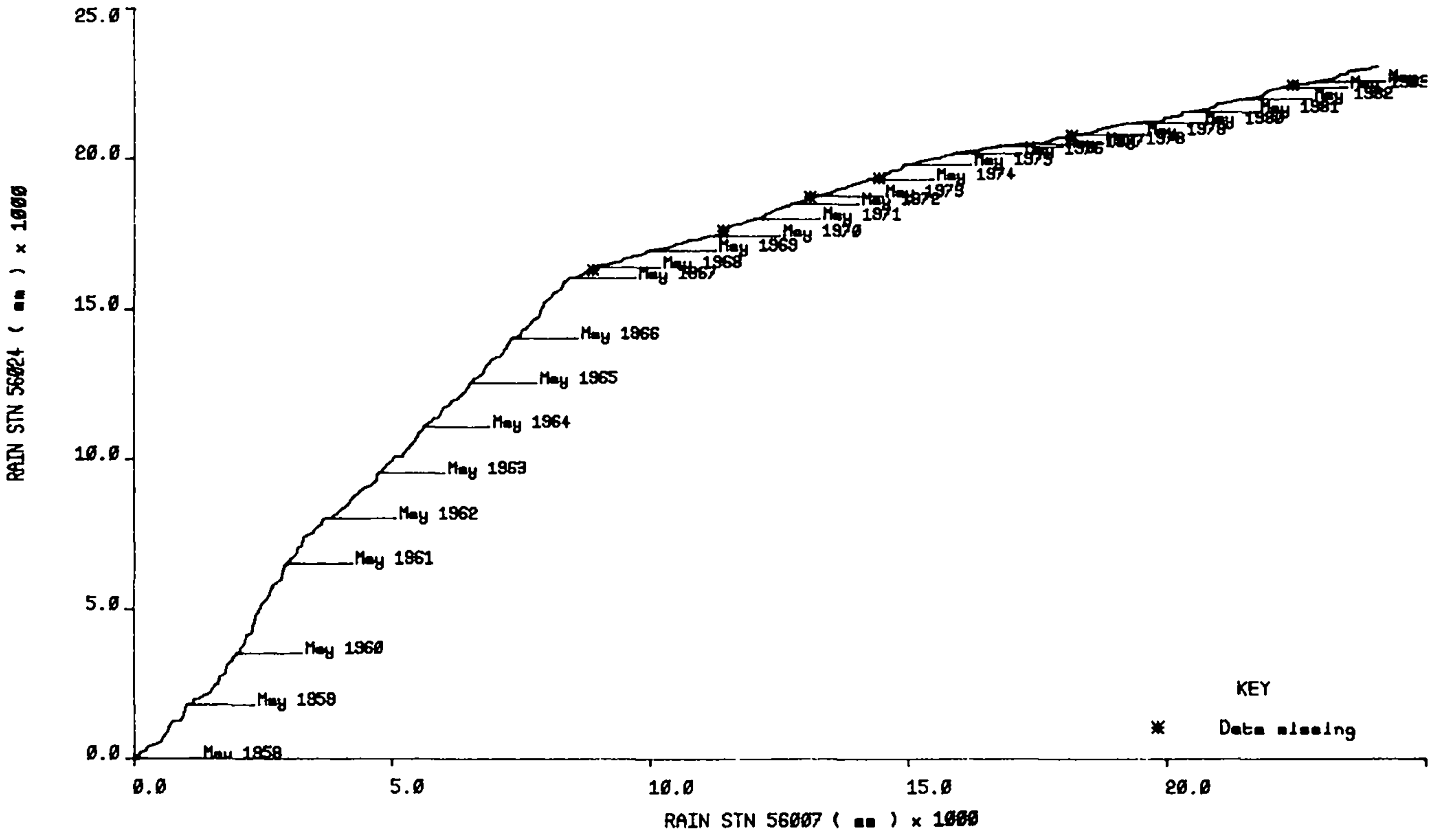


Figure 17

Canadas versus Toncontin however clearly shows a break in slope (Figure 17). The data for this station are therefore considered to be unreliable. Further investigation is required to determine the reason for the change before these data are used in any analysis.

4.0 ANALYSIS OF THE RIO SABACUANTE CATCHMENT

The aim of the analysis of the data from the Rio Sabacuante catchment was to determine the long term yield of the catchment at the location of the pipe offtake.

The present data available consists of the flow records for the period May 1970 to April 1986, observed at the El Aguacate gauging station as described in Section 3.0. These data do not represent the natural river flow at the pipe offtake. This is because the gauging station is sited 3.9 km downstream of the pipe offtake, increasing the effective catchment area from 42.7 km^2 at the offtake to 80.3 km^2 at El Aguacate. The inflow to the river from the additional area of 37.6 km^2 is therefore measured at El Aguacate but does not contribute to the pipe offtake. Furthermore, the flow in the pipe is not recorded since it is abstracted upstream of the gauging station.

Nevertheless the natural flow of the catchment above the Sabacuante offtake can be estimated from the El Aguacate record using the following procedure.

4.1 Naturalising the Rio Sabacuante flow data

Firstly the El Aguacate catchment is divided into two sub-catchments as shown on Figure 18. From the principle of continuity :

$$A = D + U - P \qquad (1)$$

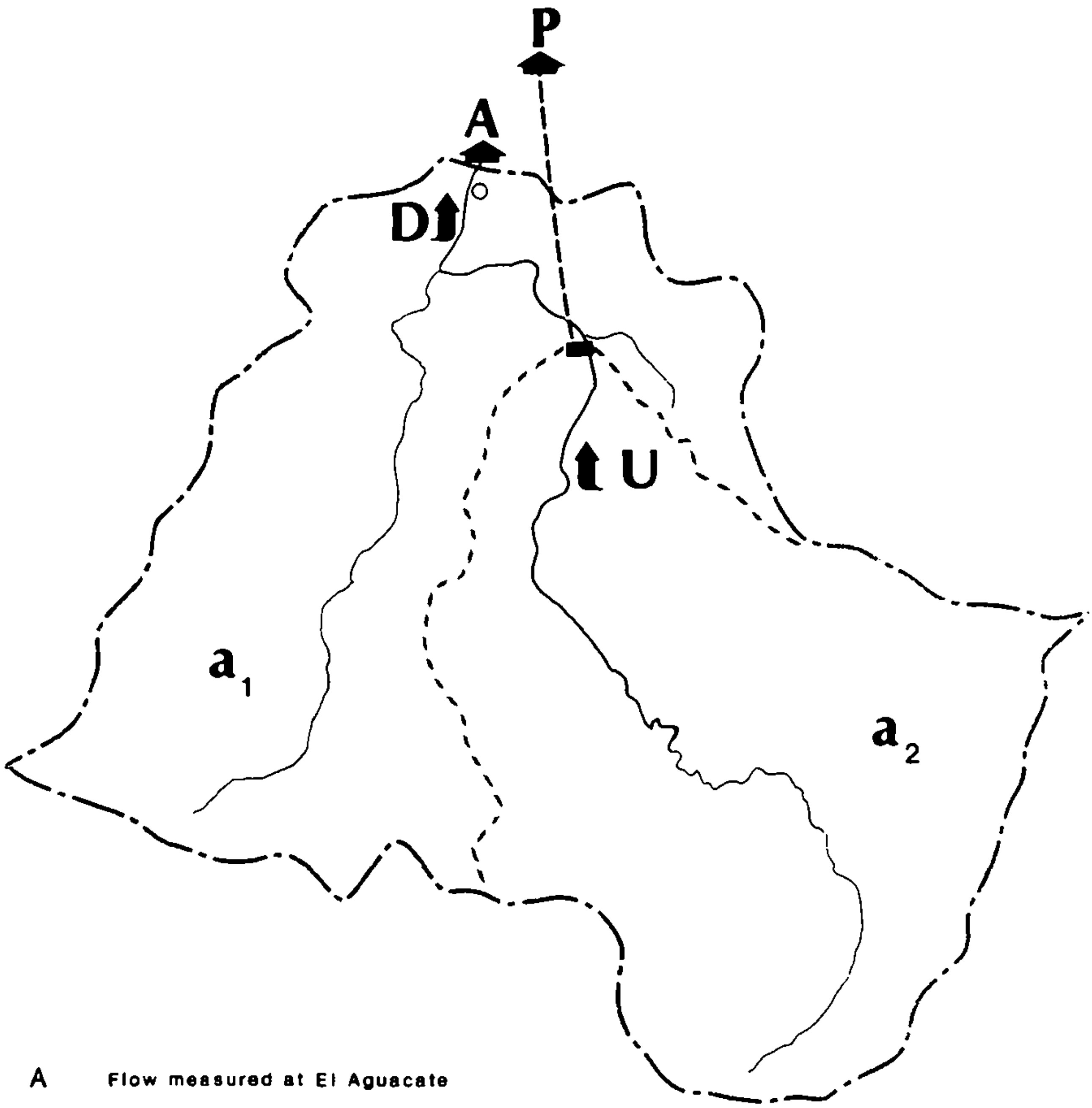
where A is the flow measured at El Aguacate
D is the natural inflow between the offtake and El Aguacate
U is the natural flow upstream of the offtake
P is the pipe flow

The offtake structure may be considered to be a simple weir across the river offering no significant storage with the pipeline drawing water from beneath the weir crest. Therefore, if U is greater than the pipe capacity, Pmax, the pipe flows full and excess water spills over the weir to rejoin the river. If U is equal to Pmax, the pipe is full and no water is lost downstream. Furthermore, if U is less than Pmax, the flow in the pipe is U and no contribution is made to the downstream flow. These three conditions are summarized below

CONDITION	PIPE FLOW	SPILLAGE	
U > Pmax	Pmax	U - Pmax	
U = Pmax	Pmax	0	(2)
U < Pmax	U	0	

The situation is complicated by a stream (La Chorrera) situated downstream of the weir but which contributes to the offtake via a 75mm (3 inch) diameter pipeline. The magnitude of this additional supply is small and is governed by the pipe capacity which is in the order of 3 ls^{-1}. It was assumed that the flow in the 75mm pipe was in the same order as the

Analysis of the Rio Sabacuante catchment



A	Flow measured at El Aguacate
U	Natural flow upstream of offtake
D	Natural inflow between offtake and El Aguacate
P	Flow in pipe
a_1	Catchment area between offtake and El Aguacate
a_2	Catchment area above offtake
■	Offtake structure
○	El Aguacate

leakage under the weir which is known to occur. If this assumption is made the underflow effectively cancels out the contribution of the 75mm pipe and simplifies the analysis.

Assuming the areas of the two sub-catchments, a1 and a2, to be physiographically similar and exposed to the same rainfall regime, the discharges from the two areas may be related by a ratio, r, where

$$r = \frac{D}{U} \qquad (3)$$

The value 'r' may be obtained by gauging the river to determine A and U during low flows when U < Pmax, that is :

$$r = \frac{A}{U} \quad \text{when } U < P_{max} \qquad (4)$$

As a first approximation, 'r' may be obtained from the ratio of the two areas a1 and a2

$$r = \frac{a1}{a2} \quad \text{therefore, } r = \frac{37.6}{42.7} = 0.88 \qquad (5)$$

The natural flow upstream of the offtake, U, can now be estimated for any situation by combining equations (1) and (3)

$$A = U + (U.r) - P$$

$$\text{therefore } U = \frac{(A + P)}{(1 + r)} \qquad (6)$$

The conditions of upstream flow ((2) above) are used to derive the following equations :

(a) when U > Pmax

$$U = \frac{(A + P_{max})}{(1 + r)} \qquad (7)$$

(b) when U = Pmax

$$A = r.P_{max} \qquad (8)$$

(c) when U < Pmax

$$U = \frac{A}{r} \qquad (9)$$

The following steps can now be taken to determine the naturalised flow at the pipe offtake, U, if Pmax and the ratio 'r' are known :

Step 1. For each daily flow data at El Aguacate, A, equation (8) is used to find if 'A' was greater or less than the product (r.Pmax), that is, determine whether the pipe was flowing full or not.

Step 2. The result of Step 1, determine whether equation (7) or (9) is used to estimate U.

4.2 Field Measurements

Field measurements were made to estimate values of the maximum pipe capacity, Pmax, and the ratio, r, of the flows recorded in the downstream sub-catchment, a1, and the upstream sub-catchment, a2 as shown on Figure 18. The maximum pipe capacity, Pmax, was estimated on the 1st December 1986 when the weir was spilling and the pipe was therefore flowing full. A pitot tube, connected to a manometer, was used to measure the flow in the pipe about 500m downstream of the offtake. The pipe capacity was found to be 56 ls^{-1} (0.056 m^3s^{-1}).

River gaugings using current metering were also taken on the same day to determine the value of the ratio 'r'. The following results were recorded :

LOCATION	FLOW (ls^{-1})
Immediately upstream of the offtake	101
Immediately downstream of the offtake	44
El Aguacate	52
100m downstream of El Aguacate	59

An additional 3 ls^{-1} from the La Chorrera stream contributed to the flow available at the pipe offtake.

The first two river gaugings were an approximate check the measured pipe capacity of 56 ls^{-1}. The flow abstracted by the pipe is equal to the flow available at the offtake minus the flow recorded immediately downstream of the offtake, that is :

Estimated pipe flow = 101 + 3 - 44 = 60 ls^{-1}
from river gaugings

The current meter measurements were subject to large measurement errors due to the difficulty of gauging low flows in the rocky stream bed and so could only be considered to be a rough check on the more accurate direct measurement. Nevertheless the two estimates of pipe flow agreed to within 4 ls^{-1}.

The ratio, r, of the flow in the downstream sub-catchment, a1, and the flow in the upstream sub-catchment, a2, was calculated directly from the river gaugings :

$$\text{Ratio } r = \frac{D}{U} = \frac{59 - 44}{101} = 0.15$$

The value of flow recorded 100m downstream of El Aguacate was used in the calculation of 'r' because flow under the river bed was suspected at El Aguacate. The value of the under flow was in the order of 7 ls^{-1} as indicated by the gauging results. This trend was also apparent during previous gaugings taken between 25-27 November 1986 although no information is available before this date.

This value of the ratio, r, calculated from field measurements was considerably less than the value of 0.88 obtained from the ratio of the sub-catchment areas. This indicates that the major contribution of the natural flow at El Aguacate comes from the upstream sub-catchment and the natural inflow between the offtake and El Aguacate is relatively small. The contribution from the downstream catchment on 1st December 1986 was verified independently by walking the length of the Rio Sabacuante between the offtake and El Aguacate. The flow of each tributary was estimated by eye. The cumulative total of 15 ls^{-1} obtained was in good agreement with the current metre gaugings. In addition no evidence of water extraction for local settlements was found in this reach.

4.3 Results of the Analysis

A computer program, SABPROG, was written to obtain the naturalised flow upstream of the offtake as well as an estimate of the pipe flow using the method described in Section 4.1. The program automatically transfers the resulting flow records to the Hydrological Database. The operation of the program SABPROG is discussed in Section 7.2.

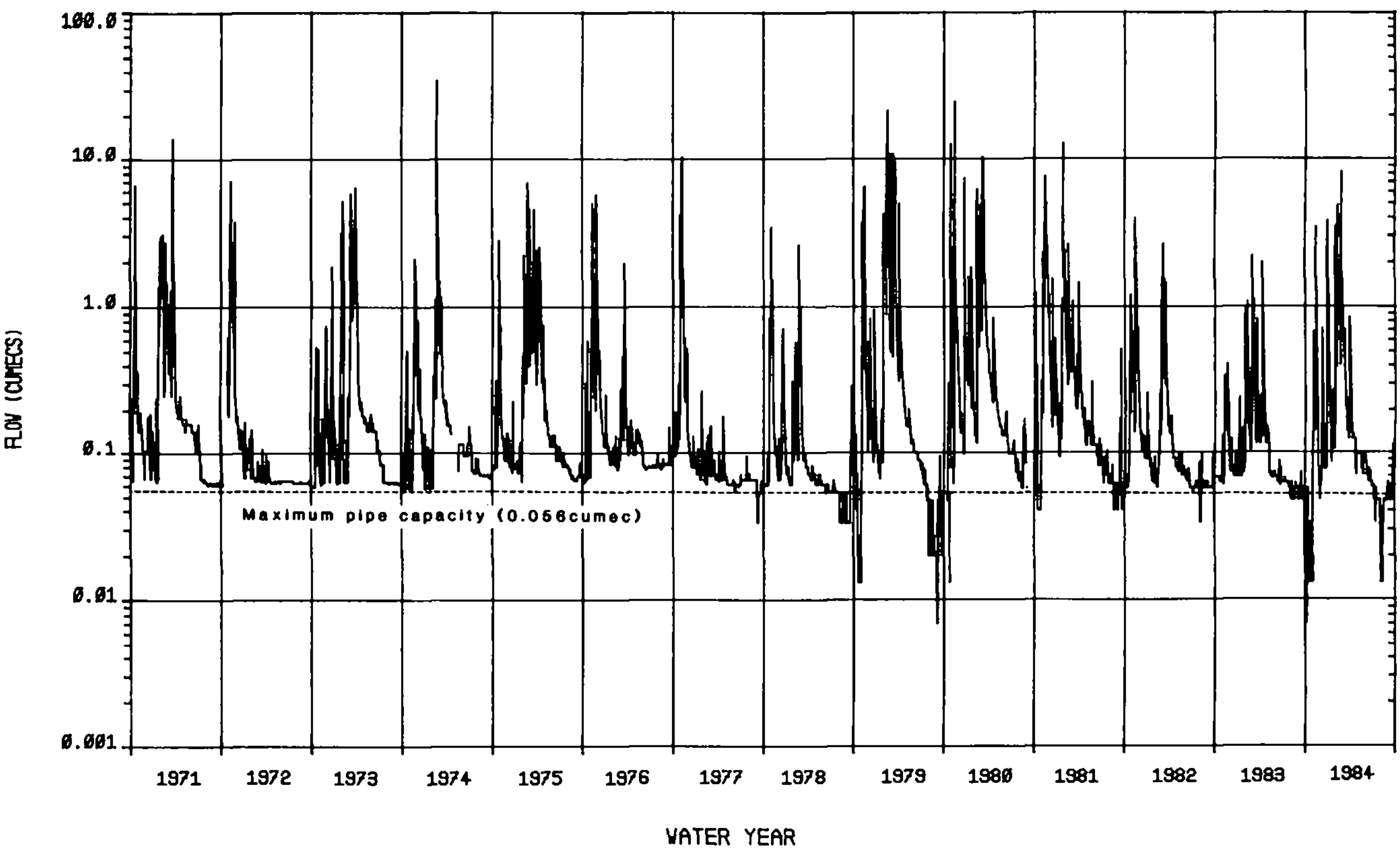
The results of the analysis indicated that the pipe was carrying water at its maximum capacity of 0.056 m^3s^{-1} for 92% of the time between May 1970 - April 1985. The 14 year record was considered to be of adequate length to represent the long term flow characteristics of the offtake site. The results are illustrated by Figure 19 which shows the maximum pipe capacity superimposed on the naturalised flow record of the river, upstream of the offtake. Periods where the naturalised river flow drops below Pmax represents the time when the pipe was not flowing full. The flow record shows that all the deficits occured in recent years which may be genuine or may indicate further problems with the flow data. Re-working the original data as suggested in Section 3.0 to generate a more accurate flow record may alleviate this possible inconsistancy.

A flow duration curve of the naturalised flow is shown on Figure 20. This flow duration curve gives the naturalised river flow at the pipe offtake, drawn on a log scale, against the percentage of time the flow is exceeded, drawn on a probability scale. The maximum pipe capacity of 0.056 m^3s^{-1} has been superimposed onto this curve. This indicates that the river flow exceeds 0.056 m^3s^{-1} 92% of the time over the period of the record. The pipe was therefore running full for for the same percentage of time. This curve can also be used to determine the percentage of time a replacement pipeline, of any capacity, would be running full. If the pipe capacity was increased to 0.1 m^3s^{-1}, the percentage of time it was running full would be reduced to 48%. The curve exhibits a 'plateau' region between 0.05 and 0.1 m^3s^{-1} where an increase in the pipe capacity results in a correspondingly greater percentage of time the pipe would not be full. This indicates that the present pipeline has been well designed.

4.4 Sensitivity Analysis

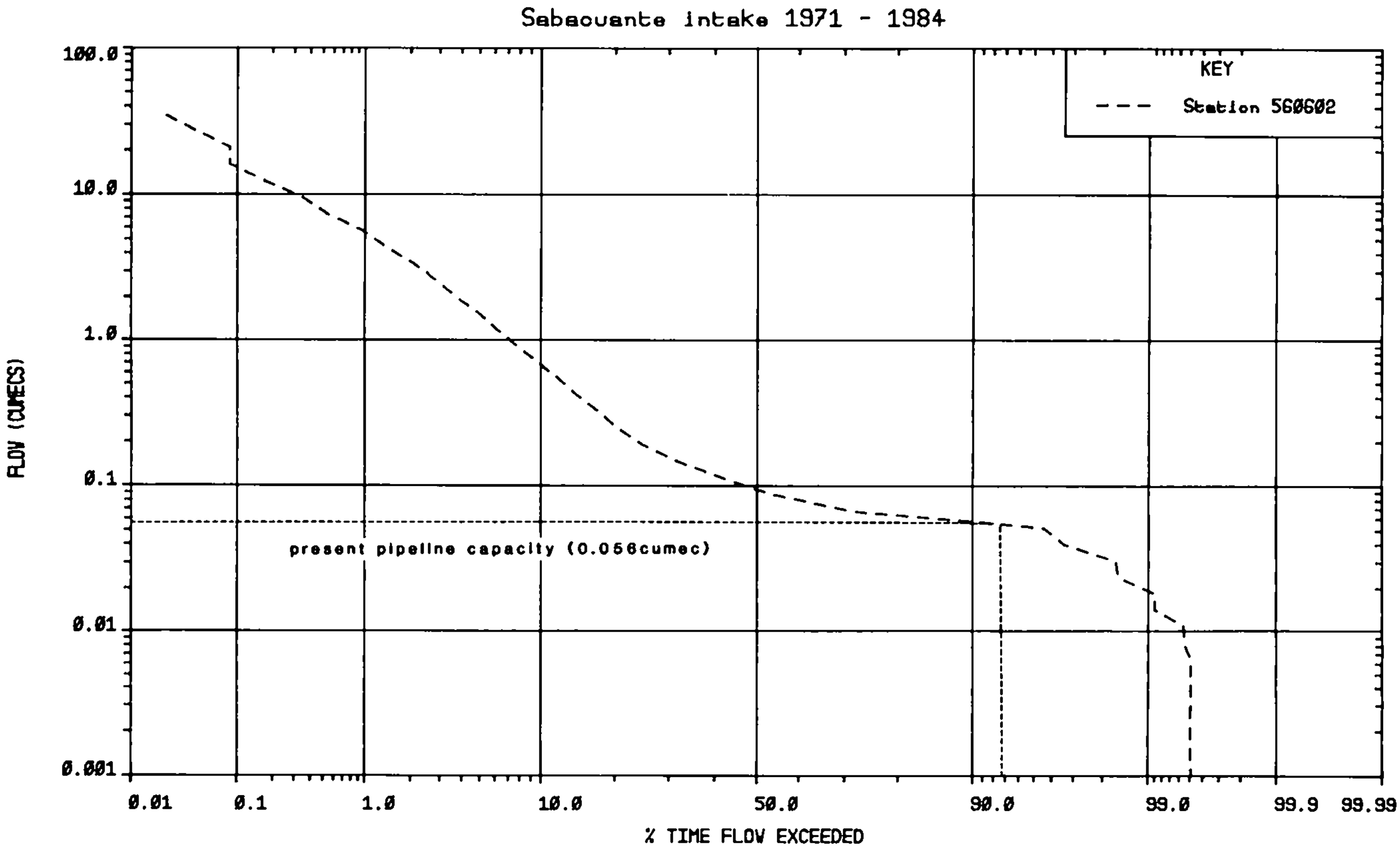
An investigation was carried out to determine the effect a change in the measurement of the ratio, r, or Pmax would have on the results of the Rio Sabacuante offtake analysis. The study was required because the field measurements were prone to error. The ratio, r, was determined by river gaugings giving only approximate results due to difficulties in gauging low flows in a rocky stream bed. Furthermore the value of 'r' may alter with changes in the flow regime. Pmax was less likely to be prone to variation because it was measured more accurately in the field and was expected to remain fairly constant with time.

Rio Sabacuate above Intake(Est.)



(Water year starting in May of year shown)

Figure 19



Sabaouante intake 1971 - 1984
KEY
Station 560602
FLOW (CUMECS)
100.0
10.0
1.0
0.1
0.01
0.001
present pipeline capacity (0.056cumec)
0.01
0.1
1.0
10.0
50.0
90.0
99.0
99.9
99.99
% TIME FLOW EXCEEDED

Figure 20

The sensitivity of the ratio, r, was first investigated. The analysis of the El Aguacate flow record was repeated for a range of values of the ratio, r, from 0.05 to 0.25 while keeping Pmax constant. The range was much wider than any anticipated error in the field measurements. By running the program SABPROG for each value of the ratio, r, the naturalised river flow at the pipe offtake was re-computed and transferred to the Database. The results were again displayed by flow duration curves as shown on Figure 21. By superimposing the maximum capacity of the pipe, fixed at 0.056 m^3s^{-1}, the curves show that for 'r' values of 0.05, 0.15, and 0.25 the percentage of time the pipe was running full was 84%, 92% and 98% respectively. The results therefore indicate that the results would not be significantly effected by any anticipated variation of the ratio, r, over the design region of the curve.

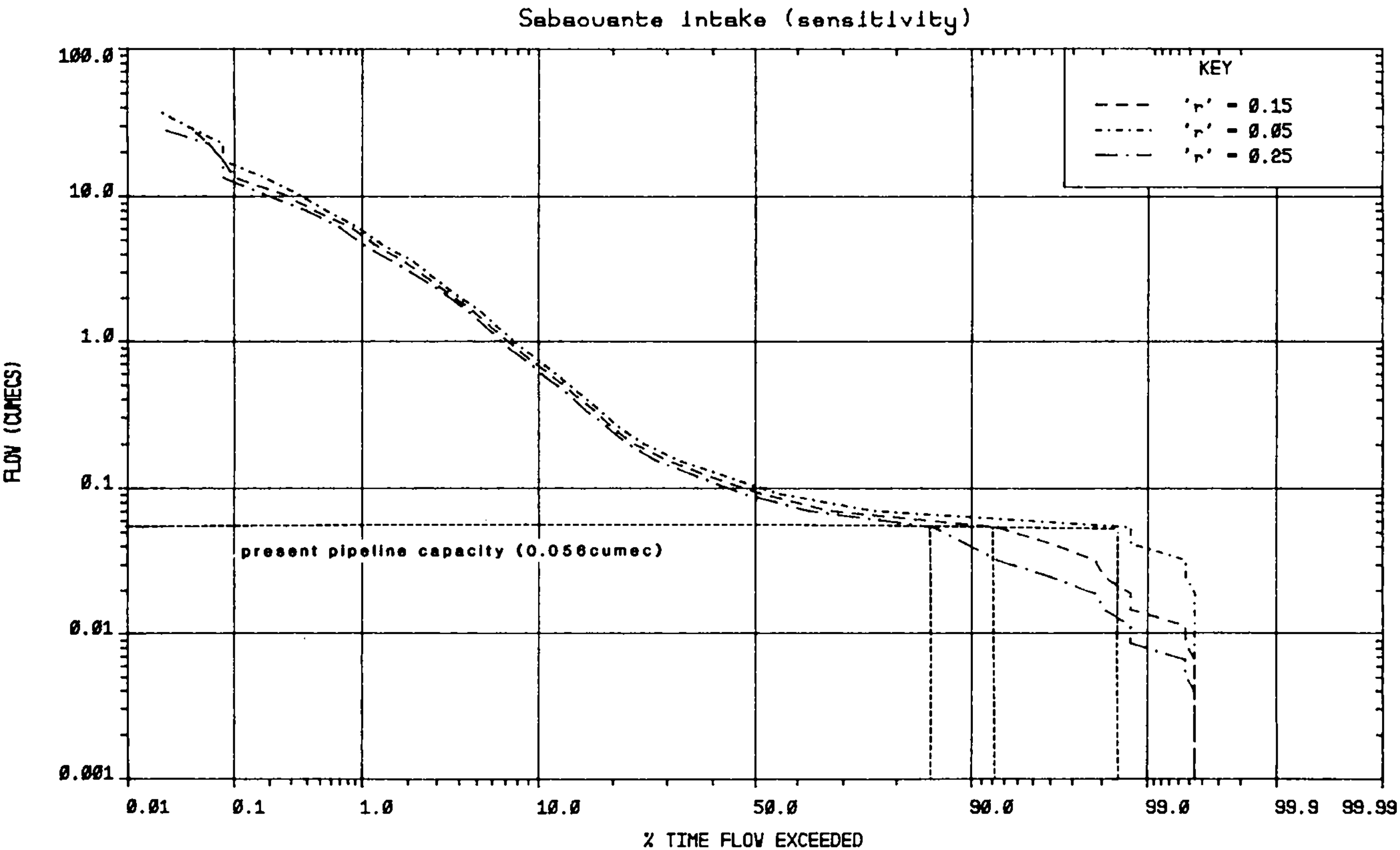
The investigation was extended by varying the ratio, r, over a much wider range while maintaining the same value of Pmax. The results are presented on Figure 22a where the ratio, r, versus the percentage of time the pipe was running full is plotted. The curve again demonstrates the insensitivity of the parameter, for example, if the ratio, r, was in error by as much as 50%, the results show that the pipe would be running full between 86 - 94% of the time.

The next stage in the sensitivity analysis was to hold the value 'r' constant at 0.15 and determine the effect of varying the maximum pipe capacity, Pmax. The results are presented on Figure 22b where Pmax versus the percentage of time the pipe was running full is plotted. The results show the the percentage of time the pipe is running full remains more or less constant over a wide range of Pmax.

The sensitivity analysis therefore indicates that a high degree of confidence can be given to the results with respect to uncertainties in estimating the values of 'r' and Pmax.

4.5 Conclusions

The main conclusion drawn from the analysis of the Rio Sabacuante catchment is that the existing pipeline has been full 92% of the time over the period May 1970 - April 1985 indicating that the original design capacity was a good one. Furthermore, the position of the offtake has been well sited since the runoff between the existing weir and El Aguacate is relatively small. An offtake situated further downstream would therefore have little increased yield and may result in poorer quality water being extracted due to effluent from farming activities.



Sabaouante intake (sensitivity)
KEY
'r' = 0.15
'r' = 0.05
'r' = 0.25
present pipeline capacity (0.056cumec)
FLOW (CUMECS)
100.0
10.0
1.0
0.1
0.01
0.001
0.01
0.1
1.0
10.0
50.0
90.0
99.0
99.9
99.99
% TIME FLOW EXCEEDED

Figure 21

Sensitivity analysis

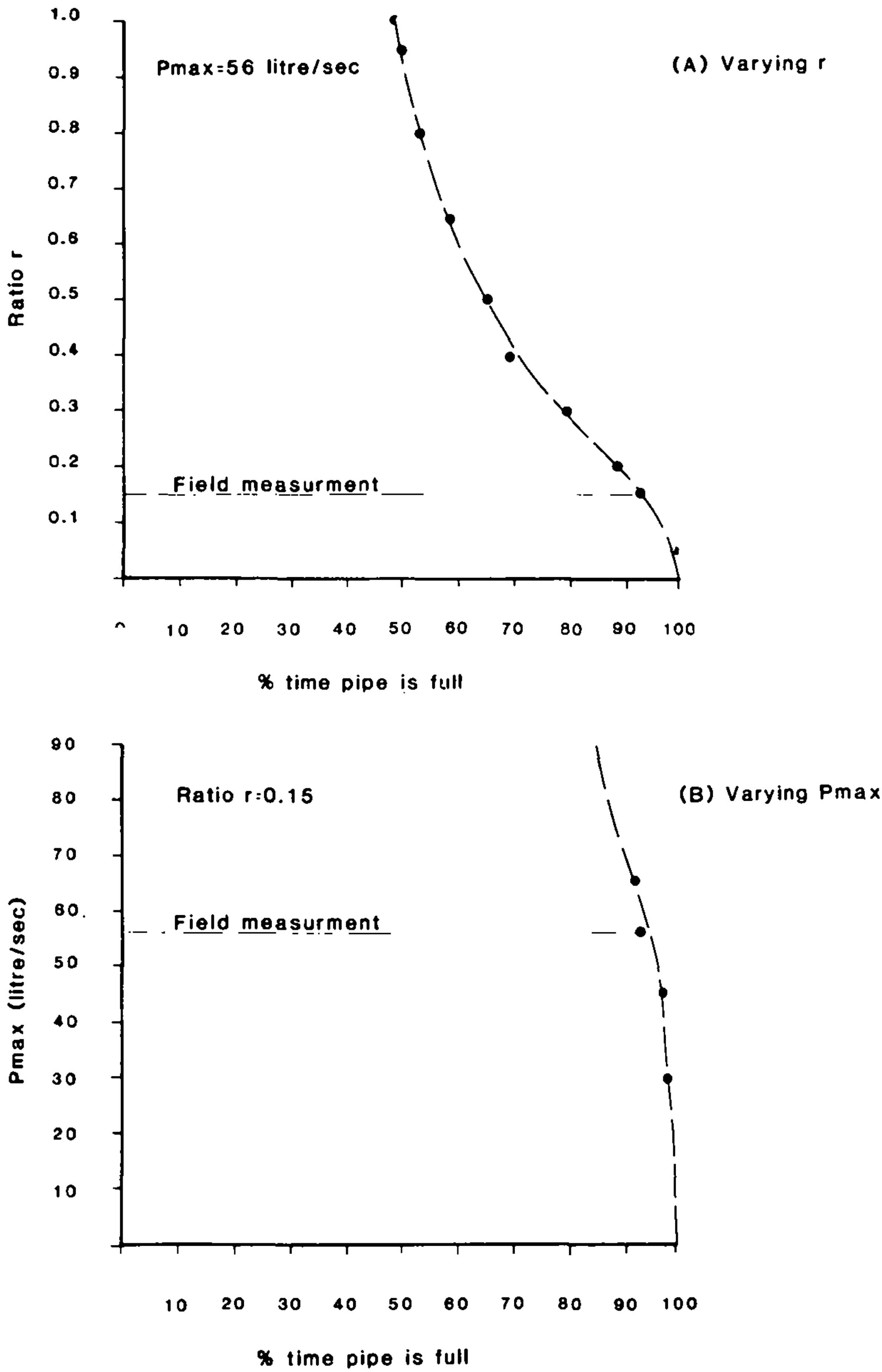


Figure 22

5.0 ANALYSIS OF THE SAN JUANCITO MOUNTAIN CATCHMENTS

The aim of this part of the present study was to predict the long term yields of the Las Trojas, San Juan and Las Canas catchments in order to assess the conjunctive use of an existing pipeline with the development of groundwater extraction along the Rio Chiquito.

Unfortunately the recent available flow data, discussed in Section 3.0, were not of sufficient quality to generate flow duration curves for the catchments. The most relevant information available is contained in a report by R.P. Barahona and E.B. Romero (1977). Their analysis generated flow duration curves for each of the catchments based on monthly flow data. A summary of the method used in their study is described below.

The gauging sites were visited and the weirs recalibrated by current meter. Corrections were applied to the original flow data which were found to be inaccurate due to excessive silting behind the weirs and mistakes made in the conversion of stage data to flow. The relationship between the rainfall record at Nuevo Rosario, which began in 1913, and the longest available flow record at Jutiapa was then studied. Multiple regression techniques were used to derive the relationship

$$Q(1) = 45.049 + 0.049P(1) + 0.113P(2)$$

where $Q(1)$ is the present month mean flow in ls^{-1}
$P(1)$ is the present month total rainfall in millimetres
$P(2)$ is the previous month total rainfall in millimetres

The significance of each coefficient was checked using the Student's t test which showed all the chosen variables to be relevant.

The monthly flow record for Jutiapa was extended backwards to 1913 using the regression equation. The flow data of the neighbouring catchments were then extended backwards using simple regression with the Jutiapa record.

Personal discussion with Engineer Barahona confirmed that the method used to extend the monthly flow records for the San Juancito Mountain catchments was carried out competently and thoroughly. The extended monthly flow data were input to the Hydrological Database which was used to generate flow duration curves for Las Trojas, San Juan and Las Canas as shown on Figure 23. The curves show that the flow at Las Trojas, San Juan and Las Canas exceeds 16.5, 15.0 and 35.0 ls^{-1} respectively for 90% of the time record. Similary, the flows at Las Trojas, San Juan and Las Canas exceeds 22.0, 27.0 and 56.0 ls^{-1} respectively for 50% of the time. The curves can therefore be used to ascertain the percentage of time the pipe offtakes were running full, knowing the maximum capacity of the pipes, in a similar manner to that described in Section 4.3.

A comparison was made between the flow duration curves derived using the Hydrological Database and those generated by R.P. Barahona & E.B. Romero (1977). Descrepancies were apparent for all three catchments. Further investigation of how the curves of Barahona and Romero were derived is required to ascertain the cause of the difference.

The accuracy of the present analysis could have been improved if daily flow data were used rather than monthly data (Section 3.0). The original corrected daily data recorded up to 1973 would be the best source with which to repeat the analysis on a daily basis but regrettably they appear to be lost. No data were recorded between 1974 - 1984 and the recent information is of insufficient quality. Therefore, at present, the analysis cannot be

San Juancito Mtn. catchments

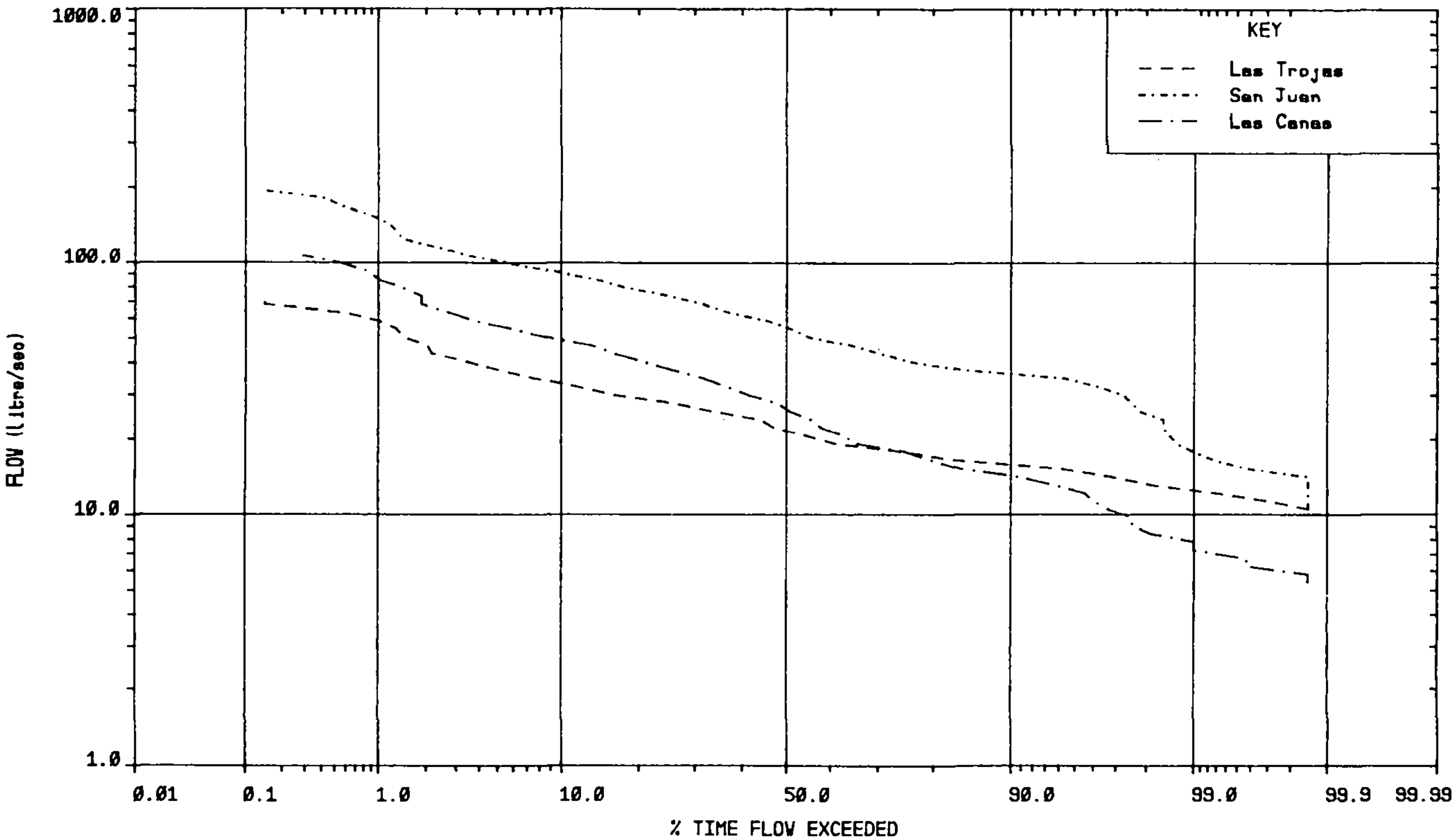


Figure 23

improved until more good quality data becomes available with the implementation of the recommendations described in Section 9.0.

6.0 TRAINING UNDERTAKEN

A series of training sessions were undertaken to teach staff from the Hydrology Unit of Plan Maestro, SANAA in the use of the Hydrological Database and analysis software supplied by the Institute of Hydrology as part of this project.

Each section of the package was demonstrated using local data and the participants encouraged to gain 'hands on' experience.

The course provided a basic training in the database and analysis packages. This included :

(1) Addition and deletion of stations

(2) Editing, checking, printing and plotting stage data

(3) Entry of river gauging data, plotting and fitting of rating equations

(4) Use of rating equations to derive daily flow data

(5) Editing, checking, printing and plotting of daily flow data

(6) Editing, checking, printing and plotting of daily rainfall data

(7) Analysis of data to produce flow duration curves and double mass plots

(8) Security backup of hydrological data

(9) System management such as the addition of passwords

The capabilities of the software to store hydrological data, check its validity and subsequently analyse the data was met by great enthusiasm from the participants.

The training sessions were undertaken on an IBM AT computer presently being used by the French Consultants, BCEOM. This computer has been designated for the Operations & Maintenance Department, SANAA after April 1987. The COMPAQ computer used by the Institute of Hydrology for the analysis associated with the current project was returned to the U.K. on completion of the project. Consequently, there was no computer available for use of the Database system by the Hydrology Unit staff of Plan Maestro. This system would enable hydrological data to be processed efficiently for assessment of future water supply projects. It is therefore recommended that a suitable computer should be purchased as a matter of urgency for the use of the Hydrology Section at Plan Maestro.

7.0 SOFTWARE DEVELOPMENT

Two computer programs were written specifically for the project and are described below These programs will be available for use by Plan Maestro staff as soon as a suitable computer can be obtained for the Hydrology Section.

7.1 JAPRAIN

Daily rainfall data for the Tegucigalpa region are presently being utilised by the Japanese company, Nippon Koei, in conjunction with ENEE to assess water resources for use in small hydro-electric schemes. The information is stored on an IBM compatible micro computer. In order to avoid manual re-entry of these data for the current study, the program JAPRAIN was written to transfer daily rainfall data from floppy disks produced by Nippon Koei to the SANAA Hydrological Database. A description of the program follows so that futher stations can be transferred once a suitable computer has been obtained (Section 6.0).

The program begins by reminding the user that a station must first have been added to the database and that space must have been allocated for all years of available data. The Nippon Koei data is stored in blocks of calender years whereas SANAA operates in water years. This means that the start date on the database must be one year earlier than that stated within the data file to be transferred.

The following example demonstrates the use of the JAPRAIN program by describing the steps required to transfer a file containing Toncontin's daily rainfall from floppy disk to the database. The user response is typed in **bold**.

C:\HDB>**JAPRAIN**

Program to transfer Japanese daily rainfall data from floppy disk to database

Note that the station must first have been added to the database
and that space must have been allocated for all years

The start year on the database must be ONE year before
the start year on floppy disk because we store in water
years and data on floppy are in calander years

Enter filename of input data (if file is on floppy, prefix with A:)
eg A:TONCON > **A:TONCON**

Enter database station number for this station > **56007**

First line of file is : TONCONTIN

Proceed yes/no > **Y**

1951
1952

1984
1985

Transfer data to HDB database now yes/no > **Y**

What is your password (in LARGE letters) > **MAB**

data is now transferred to Database.

The data transfer may take some minutes and the user should wait while this takes place.

7.2 SABPROG

Program SABPROG was written to carry out the naturalisation of flows of the Rio Sabacuante catchment as described in Section 4.0. SABPROG utilises daily flow data measured at El Aguacate to predict the daily naturalised flow upstream of the pipe offtake and the flow of water in the pipe itself. The prediction is based on values of 'r', the ratio of the flow upstream and downstream of the offtake and the maximum capacity of the pipe, Pmax, as defined in Section 4.1. This information can be stored in the Hydrological Database for further analysis. A desrciption of the program follows to enable the process to be repeated using revised daily flow data for El Aguacate, different values of the ratio 'r' or different values of original pipe capacity, Pmax.

The program first asks the user to input the date from which to start the process and then asks for the corresponding end date. The number of days of data used in the analysis is then displayed before prompting the user to input the maximum capacity of the pipe in units of m^3s^{-1}. The ratio of the downstream/upstream flow is next input followed by the value of any subsurface flow occuring at the El Aguacate gauging station (this should normally be zero). SABPROG then proceeds with the analysis and displays the percentage of time that the pipeline has been operating at maximum capacity. At this point the user has the option to transfer the daily flow data predicted upstream of the intake and the estimated flow in the pipeline to the database. After a password is supplied, the program proceeds to transfer the information to the database.

This program can be used to determine the influence of variations in the ratio of the measured upstream/downstream flow and to observe the effect of changing the original pipeline capacity.

It is important to note that SABPROG relates only to the pipe capacity of the existing pipeline. SABPROG cannot be be used directly to estimate the effectiveness of a possible replacement pipeline. It is the naturalised flows generated upstream of the existing pipe intake produced by SABPROG which are then analysed for the design of a replacement pipe as in Figure 20.

The following example describes how SABPROG is operated :

C:\HDB>**SABPROG**

Program to estimate natural flows upstream of the intake from daily flows recorded at El Aguacate and stored on the HDB database. Flows in the pipeline are also estimated.

Enter date from which to start the process eg 1,5,1971 > **1,5,1971**

Enter date to end process eg 30,4,1985 > **30,4,1985**

Naturalising over 5114 days

Enter maximum pipe capacity in cumecs (eg 0.056) > **0.056**

Enter subsurface flow at El Aguacate (cumecs) > **0.0**

Start date 1/5/1971 End date 30/4/1985 Days in period : 5114

Maximum pipe capacity (cumecs) = 0.056
Ratio of downstream/upstream flows = 0.150
Subsurface flow at El Aguacate (cumecs) = 0.000

Please wait

Days total 5114 Days missing 87 Days full 4645 Days not full 382
Pipe full (% of time) = 92.4

Transfer upstream & pipe flows to HDB Y/N > **Y**

What is your password (in LARGE letters) > **RD**

data is now transferred to the database.

The transfer of the data may take some minutes and the user should wait while this takes place.

Staff of Plan Maestro were trained in the use of both JAPRAIN and SABPROG so that further data could be transfered from Nippon Koei and the Sabacuante catchment analysis repeated if required.

8.0 APPRAISAL OF THE STREAM-GAUGING NETWORK

An assessment of the stream-gauging network of the rivers contributing to Tegucigalpa's water supply .concluded that three additional stations (staff gauges) are required to improve the hydrological information being collected at present.

The first location of a new gauging station is upstream of the Sabacuante pipe offtake. Such a station is important for the design and operation of the proposed new pipeline and possible dam. A suitable site has been identified, as shown on Plate I, and discussed with Plan Maestro staff. The location selected corresponds to the site of a previous weir which was constructed in 1964 but destroyed in 1974 by hurricane Fifi, the data for which has been lost.

The sites of the other two gauging stations required are located on the Rio Chiquito which is the only major ungauged tributary of the Rio Choluteca near Tegucigalpa. Two stations are required to quantify any groundwater supply or loss in the reach between El Chimbo and La Sosa. There is easy access to both sites, the first of which is situated close to a new road bridge, 0.9 km from the road junction at El Chimbo which leads to the El Piliguin valley, travelling towards Tegucigalpa. A site for the staff gauge has been identified 30m downstream of the bridge as shown on Plate II. A suitable location for current meter measurements with good control downstream is positioned 10m upstream of the bridge. The second location of a gauging station is situated 3.8 km from the El Chimbo road junction, travelling towards Tegucigalpa where a private pathway leads down to the river. The proposed position of the staff gauge and a suitable current measurement site is shown on Plate III. Both the sites have been discussed with Plan Maestro staff.

Recommendations concerning the operation of the existing hydrometric network are given below in Section 9.2.

Plate 1
Rio Sabacuante
upstream
of offtake

Plate 2
Rio Chiquito
(upstream)

Plate 3
Rio Chiquito
(downstream)

Key
suggested
position of
staff gauge

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The main conclusions of the present study are :

(1) The quality of the hydrological data currently being collected for the catchments contributing to Tegucigalpa's water supply is generally of poor quality, primarily due to lack of supervision and training of observers. There was also a common problem of measuring equipment not being properly maintained or having insufficient accuracy to measure low flows.

(2) There is a need for three additional gauging stations (staff gauges) to supplement the existing gauging network, as described in Section 8.0.

(3) The analysis of the Rio Sabacuante offtake found the capacity of the present pipeline to be well designed. The position of the offtake was also well sited. The resulting flow duration curve of the natural river flow at the offtake is presented on Figure 20.

(4) Analysis of the San Juancito mountain catchments was impeded by a lack of suitable flow data. However, the long term yields of the catchments can be estimated from work carried out by R.P. Barahona and E.B. Romero (1977). The flow duration curves for Las Trojas, San Juan and Las Canas are presented in Figure 23, based on extended monthly flow data.

9.2 Recommendations

The following recommendations are made to improve the quality, availibility and usefulness of the hydrological data collected by Plan Maestro :

(1) There should be increased contact between Plan Maestro hydrology unit senior staff and the field observers. The following are required to achieve this objective :

(i) A vehicle should be made available for hydrology unit staff to visit each site twice per month.

(ii) A vehicle should be made available for the gauging crew to make regular current meter measurements.

(iii) Field expenses should be made available to staff when visiting El Chile.

(iv) The present situation of data being forwarded through SANAA Operations and Maintenance should end because this system removes the contact between Plan Maestro hydrology unit staff and the observers in the field. Observers should pass data directly to hydrology unit staff during the two weekly visit described in (i) above. This will enable any difficulties the observers have in measuring the hydrological data to the discussed on site. Furthermore, regular assessment of the data in the field will enable any problems to be identified and rectified quickly and so improve the quality of the information being collected.

(2) Arrangements should be made to enable observers to record data during weekends.

(3) A gauging station (staff gauge) should be established on the Rio Sabacuante upstream of the present offtake as described in Section 8.0.

(4) Two further gauging stations (staff gauges) should be established on the Rio Chiquito which are discussed in Section 8.0.

(5) White plastic millimetre rulers should be fixed behind the weir plates on the San Juancito stations to enable stage to be read to 1mm accuracy.

(6) The weir plates at Jutiapa and La Tigra should be fixed behind concrete supports as at Las Trojas, San Juan, Las Canas and La Tigrita. Sediment collected from behind each weir should be removed monthly and each weir calibration checked by current meter. Gaugings should be carried out both below the maximum capacity of the 'V' to check the theoretical weir formula and also above the 'V' to extend the usefulness of data at medium and flood flows.

(7) The raingauge at Jutiapa should be replaced.

(8) The missing chart recorder at El Aguacate should be replaced.

(9) The missing equipment at the El Aguacate climate station should be replaced.

The measures described above should be implemented as soon as possible and will produce a worthwhile improvement in the quality and range of hydrological data collected at Plan Maestro at very little additional cost.

The hydrological data at Plan Maestro should also be improved by entering all such data onto a single computer database. A suitable computer (eg IBM AT), should be assigned exclusively to this task. The system should be consistent with the database used in the San Juancito and Sabacuante studies with which the hydrology unit staff have received training.

10.0 REFERENCES

1. BARAHONA, R.P. and ROMERO, E.B., 'Estimacion de las aportaciones en las fuentes actuales y futuras para el abastecimiento de agua del distrito metropolitano', March 1977.

2. Institute of Hydrology, 'Hydrological Database Operation Manual', 1986.

3. PENMAN, H.L., 'Vegetation and Hydrology', Technical Communication No.53, Commonwealth Bureau of Soils, Harpenden. Commonwealth Agricultural Bureau, 1963.