INSTITUTE of HYDROLOGY

Microhydro Power

Schemes in

Sri Lanka

MICROHYDRO POWER SCHEMES

IN SRI LANKA

This report is prepared for

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Introduction

This report describes an assessment of the river flow characteristics at two proposed microhydro sites in South West Sri Lanka. The most northerly site (Figure 1) is at the Alupolla tea factory (80^{o} 32' E, 6^{o} 42' N) about 20 kilometres east of Ratnapura at an altitude of 605 m. The catchment area draining to the site is 18.4 km^2. The other site is at Beverley (6^{o} 22' N, 80^{o} 32' E) located approximately 40 kilometres south east of Ratnapura at an altitude of 305 m. It has the smaller catchment area of 5.3 km^2. Both sites are ungauged and it has been necessary to infer the streamflow hydrograph from the flow characteristics of gauged catchments in the region. The study is based on data published by the Irrigation Department of Sri Lanka[1] and rainfall and daily flow data collected by the Intermediate Technology Development Group.

The flow duration curve (cumulative frequency diagram) has been used to summarise the discharge characteristics of each site. Average discharge has been estimated from the long term annual average catchment rainfall and a regional rainfall runoff relationship. The seasonal distribution of flows has been investigated by studying the average number of days in each month when the daily discharge is below a given threshold. The report concludes with a discussion of the errors in the estimation and recommendations as to how they may be reduced by further data collection and analysis. Metric units are used throughout the report with the exception of Figure 7 where the published units of acre feet per square mile are used (1 acre ft/sq ml = 0.476 mm).

Available Data

Details of the gauging stations used in this report and the available flow data are summarised in Table 1. Each station has been assigned a reference number. Three years of average daily flow data was available at each of five stations and eighteen years of average monthly flow data at a further two stations. The location of these gauges, their catchment boundaries, and those of the two proposed microhydro sites are shown in Figure 1. The daily flow data for each station was listed by computer as shown in Table 2 (Sitawaka Ganga (01)

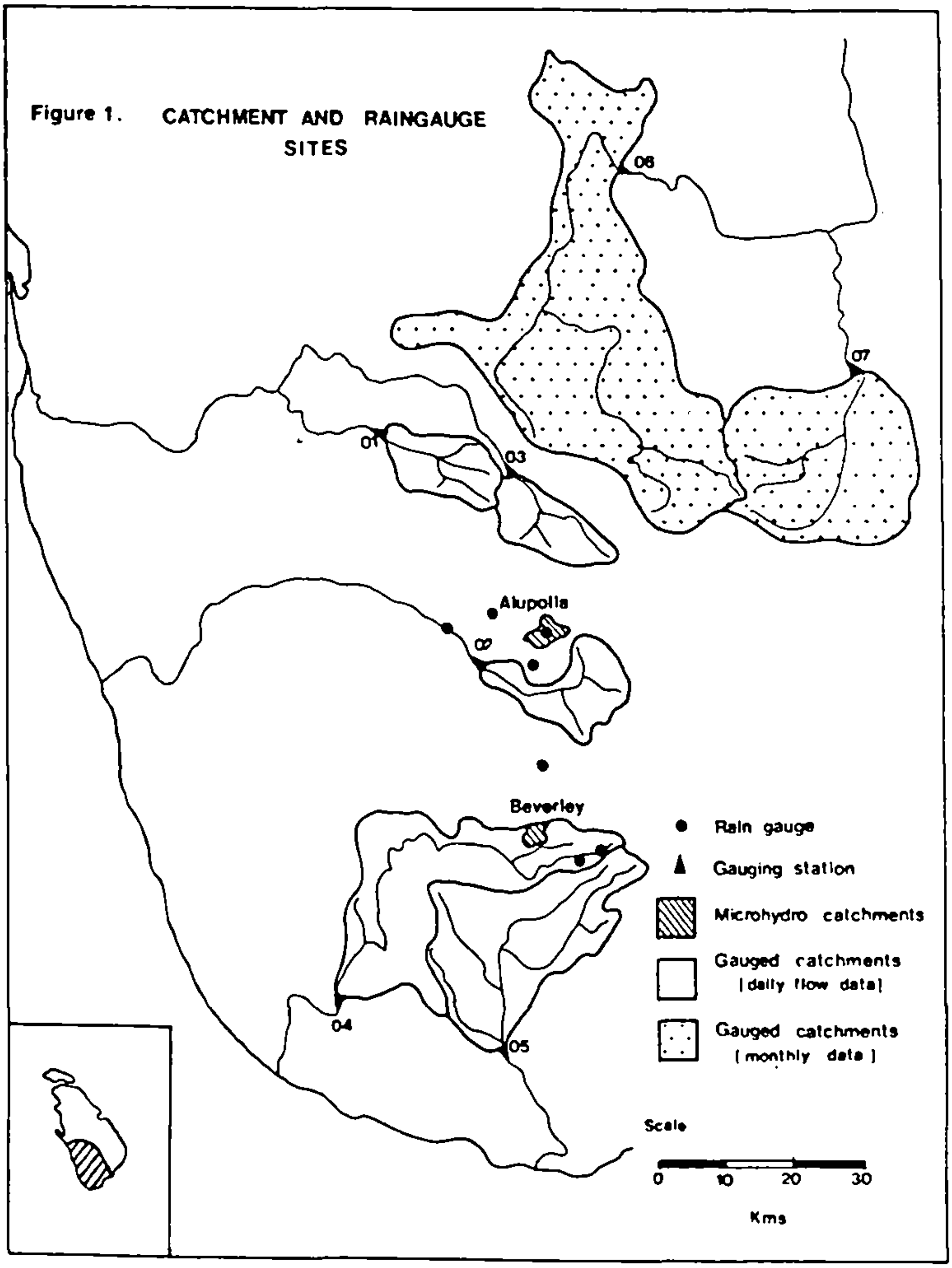


Figure 1. CATCHMENT AND RAINGAUGE SITES
06
07
01
03
Alupolla
02
Beverley
04
05
Rain gauge
Gauging station
Microhydro catchments
Gauged catchments (daily flow data)
Gauged catchments (monthly data)
Scale
0 10 20 30
Kms

TABLE I FLOW DATA

Ref. No.	Gauging Station	Location	Area (Km^2)	Data interval	Record length	Average annual runoff (mms)
01	Sitawaka Ganga at Deraniyagala	80° 20' E 6° 55' N	154	Daily	Oct 1974 - Sept 1977	4218
02	Way Ganga at Dela	80° 27' E 6° 37' N	220	Daily	Oct 1978 - Sept 1981	1301
03	Maskeli Oya at Laxapana	80° 31' E 6° 53' N	154	Daily	Oct 1966 - Sept 1969	4240
04	Gin Ganga at Jesmin Dam	80° 19' E 6° 20' N	377	Daily	Oct 1978 - Sept 1981	1952 *
05	Nilwala Ganga at Bingamahara	80° 28' E 6° 04' N	333	Daily	Oct 1975 - Sept 1979	1666 *
06	Mahaweli Ganga at Gurudeniya	80° 40' E 7° 16' N	1417	Monthly	Oct 1956 - Sept 1975	1736
07	Uma Oya at Thalawakanda	80° 58' E 7° 0' N	505	Monthly	Jan 1958 - Oct 1975	663
Microhydro sites						
	Alupolla	80° 32' E 6° 42' N	18.4			
	Beverley	80° 32' E 6° 22' N	5.3			

* estimated from Figure 7.

TABLE 2 AVERAGE DAILY FLOWS - SITAWAKA GANGA (01) FOR 1975

SITAWAKA GANGA AT DERANIYAGALA   DATA FROM GOFLOWS

YEAR 1975 NUMBER OF DAYS WITH DATA= 365 MEAN= 27.172 MINIMUM = 0.849 MAXIMUM = 154.943 (CUMECS)

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	4.446	1.019	3.256	1.736	16.225	24.975	20.473	22.030	77.361	25.315	73.605	13.123
2	3.905	1.104	2.152	6.935	15.715	22.795	15.532	19.755	59.077	22.393	93.473	16.424
3	3.370	1.213	1.314	11.927	15.715	23.220	17.415	17.523	29.109	45.927	108.113	14.725
4	2.332	1.359	3.171	6.255	13.232	49.752	15.999	15.271	25.145	26.391	[illegible].343	13.705
5	2.294	1.274	6.025	4.514	10.307	35.574	15.241	14.155	21.464	79.711	53.417	12.459
	1.735	1.139	1.312	6.201	63.617	59.535	14.725	18.293	13.293	133.031	131.233	11.123
	1.614	1.104	5.324	7.551	106.794	53.979	14.153	37.575	16.792	96.347	100.580	15.574
	1.472	1.019	2.010	5.920	74.141	51.736	11.950	44.146	15.271	40.634	71.733	20.076
	1.472	0.991	3.313	10.449	43.255	34.405	11.270	25.763	14.510	37.153	35.675	18.009
	1.355	0.963	4.537	11.555	54.010	29.274	10.590	29.194	14.326	31.494	45.540	15.517
11	1.359	0.906	3.171	11.945	41.144	33.227	10.194	32.521	13.647	27.325	30.278	13.195
12	[illegible]	0.906	1.736	7.495	25.391	35.431	14.272	41.525	12.601	19.349	55.015	10.374
13	[illegible]	0.905	1.472	10.104	21.[illegible]	35.679	15.241	104.470	11.950	19.322	49.752	9.628
14	1.214	0.906	1.472	11.723	16.252	27.640	16.282	47.572	10.930	24.037	25.672	3.920
15	[illegible]	1.133	6.428	13.337	19.452	75.193	13.847	39.841	9.911	29.653	99.674	6.153
16	1.213	1.019	4.106	15.391	16.595	63.401	11.803	35.254	70.430	35.227	90.890	11.605
17	1.213	0.906	1.756	11.952	15.291	51.310	31.593	41.144	25.765	22.030	32.115	11.270
18	1.215	0.675	1.472	10.675	26.[illegible]	39.213	26.877	47.034	22.936	22.736	50.455	11.355
19	1.213	0.349	1.359	9.375	26.589	33.631	24.211	31.092	20.614	22.767	34.794	11.412
20	1.215	0.349	1.501	3.070	59.465	40.099	21.562	25.457	19.293	22.563	35.652	10.937
21	1.219	0.349	2.719	5.762	75.535	51.455	19.057	26.929	57.337	17.559	32.791	10.647
22	1.245	0.349	2.124	6.345	59.[illegible]	46.903	16.452	25.455	116.353	69.177	33.001	10.307
23	1.246	1.274	1.954	7.551	51.164	42.317	13.947	24.041	77.729	111.705	37.603	3.920
24	1.215	1.699	1.472	5.925	52.434	45.731	17.754	22.563	76.145	154.945	37.576	7.649
25	1.219	1.303	4.214	14.953	63.712	42.550	21.562	13.123	71.525	39.112	34.023	6.033
26	1.213	0.905	3.143	20.543	64.957	37.123	19.522	17.132	60.997	114.739	33.930	5.093
27	1.210	0.876	1.472	12.[illegible]	43.[illegible]	30.299	14.151	21.652	62.[illegible]	140.337	47.731	5.374
28	1.219	0.974	1.416	[illegible]	41.[illegible]	23.770	16.452	31.092	45.595	117.117	33.497	5.720
29	1.133		1.331	22.565	33.[illegible]	25.533	9.090	48.365	34.031	92.573	25.145	6.083
30	1.019		1.331	11.707	33.[illegible]	22.505	13.357	56.974	28.500	60.799	21.034	5.405
31	1.019		1.303		27.156		20.376	59.112		74.645		5.720
DAYS WITH DATA	31	23	31	30	31	30	31	31	30	31	30	31
MEAN	1.611	1.041	2.590	11.240	41.445	44.712	13.454	33.992	37.976	56.659	52.341	11.014
MIN FLOW	1.019	0.349	1.019	1.755	10.307	22.558	9.090	14.155	9.911	17.639	21.034	5.324
MAX FLOW	4.446	1.699	6.428	24.059	135.754	38.531	81.693	104.470	116.353	154.942	135.113	20.076

in 1975) and each year of record was plotted as an annual hydrograph (see Figures 2.1 to 2.5). These plots assisted in the quality control of data prior to analysis.

The available rainfall data, in the form of monthly and annual totals, was limited to seven gauges each with an average of nine years of record. The location of the gauges is shown in Figure 1, and their annual rainfall totals summarised in Table 3.

In addition long term annual average rainfall and average runoff data was extracted from published records[1] for some 70 stations and used to derive a simple rainfall runoff relationship for Sri Lanka. This is shown in Figure 3; units are as published, namely acre feet/square mile and inches, but can easily be converted to mms using the scales provided. The data set includes three stations with daily flow data, and it can be seen that one of these, the Maskeli Oya (03) plots as a distinct outlier. The abnormally high average runoff from this catchment (in some years exceeding rainfall), probably results from the presence of a large reservoir and associated imports of water by catchwaters from adjacent catchments. This catchment is therefore considered unsuitable for deriving the natural flow regime at the two microhydro sites.

Catchment characteristics were derived in order to compare the topography of the gauged catchments with the Alupolla and Beverley catchments and these are summarised in Table 4. The catchment area, length of longest stream, and the slope along this stream length (expressed as m/km), were extracted from 1 inch to 1 mile topographic maps. The predominant soil types in each catchment were assessed from the 8 miles to 1 inch scale soil map of Sri Lanka[2]. The dominant soils are podzols associated with hilly and rolling terrain, although in the Sitawaka Ganga (01) and Maskeli Oya (03) catchments very steep rockland is present. An overall index of the flow regime at each of the five catchments was provided by the baseflow index[3]. This index is calculated from the mean daily flow hydrograph and represents the proportion of baseflow or slow response runoff.

Figure 2·1 SITAWAKA GANGA AT DERANIYAGALA ANNUAL HYDROGRAPH 1975

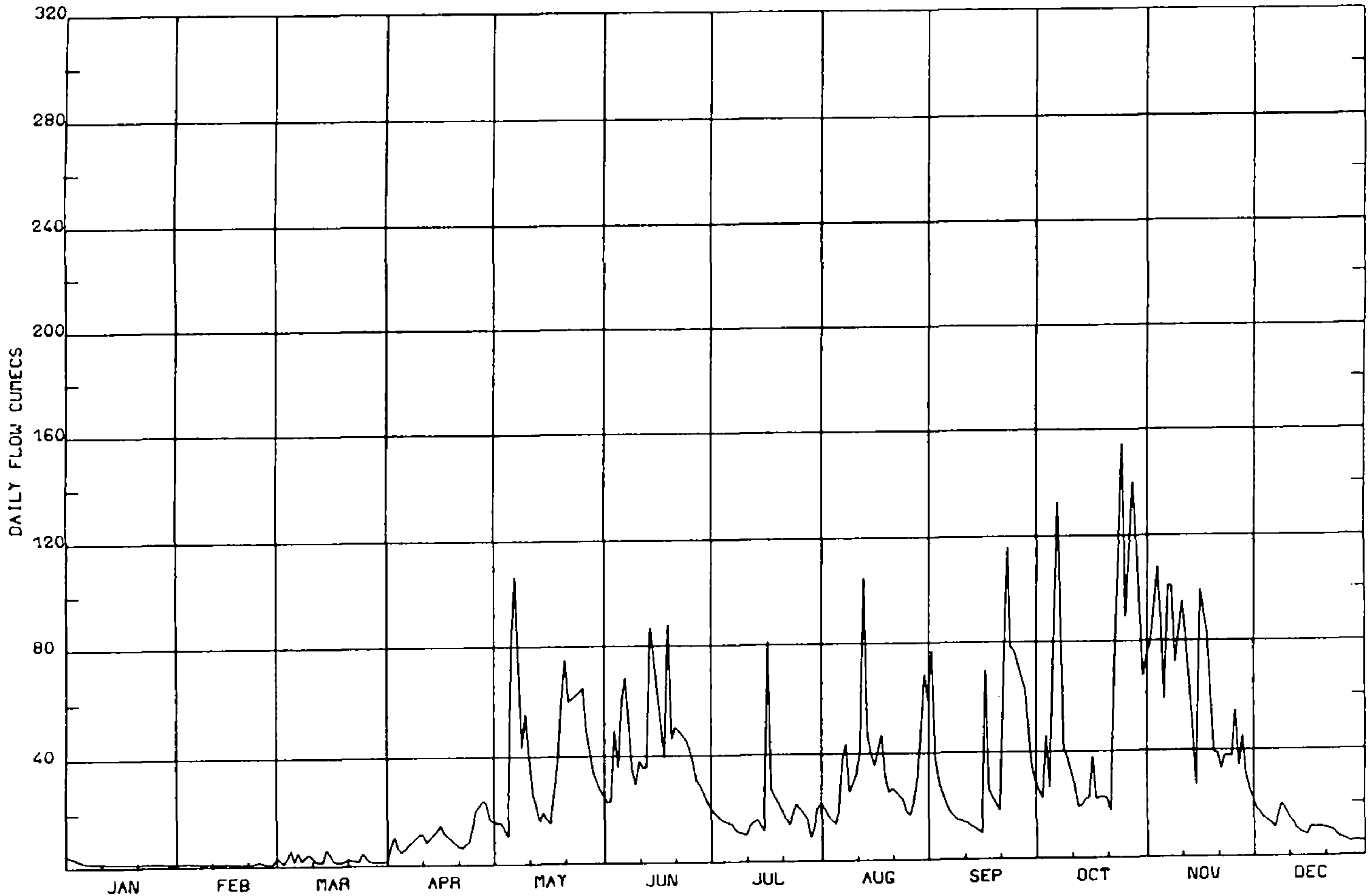


Figure 2·2 WAY GANGA AT DELA

ANNUAL HYDROGRAPH 1979

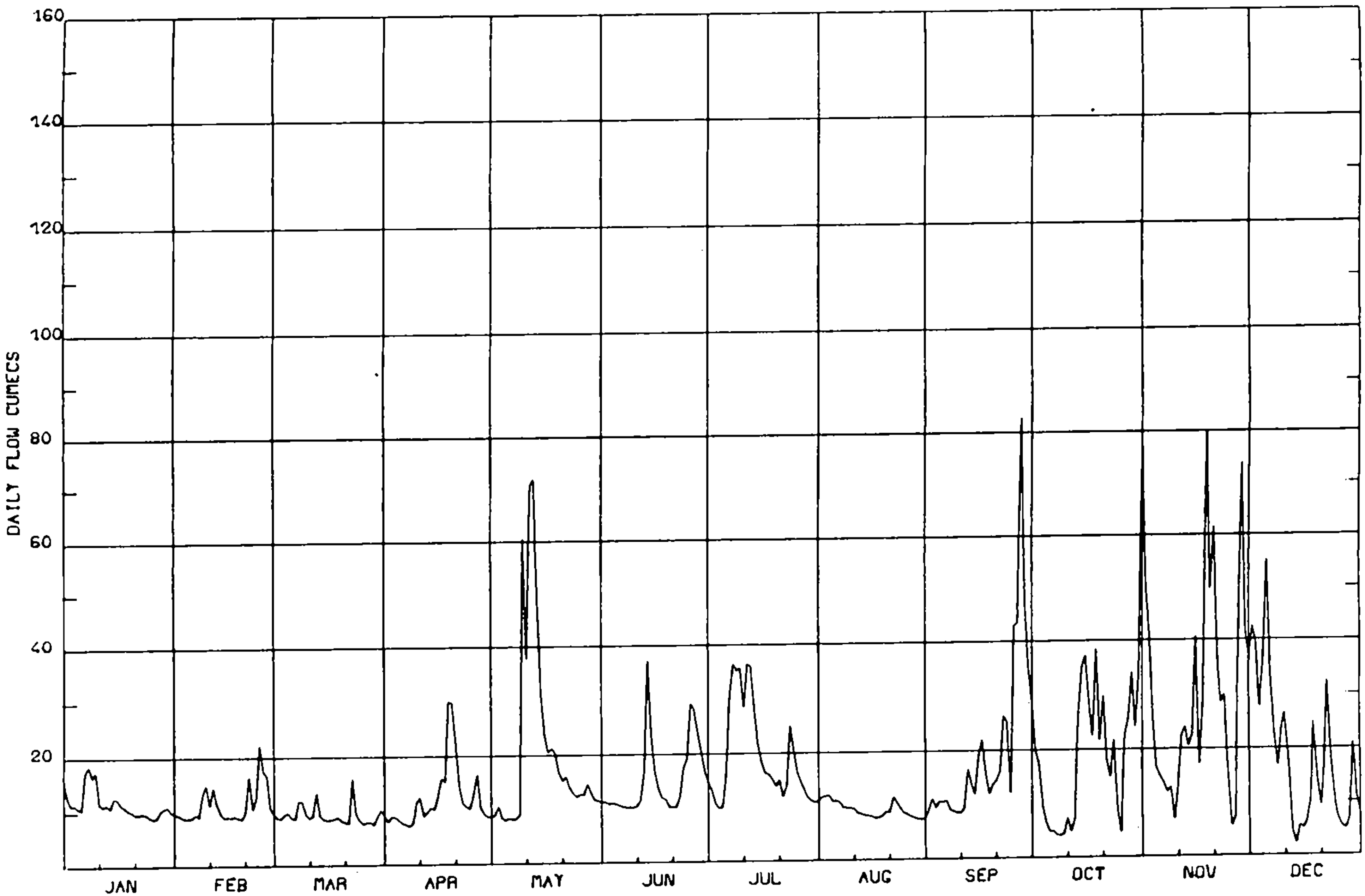


Figure 2·3 MASKELI OTA AT LAXAPANA
ANNUAL HYDROGRAPH 1968

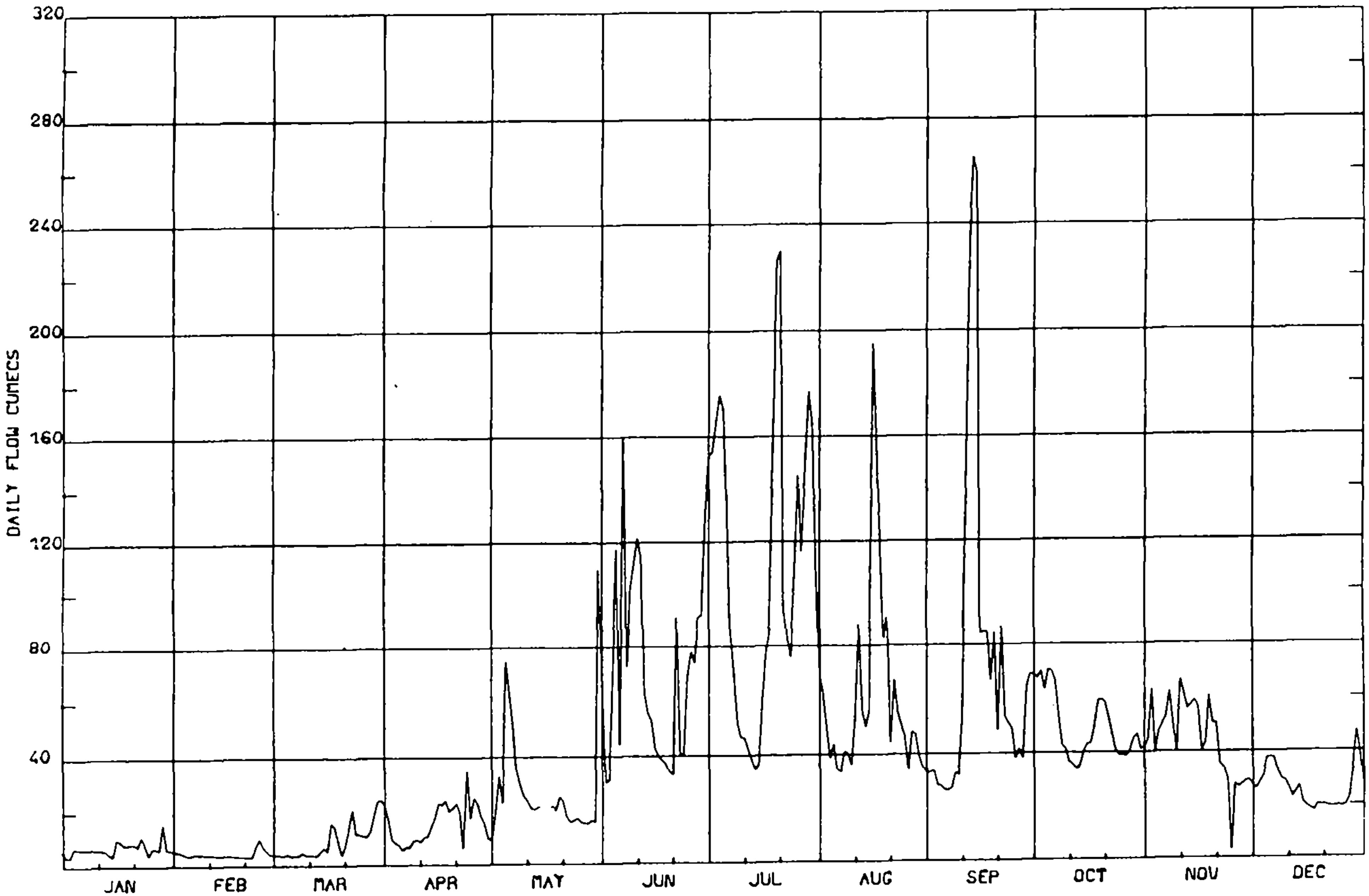


Figure 2·4 GIN GANGA AT JESMIN DAM
ANNUAL HYDROGRAPH 1979

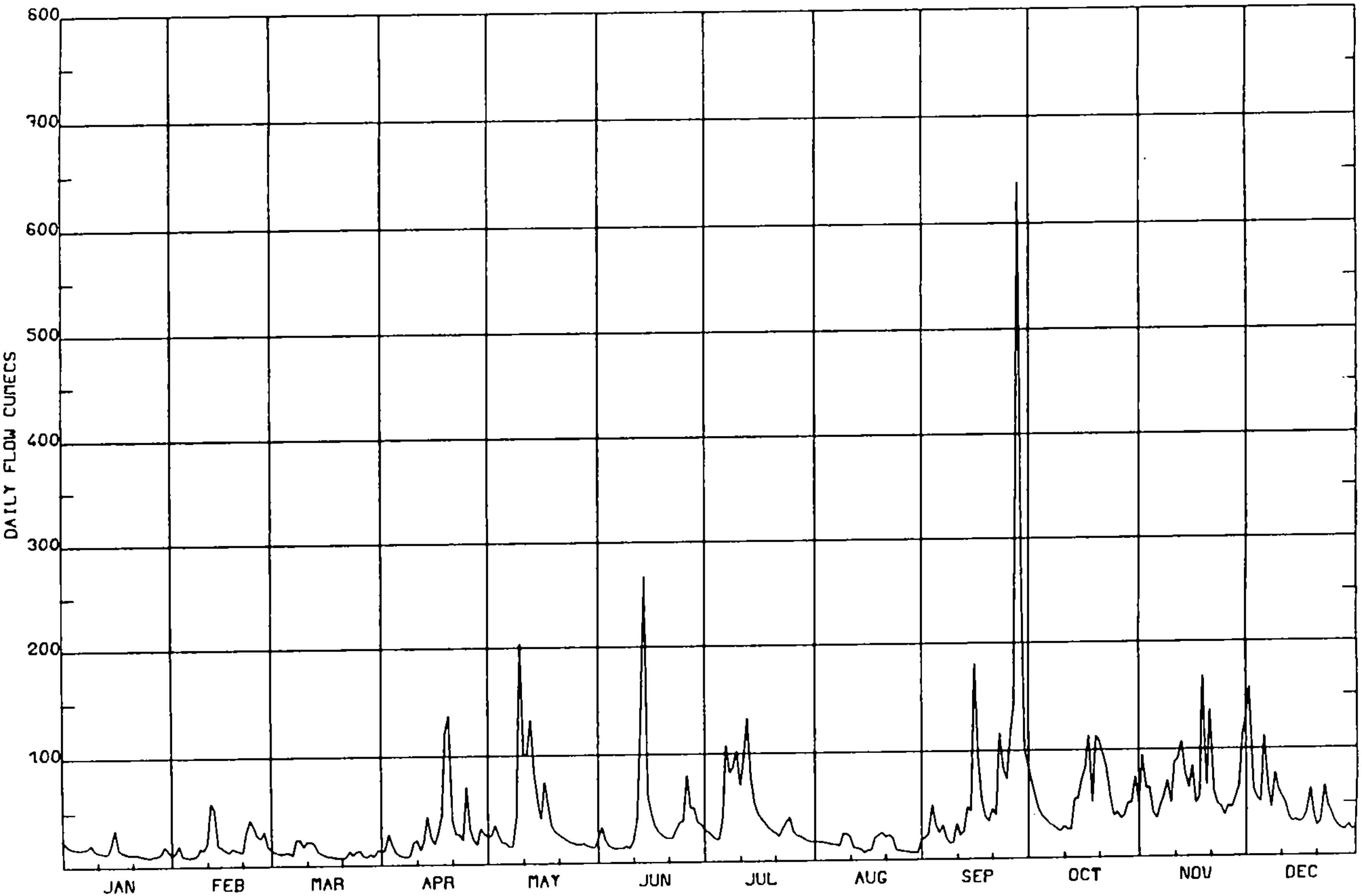


Figure 2·5 NILWALA GANGA AT BINGAMAHARA
ANNUAL HYDROGRAPH 1976

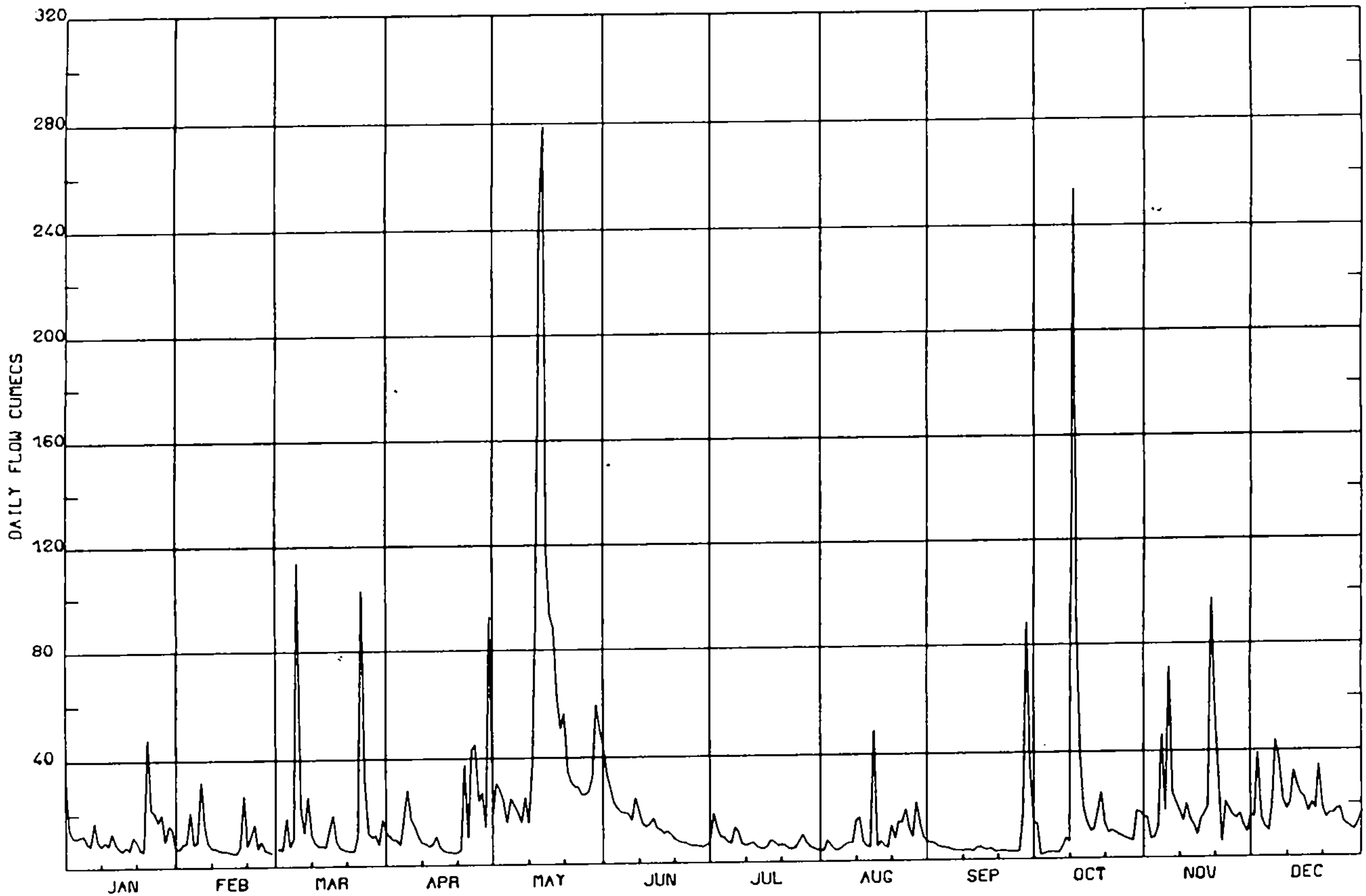


Figure 3. RAINFALL RUNOFF RELATIONSHIP FOR SRI LANKA

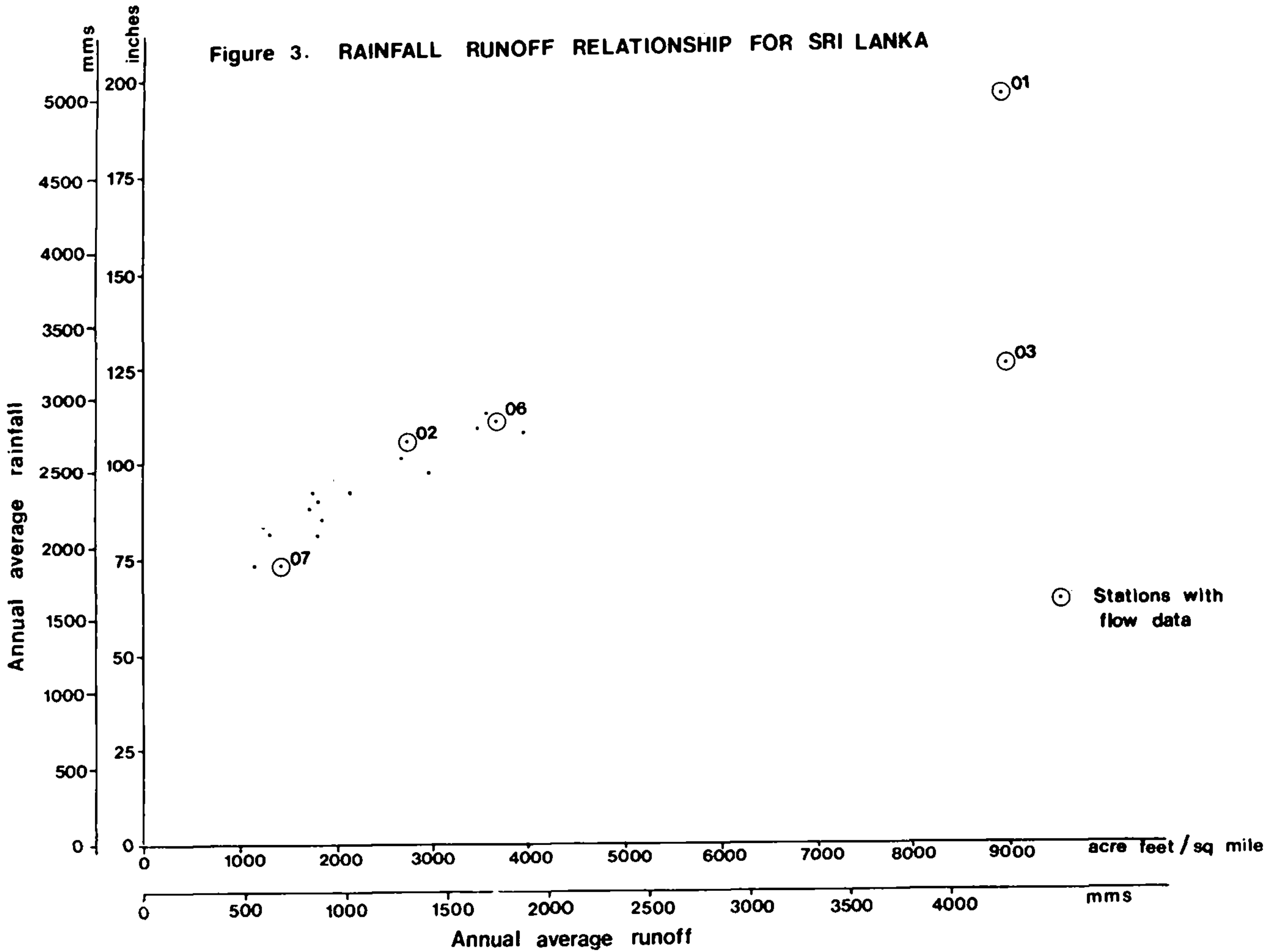


TABLE 3 RAINFALL DATA

Year	Alupolla	Ratnapura	Pelmadura	Hapugaseme	Panilkanda	Anningkanda	Dependene
	Annual rainfall (mms)						
1966	6709						
1967	4173						
1968	4791						
1969	3756						
1970	3840						
1971	4842						
1972	4844				3455		
1973	3437	3008	3353	3880	2940	3231	2894
1974	3827	3905	3421	5315	1752	2403	2373
1975	4275	4675	4020	6560	-	4295	2925
1976	2983	3380	2696	3984	-	2634	2129
1977	3201	3579	2991	4257	-	3334	2275
1978	3733	3743	4437	5095	-	3895	2523
1979	3237	3491	3009	4836	2714	3219	3217
1980	3043	3271	2338	3813	2783	2720	2910
1981	3742	3098	2233	4135	2581	2678	2309
Annual average (mms)	4027	3572	3166	4653	2704	3157	2617
Long term annual average (mms)	4353 [1]	3861 [2]	3422 [1]	5030 [1]	3362 [2]	3413 [1]	2829 [1]

Based on adjusting short term rainfall using long term rainfall from Ratnapura gauge

From Year Book

TABLE 4 CATCHMENT CHARACTERISTICS

Catchment Number	Area (Km^2)	Main Stream length (Kms)	Slope (m/Km)	BFI	Soil
01	154	22.7	72.4	0.462	28% steep rockland; 72% red yellow podzolic soils on steep hilly terrain.
02	220	41.0	13.5	0.469	98% red yellow podzolic and mountain soils on steep hilly terrain
03	154	24.0	45.8	0.543	25% steep rockland; 75% red, yellow podzolic soils on steep hilly terrain
04	377	49.7	22.9	0.494	45% red yellow podzolic soils on steep, hilly terrain; 55% podzolic soils on rolling terrain.
05	333	43.8	17.0	0.437	98% red yellow podzols on steep, hilly terrain.
Alupolla	18.4	7.6	76.1		100% red yellow podzolic soils on steep hilly terrain
Beverley	5.3	3.6	129.5		100% red yellow podzolic soils on rolling terrain.

Estimation of flow duration curves

Figures 4.1 to 4.5 show the flow duration curves for each of the five gauged catchments. Discharge, expressed as a percentage of the average daily flow (ADF) is plotted on a logarithmic scale and frequency on a normal probability scale. (Thus if the data plots as a straight line the daily flow data has a log-normal frequency distribution). From each figure the discharge exceeded for a given percentage of the time can be estimated. For example, Figure 4.1 indicates that for 90% of the days on record the discharge will be greater than 7% ADF, or conversely, that the discharge will be less than this rate for 10% of the time or on average 37 days each year. The 10 day curve on Figure 4.1 is derived from passing a 10 day moving average through the daily flow data. The curve thus shows the proportion of 10 day periods when the average flow is above a given discharge.

A comparison of Figures 4.1 - 4.5 indicates that station (01), the Sitawaka Ganga, has the greatest flow variability with the one day 95 percentile discharge (Q95) equal to 6% ADF. The equivalent discharge for the Way Ganga (02) and Maskeli Oya (03) is 16% ADF and 15% ADF with the Gin Ganga (04) and Nilwala Ganga(05) having the least variability with Q95 equal to 23% ADF and 21% ADF respectively. An analysis of the flow duration curves for individual years showed a small between year variation and gave greater confidence in interpreting these results. In order to test how representative the short (and different) periods of records were of the long term flow variability, the analysis was extended by deriving monthly flow duration curves for the two monthly flow stations with 18 years of data (Table 1). Figure 5 shows a comparison of these two monthly curves with the five curves derived by passing a 30 day moving average through the daily flow data (equivalent to calendar month curves). The close agreement between the curves suggests a general similarity in the pattern of flows over this region. This is further confirmed by the small variation in the base flow indices (Table 4) for the five catchments.

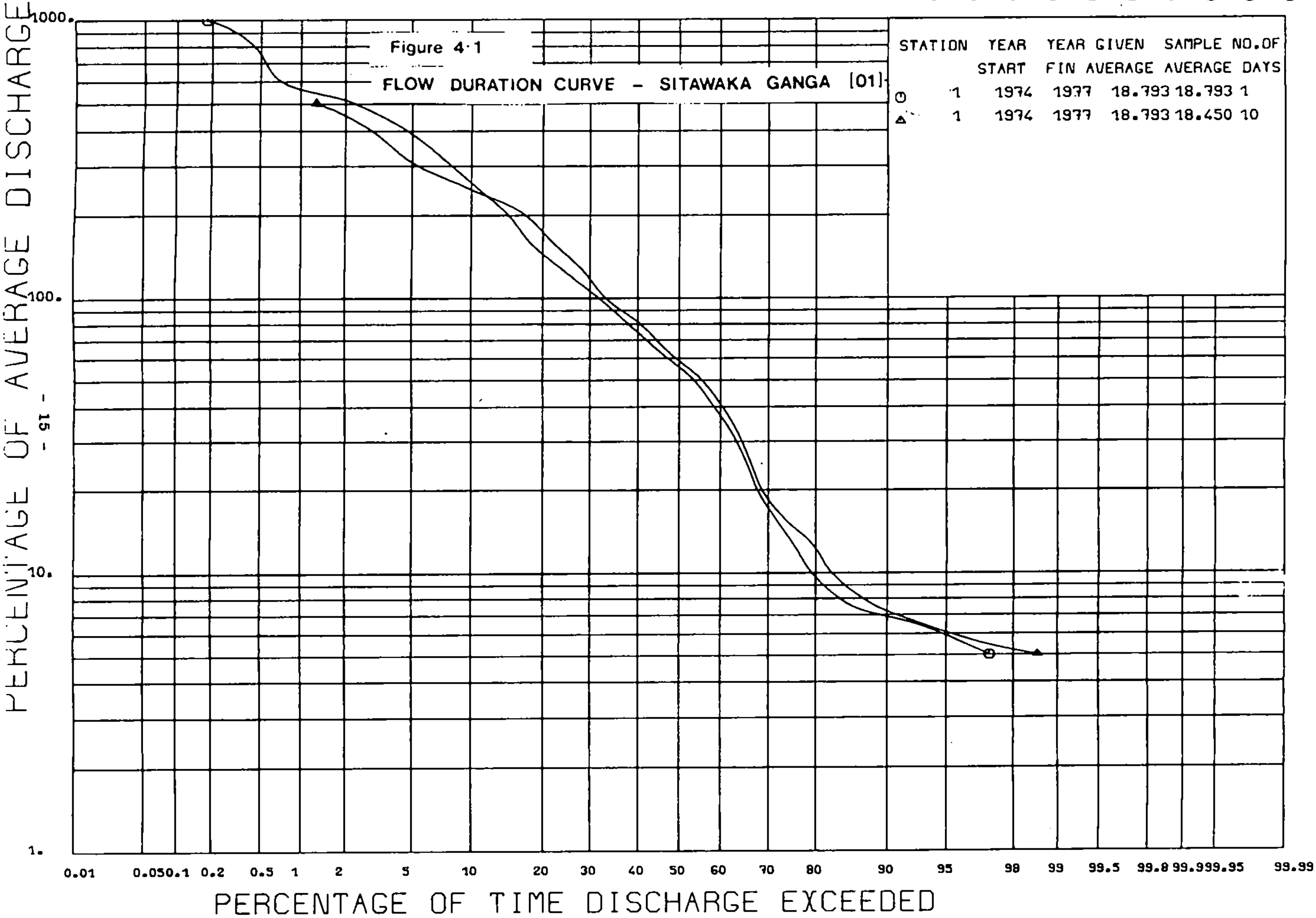
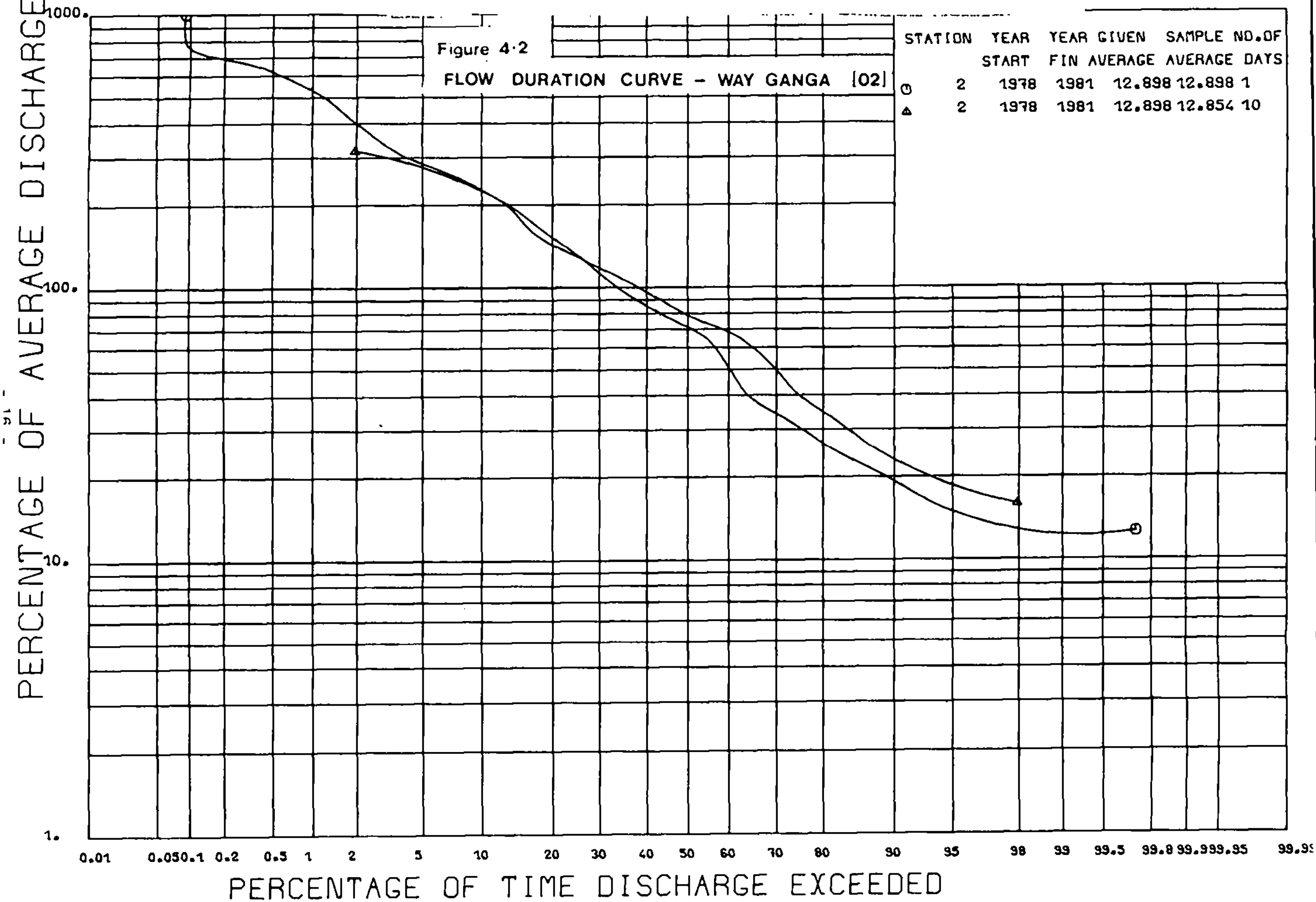


Figure 4·1
FLOW DURATION CURVE – SITAWAKA GANGA [01]
STATION YEAR START YEAR FIN GIVEN AVERAGE SAMPLE AVERAGE NO.OF DAYS
1 1974 1977 18.793 18.793 1
1 1974 1977 18.793 18.450 10
1000.
100.
10.
1.
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.95 99.99
PERCENTAGE OF TIME DISCHARGE EXCEEDED
PERCENTAGE OF AVERAGE DISCHARGE

Figure 4·2

FLOW DURATION CURVE - WAY GANGA [02]



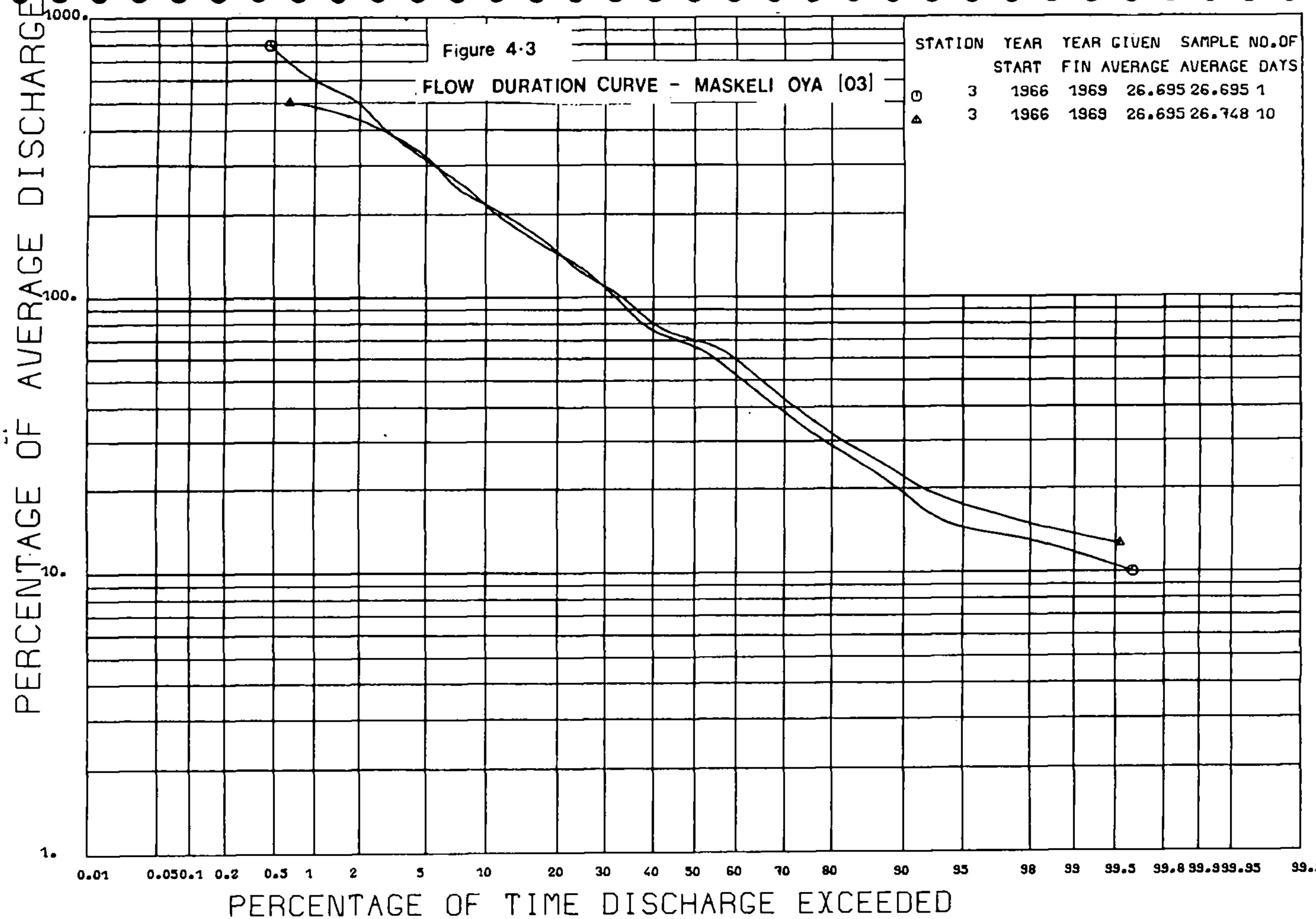


Figure 4·3
FLOW DURATION CURVE - MASKELI OYA [03]
STATION YEAR START YEAR FIN GIVEN AVERAGE SAMPLE AVERAGE NO.OF DAYS
3 1966 1969 26.695 26.695 1
3 1966 1969 26.695 26.748 10
1000.
100.
10.
1.
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.95
PERCENTAGE OF AVERAGE DISCHARGE
PERCENTAGE OF TIME DISCHARGE EXCEEDED

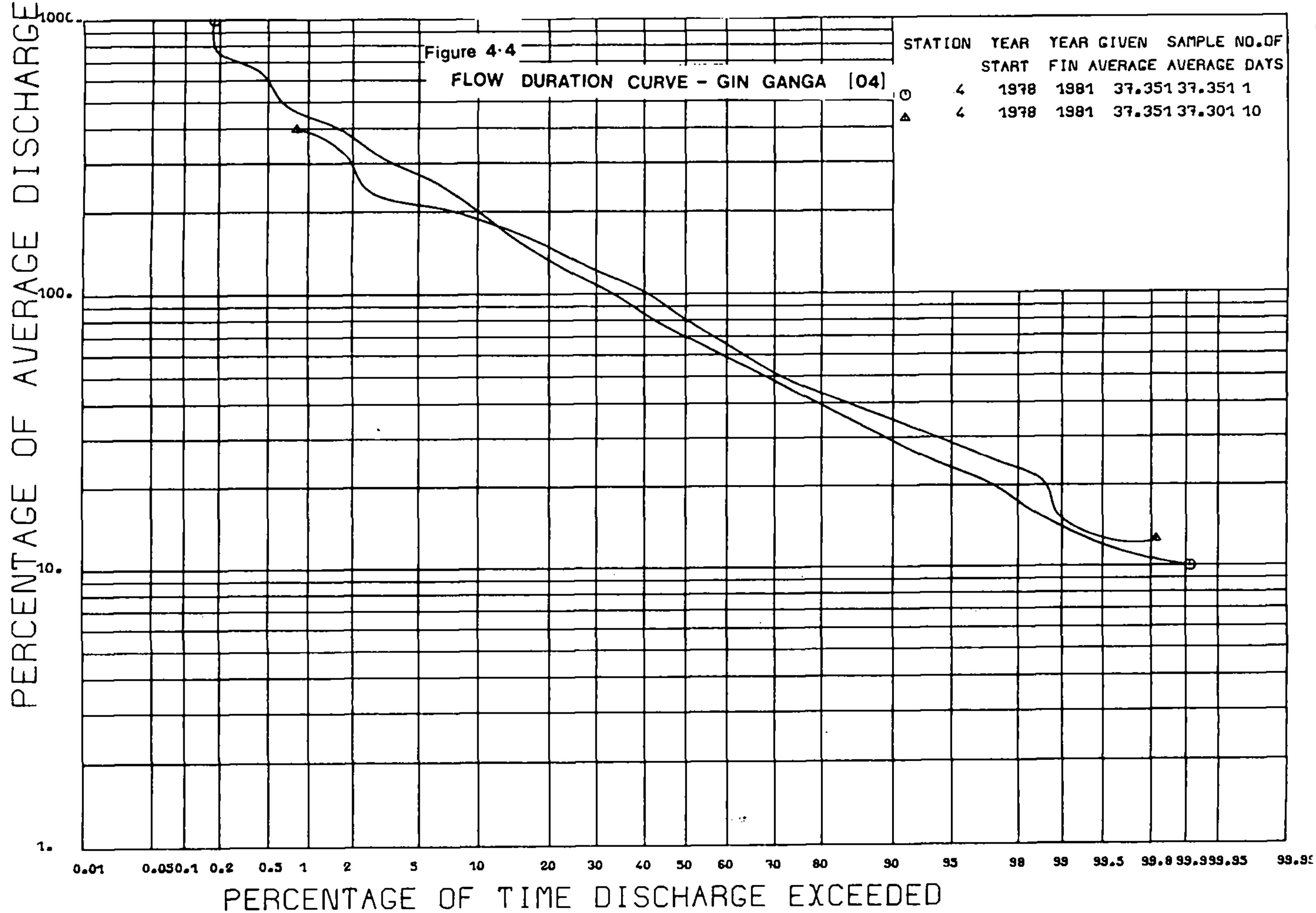


Figure 4·4
FLOW DURATION CURVE - GIN GANGA [04]
STATION YEAR START YEAR FIN GIVEN AVERAGE SAMPLE AVERAGE NO.OF DAYS
ʘ 4 1978 1981 37.351 37.351 1
Δ 4 1978 1981 37.351 37.301 10
PERCENTAGE OF AVERAGE DISCHARGE
1000.
100.
10.
1.
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.95
PERCENTAGE OF TIME DISCHARGE EXCEEDED

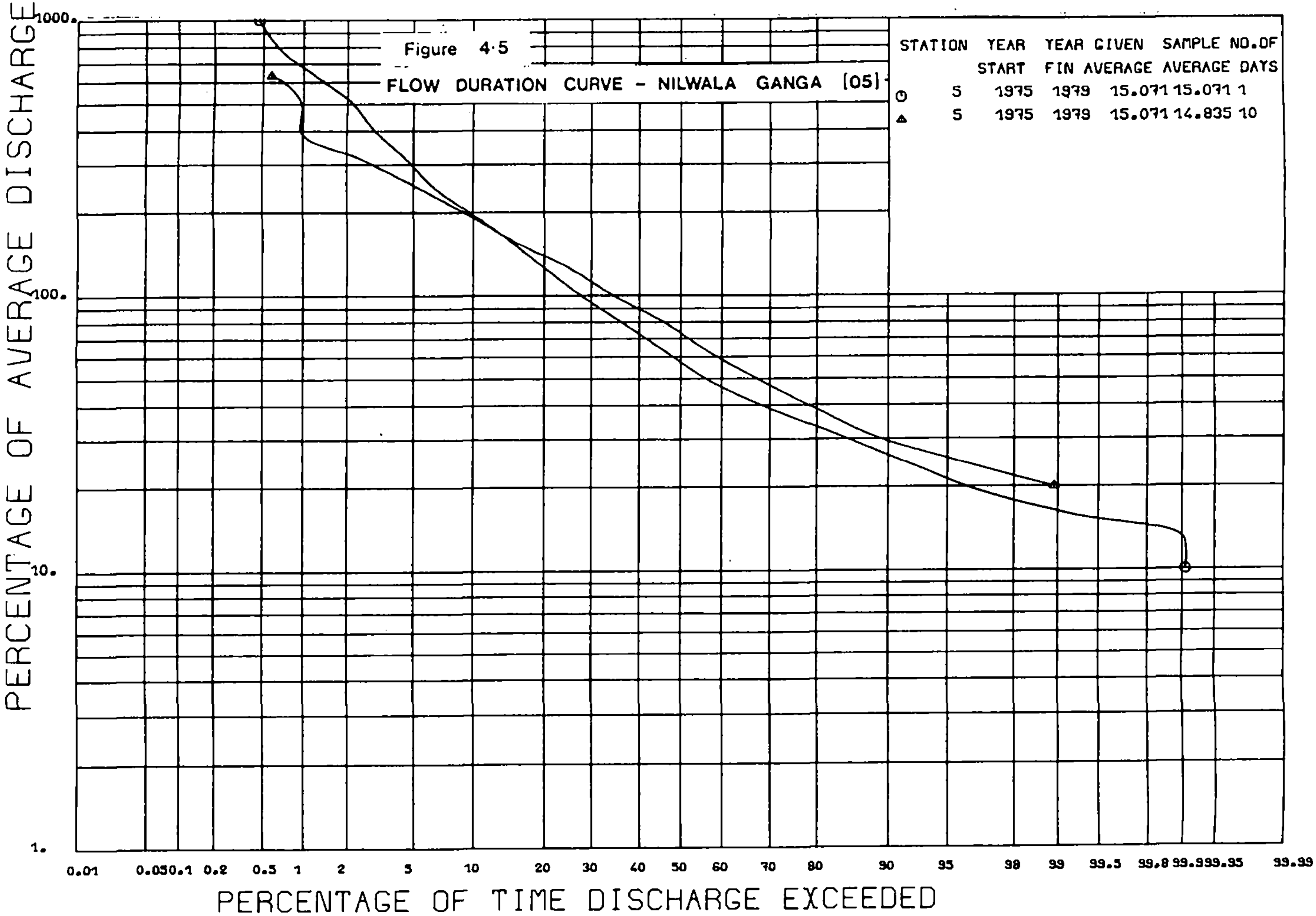


Figure 4·5
FLOW DURATION CURVE - NILWALA GANGA [05]
STATION YEAR START YEAR FIN GIVEN AVERAGE SAMPLE AVERAGE NO.OF DAYS
5 1975 1979 15.071 15.071 1
5 1975 1979 15.071 14.835 10
PERCENTAGE OF AVERAGE DISCHARGE
1000.
100.
10.
1.
0.01 0.05 0.1 0.2 0.5 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.5 99.8 99.9 99.95 99.99
PERCENTAGE OF TIME DISCHARGE EXCEEDED

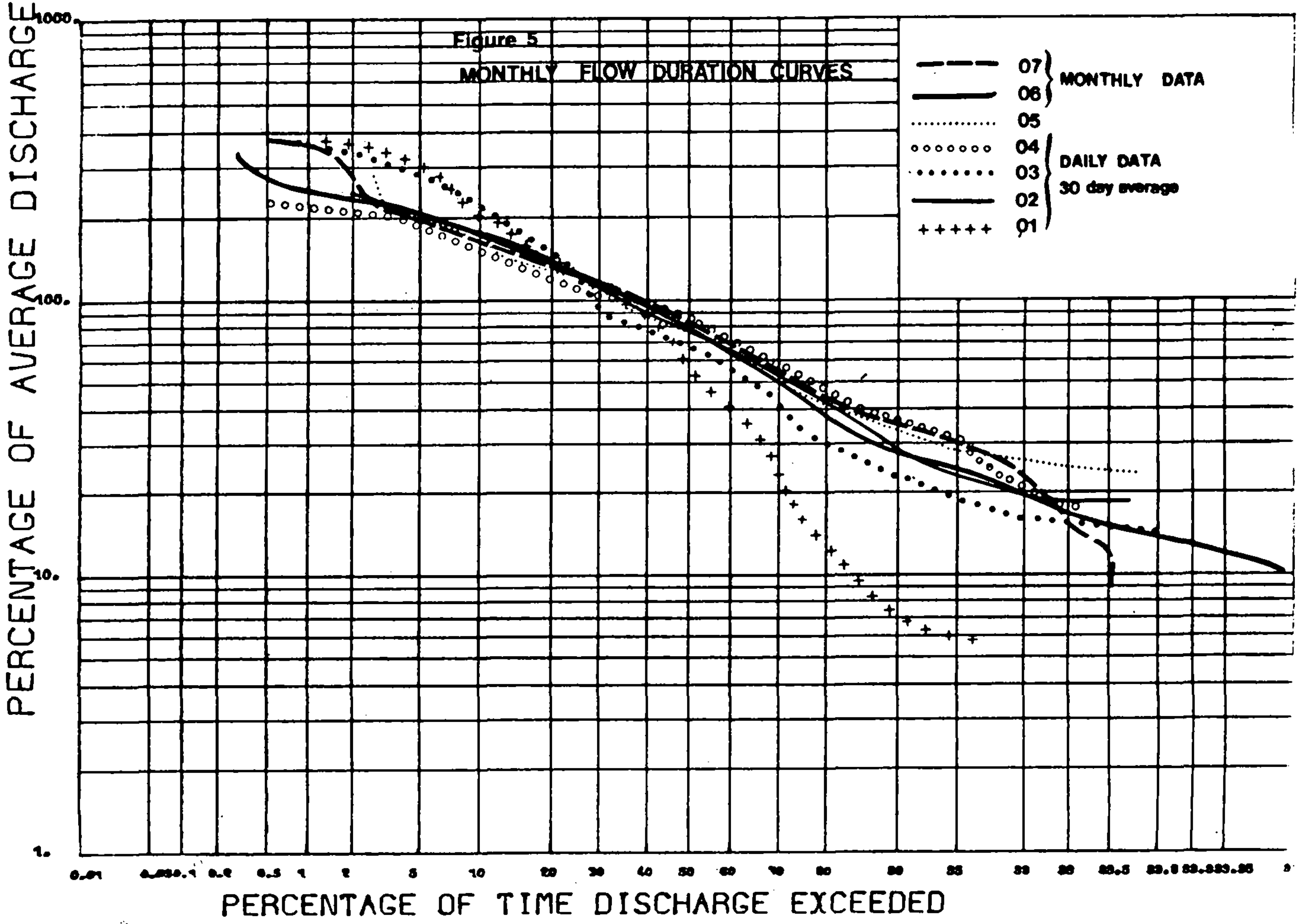


Figure 5
MONTHLY FLOW DURATION CURVES
07
06
MONTHLY DATA
05
04
03
02
01
DAILY DATA
30 day average
1000.
100.
10.
1.
10
20
30
40
50
60
70
80
PERCENTAGE OF AVERAGE DISCHARGE
PERCENTAGE OF TIME DISCHARGE EXCEEDED

The estimation of the most appropriate curve to use at each microhydro site is difficult because of the small number of flow records analysed, their relatively short record and their very small catchment areas in relation to the gauged catchments. With such small catchments local hydrogeological conditions (for example the presence or absence of a spring line) can have a marked control on the natural flow regime of a catchment. Such features cannot be identified in a preliminary desk study and require site investigations.

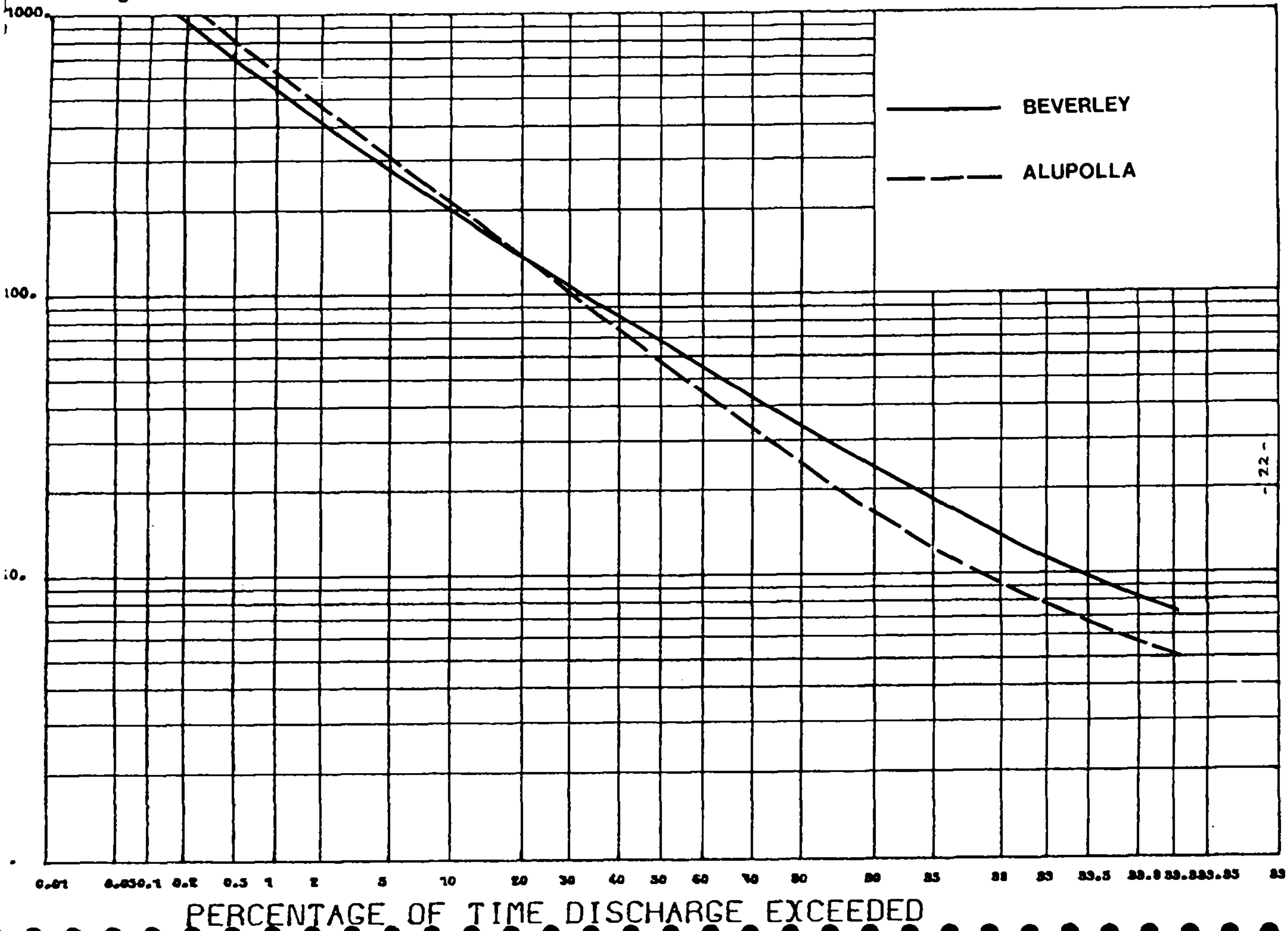
Comparison of the catchment characteristics of the gauged and ungauged catchments can however assist in selecting the most appropriate analogue catchment from which the flow regime of the ungauged site can be estimated.

It is considered that the Sitawaka Ganga (01) and Maskeli Oya (03) are unsuitable analogue catchments for Alupolla. Flows at the Sitawaka Ganga show a much greater variability than other catchments (Figure 5) and this is thought to reflect the large area of bare rock (Table 4), not present at either Alupolla or Beverley. This increases the rapid response flood runoff and reduces the available natural soil water storage which maintains low flows in dry weather. The Maskeli Oya (03) was rejected as flows are affected by artificial controls. The Way Ganga (02) is recommended as the best analogue for Alupolla due to its similar soil type and close geographical location. The Gin Ganga (04) (which encloses the Beverley site) and Nilwala Ganga (05) have very similar flow duration curves, and either of them would be suitable analogues for the Beverley site.

Both microhydro sites are however on small and steep headwater tributaries where the flow regime may be expected to show greater variability than the larger gauged catchments. This has been allowed for by steepening the 'best' analogue curves by an amount equivalent to a reduction in discharge of 5% ADF at the 95 percentile frequency. The final curves to use for Alupolla and Beverley are shown on Figure 6.

Figure 6

FLOW DURATION CURVES FOR MICROHYDRO SITES



Estimation of average discharge

In order to scale the flow duration curves derived for the Beverley and Alupolla catchments (Figure 6) it was necessary to obtain an estimate of the average discharge at each site.

Two approaches were possible. Firstly the annual average runoff for each catchment could be obtained directly from a runoff map, produced by the Irrigation Department, Sri Lanka[1] and reproduced here as Figure 7. This annual value could then be simply converted to an average discharge. The runoff isolines are expressed in acre feet/ square mile (1 acre foot/sq. mile = 0.476 mms). A second approach is to obtain an estimate of the annual average rainfall for each catchment and use the rainfall runoff relationship in Figure 3 to give an annual runoff value, which could be converted to an average daily flow as before. The second of the two approaches was preferred, since it was felt that the runoff map was insufficiently detailed to allow accurate interpolation to small catchment areas and did not make use of local rainfall data.

With the exception of the Alupolla raingauge, only nine years of rainfall data was available at each gauge on which to base an estimate of the annual average rainfall (Table 3). Comparison with longterm averages based on a 50 year record was possible for two raingauges at Ratnapura and Pannilkanda using a climate map of Ceylon[4], and revealed that short term values were lower than the long term averages. The short term averages were therefore adjusted on the basis of the Ratnapura gauge, as shown in Table 3.

This data is plotted on Figure 8, together with isohyets of annual average rainfall. In view of the relatively sparse raingauge coverage, use was also made of a detailed rainfall map for the Mahaweli Ganga basin[5], located just north of the study area. This map enabled the general trends of the isohyets to be established with greater confidence.

Figure 7 ANNUAL AVERAGE RUNOFF

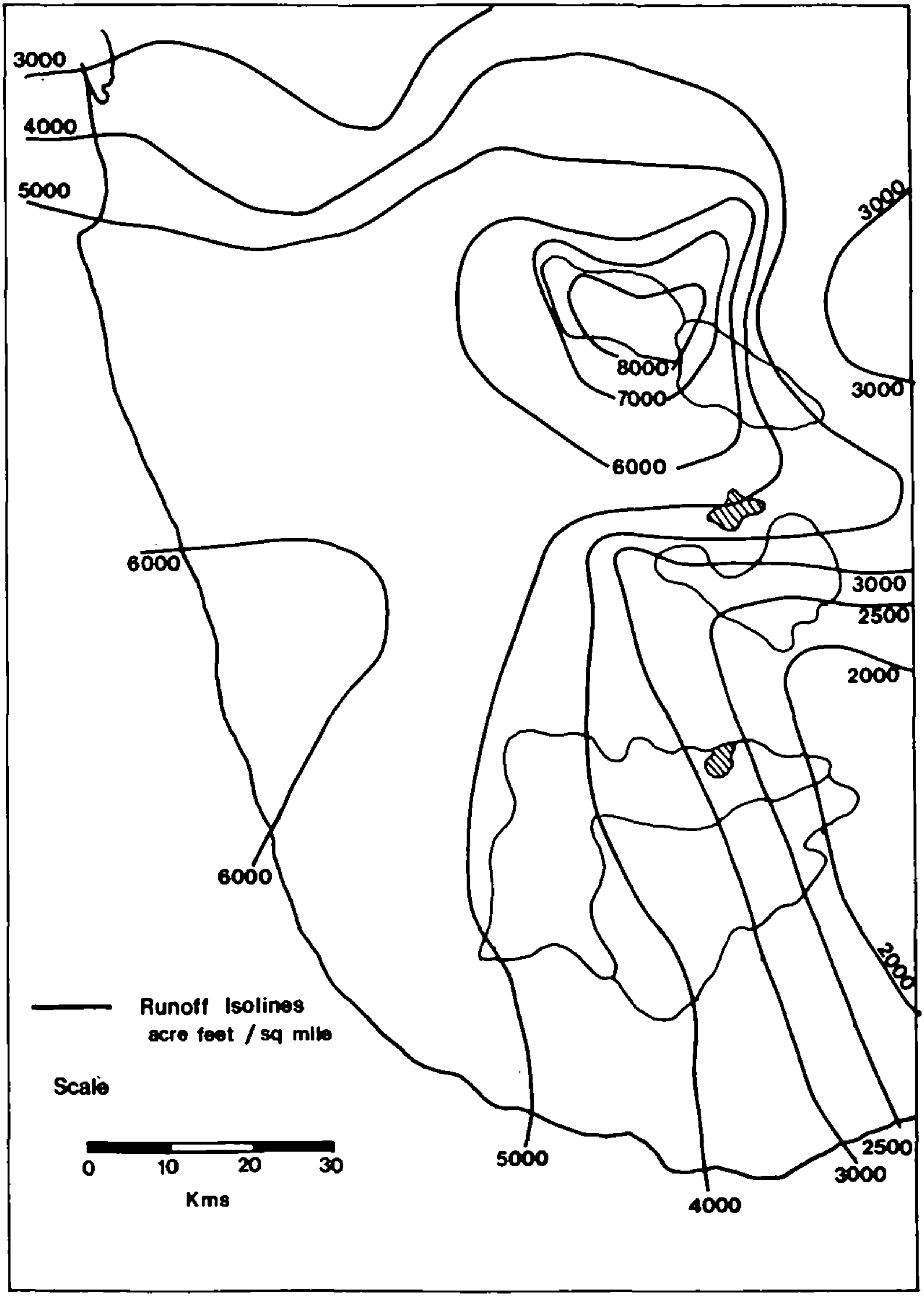


Figure 8. ISOHYETAL MAP

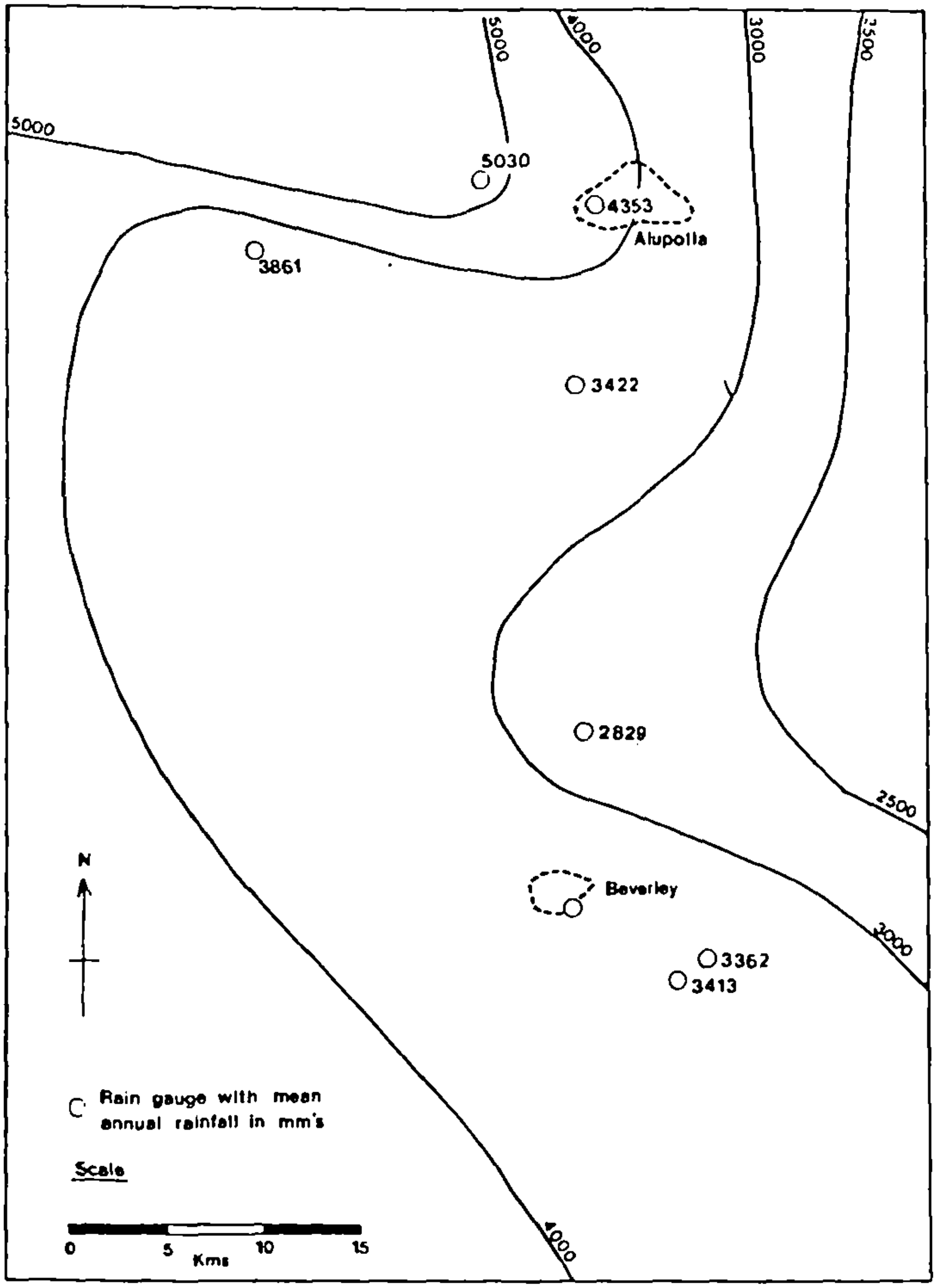


Table 5 shows the average annual rainfall for each catchment, and the average daily flows in cumecs calculated using Figure 3.

TABLE 5 AVERAGE RUNOFF FOR MICROHYDRO SITES

Site	Average annual rainfall (mms)	Average annual runoff (mms)	Average daily flow (cumecs)
Alupolla	4000	2689	1.568
Beverley	3500	2166	0.364

5 Seasonal variation

The seasonal variation in discharge was examined by calculating the average number of days in each calendar month when the discharge was below Q50, Q70 and Q90. Figures 9.1 - 9.5 illustrate the results of this analysis. A comparison of the histograms and Table 1 suggests that the catchments with the highest annual average runoff depth (Sitawaka Ganga, (4218 mm) and Maskeli Oya, (4240 mm)) have the greatest proportion of low flows in January to March. The drier catchments (Way Ganga, (1301 mm) and Nilwala Ganga, (1663 mm)) have a more even distribution with the peak number of low flows occurring in both January to March and July to October.

Given this link between the seasonal flow distribution and runoff depth the station having the nearest annual average runoff depth to Alupolla and Beverley was used to indicate the seasonal variation in runoff. Thus Figure 9.3 is proposed as the best indicator of the seasonal variation of the number of days below the given threshold discharges. From this figure it can be seen for example that on average there are 33 days when the flow is below Q90 between January

MONTHLY DISTRIBUTION OF FLOWS LESS THAN GIVEN THRESHOLD DISCHARGE

Figure 9·1

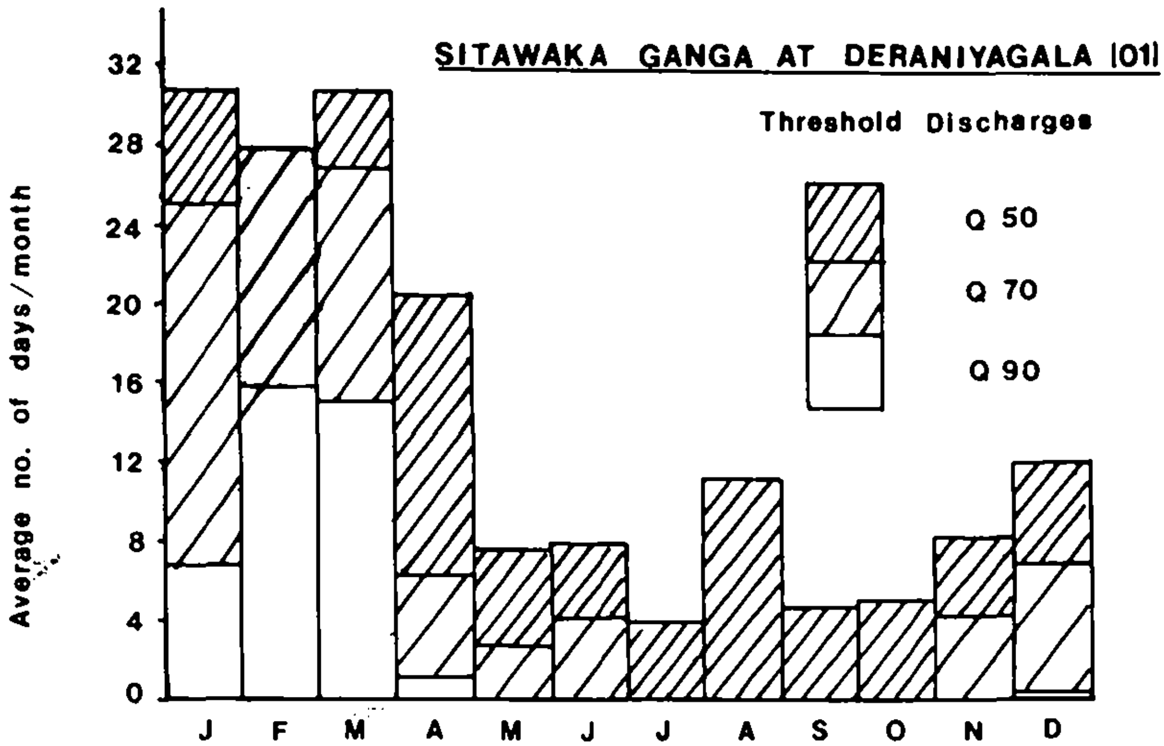


Figure 9·2

MASKELI OYA AT LAXAPANA (03)

MONTHLY DISTRIBUTION OF FLOWS LESS THAN GIVEN THRESHOLD DISCHARGE

Figure 9·3

GIN GANGA AT JESMIN DAM (04)

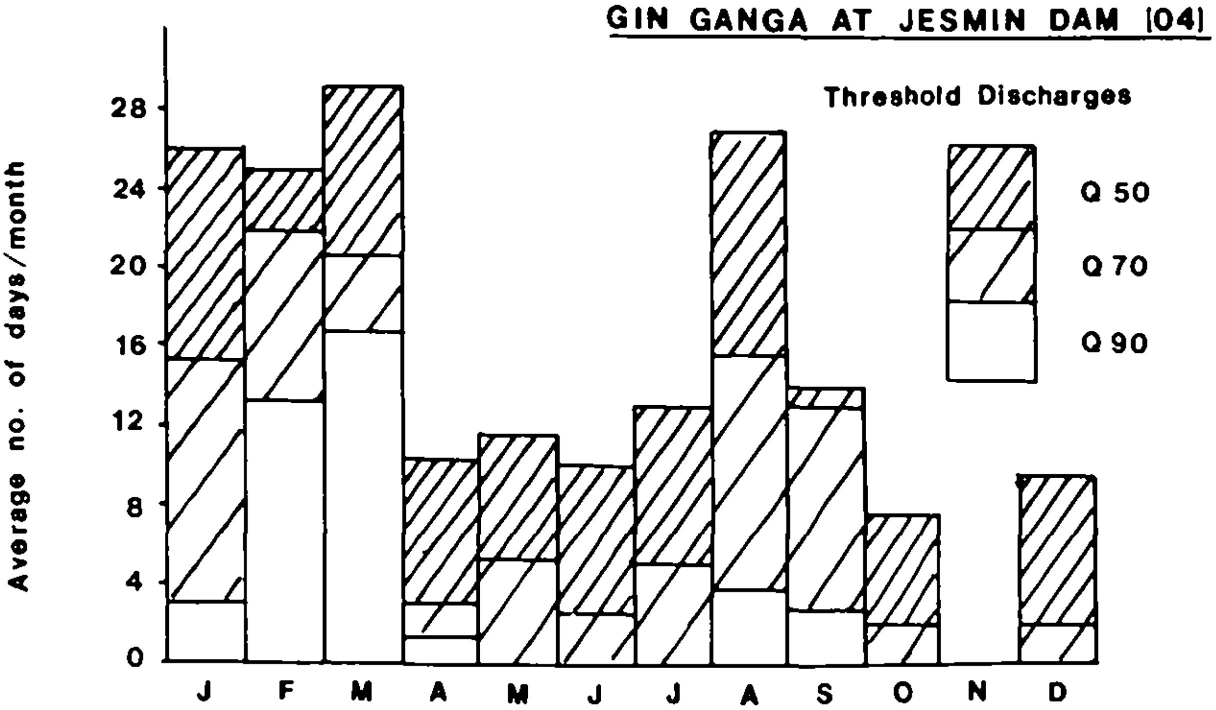
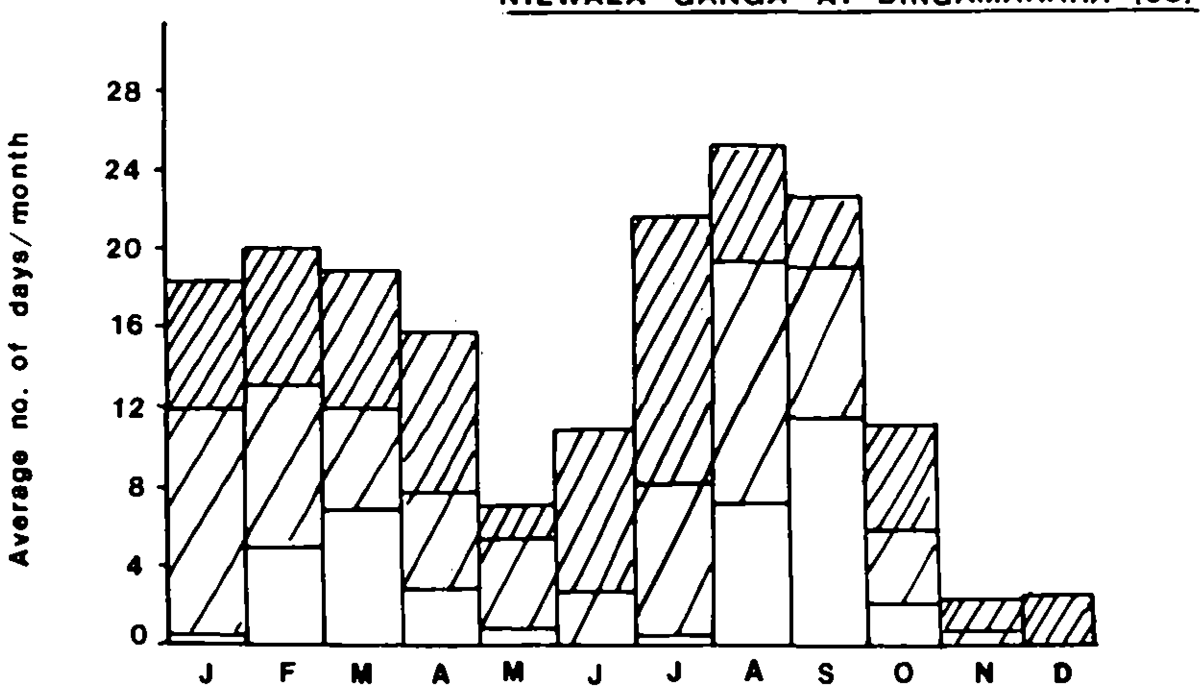


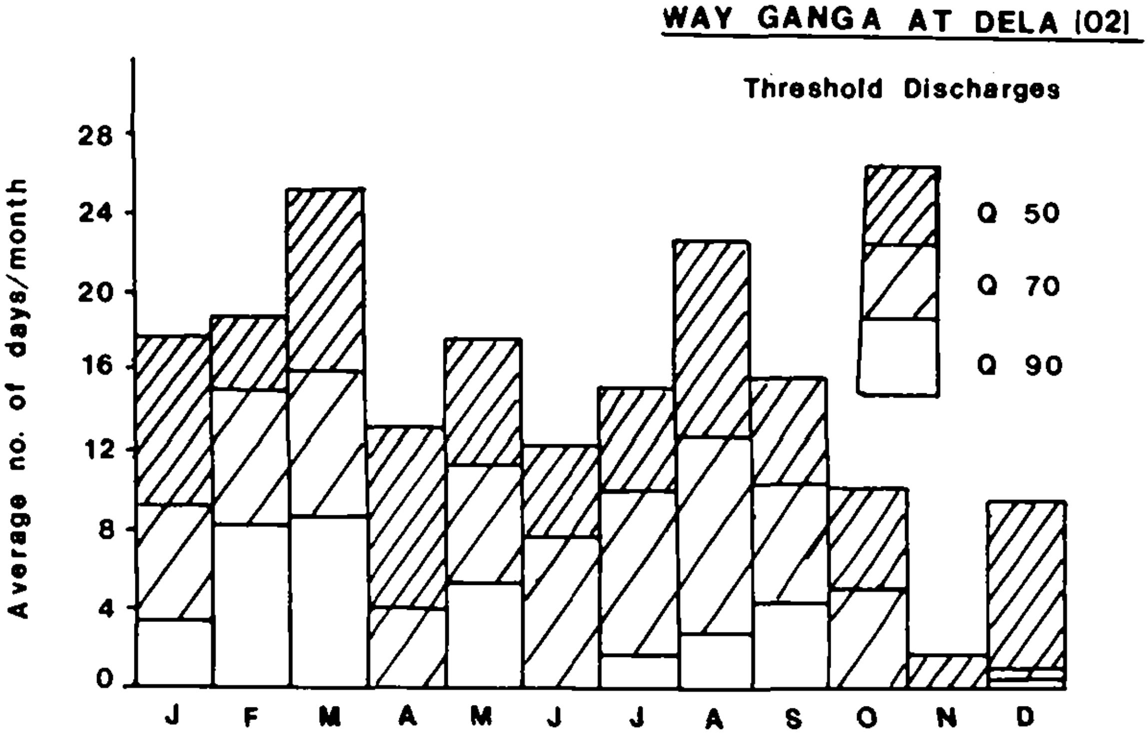
Figure 9·4

NILWALA GANGA AT BINGAMAHARA (05)



MONTHLY DISTRIBUTION OF FLOWS LESS THAN GIVEN THRESHOLD DISCHARGE

Figure 9·5



and March. This will therefore be a critical time for supplying power. A second critical period will occur in October to November. This seasonal variability of run-off reflects the monthly rainfall distribution of the region[2].

The seasonal distribution of flows other than Q30, Q70 and Q50 could be estimated by interpolation between these points. This should be done by plotting on log-normal graph paper the threshold discharge (expressed as a percentage of ADF) against the percentage of days in each month that this discharge is exceeded. This will enable twelve monthly flow duration curves to be very approximately estimated.

Summary and Recommendations

Estimation of the discharge exceeded for any given percentage of time for the Alupolla and Beverley microhydro sites can be made by reference to the appropriate flow duration curve on Figure 6. This must then be scaled by the estimated average daily flow (1.57 cumecs for Alupolla and 0.36 cumecs for Beverley). The seasonal distribution of low flows can be inferred for both sites from Figure 9.3.

The largest errors in the estimation procedure are in the validity of extrapolating data from the large gauged catchments to the small ungauged headwater catchments and in the estimation of average catchment rainfall from insufficient rainfall data. It may be possible to reduce the first of these errors by analysing additional daily flow records from smaller catchments in the region. The second error (which results in incorrect estimation of the average runoff) may be reduced by analysing more long term annual average rainfall data and producing an improved annual rainfall isohyet map. This could be done in conjunction with the Irrigation Department of Sri Lanka or the appropriate Meteorological Organisation.

Improvements could also be made by using longer flow records and by incorporating spot gaugings from the two microhydro sites. The latter approach would involve plotting discharge (measured at the site by a current meter or portable weir) against percentage exceedence derived on the same day from a nearby gauging station. The dry season from January to March and October to November would be the most appropriate time for this fieldwork.

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