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VARIATION OF RAINFALL WITH AREA IN PENINSULAR MALAYSIA

1989

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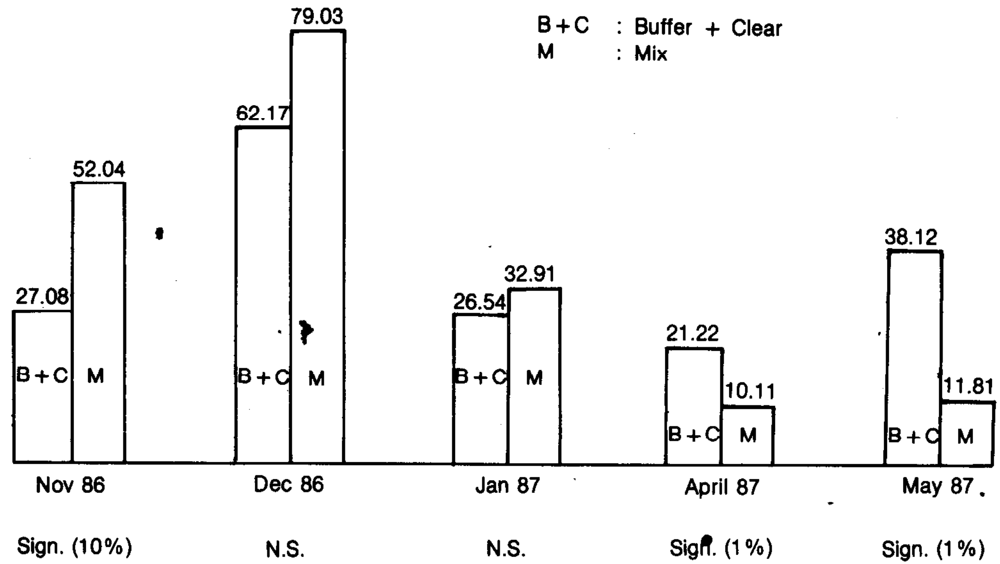
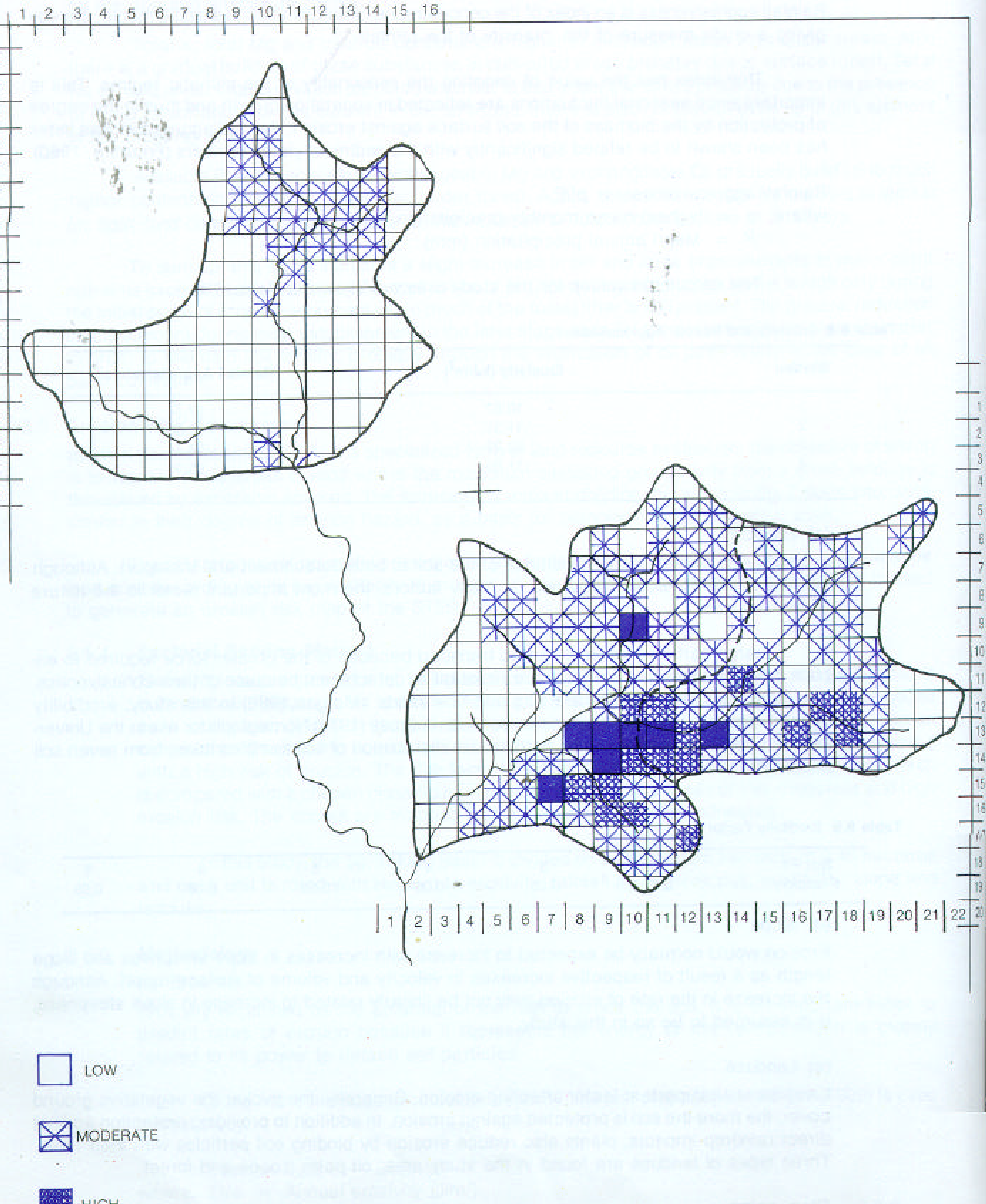


Fig. 9.13 Monthly Soil Loss (g/ha/mm)

Fig. 8.2 Sungai Tekam — Erosion risks.



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SUNGAI TEKAM EXPERIMENTAL BASIN
FINAL REPORT
JULY 1977 TO JUNE 1986

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Price: $10.00
Bahagian Pengairan dan Saliran
Kementerian Pertanian, Malaysia.

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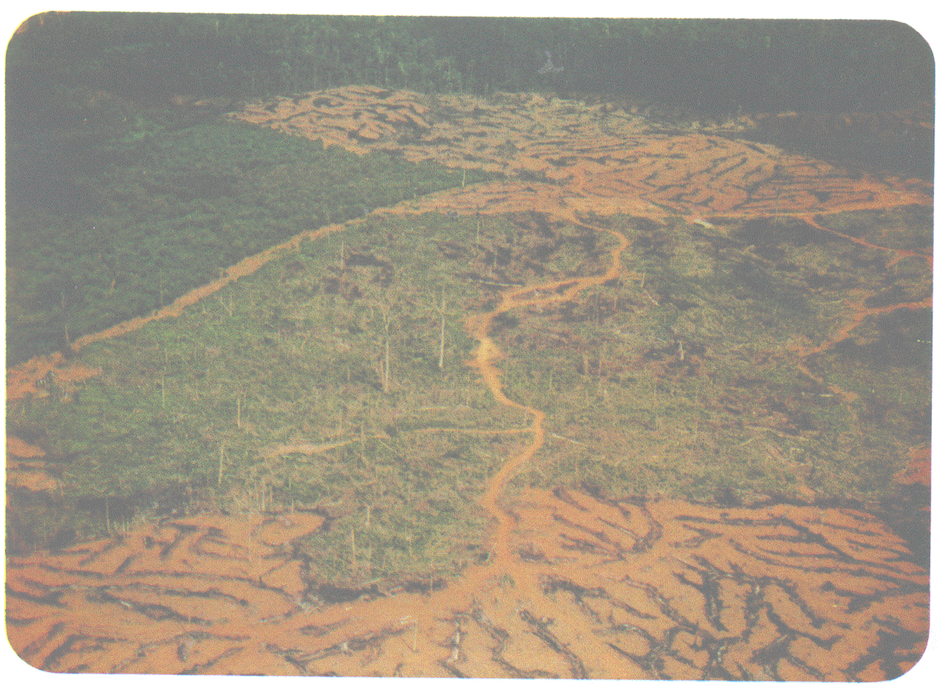

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CHAPTER 1

INTRODUCTION

The Sungai Tekam Experimental Basin (STEB) initiated in September 1973 is an integrated research project carried out jointly by several governmental agencies and local universities to study the effects of landuse changes on the hydrological regime, soil fertility and water quality. Due to problems of field installation and instrumentation, actual basin calibration did not commence until July 1977.

In recent years, agricultural development has been extended into inland undulating areas. The development involves felling extensive tracts of forest, followed by the stacking and burning of felled trees and planting of crops. The process of land clearance and the change in its use have great impacts on river basins which often show changes in water quality and quantity. The Sungai Tekam Experimental Basin Study was undertaken to monitor and evaluate:

(a) the effects of landuse changes on the hydrology of the basin, focussing particularly on the components of rainfall, streamflow and water balance.
(b) the effects on water quality from the various stages of agricultural development.
(c) the effects of landuse changes on soil fertility as affected by the return of organic matter to the soil, infiltration, soil erosion and soil chemical content.
(d) the effectiveness of buffer strips and cover crops in soil and water conservation.

The study consists of three periods, namely the calibration period involving the collection of baseline data, the transition period of land clearing and crop establishment, and the evaluation period after crop establishment. These periods are referred to as Calibration, Transition and Evaluation in the text. The schedule of study is shown in Table 1.1.

Table 1.1 Schedule of Study

Catchment	Calibration period	Transition period	Evaluation period
A	July 1977—Sept 1982	Oct 1982—June 1986	July 1986—thereafter
Sub—catchment B*	July 1977—June 1980	July 1980—June 1983	July 1983—thereafter
C	Control Catchment		

* Sub-catchment B is located downstream of Catchment A. Catchment A and Sub-catchment B together form the main Catchment B.

Development of Sub-catchment B (see Figure 2.1) for oil palm started in July 1980, followed by Catchment A for cocoa in October 1982. This report deals specifically with the evaluation period after July 1983.

CHAPTER 2

PROJECT DETAILS

2.1 Basin Description

The STEB is located in an area of logged-over forest within the Tekam Forest Reserve of the Tun Razak Agricultural Research Centre (TRARC) in Jerantut District, Pahang, Peninsular Malaysia. It lies about 200 km northeast of Kuala Lumpur, between latitudes 3° 53' 45" N to 3° 55' 00" N and longitudes 102° 31' 30" E to 102° 33' 00" E (Fig. 2.1).

The STEB consists of three Catchments — A, B and C. Catchment A is a part of the larger Catchment B, both of which are operational catchments whilst Catchment C, still forested, acts as a control for comparative purposes.

The area, mean elevation and mainstream gradient for the three catchments are shown in Table 2.1

Table 2.1 Area, Mean elevation and Mainstream Gradient of each catchment.

Catchment	Area (ha)	Mean Elevation (m)	Mainstream Gradient (m/m)
A	37.7	72.5	0.013
B	96.9	68.5	0.009
C	56.2	70.0	0.008

The mainstream channels are alluviated with fine-textured materials with occasional occurrences of lag deposits. Steeper channel gradients and lower width: depth ratios occur at the headwater reaches of the streams. These are predominantly incising first-order streams. Basin slopes are mostly gentle with gradients of 6° to 8° (Fig.2.2). Along the valley sides the streams have steeper slopes of 12° to 15°.

2.2 Climate

The climate of the area is humid tropical with a dry period from January to February and a wet spell from September to December. The average annual rainfall is 1878 mm which is lower than the average rainfall of Peninsular Malaysia.

Mean daily sunshine is 6 hours. Sunshine is generally abundant in the drier months and less during the monsoonal period.

Mean relative humidity at 8.00 am is 98% and at 2.00 pm is 65%. Monthly variation of the former is small compared with that of the latter. Higher relative humidity generally occurs during the monsoonal months.

The mean monthly temperature is 29°C and mean monthly pan evaporation (U.S. Class A white pan) is 105 mm

2.3 Soil Types

The distributions of soils in Catchment A, Sub-catchment B and Catchment C are given in Table 2.2. The soil map (Fig.2.3) and Table 2.2 show that the predominant soil in Catchment A is Segamat series (Haplic Acrorthox) derived from andesite, in Sub-catchment B Katong series (Tropeptic Haplorthox)

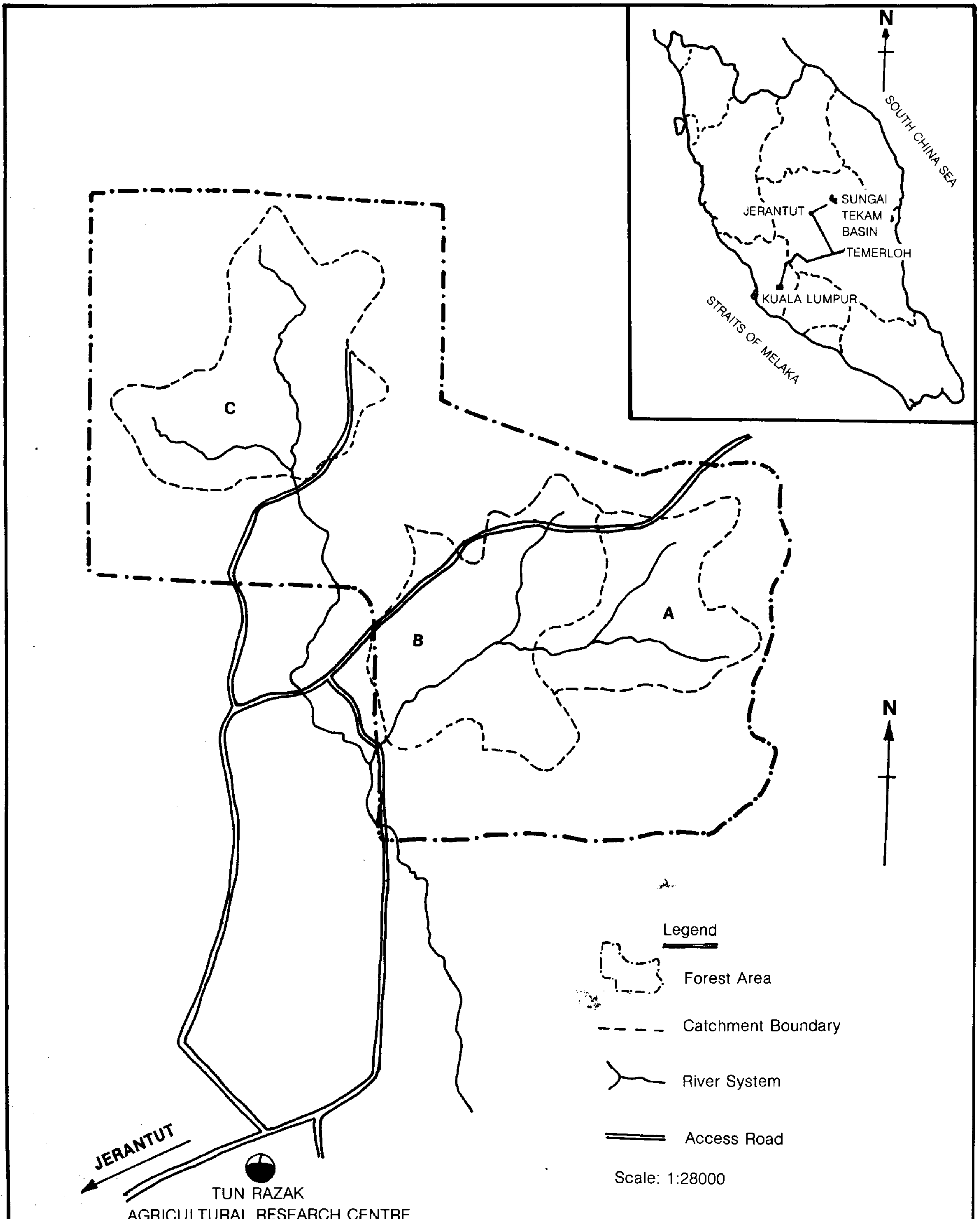


Fig. 2.1. Location Map of Sg. Tekam Experimental; Basin.

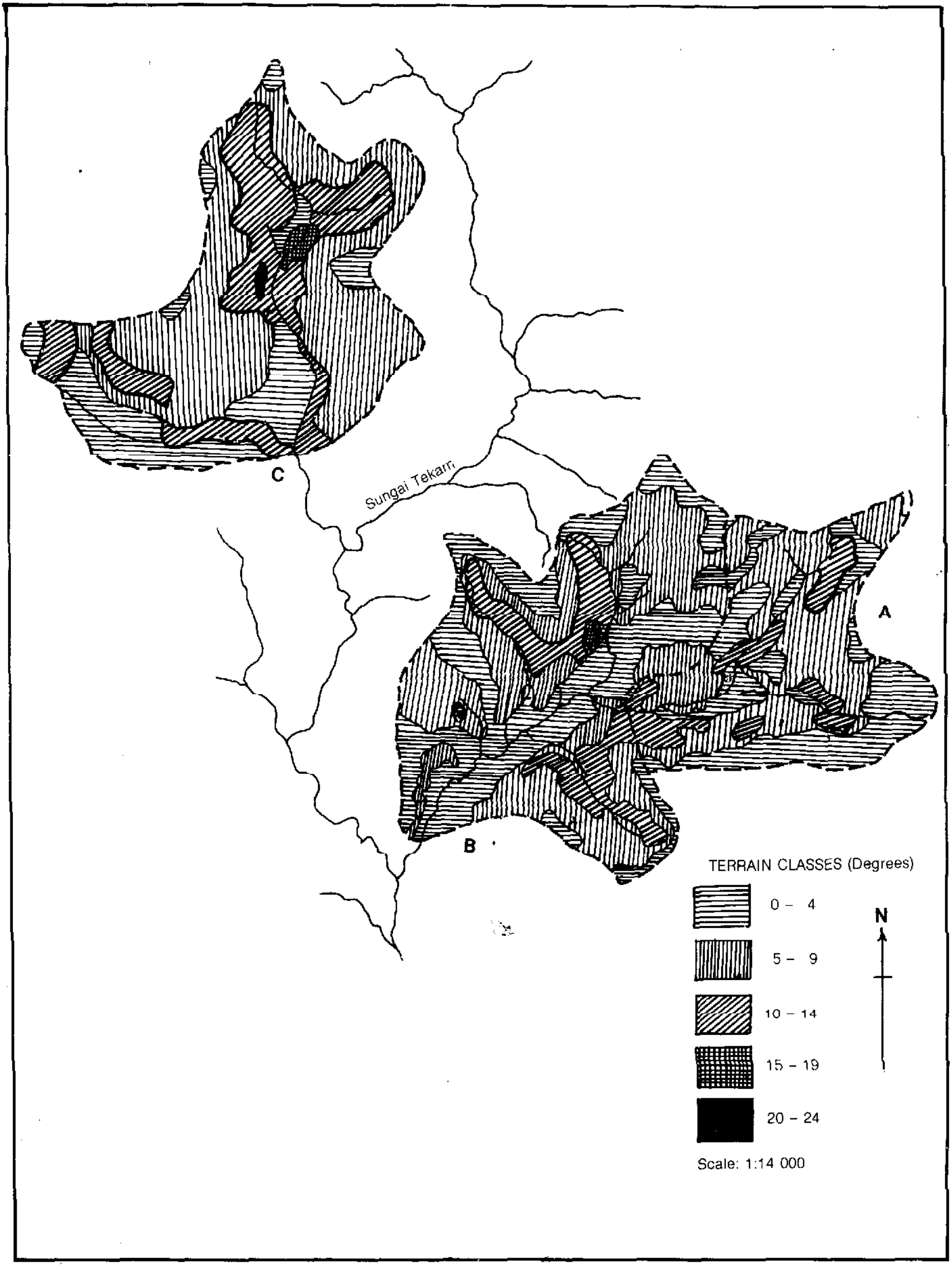


Fig. 2.2 Terain Map

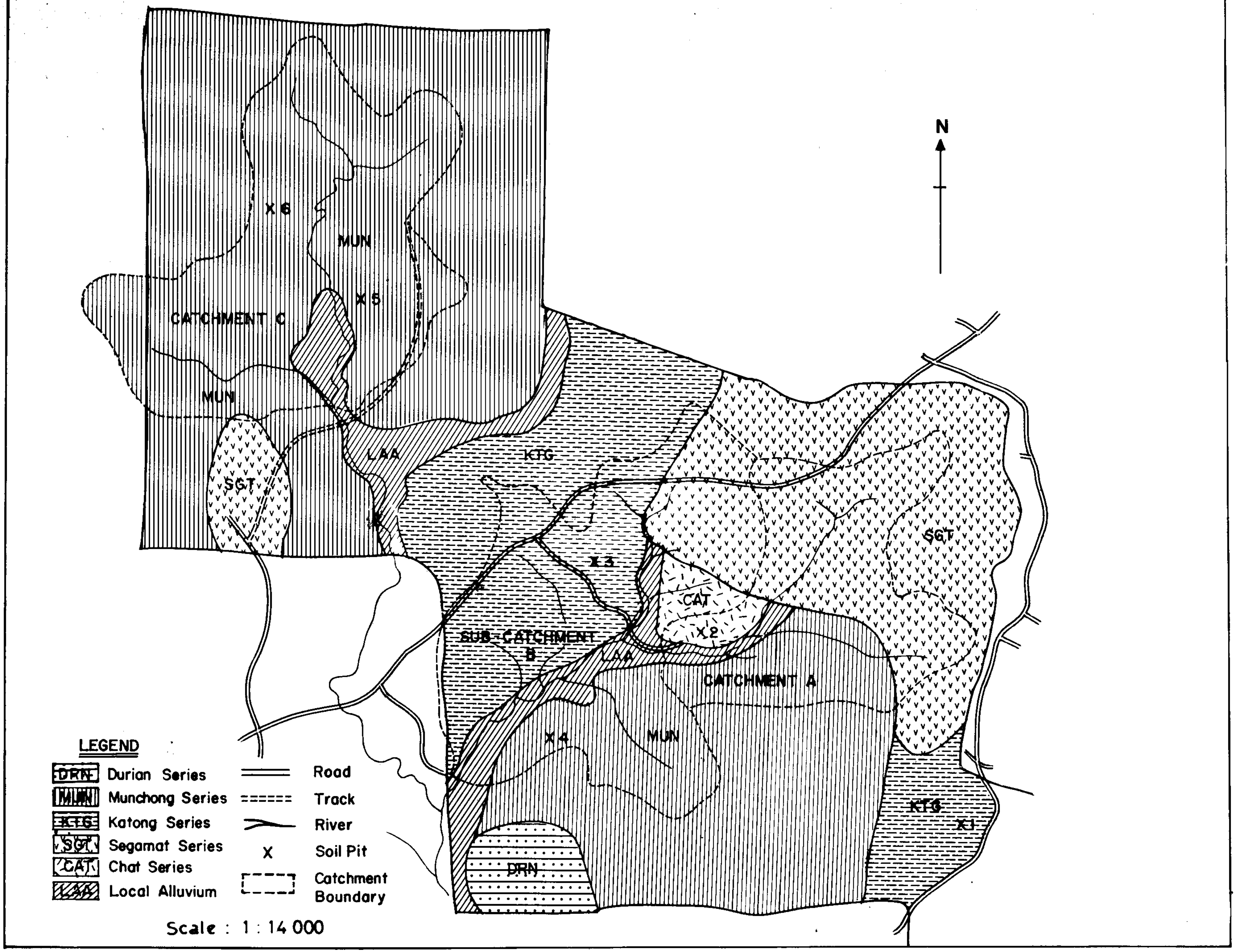


Fig 2.3: Soil Map of Sungai Tekam Experimental Basin, Jerantut, Pahang

Table 2.2 Distribution of Soil Types.

Catchment	Soil Types	Area of each Soil Type (ha)	• Area of each Soil Type to Catchment Area
Catchment A	Segamat	21.1	55.9
	Munchong	1.8	4.8
	Chat	2.1	5.6
	Local Alluvium	12.7	33.7
	Sub total	37.7	100.0
Sub-catchment B	Katong	25.6	43.3
	Munchong	13.8	23.3
	Segamat	10.4	17.6
	Local Alluvium	7.0	11.8
	Chat	2.4	4.0
Sub total		59.2	100.0
Catchment C	Munchong	53.0	94.3
Local Alluvium		3.2	5.7
	Sub total	56.2	100.0

derived from andesite,andesitic and tiachy andesite tuffs and in Catchment C Munchong series (Tropeptic Haplorthox) derived from shale.

In its natural state, Segamat series has a high infiltration rate and is excessively drained. This is because the clay particles are aggregated to form pseudo-silts and pseudo-sands making the soil porous even though it is clayey in texture (Paramanathan, 1978). This soil has an oxic horizon with a weak structure and thus is more prone to compaction. After land clearance with heavy machinery, for example, substantial reduction in infiltration resulted.

Munchong series also has anoxic horizon but with a stronger structure than Segamat series. This is in contrast to Katong series which has an oxic horizon but a moderate structure and variable consistency.

Both Segamat and Munchong soils have low nutrient contents, low nutrient retention and high phosphorus-fixing capacities.. Katong series, however, has a higher nutrient retention capacity.

2.4 Basin History and Landuse.

Baseline data collected during the calibration period were deemed sufficient. In Sub-catchment B, the transition period began in 1980 when the forest was felled. Logging began in July. By November, the forest was completely felled and burning was carried out in February 1981. However the burn was poor and partially burnt logs were mechanically stacked (with a D6 bulldozer) and reburnt. Planting of leguminous covers began in April and was completed by May. Legumes planted were Centrosema pubescens and Pueraria javanica at a seed mix ratio of 4:5 by weight, and sown at 12.5 kg/ha.

To ease operations, agricultural roads were constructed from July to August and a section of the stream in Sub-catchment B was realigned and deepened from October to December. Planting of oil palm was carried out from August to November 1982. During the evaluation period the oil palm was fully established.

Catchment A was developed for cocoa. Logging was done from October to December 1982. This was followed by underbrushing in January/February 1983. Clear felling began after this and was completed by March. Burning of felled logs was done in April. However, the burn was unsatisfactory necessitating restacking and reburning as in Sub-catchment B. This was done in June 1983. Agricultural roads were constructed from May to June 1983. Realignment of stream was carried out from the middle to the end of August 1983. Planting of shade trees was done from October to November 1983 and tha cocoa immediately after.

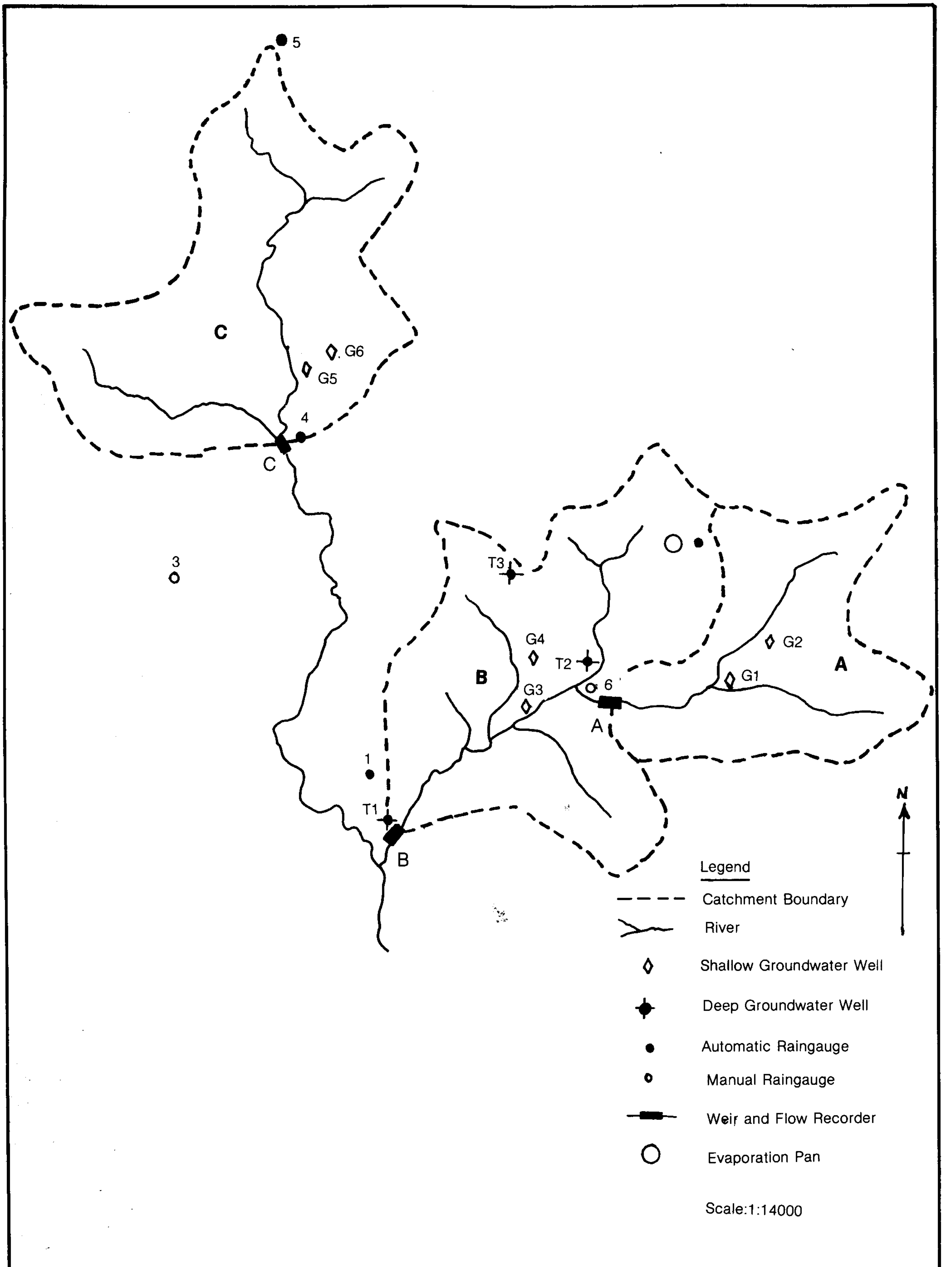


Fig. 2.4 Hydrological Stations of Sungai Tekam Experimental Basin.

2.5 Instrumentation and Data Collection

Climatic parameters measured at TRARC include air temperature, relative humidity, sunshine duration, wind speed and pan evaporation. Potential evapotranspiration was estimated by Penman's method, using climatic data from TRARC. There are four weekly automatic rainfall recorders with check gauges and one storage gauge (Fig.2.4).

In late 1973, flow measurements for the basins were carried out by means of automatic water level recorders and supplemented by stremflow gaugings. However, current meter gauging was not sensitive enough for measuring low flows and thus a 1.22 m HL flume with concrete wingwalls was constructed in early 1976 in each of the catchments.

While flow measurements under normal and low flow conditions were improved, flood flows were severely affected by backwater effects. Since the rating for the flumes was based on free flow conditions, stream alignment was carried out to improve flow conditions.

In 1976, due to prolonged periods of dry weather, the streamflow levels fell below the intake pipe of the recorder thereby exposing it. To measure extremely low flows and to improve the sensitivity of the flumes a 120° V-notch weir was constructed. These modification works were completed in March 1977, prior to the commencement of the Calibration Period.

River stages were recorded at three flow gauging sites using float-type water level recorders (Fig. 2.4). Regular streamflow gaugings were carried out by current meter or volumetric methods.

CHAPTER 3

RAINFALL AND EVAPOTRANSPIRATION

3.1 Rainfall

Monthly rainfalls at the four automatic stations were little different. Correlations between them from 1977/78 to 1985/86 were highly significant and are shown in Table 3.1 However, in individual storms, spatial distribution of rainfall vary considerably even over a small area.

Table 3.1 Correlation Coefficients between Rainfall Stations.

	Station 1	Station 2	Station 4	Station 5
Station 1	—	0.97	0.98	0.95
Station 2	0.97	—	0.97	0.96
Station 4	0.98	0.97	—	0.97
Station 5	0.95	0.96	0.97	—

Rain depth frequency analysis using daily rainfalls of station 2 was performed. Light rains occurred frequently throughout the study period. The average number of raindays (daily rainfall> 0.5mm) per year was 165. Raindepths greater or equal to 50.5mm occurred for only 6 days. The number of rainless days increased from 195 (1977/78—1980/81) to 228 (1981/82 — 1982/83) but depth-frequency is shown in Fig. 3.1.

Maximum raindepth for different durations (15 minutes to 30 days) for 1977 to September 1986 for each of the automatic rainfall recorders are presented in Tables 3.2, 3.3, 3.4 and 3.5.

Table 3.2 Maximum Raindepth for different durations for Station 1.

YEAR DURATION	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
15 mins	16.0	28.7	19.2	25.7	38.0	37.2	20.4	37.3	39.2	23.9
30 mins	30.5	43.3	30.7	31.0	40.7	44.3	35.9	50.3	61.5	33.5
1 Hr.	46.4	65.8	58.0	44.5	55.4	59.2	53.2	73.8	61.5	45.5
2 Hrs.	68.0	81.8	70.5	49.0	97.8	75.0	91.5	93.0	83.5	71.9
3 Hrs.	79.6	87.5	73.1	55.1	102.5	84.6	93.5	100.5	83.5	75.1
6 Hrs.	90.0	91.5	76.7	57.5	102.5	111.5	94.0	113.9	83.5	78.0
12 Hrs.	90.2	93.0	90.5	57.5	102.5	112.0	94.0	114.0	89.0	78.0
24 Hrs.	104.4	93.0	99.5	88.5	132.5	112.0	95.0	114.0	89.0	78.0
48 Hrs.	107.0	96.5	123.0	93.5	133.0	112.5	132.5	128.0	138.5	124.0
72 Hrs.	107.0	129.5	155.5	96.5	135.0	118.5	133.0	154.5	160.5	124.0
5 days.	114.5	133.0	190.9	137.0	165.5	120.0	133.0	188.0	173.0	131.0
7 days.	143.0	134.0	215.8	137.0	189.5	134.8	133.0	219.0	215.0	133.0
14 days.	203.5	165.0	323.0	179.0	231.5	222.5	205.0	341.0	302.0	221.5
30 days.	316.0	277.0	480.0	254.0	338.5	350.0	290.0	520.0	461.5	307.0

Table 3.3 Maximum Raindepth for different durations for Station 2.

YEAR / DURATION	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
15 mins	31.8	39.8	30.1	24.7	31.6	39.6	35.2	19.0	21.0	27.5
30 mins	56.4	49.4	46.8	41.5	56.2	52.2	57.5	38.1	26.2	35.0
1 Hr.	71.0	71.6	59.3	51.0	90.5	57.0	86.8	69.0	34.1	53.8
2 Hrs.	91.6	79.7	69.0	60.1	115.5	57.0	109.5	103.2	51.7	66.0
3 Hrs.	94.0	81.0	77.4	69.2	121.5	57.0	122.6	106.1	66.5	71.4
6 Hrs.	101.0	82.5	83.1	75.5	122.0	74.5	127.5	113.0	73.0	80.0
12 Hrs.	101.0	83.0	88.0	75.5	122.0	75.5	127.5	113.5	88.0	80.0
24 Hrs.	108.4	85.0	91.5	75.5	149.5	93.5	129.0	113.5	88.0	80.0
48 Hrs.	109.5	102.1	127.0	75.5	150.5	96.5	164.0	130.0	147.1	101.5
72 Hrs.	109.5	121.0	160.0	90.0	154.5	96.7	165.5	144.5	169.1	114.5
5 days.	117.5	140.5	198.0	91.0	183.0	107.5	165.5	189.0	173.0	126.0
7 days.	135.0	144.5	220.5	112.0	183.0	126.7	228.0	225.0	229.0	134.5
14 days.	230.5	183.0	248.5	176.0	267.5	164.5	274.5	266.5	306.5	251.5
30 days.	330.5	279.0	378.0	322.3	402.0	243.0	385.5	455.5	428.5	326.5

Table 3.4 Maximum Raindepth for different durations for Station 4.

YEAR / DURATION	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
15 mins	41.0	23.5	26.5	29.6	33.4	18.9	19.9	33.3	23.1	15.4
30 mins	46.2	38.2	41.4	41.7	34.3	37.8	37.7	47.8	41.6	30.4
1 Hr.	64.9	56.9	68.6	53.2	45.7	56.3	55.6	55.9	47.0	53.8
2 Hrs.	83.6	73.0	75.2	75.9	54.5	75.8	76.8	68.7	55.1	59.4
3 Hrs.	88.0	74.6	83.6	79.7	58.2	95.2	97.6	81.5	58.5	64.8
6 Hrs.	98.5	76.0	102.3	83.0	81.7	125.0	98.9	89.5	64.0	73.5
12 Hrs.	99.0	76.0	109.5	86.5	84.5	125.5	99.0	89.5	64.5	73.5
24 Hrs.	114.8	76.0	111.5	87.5	84.5	125.5	99.0	98.5	64.5	73.5
48 Hrs.	116.0	89.0	127.5	96.0	84.5	126.0	150.0	108.0	89.0	75.5
72 Hrs.	116.0	104.0	159.5	110.0	98.0	135.0	150.5	145.5	89.0	118.0
5 days.	120.5	104.5	205.0	152.5	129.5	140.0	166.9	145.5	94.0	126.0
7 days.	140.5	119.5	246.5	155.0	159.0	140.4	235.5	167.0	101.5	137.5
14 days.	193.5	167.5	374.0	193.5	212.0	160.5	287.0	255.5	199.9	254.0
30 days.	295.5	280.5	507.5	284.0	327.0	228.5	378.0	417.5	256.4	325.0

Table 3.5 Maximum Raindepth for different durations for Station 5.

YEAR / DURATION	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
15 mins	40.4	27.4	30.8	27.3	44.1	25.3	17.5	27.2	40.8	23.9
30 mins	45.8	36.9	41.7	37.9	50.5	48.0	23.5	45.1	47.5	40.4
1 Hr.	67.8	61.6	65.0	58.9	58.1	56.8	47.1	57.0	59.4	63.9
2 Hrs.	81.2	82.0	72.5	71.7	61.6	69.4	69.3	65.3	80.0	100.3
3 Hrs.	82.6	83.4	78.8	95.6	63.3	82.0	91.0	73.8	80.0	101.5
6 Hrs.	90.5	91.0	96.5	100.5	75.5	111.0	104.6	77.5	88.7	104.5
12 Hrs.	91.0	100.5	106.0	100.5	75.5	111.5	105.0	77.5	106.5	104.5
24 Hrs.	103.2	100.5	108.0	102.0	75.5	111.5	105.0	88.5	106.5	104.5
48 Hrs.	105.0	107.0	127.0	121.1	75.5	120.8	164.1	106.6	139.0	114.5
2 Hrs.	105.0	113.0	150.5	124.0	75.5	126.0	166.5	137.5	160.5	152.0
5 days.	112.5	119.5	200.0	172.0	75.5	132.5	166.5	160.0	214.0	168.5
7 days.	137.0	147.5	228.5	173.5	91.5	132.5	232.0	206.5	243.5	168.5
14 days.	219.0	187.0	270.0	222.0	95.5	176.1	288.0	293.0	285.5	300.0
30 days.	278.0	299.5	405.5	377.5	95.5	278.5	422.5	472.0	450.5	370.5

The arithmetic mean was taken as the areal rainfall for the catchments in view of the high rainfall correlation between stations. Catchment A is represented by station 2, Catchment B by stations

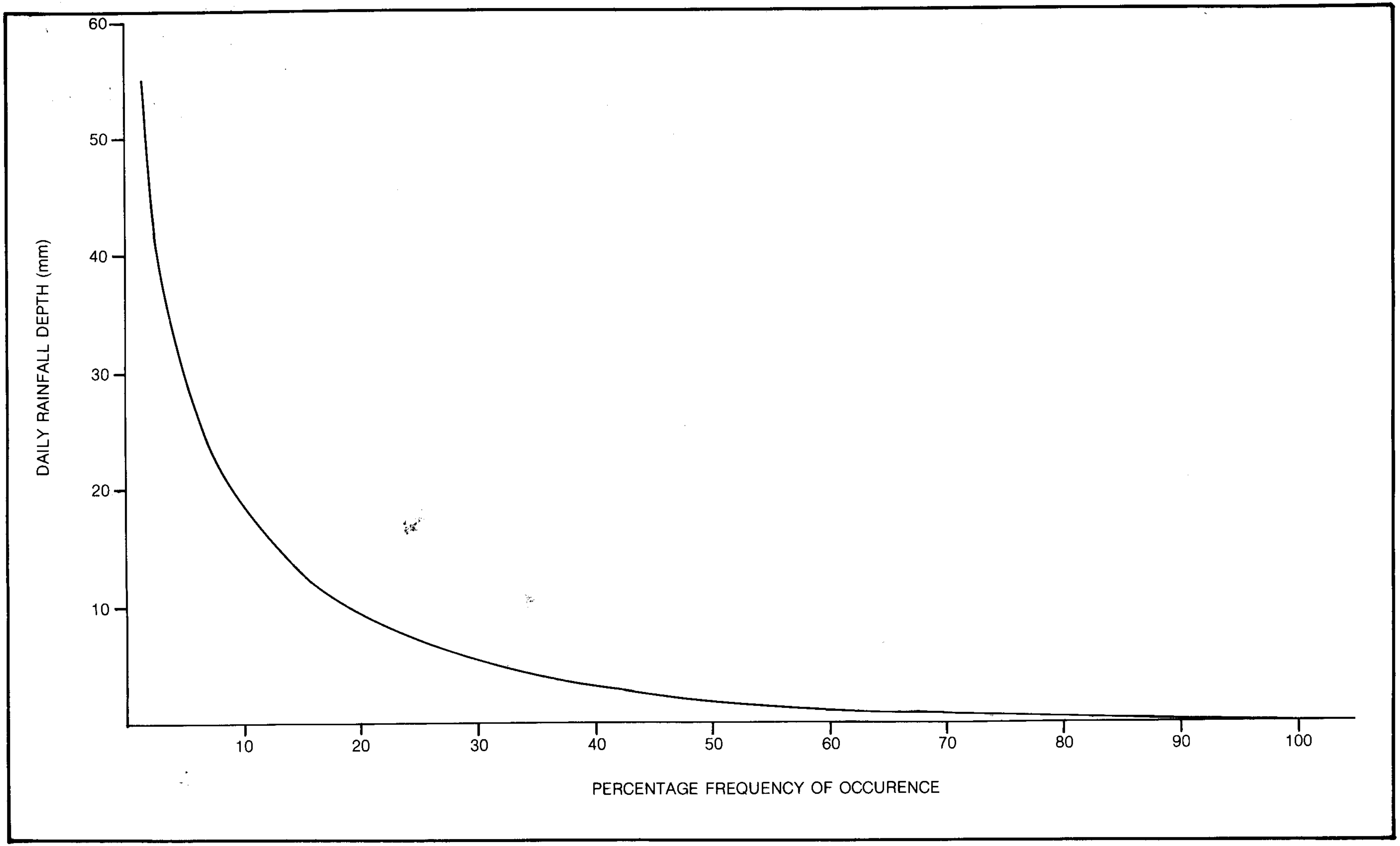


Fig. 3.1. Percentage frequency curve of 1 – day rainfall depth for station 2 (July 1977 – June 1986).

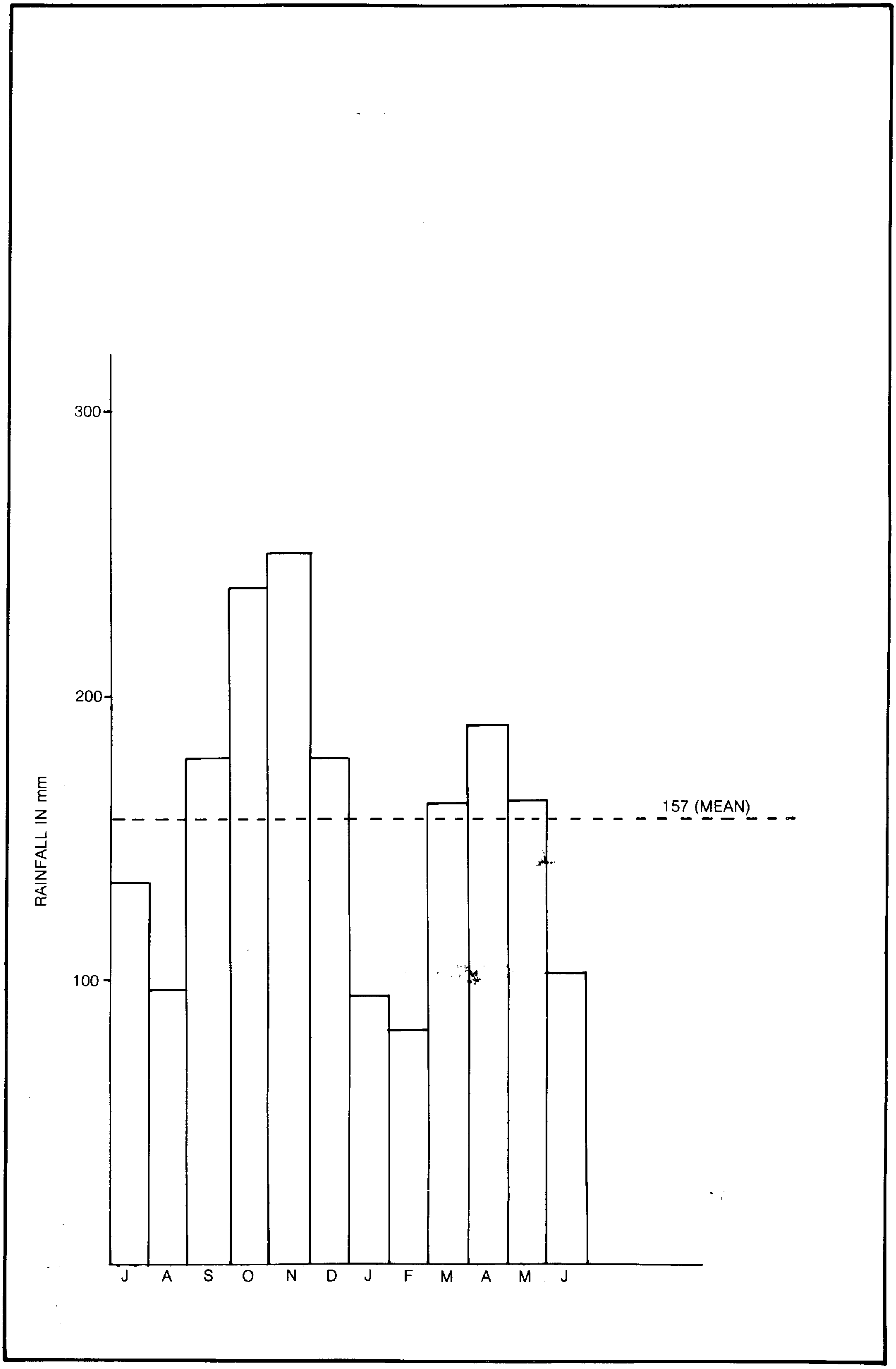


Fig. 3.2. Mean Monthly Areal Rainfall for Catchment A.

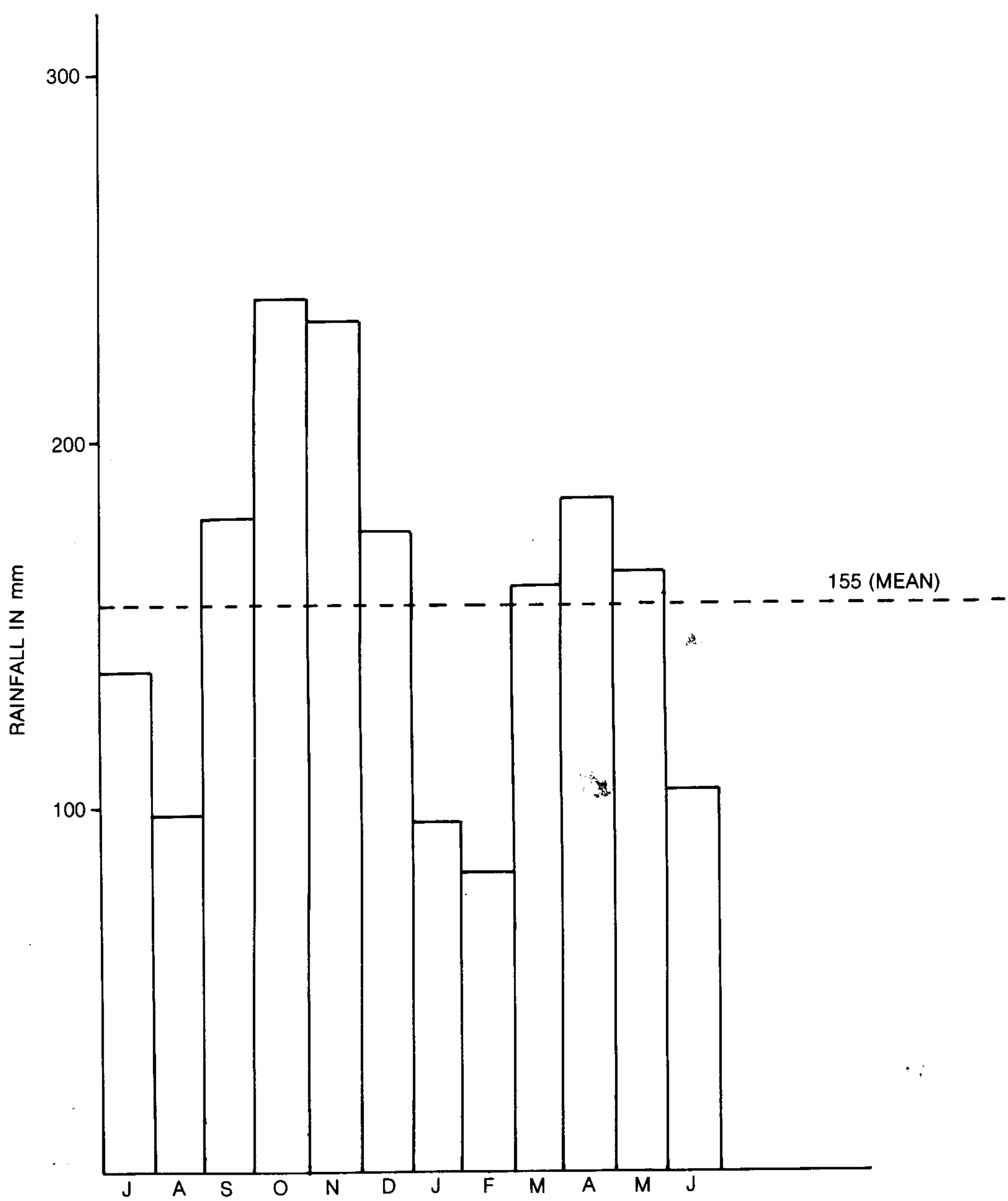


Fig. 3.3. Mean Monthly Areal Rainfall for Catchment B.

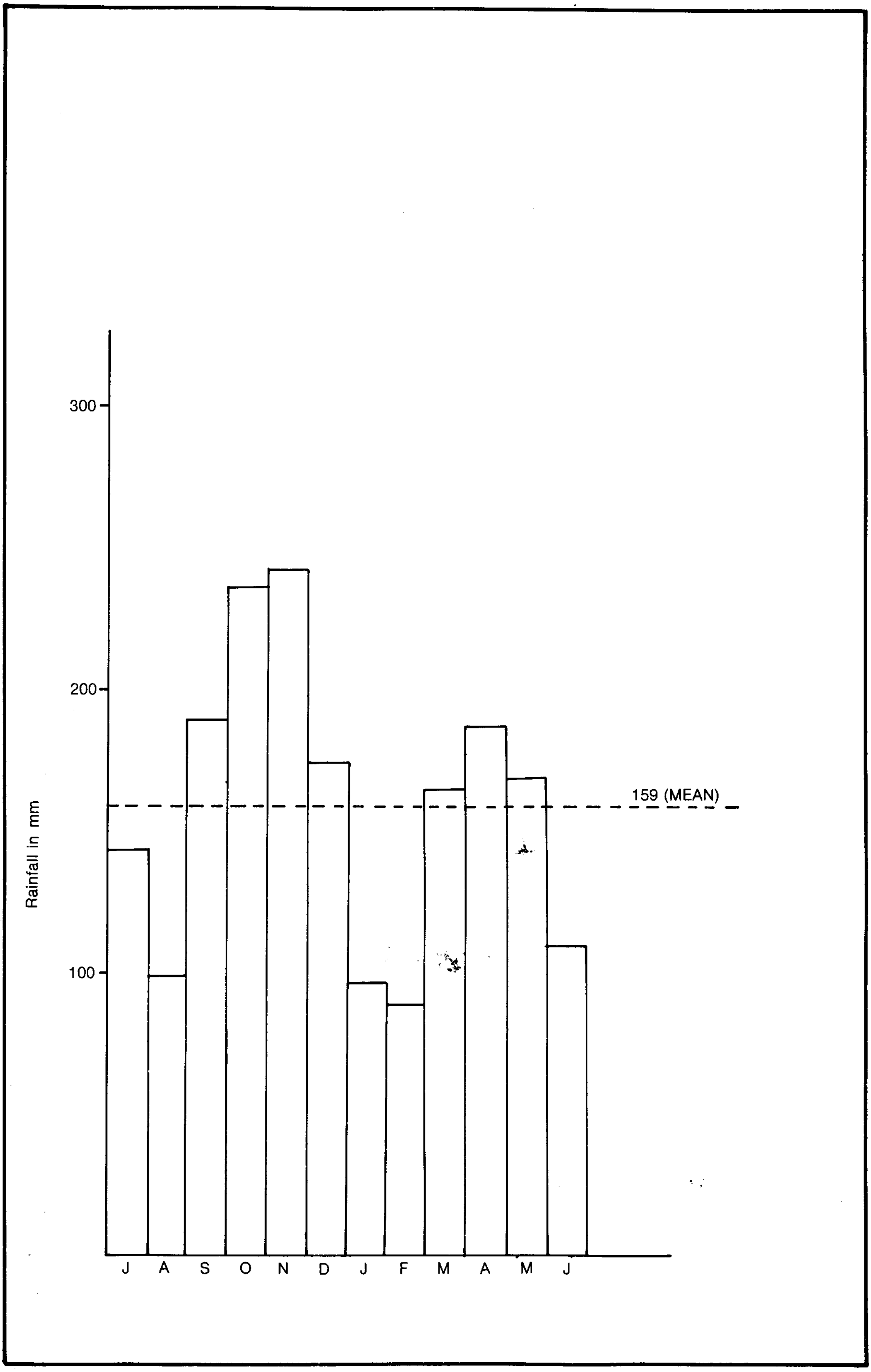


Fig. 3.4. Mean Monthly Areal Rainfall for Catchment C.

1 and 2, and Catchment C by stations 4 and 5. Over the three periods, all the catchments received the most rainfall during the evaluation period (annual mean of 2191 mm), because of the wet 1983/84 (annual mean of 2303 mm) and 1984/85 (annual mean of 2343 mm) water years. They received slightly lower rainfall during the transition period (annual mean of 1653 mm) because of the relatively dry 1982/83 (annual mean of 1442 mm) water year.

The mean annual rainfall for the period 1977/78 to 1985/86 was 1878 mm, which is about 20% less than the average rainfall of Peninsular Malaysia (2400 mm).

Figures 3.2, 3.3 and 3.4 show the mean monthly basin rainfall distribution for Catchments A, B and C respectively. Two rainfall maxima were experienced during the North-east monsoon (October to December) and South-west monsoon (April to May). For Catchment A, November had the highest rainfall (251 mm) and February the least (83 mm). For Catchment B, October had the most (238 mm) and February the least (82 mm) and for Catchment C November had the most (243 mm) and again February had the least (89 mm).

3.2 Evapotranspiration

Several methods were used to estimate forest evapotranspiration (ET), one of which was the pan method (U.S. Galvanised Iron white pan). A coefficient of 1.01 (DID Report, 1984) was adopted. Using this, average annual forest ET was estimated to be 1252 mm. However, this was too low to fully explain the discrepancy in the water balance.

To improve the estimate of ET, potential evapotranspiration (PE) was estimated from Penman's equation (Penman, 1948) using monthly climatic data for 9 water years from TRARC. An albedo of 0.18 for tropical forest (Scarf, 1976) was adopted. A figure of 1686 mm was obtained — 35% higher than the estimate by evaporation pan. Penman ET was therefore used in water balance computations and the monthly computations are presented in Chapter 5.

To estimate actual forest evapotranspiration (AE) of Catchment C, the Thornthwaite and Mather Daily Water Balance Model (1955) with implicit daily soil moisture accounting was used. Table 3.6, indicates that annual discrepancy were markedly reduced for the drought years.

Table 3.6 Comparison of Penman & Thornthwaite Methods in the Estimation of Forest ET for Catchment C (mm).

Water year	Rainfall (P)	Runoff (Q)	Penman ET (PE)*	Thornwaite ET (AE)**	Discrepancy Term (P—Q—PE)	Discrepancy Term (P—Q—AE)
1977/78	1835	191	1567	1545	+77	+99
1978/79	1663	226	1527	1476	−90	−40
1979/80	1980	366	1482	1512	+132	+102
1980/81	1820	274	1514	1547	+32	0
1981/82	1597	186	1557	1442	−146	−31
1982/83	1464	128	1567	1374	−231	−38
1983/84	2391	535	1449	1527	+407	+329
1984/85	2430	733	1495	1583	+202	+114
1985/86	1937	255	1476	1497	+206	+185
Mean	1902	322	1515	1500	+65	+80

* Penman ET: Albedo = 0.18
** Thornwaite AE: Available Water Holding Capacity of Soil (AWHC) = 300 mm

CHAPTER 4

STREAMFLOW

4.1 Components of Runoff

Total runoff (Q_t) of each catchment was separated into baseflow (Q_u) and direct runoff (Q_s). The runoff of Sub-catchment B was derived using area weighted flow-subtraction method (Table 4.1).

Q_s/Q_t decreased 21%, 38%, 44% and 49% from Calibration to Transition for Catchments A, B, C and Sub-catchment B respectively whereas Q_u/Q_t increased 9%, 18%, 18% and 29% during the same period.

Table 4.1. Annual Baseflow and Direct Runoff (mm).

Periods	Water Year	Catchment A		Catchment B		Sub-catchment B		Catchment C	
		Qu	Qs	Qu	Qs	Qu	Qs	Qu	Qs
Calibration	1977/78	69	36	70	44	71	48	140	51
	1978/79	103	40	92	32	85	26	184	42
	1979/80	203	73	165	81	141	85	248	118
Transition	1980/81	159	25	254	63	315	88	254	20
	1981/82	115	55	232	33	307	18	148	38
	1982/83	115	35	88	50	70	62	94	34
Evaluation	1983/84	764	236	604	215	506	203	407	66
	1984/85	811	107	676	117	594	124	595	138
	1985/86	374	119	390	85	402	64	208	46

Q_u and Q_s both increased substantially during Evaluation for all catchments as the rainfall was higher (2191 mm) than Calibration (1791 mm) and Transition (1653 mm). Q_s/Q_t and Q_u/Q_t differed little from Transition to Evaluation for all catchments.

The proportion of baseflow to direct runoff depends essentially on factors such as rainfall characteristics and catchment conditions. The results in Table 4.2 show that the absolute quantity of direct runoff of Catchment A and Sub-catchment B did not greatly increase after deforestation whereas baseflow increased. This could be a consequence of the forest clearing when felled logs and debris were left in stream channels for long periods. They acted as debris dams which reduced storm peak flows by ponding up some runoff. Thus, substantial volume of direct runoff were rerouted into base flow. Furthermore, baseflow increase could also be caused by a general rise in groundwater table resulting from lower evapotranspiration after forest clearing.

Table 4.2 Comparison of Average Annual Baseflow and Direct Runoff.

Components Of Runoff (mm)	Catchment A			Catchment B			Sub-catchment B			Catchment C		
	C.P	T.P	E.P	C.P	T.P	E.P	C.P	T.P	E.P	C.P	T.P	E.P
Baseflow, Q_u	125	130	650	109	191	557	99	231	501	190	165	424
Direct Runoff, Q_s	50	38	154	52	48	139	57	55	130	70	30	83
Total Runoff, Q_t	175	168	804	161	239	696	157	286	631	260	195	508
Q_s/Q_t	0.29	0.23	0.19	0.32	0.20	0.20	0.37	0.19	0.21	0.27	0.15	0.16
Q_u/Q_t	0.71	0.77	0.81	0.68	0.80	0.80	0.63	0.81	0.79	0.72	0.85	0.84

C.P — Calibration Period
T.P — Transition Period
E.P — Evaluation Period

4.2 Flow Duration and Distribution

Extremes of discharge were observed in all three catchments. During Calibration and Transition the streams were intermittently dry. Flow duration analyses using daily discharge data were performed for all the catchments and the derived curves are shown in Fig. 4.1. The flow duration of Catchment A was not markedly changed from Calibration to Transition, but higher flows were observed during Evaluation. Catchment B, had higher flows during Transition after deforestation and even higher flows were experienced during Evaluation. Control Catchment C had less runoff during Transition but had higher flows during Evaluation. Although some of the increase in runoff from the catchments during Evaluation may be explained by the higher rainfall during that period, other explanations for the differences in the increases in individual catchments will be discussed in Section 5.3.

4.3 Streamflow Recession.

If groundwater storage within the three small catchments is homogeneous and can be represented by a single-linear reservoir, the recession curve can be expressed by the equation:

$$q_t = q_o . k^t$$

where, q_t is the flow at t time units later,
q_o is the flow at any time,
k is the recession constant.

The recession constant k for 24 hour periods of the catchments was derived by plotting successive values of q_{t+1} versus q_t and fitting a straight line. There was no significant difference between the three periods of study for all three catchments (Table 4.3).

Table 4.3 Comparison of Recession Constants (k)

Catchment	Period (N)	*Mean daily recession constants (k)	Standard deviation (s)
A	Calibration	0.824	0.112
	Transition	0.813	0.099
	Evaluation	0.832	0.043
B	Calibration	0.795	0.127
	Transition	0.802	0.199
	Evaluation	0.848	0.047
C	Calibration	0.870	0.103
	Transition	0.923	0.077
	Evaluation	0.903	0.039

For Catchment A, from Calibration to Transition, k decreased by 1% but it increased by 1% from Transition to Evaluation. For Catchment B, k increased 1% and 6% from Calibration to Transition and Transition to Evaluation respectively. For Catchment C, k increased 6% from Calibration to Transition but decreased 2% from Transition to Evaluation. Linear plots of recession curves for all the Catchments are shown in Figs. 4.2, 4.3 and 4.4.

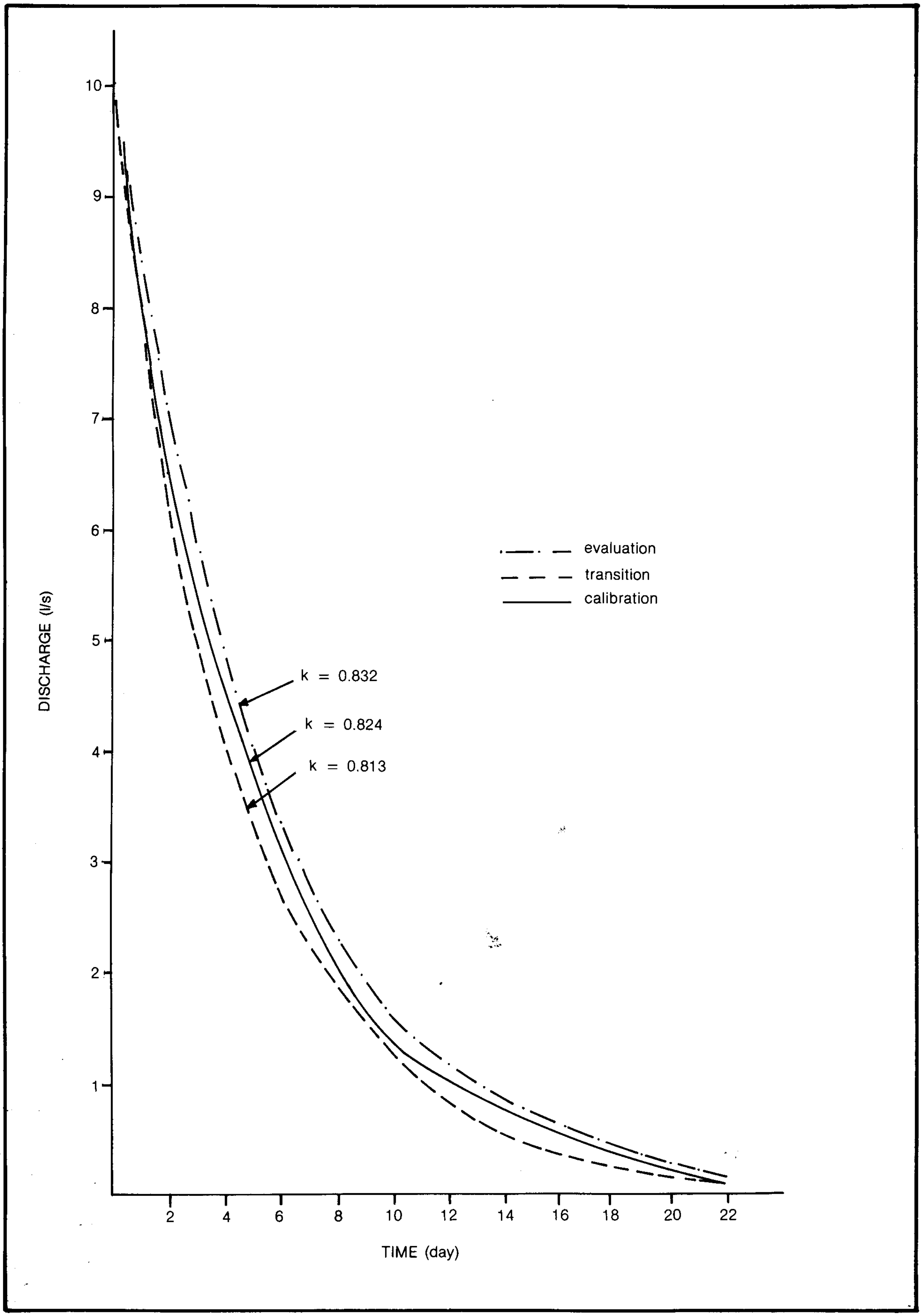


Fig 4.2. Recession Curves of Catchment A.

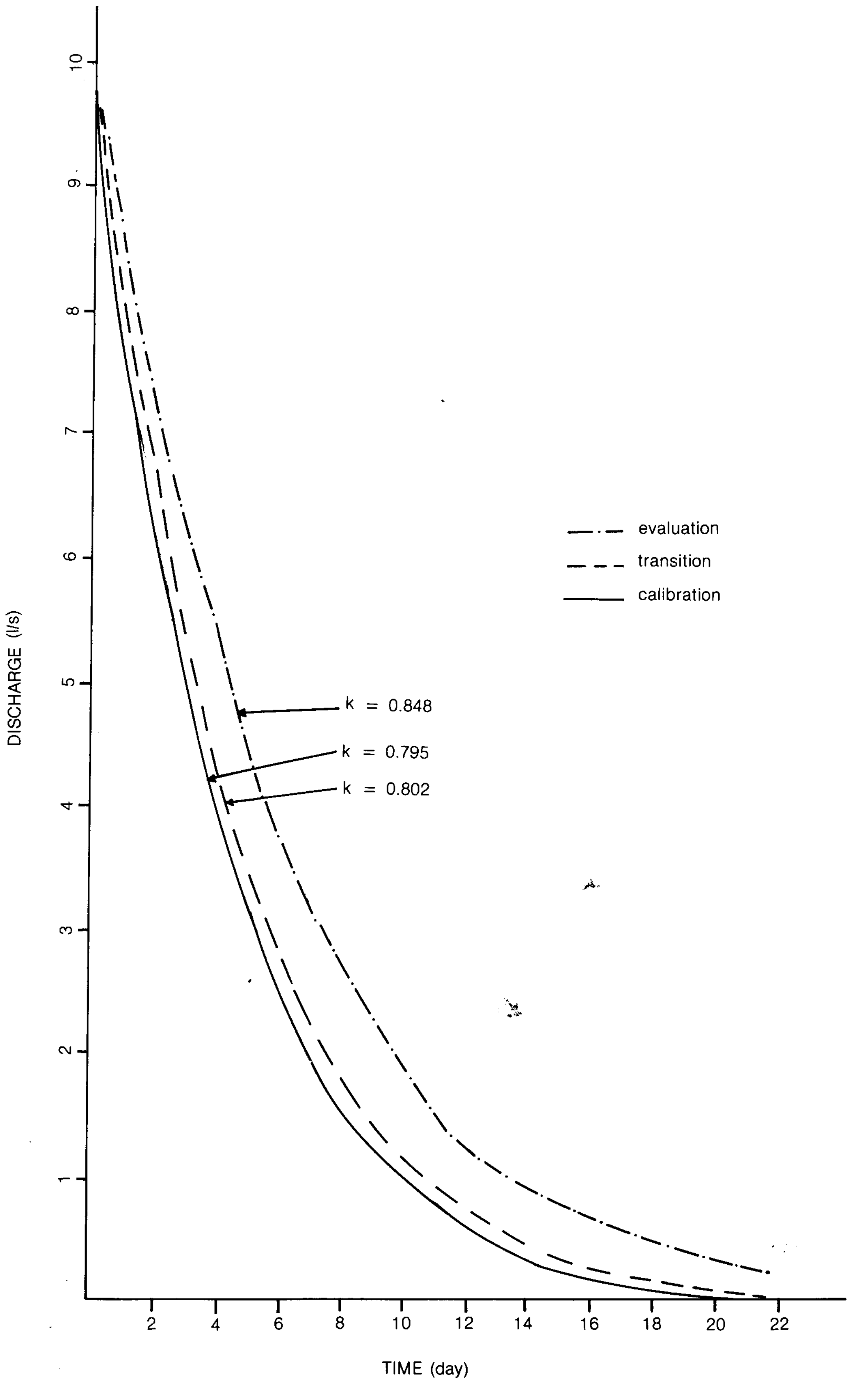


Fig. 4.3. Recession Curves of Catchment B.

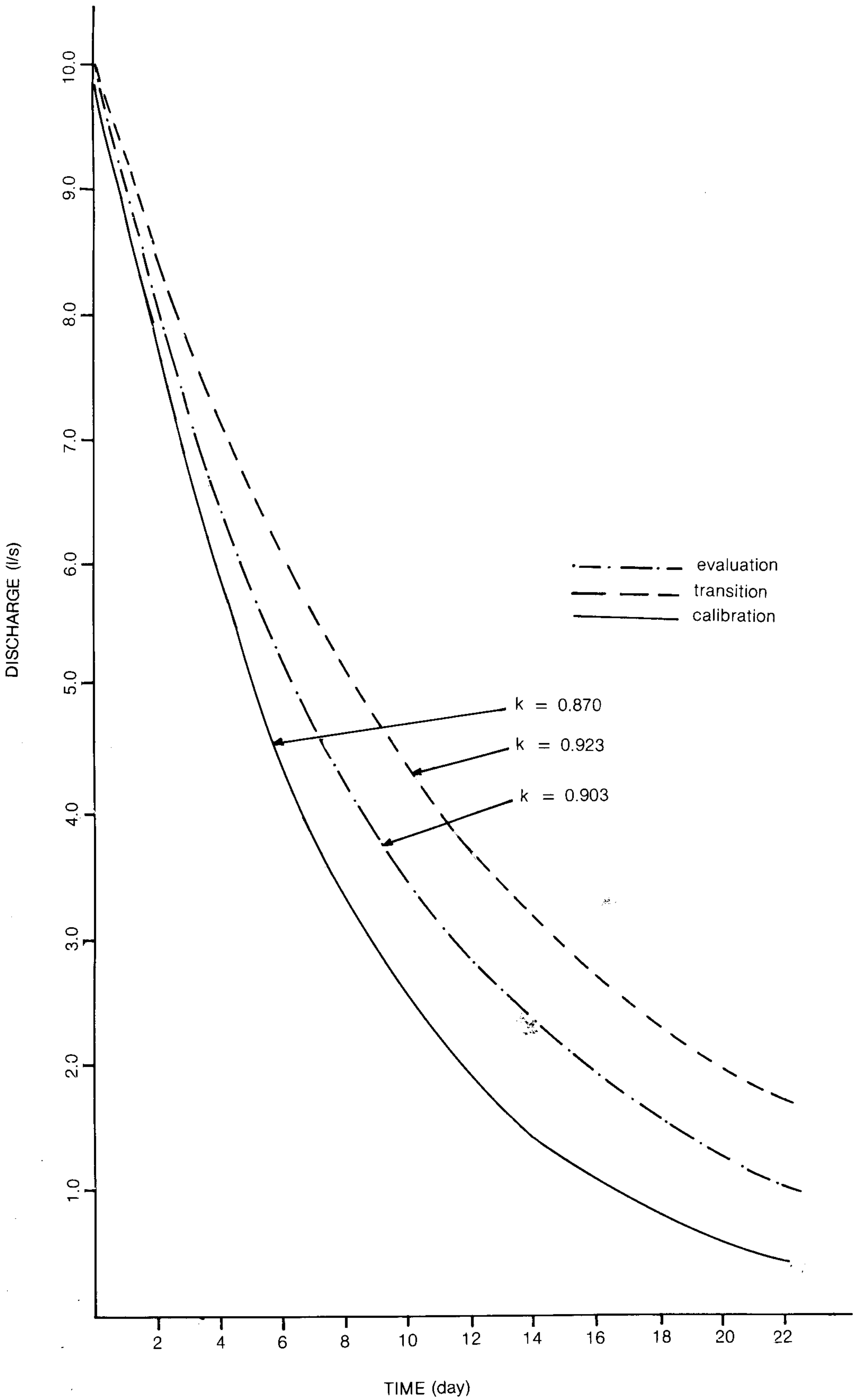


Fig 4.4. Recession Curves of Catchment C.

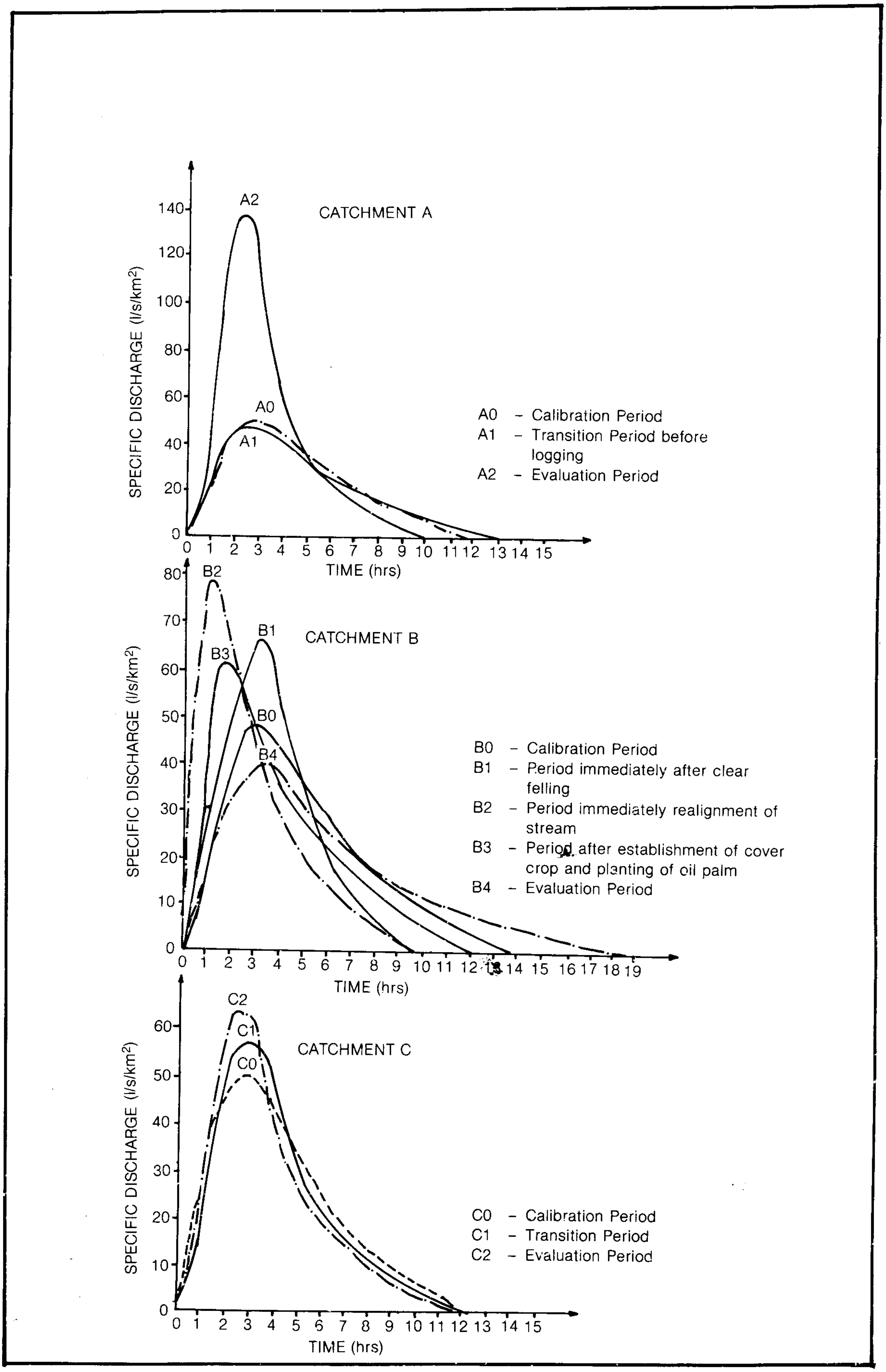


Fig. 4.5. One hour unit hydrographs of Catchment A, B and C.

4.4 Unit Hydrograph

Unit hydrographs were developed for specific land use modifications in Catchment B. However because Catchment A was modified at different times to Sub-catchment B, the unit hydrographs reflect the changes in Sub-catchment B but are also affected by the extent of moditications of Catchment A. Separate Calibration, Transition and Evaluation unit hydrographs were therefore developed for Catchment A, as shown in Figure 4.5.

The unit hydrographs showed that after deforestation, peak specific discharge (Q_p) increased whereas time-to-peak ($T_{p)}$ and base time (T_b) decreased significantly. The magnitude of change varied with the developmental activity.

When Sub-catchment B was cleared, Q_p increased from 48 l/s/km^2 under forest to 66 l/s/km^2. Q_p would have been even higher if the unit hydrographs could have been obtained without fallen logs obstructing the natural streamflow. In the period after channel clearing but before full establishment of cover rops, Q_p further increased to 79 l/s/km^2 65% higher than that during Calibration. After full establishment of cover crops, Qp was reduced to 62 l/s/km^2 which was still 30% higher than that during Calibration. Q_p was further reduced to 40 l/s/km^2 during Evaluation when the oil palms were fully grown. Q_p of Catchment A under forest for Calibration and Transition were 50 and 49 l/s/km^2 respectively. During Evaluation Q_p for Catchment A increased to 140 l/s/km^2 following completion of deforestation of the steeper headwaters. Q_p of Catchment C showed a slight change from 50 to 57 l/s/km^2 from Calibration to Transition but during Evaluation increased to 64 l/s/km^2.

T_p of Catchment B di not change significantly immediately after deforestation because of the logs in the channel delaying flood runoff.After channel clearance, T_p decreased from 3 hours to only 1 hour. After full establishment of cover crops and oil palm, T_p increased to 3 hours. T_p of Catchment A showed a slight reduction from 3.0 to 2.5 hours after deforestation. Similarly, T_p of Catchment C decreased slightly from 3.0 to 2.8 and then to 2.5 hours.

CHAPTER 5

WATER BALANCE STUDY

5.1 Water Balance

The water balance equation first considered was:

$P = ET + Q + L + \Delta WS + \Delta G$

Where P = catchment rainfall
ET = estimate of evapotranspiration
Q = surface runoff
L = deep seepage
Δ WS = change in soil moisture storage
Δ G = change in groundwater storage

However, as deep seepage was negligible, L was removed. Maximum Δ WS and Δ G, computed from limited data and which might amount to 158 and 250 mm respectively, were not considered as explained previously in the transition report. The equation was therefore reduced to:

$P = ET + Q$

Monthly values of P and Q were derived from daily observed data. ET was estimated from Penman's equation using mean monthly climatic data. An albedo (r) of 0.18 was used for forest evapotranspiration and, after forest clearing, an r of 0.25 (Scarf, 1976) for grassland (Table 5.1).

Table 5.1 Albedo Values and Period of Use

Catchment	r = 0.18	r = 0.25
A	July 77 — March 83 & July 85 — June 86	April 83 — June 85
Sub - B	July 77 — Oct. 80 & July 83 — June 86	Nov. 80 — June 83
C	July 77 — June 86	Nil

A summary of annual water balances is presented in Table 5.2. The table shows that during Calibration average annual discrepancies were +81, +89 and +40 mm for Catchment A, Sub-catchment B and Catchment C, respectively. These discrepancies could be due to unaccounted net change in sub-surface storage. They are less than 5% of annual rainfall and are well within the acceptable range of error.

For Transition, average annual discrepancies were −15, −66 and −1.1.5 mm for Catchment A, Sub-catchment B and Catchment C respectively. The negative residuals were possibly due to two factors, net change in sub-surface storage, and over-estimation of basin evapotranspiration as 1981/82 and 1982/83 were dry years.

For Evaluation, average annual discrepancies were −19, +40 and +272 mm for Catchment A, Sub-catchment B and Catchment C respectively. The negative residuals could be due to net changes in sub-surface storage and the positive residuals due to under-estimation of basin evapotranspiration as 1983/84 — 1985/86 were wet years.

Table 5.2 Summary of Annual Water Balance

Catchment	Parameter	Annual Totals (mm)									
		Calibration Period			Transition Period			Evaluation Period			9 years average
		1977/78	78/79	79/80	80/81	81/82	82/83	83/84	84/85	85/86	
A	P	1839	1547	1958	1831	1742	1488	2274	2284	1956	1880
	Q	105	143	276	184	170	150	1000	918	493	382
	ET	1567	1527	1482	1514	1557	1531	1323	1360	1476	1482
	P-Q-ET	167	– 123	200	133	15	– 193	– 49	6	– 13	16
	Average P-Q-ET		+ 81			– 15			– 19		
B	P	1775	1584	1940	1816	1692	1429	2244	2316	1884	1853
	Q	114	124	246	317	265	138	819	793	475	366
	ET	1567	1527	1482	1462	1473	1467	1449	1495	1476	1489
	P-Q-ET	94	– 67	212	37	– 46	– 176	– 24	28	– 67	– 1
	Average P-Q-Et		+ 80			– 62			– 21		
Sub-B	P	1775	1584	1940	1816	1692	1429	2244	2316	1884	1853
	Q	119	111	226	403	325	132	711	725	467	358
	ET	1567	1527	1482	1482	1419	1428	1449	1495	1476	1475
	P-Q-ET	89	– 54	232	– 15	– 52	– 131	84	96	– 59	21
	Average P-Q-ET		+ 89			– 66			+ 40		
C	P	1835	1663	1980	1820	1597	1464	2391	2430	1937	1902
	Q	191	226	366	274	186	128	535	733	255	322
	ET	1567	1527	1482	1514	1557	1567	1449	1495	1476	1515
	P-Q-ET	77	– 90	132	32	– 146	– 231	407	202	206	65
	Average P-Q-ET		+ 40			– 115			+ 272		

5.2 Rainfall-Runoff Relationship

From Table 5.3, annual rainfall-runoff coefficient for Catchment A averaged 9.7% and 10% for Calibration and Transition respectively. Subsequently, it increased to 44% and 40.2% in the first two years after forest clearing decreasing to 25.2% in the third year (1985/86) as plant cover became fully established. Average annual rainfall-runoff coefficients for Sub-catchment B increased from 8.6% during Calibration to 20.7% during the first two years after forest clearing (1980/81 and 1981/82). The decrease to 9.2% in the third year (1982/83) possibly reflects both newly complete plant cover and a somewhat lower rainfall.

Control Catchment C indicated a 17% decrease in runoff coefficients from Calibration to Transition and an 86% increase from Transition to Evaluation. The decrease was probably due to the consecutively dry water-years 1981/82 and 1982/83 and the increase was probably due to the consecutively wet water-years 1983/84 and 1984/85. These events produce a non-linear rainfall-runoff relationship. Possible dry period processes affecting runoff are 'oasis' effects leading to increased evapotranspiration and changes in groundwater regime. In the wet period, there is a possibility that the groundwater table was raised and the soil saturated thus increasing runoff coefficient.

Although the high rainfall in the Evaluation period may account for some of the increase in the runoff coefficients for all the catchments, the coefficients for Catchment A decreased in the final year (1985/86), as that for Sub-catchment B had establishment of a complete vegetative cover with a high transpiration potential.

If the ratios of the runoff coefficients for the treated catchments to those for the control Catchment C are calculated, the influence of catchment disturbance is clear. The deforestation of Sub-catchment B fell in the 80 — 83 period giving rise to a high ratio of 1.461 (Table 5.3) while that of Catchment A fell largely in the 83 — 86 period with a ratio of 1.667. The recovery of Sub-catchment B is apparent from the decrease in the ratio for 1983 — 86. The effects of treatment timing are readily apparent from the changes of the ratios in the three periods.

Coefficients of storm runoff to rainfall were computed from 24 selected storm runoff hydrographs for each catchment (see Table 5.4). All the catchments had low coefficients ranging from a minimum of 1.1% to a maximum of 12.8%. The average was 6% indicating that a considerable amount of storm rainfall went to replenish catchment moisture storage apart from some interception.

Table 5.3 Annual Rainfall-Runoff Coefficients

		Calibration Period			Transition Period			Evaluation Period		
	Water/Year	**77/78**	**78/79**	**79/80**	**80/81**	**81/82**	**82/83**	**83/84**	**84/85**	**85/86**
Catchment A	Rainfall P (mm)	1839	1547	1958	1831	1742	1488	2274	2284	1956
	Runoff Q (mm)	150	143	276	184	170	150	1000	918	493
	Q/P (%)	5.7	9.2	14.1	10.0	9.8	10.1	44.0	40.2	25.2
	Average Q/P (%)		9.7			10.0			36.5	
Average Q/P of A÷ Average Q/P of C			0.678			0.848			1.667	
Catchment B	Rainfall P (mm)	1775	1583	1940	1816	1692	1429	2244	2316	1884
	Runoff Q (mm)	114	124	246	317	265	138	819	793	475
	Q/P (%)	6.4	7.8	12.7	17.5	15.7	9.7	36.5	34.2	25.2
	Average Q/P (%)		9.0			14.3			32.0	
Average Q/P of B÷ Average Q/P of C			0.629			1.212			1.461	

		Calibration Period			Transition Period			Evaluation Period		
	Water Year	1977/78	78/79	79/80	80/81	81/82	82/83	83/84	84/85	85/86
Sub-catchment B	Rainfall P (mm)	1775	1584	1940	1816	1692	1429	2244	2316	1884
	Runoff Q (mm)	119	111	226	402	325	132	709	718	466
	Q/P (%)	6.7	7.0	11.6	22.1	19.2	9.2	31.6	31.0	24.7
	Average Q/P (%)		8.6			16.8			29.1	
Average Q/P of Sub-B ÷ Average Q/P of C			0.601			1.424			1.329	
Catchment C	Rainfall P (mm)	1835	1663	1980	1820	1597	1464	2392	2430	1937
	Runoff Q (mm)	191	226	366	274	186	128	535	733	255
	Q/P (%)	10.4	13.6	18.5	15.1	11.6	8.7	22.4	30.2	13.2
	Average Q/P (%)		14.3			11.8			21.9	

Table 5.4 Storm-Runoff Coefficients (%)

Calibration Period/ Catchment				Transition Period/ Catchment				Evaluation Period Catchment			
Date of Storms	A	B	C	Date of Storms	A	B	C	Date of Storms	A	B	C
29/10/77	3.6	5.7	7.9	26/12/80	8.3	10.0	12.6	11/11/83	7.7	7.1	7.1
17/07/78	4.2	2.9	3.2	06/01/81	4.5	9.6	6.5	06/05/84	12.8	3.3	5.4
23/11/78	5.8	7.2	6.1	29/05/81	4.5	2.1	3.3	14/07/84	3.0	3.3	5.9
06/12/78	6.2	5.6	7.1	20/10/81	10.9	5.9	6.5	04/05/85	8.9	1.6	8.6
31/12/78	4.0	3.0	3.3	06/05/82	7.7	5.7	5.4	15/06/85	4.0	1.3	2.7
18/07/79	3.5	4.7	4.3	21/05/82	7.6	4.3	8.5	19/04/86	8.4	6.7	7.0
09/04/80	5.8	7.2	4.4	03/07/82	4.4	4.0	7.7	21/04/86	12.1	9.0	9.9
26/04/80	6.4	8.7	5.7	20/06/83	5.2	1.9	1.1	15/06/86	8.9	11.5	3.6
Mean	4.9	5.6	5.3		6.6	5.4	6.5		8.2	5.5	6.3
Std. Deviation	1.2	2.1	1.7		2.4	3.1	3.5		3.4	3.7	2.4

5.3 Water Yield Responses to Forest Conversion

5.3.1 Analysis of Water Yield Changes.

One of the most direct method of analyses of water yield changes is the plotting of double mass curves. Essentially this method involves the plotting of cumulative totals of a characteristic understudy against cumulative totals of a control's parameter. In the present analysis, monthly runoff values of Catchments A and B were plotted against that of C. These double mass curves clearly showed a break in the trends of runoff commencing at the time of treatment imposed and continued thereafter. (Fig.5.1 and 5.2). The rate of change in the trends between the two catchments reflects different intensity of responses. The above phenomenon qualitatively suggests an immediate impact of forest conversion on the flow regimes once the operation has taken place. However, with this method, it may be difficult to reach an objective conclusion except providing the general trends (Reinhart, 1965).

Flow extremes are common in all catchments. This inherent characteristic affords another qualitative method of detecting hydrological changes which is the frequency of flow distribution. Frequencies of monthly runoff of Catchments A and B were computed and compared between the Calibration and post-Calibration periods (Fig. 5.3 and 5.4). Different patterns of runoff frequency were clearly discernible between the two periods for the same catchment, particularly for the low flow classes. A remarkable change occurred in the zero flow distributions which were quite prominent during dry months of the Calibration. Conversely, no instances of stream drying up after the treatment had taken place in both catchments.

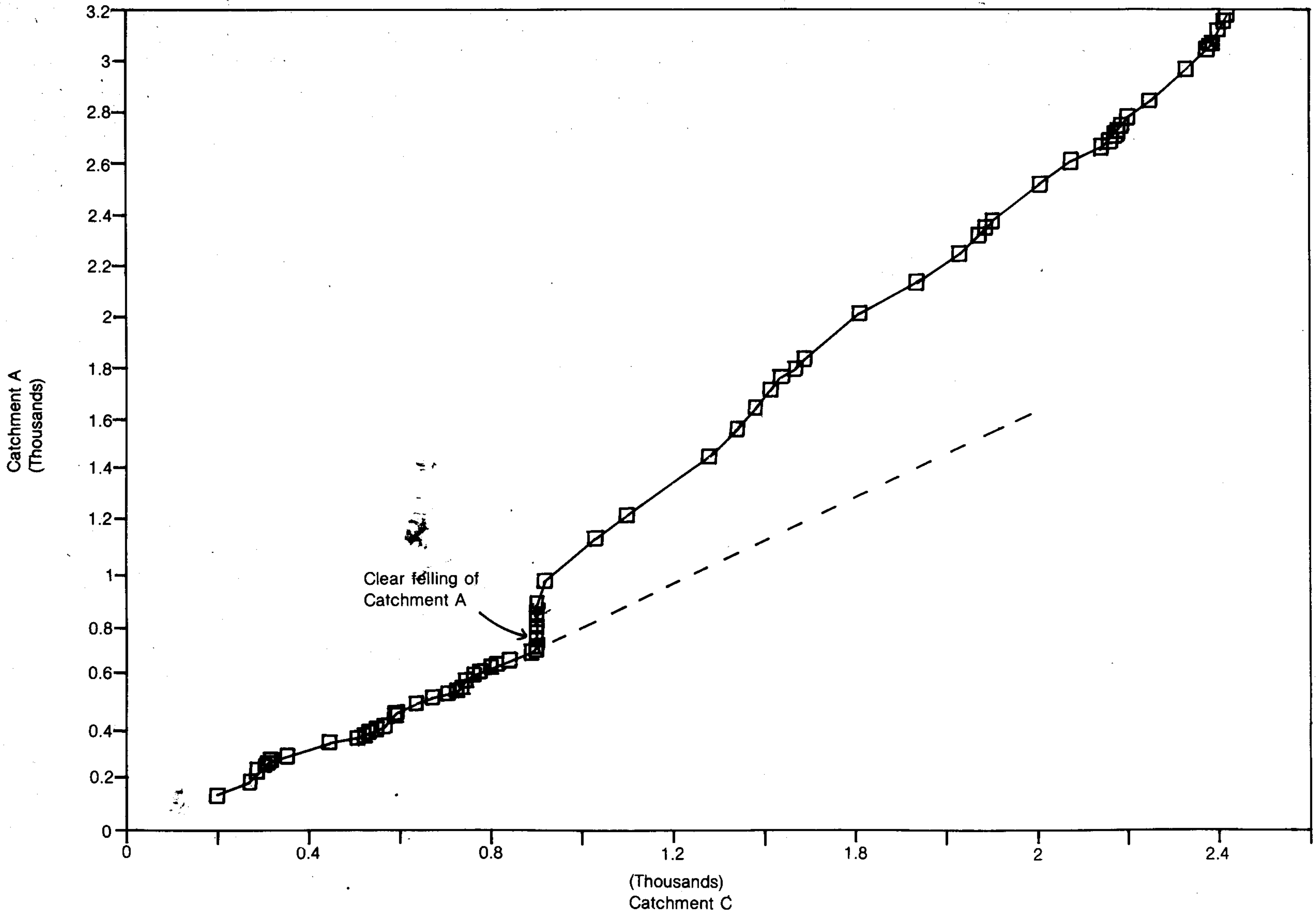


Fig. 5.1. Double Mass Curve of Monthly Runoff (mm) of Catchment A against Catchment C, a control.

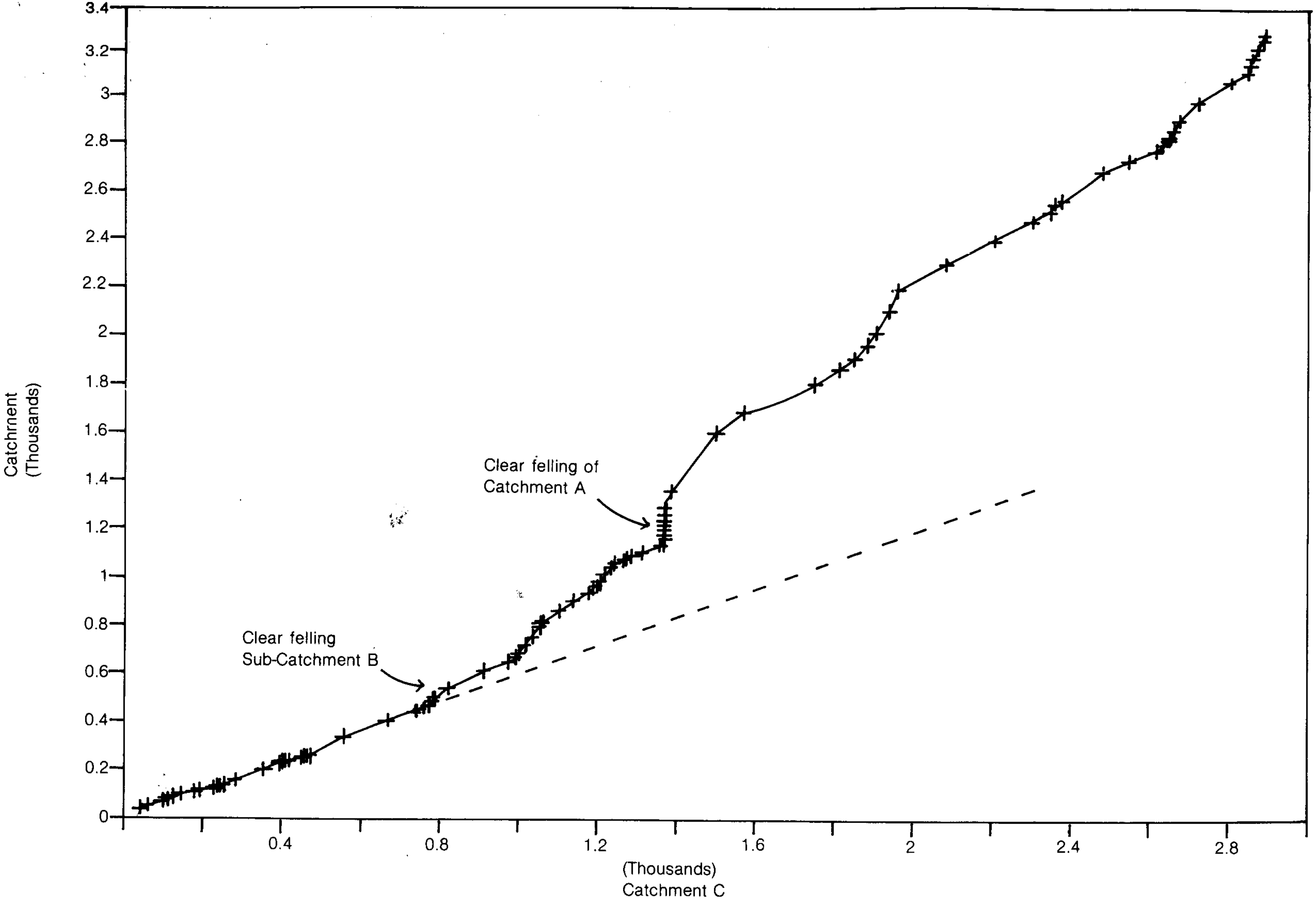


Fig. 5.2. Double Mass Curve of monthly Runoff (mm) of Catchment B against Catchment C, a control.

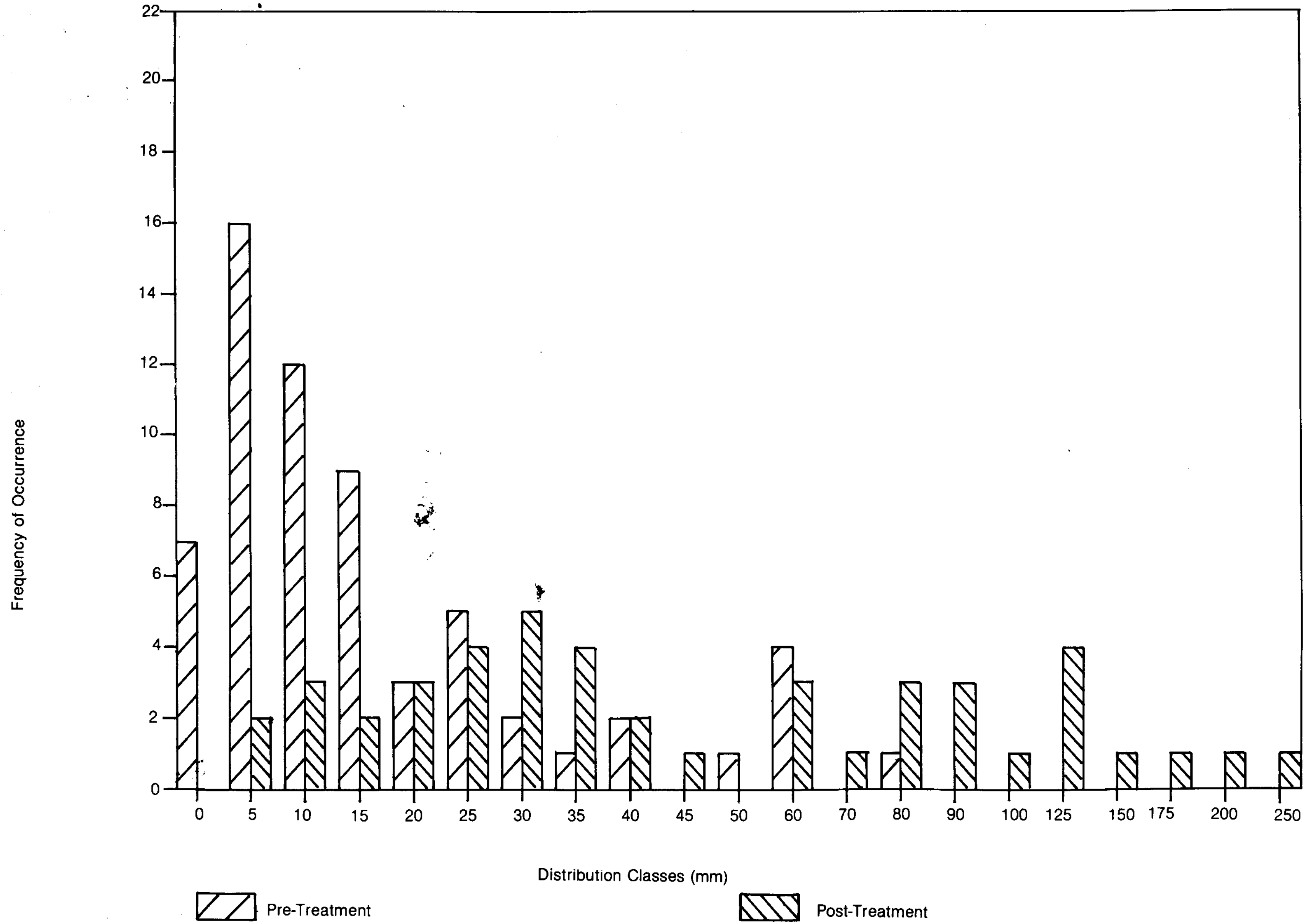


Fig. 5.3. Frequency and Distribution of Monthly Runoff mm) during the Calibration and Post-treatment for Catchment A.

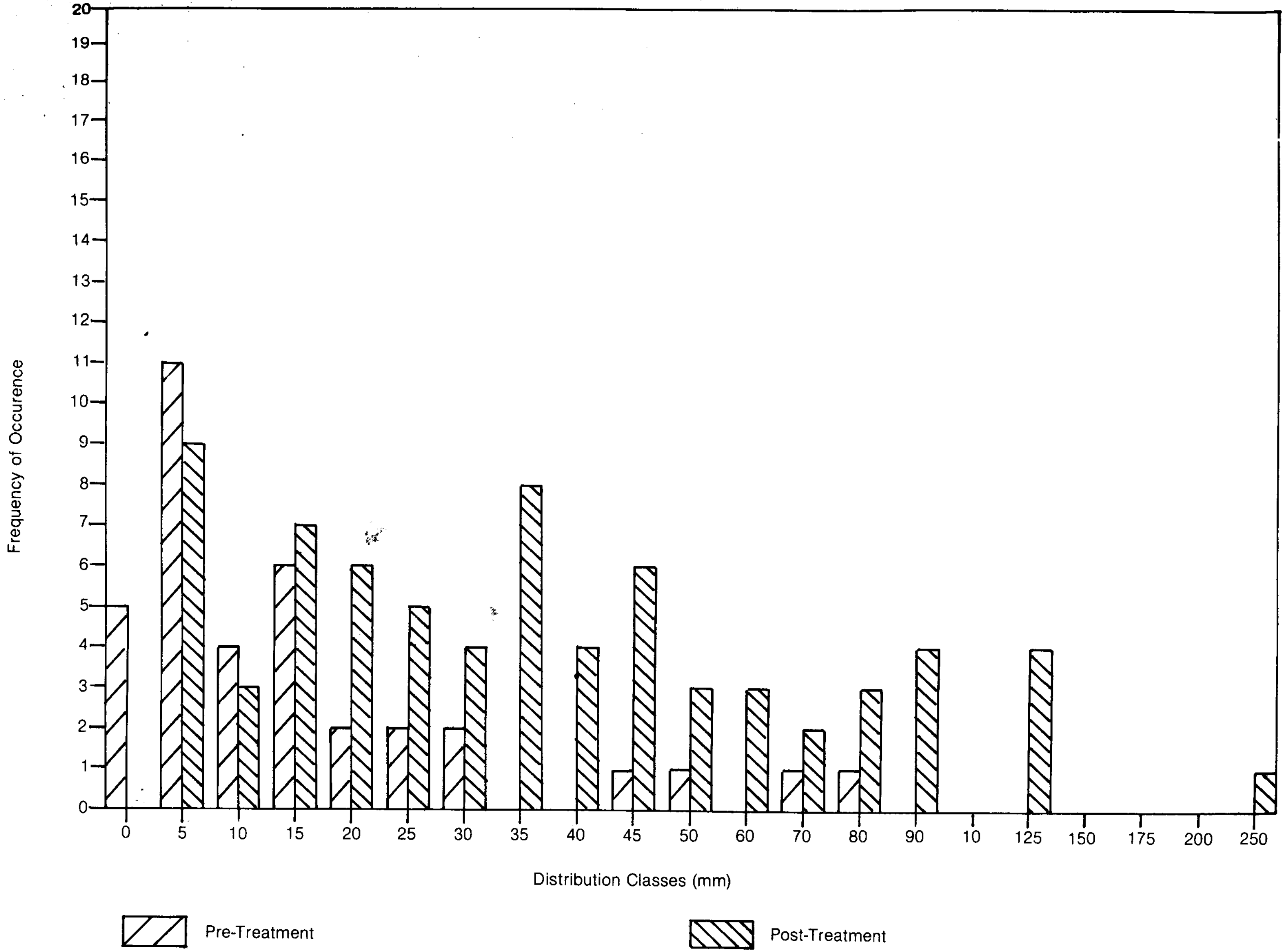


Fig. 5.4. Frequency and Distribution of Monthly Runoff (mm) during the Calibration and Post-treatment for Catchment A.

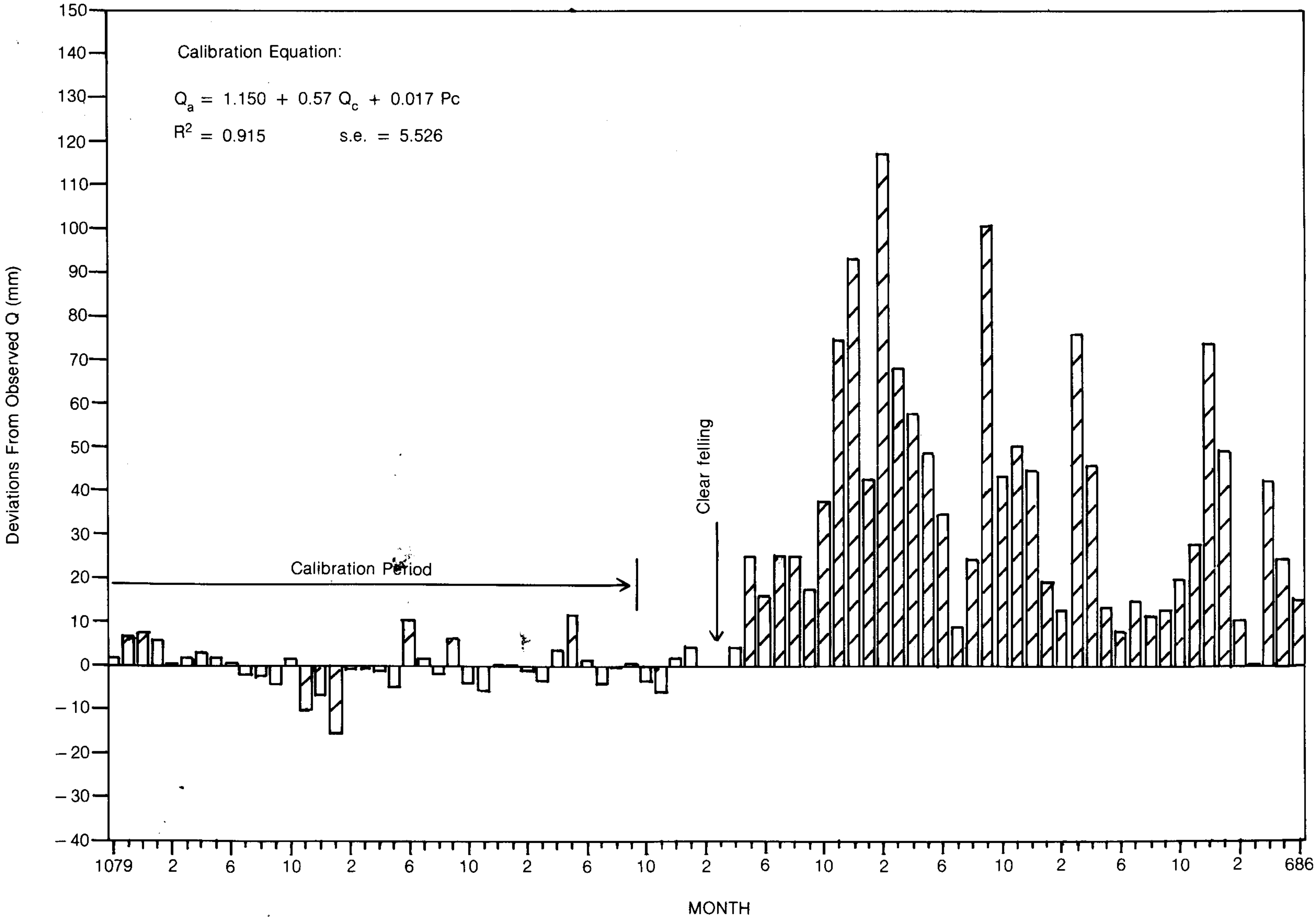


Fig. 5.5 Deviations between Observed and Predicted Runoff (mm) for Catchment A.

5.3.2 Water Yield Prediction.

Statistical regression procedure provides a quantitative approach to describing treatment changes and associated responses in hydrological parameters. This method consists of fitting regression models for the calibration as well as post-treatment periods — always treating data from the control catchment as independent variables (Hewlett, 1971). Once a satisfactory fit has been achieved, regression models may be employed to predict runoff from the treated catchments based on selected predictor variables of the control catchment. Accordingly, prediction models are tested for significance, accuracy and validity before being used to detect changes after treatment. In this regard, regression model gives the most precise unbiased estimates of the linear function of the observations if the basic statistical assumptions are met (Daniel and Wood, 1971). One of the assumptions is that the data are representative sample from the entire range on which generalisations are made.

Several regression models were fitted and tested for calibration periods using different predictor variables including monthly runoff, rainfall and runoffs for the immediately antecedent month. Rigorous statistical tests were performed in selecting the best fit, thus giving a reliable prediction model. Due to inherent variability of monthly runoffs, calibration models employed only a segment of the entire period of the calibration in order to maintain a statistiscal reliability and accuracy. Accordingly, the calibration equations for Catchments A and B used 36 and 32 months of observations, respectively. The final model which gave the best fit comprised multiple linear regressions with monthly runoff and rainfall as predictor variables. The calibration equations for catchments A and B are as follows:

$$Q_a = 1.150 + 0.57Q_c + 0.017P_c \quad (1)$$

$r - \text{square} = 0.915$ s.e. $= 5.526$

$$Q_b = -4.891 + 0.614Q_c + 0.034P_c \quad (2)$$

$r - \text{square} = 0.937$ s.e. $= 5.025$

where Q — monthly discharge
P — monthly rainfall
a, b, c — name of catchments
s.e. — standard error of estimates

In addition, a dummy technique was used in the regression analyses to test the significance of responses of forest conversion as described by Gujarati (1978). The above test involves comparing of the residual error from a full model containing a treatment effect with a reduced model without the treatment effect by treating calibration and treatment periods in the same regression. The dummy variable is assigned and coded 0 during Calibration and 1 during both the Transition and Evaluation. Fitted regression models explained 92% and 94% of the variations in monthly runoffs of Catchments A and B, respectively. Relatively high r-square and low standard error of estimates are measures of adequacy of the calibration equations in both catchments.

5.3.3 Water Yield Changes.

5.3.3.1 Water Yield Changes in Catchment A.

The equation 1 was eventually used to predict monthly runoff in catchment A for the entire period. Deviations in monthly runoffs between observed and predicted values are shown in Fig. 5.5. Evidently, monthly runoff increased substantially and hence annual water yields, from clearfelling of the forest and through subsequent operations. In the first-year, water yield increase was 110.1 mm or 117 % and further increased in the subsequent year by 706.3 mm or 157%. The third and fourth year showed a lower rate of increase in absolute amount as compared to the previous years. Water yield increases during the Transition and Evaluation were statistically significant at $p<0.01$ using the dummy techniques in regression analysis with an F-value of 22 and degrees of freedom of 5 and 75.

5.3.3.2 Water Yield Changes in Catchment B

In this analysis, catchment B includes both Catchment A and Sub-catchment B.

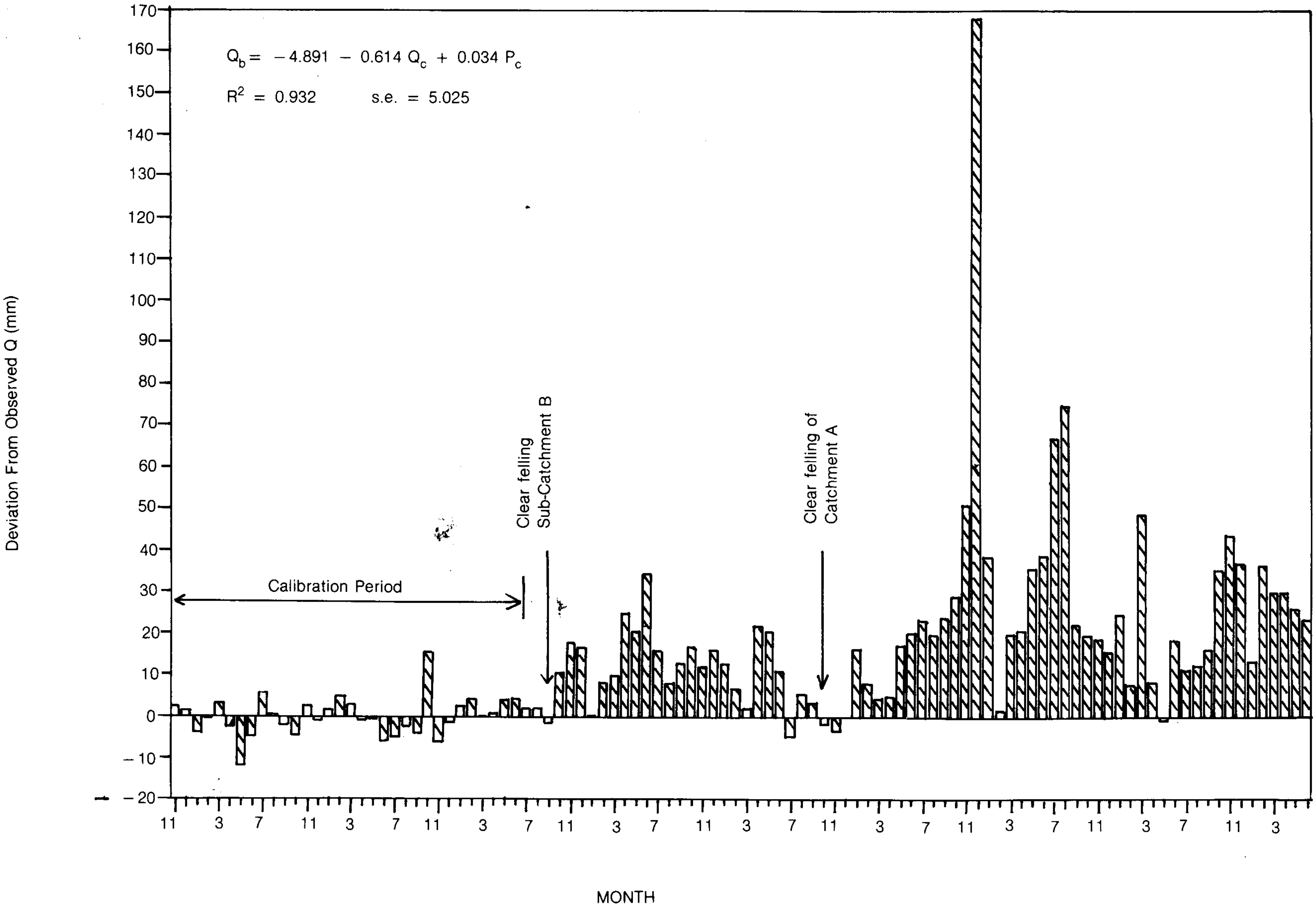


Fig. 5.6. Deviations between Observed and Predicited Runoff (mm) for Catchment B.

However, due to different timings of treatment for the two sub-catchments as explained earlier, water yield changes should proportionally reflect the above schedule.

The equation 2 was used to predict the monthly runoffs of catchment B and subsequently subtracted from observed values to get the deviations in monthly runoffs for the entire period (Fig. 5.6). Due to inherent physical set-up of this catchment, the first two to three years after the treatment reflected that of Sub-catchment B which comprised of 60% of Catchment B. The first three-year of water yield increments were 145.4 (85%), 155 (142%) and 137 mm (97%) respectively. The fourth year increment, coinciding with the logging and clearfelling of Catchment A, amounted to 822.2 mm or 470%. The fifth and sixth year saw further increases in water yields but at decreasing rates, which were 793.2 mm (270%) and 476.2 mm (314%) respectively. The increases in water yield during Transition and Evaluation were significant at $p<0.01$ with F-value of 9.2 and degrees of freedom of 5 and 98.

5.3.4. **Discussion.**

Apparent differentials in water yield changes after the treatment possibly reflect the various types of operations undertaken during the conversion schedule, and, in part, the prevailing rainfall regimes. However, the latter factor might not play as important a role as the former because the rainfall pattern over all catchments are generally uniform. Therefore, the changes in water yield observed in the Transition and Evaluation probably mainly reflect more of the impact of transformation from forest to landuses.

The fact that different crops were planted in catchments A and Sub-catchment B should permit a good comparison in water yield responses. Unfortunately, the nesting of the two catchments into the larger Catchment B created some difficulties in comparison. However, different rates of water yield changes during Transition and Evaluation between catchments can be elucided as indications of crop influence to a certain extent.

As crops require some time to become fully established, an adequate data set would be necessary in order to elucide and document further responses, particularly the time taken for the water regime to revert to the previous forest characteristics, if it ever would do so.

CHAPTER 6

WATER QUALITY

Water quality parameters were analysed to assess the changes resulting from the logging, clear-cutting, burning of logs, and planting of commercial crops in Catchment A and sub-catchment B relatlive to Catchment C (control catchment). Although 22 individual parameters were analysed, interpretation of data was based on the more important ones: pH, alkalinity, conductivity, total suspended solids, turbidity, dissolved silica, nitrate-nitrogen, potassium, sodium, iron, calcium and magnesium.

6.1 Trends of Parameters

The monthly mean variations of the selected parameters are shown in Figures 6.1 to 6.12. Higher values for suspended solids, turbidity, calcium, iron and magnesium were observed in Catchment A and Sub-catchment B especially after the treatments in Catchment A were completed whereas the values for Catchment C were almost uniform. It was expected that the treatment effects would be more obvious when the treatments were still in progress or immediately after but the trends did not reflect the situation probably due to the lack of sampling during high flows. Catchment A experienced higher monthly mean values than Catchment B as a whole because the effects of the earlier treatment in Sub-catchment B; the lower two-thirds of Catchment B as a whole, were diluted by unchanged runoff from Catchment A.

Higher monthly mean values for turbidity, suspended solids and iron generally coincided with the wet months (Figure 6.13). This demonstrates the role of surface runoff in transporting the dissolved and solid materials into the stream. Meanwhile values for conductivity, pH, magnesium and calcium were higher during the dry months. This phenomenon can be explained by the dominance of ground water discharge containing high solute concentrations during extreme low flow conditions.

6.2 Treatment Effects

Mean monthly values of the selected parameters of the treated catchments were compared with the values from the control catchment (Catchment C) using paired t-test analysis (Table 6.1). The analyses for conductivity, calcium and magnesium showed significant increases in values for both catchments following the treatments. However suspended solids and turbidity showed no significant differences, and the reason again being the inadequate sampling during storm periods.

The degradation of water quality due to land development will directly or indirectly affect the water usage downstream. Parameters analysed in the study that would affect the drinking water standards include total suspended solids, turbidity, nitrate-nitrogen and iron. These parameters exceeded the stipulated standards during and after catchment treatments (see corresponding figures and Table 6.2). However iron occurs in relatively high quantities, exceeding the standards cited, in many undisturbed streams under Malaysian condition. Water treatment plants downstream have to adjust their treatment capabilities to ensure the quality of water supplies, such adjustments usually entailing increases in costs. Other environmental changes that might occur but which would be hard to quantify, include decrease of biological diversity, impacts on fishery and the deterioration of the aesthetic value of the river.

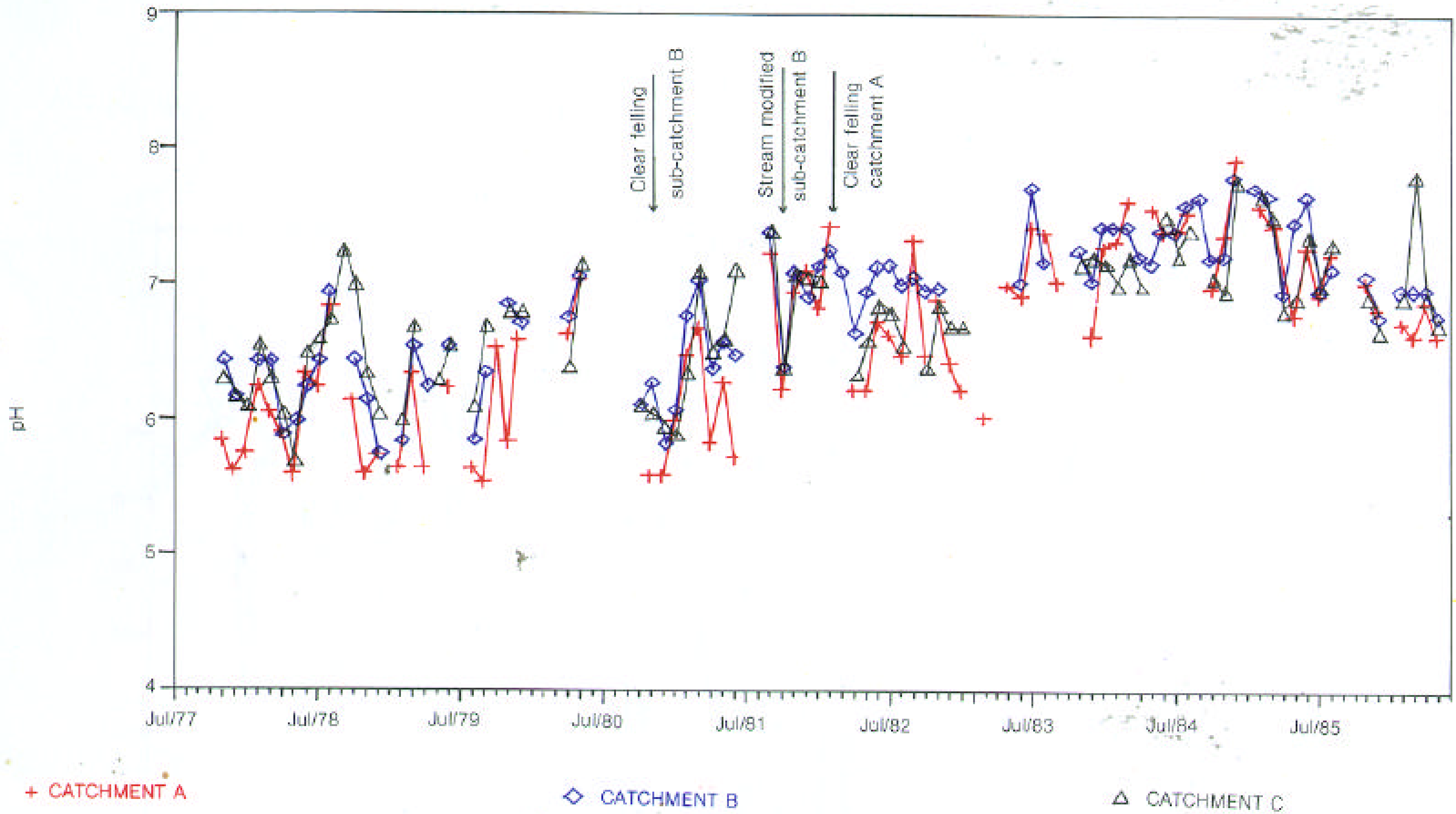


Fig. 6.1 Trends of pH During the Calibration, Transition and Evaluation Periods.

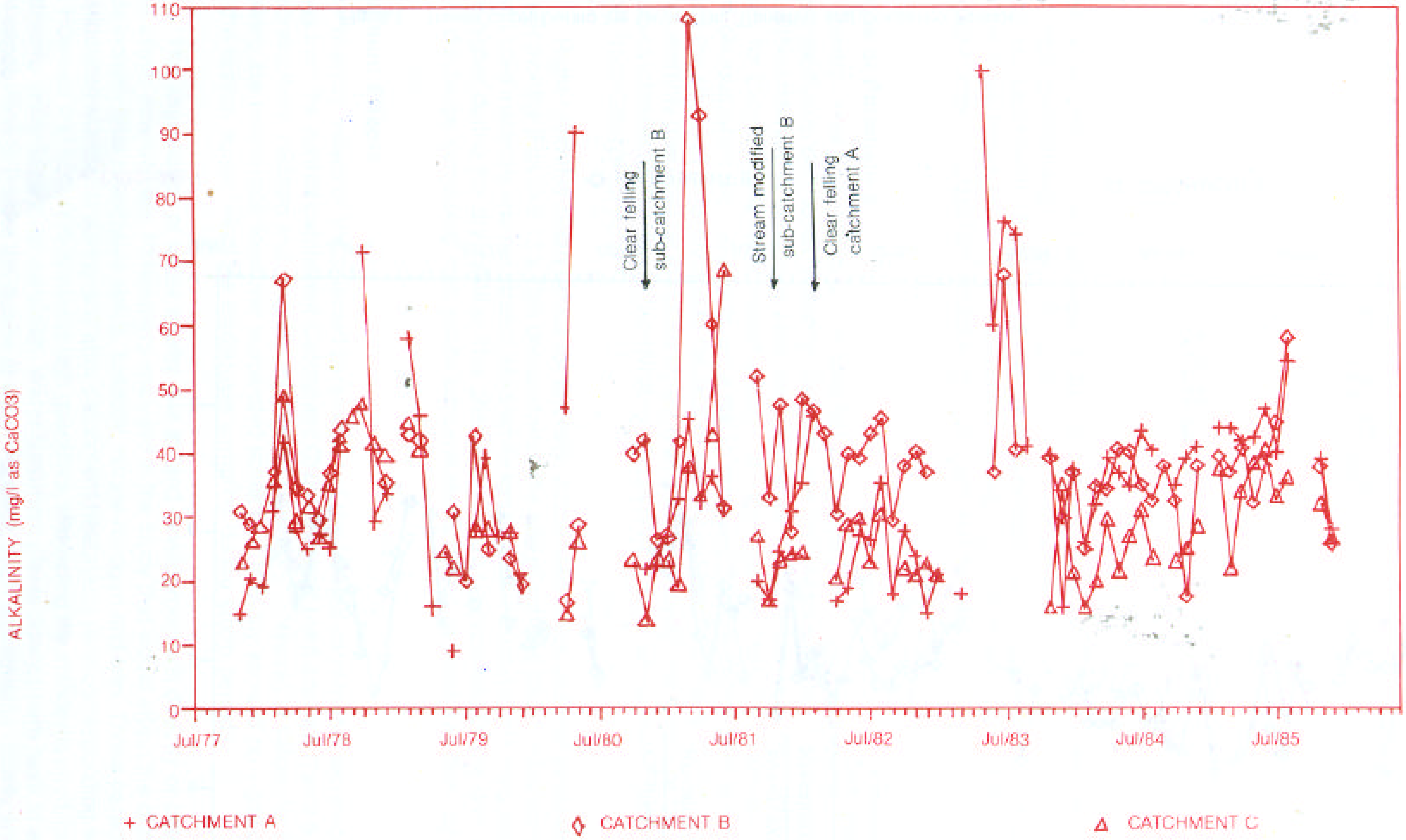


Fig. 6.2 Trends of Alkalinity (mg/l as $CaCO_3$. During the Calibration, Transition and Evaluation Periods

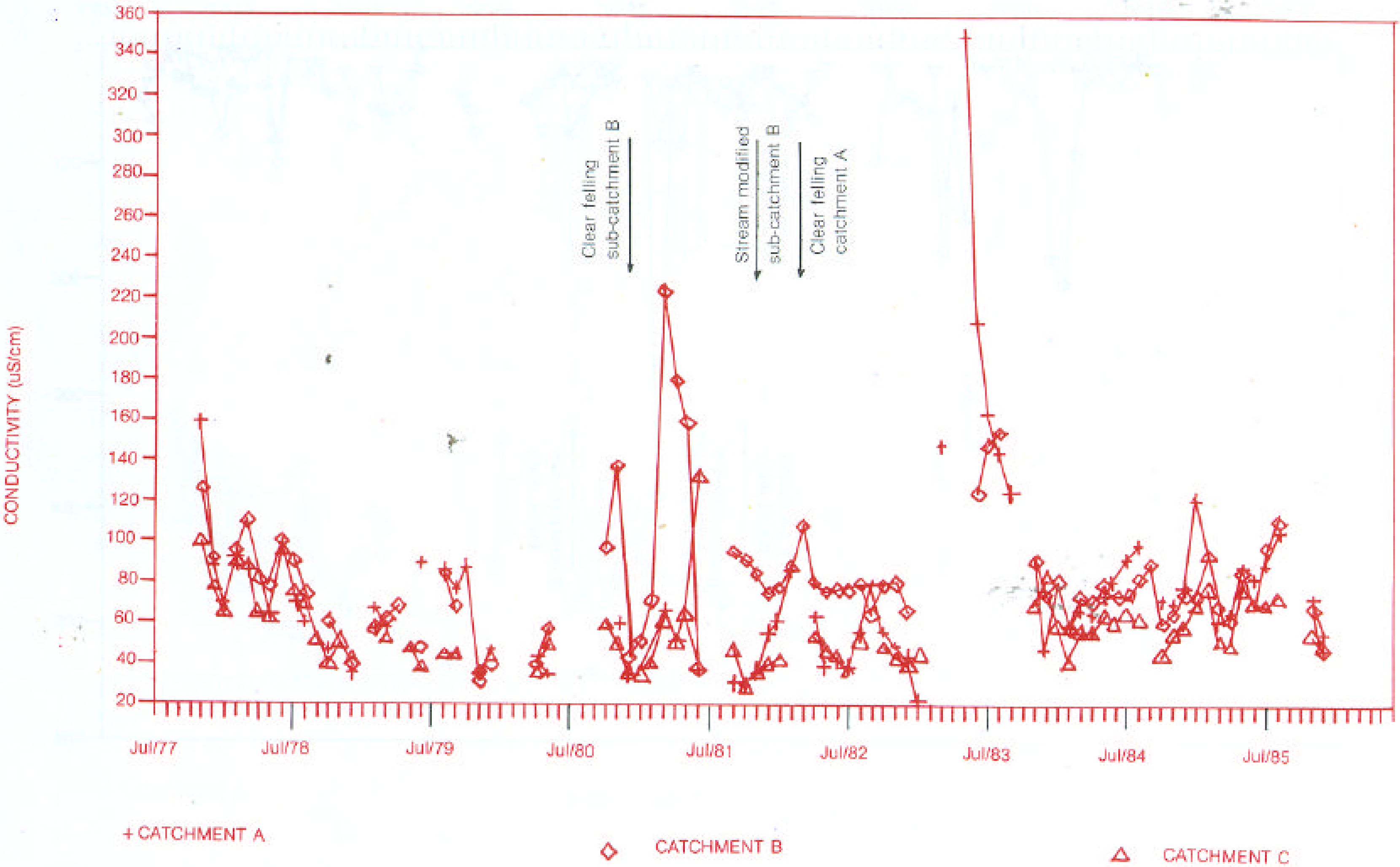


Fig. 6.3. Trends of Conductivity (uS/cm). During the Calibration, Transition and Evaluation Periods.

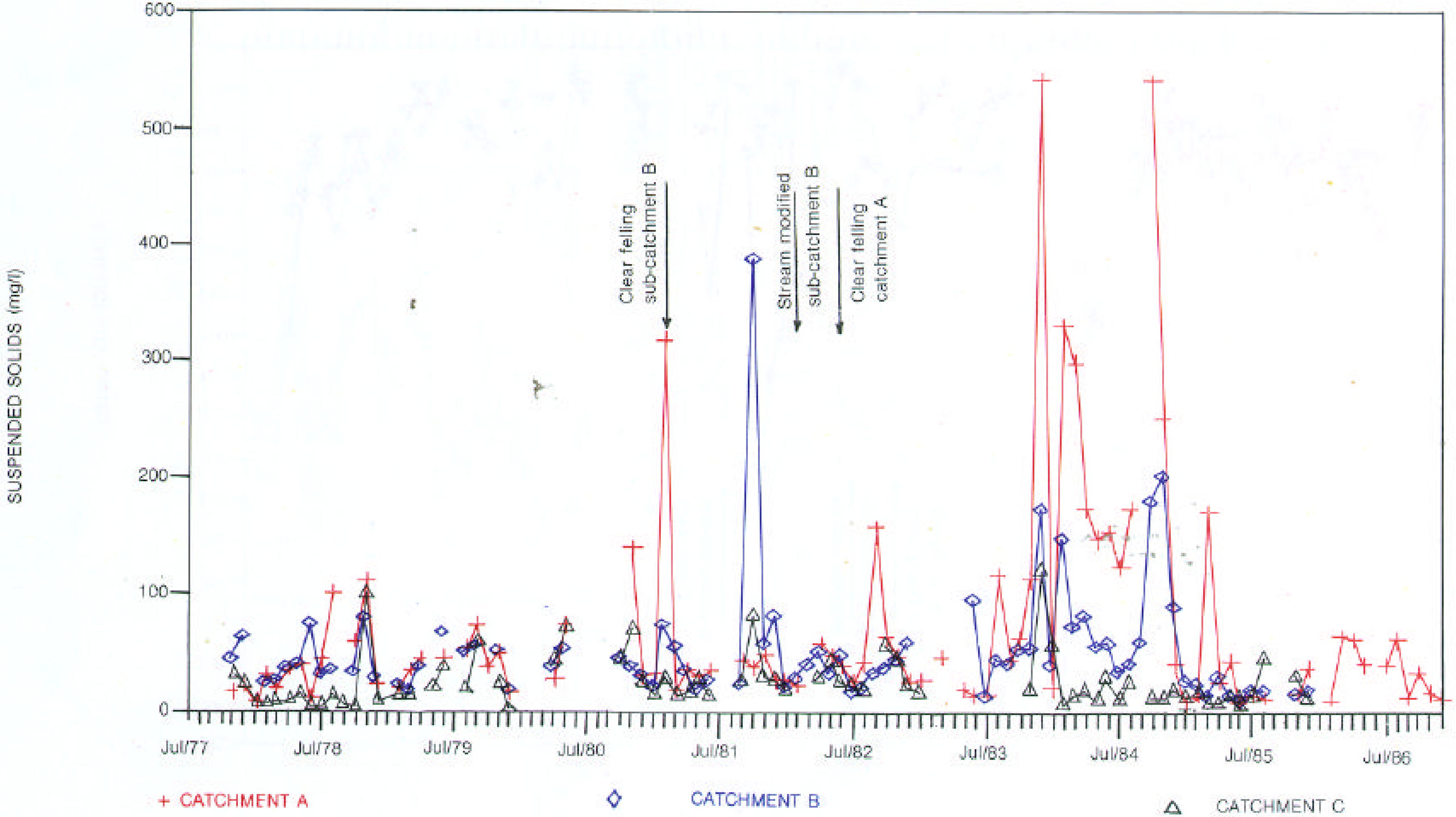


Fig. 6.4 Trends of Suspended Solids (mg/l), During the Calibration, Transition and Evaluation Periods.

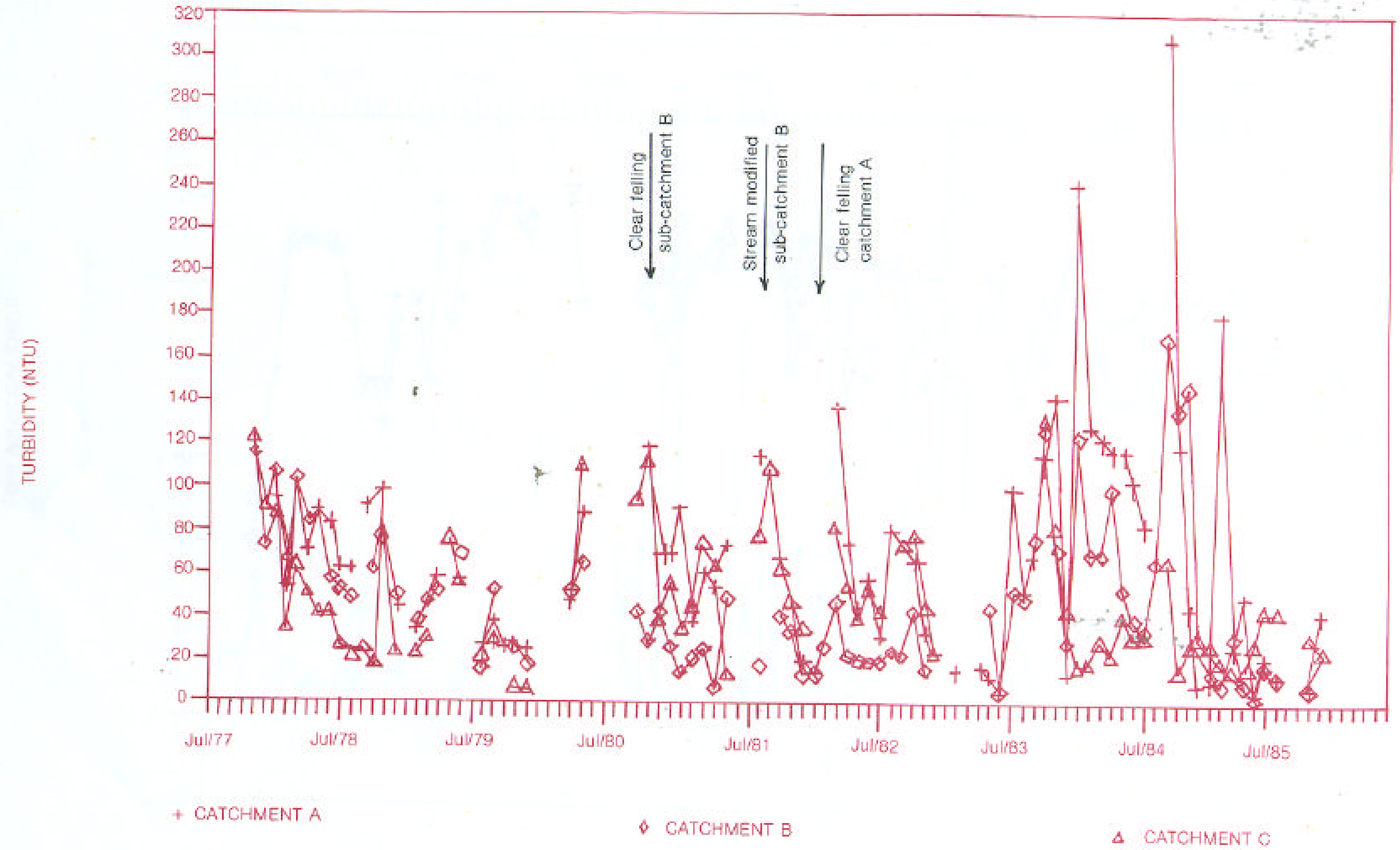


Fig. 6.5 Trends of Turbidity (NTU). During the Calibration, Transition and Evaluation Periods.

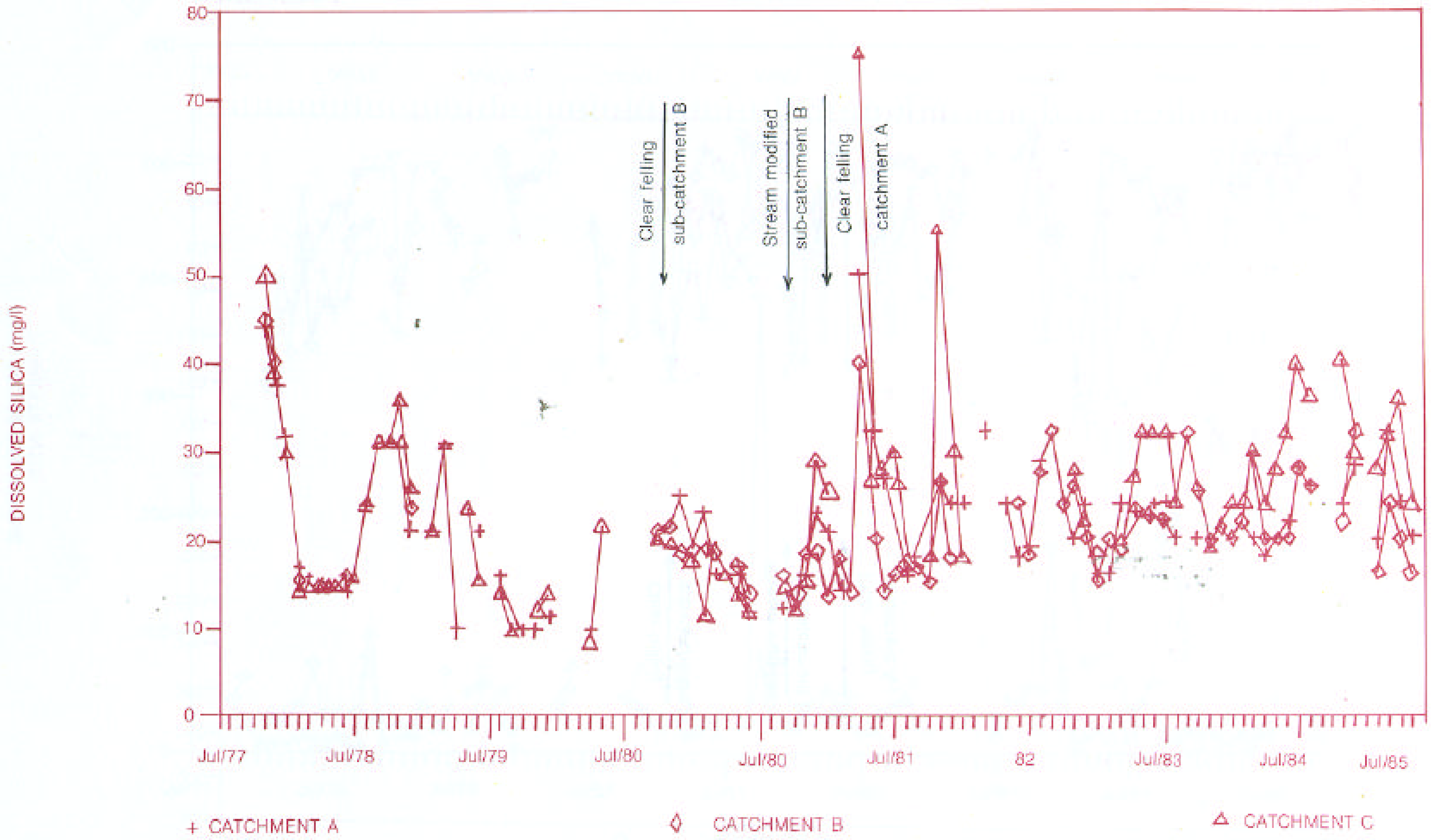


Fig. 6.6 Trends of Dissolved Silica (mg/l). During the Calibration, Transition and Evaluation Periods.

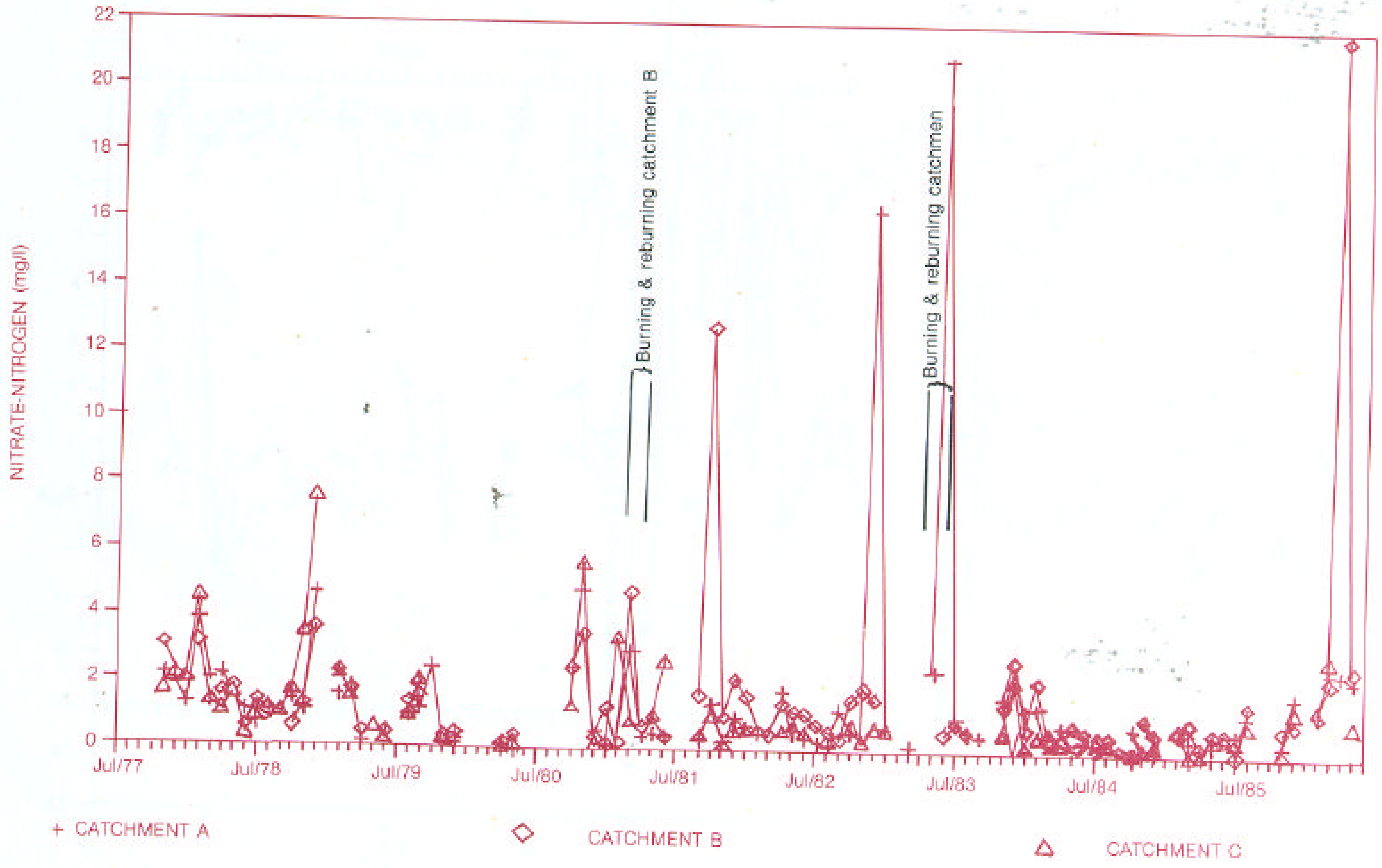


Fig. 6.7. Trends of Nitrate — Nitrogen (mg/l). During the Calibration, Transition and Evaluation Periods.

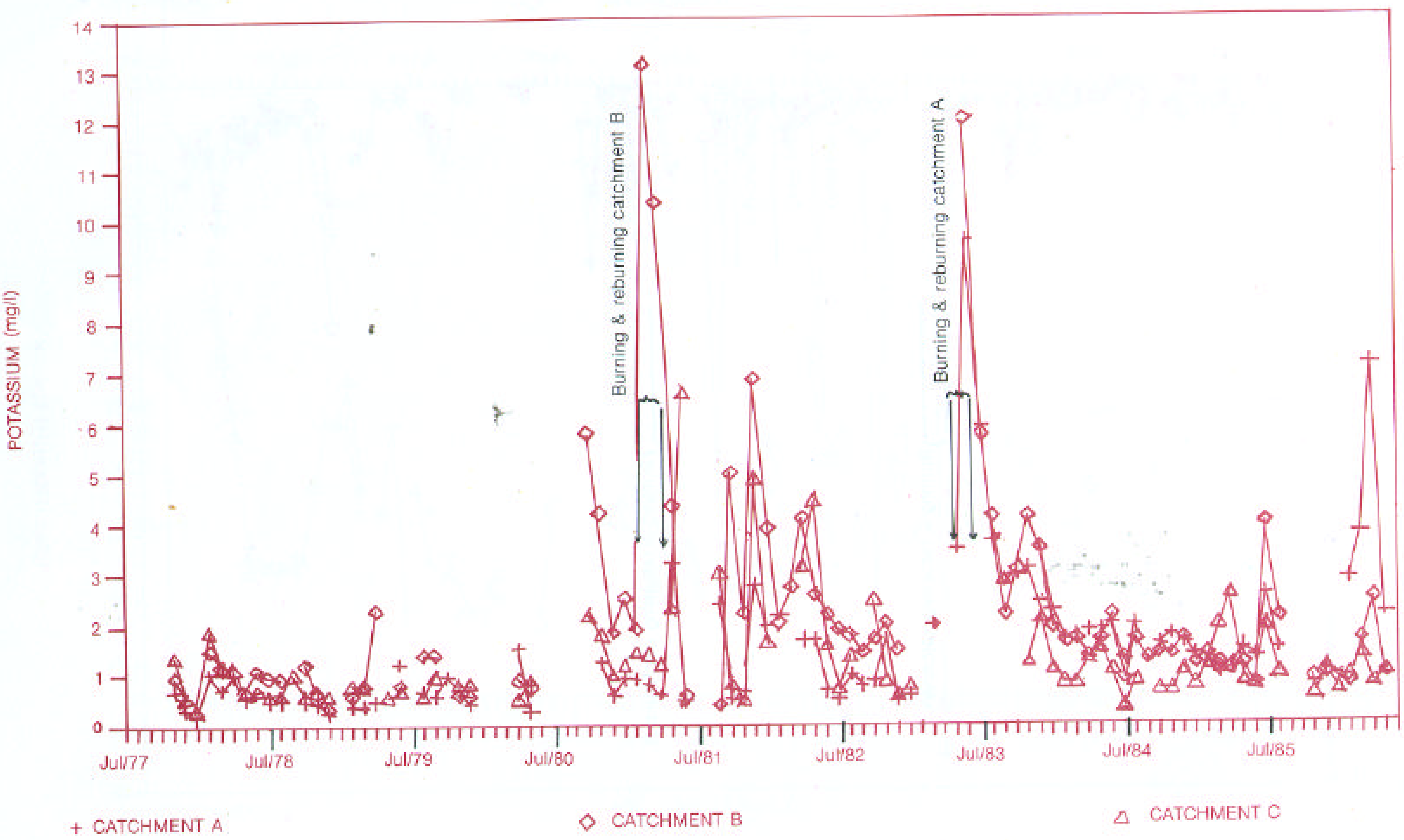


Fig. 6.8. Trends of Potassium (mg/l). During the Calibration, Transition and Evaluation Periods.

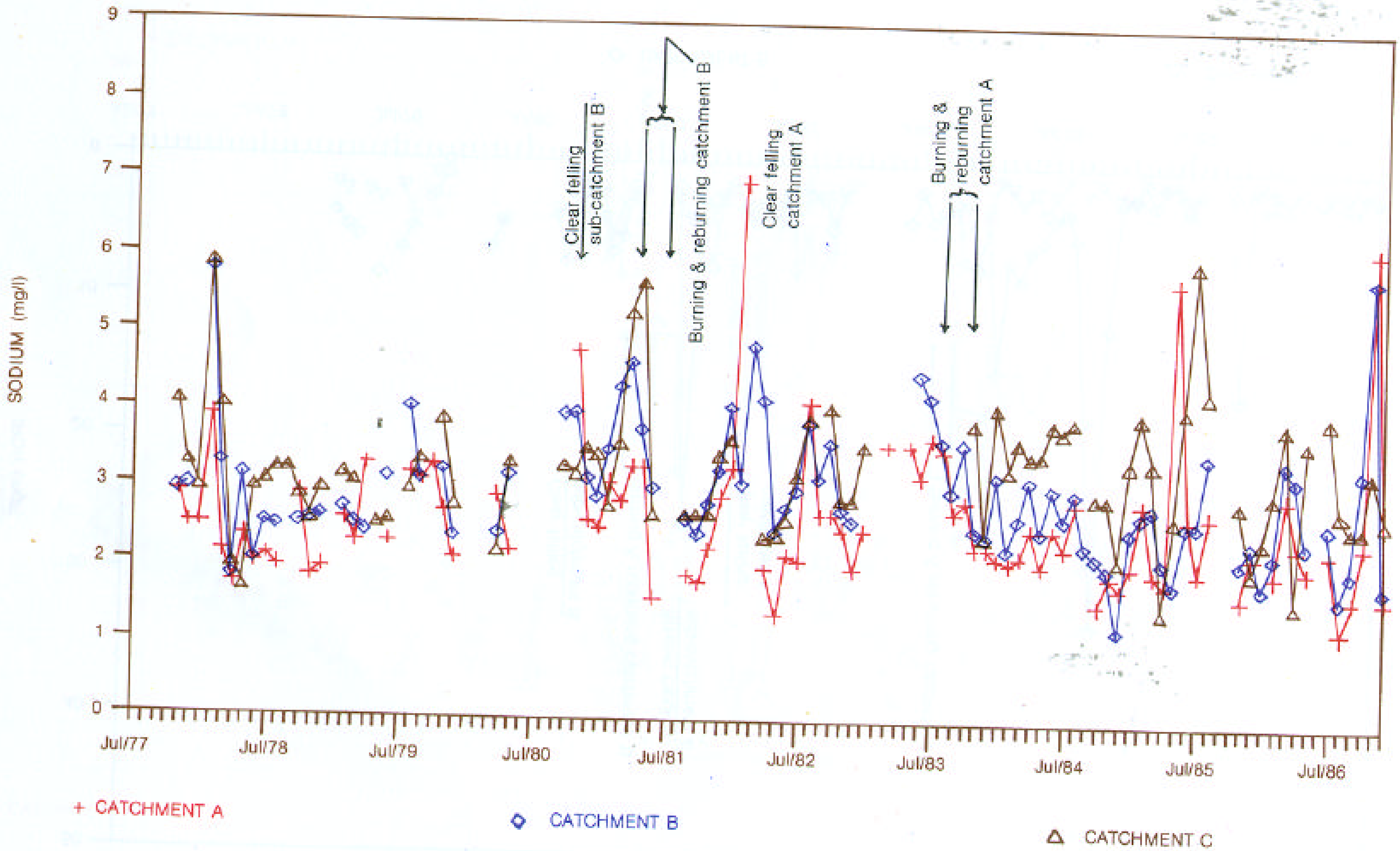


Fig. 6.9. Trends of Sodium (mg/l). During the Calibration, Transition and Evaluation Periods.

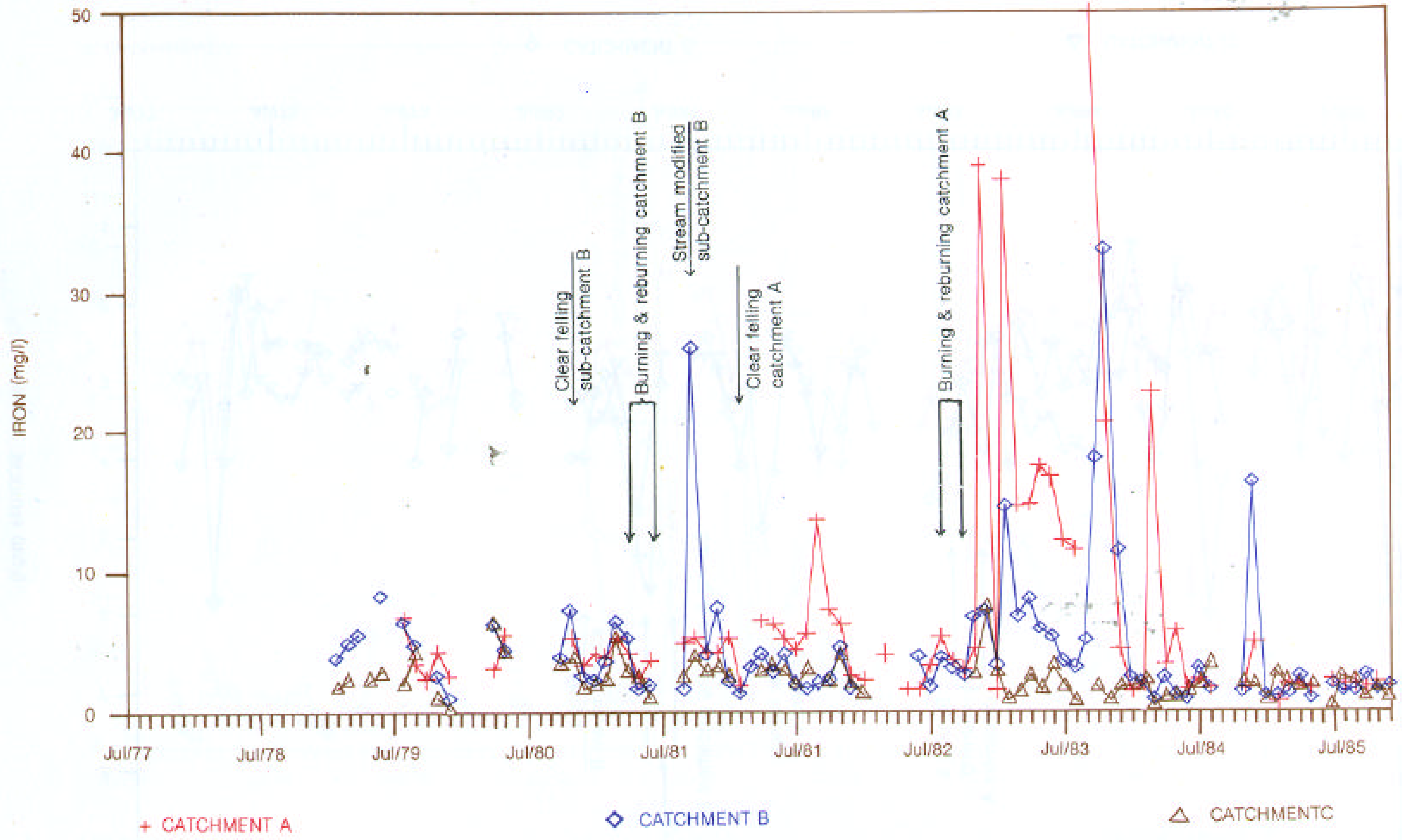


Fig. 6.10. Trends of Iron (mg/l) . During the Calibration, Transition and Evaluation

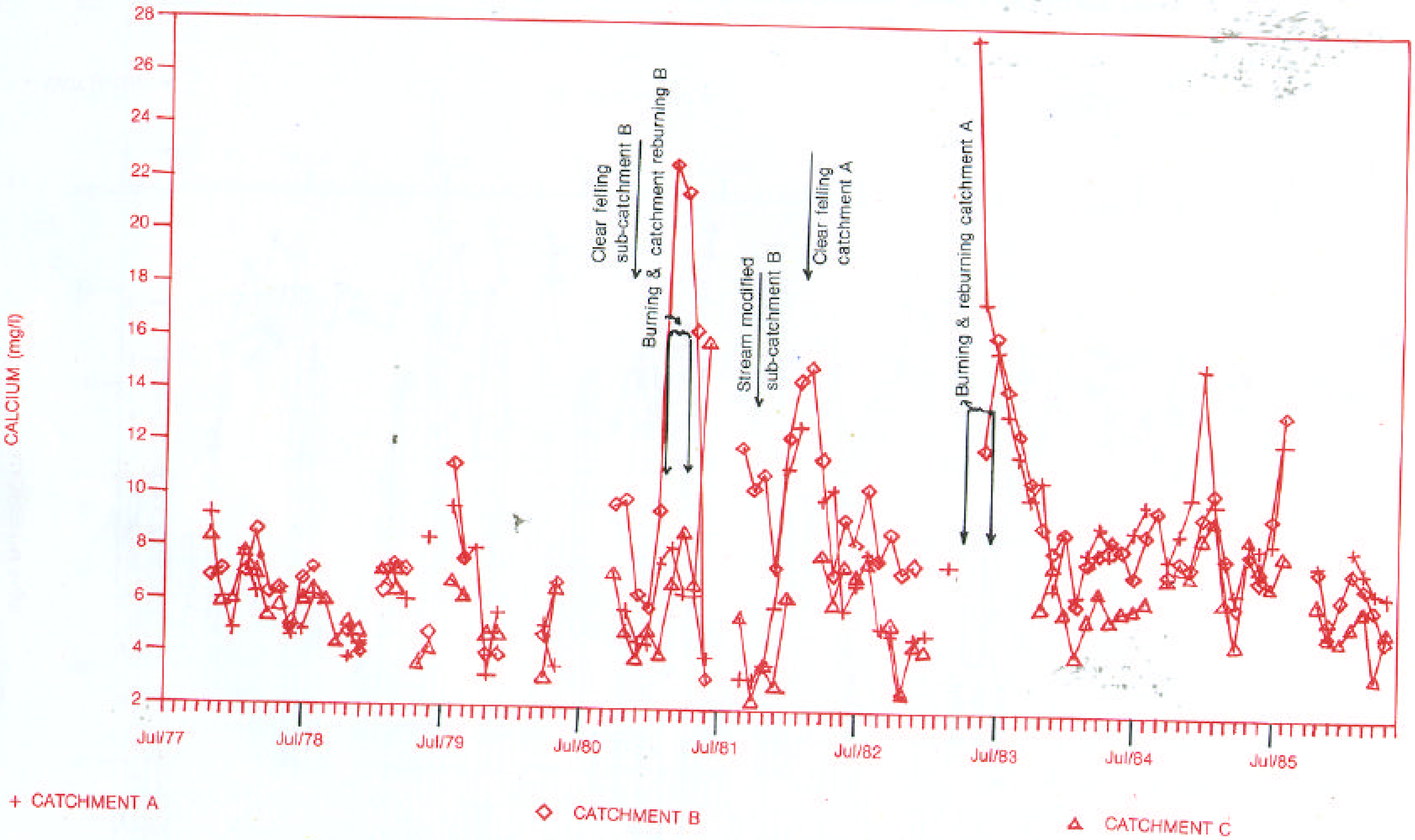


Fig. 6.11. Trends of Calcium (mg/l). During the Calibration, Transition and Evaluation Periods.

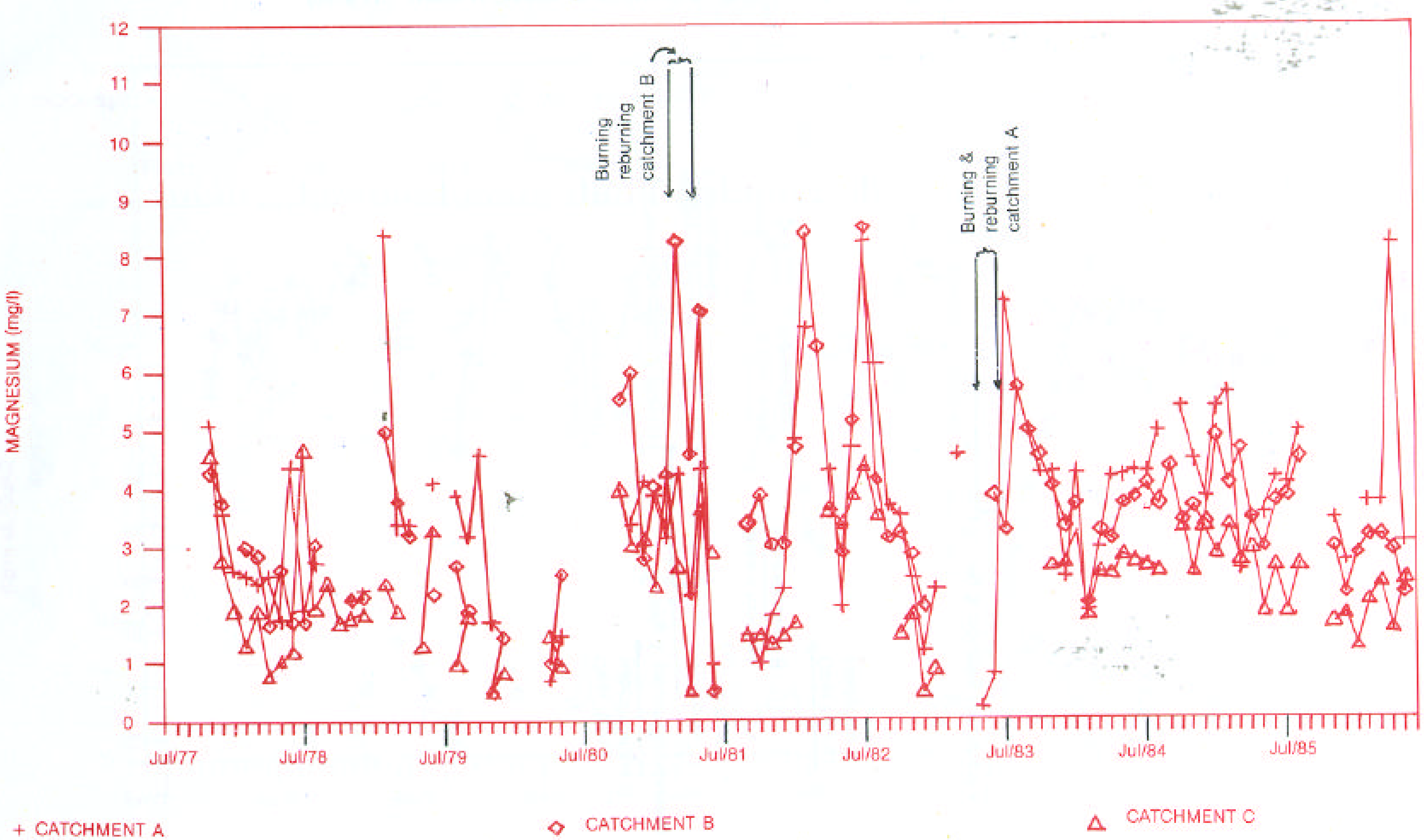


Fig. 6.12. Trends of Magnesium (mg/l). During the Calibration, Transition and Evaluation Periods.

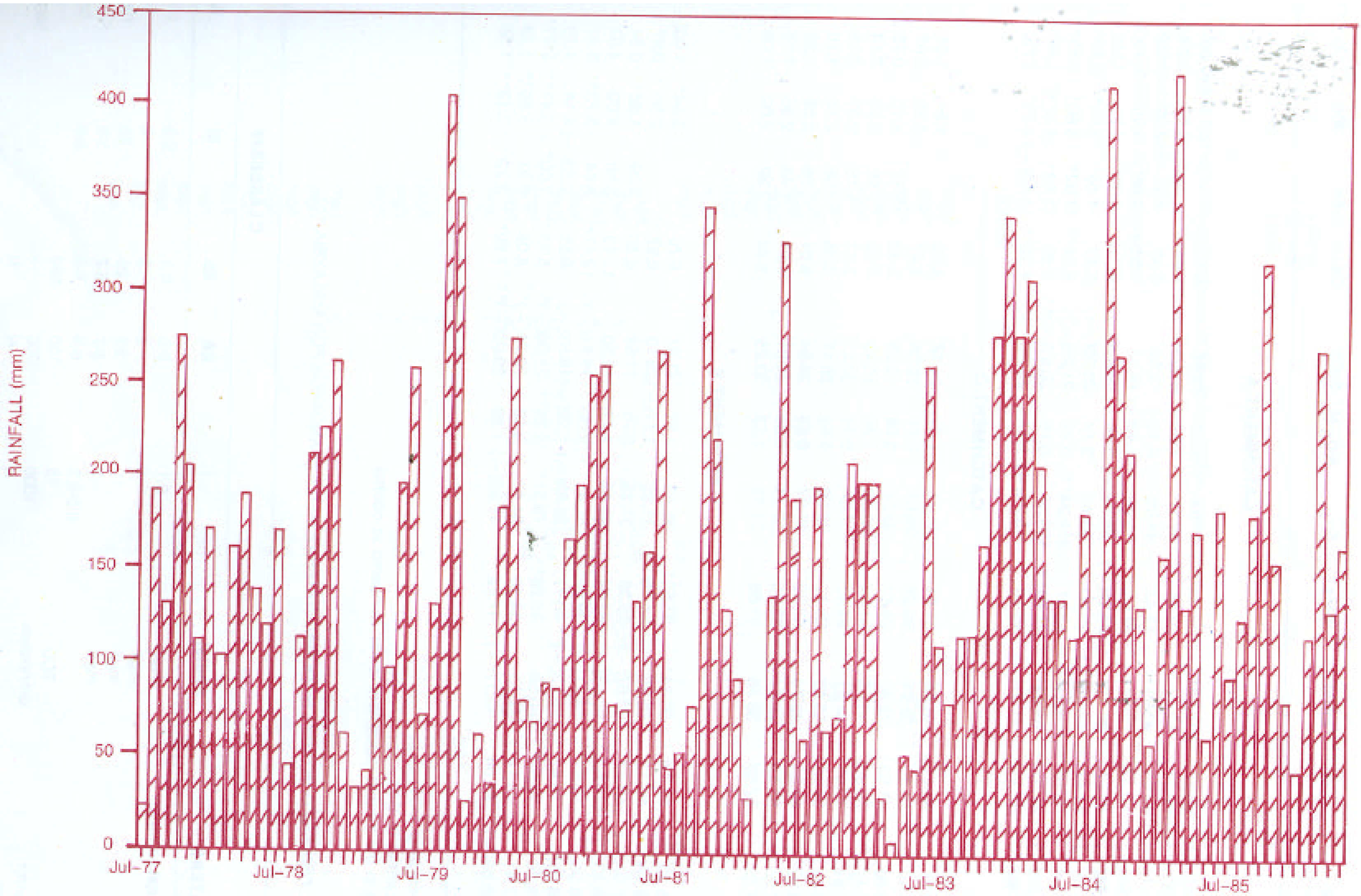


Fig. 6.13. Mean Monthly Rainfall.

Table 6.1: Summary of Paired t-test Analysis Based On Monthly mean Values between treated catchment and control Catchment C

Year	pH	Cond	Turbid	Alka	Ss	NO_3-N	SiO2	Ca	Fe	Mg	K	Na
						CATCHMENT A						
77/78	5.87(-) **	93.22	115.75*	26.10(-)**	17.94	2.02	23.66	6.40(-)		3.10**	0.66(-)*	2.51(-)*
78/79	6.00(-)	60.33	62.17	39.44	49.11	1.59(-)	24.50	5.94		3.54	0.53(-)	2.24(-)*
79/80	6.17(-)	54.00	43.25	42.42	44.83	0.45(-)	13.33	5.80	4.22	2.08	0.68(-)	2.70(-)
80/81	5.99(-)	50.32(-)	72.67	31.31	75.38	1.40(-)	18.44	5.94(-)	3.88*	3.30	1.10(-)	3.00(-)
81/82	**6.66(**−)**	45.27	96.79	23.95(−)	36.76(−)	5.15	26.09(−)	6.71	5.01**	2.82	1.56(−)*	2.21(−)*
82/83	6.49(−)	44.43	48.03(−)	25.00	33.81	3.12	23.09(−)	5.37	4.46*	3.99**	0.87(−)	2.66(−)*
83/84	7.04	70.79	124.51*	32.81	219.24**	0.75	21.25(−)	8.34**	17.92*	3.60*	2.15**	2.28(−)*
84/85	7.29(−)	84.53**	85.43*	41.88**	123.30	0.46	20.67(−)**	9.39	11.89*	4.37**	1.46	2.53(−)
85/86	6.83(−)	81.25*	21.37(−)	40.38	15.25(−)	1.47	25.26(−)**	8.00**	1.62(−)	4.29*	2.75	2.26(−)
						CATCHMENT C						
77/78	6.21	80.41	66.96	31.44	14.34	1.89	24.12	6.43		1.94	1.01	3.38
78/79	6.48	52.56	39.94	39.25	25.61	2.41	25.06	5.47		2.40	0.67	2.92
79/80	6.66	42.50	38.92	24.67	38.67	0.68	13.25	5.40	3.17	1.10	0.78	3.11
80/81	6.41	59.95	60.18	31.94	30.08	1.96	16.49	7.09	2.95	2.95	2.13	3.74
81/82	6.84	42.93	64.57	24.42	37.64	0.65	30.21	5.37	3.15	2.31	2.15	2.84
82/83	6.67	44.29	53.42	23.42	32.00	2.92	28.17	5.35	2.58	2.12	1.16	3.44
83/84	6.99	61.85	48.74	23.32	36.37	0.63	24.94	6.01	2.98	2.66	1.28	3.54
84/85	7.25	62.59	28.04	30.35	16.14	0.36	25.91	11.21	1.46	2.85	1.09	3.17
85/86	7.02	62.62	36.38	31.88	28.25	1.22	33.25	5.84	2.32	2.00	1.08	3.42
						CATCHMENT B						
77/88	6.29	84.74	86.44*	37.57*	35.43	1.97	21.07	6.70		2.84*	1.03(−)	3.11(−)
78/79	6.38(−)	60.39	55.50	34.75(−)	31.33	1.57(−)	25.10	6.07		2.90	0.97	2.61(−)*
79/80	6.64(−)	53.42	38.67(−)	25.36	37.33(−)	0.76	11.58	6.40	4.29	1.68	0.94	3.03(−)
80/81	6.42	111.62	28.83(−)	52.24	30.48	1.77(−)	18.30	11.73	3.88	4.69	4.97	3.67(−)
81/82	6.96	82.57**	54.41(−)	39.82**	81.41	2.90	19.81(−)	10.17**	6.44	3.73**	3.41	3.06*
82/83	6.95*	76.87**	24.13(−)**	40.77**	28.83(−)	1.32(−)	18.53(−)	8.51	2.30(−)	4.14	1.79	3.16(−)*
83/84	7.26	75.50**	80.58	35.26**	79.51*	1.25**	21.06(−)*	8.17**	7.00*	3.41**	2.27*	2.70(−)*
84/85	7.41	74.18**	56.11	34.30	54.47	0.66	22.21(−)*	8.08	6.91	3.86**	1.28	2.32(−)*
85/86	6.88(−)	81.04	15.17(−)	41.62	11.96(−)	1.38	23.00(−)**	7.59*	3.22	3.12**	1.66	2.71(−)

*:significant at (p 0.05)
**:significant at (p 0.01)
(-): values in the treated catchment lower compared to control

Table 6.2 PROPOSED INTERIM NATIONAL WATER QUALITY STANDARDS FOR MALAYSIA.***

PARAMETERS	(units)	CLASSES## I	IIA	IIb	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
BOD	mg/l	1	3	3	6	12	> 12
COD	mg/l	10	25	25	50	100	> 100
DO	mg/l	7	5-7	5-7	3-5	< 3	< 1
pH		6.5-8.5	6-9	6-9	5-9	5-9	-
Colour	TCU	15	150	150	-	-	-
Elect. Cond.*	umhos/cm	1000	1000	-	-	6000	-
Floatables		N	N	N	-	-	-
Odour		N	N	N	-	-	-
Salinity*	/00	0.5	1	-	-	2	-

							IV
Taste		N	N	N	-	-	-
Total Diss. Solid*	mg/l	500	1000	-	-	4000	-
Total Susp. Solids	mg/l	25	50	50	150	300	> 300
Temperature	C	-	Normal*2	-	Normal*2	-	-
Turbidity	NTU	5	50	50	-	-	-
F. Colif.**	counts/ 100mL	10	100	400	5000 (20000)	500 (20000)	
Tot. Colif.	counts/ 100mL	100	5000	5000	50000	50000	> 50000

N = No visible floatable materials/debris or No objectionable odour, or No objectionable taste.

* = Related parameters, only one recommended for use

** = Geometric mean

a = Maximum not to be exceeded

	(units)	I				
A1	mg/l		-	- (0.06)	0.5	
As	mg/l		0.05	0.04(0.05)	0.1	
Ba	mg/l		1	-	-	
Cd	mg/l		0.01	0.01*(0.001)	0.01	
Cr(VI)	mg/l		0.05	1.4 (0.05)	0.1	
Cr(III)	mg/l		-	2.5	-	
Cu	mg/l		1	-	0.2	
Hardness	mg/l		250	-	-	
Ca	mg/l		-	-	-	
Mg	mg/l		-	-	-	
Na	mg/l		-	-	3 SAR	
K	mg/l		-	-	-	
Fe	mg/l		0.3	1	1(leaf) 5(Others)	
Pb	mg/l		0.05	0.02* (0.01)	5	
Mn	mg/l	N	0.1	0.1	0.2	L
Hg	mg/l	A	0.001	0.004(0.0001)	0.002	E
Ni	mg/l	T	0.05	0.9*	0.2	V
Se	mg/l	U	0.01	0.25 (0.04)	0.02	E
Ag	mg/l	R	0.05	0.0002	-	L
Sn	mg/l	A	-	0.004	-	S
U	mg/l	L	-	-	-	
Zn	mg/l		5	0.4*	2	A
		L				B
B	mg/l	E	1	- (3.4)	0.8	O
C1	mg/l	V	200	-	80	V
C1	mg/l	E	-	- (0.02)	-	E
		L				
CN	mg/l	S	0.02	0.06(0.02	-	VI
F	mg/l		1.5	10	1	
No	mg/l		0.4	0.4(0.03)	-	
No	mg/l		7	-	5	
P	mg/l		0.2	0.1	-	
si	mg/l		50	-	-	
SO	mg/l		250	-	-	
S	mg/l		0.05	- (0.001)	-	
CO	mg/l		-	-	-	
Gross-	Bq/l		0.1	-	-	
Gross-	Bq/l		1	-	-	

CLASSES##

PARAMETERS	**(units)**	**I**	**IIA**		
Ra-226	Bq/l		<0.1	-	-
Sr-90	Bq/l		<1	-	-
CCE	ug/l		500	–	-
MBAS/BAS	ug/l	N	500	5000 (200)	-
O&G (mineral)	ug/l	A	40;N	N	-
O&G (emulsified edible)	ug/l	T	7000;N	N	-
PCB	ug/l	L	0.1	6 (0.05)	-
Phenol	ug/l	E	10	--	-
		V			
Aldrin/Dieldrin	ug/l	E	0.02	0.2 (0.01)	-
		L			
BHC	ug/l	S	2	9 (0.1)	-
Chlordane	ug/l		0.08	2 (0.02)	-
t-DDT	ug/l	O	0.1	1 (0.01)	-
Endosulfan	ug/l	R	10	–	-
Heptachlor/Epoxide	ug/l		0.05	0.9 (0.06)	-
		A			
Lindena	ug/l	B	2	3 (0.4)	-
		S			
2,4-D	ug/l	E	70	450	-
2,4,5-T	ug/l	N	10	160	-
2.4.5-TP	ug/l	T	4	850	-
Paraquat	ug/l		10	1800	-

* = At hardness 50mg/$CaCO_3$
# = Maximum (unbracketed) and 24-hr average (bracketed) concentrations
N = Free from visible film, sheen, discoloration and deposits

##WATER QUALITY CLASSFICATION

The system of use classification proposed is defined sa follows:

CLASS	USES
I	Conservation of natural environment Water supply I - practically no treatment necessary (except by disinfection or boiling only) Fishery I - very sensitive aquatic species
IIA	Water supply II -conventional treatment required Fishery I - sensitive aquatic species
IIB	Recreational use with body contact
III	Water supply III - extensive treatment required Fishery III - common, of economic value, and tolerant species Livingstock drinking
IV	Irrigation
V	None of the above

*** Source: Department of Enviroment Malaysia (1986)

CHAPTER 7

SEDIMENT YIELD

7.1 Methodology

The effect of landuse changes on stream sediment yields is well demonstrated by 9 years of sediment measurement in this experiment. The conversion of landuse from forest to oil palm and cocoa cultivation resulted in substantial increases in stream sediment loads.

The experimental design permits both a paired-catchment analysis where sediment yields from a treated catchment are compared with those from a control, before and after analysis, in which sediment yields from a given catchment during an undisturbed Calibration period is compared with that after treatment of the catchment.

Stream water sampling was carried out using USDH-48 depth integrating sampler and single stage rising sampler for high flow events. Suspended sediment load values were calculated on a daily basis using sediment rating curves and mean daily discharges for each watershed. The data were then summed for each water year to obtain the annual loads from Calibration up to the end of Evaluation in June 1986 (Table 7.1).

7.2 Treatment Effects

Figures 7.1 to 7.3 showed the pattern of sediment production for the same periods on a monthly basis. sediment loads had been low for all catchments during the Calibration period. For example, loads of 10 t/km²/yr to 13 t/km²/yr from 1977 to 1981/82 were transported for Catchment A before logging began at the end of 1982 and clearfelling in the early months of 1983. The sediment load increased almost four times during that water year and three and a half times higher than control Catchment C for the same period.

Table 7.1 Suspended Sediment Loads for Sg. Tekam Experimental Basins

Water Year (1st July — 30 June)	**Basin A**	**Basin B**	**Basin C**
		(tonnes/km²/yr)	
Calibration Period:			
1977/78	10	20	20
1978/79	14	25	20
1979/80	35	39	64
Ratio of 3-yr Periods to C	0.57	0.81	
Transition Period:			
1980/81	13	414	26
1981/82	13	158	16
1982/83	50	105	14
Ratio of 3-yr Periods to C	1.36	12.09	
Evaluation period:			
* 1983/84	125	156	80
* 1984/85	105	10	13
* 1985/86	56	12	7
Ratio of 3-yr Periods to C	10.21	6.68	

*values do not include dissolved sediment load.

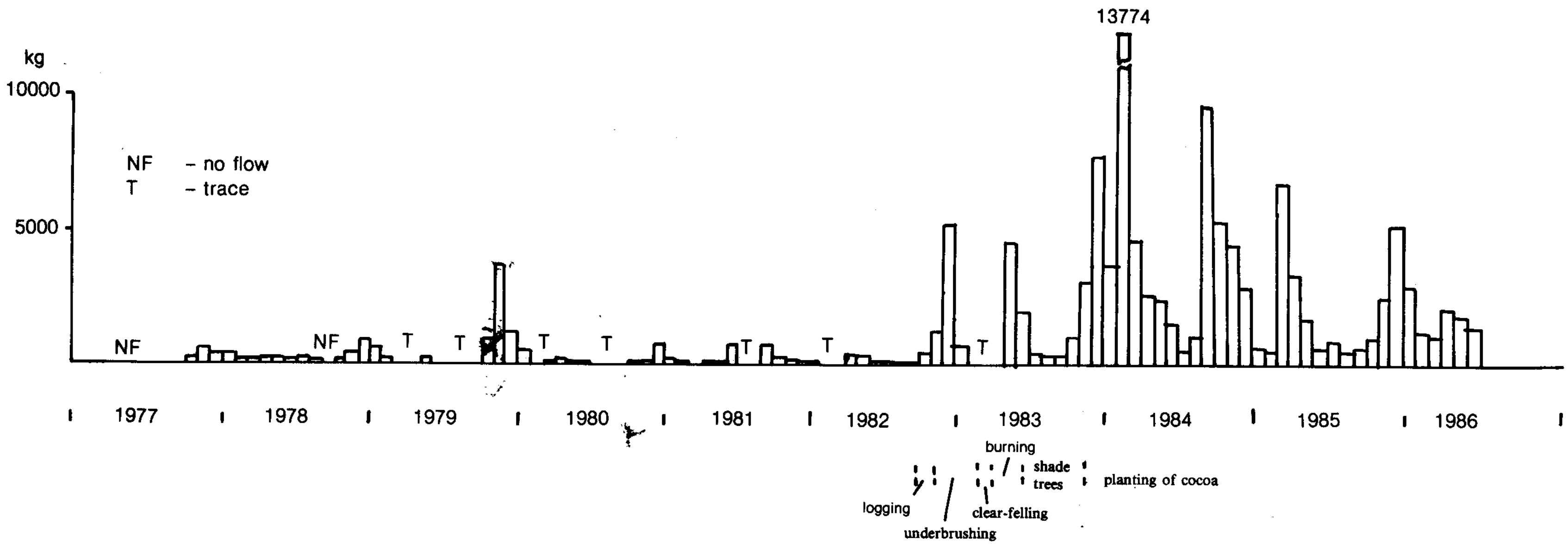


Fig. 7.1. Monthly suspended sediment load of Catchment A.

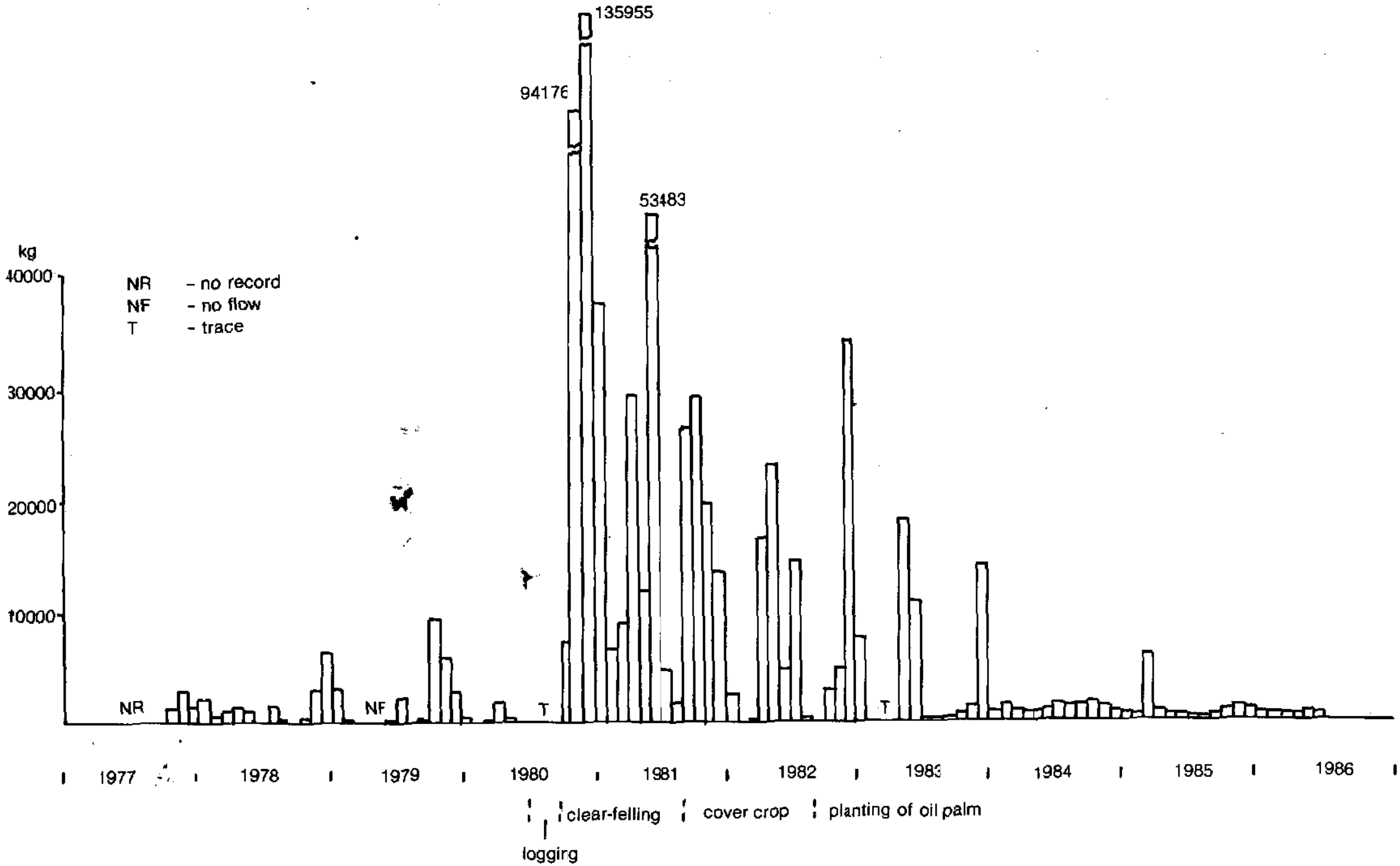


Fig. 7.2 Monthly suspended sediment load of Catchment B.

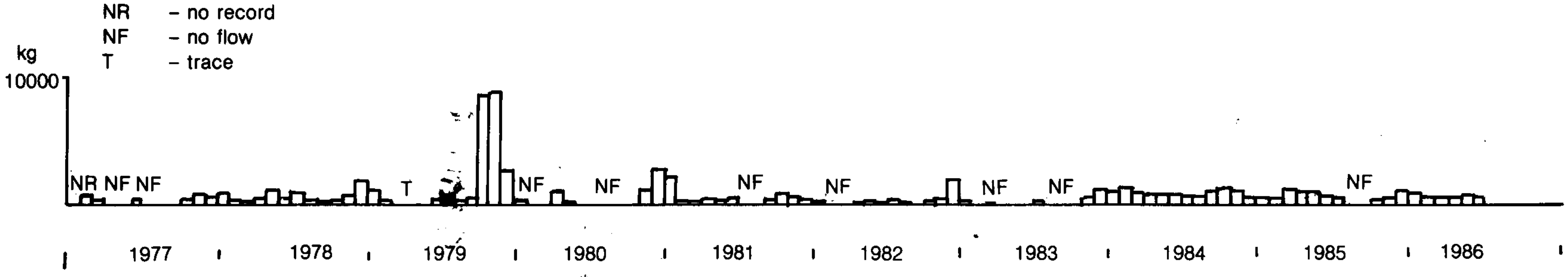


Fig. 7.3. Monthly suspended sediment load of Catchment C.

In Catchment B where the lower two-thirds had undergone earlier changes in vegetation cover, as much as 414 t/km²/yr of sediment loads were lost after clearfelling in contrast to low values of 20 to 39 t/km²/yr during Calibration. The sediment yields declined following the planting of cover crops and later oil palm during Evaluation. The important role of vegetative cover in reducing soil erosion and sedimentation in streams has been well demonstrated during the course of this experiment. Other sources of sediment were bank erosion and collapse during high flood flows.

The nesting of Catchment A at the upper catchment B means that the effects of recovery from clearing and planting of the lower part of Catchment B were masked by clearfelling in Catchment A. The latter disturbance was expected to be apparent at the outlet of Catchment B, as indicated by the high loads in the monsoon months of November and December 1982, January and May 1983. However in the following period, sediment loads from Catchment B declined, probably because channel dredging improved water flow in the lower part of Catchment B and created storage capacity for excess sediment from Catchment A. Such observed sediment will probably be removed episodically by heavy storms.

Sediment yields from the control Catchment C were relatively low throughout the study, ranging from 7 t/km²/yr in 1985/86 to 64 t/km²/yr in 1979/80. The study shows that sediment yields can increase up to 16 times through clearfelling and preparation for cultivation, but after crops are established, sediment yields may be reduced to levels only a few times greater than those under forest.

CHAPTER 8

SOIL FERTILITY

8.1 Organic Matter

Leaves and small twigs of less than 2 cm diameter from forest litter were sampled regularly using two 1 m^2 litter traps set up in each of the three a Catchments. Such litter was collected from six plots until July 1980 when the two in Sub-catchment B were removed when logging began. Two other plots were removed in October 1982 when Catchment A was logged.

Legume cover crops were planted in April 1981. When full cover was established, the samples of legume litter were hand-picked from 48 premarked plots of 1 m^2 each.

Leaf litter was not collected from oil palm as it was not planted until August 1982. First pruning of the leaves was done in early 1985 before harvesting commenced. There was a minimal production of oil palm leaf litter during this period and therefore it was not considered in this analysis.

Analytical results for bulked litter samples are shown in Table 8.1. The mean annual amount of dry matter of the forest litter over 8 years was 8.93 t/ha, (893 t/km^2) containing 0.91 t (91 t/km^2) ash and 8.02 t (802 t/km^2) of volatile substances. Plant nutrients in the ash amounted to 140, 5, 24 and 87 Kg/ha/year of N, P, K, Mg and Ca, respectively.

Table 8.1 Forest and Legume Litter and their Nutrient Content (kg/ha).

	Year	Dry Matter	Ash	Organic Carbon	N	P	K	Mg	Ca
Forest	1978	11239.0	639.3	NA	126.1	4.2	30.8	31.1	112.2
	1979	11825.9	1008.7	3452.8	230.1	10.9	28.7	33.1	122.4
	1980	8597.1	1140.8	3668.5	124.7	5.5	17.5	21.0	71.8
	1981	6463.6	721.8	1659.7	102.4	2.8	22.5	17.6	72.1
	1982	6291.0	977.8	3072.0	103.0	2.9	35.0	18.5	68.0
	1983	10145.8	1280.6	5146.5	161.7	4.8	45.3	28.6	86.2
	1984	9466.8	900.5	5299.0	153.3	4.6	23.4	25.2	83.6
	1985	7418.4	618.6	4305.3	114.3	3.1	25.9	18.8	77.1
Mean	(1978-85)	8931.0	911.0	3800.4	139.5	4.9	28.6	24.2	86.7
Legume	1982	3242.8	463.6	1380.9	71.6	2.6	22.3	11.3	38.9
	1983	6002.5	979.2	3008.7	141.1	4.8	30.4	20.6	75.5
	1984	5243.7	798.9	2888.2	154.5	7.6	30.3	16.7	60.4
	1985	3241.7	327.9	1912.9	81.5	3.1	26.0	12.3	42.2
	1986	2636.0	260.0	1467.9	70.3	3.1	16.2	10.3	41.7
Mean	(1982-86)	3129.5	565.9	2131.7	103.8	4.2	25.0	14.2	51.7

Note: NA — not available

The legume litter increased from 3.24 t/ha (324 t/km^2) in the first year after full establishment to 6.00 t/ha (600 t/km^2) in the second year. Subsequently, the litter production gradually decreased to about 2.64 t/ha (264 t/km^2) in the fifth year after full establishment. Such a decrease was mainly due to the gradual reduction of light penetration to the legume cover as the canopy of the oil palm enlarged. In general, the legume cover crops will almost completely die off 7 to 8 years after planting.

The mean annual production of legume litter was about 3.13 t/ha (313 t/km^2) containing 0.57 t ash and 2.56 t volatile substances. Plant nutrients in the ash amounted to 104, 4, 25, 14 and 52 kg/ha/year of N, P, K, Mg and Ca, respectively.

Comparing the above data, the annual amount of dry matter from the forest litter returned to the soil is much higher than that of the legume litter. However, the quantities of nutrients from the forest litter are similar to those from the legume litter except N, Mg and Ca. In general, the annual amounts of N, Mg and Ca from the forest or the legume litter are equivalent to the fertilizer requirements of oil palm for the first two to three years of growth. The amounts of P and K are only equivalent to 50% of the fertilizer requirements of this crop for the first year of growth.

The dry matter and plant nutrients from the legume litter are insufficient to compensate for those of the forest when the latter is felled and burnt prior to crop production. Fertilizer usage could be considerably reduced if most of the organic matter of the forest were to be allowed to undergo natural biodegradation instead of complete burning.

8.2 Infiltration

A double-ring infiltrometer was used to determine the rate of infiltration in Munchong and Segamat series soils under forested, deforested and legume-cover conditions in Sub-catchment B. The deforested condition is a stage where the trees were felled, partially burnt and mechanically stacked by a D6 bulldozer but before the planting of leguminous cover. The legume cover condition was that at approximately four years after it had been planted.

Results of this study comprising averages of 5 to 6 samples (Fig. 8.1), show great changes in the saturated infiltration rate from forested (30 cm/hr) to deforested (20 cm/hr) and legume cover (73 cm/hr) conditions for the Munchong series. For the Segamat series soil, the infiltration rate decreased drastically from the forested condition (26 cm/hr) to the deforested condition (3 cm/hr). However, the rate increased significantly (to about 65 cm/hr) at four years after the planting of the legume cover.

The fall in infiltration rate for both the Munchong and Segamat series soils under the deforested condition may be attributed mainly to compaction by heavy machinery. The greater reduction in infiltration of the Segamat series than in the Munchong series is due to the relatively weak structure coupled with high clay content (exeed 80 %) of the former. In general, the use of heavy machinery such as a D6 bulldozer will result in a compacted soil layer which is detrimental to plant growth. The planting of legume cover will serve to break up the compacted soil layer and thereby improve the infiltration rate as evidenced above, besides its usual functions of nitrogen fixation and soil conservation. The loss in infiltration capacity caused by heavy machinery clearly needs to be rectified by planting legumes or retaining a natural cover.

8.3 Soil Erosion

A soil erosion study was carried out on Munchong and Segamat series soil on four different slopes of 4, 9, 16 and 25% (2.3°, 5.1°, 9.1° and 14.1°) under forested and deforested conditions. The latter condition related to an area of felled trees which were partially burnt, mechanically stacked by a bulldozer, reburnt and eventually planted with leguminous cover and oil palm. Erosion plots for Segamat and Munchong series under forest were in Catchments A and C respectively. The deforested erosion plots were located in Sub-catchment B.

A pin method was employed for this study. Plot size was 10 × 15 m with 24 pins stacked at 2 m intervals. Depths of erosion were measured fortnightly.

Results from this study are shown in Table 8.2. In the first year (15/6/81 to 22/6/82 most treatments showed increase in erosion with slope. However, there were some discrepancies in the results such as those for Munchong series forested (MF) at 9% slope and Munchong series deforested (MD) at 16% slope. Erosion in Segamat deforested (SD) at both 9% and 16% slopes and MD at 4% slope was high, because plots were only 20 — 40% protected by cover crops during the first year, compared with full

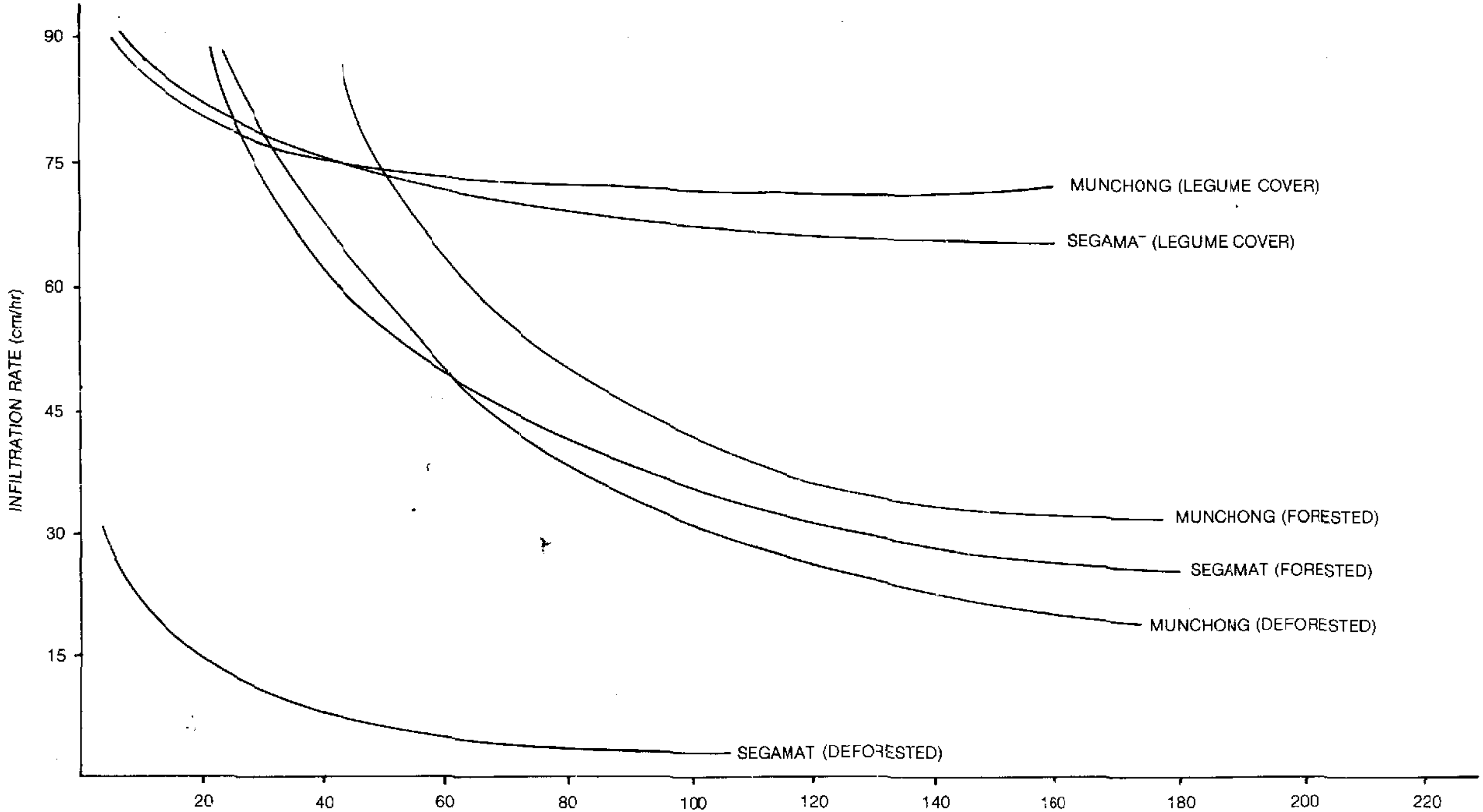


Fig. 8.1. Infiltration curves for two soils series under forested, deforested and legume cover condition.

establishment of cover crops on other plots. In general, erosion (average of 4 slopes)under SD is about 7 times that of SF and under MD is about 5 times that of MF in the first year after planting the legume cover. During the same period, erosion under SF is comparable to that under MF but erosion under SD is 1.5 times that of MD.

In the second year (22/6/82 to 4/7/83) pin measurement on treatments SD at 4% , 16% and 25% slopes and treatments MD at 16% and 25% slopes, showed deposition of soil eroded from further up slope instead of net erosion. This suggests that soil movement downslope is continuing even in the second year after planting the legume cover. The results imply that the pin method may not be reliable for soil erosion measurements under this condition and that a long period of observation would be needed to establish the general trends of erosion following landuse change.

Table 8.2 Soil Erosion (cm)

Period	Treatment	4%	9%	16%	25%	Average of 4 slopes
15/6/81-22/6/82	SF	0.10	0.21	0.45	0.55	0.33
	SD	1.25	2.50*	2.91*	3.33	2.50
	MF	0.37	0.18	0.42	0.52	0.37
	MD	1.31*	1.99	1.69	1.88	1.72
22/6/82-4/7/83	SD	-0.39	0.22	-0.41	-1.35	-0.48
	MF	0.14	0.38	0.49	0.99	0.50
	MD	0.47	0.08	-0.20	-0.59	-0.06
4/7/83-10/7/84	SD	0.10	0.32	0.64	0.92	0.50
	MF	0.24	0.30	0.43	0.61	0.40
	MD	0.16	0.16	0.34	0.56	0.31
10/7/84-2/7/85	SD	0.34	0.29	0.52	0.70	0.46
	MF	0.10	0.17	0.35	0.65	0.32
	MD	0.16	0.18	0.27	0.41	0.26
2/7/85-24/6/86	SD	0.26	0.52	0.53	0.66	0.49
	MF	0.18	0.29	0.34	0.44	0.31
	MD	0.21	0.36	0.40	0.47	0.36
4/7/83-24/6/86 (average erosion per year)	SD	0.23	0.38	0.56	0.76	0.48
	MF	0.17	0.25	0.37	0.57	0.34
	MD	0.18	0.23	0.34	0.48	0.31

Key:
- SF - Segamat Forested
- SD - Segamat Deforested
- MF - Munchong Forested
- MD - Munchong Deforested

* Cover-crop establishment in these plots was only about 20-40%fo full cover fro the perios from 15/6/81 to 22/6/82.

NOTE: Cover-crop was planted in April 1981. The forest in the Segamat series was felled in July 1982.

Results from the third year onwards (1983/84 to 1985/86) show a clearer trend of erosion for the various treatments, suggesting soil conditionsr becoming more stable in the deforested treatments. The summarised results from 1983/84 to 1985/86 indicate that erosion for MD is comparable to that of MF and that erosion for SD during this period is also much lower than that during the first year of planting the legume cover. This implies that by the third year of planting, the legume cover has stabilised the soil condition and reduced erosion probably through lowering rain impact and improving water infiltration. The higher erosion for SD compared to that of MD also confirms the weaker structure of the Segamat series.

Planting of cover crops during land development is especially necessary in the case of highly erodible soil such as the Segamat series.

8.4 Soil Chemical Content

The changes in soil chemical content arising from the conversion of forest to oil palm were monitored in Munchong series. A pit was dug in forested Catchment C and another in deforested Sub-catchment B. Soil samples were taken at 0-5, 5-10, 10-15, 15-30 and 30-60 cm depths around each pit at 6 monthly intervals. At each depth six samples were taken and bulked for chemical analysis. Analyses included pH, organic carbon, cation exchange capacity (C.E.C), total N, P, K, Mg, Ca and Na, available P and exchangeable K, Mg, Ca and Na.

In general, the results of this study (Table 8.3) indicate smaller variations in the values of each parameter in the lower soil depths (10-15, 15-30 and 30-60 cm) compared to those for the surface and near-surface soil (0-5 and 5-10 cm). Hence, the following descriptions are confined to the upper two layers of soil. Under the forested Catchment C there was little change in pH values during the study period. However, under oil palm cultivation with legume cover in Sub-catchment B the pH tends to increase slightly, probably due to the application of fertilizers, especially rock phosphate, containing high proportions of calcium.

Table 8.3 Soil Chemical Content

			Munchong series in Catchment C						Munchong series in Sub-catchment B				
Date	**Element**	**Condition**	**0-5 cm**	**5-10 cm**	**10-15 cm**	**15-30 cm**	**30-60 cm**	**Condition**	**0-5 cm**	**5-10 cm**	**10-15 cm**	**15-30 cm**	**30-60 cm**
22.8.81	pH	F	4.4	4.4	4.5	4.5	4.6	cover-crop	4.1	4.1	4.2	4.3	NA
24.2.82		F	4.4	4.3	4.2	4.3	4.4	cover-crop	4.6	4.5	4.4	4.3	4.5
24.2.82		F	4.6	4.7	4.8	5.2	5.0	oil palm	4.7	4.4	4.5	4.4	4.3
23.2.83		F	4.5	4.5	4.6	4.8	5.0	oil palm	4.4	4.5	4.4	4.3	4.5
24.3.83		F	4.3	4.4	4.5	4.8	5.1	oil palm	4.5	4.3	4.5	4.4	4.5
9.2.84		F	4.4	4.4	4.4	4.5	4.7	oil palm	4.6	4.4	4.3	4.2	4.3
7.8.84		F	4.5	4.3	4.5	4.9	4.9	oil palm	4.3	4.3	4.4	4.4	NA
7.2.85		F	4.2	4.5	4.4	4.3	4.3	oil palm	4.6	4.8	4.9	4.5	4.5
20.8.85		F	4.2	4.4	4.6	4.6	5.0	oil palm	5.8	6.1	4.6	4.5	4.4
14.2.86		F	4.1	4.2	4.4	4.6	4.7	oil palm	4.9	4.5	4.3	4.3	4.3
13.8.86		F	4.1	4.4	4.5	4.4	4.6	oil palm	4.4	4.3	4.2	4.2	4.2
19.7.80	Org.C	F	3.99	1.84	1.65	0.82	0.58	F	NA	NA	NA	NA	NA
22.1.81	(%)	F	3.00	1.39	NA	0.69	0.41	Felling	2.95	1.26	NA	0.77	NA
22.8.81		F	2.16	1.75	1.50	0.94	0.87	cover-crop	2.97	2.56	2.31	2.08	NA
24.2.82		F	3.13	2.22	1.80	1.21	0.81	cover-crop	2.03	1.85	1.74	1.32	0.99
24.8.82		F	2.19	1.75	1.46	0.67	0.62	oil palm	1.60	1.34	1.66	0.92	1.03
23.2.83		F	2.19	1.65	1.55	1.06	0.74	oil palm	2.53	2.18	2.03	1.25	0.94
24.8.83		F	2.84	2.01	1.69	0.95	0.77	oil palm	2.46	2.01	1.89	1.05	1.16
9.2.84		F	3.11	2.05	1.48	1.14	1.10	oil palm	2.13	1.83	1.61	1.40	1.38
7.8.84		F	2.05	1.80	1.27	0.93	0.74	oil palm	2.64	2.00	2.10	1.39	NA
7.2.85		F	2.82	1.68	1.42	1.22	0.93	oil palm	3.08	3.73	3.75	1.68	1.43
20.8.85		F	1.78	1.76	1.13	1.02	0.87	oil palm	3.17	3.46	2.35	1.40	1.10
14.2.86		F	3.42	2.03	1.33	1.15	0.82	oil palm	2.10	1.54	1.57	1.07	1.01
13.8.86		F	2.21	1.80	1.34	1.01	0.69	oil palm	2.85	2.70	2.34	1.94	1.38
19.7.80	C.E.C.	F	14.60	9.10	7.10	6.50	6.00	F	NA	NA	NA	NA	NA
22.1.81	(% meq)	F	4.50	6.00	NA	11.30	8.50	Felling	4.20	3.60	NA	3.60	NA
22.8.81		F	6.00	6.50	5.30	4.50	4.00	Cover-crop	9.70	8.50	8.50	6.70	NA
24.2.82		F	8.80	5.00	5.10	5.30	4.20	cover-crop	7.40	7.20	6.30	5.60	5.30
24.8.82		F	6.00	5.30	5.10	3.60	3.40	oil palm	5.80	5.60	5.70	4.80	4.30
23.2.83		F	7.30	6.40	5.60	5.10	4.70	oil palm	8.50	7.70	7.50	6.20	5.60
24.8.83		F	8.70	7.00	6.50	4.80	4.80	oil palm	8.80	7.40	7.30	5.60	5.50
9.2.84		F	5.40	7.90	6.70	6.80	6.30	oil palm	7.30	6.40	6.10	5.60	5.40
7.8.84		F	6.40	5.80	5.00	4.60	4.10	oil palm	8.80	6.70	8.00	6.30	NA
7.2.85		F	8.90	6.60	5.70	5.40	5.20	oil palm	10.70	11.70	10.30	6.60	5.90
20.8.85		F	7.50	6.70	5.70	5.30	5.00	oil palm	10.10	10.40	8.10	6.10	5.90
14.2.86		F	10.50	7.10	5.90	5.50	4.70	oil palm	9.40	6.80	7.30	6.10	5.50
13.8.86		F	8.50	7.20	6.00	5.20	4.50	oil palm	10.90	9.70	8.80	7.90	6.40

Table 8.3 Continuation...

Date	Element	Condition	Munchong series in Catchment C 0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-60 cm	Condition	Munchong series in Sub-catchment B 0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-60 cm
19.7.80	Total	F	0.36	0.21	0.14	0.11	0.08	F	NA	NA	NA	NA	NA
22.1.81	N (%)	F	0.16	0.05	NA	0.01	0.02	Felling	NA	NA	NA	NA	NA
22.8.81		F	0.19	0.17	0.13	0.08	0.07	cover-crop	0.25	0.18	NA	0.20	0.19
24.2.82		F	0.18	0.16	0.11	0.09	0.07	cover-crop	0.15	0.14	0.11	0.10	0.10
24.8.82		F	0.19	0.14	0.14	0.07	0.06	oil palm	0.12	0.11	0.11	0.09	0.10
23.2.83		F	0.18	0.13	0.12	0.09	0.07	oil palm	0.17	0.19	0.16	0.10	0.09
24.8.83		F	0.20	0.14	0.11	0.06	0.05	oil palm	0.16	0.14	0.11	0.17	0.07
9.2.84		F	0.26	0.19	0.15	0.11	0.11	oil palm	0.21	0.19	0.15	0.12	0.12
7.8.84		F	0.15	0.13	0.11	0.08	0.07	oil palm	0.17	0.14	0.12	0.09	NA
7.2.85		F	0.23	0.16	0.11	0.10	0.10	oil palm	0.26	0.27	0.24	0.14	0.09
20.8.85		F	0.19	0.15	0.11	0.09	0.08	oil palm	0.25	0.27	0.18	0.11	0.10
14.2.86		F	0.30	0.19	0.15	0.12	0.09	oil palm	0.21	0.14	0.16	0.11	0.11
13.8.86		F	0.23	0.18	0.16	0.10	0.07	oil palm	0.30	0.30	0.26	0.20	0.16
19.7.80	Total	F	NA	NA	NA	NA	NA	F	NA	NA	NA	NA	NA
22.1.81	P	F	NA	NA	NA	NA	NA	Felling	NA	NA	NA	NA	NA
22.8.81	(ppm)	F	198.0	186.0	171.0	160.0	130.0	cover-crop	175.0	185.0	183.0	180.0	NA
24.2.82		F	220.0	185.0	175.0	165.0	145.0	cover-crop	175.0	175.0	155.0	150.0	135.0
24.8.82		F	200.0	185.0	180.0	175.0	160.0	oil palm	155.0	150.0	150.0	140.0	135.0
23.2.83		F	202.0	180.2	181.9	171.0	148.4	oil palm	212.0	202.8	182.0	150.8	133.9
24.8.83		F	234.0	210.0	207.1	173.3	156.0	oil palm	225.8	197.6	187.2	149.4	145.6
9.2.84		F	263.0	187.0	151.0	137.0	135.0	oil palm	232.0	203.0	177.0	182.0	177.0
7.8.84		F	209.0	199.0	187.0	179.0	179.0	oil palm	214.0	184.0	179.0	143.0	NA
7.2.85		F	258.0	221.0	194.0	157.0	170.0	oil palm	247.0	216.0	237.0	201.0	194.0
20.8.85		F	227.0	202.0	177.0	177.0	166.0	oil palm	227.0	265.0	217.0	162.0	136.0
14.2.86		F	258.0	214.0	184.0	177.0	158.0	oil palm	516.0	309.0	255.0	173.0	186.0
13.8.86		F	209.0	201.0	191.0	185.0	155.0	oil palm	288.0	240.0	209.0	199.0	204.0
19.7.80	Total	F	1.00	0.90	0.75	0.70	0.65	F	NA	NA	NA	NA	NA
22.1.81	K	F	0.45	0.45	NA	0.45	0.40	Felling	0.50	0.30	NA	0.20	NA
22.8.81	(%	F	0.21	0.32	0.25	0.15	0.15	Cover-corp	0.25	0.30	0.25	0.30	NA
24.2.82	meq)	F	0.45	0.55	0.40	0.40	0.35	cover-corp	0.65	0.50	0.40	0.35	0.25
24.8.82		F	0.30	0.30	0.32	0.30	0.30	oil palm	0.51	0.36	0.34	0.26	0.21
23.2.82		F	0.36	0.35	0.32	0.30	0.27	oil palm	0.51	0.36	0.34	0.26	0.21
24.8.83		F	0.60	0.47	0.42	0.39	0.36	oil palm	0.77	0.35	0.47	0.42	0.37
9.2.82		F	0.54	0.65	0.46	0.34	0.31	oil palm	0.47	0.42	0.42	0.38	0.38
7.8.84		F	0.39	0.38	0.30	0.29	0.29	oil palm	0.44	0.32	0.37	0.34	NA
7.2.85		F	0.45	0.38	0.39	0.33	0.41	oil palm	0.68	0.51	0.49	0.33	0.37
20.8.85		F	0.41	0.43	0.34	0.30	0.30	oil palm	1.23	0.10	0.61	0.39	0.25
14.2.86		F	0.70	0.42	0.55	0.49	0.34	oil palm	1.07	0.75	0.58	0.59	0.44
13.8.86		F	0.34	0.27	0.18	0.25	0.33	oil palm	0.75	0.40	0.40	0.39	0.35
19.7.80	Total	F	0.97	0.68	0.70	0.60	0.52	F	NA	NA	NA	NA	NA
22.1.81	Mg (%	F	0.78	0.53	NA	0.84	0.75	Felling	1.52	1.12	NA	1.34	NA
22.8.81	meq)	F	0.68	0.59	0.41	0.41	0.25	cover-crop	0.69	0.54	0.62	0.63	NA
24.2.82		F	0.47	0.37	0.37	0.35	0.31	cover-crop	0.43	0.60	0.45	0.31	0.35
24.8.82		F	0.45	0.41	0.33	0.37	0.41	oil palm	0.47	0.42	0.52	0.58	0.53
23.2.83		F	0.64	0.54	0.52	0.52	0.52	oil palm	0.72	0.62	0.71	0.69	0.87
24.8.83		F	0.57	0.55	0.49	0.50	0.45	oil palm	0.75	0.58	0.56	0.46	0.63
9.2.84		F	0.87	1.00	1.28	1.28	0.99	oil palm	0.58	0.45	0.43	0.41	0.46
7.8.84		F	0.50	0.49	0.46	0.58	0.59	oil palm	0.57	0.54	0.60	0.51	NA
7.2.85		F	0.45	0.45	0.34	0.30	0.39	oil palm	1.05	0.92	0.97	0.65	0.69
20.8.85		F	0.43	0.42	0.37	0.36	0.35	oil palm	1.18	1.17	0.60	0.44	0.38

Table 8.3 Continuation....

Date	Element	Condition	Munchong series in Catchment C 0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-60 cm	Condition	Munchong series in sub-catchment B 0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-60 cm
14.2.86		F	0.39	0.47	0.33	0.29	0.47	oil palm	1.28	0.59	0.70	0.85	0.67
13.8.86		F	0.59	0.39	0.38	0.39	0.28	oil palm	1.42	0.75	0.71	0.59	0.50
19.7.80	Total	F	NA	NA	NA	NA	NA	F	NA	NA	NA	NA	NA
22.1.81	Ca (%	F	NA	NA	NA	NA	NA	Felling	NA	NA	NA	NA	NA
22.8.81	meq)	F	2.01	1.56	1.50	1.25	1.25	cover-crop	3.19	1.76	2.03	2.07	NA
24.2.82		F	1.56	1.38	1.31	1.19	1.19	cover-crop	2.18	2.06	1.88	1.50	1.44
24.8.82		F	1.38	1.38	2.01	1.56	1.25	oil palm	2.06	1.49	1.77	1.56	2.50
23.2.83		F	1.30	1.33	1.27	1.21	1.06	oil palm	1.73	1.56	1.36	1.18	1.55
24.8.83		F	1.10	1.08	1.94	0.92	0.95	oil palm	2.07	1.18	1.13	1.14	1.46
9.2.84		F	1.52	2.27	1.42	2.39	2.00	oil palm	1.78	1.27	1.12	1.10	1.26
7.8.84		F	0.97	0.87	0.88	0.80	0.85	oil palm	1.64	1.42	1.36	1.13	NA
7.2.85		F	1.05	0.91	0.70	0.66	1.16	oil palm	5.84	6.84	6.42	3.52	2.33
20.8.85		F	2.45	2.00	1.25	0.83	0.78	oil palm	1.81	1.51	1.52	1.31	0.93
14.2.86		F	0.99	0.86	0.90	0.89	0.61	oil palm	7.45	3.69	3.12	2.21	2.33
13.8.86		F	0.57	0.72	0.66	0.89	0.66	oil palm	6.11	7.56	6.49	5.86	1.85
24.8.83	Total	F	0.97	1.16	1.08	1.25	1.33	oil palm	1.00	0.93	1.30	1.11	0.94
9.2.84	Na	F	1.23	1.16	1.20	1.15	1.12	oil palm	1.15	1.47	1.07	1.36	1.37
7.8.84	(%	F	NA	NA	NA	NA	NA	oil palm	NA	NA	NA	NA	NA
7.2.85	meq)	F	2.15	2.28	2.01	1.80	1.91	oil palm	1.86	2.37	1.75	2.91	1.89
20.8.85		F	2.40	2.18	1.78	2.32	2.30	oil palm	2.28	2.12	1.95	1.92	2.37
14.2.86		F	1.69	1.67	1.55	1.58	1.47	oil palm	1.59	1.43	1.27	1.11	1.02
13.8.86		F	1.09	1.18	1.13	1.51	1.06	oil palm	1.09	1.05	1.06	1.19	1.02
19.7.80	Avai.	F	3.70	2.40	0.60	1.50	1.90	F	NA	NA	NA	NA	NA
22.1.81	P	F	3.20	3.60	NA	3.60	4.60	Felling	4.80	2.10	NA	3.80	NA
22.8.81	(ppm)	F	5.40	4.20	4.00	3.00	4.00	cover-crop	8.00	6.50	5.5	5.50	NA
24.2.82		F	6.80	5.00	3.30	2.80	3.00	cover-crop	8.50	6.50	10.3	5.00	3.50
24.8.82		F	3.50	6.80	3.70	3.30	2.80	oil palm	4.00	5.20	3.2	3.60	4.00
23.2.83		F	4.20	4.00	3.70	3.70	3.70	oil palm	6.10	5.20	4.4	2.90	2.30
24.8.83		F	5.20	4.20	4.40	4.70	5.70	oil palm	5.80	5.20	4.2	4.10	5.70
9.2.84		F	4.00	4.00	3.00	4.00	2.00	oil palm	12.00	6.00	5.0	4.00	3.0
7.8.84		F	3.00	4.00	4.00	4.00	4.00	oil palm	6.00	4.00	3.0	3.00	NA
7.2.85		F	5.00	4.00	4.00	4.00	4.00	oil palm	5.00	5.00	5.0	4.00	4.00
20.8.85		F	3.00	3.00	3.00	3.00	2.00	oil palm	14.00	20.00	5.0	3.00	2.00
14.2.86		F	4.00	4.00	3.00	3.00	4.00	oil palm	128.00	38.00	20.0	7.00	10.00
13.8.86		F	3.00	2.00	2.00	3.00	2.00	oil palm	18.00	6.00	5.0	7.00	10.00
19.7.80	Ex.K	F	0.33	0.20	0.18	0.11	0.08	F	NA	NA	NA	NA	NA
22.1.81	(%	F	0.08	0.06	NA	0.02	0.02	Felling	0.10	0.06	NA	0.03	NA
22.8.81	meq)	F	0.14	0.16	0.14	0.07	0.06	cover-crop	0.23	0.21	NA	0.20	0.18
24.2.82		F	0.19	0.52	0.27	0.13	0.10	cover-crop	0.31	0.34	0.25	0.29	0.05
24.8.82		F	0.08	0.06	0.04	0.03	0.03	oil palm	0.14	0.13	0.14	0.12	0.08
23.2.83		F	0.11	0.10	0.10	0.07	0.03	oil palm	0.34	0.26	0.21	0.15	0.06
24.8.83		F	0.28	0.20	0.17	0.11	0.09	oil palm	0.56	0.37	0.36	0.16	0.22
9.2.84		F	0.17	0.29	0.27	0.11	0.09	oil palm	0.25	0.24	0.18	0.17	0.17
7.8.84		F	0.13	0.11	0.08	0.07	0.09	oil palm	0.27	0.18	0.19	0.14	NA
7.2.85		F	0.26	0.11	0.12	0.08	0.35	oil palm	0.43	0.26	0.28	0.13	0.12
20.8.85		F	0.15	0.11	0.07	0.08	0.06	oil palm	0.79	0.73	0.34	0.21	0.11
14.2.86		F	0.30	0.19	0.15	0.12	0.09	oil palm	0.80	0.57	0.34	0.38	0.26
13.8.86		F	0.16	0.15	0.10	0.08	0.08	oil palm	0.32	0.22	0.20	0.19	0.14
19.7.80	Ex.	F	0.49	0.25	0.18	0.12	0.09	F	NA	NA	NA	NA	NA
22.1.81	Mg	F	0.30	0.14	NA	0.12	0.16	Felling	0.66	0.37	NA	0.35	NA
22.8.81	(%	F	0.38	0.34	0.30	0.22	0.25	cover-crop	0.58	0.38	0.49	0.44	NA

Table 8.3 Continuation...

Date	Element	Condition	Munchong series in Catchment C 0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-60 cm	Condition	Munchong series in Sub-catchment B 0-5 cm	5-10 cm	10-15 cm	15-30 cm	30-60 cm
24.2.82	meq	F	0.28	0.21	0.20	0.20	0.19	cover-crop	0.58	0.49	0.44	0.27	0.29
24.8.82		F	0.27	0.22	0.18	0.13	0.15	oil palm	0.18	0.19	0.26	0.20	0.23
23.2.83		F	0.22	0.21	0.16	0.15	0.15	oil palm	0.42	0.32	0.26	2.20	0.33
24.8.83		F	0.42	0.28	0.23	0.18	0.20	oil palm	0.69	0.37	0.38	0.22	0.45
9.2.84		F	0.28	0.75	0.68	0.46	0.34	oil palm	0.42	0.33	0.20	0.18	0.16
7.8.84		F	0.24	0.20	0.14	0.11	0.11	oil palm	0.34	0.22	0.21	0.13	NA
7.2.85		F	0.25	0.18	0.13	0.10	0.08	oil palm	0.81	0.74	0.73	0.34	0.29
20.8.85		F	0.22	0.15	0.12	0.12	0.14	oil palm	0.81	0.85	0.39	0.26	0.19
14.2.86		F	0.30	0.19	0.16	0.17	0.16	oil palm	1.07	0.47	0.31	0.23	0.23
13.8.86		F	0.38	0.26	0.29	0.25	0.19	oil palm	1.00	0.70	0.57	0.48	0.35
22.8.81	Ex.Ca	F	0.32	0.46	0.40	0.60	0.30	cover-crop	1.88	1.02	1.33	1.32	NA
24.2.82	(%	F	0.40	0.35	0.30	0.40	0.50	cover-crop	1.89	1.95	1.45	0.80	1.10
24.8.82	meq	F	0.50	0.24	0.48	0.40	0.50	oil palm	0.55	0.32	0.76	0.57	0.35
23.2.83		F	0.73	0.69	0.64	0.61	0.53	oil palm	0.82	0.73	0.62	0.52	0.46
24.8.83		F	0.48	0.34	0.27	0.21	0.23	oil palm	1.39	0.81	1.00	0.37	0.73
9.2.84		F	0.29	1.80	0.81	1.85	1.65	oil palm	1.07	0.89	0.53	0.44	0.45
7.8.84		F	0.36	0.31	0.21	0.23	0.24	oil palm	1.06	0.78	0.74	0.50	NA
7.2.85		F	0.42	0.24	0.24	0.24	0.15	oil palm	5.00	5.54	5.75	2.41	2.04
20.8.85		F	0.30	0.31	0.29	0.29	0.41	oil palm	6.50	8.77	2.70	1.49	0.70
14.2.86		F	0.49	0.75	0.30	0.25	0.28	oil palm	4.97	2.43	2.08	1.59	1.61
13.8.86		F	0.40	0.34	0.32	0.30	0.45	oil palm	5.59	4.31	3.32	2.45	1.48
24.8.82	Ex.	F	0.05	0.04	0.05	0.04	0.05	oil palm	0.04	0.03	0.04	0.05	0.04
23.2.83	Na	F	0.08	0.07	0.08	0.07	0.06	oil palm	0.07	0.08	0.07	0.06	0.07
24.8.83	(%	F	0.07	0.06	0.05	0.06	0.06	oil palm	0.06	0.05	0.07	0.07	0.06
9.2.84	meq)	F	0.06	0.06	0.05	0.06	0.05	oil palm	0.05	0.05	0.05	0.05	0.04
7.8.84		F	0.05	0.05	0.04	0.06	0.05	oil palm	0.06	0.06	0.05	0.05	NA
7.2.85		F	0.08	0.09	0.08	0.07	0.07	oil palm	0.07	0.06	0.07	0.12	0.07
20.8.85		F	0.16	0.15	0.12	0.14	0.12	oil palm	0.17	0.12	0.02	0.15	0.14
14.2.86		F	0.04	0.04	0.04	0.03	0.03	oil palm	0.04	0.04	0.04	0.04	0.04
13.8.86		F	0.07	0.06	0.05	0.05	0.05	oil palm	0.06	0.06	0.06	0.00	0.06

Note: F — Forest.
Felling — felling and burning of jungle.
Cover-crop — planting and initial establishment.
Oil palm — planting and initial establishment of oil palm and full establishment of cover crop.
NA — not available

The ERA process is normally presented in the form of an erosion risk map which classifies the land area according to its susceptibility to erosion. In this study,the factorial scoring method is used to generate an erosion risk map of the STEB.

Variations in organic carbon content were greater during Transition for crop development than under forest. During felling and initial cover crop establishment, values were high, probably due to the large amount of organic matter returned to the soil through forest felling and incomplete combustion. However, the content diminished thereafter probably due to the removal of organic matter through subsequent reburns and erosion.

Organic carbon appears to decline as the oil palm matures (5th to 6th year of its growth) and its canopy gradually becomes extensive enough to reduce light penetration to the legume cover, which consequently dies.

The fluctuations of C.E.C and total N under the deforested condition follow closely those of organic carbon content. The C.E.C. values under the crop establishment are higher than those under the forest, probably due to the slight improvement in organic carbon content. Total N is also higher under crop establishment, probably due to both the above reasons and fertilizer application.

Total P content under crop establishment is only slightly higher than that under the forest, even with the application of P fertilizer within the weeded circle and one round of this fertilizer broadcast over the legume cover. This is due to the poor mobility of P in the fertilizers through its rapid fixation by the iron and aluminium oxides.

Total K, total Mg and total Ca contents are higher in cultivated areas than under forest. Also there is a gradual build up of these substances in cultivated areas probably due to surface runoff. Total Na content under crop cultivation (oil palm) is similar to that under the forest, probably due to the presence of low concentrations of this element in the fertilizers. There is also no distinct build up of this element in the cropping area.

Available P, exchangeable K, exchangeable Mg and exchangeable Ca gradually build up to much higher contents in cultivated areas than under forest. Again, the exchangeable Na content is similar for both land conditions, probably due to the influence of low concentrations in fertilizers.

To sum up, this study indicates a slight increase in pH and large improvements in major plant nutrients except Na, mainly due to the application of fertilizers. Organic carbon status is high only during the initial stage of crop development when much of the forest litter is still present. The gradual reduction in this element during crop establishment in the later stage calls for the preservation of organic matter in order to maintain soil fertility, probably through the application of oil palm waste in the case of oil palm cultivation.

8.5 Erosion Risk Assessment

Erosion risk assessment (ERA) is a specialized form of land resource evaluation, the objective of which is to identify those areas of land where the maximum sustained productivity from a given landuse is threatened by excessive soil loss. The assessment aims at dividing the areas of Sg. Tekam into units, similar in their degree of erosion hazard, as a basis for planning soil conservation work.

The ERA process is normally presented in the form of an erosion risk map which classifies the land area according to its susceptibility to erosion. In this study, the factorial scoring method is used to generate an erosion risk map of the STEB.

8.5.1 Factorial Scoring Method

This simple scoring system for rating erosion risk was devised by Stocking and Elwell (1973) in Zimbabwe. The land area is divided into a grid system of known land area. Each unit is rated on a scale from 1 to 5 in respect of erosivity, erodibility, slope, ground cover and human occupation. The scoring is arranged so that 1 is associated with a low risk of erosion and 5 with a high risk of erosion. The five factorial scores are summed to give a total score which is compared with a chosen classification system to categorize areas of low, moderate and high erosion risk. The scores are mapped and areas of similar risk delineated.

In this study, the Sg. Tekam Basin is divided on a grid system into units of 0.49 hectares and each unit is rated with respect to erosivity, rainfall aggressiveness, erodibility, slope and landuse.

8.5.2 Methodology

(a) Erosivity

Erosivity is defined as the potential of the rain to erode the soil. It is an important index to predict rates of erosion because it represents the energy of the rainfall which is closely related to its power to detach soil particles.

Of the many methods to calculate erosivity, the one proposed by Morgan (1986) is used in this study.

$$EVa = 9.28\,P - 8838.15$$

where, EVa = Annual erosivity (J/m^2)
P = Annual Rainfall (mm)

Mean annual erosivity values for the three years (1983/84 to 1985/86) for all 4 recording rainfall stations are used in the scoring (Table 8.4).

(b) Rainfall Aggressiveness

Rainfall aggresiveness is an index of the concentration of precipitation in a single month, thereby giving a crude measure of the intensity of the rainfall.

This index has the value of denoting the seasonality of the climatic regime. This is important since seasonal fluctuations are reflected in vegetation growth and thus in the degree of protection by the biomass of the soil surface against erosion. Rainfall aggressiveness index has been shown to be related significantly with the sediment yields of rivers (Fournier, 1960).

Rainfall aggressiveness = p^2/P
where, p = highest mean monthly precipitation (mm)
P = Mean annual precipitation (mm)

The calculated values for the study area are shown in Table 8.4).

Table 8.4: Erosivity and Rainfall Aggressiveness

Station	Erosivity (kJ/m^2)	Rainfall Aggressiveness
1	10.87	57.74
2	11.31	60.06
3	12.28	57.34
4	11.85	65.96

(c) Erodibility

Erodibility is defined as the resistance of the soil to both detachment and transport. Although soil resistance to erosion depends on many factors, the most important factor is the nature of the soil itself.

Large particles are resistant to transport because of the greater force required to entrain them whereas fine particles are resistant to detachment because of their cohesiveness. The least resistant particles are silts and fine sands. (Morgan,1986) In this study, erodibility of soil is derived from the Wischmeier, Johnson & Cross (1971) Nomograph for use in the Universal Soil Loss Equation, based on particle size distribution of soil samples taken from seven soil pits in the STEB (Table 8.5).

Table 8.5: Erodibilty Factor

Soil Pit	2	3	4	5	6	7
Erodibilty	0.07	0.05	0.06	0.08	0.06	0.05

(d) Slope

Erosion would normally be expected to increase with increases in slope steepness and slope length as a result of respective increases in velocity and volume of surface runoff. Although the increase in the rate of erosion may not be linearly related to increase in slope steepness, it is assumed to be so in this study.

(e) Landuse

Landuse is an important factor affecting erosion. Generally, the thicker the vegetative ground cover, the more the soil is protected against erosion. In addition to providing protection against direct raindrop impacts, plants also reduce erosion by binding soil particles with their roots. Three types of landuse are found in the study area; oil palm, cocoa and forest.

8.5.3 Discussion

By superimposing the five maps on erosivity, rainfall aggressiveness, erodibility, slope and landuse, a composite map of erosion risk over the STEB was obtained (Fig. 8.2). Four categories of erosion prevention priority are used in this assessment: low, moderate, high and severe.

The assessment above showed that Catchment B has a higher erosion potential than Catchment C. Catchment B has erosion risks ranging from low to severe risk whereas Catchment C has erosion risk ranging from low to moderate only.

In Catchment B, high erosion occurs in the southern parts of the basin, especially in the south-west, due to the presence of short steep slopes. In Catchment C, most of the catchment area experiences low erosion except for the northern area which experiences moderate erosion. The percentage of land experiencing various erosion risks are shown in Table 8.6.

Table 8.6: Percentage of Area and Erosion Risk

Erosion Risk	Percentage of land: Catchment B	Percentage of land: Catchment C
Low	29.9	74.3
Moderate	58.2	25.7
High	7.9	—
Severe	4.0	—

CHAPTER 9

BUFFER STRIP STUDY

9.1 Methodology

To evaluate the effectiveness of buffer strip and the use of cover crops to conserve soil and water a series of runoff plot studies were conducted.

Plot description

The soil series of the study area is Munchong (Tropeptic Haplorthox). Nine runoff plots of 22 m by 5.46 m and three plots of 44 m by 5.46 m on 16% slope were used in this study. The treatment of the plots were:-

Treatments	Plot size (m)	Replication
Clear (bare) (C)	22 × 5.46	3
Buffer (B)	22 × 5.46	3
Legumes (L)	22 × 5.46	3
Mixed (Clear + Buffer) (M)	44 × 5.46	3

The layout of the plots is presented in Figure 9.1. The species and diameters of trees in the buffer plots and in the mixed plots are given in Table 9.1. The legumes used were **Centrosema pubescens** and **Pueraria javanica** at a mixing ratio of 4:5 by weight and planted at a rate of 12.5 kg/ha. The spacing between the legume rows was 1.0 m.

Collecting equipment

The collecting equipment consisted of a rectangular tank, a multislot divisor and two drums. The layout of the runoff plots with the collection equipment is shown in Figure 9.2. During high runoff events, water flowing through one slot of the nine-slot divisor was collected for analysis, but in small storm the total volume of runoff was collected. A daily recording rain gauge and a check gauge were used to record the rainfall of the area.

Sampling Technique

The runoff and soil loss from each plot were taken on a per storm basis. After every storm the water levels in the tanks were recorded to calculate the volume of runoff. For the soil loss calculation a total of 3 aliquot samples of 150 ml each at 3 different depths were taken to get a depth-integrated sample. Analysis of samples were done at the Chemistry Department, Petaling Jaya and at the Soil Management Branch Laboratory, Department of Agriculture, Kuala Lumpur.

9.2 Vegetation Study

Enumeration of all trees with a diameter, at breast height, of 10 cm and above was carried out in six different plots viz; buffer plot 1 (6B), buffer plot 2 (5B), buffer plot 3 (4B), mixed plot 1 (1M), mixed plot 2 (2M) and mixed plot 3 (3M).

Among the parameters recorded during enumeration were species name, diameter at breast height (DBH), total and merchantible height and crown diameter (Table 9.1) The location of each tree enumerated was mapped.

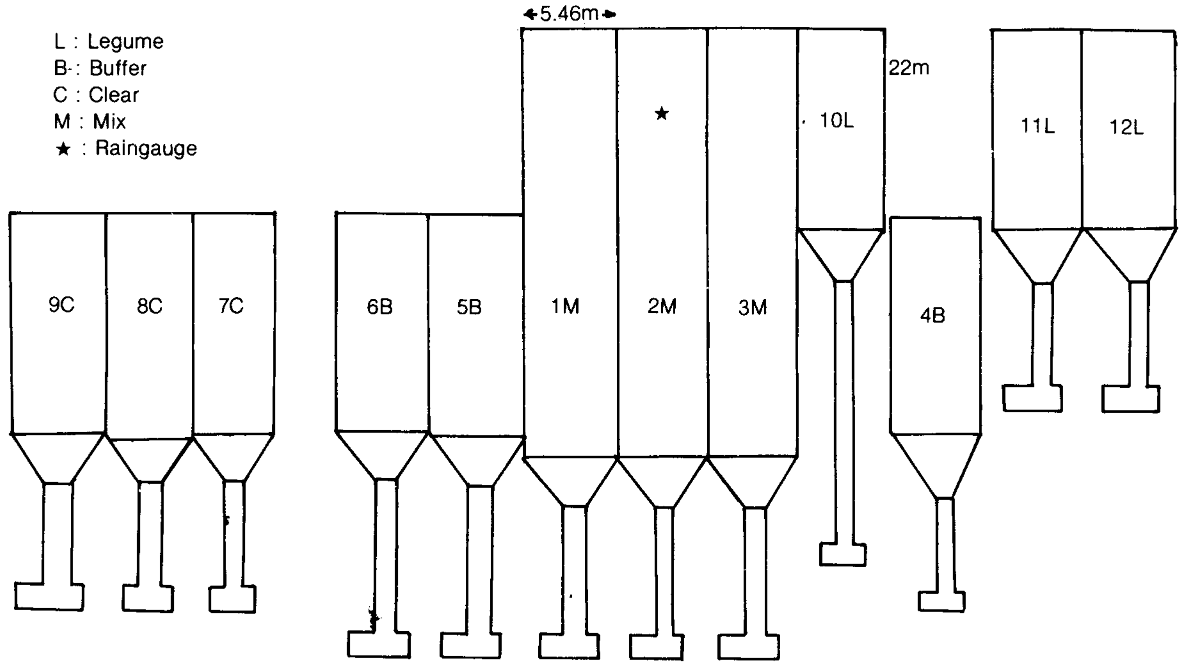
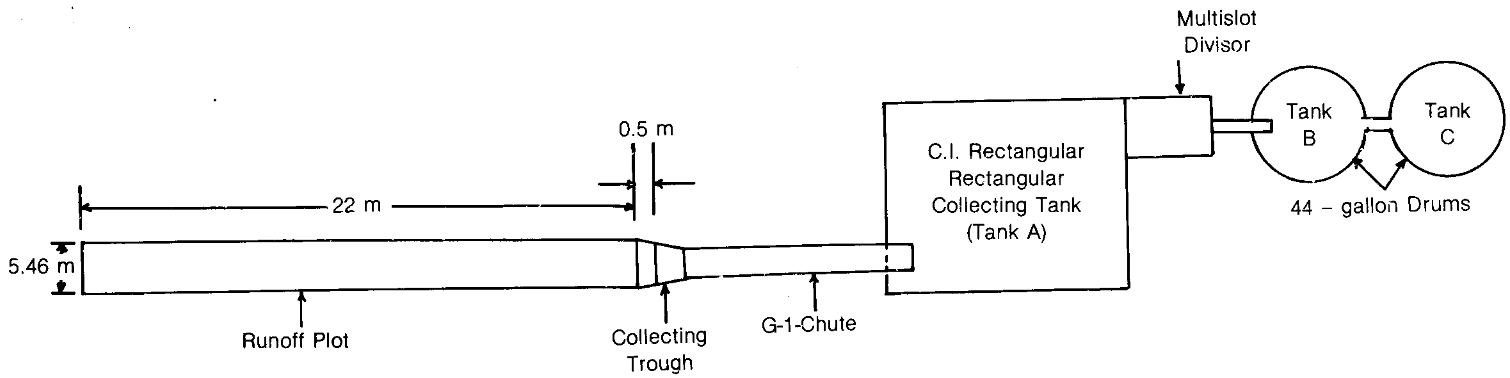


Fig. 9.1. Lay-out of the Runoff Plot.



Typical Lay-out of a Runoff Plot-Plan

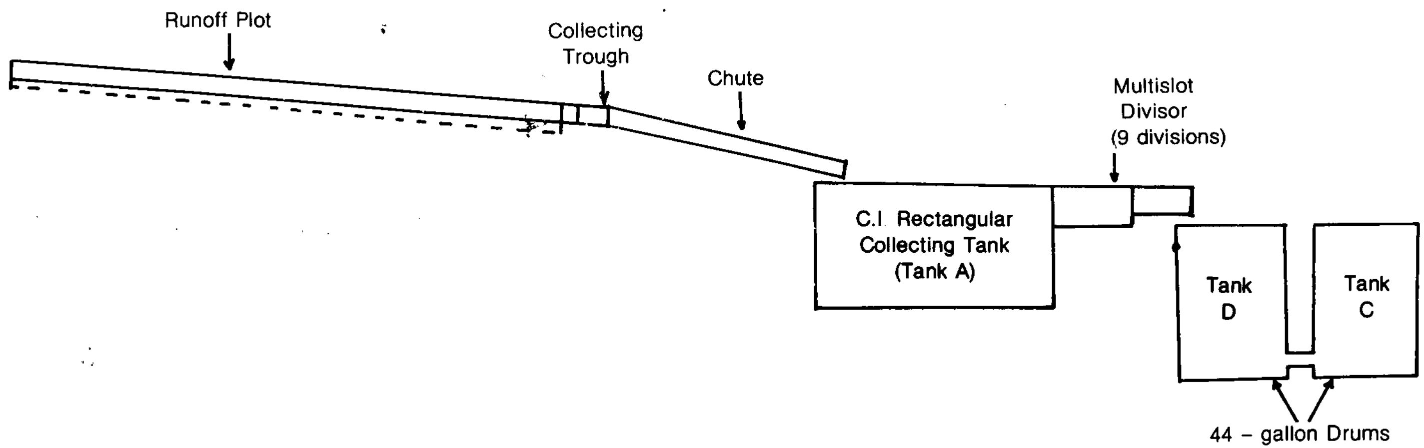


Fig. 9.2. Typical Lay-out of a Runoff Plot — Side view.

Table 9.1 Results of Inventory in the Study Plot

Plot Buffer No. 1 (6B).

	Species	dbh (cm)	Total hgt. (m)	Merch hgt. (m)	Total Vol. (m)	Av. Crown dia (m)
1.	Parah	21.00	21.51	16.06	0.36	3.45
2.	Mempisang	11.50	13.33	4.70	0.05	1.60
3.	Keiat	17.20	16.97	11.21	0.17	2.15
4.	Perah	21.30	20.30	13.94	0.33	2.65
5.	Kelat	10.80	10.61	3.64	0.02	2.60
6.	Kubin	24.50	24.54	11.82	0.44	6.40
7.	Kelat	40.40	31.82	20.00	1.74	3.80
8.	Medang	10.00	16.06	9.09	0.06	2.65
9.	Kubin	17.80	7.27	4.55	0.11	4.50
	Total	174.50	162.41	95.01	3.28	29.80
	Average	19.39	18.05	10.56	0.36	3.31

Estimated Canopy Closure = 56%

Plot Buffer No. 2 (5B).

	Species	dbh (cm)	Total hgt. (m)	Merch. hgt. (m)	Total Vol. (m)	Av. Crown dia. (m)
1.	Mahang	28.30	27.72	11.36	0.57	5.10
2.	Medang	10.20	12.42	8.48	0.06	2.90
3.	Medang	17.20	23.63	16.36	0.28	3.70
4.	Mahang	17.50	24.54	22.42	0.38	2.55
5.	Mahang	11.80	20.00	17.27	0.14	2.00
6.	Kubin	17.20	29.09	23.94	0.38	2.75
7.	Medang	15.60	17.58	7.58	0.13	4.25
8.	Medang (dead)	11.50	0.00	0.00	0.00	0.00
9.	Kedondong (deffect)	37.90	11.51	11.51	1.04	0.00
	Total	167.20	166.49	118.92	2.98	23.25
	Average	18.58	20.81	14.87	0.37	3.32

Estimated Canopy Closure = 41%

Plot Buffer No. 3 (4B).

	Species	dbh (cm)	Total hgt. (m)	Merch. hgt. (m)	Total Vol. (m)	Av. Crown dia. (m)
1.	Meranti Sarang Punai	13.40	15.45	11.51	0.13	2.05
2.	Medang (deffect)	10.00	9.09	9.09	0.06	1.25
3.	Medang (dead)	32.50	6.06	6.06	0.46	0.00
4.	Medang (patah)	12.40	3.33	3.33	0.04	0.00
5.	Kelat	10.20	11.06	3.94	0.02	3.40
6.	Medang teja	13.40	16.06	4.24	0.06	4.05
7.	Meranti Sarang Punai	10.50	14.85	9.24	0.07	2.15
8.	Tualang	15.00	3.33	3.33	0.04	2.85
	Total	177.40	79.23	50.74	0.89	20.00
	Average	14.60	9.90	6.34	0.11	2.86

Estimated Canopy Closure = 30%

Plot Mix No. 1 (1M).

	Species	dbh (cm)	Total hgt. (m)	Merch. hgt. (m)	Total Vol. (m)	Av. Crown dia. (m)
1.	Medang	28.60	18.48	8.03	0.44	6.25
2.	Kedondong	23.20	22.12	13.64	0.45	4.48
3.	Kelat	10.80	16.06	9.70	0.06	3.40

Table 9.1 Continuation.

	Species	dbh (cm)	Total hgt. (m)	Merch. hgt. (m)	Total Vol. (m)	Av. Crown dia (m)
4.	Temponek	15.30	20.91	9.70	0.12	3.70
5.	Kasai	56.34	30.91	16.06	2.90	7.30
6.	Kelat	11.80	15.76	9.54	0.07	2.35
7.	Medang	11.80	16.36	5.76	0.06	2.80
	Total	157.84	140.60	72.43	4.09	30.28
	Average	22.55	20.09	10.35	0.58	4.33

Estimated Canopy Closure = 80%

Plot Mix No. 2 (2M).

	Species	dbh (cm)	Total hgt. (m)	Merch. hgt. (m)	Total Vol. (m)	Av. Crown dia. (m)
1.	Medang	12.40	13.94	11.21	0.11	2.65
2.	Meranti melantai	18.10	25.45	12.42	0.26	4.95
3.	Medang	24.80	19.85	11.67	0.45	4.80
4.	Kelat (dead)	10.80	0.00	0.00	0.00	0.00
5.	Kelat	39.50	22.73	10.91	0.97	5.60
6.	Kelat	13.70	17.57	12.12	0.11	3.50
7.	Merawan	14.00	16.36	9.70	0.11	2.70
8.	Kelat	14.30	12.42	3.03	0.04	4.15
9.	Meranti tembaga	73.20	33.33	24.85	7.37	8.65
10.	Kelat	13.40	15.45	8.48	0.08	3.05
11.	Medang	16.20	19.70	11.51	0.19	3.45
12.	Kedondong	36.60	20.91	13.33	1.09	5.20
	Total	287.00	217.71	129.23	10.78	48.70
	Average	23.92	19.79	11.75	0.98	4.43

Estimated Canopy Closure = 74%

Plot Mix No. 3 (3M).

	Species	dbh (cm)	Total hgt. (m)	Merch. hgt. (m)	Total Vol. (m)	Av. Crown dia. (m)
1.	Kelat	14.60	16.06	6.67	0.08	2.40
2.	Kelat	17.80	15.15	8.33	0.14	3.45
3.	Kelat	32.50	17.88	14.54	0.83	3.60
4.	Medang	18.80	13.79	9.09	0.21	5.00
5.	Medang	13.40	17.57	14.54	0.16	3.85
6.	Kasai	18.10	20.00	10.91	0.19	4.85
7.	Mempisang	13.40	10.30	3.64	0.05	3.25
8.	Meranti melantai	17.20	16.67	10.45	0.20	4.05
9.	Mempening (dead)	10.80	13.64	9.09	0.05	0.00
	Total	156.60	141.06	87.26	1.91	30.45
	Average	17.40	15.67	9.70	0.21	3.81

Estimated Canopy Closure = 64%

The enumerated plots were rich in non-dipterocarp species, namely, Medang (**Litsea** spp.) and Kelat (**Eugenia** spp). Only four species of Dipterocarp were recorded i.e. **Shorea macroptera, Shorea leprosula, Shorea parvifolia** and **Hopea** spp.) The dominance of secondary/pioneer species such as Mahang (**Macaranga** spp.) and Kubin (**Macaranga gigantea,**) generally found in open areas, confirms that the area is a logged-over forest.

The forest profile of each plot was drawn as illustrated in Figures 9.3 to 9.8. Generally, the trees were intermediate in size and sparsely distributed. Most of the trees forming the main canopy had previously been removed.

Fig. 9.3. Forest Profile — Buffer Plot 1 (6B)

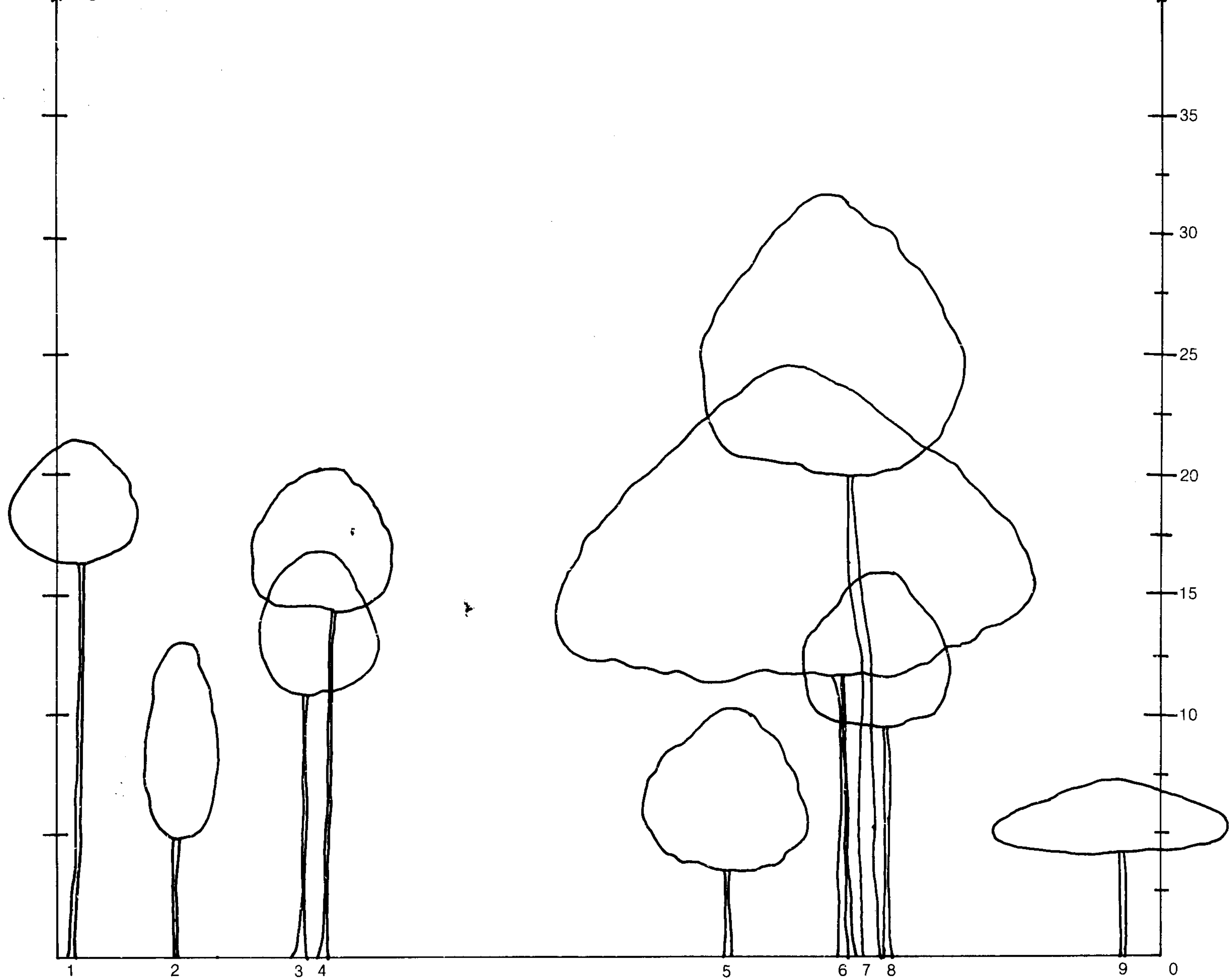


Fig. 9.4 Forest Profile — Buffer Plot 2 (5B).

Fig 9.5. Forest Profile — Buffer Plot 3 (4B).

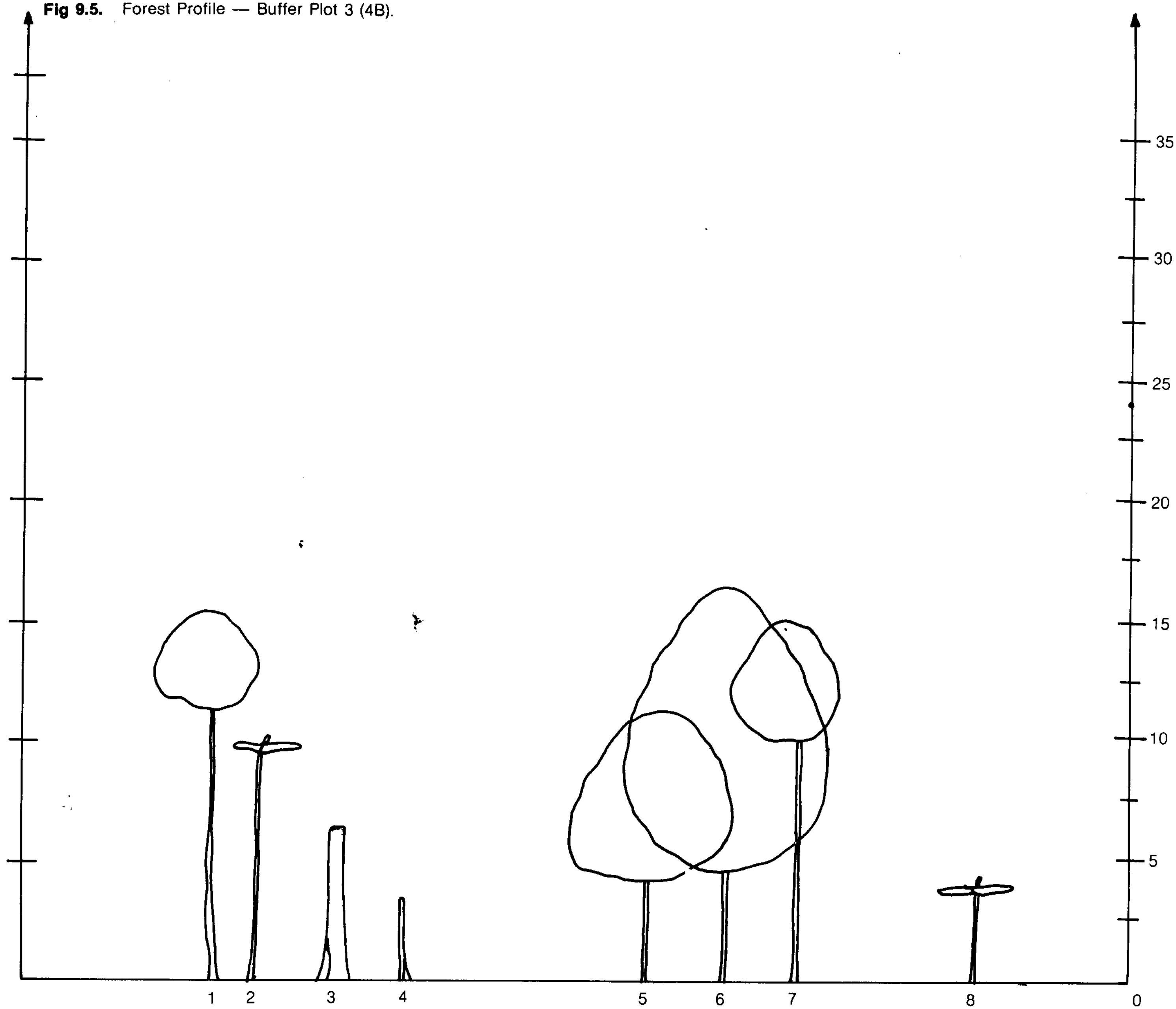


Fig. 9.6. Forest Profile — Mix Plot 1 (1M).

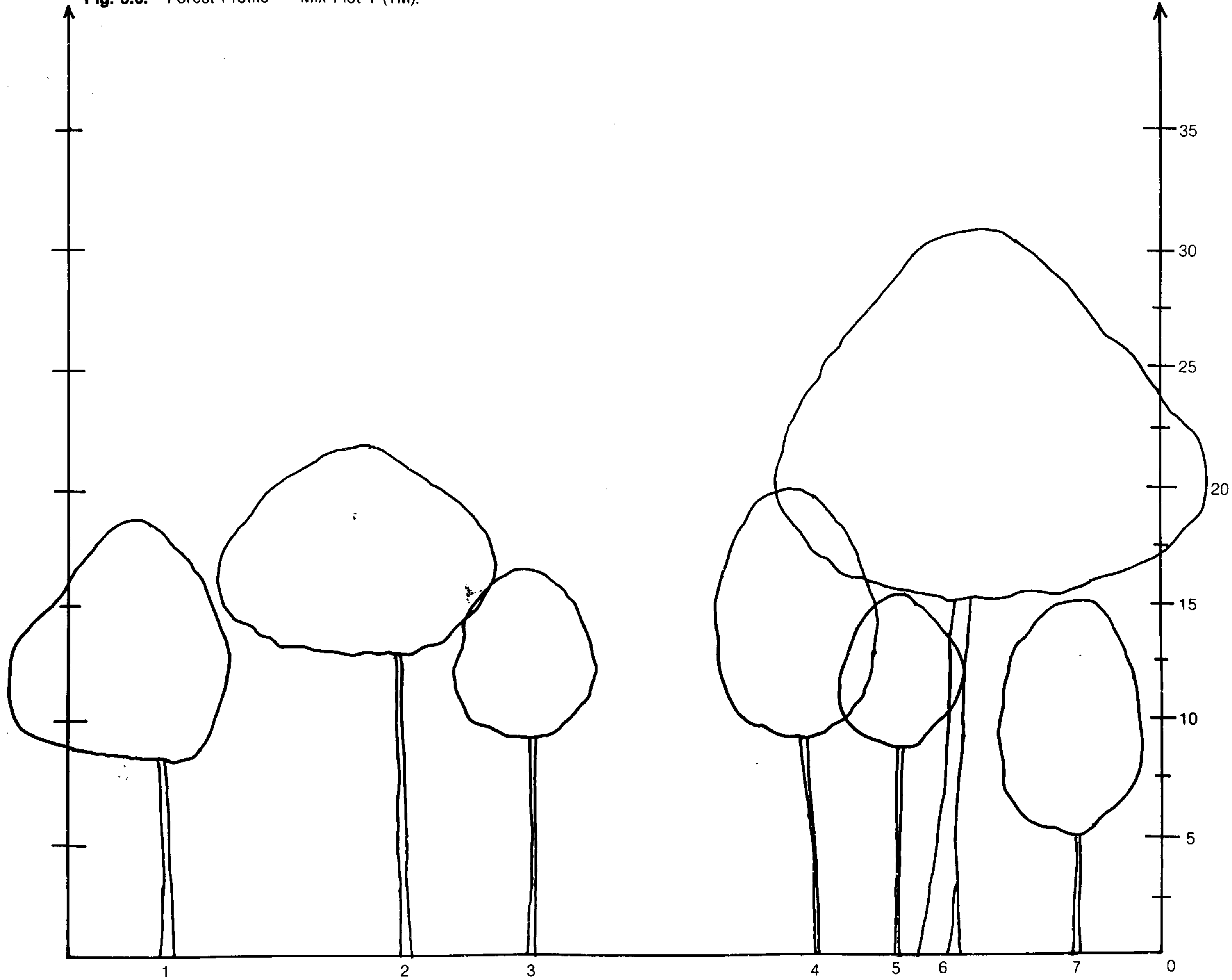


Fig. 9.7. Forest Profile — Mix Plot 2 (2M).

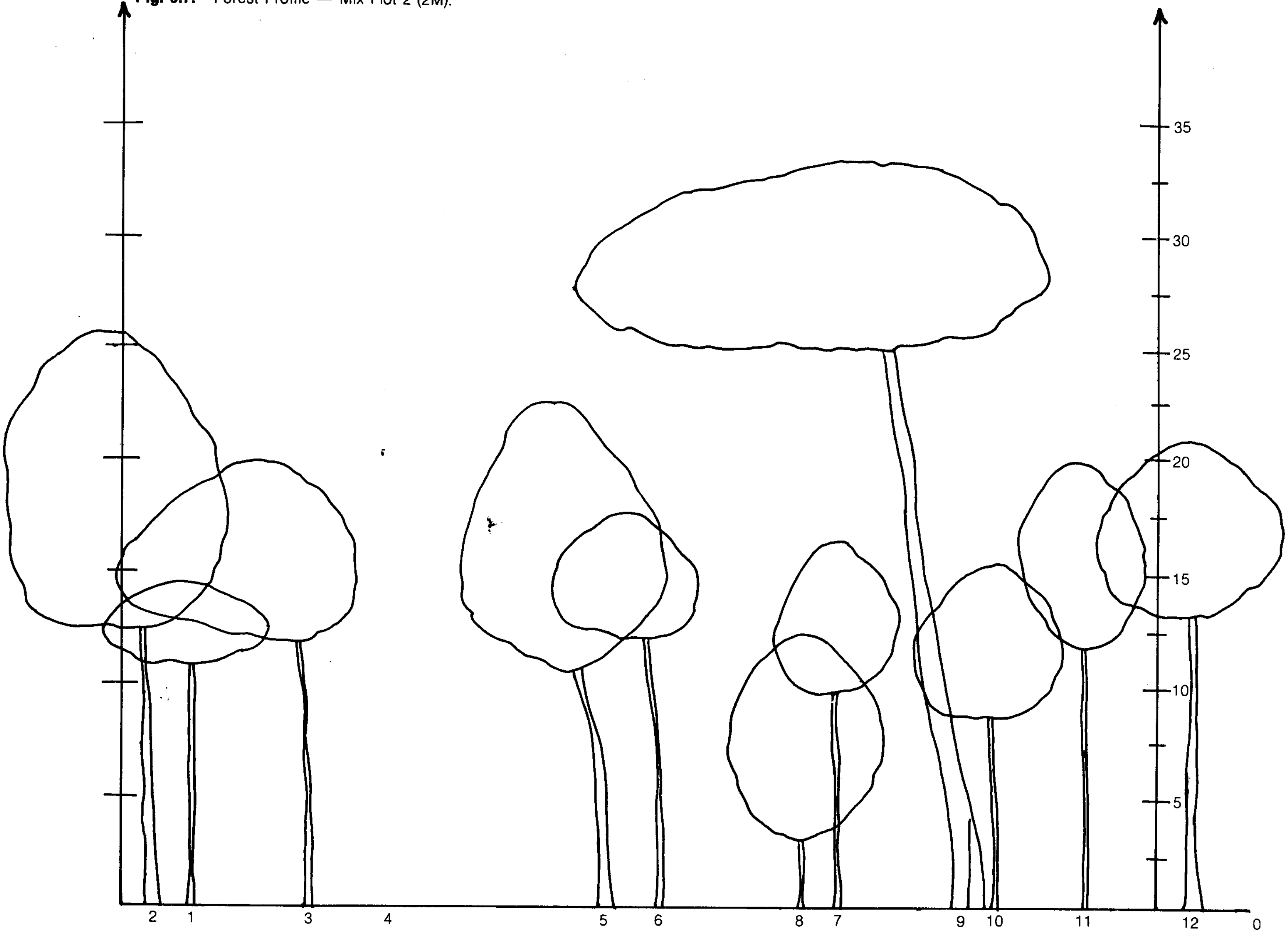


Fig. 9.8. Forest Profile — Mix Plot 3 (3M).

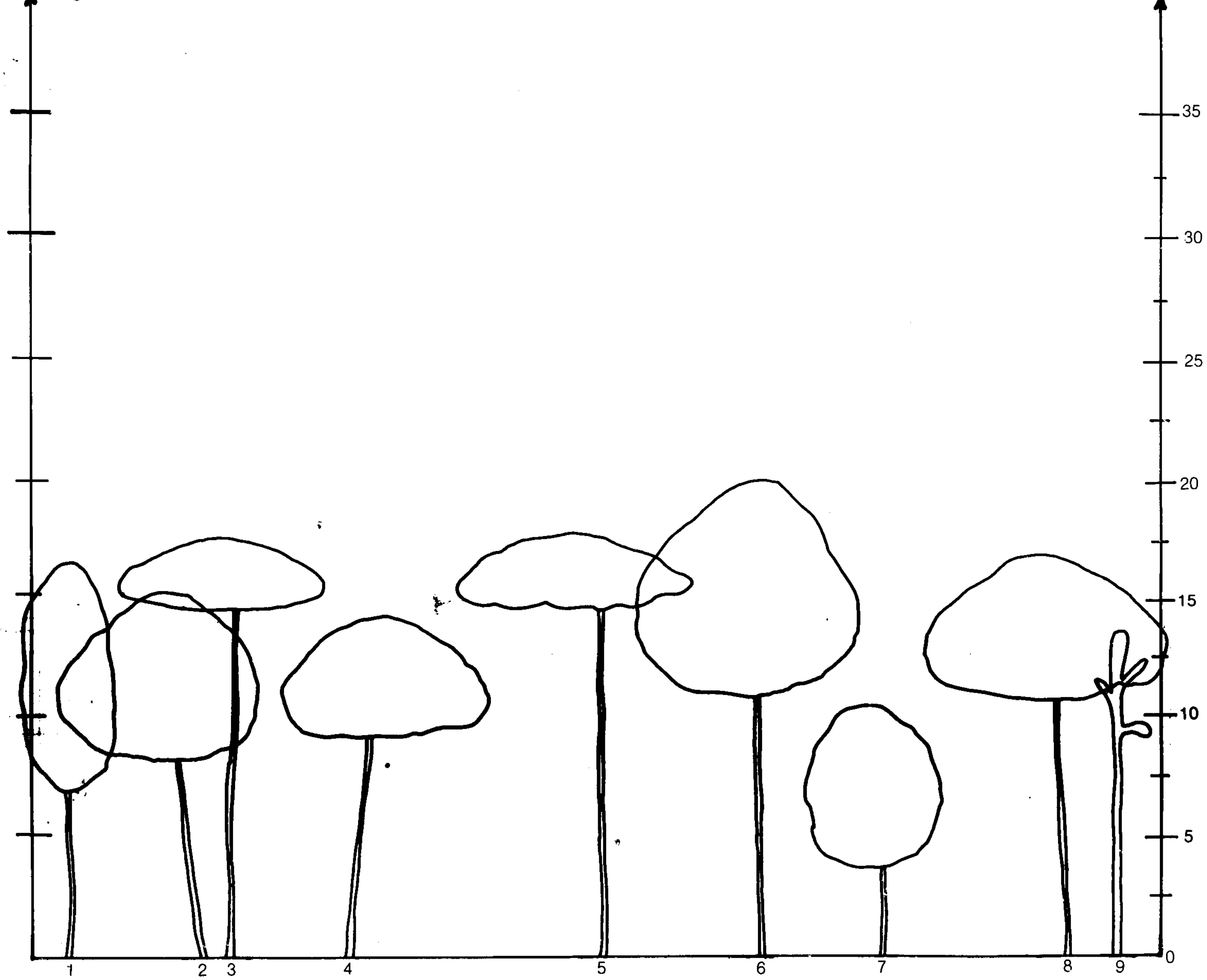
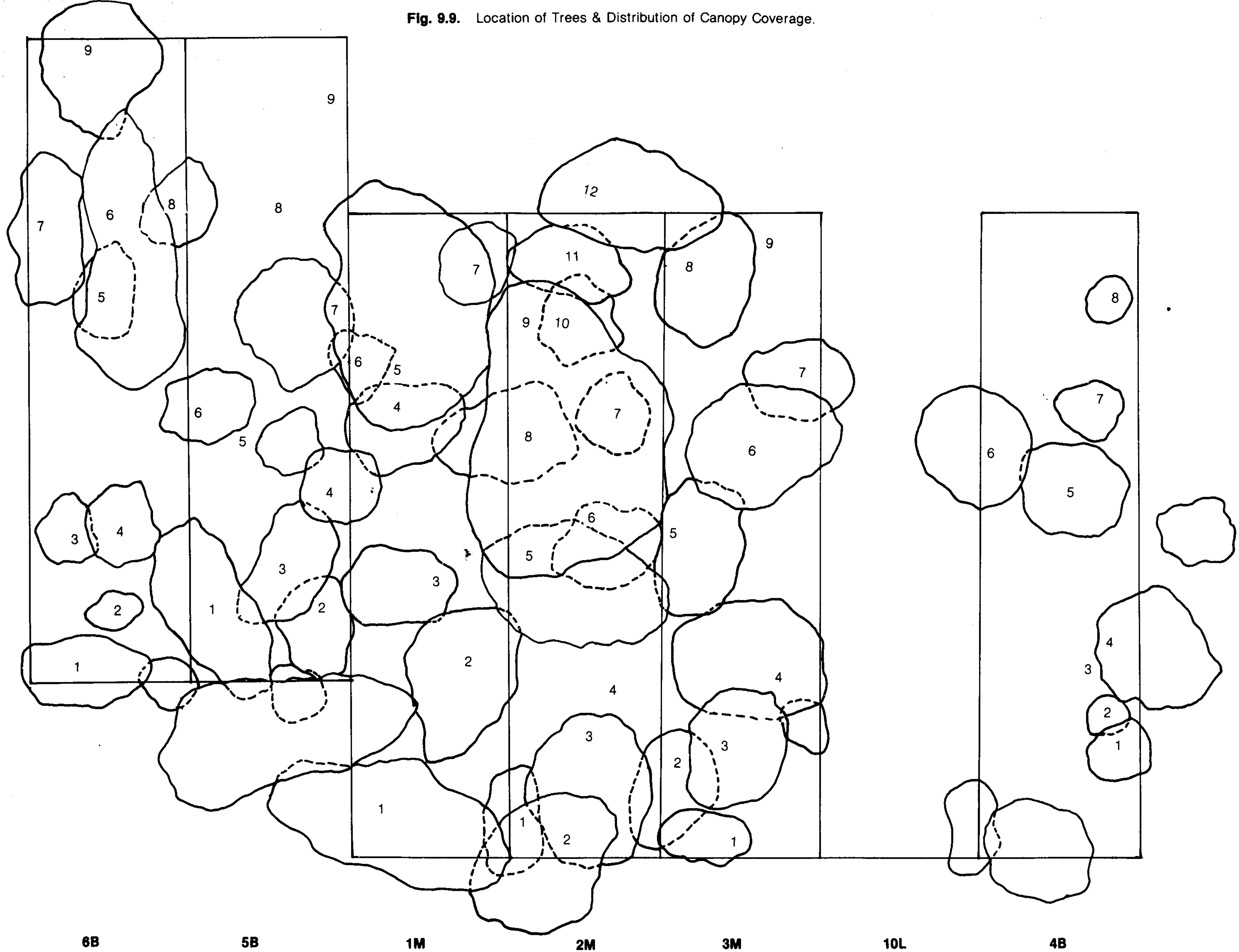


Fig. 9.9. Location of Trees & Distribution of Canopy Coverage.



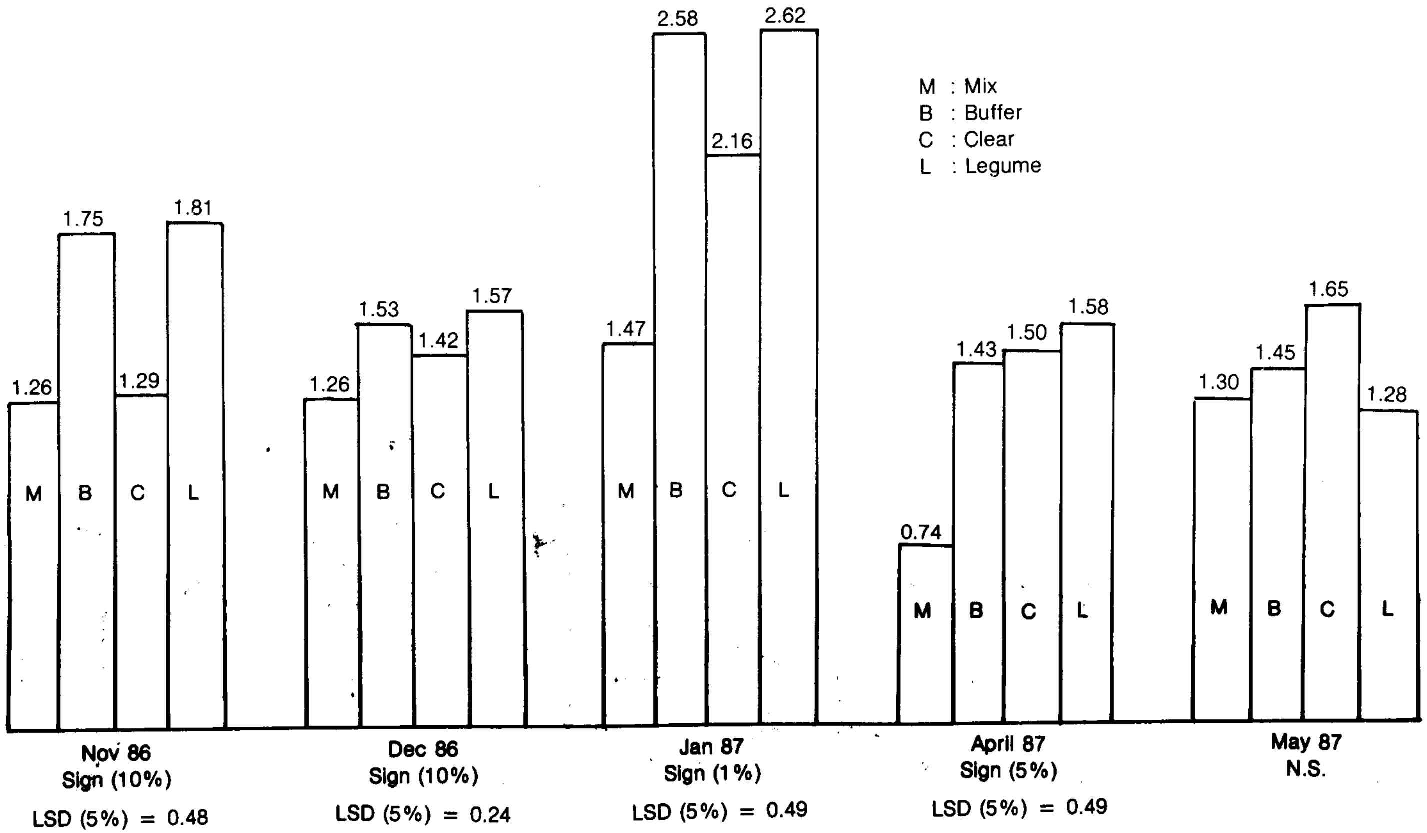


Fig. 9.10 Monthly Rainfall-Runoff Coefficients (%).

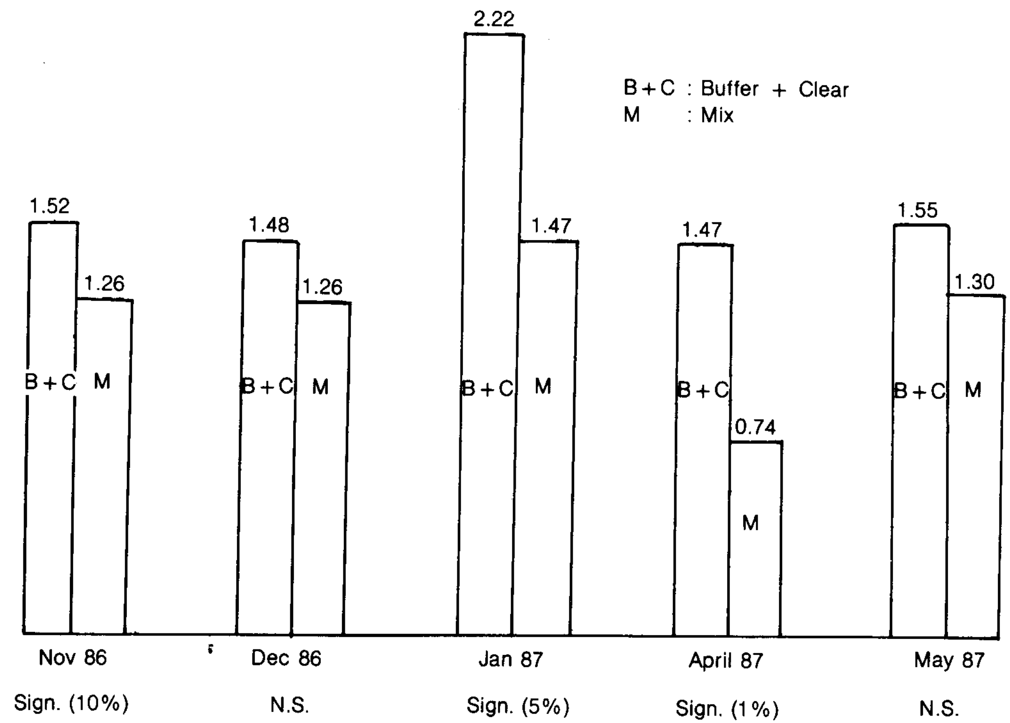


Fig. 9.11. Monthly Rainfall-Runoff Coefficients (%).

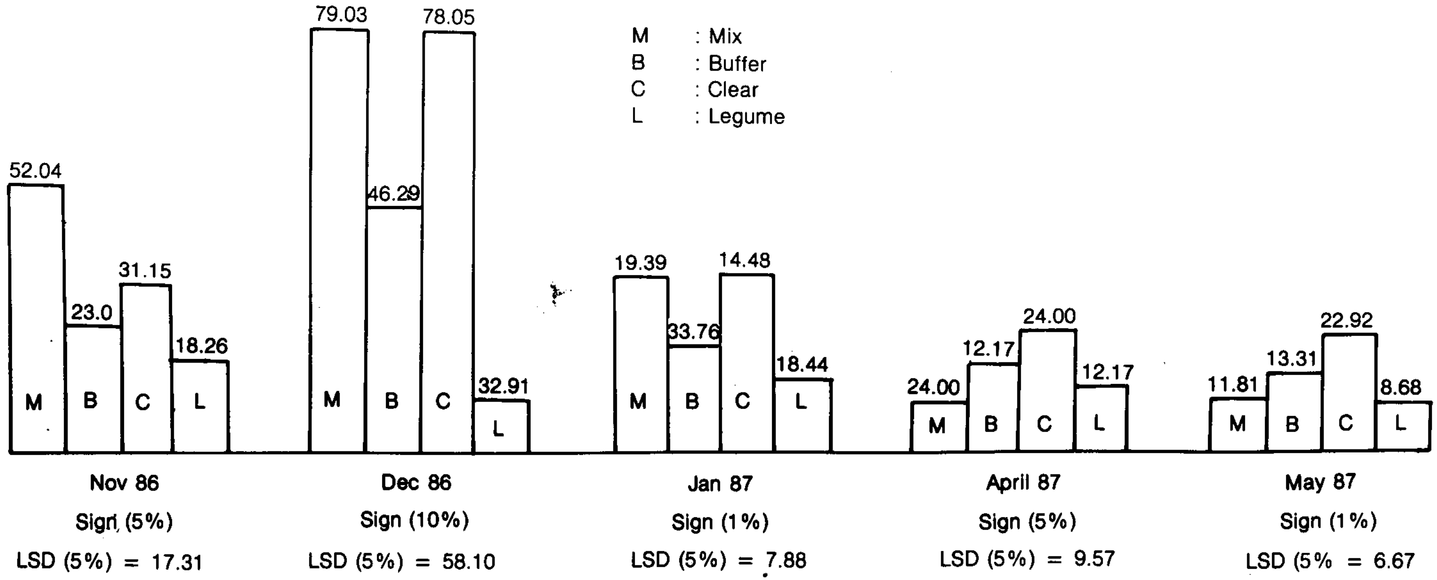


Fig. 9.12 Monthly Soil Loss (g/ha/mm).

Table 9.2 Daily Rainfall from November 1986 to May 1987

Rainyday	Rainfall (mm)	Rainyday	Rainfall (mm)
November 86		December 86	
1	15.5	3	15.5
3	6.0	4	3.0
6	1.5	6	25.0
7	4.2	7	2.5
8	0.5	8	2.0
9	2.0	9	24.5
11	10.0	10	9.5
16	30.0	11	12.5
17	10.0	16	3.0
18	5.0	17	34.0
19	12.0	18	10.5
20	24.5	19	60.0
21	8.5	20	1.0
22	3.0	27	7.5
24	19.0	29	5.5
25	16.0		
26	27.0		
27	9.5		
28	12.0		
29	22.5		
30	12.5		
January 87		February 87	
3	13.0	27	1.0
6	13.0	28	8.0
7	5.5		
9	16.0		
10	7.5	March	
11	14.0	1	8.0
12	1.0	2	0.2
13	2.5	3	0.1
18	0.5	5	14.0
20	17.5	6	2.0
21	19.5	20	1.5
24	4.0	21	4.5
25	43.0	23	8.5
27	12.0	28	3.9
28	1.0	31	1.5
30	3.5		
April 87		May 87	
1	7.5	2	52.0
2	43.2	3	1.5
3	1.5	5	60.0
8	6.5	7	10.0
10	19.3	8	51.0
11	1.5	10	3.5
14	62.0	12	7.5
15	19.0	14	24.5
18	13.0	15	1.0
19	1.0	17	9.2
21	16.3	27	1.0
22	25.5	28	17.5
25	6.5	30	8.0
26	1.5		
27	12.5		
28	6.0		
29	8.5		

Despite a variety of crown cover conditions caused by timber extraction in the past, there was little difference in the measured crown cover in the six plots. Past disturbance has indicated that the average crown coverage is about 60 to 70% (Figure 9.9).

9.3 Surface Runoff

Data for the period November 1986 — May 1987 derived from the buffer strip plot studies comprises daily rainfall (Table 9.2), monthly percent cover by legumes (Table 9.3), monthly runoff coefficients and quantities (Figures 9.10 and 9.11) and soil loss in g/ha/mm of rain (Figures 9.12 and 9.13). The contrast in runoff between the derived treatment B and C and treatment M indicates the effectiveness of the buffer strip. Runoff under treatment M is the lowest in most months (Figure 9.10). Although Foong (1984) found infiltration in Munchong soil under forest to be higher than after clearing, in the first three months of the study, the buffer plots had higher runoff volumes than those which had been cleared.

Ponding in small depressions in the C plots probably increased infiltration, which also may have been enhanced by the breaking up of the ground surface during clearing. Gradual closing up of soil surface cracks and openings by raindrop splash and inwash of materials, with further compaction of the surface led to higher runoff values some months after clearance as in occurred May 1987.

The greater runoff from the legume plots may also arise from the probable enhancement of infiltration in the cleared plot. However after April 1987, the legume covers began to reduce runoff. Overall, the buffer strip reduced runoff in all five months, but its benefits were most marked in the high rainfall months, when soil loss potential was greatest, in January and April.

Table 9.3: Legume Cover

Month	Coverage (%)
November 86	5
December 86	10
January 87	20
April 87	60
May 87	85

9.4 Soil Loss

Soil loss in all months was significantly different for all plots (Figure 9.12). Lowest losses were in the legume plot as such a cover effectively reducing erosion. The cleared plot, treatment C, experienced the greatest erosion due to the direct action of rain on the exposed soil.

The overall effect of the buffer strip at the initial stage is not clear (Figure 9.13), there being no significant differences between treatments M, B and C. However the influence was clear by April and May 1987 when soil loss from the buffer strip was only one-third that from treatments B and C.

9.5 Discussion

Both buffer strips and legume covers reduce soil erosion, but the buffer strip is more effective than legumes in reducing runoff, as the legume cover does not become effective until it provides sufficient protection four to five months after planting. The study thus leads to the following recommendations:

(1) A buffer strip and legume cover should be maintained as a standard practice when opening up land for agriculture.

(2) More studies with different widths of buffer strips should be carried out to obtain the optimum width of buffer strips for Malaysia.

CHAPTER 10

MANAGEMENT IMPLICATIONS

10.1 INTRODUCTION

This section attempts to synthesis the results of the Sungei Tekam Experimental Basin study into a state-of-knowledge on the effects of forest conversions to tree crops in the humid tropical watersheds. It is based on nine years of intensive data collection on all aspects of hydrological research, namely, flow regime, water balances, nutrient losses, erosion, sediment yields and riparian controls. It provides some of the answers to existing controversies and conflicting views on:

— increases in flood frequency and higher flood peaks as a result of deforestation.
— will the amount of sediment loss during conversion be revert back to its original levels after tree crop establishment?
— are there any differences in water and sediment yields between forest and tree crop cultivation?
— what is the water quality like before and after deforestation and the establishment of tree crops?
— are there any significant changes in water yields before and after conversion?
— what nutrients are returned to the soil during conversion?

The STEB Study Group hopes that with the information now available in humid tropical areas, policy and decision makers in watershed management in such regions will have a better perception and awareness of the impacts of land development and the consequences of conversion from one functional use to another.

10.2 Effects on Total Rainfall

There was no significant change observed in the total rainfall and rainfall patterns between pre-clearance and the periods after conversion at all the four recording stations. Correlation coefficients between rainfall stations remain quite constant from 0.95 to 0.98 throughout the nine years of records. However mean annual fluctuations occur by as much as 20%. This is due primarily to the influences of the north-east and south-west monsoons, the exceptionally wet and dry years recorded nation-wide and not particularly for the watersheds only, and the insular location of the watersheds. Thus, there is still no evidence to conclude that forest clearance and its conversion to tree crops will enhance or reduce gross rainfall in an area. Perhaps the smallness of the watersheds exclude themselves from such conclusions to be made concerning this effect.

These findings conform with reviews of forest influences world-wide by Hewlett (1967) and Hamilton **et al** (1985) who concluded that in the absence of convincing evidence to the contrary, one must assume that the mere presence of forest cover does not in itself affect the gross precipitation over an area. Although the above conclusion is based mainly on studies in temperate regions, there are no reasons to believe that the same would not occur in the humid tropics.

10.3 Effects on Runoff

There is an increase in runoff immediately in response to deforestation. The increase declines gradually with the planting of cover crops and tree crops. The quantum and timing of increases vary from catchment to catchment depending on the speed of deforestation, the rate of replanting, types of crops grown, physiographic and hydrometeorological characteristics. It has been found that while baseflow, direct runoff and total flows have all increased, the ratios between base flow and total flow increased much higher, 9% — 29%, in the catchments following deforestation, while the ratio between direct runoff and total flow decreased by 21% — 49%. Thus comparatively, direct runoff did not increase as much as baseflow after deforestation. The large increase in base flow is mainly related to rise in water table due to reduced evapotranspiration and ponding effects immediately after deforestation. Water yields increased by 117% and 157% in the first two years following deforestation in catchment A, while in Catchment B, the increases were 85%, 142% and 97% for the first three years respectively.

In the temperate regions, increases of more than 50% were observed by Hibbert (1967) and Bosch & Hewlett (1982) after reviewing data from 39 and 94 catchments respectively. In East Africa, 80% increases were recorded (Pereira, 1964).

Peak discharge increased in both catchment A and B after deforestation but time-to-peak decreased significantly. Peak discharge in catchment A was increased by 185% immediately after deforestation due to its location as the upper and steeper catchment within catchment B. In catchment B, the peak discharge increased by 38% after deforestation of sub-catchment B which is the lower catchment. The range of peak flow increases seems to relate closely with those observed in catchment studies in Japan where increases from 69% to 114% were recorded following deforestation (Nakano, 1967).

Time-to-peak decreased from 3 hours to 1 hour immediately after deforestation in catchment A. However, it increased again to 3 hours after the establishment of oil palms.

10.4 Effects on Soil Loss

Erosion is never excessive under forested conditions. However when forests are cleared, excessive erosion occurs and this study provides indicative information on the rates of erosion at different phases of land development after deforestation on-site as measured in erosion plots and in stream channels.

Sediment loads in catchment A increased 4 times after deforestation, and was 3.5 times higher than that of the control catchment C. In catchment B, clear-felling resulted in soil losses up to 414 t/sq.km/yr. as compared to 20 — 39 t/sq.km/yr. prior to that. However sediment load in catchment B returned to its original level after the oil palms were about two years old but in catchment A, which was planted with cocoa, even after three years, the sediment load had not returned to its original level. It has been found that the shade trees in the cocoa areas are not good ground covers compared to legume in the oil palm area.

Results from erosion plots on two soil types revealed increases in erosion with slope. It was observed that erosion on deforested land was 5 — 7 times greater than that on forested lands during the first year after planting the legume cover. However after the third year, erosion under legume had declined considerably.

Deforestation activities such as timber harvesting, construction of roads and skid tracks, and preparation of land for crop planting account for as much as 90% of all the sediments exported from the catchments. The effects of these activities are observed to be more adverse than in the temperate regions on account of the deeply weathered profiles frequently encountered and the high intensity rainfalls. Since the amount of suspended sediment in the streams is governed by the rate of supply of materials, careful construction of the access systems and management of stream buffers may reduce the rate of sediment transport as indicated in the buffer strip studies. Other studies concerning the removal of forests and the subsequent soil erosion in Malaysia have been studied by a number of researchers; among them, Shallow (1956), Douglas (1968), Burgess (1971), Low & Leigh (1972), Leigh (1973) and Liew (1974), Salleh et al (1983) and Low & Peh (1985). All the results indicate as in this study that removal of forest cover will increase soil erosion and sediment in streams.

10.5 Effects on Infiltration

Infiltration rates are known to decrease after deforestation but will revert back rather quickly with ground covers depending on soil types. Experiments on infiltration rates on two soil types showed these changes. Infiltration rates on. Munchong series decreased from 30 cm/hr under forest to 20 cm/hr on deforested land, but under legume, the rate was 73 cm/hr. On Segamat series (a more friable type of soil), the rate of infiltration decreased from 26 cm/hr under forest to 3 cm/hr on deforested land but increased to 65 cm/hr four years after planting of legume.

Deforestation can affect infiltration capacity of soils in a number of ways. Removal of forests result in reduced evapotranspiration and an increase in the level of soil moisture storage which resulted in soils reaching field capacities earlier during rainfall events. Infiltration rates will also be reduced during the period immediately after deforestation because of compaction of soils due to heavy machinery, which seals the soil surface and reduce water entry. However with the establishment of crops, the rate of infiltration increases because new organic matter is provided to maintain the porosity of the soils (Cassells, *et al,* 1982).

10.6 Effects on Nutrient Outflow

It is often said that in the tropical rainforest, the distruptions in the tight nutrient cycling pattern, the change in the micro-climate and in the biological activity would be much more dramatic than in the temperate zone (Hamilton et al, 1983). This would probably result in greater nutrient outflows following clearing and burning of the forest. The greatly increased outflow of nutrients from the deforested ecosystem results primarily from the alteration of the nitrogen cycle within the ecosystem.

The results in STEB showed that the annual amount of dry matter from the forest litter returned to the soil is much higher than that of the legume litter, being 8.93 t/ha (893 t/sq.km) consisting of 0.91 t/ha ash and 8.02 t/ha of volatile substances compared to 3.13 t/ha of mean annual legume litter production consisting of 0.57 t/ha of ash and 2.56 t/ha of volatile substances. However the quantities of nutrients from the forest litter are nearly similar to those of the legume litter except N_tMg and Ca. These were reduced by 25%, 42% and 40% respectively from forest to legume litter indicating the alteration of the nitrogen cycle within the catchments.

Results from water quality measurements showed that there were changes in conductivity, suspended solids, turbidity, calcium, iron and magnesium in catchment A and sub-catchment B after deforestation. However only the increases in conductivity, calcium and magnesium were found to be statistically significant. It was also noticed that the pre-clearance concentration of these three parameters were relatively high as compared to studies in the undisturbed watershed of Bukit Berembun Forest Reserve (Rahim & Zulkifli, 1986). The increases were 16%, 26% and 37% respectively and were 26%, 12% and 63% higher than those of the control catchment C. The increases in conductivity, Ca and Mg are low compared to studies by Likens **et al** 1970) in the Hubbard Brook Watershed where increases up to 417% and 408% in the concentration of calcium and magnesium respectively. Inadequate sampling during high flows is probably the main reason for turbidity and suspended solids not being significant. These two parameters are known to increase considerably following forest clearance. Zulkifli **et al** (1987) have reported 9 fold-increase in turbidity and 12 fold-increase in suspended solids following logging activities in Bukit Berembun Forest Reserve.

K, Na and pH values did not show any changes. In contrast to this, Likens **et al** (op. cit) have reported increases up to 1558% and 177% in K and Na and a 5-fold increase in the concentration of hydrogen ions (calculated from pH measurements).

10.7 Conclusion

There are only a few watershed management researches such as the STEB study in the humid tropics. This is no doubt due to the comparatively high cost and manpower required and the time taken to successfully complete the study. In the STEB study, it took 15 years from conceiving the idea to choosing the basins and implementing the study. However the results, as seen above, is well worth the resources spent because it does clear up most of the grey areas in tropical hydrology relating to one complete cycle of basin treatment from forest to tree crop cultivation in a tropical lowland area (Table 10.1). These considerations not withstanding, it also provides indicative information for all watershed planners and policy makers when planning for land development schemes in the future.

Table 10.1 Effects of Landuse Change on Soil and Water Resources in Sungai Tekam Experimental Basin

	Pre-clearance	**Clearance**	**Crop Establishment**
Rainfall	Normal	Normal	Normal
Streamflow (i) Water Yield	Normal	Increases up to 157%	Declines but still higher than pre-clearance stage
(ii) Peak flow	Normal	Increases up to 185%	Declines but still higher than pre-clearance stage
(iii) Time-to-peak	Normal	Decrease up to 67%	Increased by 2 hours
Infiltration	Normal	Decreased by 33—88%	Increased to a level higher than pre-clearance stage
Soil Erosion	Minimal	5—7 times greater	Declined to almost the pre-clearance level
Sediment in streams	Minimal	Sediment loads were 4 times greater	Declined to almost the pre-clearance level
Nutrient balance	Normal	Increased outflow of Ca and Mg by 26% and 37%. Increased conductivity	Increased but lower than clearance stage

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