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SUNGAI TEKAM EXPERIMENTAL BASIN TRANSITION REPORT JULY 1980 TO JUNE 1983

1986

JABATAN PENGAIRAN DAN SALIRAN
KEMENTERIAN PERTANIAN MALAYSIA

Water Resources Publication No. 16

SUNGAI TEKAM EXPERIMENTAL BASIN
TRANSITION REPORT
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Bahagian Parit dan Taliair
Kementerian Pertanian, Malaysia

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Bahagian Parit dan Taliair
Kementerian Pertanian, Malaysia

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ABBREVIATIONS

A_L, B_L	:	Logging in catchments A and B, respectively
A_f, B_f	:	Felling
A_b, B_b	:	Burning
A_{rb}, B_{rb}	:	Reburning
B_p	:	Planting of cover crop in Catchment B
B_{po}	:	Planting of Oil Palm in Catchment B
n.f	:	no flow
n.d.	:	not detected

* These abbreviations are for figures 4.10 to 4.27 only.

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SUMMARY

The Sungai Tekam Experimental Basin Study was initiated in September 1973 to study the effects of landuse changes on the hydrological regime, soil fertility and water quality. The calibration, methodology and initial results were reported in the Calibration Report 1982. This second report, referred to as the Transition Report, covers specifically the second period of the study for Sub-catchment B and Catchment A where landuse changes were effected.

In Sub-catchment B, the forest was felled in July 1980 and planted with leguminous covers in April/May 1981. Planting of oil palm was carried out from August to November 1982. Catchment A was developed for cocoa after July 1983.

Data were collected for climatological, hydrological and soil parameters and analysed.

Results showed that all the catchments received slightly lower rainfall during transition (1644mm) than in the calibration period. This was due to the dry 1982/83 water year.

The water balances indicated there were increases in total runoff after forest clearance. Annual rainfall-runoff coefficients were computed to reduce the effect of the variations. The average coefficient for Sub-catchment B increased from 8.6% during calibration to 20.7% during the first 2 years of transition. There were no substantial increases for Catchment A and Catchment C (Control) which remained at 10.0% and 13.0% respectively.

Soil types, soil compaction and slopes were found to have significant impacts on erosion. Soil erosion increased with increasing slope especially on highly weathered soils after deforestation during the first 2 years of treatment.

Changes in soil chemical content, especially increases in exchangeable K and Mg, were detected after deforestation and establishment of leguminous covers.

Twenty-two water quality parameters were monitored. Generally higher concentrations for most parameters were observed after logging and clear-felling in Catchment A and Sub-catchment B compared to the control catchment. Total suspended solids and total solids increased substantially after clear-felling due to accelerated soil erosion.

PLATE 1. TYPICAL VEGETATION OF THE BASIN

PLATE 2. DEFORESTATION OF SUB-CATCHMENT B

PLATE 3. BURNING OF LOGS

PLATE 4. STACKING OF LOGS

PLATE 5. ESTABLISHMENT OF COVER CROP

PLATE 6. ESTABLISHMENT OF OIL PALM

1 INTRODUCTION

This study was initiated in September 1973 to study the effects of landuse changes on the hydrological regime, soil fertility and water quality of Sungai Tekam Experimental Basin. Actual basin calibration commenced in July 1977.

The study is divided into three periods, namely, a calibration period involving collection of baseline data, a transition period of forest felling, burning and initial crop establishment, and finally an evaluation period after crop establishment.

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
B*	July 1977 - June 1980	July 1980 - June 1983	July 1983 thereafter
C	Control Catchment		

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

Development of Sub-catchment B for oil palm started in July 1980, followed by Catchment A for cocoa in October 1982. This report presents findings in the transition period for Sub-catchment B and initial developmental activities in Catchment A.

2 PROJECT DETAILS

2.1 Objectives

Large scale agricultural development has, in recent years, been extended to undulating inland areas. Development of these areas involves the felling of forest, followed by stacking and burning of felled trees and planting of crops.

The methods used and the change in landuse have great impacts on river basins which often show changes in short and long-term runoff volumes and timing, and water quality. To monitor these changes, the Sungai Tekam Experimental Basin Study was undertaken with the following objectives:

(a) to study the effects of landuse changes on the hydrology of the basin focussing particularly on the various components affected by surface processes, namely, streamflow, sub-surface storage, magnitudes of high and low flows and water yields.

(b) to study the effects of landuse changes on soil fertility resulting from the return of organic matter to the soil, infiltration, soil erosion and soil chemical content.

(c) to study the effects on water quality from the various stages of agricultural development.

2.2 Basin Description

2.2.1 Location

The Sungai Tekam Experimental Basin is in a selectively logged forest within the Tekam Forest Reserve of the Tun Razak Agricultural Research Centre (TRARC) in Jerantut district, Pahang. It lies between latitudes 3° 53′ 45" N - 3° 55′ 00" N and longtitudes 102° 31′ 30" E - 102° 33′ 00" E, 210 km from Kuala Lumpur by road due northeast (Fig. 2.1).

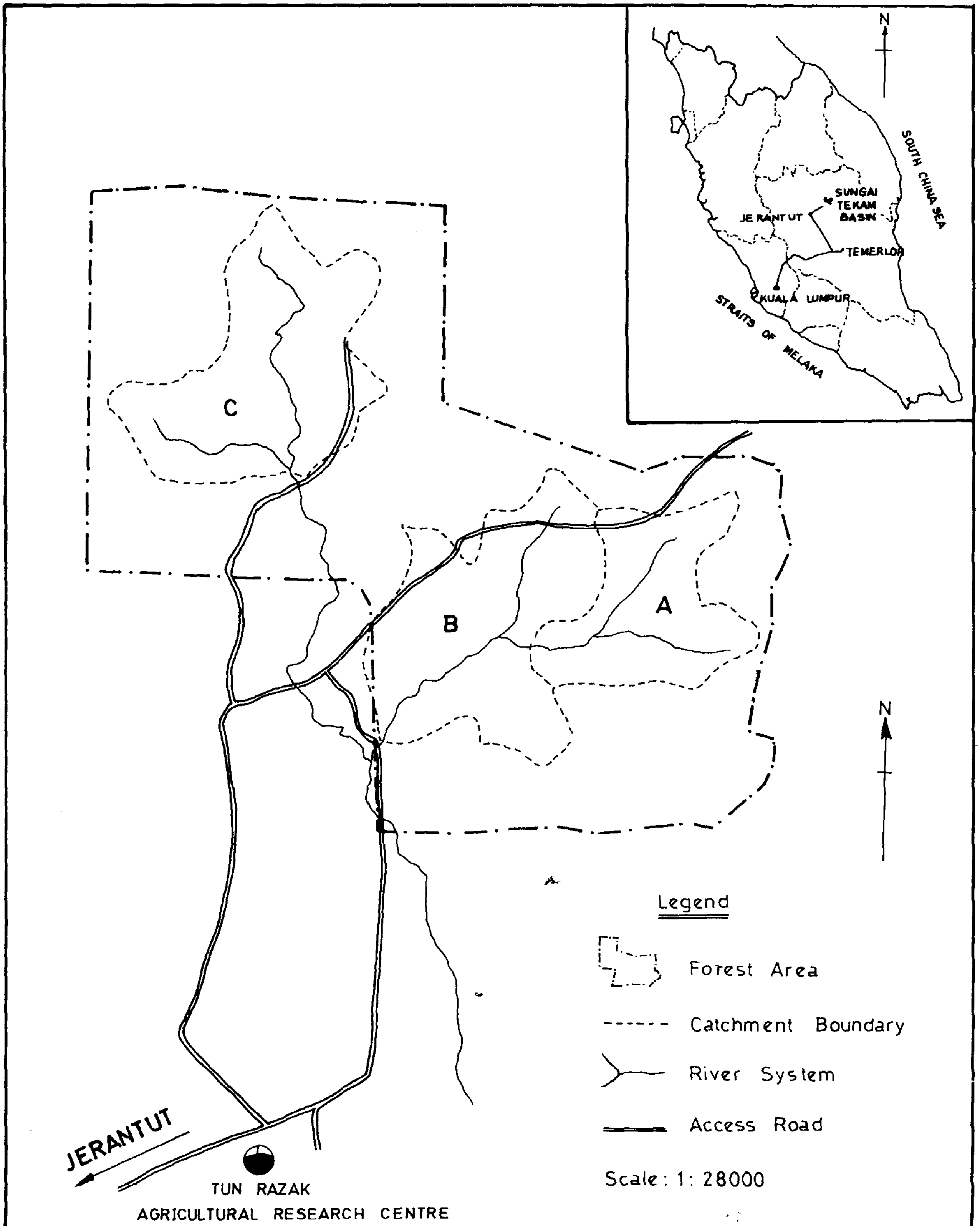


FIGURE 2·1 LOCATION MAP OF SG. TEKAM EXPERIMENTAL BASIN

2.2.2 Climate

The climate of the Basin is humid tropical. Mean monthly climatic data from TRARC are shown in Table 2.1.

Mean annual rainfall is 1916 mm. There is a distinct dry spell in January/February sometimes overspilling into March as shown by the low median values in these months. A distinct wet spell occurs from October to December and occasionally extends to January when the northeast monsoon is prolonged. Monthly rainfall is variable as evidenced by the values recorded.

Mean daily sunshine is 5.6 hours. Sunshine is generally abundant in the drier months and less during the monsoonal period in the last three months of the year.

Mean monthly maximum temperature is 32.1^{o}C with the highest in April (33.5^{o}C) and the lowest in December (30.0^{o}C). Mean monthly minimum temperature is 21.4^{o}C with a high of 22.6^{o}C in July and a low of 19.9^{o}C in January.

Mean daily pan evaporation (US Class A white pan) is 3.49 mm with the highest in March (4.39 mm) and the lowest in December (2.91 mm).

Mean daily windrun is 52 km, with extremes of 66 km in February and 41 km in June.

Mean relative humidity at 8.00 am is 98% and at 2.00 pm is 63%. Monthly variation of the former is small compared with that of the latter. Higher relative humidity generally occurs during the monsoonal months of October to December.

2.2.3 Catchment Geomorphology

The three catchments are drained by third order streams. Mainstream gradients were estimated to be 0.013, 0.009 and 0.008 m/m for Catchments A, B and C respectively, with width:depth ratios of 3 to 5 along mainstream channels.

Mainstream channels which can be classified as suspended-load channels were alluviated with fine-textured materials with occasional lenses of coarse sandy stream-bed lag deposits. Steeper channel gradients and lower width:depth ratios were observed at the headwater reaches of

Table 2.1 : Climatic Data at Tun Razak Agricultural Research Centre (TRARC)

Element	Period		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Mean
Rainfall	3/69-6/83	Mean	106.7	73.3	113.4	189.2	182.7	124.5	114.4	158.1	173.3	228.1	208.3	244.4	1916.4
(mm)		Median	16.2	59.5	114.4	176.7	196.7	123.2	116.6	133.6	164.8	218.0	210.3	216.3	-
		Highest	530.5	160.9	252.9	375.2	312.4	212.1	227.7	315.9	329.0	444.6	341.7	556.7	-
		Lowest	12.4	4.1	12.1	22.1	72.6	52.1	17.2	65.0	70.2	109.1	104.8	21.6	-
Sunshine	1/73-6/83	Mean	5.60	6.03	6.82	6.28	6.37	5.87	6.25	5.69	5.28	5.15	3.82	4.29	5.62
(hrs/day)		Median	5.33	6.26	6.97	6.25	6.22	6.01	6.63	5.39	5.22	5.36	3.90	4.14	-
		Highest	6.96	8.12	7.55	7.95	7.57	6.97	7.42	7.55	6.11	5.75	5.32	6.90	-
		Lowest	4.66	3.65	6.00	4.59	5.60	5.18	4.95	3.92	4.84	4.00	2.24	2.53	-
Max. temp	4/71-6/83	Mean	30.9	32.2	33.4	33.5	33.2	32.6	32.4	32.4	32.1	32.0	31.0	30.0	32.1
(°C)		Median	31.1	32.2	33.5	33.4	33.4	32.9	32.3	32.7	32.3	32.2	31.2	29.8	-
		Highest	31.8	34.3	35.9	36.4	34.8	33.3	33.8	32.8	33.0	33.0	32.2	31.5	-
		Lowest	30.6	30.7	31.0	30.4	31.4	31.0	30.6	29.7	31.1	30.7	29.8	26.6	-
Min. temp	4/71-6/83	Mean	19.9	20.5	20.9	21.7	22.3	21.9	22.6	21.5	21.7	21.6	21.7	21.0	21.4
(°C)		Median	20.2	20.7	20.7	22.2	22.7	22.4	21.6	21.6	21.6	21.7	22.0	21.2	-
		Highest	20.8	21.2	21.9	23.1	23.6	23.1	22.6	23.0	22.4	22.9	22.6	21.8	-
		Lowest	17.6	18.9	19.4	19.9	21.0	20.3	19.4	19.6	20.0	19.7	19.8	19.8	-
Pan Evap.	11/74-6/83	Mean	3.00	3.52	4.39	3.97	3.70	3.49	3.32	3.56	3.58	3.51	2.92	2.91	3.49
(mm/day)		Median	3.01	3.52	4.34	4.19	3.90	3.79	3.38	3.84	3.63	3.65	2.79	2.59	-
		Highest	3.77	4.44	5.26	5.40	4.37	4.00	4.18	4.13	3.88	4.29	3.48	3.20	-
		Lowest	2.54	2.44	3.55	2.90	2.97	2.80	2.77	2.65	3.15	2.69	1.84	2.19	-
Windrun	1/78-6/83	Mean	55.13	65.98	61.61	52.65	44.86	41.36	52.23	54.00	54.09	51.02	46.64	47.53	52.26
(km/day)		Median	63.54	70.58	67.41	59.98	53.85	49.83	53.03	53.20	51.72	48.25	47.61	54.30	-
		Highest	64.10	75.73	70.94	67.60	56.42	54.20	60.30	60.50	60.50	61.26	55.07	56.20	-
		Lowest	31.91	48.32	34.16	17.90	6.50	9.63	51.25	48.01	49.99	39.70	33.21	35.33	-
Rel. Hum.	4/71-6/83	Mean	98	97	98	98	98	98	99	98	98	98	98	98	98
(%)		Median	98	98	98	98	98	98	98	98	98	98	98	98	-
8.00 am		Highest	100	100	100	100	100	100	100	100	100	100	100	100	-
		Lowest	92	91	93	95	97	96	97	93	96	95	98	98	-
2.00pm		Mean	62	61	59	59	64	62	58	61	62	65	69	69	63
		Median	59	61	58	60	62	62	60	60	62	62	70	70	-
		Highest	69	67	78	64	78	66	66	71	63	78	78	76	-
		Lowest	58	50	51	47	52	59	43	57	61	55	63	61	-

streams in the catchments. These are predominantly incising first-order streams. Basin slopes are mostly gentle with 6^{o} to 8^{o} gradients (Fig. 2.2). Moderately steep slopes of 12^{o} to 15^{o} are commonly encountered along the valley sides of such streams.

2.2.4 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), in Sub-catchment B Katong Series (Tropeptic Haplorthox) and in Catchment C Munchong Series (Tropeptic Haplorthox).

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 more porous even though it is clayey in texture (Paramananthan, 1978). This soil has an oxic horizon with a weak structure. Thus when heavy machinery are used it is prone to compaction. After land clearance with heavy machinery, for example, a low infiltration rate results.

Munchong series also has an oxic 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 friable 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.

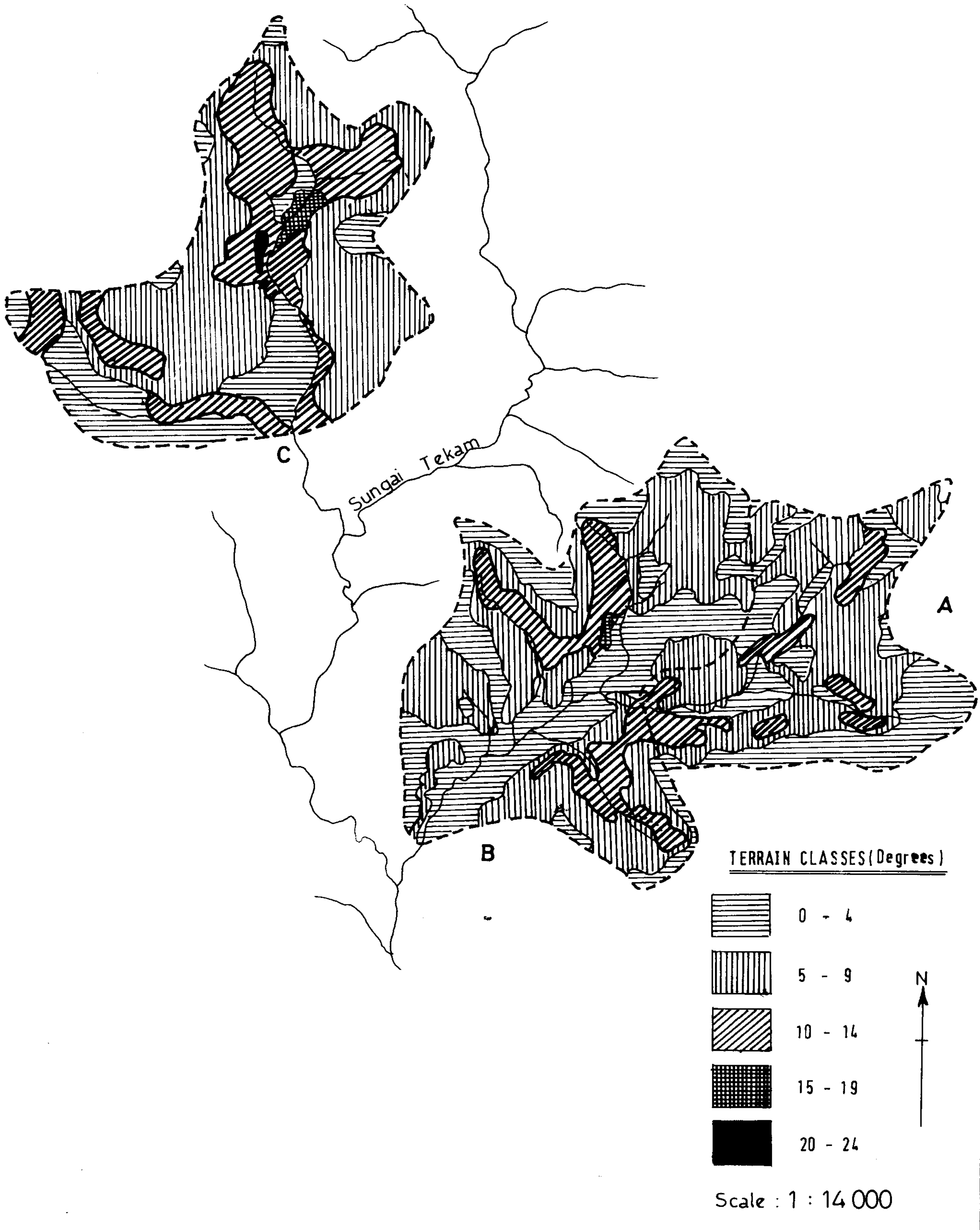


FIGURE 2.2 TERRAIN MAP

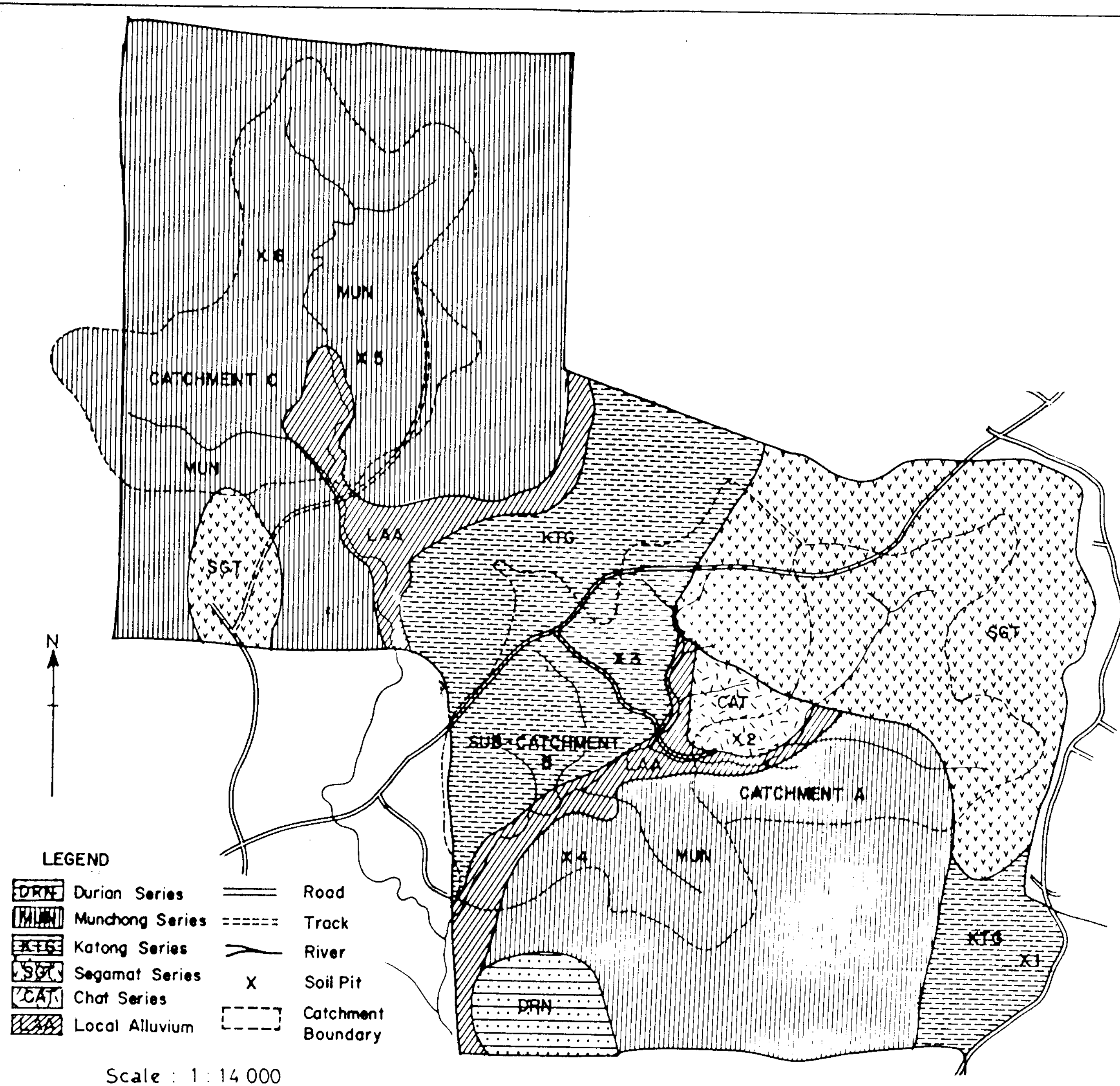


FIGURE 2.3 SOIL MAP

Table 2.2 : Distribution of Soil Types in the Sungai Tekam Experimental Basin

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

2.3 Sequence of Landuse Change

After three years of calibration, baseline data were deemed sufficient. In Sub-catchment B, transition began in 1980 when the forest was felled. The sequence of developmental activities is illustrated in Fig. 2.4. Logging began in July. By November, the forest was completely felled and burning was done in February 1981. However, the burn was poor and partially burnt logs were mechanically stacked (with D6 bulldozer) and reburnt. Planting of leguminous covers began in April and was completed by May. Legumes used were Centrosema pubescens and Pueraria javanica at a seed mixing 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.

Catchment A was developed for cocoa. The sequence of developmental activities is illustrated in Fig. 2.5. Logging was done from October to December 1982. This was followed by underbrushing in January/February 1983. Clear-felling began after the underbrushing 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 carried out in June 1983.

3.0 INSTRUMENTATION AND DATA COLLECTION

3.1 Rainfall

The basin was equipped with a network of five rainfall stations (Fig. 3.1) comprising four weekly automatic recorders with checkgauges and one storage gauge.

3.2 Evaporation

Daily evaporation data were obtained from a US Class A white painted galvanised-iron pan at TRARC. For comparative purposes, a US Class A unpainted aluminium pan was installed in the basin in September 1982.

3.3 Streamflow

During the transition, the 120^{o} V-notch weirs continued to serve to improve the sensitivity of low

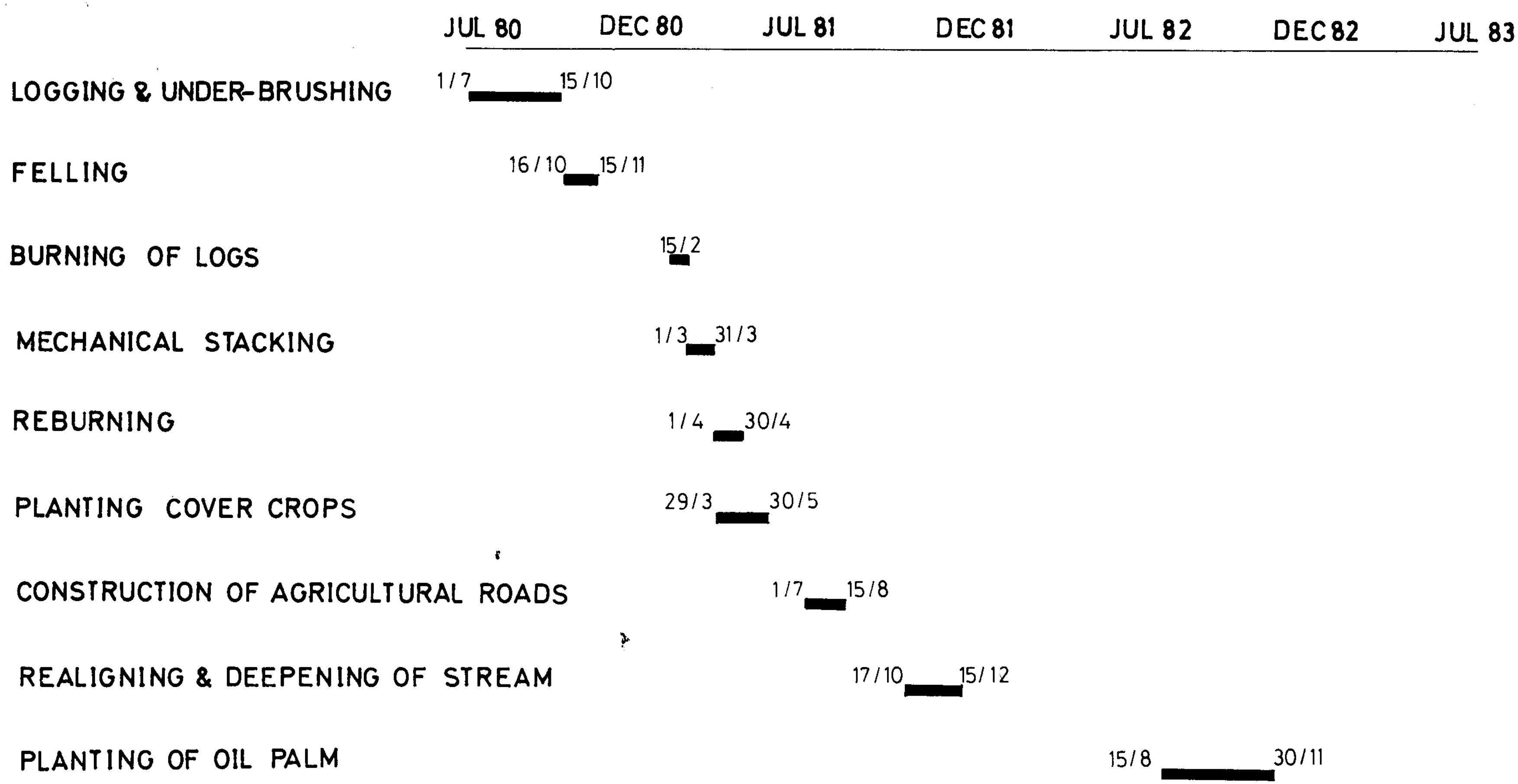


FIGURE 2.4 DEVELOPMENTAL ACTIVITIES FOR SUB-CATCHMENT B

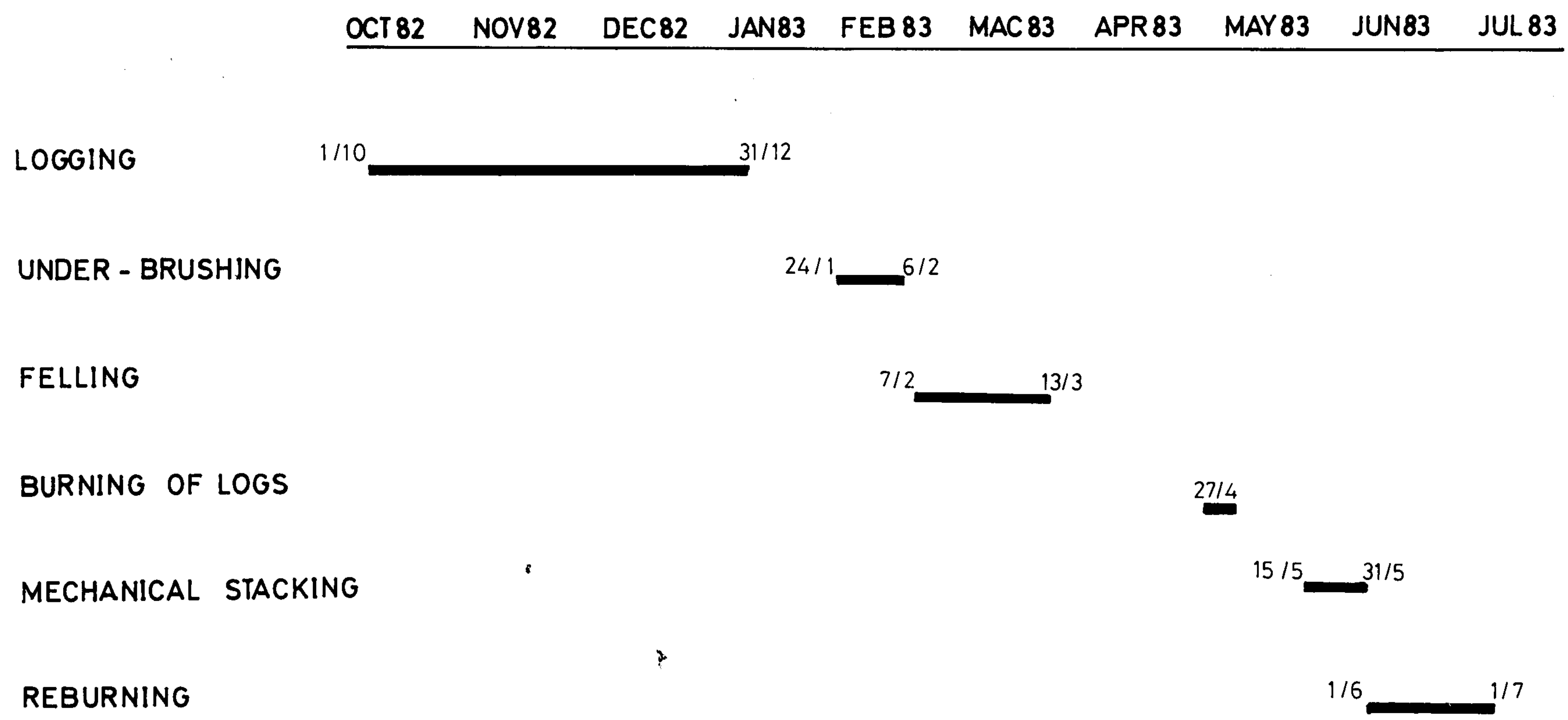


FIGURE 2.5 DEVELOPMENTAL ACTIVITIES FOR CATCHMENT A

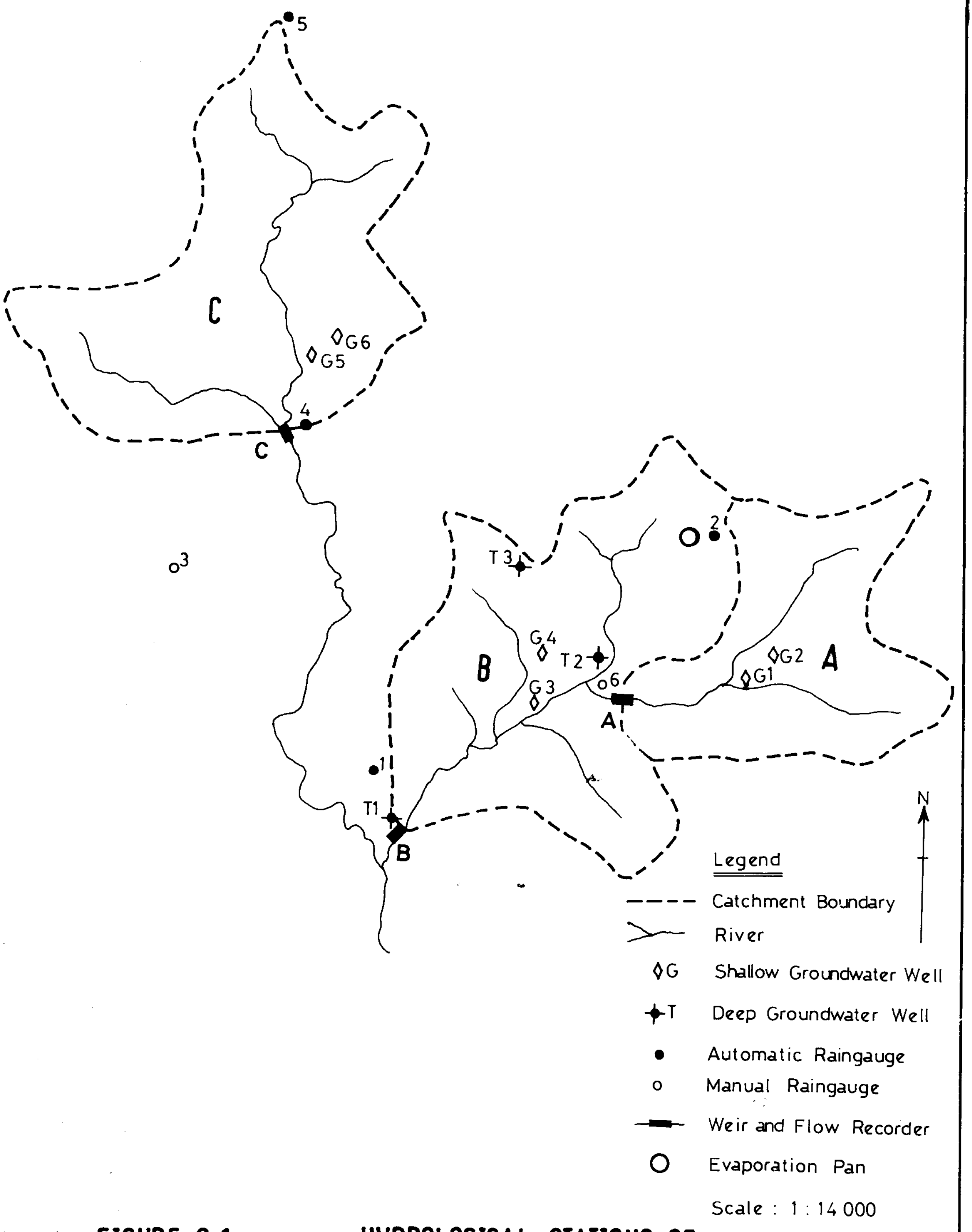


FIGURE 3·1 HYDROLOGICAL STATIONS OF SUNGAI TEKAM EXPERIMENTAL BASIN flow measurements. River stages were recorded at three flow gauging sites using float-type water level recorders. Regular streamflow gaugings were carried out by current meter or volumetric methods.

3.4 Groundwater

Pursuant to recommendations in the Calibration Report (DID, 1982) to assess groundwater characteristics of the basin, 5 shallow groundwater observation wells were established. Manual observation of the groundwater table was carried out weekly, commencing December 1980.

3.5 Water Quality

Fortnightly collection of water samples began in April 1974. All grab samples were taken from the mid upstream of each weir and sent to the Chemistry Department for analysis. Analysis included physical and chemical parameters.

3.6 Sediments

Suspended and dissolved sediments were determined from stream water collected with a USDH-48 depth-integrated sampler. To enable sampling during storms, a multiple-stage sampler consisting of 4 sampler containers strapped on to a vertical mount at 0.1 m intervals was installed in each of the catchments. This covered a range of stage levels from 0.24 to 0.54 m.

Suspended sediment was separated from dissolved sediment by filtration (Rainwater and Thatcher, 1960) using millipore filter papers of 0.45 micron pore size (Brown, et al., 1970). To further refine the assessment, suspended and dissolved sediments were obtained by removing organic materials by ashing at 600^{o} C for 2 hours in a muffled furnace (Golterman, 1969; Janda, 1971).

Sediment loads for the catchments were computed using mean daily discharge and summed for each water year. Sediment load discharge was calculated with the general equation:

$$Q_s = \int_0^T kCQ \cdot dt$$

where,

Q_s = Sediment load
T = a given time period
k = factor depending on units employed
C = sediment concentration
Q = mean daily discharge

3.7 Soil Characteristics

Seven soil pits were dug in the study area for soil profile description (Appendices 1-7). Samples of disturbed and undisturbed soils were taken for determination of chemical and physical characteristics.

Disturbed soil samples were collected from each horizon for determination of pH, Carbon (C), nitrogen (N), organic matter, easily soluble phosphorus (P), cation exchange capacity (C.E.C), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) and base saturation.

Undisturbed soil samples were taken, using 8 cm diameter brass cores, from each horizon for determination of (a) soil particle size (pipette method), (b) soil moisture characteristic (pressure-plate method), (c) particle density (Pycnometer method), and (d) bulk density (gravimetric method). Available Water Holding Capacity was obtained by deducting soil moisture percentage at 15 bar suction from that at 1/3 bar.

3.8 Soil Fertility

3.8.1 Organic Matter

Two wire-mesh nets, each of 1 m^2, were laid in each of Catchments A and C and Sub-catchment B to collect forest litter (leaves and twigs of less than 2 cm diameter). In Sub-catchment B, after planting with cover crops and oil palm, leaf litter from the covers was hand-picked from 48 premarked plots each of 1 m^2 area. No leaf litter was available from oil palm as it was just planted in August 1982. Cover crops were planted in April 1981.

From January 1978 to June 1980, forest litter was collected from 6 plots. However, they were reduced to 4 when logging began in July 1980 in Sub-catchment B. Bulked samples of each type of litter were analysed for dry matter content, ash, organic carbon, nitrogen, phosphorus, potassium, magnesium and calcium.

3.8.2 Infiltration

A double-ring infiltronmeter was used to determine the rate of infiltration in Segamat and Munchong soils forested and deforested. This was done after mechanical stacking of partially burnt logs but before cover crops were planted.

3.8.3 Soil Erosion

Soil erosion was studied on Munchong and Segamat soils on four different slopes of 4, 9, 16 and 25% (2.3^{o}, 5.1^{o}, 9.1^{o} and 14.1^{o} respectively) forested and deforested. The latter was an area of felled trees which were burnt, mechanically stacked by bulldozer, reburnt and eventually planted with leguminous covers 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 Subcatchment B.

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

3.8.4 Soil Chemical Content

Soil chemical content was studied in the Munchong series. A pit was dug in forested Catchment C and another in deforested Subcatchment B. Soil samples were taken at 0-5, 5-10, 10-15, 15-30 and 30-60 cm depths around each pit. At each depth six samples were taken and bulked for chemical analysis. Analysis included organic carbon, cation exchange capacity (C.E.C), total N, available P, exchangeable K and Mg, total P, total K and total Mg. Changes in chemical contents with the conversion of forest to oil palm were assessed.

4 RESULTS AND DISCUSSIONS

4.1 Hydrology

4.1.1 Rainfall

Mean annual rainfall for the period 1974/75 to 1982/83 was 1822 mm with a standard deviation of 200 mm. A minimum of 1551 mm was recorded in 1982/83 and a maximum of 2172 mm in 1979/80. Variability was small with a variation coefficient of only 0.11. The time series of annual rainfall showed a normal distribution.

Monthly rainfall at the 4 automatic stations showed little differences. Correlations between them from 1977/78 to 1982/83 were highly significant and are shown in Table 4.1. However, in individual storms, spatial distribution of rainfall was considerably variable even in a small area.

Table 4.1: Correlation coefficients between rainfall stations

	Station 1	Station 2	Station 4	Station 5
Station 1	-	0.97	0.98	0.94
Station 2	0.97	-	0.97	0.95
Station 4	0.98	0.97	-	0.98
Station 5	0.94	0.95	0.98	-

Depth-frequency analysis using daily rainfalls of station 2 showed frequent occurrences of light rains. The average number of rain-days (daily rainfall $\geq$ 0.5 mm) per year exceeded 160. However rainfalls of 25 mm and 50 mm occurred, on average, once in 20 and 70 days respectively. The number of rainless days increased in 1981/82 and 1982/83 to an average of 228 from 195 in 1977/78 to 1980/81.

Rain depth-frequency is shown in Table 4.2 and Fig 4.1.

Table 4.2: Rain Depth-Frequency Analysis (July 1977 - June 1983)

Rain depth (mm)	Average no. of days in a year	Cumulative no. of days ⩾ in a year	Percentage frequency of exceedance
0	206	365	100.0
0.5-5.0	80	159	43.6
5.5-10.0	25	79	21.6
10.5-15.0	17	54	14.8
15.5-20.0	11	37	10.1
20.5-25.0	8	26	7.1
25.5-30.0	5	18	4.9
30.5-35.0	3	13	3.6
35.5-40.0	3	10	2.7
40.5-45.0	1	7	1.9
45.5-50.0	1	6	1.6
⩾ 50.5	5	5	1.4

* Measured to nearest 0.5 mm.

Maximum rain depth for different durations (15 minutes to 30 days) for 1980/81 to 1982/83 for each of the automatic rainfall recorders are presented in Table 4.3. Most storm durations were 6 hours or less. Maximum intensities varied considerably from station to station.

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 1 and 2, and Catchment C by stations 4 and 5. Total monthly rainfall of the 3 catchments are shown in Table 4.13 under the section on Water Balance. Over the period, all the catchments received slightly lower rainfall during transition (1644 mm) than in the calibration period (1790 mm). This was mainly due to the relatively dry 1982/83 (1442 mm).

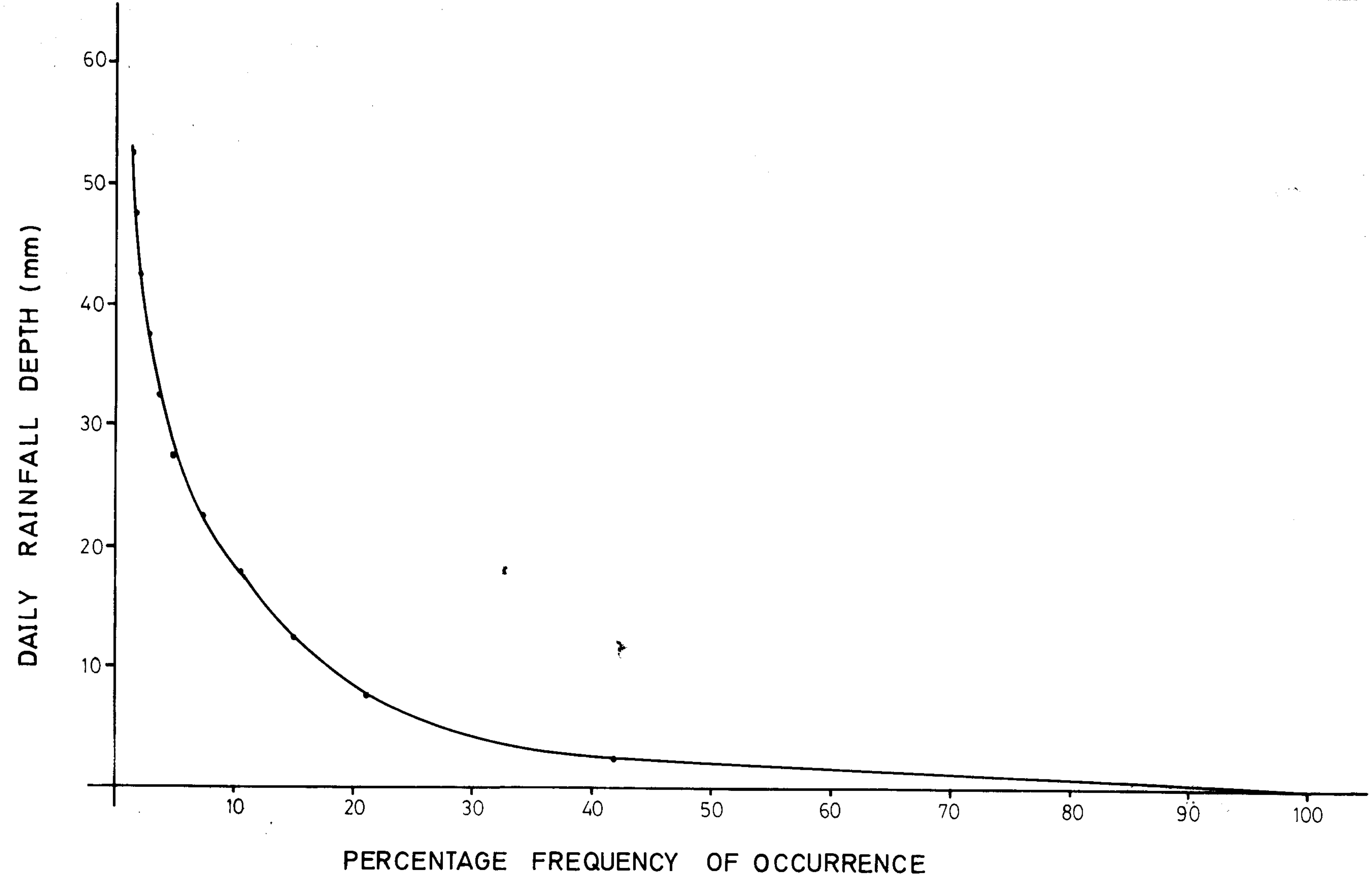


FIGURE 4·1 : PERCENTAGE FREQUENCY CURVE OF 1-DAY RAINFALL DEPTH FOR STATION 2 (JULY 1977-JUNE 1983)

Table 4.3 : Maximum Rain Depths (mm) for Different Durations

STATION	Station 1			Station 2			Station 4			Station 5		
Duration / year	80/81	81/82	82/83	80/81	81/82	82/83	80/81	81/82	82/83	80/81	81/82	82/83
15 min	26*	38	37	32	40	25	22	33	19	44	32	25
30 min	41	38	44	56	52	46	28	34	38	51	37	48
1 hour	56	40	59	90	58	57	47	37	56	55	58	56
2 hour	98	51	75	116	66	80	76	54	77	72	61	68
3 hour	103	67	84	122	69	102	79	58	99	95	62	80
6 hour	103	98	111	122	102	109	83	80	125	101	76	111
12 hour	103	103	112	122	107	110	86	85	126	101	76	112
24 hour	132	103	112	149	107	110	87	85	126	101	76	112
48 hour	133	103	133	151	107	164	87	85	150	101	76	154
72 hour	135	111	133	155	115	165	87	98	151	112	76	167
5 days	166	111	133	183	135	166	101	128	151	119	86	167
7 days	190	139	133	183	170	166	112	159	151	142	108	168
14 days	199	228	168	184	264	187	149	207	171	205	168	177
30 days	294	350	249	314	402	285	221	327	256	378	278	284

* Example - rainfall intensity of 26 mm for 15 min duration is 104 mm/hr.

4.1.2 Evapotranspiration

Forest evapotranspiration (ET) was estimated by several methods, one of which was the pan method using coefficients from 0.8 to 1.01 depending on the type of pan used. In the Calibration Report, a coefficient of 0.8 was used (Scarf, 1976). However, the evaporation pan in the basin was a US GI white pan and a value of 1.01 was adopted after a pan comparison study (DID Report, 1984). Based on this, average annual forest ET was estimated to be 1251 mm instead of 990 mm for the calibration period. However, this was still inadequate to fully explain the discrepancy in the water balance.

Groundwater investigation in December 1982 concluded that basin leakage was insignificant (DID Report,1982). Assuming no net changes in soil moisture and groundwater storage over the 3 years of calibration, forest ET could have been underestimated.

To improve the estimate of ET, potential forest evapotranspiration (PE) was derived from Penman's equation (Penman, 1948) using monthly climatic data for 6 water years from TRARC. An albedo of 0.18 for tropical forest (Scarf, 1976) was adopted. Values of ET (Penman) were then regressed against ET (Pan). The results showed that both were closely related with r = 0.84. The regression equation based on 72 monthly ET values, is

$$Y = 1.10X - 33$$

where X = ET (Penman) in mm
Y = ET (pan) in mm

The study also revealed that mean monthly Penman ET (128 mm) was consistently higher than Pan ET (108 mm). The difference was significant at 95% confidence level (t = 13.0).

In this Report, Penman ET was used in water balance computations and monthly values are presented in Table 4.13. The discrepancies (P - Q - ET) for the 6-year period for Catchment A, Sub-catchment B and Catchment C were +30 mm, +12 mm and -38 mm respectively. During the two consecutive dry years 1981/82 and 1982/83, the discrepancies were negative. For forested Catchment C, annual dicrepancies were -146 mm and -231 mm respectively. There are two possible explanations for this: in these two dry years net changes in soil moisture and groundwater storage were not taken into account and, secondly, ET could have been overestimated by Penman since limiting moisture supply was not considered.

To assess actual forest evapotranspiration (AE) of Catchment C, the Thornthwaite and Mather Water Balance Model (1955) with implicit daily soil moisture accounting was used. The results (Table 4.4) show that annual discrepancies were markedly reduced, especially for the drought years. The average annual discrepancy over the 6-year period decreased from -38 mm to +15 mm while that for 1982/83 was reduced from -231 mm to -38 mm. The Thornwaite and Mather method of estimating forest evaporation appears more reliable especially for drought years.

Table 4.4 Comparison of Penman & Thornwaite Methods in the Estimation of Forest ET for Catchment C (mm)

Period in water-year	Rainfall (P)	Runoff (Q)	Penman ET (PE)[1]	Thornthwaite ET (AE)[1]	Discrepancy Term (P-Q-PE)	Discrepancy Term (P-Q-AE)
1977/78	1835	191	1567	1545	+ 77	+99
1978/79	1663	226	1527	1476	- 91	-40
1979/80	1980	366	1482	1512	+132	+102
1980/81	1820	274	1514	1547	+ 33	0
1981/82	1597	186	1557	1442	-146	-31
1982/83	1464	128	1567	1374	-231	-38
Mean	1727	229	1536	1483	- 38	+15

1. Penman ET : Albedo = 0.18
2. Thornthwaite AE : Available Water Holding Capacity of soil (AWHC) = 300 mm.

4.1.3 Streamflow

4.1.3.1 Flow Distribution

Variations in flows were common in the catchments. The streams dry up frequently during long dry spells (Table 4.5). Flow duration analyses on daily discharge data were done for all catchments and the curves derived are shown in Fig 4.2. The figures illustrate that flow duration of Catchment A had not significantly changed between the 2 periods. Catchment B, on the other hand, showed higher flows during the transition after deforestation. For example, the 50 percentile discharge increased from 1.7 $l/s/km^2$ to 4.5 $l/s/km^2$. Control Catchment C showed less runoff during transition despite being forested. Possible causes of this are discussed in forthcoming chapters.

Table 4.5 : Percentage Time Streams Having Zero Flow

Period	Catchment A	Catchment B	Catchment C
July 1977 - June 1980	26	19	25
July 1980 - June 1983	18	7	37

4.1.3.2 Components of Runoff

Total runoff of the catchments were separated into baseflow (Qu) and direct runoff (Qs). Runoff of Sub-catchment B were derived from flow-subtraction method. Computed results are shown in Table 4.6.

Over the six years, baseflow accounted for 75% of total runoff. The relatively low direct runoff of 25% could be largely attributed to the high infiltration capacities of the predominant soils of the catchments.

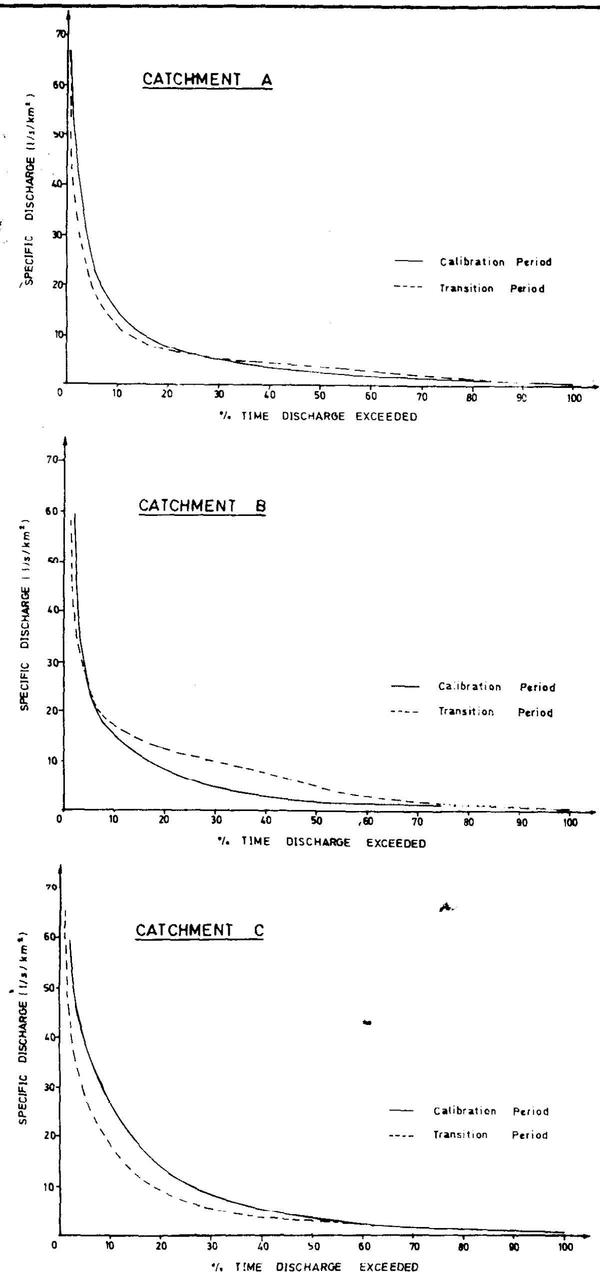


FIGURE 4.2 FLOW DURATION CURVES, CATCHMENTS A, B AND C

Table 4.6 : Annual Baseflow and Direct Runoff

Water Year	Components of runoff (mm) Catchment A		Catchment B		Sub-catchment B		Catchment C	
	Qu	Qs	Qu	Qs	Qu	Qs	Qu	Qs
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
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
Total	764	264	901	303	989	327	1068	303

The proportion of baseflow to direct runoff depends essentially on factors such as rainfall characteristics and catchment conditions. Forest clearing generally leads to lower interception, lower infiltration and increased overland flow. Table 4.7 shows that the absolute quantity of direct runoff of Sub-catchment B had not significantly increased after deforestation (from 57 mm/yr to 55 mm/yr) whereas baseflow increased by 130% (from 99 mm/yr to 231 mm/yr). This was apparently a direct consequence of prevailing forest clearing practice where felled logs and debris were abandoned in stream channels for long periods. Such logs physically acted as barricades of mini dams which effectively attenuated storm peak flows and interfered with direct runoff. The latter effect might have diverted substantial volumes of otherwise direct runoff to baseflow in streamflow hydrographs. Further, increases in baseflow could also be caused by a general rise in groundwater table resulting from lower evapotranspiration after forest clearing.

Table 4.7 also shows that baseflows of Catchments A and C showed little difference between calibration and transition. Direct runoff of Catchment A showed a slight reduction in transition (from 50 to 38 mm/yr). However in Catchment C, direct runoff decreased by 60% during transition (from 70 mm/yr to 30 mm/yr). Further investigation is required to ascertain the causes.

Table 4.7 : Comparison of Average Annual Baseflow and Direct Runoff

Components of Runoff	Catchment A		Catchment B		Sub-catchment B		Catchment C	
	C.P	T.P	C.P	T.P	C.P	T.P	C.P	T.P
Baseflow Qu (mm)	125	130	109	191	99	231	190	165
Direct runoff Qs (mm)	50	38	52	48	57	55	70	30
Total runoff QT (mm)	175	168	161	239	156	286	260	195
Qs/QT	0.29	0.23	0.32	0.20	0.37	0.19	0.27	0.15

C.P - Calibration Period

T.P - Transition Period

4.1.3.3 Rainfall - Runoff Relationship

Data collected during the 2 comparative periods showed that total runoff greatly increased after clear felling of Sub-catchment B. Average annual runoff of 148 mm during the calibration period increased to 402 mm and 325 mm in the first two years after forest clearing. It subsequently decreased to 132 mm in the third year (1982/83) possibly because of the full establishment of cover crops and vegetation and low rainfall. In Catchment A, annual runoff, averaged at 175 mm and 167 mm for the calibration and transition periods respectively, did not show any significant change. However, Catchment C experienced a slight reduction from 260 to 195 mm/yr.

Annual rainfall-runoff coefficients were computed and analysed (Table 4.8) to reduce the effect of variation of annual rainfall on runoff. Table 4.8 showed that for Sub-catchment B, the average coefficient increased from 8.6% during calibration to 20.7% during the first 2 years of transition. However, runoff coefficients for Catchment A in the same period did not increase and remained at 10%. Coefficients for Control Catchment C were 14.3% and 12.0%.

The 150% increase in runoff coefficient for Sub-catchment B after deforestation could possibily be due to the significant decrease in evapotranspiration and interception loss. In 1982/83, runoff coefficient of Sub-catchment B returned to a near pre-logging value of 9.0%, which was believed to be due to the full establishment of cover crops and secondary vegetation. The main crop, oil palm, which was planted towards the end of 1982, was not expected to cause any significant change to runoff in its initial growing period.

Control Catchment C showed a 17% decrease in runoff coefficients during transition. The decrease was probably due to the consecutively dry water-years 1981/82 and 1982/83 which caused considerable non-linearity of rainfall-runoff relationships. A possible oasis effect leading to higher evapotranspiration or a change in groundwater regime could not be fully ascertained, but could partially explain the decrease in runoff coefficient.

Coefficients of storm runoff to rainfall were computed from 16 selected storm runoff hydrographs for each catchment (Table 4.9). All the catchments had low coefficients ranging from a minimum of 1.1% to a maximum of 12.6%. The average was 5.7% indicating that a considerable amount of storm rainfall was used in replenishing catchment moisture storage besides a

Table 4.8 Annual Rainfall-Runoff Coefficients

Water-Year	Catchment A: Rainfall P (mm)	Catchment A: Runoff Q (mm)	Catchment A: Q/p (%)	Catchment A: Average Q/P (%)	Catchment B: Rainfall P (mm)	Catchment B: Runoff Q (mm)	Catchment B: Q/P (%)	Catchment B: Average Q/P (%)	Sub Catchment B: Rainfall P (mm)	Sub Catchment B: Runoff Q (mm)	Sub Catchment B: Q/P (%)	Sub Catchment B: Average Q/P (%)	Catchment C: Rainfall P (mm)	Catchment C: Runoff Q (mm)	Catchment C: Q/P (%)	Catchment C: Average Q/P (%)
1977/78	1839	105	5.7		1775	114	6.4		1775	119	6.7		1835	191	10.4	
1978/79	1547	143	9.2	9.7	1584	124	7.8	9.0	1584	111	7.0	8.6	1663	226	13.6	14.3
1979/80	1958	276	14.1		1940	246	12.7		1940	226	11.6		1980	366	18.5	
1980/81	1831	184	10.0	9.9	1816	317	17.5	16.6	1816	402	22.1	20.7	1820	274	15.1	13.4
1981/82	1742	170	9.8		1692	265	15.7		1692	325	19.2		1597	186	11.6	
1982/83	1488	150	10.1	10.1	1429	138	9.7	9.7	1429	132	9.2	9.2	1464	128	8.7	8.7

certain amount intercepted. Student's t-test at x = 5% showed no significant change in mean storm-runoff coefficients between calibration and transition. Calculated t-statistics were 1.93, 0.16 and 0.94 for Catchments A, B and C respectively.

Table 4.9 : Storm-Runoff Coefficients (%)

Calibration Period/Catchment				Transition Period/Catchment			
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
17.7.78	4.2	2.9	3.2	6.1.81	4.5	9.6	6.5
23.11.78	5.8	7.2	6.1	29.5.81	4.5	2.1	3.3
6.12.78	6.2	5.6	7.1	20.10.81	10.9	5.9	6.5
31.12.78	4.0	3.0	3.3	6.5.82	7.7	5.7	5.4
18.7.79	3.5	4.7	4.3	21.5.82	7.6	4.3	8.5
9.4.80	5.8	7.2	4.4	3.7.82	4.4	4.0	7.7
26.4.80	6.4	8.7	5.7	20.6.83	5.2	1.9	1.1
X Mean	4.94	5.63	5.25		6.64	5.44	6.45
S Standard Deviation	1.22	2.06	1.73		2.37	3.06	3.45

4.1.3.4 Unit Hydrograph

One-hour unit hydrographs for Catchments A, B and C were derived from simple storm hydrographs. Different sets of unit hydrographs were derived for significant events corresponding to different land developmental activities for Catchments A and B. Unit hydrographs plotted are shown in Fig. 4.3, while essential parameters are presented in Table 4.10 for comparison.

The unit hydrographs showed that after deforestation peak specific discharge (Qp) increased whereas time-to-peak (Tp) and basetime (Tb) decreased significantly. The magnitude of change varied with the various developmental activities.

When 60% of Catchment B was cleared, Qp increased from 48 $l/s/km^2$ under forest to 66 $l/s/km^2$. Qp would have been higher if the unit hydrographs of Sub-catchment B could have been considered and if fallen logs were not obstructing the otherwise natural streamflow. In the period after channel clearing but before full establishment of cover crops, Qp further increased to 79 $l/s/km^2$ which was 65% more than that in the calibration period. Subsequent to full establishment of cover crops, Qp was reduced to 62 $l/s/km^2$ which was still 30% higher than that of the calibration. Qp of Catchment A under forest for the calibration and transition periods were 50 and 49 $l/s/km^2$ respectively. Qp of Catchment C showed a slight change from 50 to 57 $l/s/km^2$ during these two periods.

Tp of Catchment B did not change significantly immediately after deforestation due to the presence of logs in the channel which delayed flood runoff. After channel clearance, Tp decreased from 3 hours to only 1 hour. Tp of Catchment A showed a slight reduction from 3.0 to 2.5 hours between the 2 comparative periods. Similarly, Tp of Catchment C decreased slightly from 3.0 to 2.8 hours (Table 4.10).

Tb for Catchment B decreased from 14 to 10 hours after deforestation but with the establishment of cover crops, increased to 12 hours. Tb for Catchments A and C under forest showed no significant change (Figure 4.3).

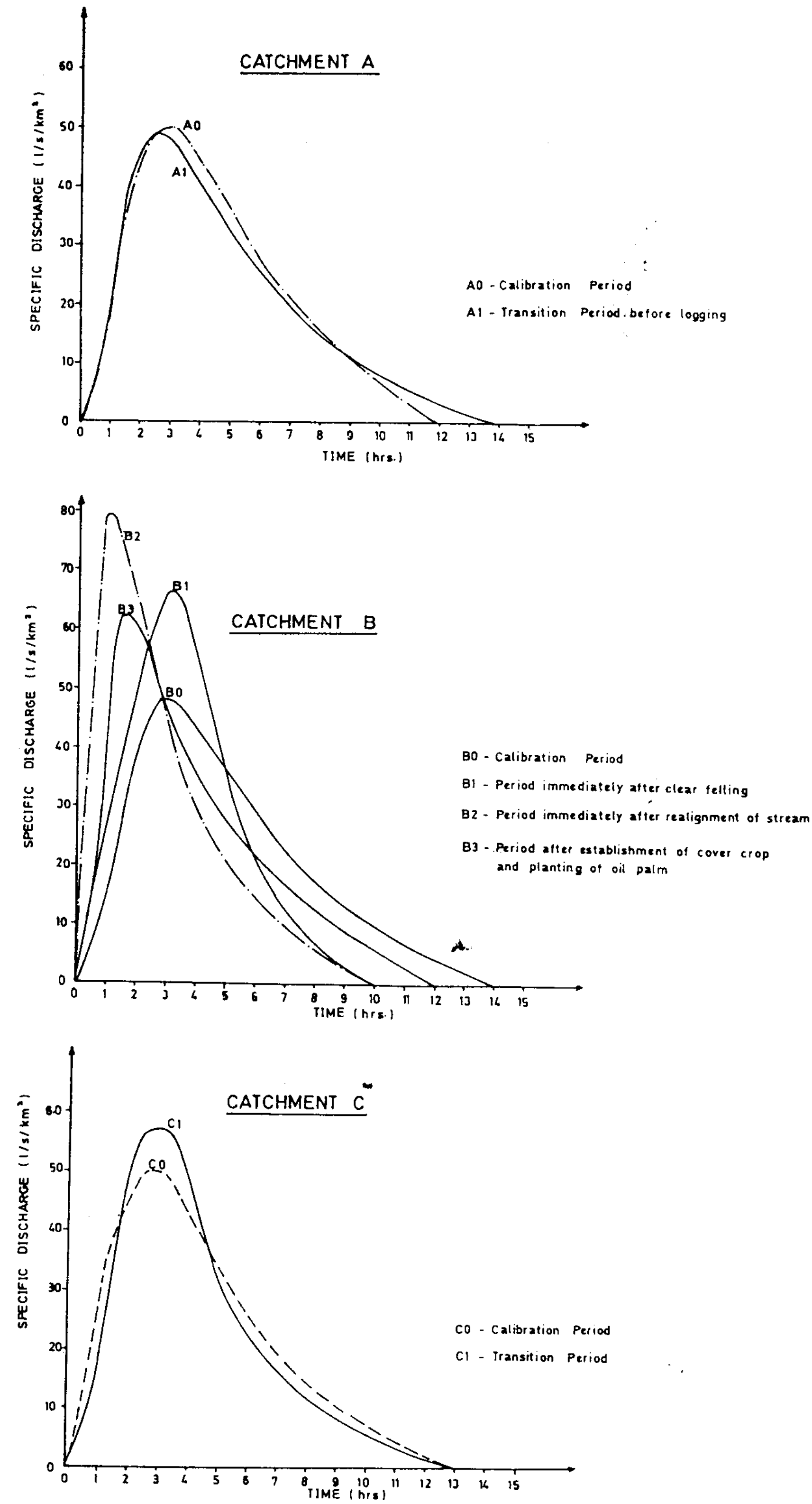


FIGURE 4.3 ONE HOUR UNIT HYDROGRAPHS OF CATCHMENTS A,B AND C

Table 4.10 : Parameters of Unit Hydrographs

Catchment	Period (mth/yr)	Catchment Condition/ activities	Specific peak discharge ($l/s/km^2$)	Time to Peak (hours)	Basetime (hours)
A	7/77-6/80	forested	50	3.0	12
	7/80-10/82	forested	49	2.5	14
	11/82-6/83	logged and deforested	*	*	*
B	7/77-6/80	forested	48	3.0	14
	7/80-9/81	logged and deforested	66	3.0	10
	10/81-12/82	channel clearing	79	1.0	10
	1/83-6/83	cover crop established	62	1.5	12
C	7/77-6/80	forested	50	3.0	13
	7/80-6/83	forested	57	2.8	13

* insufficient storm hydrographs for analysis

4.1.3.5 Streamflow Recession

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

$$q_t = q_o \cdot k^t$$

where q_o is the flow at any time,

q_t is the flow at t time units later,

and k is the recession constant

K's for 24-hour periods of the catchments were derived by plotting successive values of q_{t+1} versus q_t and fitting a straight line. Student's t-test to compare mean K's showed no significant difference (P = 95%) between calibration and transition for all three catchments (Table 4.11). Linear plots of recession curves using K = 0.80 for Catchments A and B and K = 0.90 for Catchment C are shown in Fig. 4.4.

Mean-comparison test for K of Catchment B indicated that groundwater storage characteristics was not significantly affected by deforestation and subsequent development.

K of Catchments A and B, however, are almost identical as both are nested catchments and are similar in hydrogeological characteristics. However, Catchment C had a higher K of 0.90 suggesting a larger groundwater storage capacity.

Table 4.11 : Comparison of Recession Constants (K)

Catchment	Period	No. of recession hydrographs selected (N)	Mean daily recession constants (K)	Std deviation (s)	Computed student t-statistics	Critical student t-statistics (α= 5%)
A	Calibration	10	0.824	0.112	0.23	2.09
	Transition	11	0.813	0.099		
B	Calibration	8	0.795	0.127	0.45	1.96
	Transition	10	0.802	0.199		
C	Calibration	12	0,870	0.103	1.23	2.09
	Transition	9	0.923	0.077		

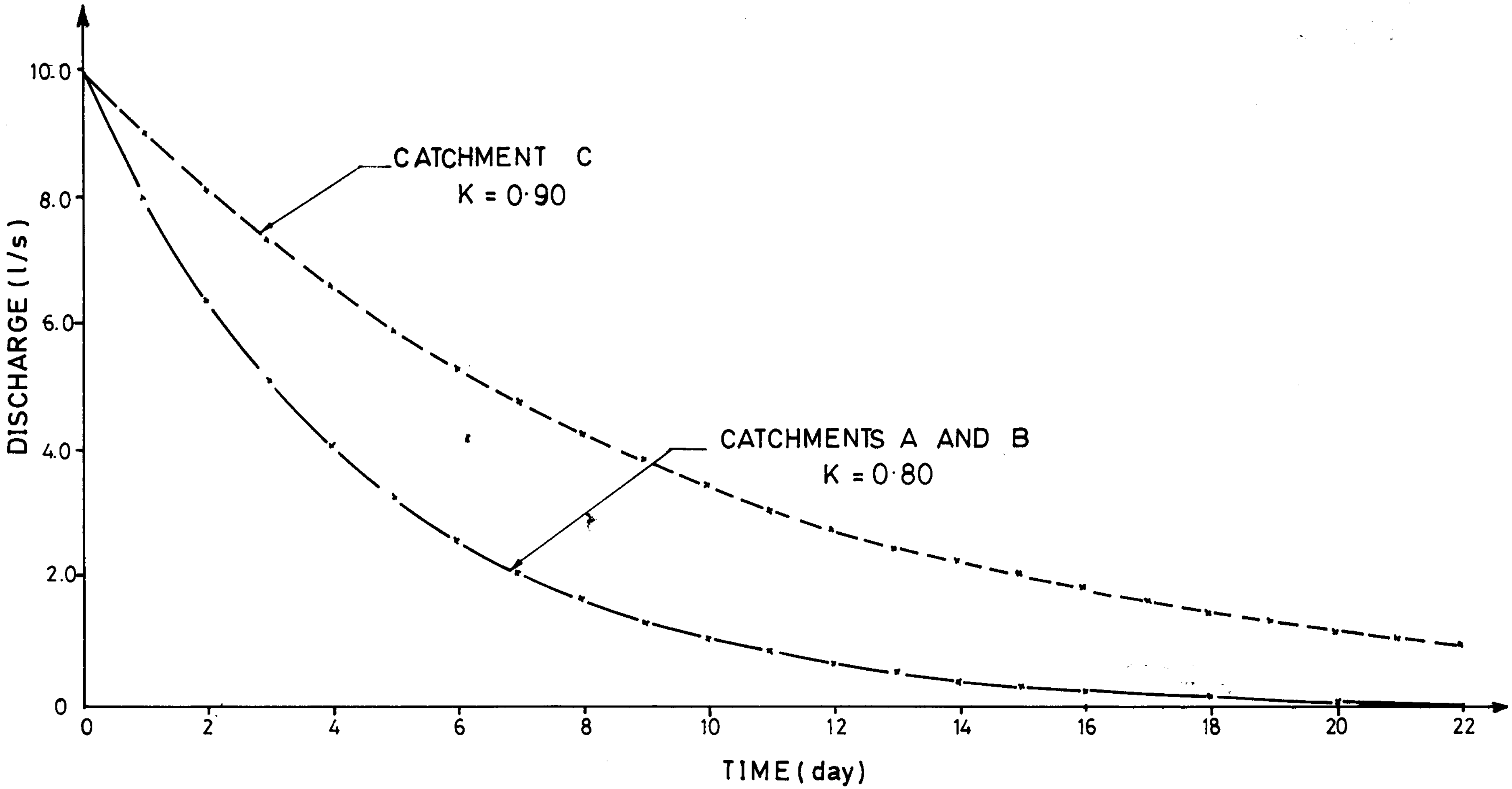


FIGURE 4.4 RECESSION CURVES FOR CATCHMENTS A,B & C
(JULY 1977 – JUNE 1983)

4.1.4 Soil moisture

There are three main soils in Sungai Tekam Basin - Segamat, Katong and Munchong series. They are deeply weathered to depths of several metres. Except for Munchong series which occurs predominantly in Catchment C, the soils generally have low available water holding capacities (Table 4.19). The low storm-runoff coefficient of 5.7% suggests a high infiltration rate. Since interception losses and forest floor storage could account for another 21% (Manokaran, 1977), the portion of storm rainfall which ultimately infiltrates the ground may approximate to 75%. This means that the soil strata have considerable influence on streamflow characteristics.

Assessment of available soil moisture data indicates that changes in soil moisture storage can be considerable and can appreciably affect monthly water balance. Moisture content of the top metre of soil can vary between 37% and 52% on a dry weight basis. With a bulk density of 1.05, the maximum equivalent water depth corresponding to a 15% moisture change for a 1 metre soil stratum can be calculated from the following equation (WMO/IHD, 1971):

$$\Delta WS = 0.1 \cdot h \cdot S_b \cdot \Delta Ww$$

where ΔWS = change in soil moisture storage in mm.
h = soil thickness in cm
S_b = soil bulk density in g/cm^3,
and ΔWw = change in soil moisture in percentage dry weight basis

$$\Delta WS = 0.1 \times 100 \times 1.05 \times 15$$
$$= 157.5\text{mm.}$$

Taking the water year as the balance period, net annual change in soil moisture storage would be insignificant, and hence was not included in the water balance computation.

4.1.5 Groundwater

The three main types of bedrock in the basin are andesite, shale and quartz andesite from which Segamat, Munchong and Katong soil series are derived respectively. The bedrock ranges from 7 to 39 meters deep and no potential water bearing formation was detected on sounding curves (DID Report, 1982). Three bore holes were drilled down to 50 meters in Sub-catchment B (Figs. 4.5, 4.6, 4.7 for borelog diagrams) and extremely low yields from the rock aquifers were

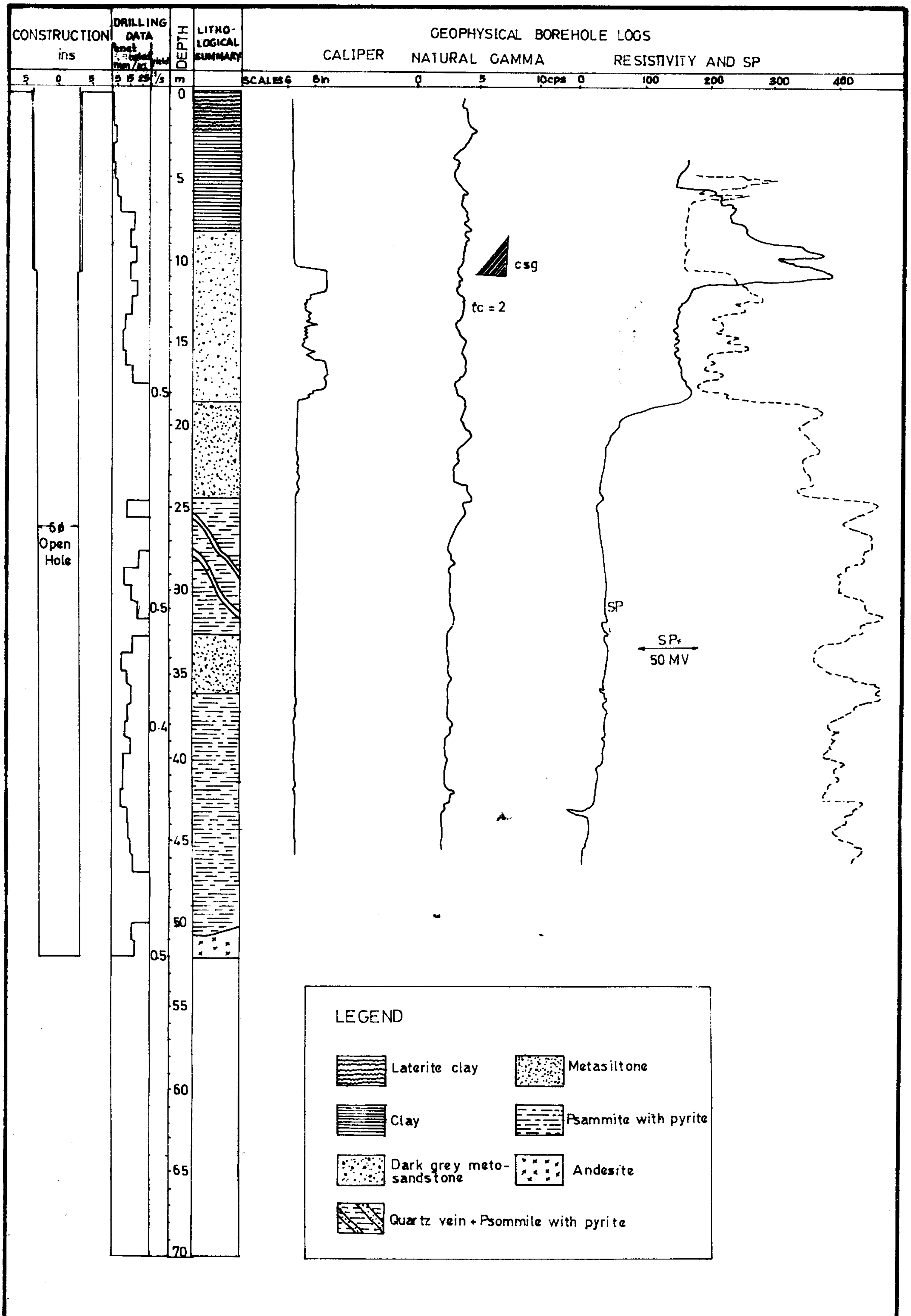


FIGURE 4.5 BORELOG 1 FOR SUB-CATCHMENT B

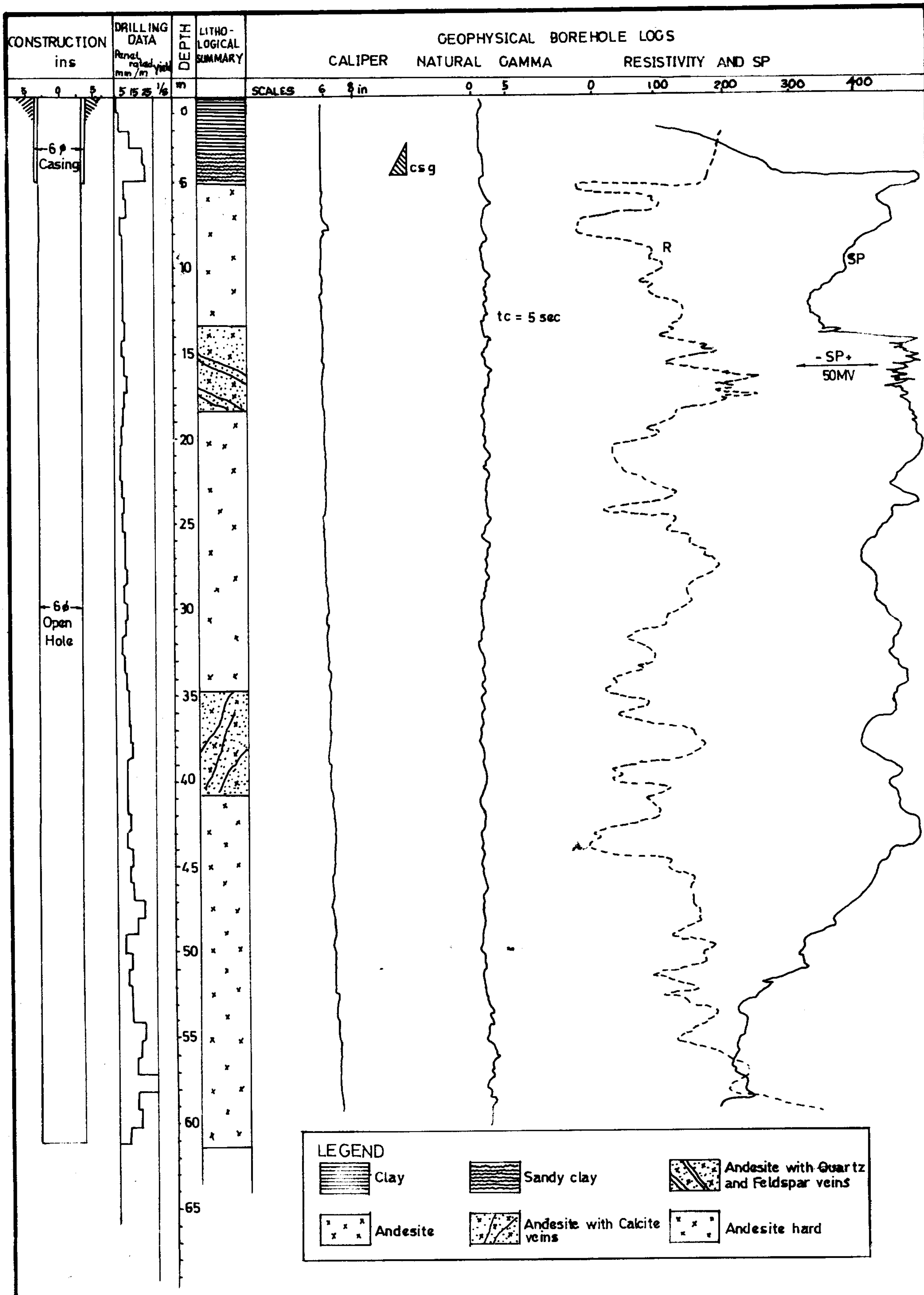


FIGURE 4.6 BORELOG 2 FOR SUB CATCHMENT B

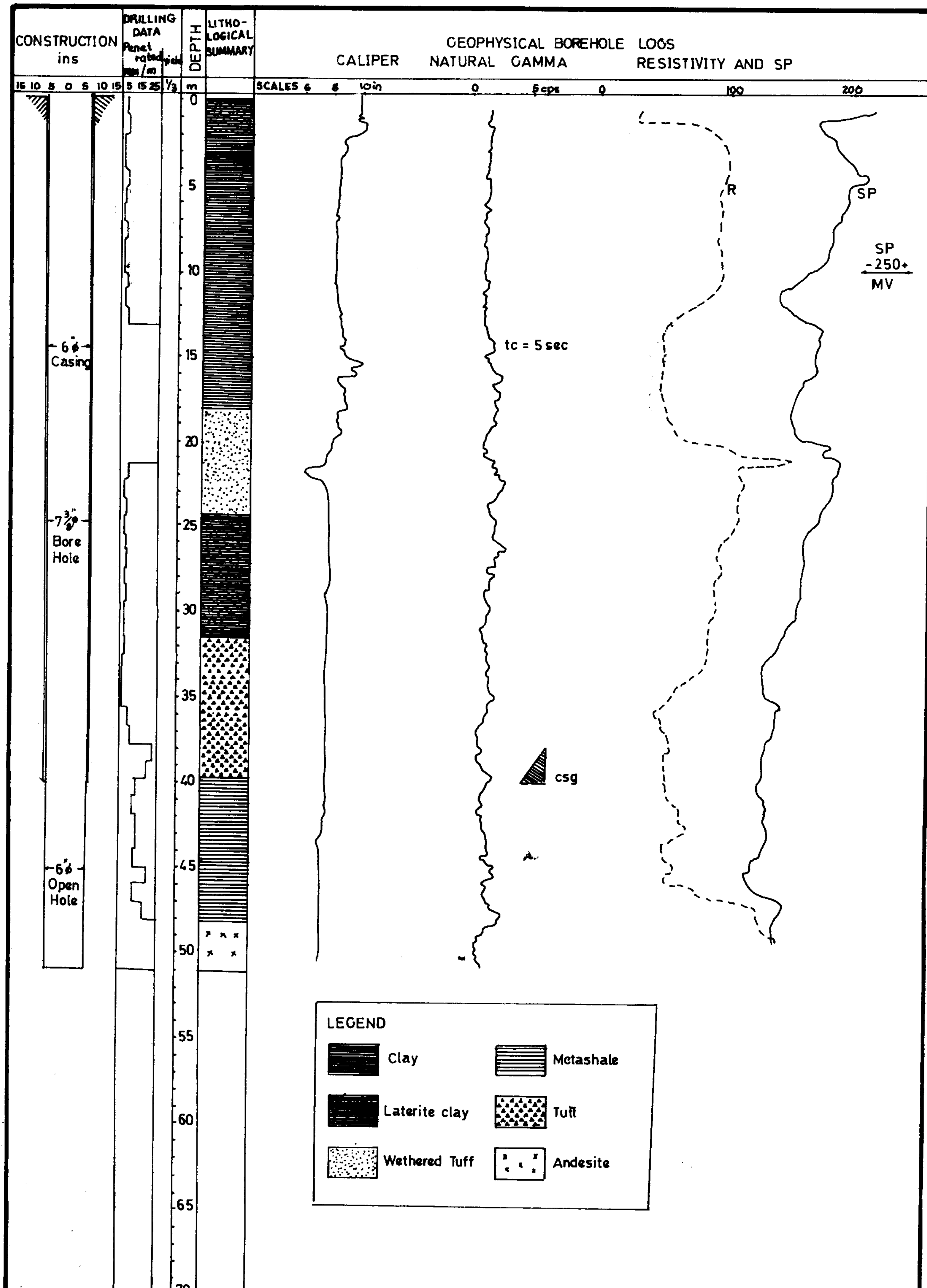


FIGURE 4.7 BORELOG 3 FOR SUB-CATCHMENT B

detected. Based on Darcy's equation and static levels of the boreholes, deep seepage of Catchment B was estimated to be 0.16 l/s, which was equivalent to a runoff depth of 5 mm annually. The investigation therefore concluded that deep seepage of the basin was insignificant.

Conversely, phreatic groundwater was thought to have greater significance on the catchments' baseflow and water balance. Phreatic groundwater is recharged by rainfall percolating from an unsaturated zone. As the groundwater table is near the surface, evaporation and transpiration are the main mechanisms in depleting groundwater. A considerable portion is also lost through effluent streams.

Weekly observations at the 5 wells were used to estimate the maximum possible change in phreatic groundwater. Depths to the groundwater table ranged from 1 to 5 m while the observed maximum fluctuation was 2.5 m. The maximum weekly rise and fall of water table were 1.6 and 1.0 m, respectively. With the following equation:

$$\Delta G = v \,.\, \Delta h \qquad \text{--- (UNESCO, 1974)}$$

where ΔG = change in groundwater storage in mm,
v = coefficient of specific yield for rising level or saturation deficit for falling level,
and Δh = change in water table level in mm,

Using maximum Δh as 2.5 m and v as 0.1 (UNESCO, 1974), the maximum change in groundwater storage can amount to 250 mm. This shows that ΔG cannot be ignored in water balance computation for short terms. However, taking the water year as the balance period, net annual change in groundwater storage is expected to be small and hence not included in the water balance computation.

4.1.6 Water Balance

The water balance equation first considered was:

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

where
P = catchment rainfall
ET = estimates of evapotranspiration
Q = surface runoff
L = deep seepage
ΔWS = change in soil moisture storage
ΔG = change in groundwater storage

However, as deep seepage was negligible, L was removed. Maximum WS and G, computed from available data and which might amount to 157.5 and 250 mm respectively, were not considered as explained previously. 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 4.12).

Table 4.12 : Albedo Values and Period of Use

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

Summaries of monthly and annual water balance are presented in Tables 4.13 and 4.14. The tables show that during calibration average annual discrepancies were +81, +89 and +39 mm for Catchment A, Sub-catchment B and Catchment C, respectively. These discrepancies could be due to unaccounted net changes in sub-surface storage. However, they are less than 5% of annual catchment rainfall and are well within the acceptable range of instrumental measurement errors.

For the transition, average annual discrepancies were -15, -66 and -115 mm for Catchment A, Sub-catchment B and Catchment C respectively. The negative residuals were possibly due to 2 factors, namely, net change in sub-surface storage and, secondly, over-estimation of basin evapotranspiration as 1981/82 and 1982/83 were dry years.

Table 4.13 : Monthly Water Balance July 1977 - June 1978

Catchment	Parameter	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mac	Apr	May	Jun	Total
A	P	24.5	184.5	122.5	302.5	228.5	115.0	165.5	103.5	166.5	189.0	118.0	120.5	1839.0
	Q	0	0	0	13.7	22.2	13.6	17.8	7.8	8.4	10.4	6.9	4.2	105.0
	ET	142.0	131.0	133.0	134.0	110.0	116.0	114.0	127.0	154.0	153.0	130.0	123.0	1567.0
	P-Q-ET	-117.5	53.5	-10.5	154.8	94.8	-14.6	33.7	-31.3	4.1	25.6	-18.9	-6.7	167.0
B	P	20.7	186.7	136.7	293.1	178.6	115.4	167.8	99.3	160.9	173.3	130.8	111.2	1774.5
	Q	0	0	0	13.0	25.6	11.9	20.7	6.4	11.5	11.4	11.0	2.3	113.8
	ET	142.0	131.0	133.0	134.0	110.0	116.0	114.0	127.0	154.0	153.0	130.0	123.0	1567.0
	P-Q-ET	-121.3	55.7	3.7	146.1	43.0	-12.5	33.1	-34.1	-4.6	8.9	-10.2	-14.1	93.7
Sub-B	P	20.7	186.7	136.7	293.1	178.6	115.4	167.8	99.3	160.9	173.3	130.8	111.2	1774.5
	Q	0	0	0	12.6	27.8	10.8	22.5	5.5	13.5	12.0	13.6	1.1	119.4
	ET	142.0	131.0	133.0	134.0	110.0	116.0	114.0	127.0	154.0	153.0	130.0	123.0	1567.0
	P-Q-ET	-121.3	55.7	3.7	146.5	40.8	-11.4	31.3	-33.2	-6.6	8.3	-12.8	-12.9	88.1
C	P	18.4	203.3	133.9	226.7	206.0	105.2	176.6	107.1	154.2	204.6	172.3	126.3	1834.6
	Q	0	0	0	7.1	33.9	19.2	38.2	12.6	12.8	19.2	35.6	12.4	191.0
	ET	142.0	131.0	133.0	134.0	110.0	116.0	114.0	127.0	154.0	153.0	130.0	123.0	1567.0
	P-Q-ET	-123.6	72.3	0.9	85.6	62.1	-30.0	24.4	-32.5	-12.6	32.4	6.7	-9.1	76.6

Table 4.13 : Monthly Water Balance July 1978 - June 1979

Catchment	Parameter	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mac	Apr	May	Jun	Total
A	P	170.0	44.5	107.0	213.5	228.5	258.5	55.5	31.5	39.0	126.5	84.5	187.5	1546.5
	Q	13.1	4.0	0.4	8.8	22.9	56.1	27.6	7.1	1.5	0.0	0.0	1.5	143.0
	ET	121.0	117.0	134.0	127.0	119.0	113.0	124.0	125.0	146.0	135.0	139.0	127.0	1527.0
	P-Q-ET	35.9	-76.5	-27.4	77.7	86.6	89.4	-96.1	-100.6	-108.5	-8.5	-54.5	59.0	-123.5
B	P	179.2	44.6	107.1	209.8	226.7	255.5	58.3	29.3	39.9	137.5	95.3	200.9	1584.1
	Q	14.0	2.3	0.3	4.4	23.9	45.4	26.3	5.2	0.5	0.0	0.0	3.2	125.5
	ET	121.0	117.0	134.0	127.0	119.0	113.0	124.0	125.0	146.0	135.0	139.0	127.0	1527.0
	P-Q-ET	44.2	-74.7	-27.2	78.2	83.8	99.1	-92.0	-100.9	-106.6	2.5	-43.7	70.7	-66.4
Sub-B	P	179.2	44.6	107.1	209.6	226.7	255.5	58.3	29.3	39.9	137.5	95.3	200.9	1584.1
	Q	14.6	1.2	0.2	1.6	24.5	35.3	25.5	4.0	0.0	0.0	0.0	4.3	111.2
	ET	121.0	117.0	134.0	127.0	119.0	113.0	124.0	125.0	146.6	135.0	139.0	127.0	1527.0
	P-Q-ET	43.6	-73.6	-27.1	81.2	83.2	107.2	-91.2	-99.7	106.1	2.5	-43.1	69.6	-54.1
C	P	161.6	44.9	123.3	211.6	221.4	269.5	72.3	38.6	47.6	156.6	114.0	201.1	1662.7
	Q	36.7	8.2	4.8	10.7	30.4	68.8	44.0	6.0	1.3	1.1	2.8	11.5	226.3
	ET	121.0	117.0	134.0	127.0	119.0	113.0	124.0	125.0	146.0	135.0	139.0	127.0	1527.0
	P-Q-ET	3.9	-80.3	-15.5	13.9	72.0	87.7	-95.7	-92.9	-99.7	20.7	-27.8	62.6	-90.6

Table 4.13 : Monthly Water Balance July 1979 - June 1980

Catchment	Parameter	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mac	Apr	May	Jun	Total
A	P	262.5	74.0	1185	388.5	362.0	20.0	68.5	37.0	189.0	276.5	92.5	69.0	1958.0
	Q	8.3	0.8	2.3	59.5	76.6	51.6	36.0	2.1	6.4	20.4	9.1	2.9	276.0
	ET	122.0	136.0	132.0	119.0	98.0	114.0	121.0	121.0	140.0	130.0	130.0	119.0	1482.0
	P-Q-ET	132.2	-62.8	-15.8	210.0	187.4	-145.6	-88.5	-86.1	42.6	126.1	-46.6	-52.9	200.0
B	P	264.0	67.6	131.1	401.3	349.8	25.3	63.1	38.1	175.4	269.8	82.5	72.3	1940.3
	Q	18.5	1.0	2.2	78.5	68.4	40.8	7.8	0.7	1.6	17.7	7.1	1.6	245.9
	ET	122.0	136.0	132.0	119.0	98.0	114.0	121.0	121.0	140.0	130.0	130.0	119.0	1482.0
	P-Q-ET	123.5	-69.4	-3.1	203.8	183.4	-129.5	-65.7	-83.6	33.8	122.1	-54.6	-48.3	212.4
SUB-B	P	264.0	67.6	131.1	401.3	349.8	25.3	63.1	38.1	175.4	269.8	82.5	72.3	1940.3
	Q	25.0	1.1	2.1	90.6	51.0	33.9	0.0	0.0	0.0	16.0	5.8	0.8	226.3
	ET	122.0	136.0	132.0	119.0	98.0	114.0	121.0	121.0	140.0	130.0	130.0	119.0	1482.0
	P-Q-ET	117.0	-69.5	-3.0	191.7	200.8	-122.6	-57.9	-82.9	35.4	123.8	-53.3	-47.5	232.0
C	P	247.2	76.3	146.3	426.9	339.2	34.1	56.1	35.0	187.6	277.9	85.9	67.5	1980.0
	Q	32.4	9.5	10.3	86.7	110.5	74.0	13.7	0.2	0.6	20.1	8.0	0.0	366.0
	ET	122.0	136.0	132.0	119.0	98.0	114.0	121.0	121.0	140.0	130.0	130.0	119.0	1482.0
	P-Q-ET	92.8	-69.2	4.0	221.2	130.7	-153.9	-78.6	-86.2	47.0	127.8	-52.1	-51.5	132.0

Table 4.13 : Monthly Water Balance July 1980 - June 1981

Catchment	Parameter	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mac	Apr	May	Jun	Total
A	P	86.5	78.5	157.0	195.0	268.5	286.0	81.5	74.0	118.0	161.5	278.5	45.5	1830.5
	Q	0.6	0.0	0.0	6.0	16.5	50.8	23.7	10.7	7.6	12.7	10.2	45.3	184.1
	ET	130.0	119.0	132.0	130.0	113.0	97.0	118.0	121.0	148.0	136.0	139.0	131.0	1514.0
	P-Q-ET	-44.1	-40.5	25.0	59.0	139.0	138.2	-60.2	-57.7	-37.6	12.8	129.3	-130.8	132.4
B	P	85.6	93.5	159.6	218.3	237.5	255.0	80.4	72.4	130.4	156.9	276.3	50.0	1816.4
	Q	0.1	0.1	0.1	12.2	44.4	75.9	37.7	16.0	15.3	36.5	34.5	44.4	317.2
	ET	130.0	119.0	132.0	130.0	106.9	92.1	111.9	114.9	140.1	128.7	131.7	124.3	1461.6
	P-Q-ET	-44.5	-25.3	27.7	76.1	86.2	87.0	-69.2	-58.5	-25.0	-8.3	110.1	-118.7	37.6
Sub-B	P	85.6	93.8	159.8	218.3	237.5	255.0	80.4	72.4	130.4	156.9	276.3	50.0	1816.4
	Q	0.0	0.2	0.2	16.1	62.2	91.9	46.6	19.4	20.2	51.7	50.0	43.8	402.8
	ET	130.0	119.0	132.0	130.0	103.0	89.0	108.0	111.0	135.0	124.0	127.0	120.0	1428.0
	P-Q-ET	-44.4	-25.4	27.6	72.2	72.3	74.1	-74.2	-58.0	-24.8	-18.8	99.3	-113.8	-13.9
C	P	96.9	88.8	188.6	176.0	257.5	239.5	74.0	82.0	157.5	165.0	251.5	43.0	1820.3
	Q	0.0	0.0	0.0	0.5	37.1	91.1	64.7	15.7	7.7	17.8	17.0	22.1	273.7
	ET	130.0	119.0	132.0	130.0	113.0	97.0	118.0	121.0	148.0	136.0	139.0	131.0	1514.0
	P-Q-ET	-33.1	-30.2	56.6	45.5	107.4	51.4	-108.7	-54.7	1.8	11.2	95.5	-110.1	32.6

Table 4.13 : **Monthly Water Balance** **July 1981 - June 1982**

Catchment	Parameter	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mac	Apr	May	Jun	Total
A	P	60.0	93.5	378.0	216.5	136.5	90.0	26.0	0.5	142.5	356.0	195.0	47.5	1742.0
	Q	3.5	1.9	38.1	21.5	19.3	14.4	5.5	0.1	0.3	30.1	26.5	9.2	170.4
	ET	139.0	148.0	131.0	126.0	107.0	107.0	124.0	126.0	147.0	141.0	133.0	128.0	1557.0
	P-Q-ET	-82.5	-56.4	208.9	69.0	10.2	-31.4	-103.5	-125.6	-4.8	184.9	35.5	-89.7	14.6
B	P	59.3	86.5	338.4	205.6	129.4	99.7	30.6	1.3	136.4	342.2	210.2	52.1	1691.7
	Q	12.7	6.8	45.8	42.0	34.5	26.7	12.8	1.8	1.8	32.6	32.9	14.4	264.8
	ET	131.0	139.0	124.0	119.0	102.0	102.0	117.0	119.0	139.0	134.0	126.0	121.0	1473.0
	P-Q-ET	-84.4	-59.3	168.6	44.6	-7.1	-29.0	-99.2	-119.5	-4.4	175.6	51.3	-83.3	-46.1
SUB-B	P	59.3	86.5	338.4	205.6	129.4	99.7	30.6	1.3	136.4	342.2	210.2	52.1	1691.7
	Q	18.6	9.9	50.7	55.1	44.2	34.5	17.4	2.9	2.8	34.2	37.0	17.7	325.0
	ET	126.0	134.0	120.0	114.0	99.0	98.0	113.0	115.0	134.0	129.0	121.0	116.0	1419.0
		-85.3	-57.4	167.7	36.5	-13.8	-32.8	-99.8	-116.6	-0.4	179.0	52.2	-81.6	-52.3
C	P	42.5	57.5	323.5	246.0	129.5	92.5	31.6	0.5	138.4	286.0	164.9	84.0	1596.9
	Q	0.4	3.1	43.8	35.5	37.8	20.1	6.5	0.0	0.0	9.7	19.0	9.6	185.5
	ET	139.0	148.0	131.0	126.0	107.0	107.0	124.0	126.0	147.0	141.0	133.0	128.0	1557.0
	P-Q-ET	-96.9	-93.6	148.7	84.5	-15.3	-34.6	-98.9	-125.5	-8.6	135.3	12.9	-53.6	-145.6

Table 4.13 Monthly Water Balance July 1982 - June 1983

Catchment	Parameter	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mac	Apr	May	Jun	Total
	P	182.0	65.5	73.0	222.5	201.5	209.0	30.5	10.0	58.0	51.5	278.5	106.0	1488.0
A	Q	13.9	4.6	3.9	8.2	13.6	33.6	12.2	1.6	2.3	6.3	30.4	19.4	150.0
	ET	133.0	125.0	132.0	125.0	122.0	97.0	117.0	137.0	162.0	143.0	127.0	111.0	1531.0
	P-Q-ET	35.1	-64.1	-62.9	89.3	65.9	78.4	-98.7	-128.6	-106.3	-97.8	121.1	-24.4	-193.0
	P	184.1	68.3	74.7	201.6	193.1	203.0	31.4	7.8	48.6	44.9	262.5	108.5	1428.5
B	Q	12.1	5.3	1.8	7.9	14.6	30.9	19.4	3.2	1.2	1.2	20.5	19.5	137.6
	ET	125.0	119.0	125.0	118.0	115.0	92.0	111.0	129.0	152.0	143.0	127.0	111.0	1467.0
	P-Q-ET	47.0	-56.0	-52.1	75.7	63.5	80.1	-99.0	-124.4	-104.6	-99.3	115.0	-22.0	-176.1
	P	184.1	68.3	74.7	201.6	193.1	203.0	31.4	7.8	48.6	44.9	262.5	108.5	1428.5
SUB-B	Q	11.0	5.7	0.5	7.7	15.2	29.2	24.0	4.2	0.5	0.0	14.2	19.6	131.8
	ET	120.0	115.0	120.0	114.0	111.0	89.0	107.0	124.0	147.0	143.0	127.0	111.0	1428.0
	P-Q-ET	53.1	-52.4	-45.8	79.9	66.9	84.9	-99.6	-120.4	-98.9	-98.1	121.3	-22.1	-131.3
	P	224.1	65.8	75.9	207.9	204.6	185.4	28.2	6.1	55.8	41.9	244.1	124.5	1464.3
C	Q	23.2	4.4	1.6	12.7	26.0	48.3	11.6	0.2	0.0	0.0	0.0	0.1	128.1
	ET	133.0	125.0	132.0	125.0	122.0	97.0	117.0	137.0	162.0	156.0	139.0	122.0	1567.0
	P-Q-ET	67.9	-63.6	-57.7	70.2	56.6	40.1	-100.4	-131.1	-106.2	-114.1	105.1	2.4	-230.8

Table 4.14 : **Summary of Annual Water Balance**

Catchment	Parameter	Annual Totals (mm) 1977/78	78/79	79/80	80/81	81/82	82/83	6 years average
A	P	1839	1547	1958	1831	1742	1488	1734
	Q	105	143	276	184	170	150	171
	ET	1567	1527	1482	1514	1557	1531	1530
	P-Q-ET	167	-124	200	132	15	-193	33
B	P	1775	1584	1940	1816	1692	1429	1706
	Q	114	124	246	317	265	138	201
	E	1567	1527	1482	1462	1473	1467	1496
	P-Q-ET	94	-66	212	38	-46	-176	9
Sub-B	P	1775	1584	1940	1816	1692	1429	1706
	Q	119	111	226	403	325	132	219
	E	1567	1527	1482	1428	1419	1428	1475
	P-Q-ET	88	-54	232	-14	-52	-131	12
C	P	1835	1663	1980	1820	1597	1464	1727
	Q	191	226	366	274	186	128	229
	E	1567	1527	1482	1514	1557	1567	1536
	P-Q-ET	77	-91	132	33	-146	-231	-38

4.2 Soil Fertility

4.2.1 Soil Chemical and Physical Characteristics.

Tables 4.15, 4.16 and 4.17 show the results of chemical analysis of soils from the 7 soil pits. All the soils have low N, very low P, K and Mg and low base saturation. Three soils series - Katong, Segamat and Chat - have moderately low cation exchange capacities (CEC´s) while Munchong Series and its lateritic phase has low CEC.

As all the soils have low nutrient levels, crops grown should be responsive to fertilizers. Munchong series, being an oxisol, is expected to have a high P-fixing capacity and thus larger amounts of phosphatic fertilizers may be needed for high yields.

Physical characteristics of soils from the seven pits are given in Tables 4.18 and 4.19. They are particle size, available waterholding capacity (AWHC), particle density, bulk density and aeration porosity. Fig. 4.8 shows the soil moisture characteristic curves.

With the exception of Chat series which has a fine sandy loam horizon, Katong series, Munchong series and its lateritic phase have soil horizons of clay. Munchong and Chat have fair AWHC´s while Katong, Segamat and Munchong lateritic phase have low AWHC´s. Thus, crops on Katong, Segamat and Munchong lateritic phase would be prone to moisture stress in dry seasons.

Aeration porosity is the proportion of bulk volume of soil filled with air under a soil moisture tension of 100 cm water (or pF 2). Most of the soils have aeration porosities exceeding 10% v/v and aeration is adequate for plant growth.

Table 4.15 : Soil Chemical Results (Soil Pit No. 1 to 3)

Soil Pit No. & Soil Series.	Soil Depth	pH on air-dry soil (1:2.5) H_2O	pH on air-dry soil (1:2.5) 0.01N Kcl	Organic Matter	C	N	C/N Ratio	Easily Soluble P.	C.E.C	Exch. Ca.	Exch. Mg.	Exch. Na.	Exch. K	Total Exch. Ca,Mg, Na,k.	Base Saturation
	cm			%	%	%		(ppm)	(meq/100 g. soil)						%
1	0-5	4.1	3.8	5.78	3.35	0.30	11	9	12.58	1.91	0.51	0.09	0.39	2.91	23
	5-125	4.8	4.1	1.64	0.95	0.09	11	1	5.64	0.08	0.14	0.06	0.04	0.32	6
Katong	125+	5.4	4.6	0.81	0.47	2.04	12	N.D	4.82	0.07	0.22	0.07	0.05	0.4	8
2	0-3	5.5	5.1	9.14	5.30	0.40	13	6	12.90	N.D	2.07	0.17	0.46	N.D	N.D
	3-71	8.0	7.5	1.16	1.02	0.12	9	1	5.50	N.D	0.11	0.06	0.05	N.D	N.D
Chat	71-118	5.5	4.5	0.91	0.53	0.05	11	1	5.28	0.27	0.07	0.06	0.04	0.44	8
	118+	5.3	4.3	1.09	0.63	0.06	11	N.D	5.70	0.49	0.08	0.06	0.05	0.68	12
3	0-4	4.3	4.0	7.28	4.22	0.38	11	8	12.16	2.27	0.95	0.07	0.39	3.68	30
	4-90	4.7	4.1	1.88	1.09	0.11	10	1	4.60	0.13	0.06	0.06	0.06	0.31	7
Katong	90+	5.1	4.4	0.91	0.53	0.03	18	1	3.92	0.13	0.06	0.07	0.07	0.33	8

Table 4.16 : Soil Chemical Results (Soil Pit NO. 4 & 5)

Soil Pit No. & Soil Series.	Soil Depth	pH air-dry soil(1:2.5) H_2O	pH air-dry soil(1:2.5) 0.01N KCl	Organic Matter	C	N	C/N Ratio	Easily Soluble P.	C.E.C	Exch. Ca.	Exch. Mg.	Exch. Na.	Exch. K	Total Exch. Ca, Mg, Na, K.	Base Saturation
	(cm)			(%)	(%)	(%)		(ppm)		(meq/100 g. Soil)				(%)	
4	0-4	4.3	4.0	7.40	4.29	0.43	10	20	19.34	1.57	0.68	0.09	0.41	2.75	14
Munchong Lateritic Phase	4-50	4.6	3.9	1.64	0.95	0.10	10	2	4.14	0.07	0.13	0.14	0.06	0.40	10
	50-95	5.1	4.1	1.03	0.60	0.60	10	2	3.68	0.23	0.05	0.09	0.03	0.40	11
	95-145	5.1	4.2	0.53	0.31	0.03	10	2	2.96	0.09	0.02	0.06	0.02	0.19	6
5	0-2	4.4	4.1	7.40	4.29	0.40	11	11	10.88	1.33	1.01	0.11	0.44	2.89	26
Munchong	2-39	4.5	3.9	2.48	1.44	0.40	9	3	4.10	0.16	0.20	0.07	0.06	0.49	12
	39-72	4.5	3.9	1.88	1.09	0.12	9	2	3.90	0.12	0.13	0.07	0.04	0.36	9
	72-130	5.0	4.4	0.81	0.47	0.04	12	2	2.64	0.13	0.09	0.06	0.02	0.30	11

Table 4.17 : Soil Chemical Results (Soil Pit NO. 6 & 7)

Soil Pit No. & Soil Series.	Soil Depth	pH air-dry soil(1:2.5) H_2O	pH air-dry soil(1:2.5) 0.01N KCl	Organic Matter	C	N	C/N Ratio	Easily Soluble P.	C.E.C	Exch. Ca.	Exch. Mg.	Exch. Na.	Exch. K	Total Exch. Ca, Mg, Na, K.	Base Saturation
	(cm)			(%)	(%)	(%)		(ppm)	(meq/100 g. Soil)					(%)	
6	0-1	4.4	4.0	7.46	4.33	0.43	10	12	10.10	1.36	0.97	0.11	0.37	2.81	28
Munchong Lateritic	1-33	4.5	3.9	2.31	1.34	0.14	10	3	5.02	0.08	0.08	0.07	0.07	2.30	6
Phase.	33-71	4.9	4.1	1.53	0.89	0.05	18	3	3.82	0.05	0.07	0.07	0.08	0.27	7
	71+	5.2	4.4	0.64	0.37	0.04	9	2	3.06	0.11	0.04	0.07	0.04	0.26	9
7	0-4	4.7	3.8	1.26	0.73	0.08	9	3	8.74	1.65	0.67	0.03	0.54	2.89	33
Segamat	4-70	4.5	4.1	1.96	1.14	0.06	19	2	8.36	0.77	0.35	0.04	0.18	1.34	16
Series	70-95	4.7	4.2	3.38	1.96	0.06	33	2	7.79	0.46	0.24	0.03	0.09	0.82	10

4.2.2 Organic Matter

Table 4.20 shows the amounts of dry matter and nutrient contents of forest litter (leaves and small twigs of less than 2 cm diameter) returned to the soil over a period of 5 years. Mean annual amount of dry matter returned was about 8.9 t/ha, containing 0.8 t ash and 8.1 t volatile substances. Plant nutrients in the ash amounted to 136, 5, 26, 34 and 69 kg of N, P, K, Mg and Ca, respectively. The amounts of N, Mg and Ca in the litter are equivalent to the fertilizer requirements of oil palm for the first 3 years of growth. However, the amounts of P and K are only equivalent to 50% of the fertilizer requirement for the first year.

If standing dead stems and branches greater than 2 cm diameter were included,the amount of forest litter returned to the soil would be greater than 8.9 t/ha/yr. Ysuyoshi et al (1974) estimated the amount of standing dead stems and branches greater than 10 cm diameter (excluding leaf litter and small twigs) to be 10.8 t/ha/yr in Pasoh Forest Reserve, West Malaysia. Hence, total forest litter returned to the soil might be in the region of 20 t/ha/yr and total plant nutrients would be greater than the amounts mentioned above.

Sampling of legume litter was started in January 1982 when full coverage of the ground was achieved. The amount of dry matter in that year was 3.2 t/ha. This was less than half of that of forest litter. Ash content in legume litter was 14.3% of dry matter as compared with 9.3% in forest litter, indicating the presence of more volatile substances in the latter. The amounts of N, P, K, Mg and Ca in legume litter in 1982 were 72, 3, 22, 11 and 39 kg, respectively. In the first year after full establishment, legume litter was much less than forest litter, and had lower nutrient contents especially of N, P, Mg and Ca.

During the first half of the second year of full establishment, i.e. January to June 1983, production of legume litter increased rapidly to 3.6 t/ha as compared with 4.8 t/ha of forest litter. Although the dry weight of legume litter was less than that of forest litter, it contained similar amounts of major plant nutrients.

Table 4.18 : Soil Particle Size Results

Pit No. & Soil Series	Soil Depth (cm)	Percentage Clay	Silt	Fine Sand	Coarse Sand	Soil Texture
		(0.002mm -		0.02mm -	2mm)	
1 Katong	0 - 5	83.6	8.1	5.3	3.0	Clay
	5 - 125	86.9	7.1	4.2	1.8	Clay
	125+	87.0	8.2	3.4	1.4	Clay
2 Chat	0 - 3	66.5	20.6	7.4	5.4	Clay
	3 - 71	10.4	15.7	49.4	24.5	Fine Sandy loam
	71 - 118	82.9	10.0	5.1	2.0	Clay
	118+	76.1	12.6	7.6	3.6	Clay
3 Katong	0 - 4	84.8	8.4	4.4	2.4	Clay
	4 - 9	89.5	5.8	2.9	1.7	Clay
	90 +	86.1	9.3	2.8	1.8	Clay
4 Munchong Lateritic Phase	0 - 44	75.4	13.5	5.7	5.3	Clay
	4 - 50	83.8	6.9	4.9	4.4	Clay
	50 - 95	83.6	6.1	3.5	6.2	Clay
	95 - 145	79.0	12.3	6.8	1.9	Clay
5 Munchong	0 - 2	63.3	21.3	8.9	6.5	Clay
	2 - 39	76.7	11.6	7.4	4.3	Clay
	39 - 72	66.5	22.4	7.9	3.3	Clay
	72 - 130	77.5	12.1	6.5	3.7	Clay
6 Munchong Lateritic Phase	0 - 1	77.9	11.1	5.9	15.1	Clay
	1 - 33	84.9	6.5	4.5	4.1	Clay
	33 - 71	84.0	8.1	3.4	4.5	Clay
	71 +	68.7	8.2	6.1	16.9	Clay
7 Segamat Series	0 - 25	84.0	11.1	3.4	1.5	Clay
	25 - 50	72.3	21.7	4.1	1.9	Clay
	50 - 100	83.7	12.5	2.8	1.0	Clay

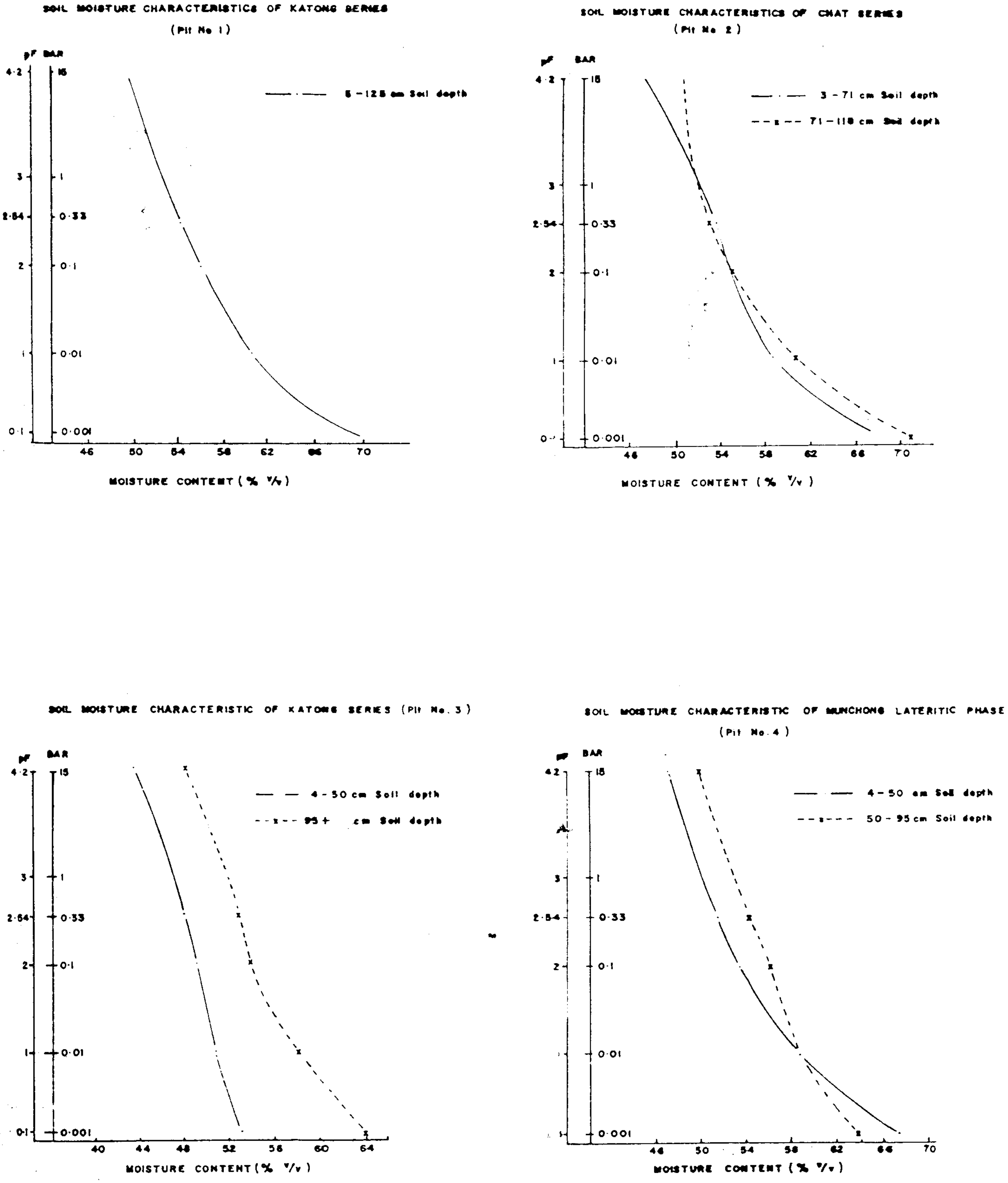
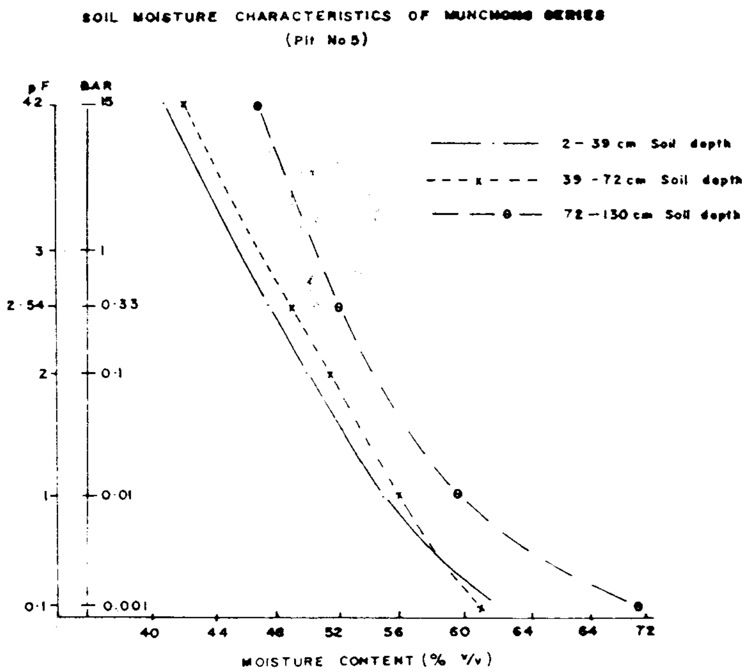
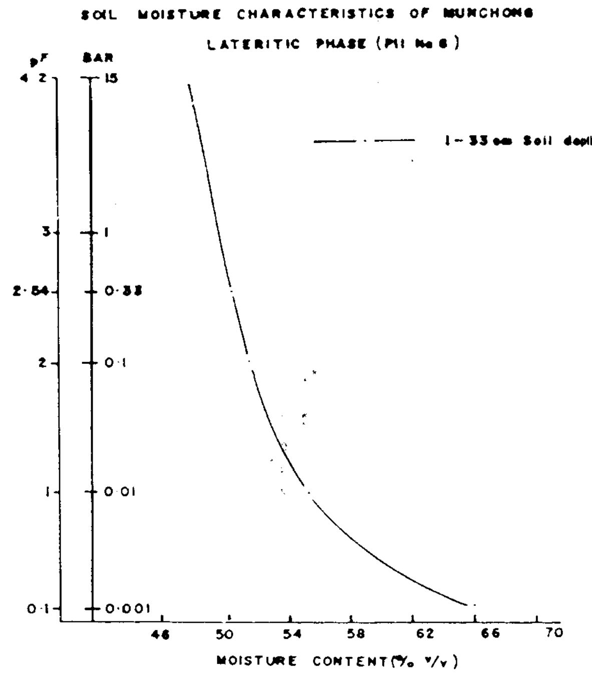


FIGURE 4.8 SOIL MOISTURE CHARACTERISTICS





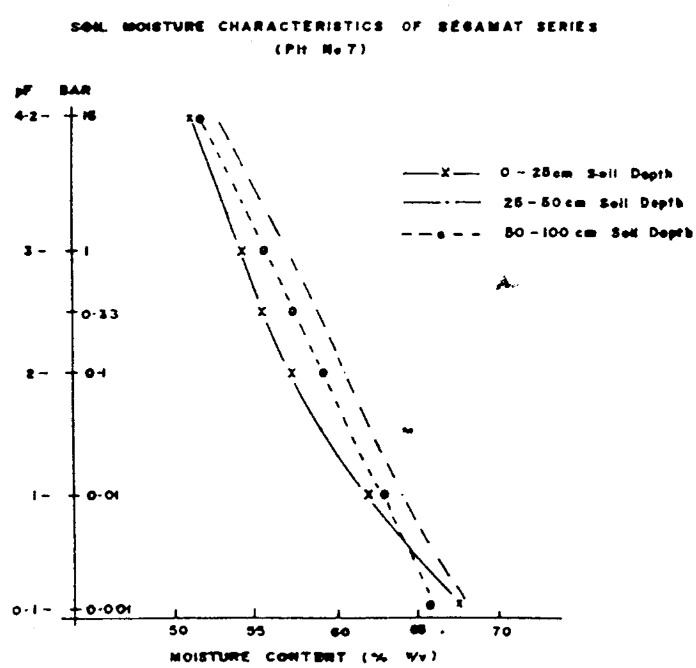


FIGURE 4.8 SOIL MOISTURE CHARACTERISTICS (CONTD.)

Table 4.19 Available Water Holding Capacity, Particle Density and Aeration Porosity Values.

Pit No.	Soil Series	Depth (cm)	Available Water Holding Capacity (% v/v)	Particle Density (g/cm^3)	Bulk Density (g/cm^3)	Aeration Porosity (% v/v)
1	KATONG	5 - 125	4.29	2.594	1.054	15.6
2	Chat	3 - 71	6.35	2.708	1.081	14.0
		71 - 118	2.21	2.562	1.086	16.8
3	KATONG	4 - 50	4.65	2.673	1.104	4.8
		50 - 95	4.97	2.712	1.132	10.8
4	MUNCHONG - LATERITIC PHASE	4 - 50	4.48	2.542	1.017	14.6
		50 - 95	4.54	2.597	1.033	8.0
5	MUNCHONG -	2 - 39	6.72	2.808	1.043	12.8
		39 - 72	6.69	2.412	1.042	10.4
		72 - 130	5.37	2.688	1.152	17.6
6	MUNCHONG - LATERITIC PHASE	1 - 33	2.77	2.717	1.066	14.6
7	SEGAMAT	0 - 25	4.3	2.61	0.98	10.6
		25 - 50	6.5	2.62	0.98	7.6
		50 - 100	6.0	2.65	0.99	6.5

Table 4.20 : Forest and Legume Litters 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	71.8	21.1
	1981	6463.6	721.8	1659.7	102.4	2.8	22.5	17.6	72.1
	1982	6291.0	633.0	2836.0	95.0	3.0	31.1	16.9	16.9
Mean (1978-82)		8883.3	828.7	2904.3	135.7	5.3	26.1	24.1	68.9
Jan ´83-Jun ´83		4786.3	718.8	2521.5	78.1	2.3	25.5	13.8	41.9
Legume : 1982		3242.8	463.6	1380.9	71.6	2.6	22.3	11.3	38.9
Jan ´83-Jun ´83		3552.0	633.6	1775.3	78.0	2.2	25.1	11.0	43.0

NOTE : NA - Not Available

4.2.3 Infiltration

Results of the infiltration study (average of 5 to 6 samples) are shown in Fig. 4.9. Generally, higher rates were observed under forested than under deforested conditions. Saturated infiltration rate for Munchong series was 30 cm/hr forested and 20 cm/hr deforested. For Segamat series, the difference was even greater - 26 cm/hr forested compared with 3 cm/hr deforested. The lower infiltration deforested could be mainly due to soil compaction during mechanical stacking of logs for burning. The drastic drop in infiltration in Segamat series after compaction was attributed to the weak structure of the soil. This low infiltration might lead to difficulty in the establishment of crops such as cocoa.

4.2.4 Soil Erosion

Results from the soil erosion study are shown in Table 4.21. In the first year, i.e. 15/6/81 to 22/6/82, most treatments showed increased in erosion with slope. However, there were some discrepancies in the results such as those for Munchong series forested (MF) and deforested (MD) at 9% slope. Cover crop establishment affected the degree of soil erosion in addition to rainfall amount and intensity, terrain and soil characteristics. Erosion in Segamat deforested (SD) at both 9 and 16% slopes and MD at 4% slope were over-estimated. This was because establishment of cover crops in these plots was only 20-40% during the first year as compared with full establishment in other plots.

Soil erosion in SD was 12 times that of SF at 4% and 9% slopes and 7 times that of SF at 16% and 25% slopes. The lower erosion on higher slopes may be due to better cover crop establishment. For Munchong series for the same period, MD at most slopes was 4 times that of MF, except at 9% slope. Mean erosion over four slopes during this period was 0.33 cm for SF, 2.50 cm for SD, 0.37 cm for MF and 1.72 cm for MD.

Results for the second year, i.e. 22/6/82 to 4/7/83, were unexpected except for MF where erosion increased with slope. Treatments SD at 4, 16 and 25% slopes and MD at 16 and 25% slopes showed deposition of soil from the upper slopes. Thus results from the pin method may not be meaningful if the period of study is too short, as in this case. However, if the period is sufficiently long, a general trend of erosion may be identified as shown by data from

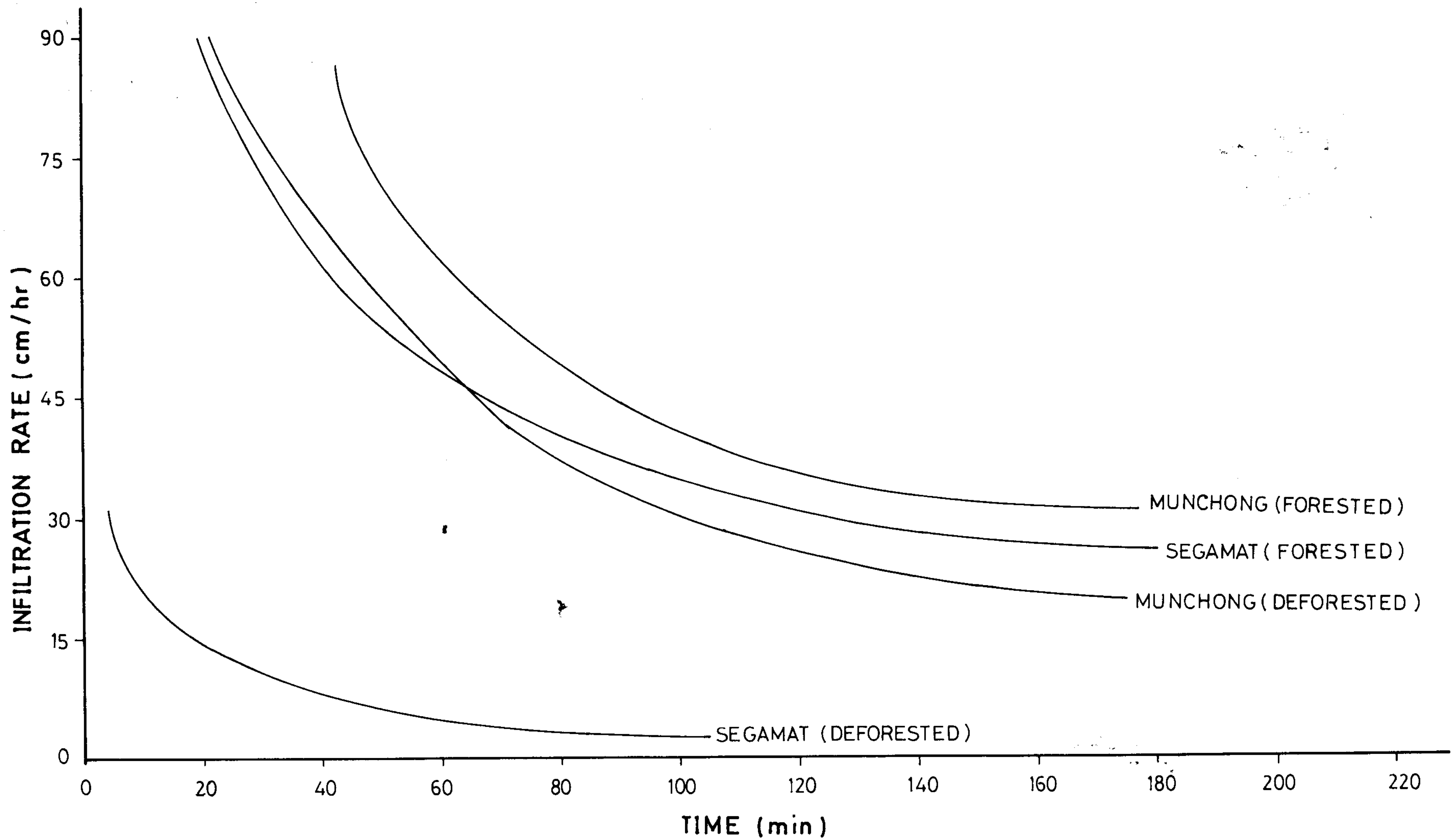


FIGURE 4.9 INFILTRATION CURVES FOR TWO SOIL SERIES, FORESTED AND DEFORESTED

Table 4.21 : Soil Erosion Depths (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
15/6/81-4/7/83	SD	0.87	2.72*	2.51*	1.98	2.02
	MF	0.51	0.56	0.91	1.51	0.87
	MD	1.77*	2.07	1.49	1.24	1.64

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

* Cover-crop establishment in these plots was only about 20 - 40% of full cover for the period 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.

15/6/81 to 4/7/83. Over the 2-year period, erosion of MD was 2 to 4 times that of MF for most slopes except that at 25%. Mean erosion over 4 slopes during this period was 2.02 cm for SD, 0.87 cm for MF and 1.64 cm for MD.

In general, under deforested condition erosion with initial establishment of cover crop was several times that of forested. Erosion for SD was higher than that of MD probably because of the greater soil compaction of the former as indicated by the lower infiltration rate. However, erosion under forest for these two soils was similar.

4.2.5 Soil Chemical Content

Changes in soil chemical content due to development are shown in Table 4.22. Variations in organic carbon content from one sampling date to another were much greater for the upper (0-5 and 5-10 cm) than for the lower soil layers. The following descriptions are confined to the top two layers of soil only. The variation in organic carbon was greater during transition for agricultural development than under forest. The high organic carbon content in samples taken on 22/1/81 and 22/8/81 might be due to the large amounts of organic matter returned to the soil by forest felling. Much of this organic matter remained because of the poor burn on 15/2/81. Organic carbon content was reduced in samples taken from 15/6/81 to 22/6/82 (Table 4.22), particularly during the monsoonal months of October to December. The top soil with high organic matter might have been lost through erosion during this period. There was an increase in organic carbon in samples taken on 23/2/83 and 24/8/83, possibly due to the high rate of return of legume litter to the soil from January to June 1983 (Table 4.20).

The pattern of fluctuation of the cation exchange capacity (CEC) and total N under deforested condition closely followed that of organic carbon content. Fluctuation of CEC under forest was less than that deforested. There was not much change in available P content under forest and deforested. Exchangeable K and Mg increased after felling. This might have been due to the return of these elements from burnt vegetation. Increases of these elements were also observed in samples taken on 23/2/83 and 24/8/83, due to the large amount of legume litter returned to the soil during this period.

Furthermore, there was a substantial increase in total P, K and Mg under deforested condition and

Table : 4.22 Soil Chemical Content Under Forested and Deforested Conditions

Date	Element	Munchong series in Catchment C						Munchong series in Sub-catchment B					
		Condition	0-5cm	5-10cm	10-15cm	15-30cm	30-60cm	Condition	0-5cm	5-10cm	10-15cm	15-30cm	30-60cm
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
19.7.80	C.E.C (% meq)	F	14.60	9.10	7.10	6.50	6.00	F	NA	NA	NA	NA	NA
22.1.81	"	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
19.7.80	Total N(%)	F	0.36	0.21	0.14	0.11	0.08	F	NA	NA	NA	NA	NA
22.1.81	"	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	0.07	0.07

Note : F - Forest
Felling - felling and burning of jungle
Cover-crop - planting and initial establishment of cover-crop
Oil palm - planting and initial establishment of oil palm and full establishment of cover crop
NA - Not Available

Table : 4.22 Soil Chemical Content Under Forested and Deforested Conditions (Cont.)

Date	Element	Munchong series in Catchment C						Munchong series in Sub-catchment B					
		Condition	0-5cm	5-10cm	10-15cm	15-30cm	30-60cm	Condition	0-5cm	5-10cm	10-15cm	15-30cm	30-60cm
19.7.80	Total P	F	NA	NA	NA	NA	NA	F	NA	NA	NA	NA	NA
22.1.81	(ppm)	F	NA	NA	NA	NA	NA	Felling	NA	NA	NA	NA	NA
22.8.81	"	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	1275.0	675.0	325.0	417.0	Oil palm	155.0	150.0	150.0	140.0	135.0
23.2.83	"	F	202.8	180.2	181.9	171.2	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
19.7.80	Total K	F	1.00	0.90	0.75	0.70	0.65	F	NA	NA	NA	NA	NA
22.1.81	(% meq)	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-crop	0.25	0.30	0.25	0.30	NA
24.2.82	"	F	0.45	0.55	0.40	0.40	0.35	Cover-crop	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
23.2.83	"	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
19.7.80	Total Mg	F	0.97	0.68	0.70	0.60	0.52	F	NA	NA	NA	NA	NA
22.1.81	(% meq)	F	0.78	0.53	NA	0.84	0.75	Felling	1.52	1.12	NA	1.34	NA
22.8.81	"	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

Table : 4.22 Soil Chemical Content Under Forested and Deforested Conditions (Cont.)

Date	Element	Munchong series in Catchment C						Munchong series in Sub-catchment B					
		Condition	0-5cm	5-10cm	10-15cm	15-30cm	30-60cm	Condition	0-5cm	5-10cm	10-15cm	15-30cm	30-60cm
19.7.80	Avai. I	F	3.70	2.40	0.60	1.50	1.90	F	NA	NA	NA	NA	NA
22.1.81	(ppm)	F	3.20	3.60	NA	3.60	4.60	Felling	4.80	2.10	NA	3.80	NA
22.8.81	"	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
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	(% meq)	F	0.08	0.06	NA	0.02	0.02	Felling	0.10	0.06	NA	0.03	NA
22.8.81	"	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
19.7.80	Ex. Mg	F	0.49	0.25	0.18	0.12	0.09	F	NA	NA	NA	NA	NA
22.1.81	"	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
24.2.82	"	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	0.20	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

smaller increases under forest for samples taken from 24/8/82 to 24/3/83. The former increase might be due to the return of these elements from legume litter.

4.3 Water Quality

Water quality parameters were analysed to assess changes resulting from agricultural development in the catchments. Trend analyses were done on concentration and load values. Although 22 parameters were monitored, interpretation of data were based on selected parameters deemed the more important ones. These included nitrate, phosphate, iron, magnesium, potassium, sodium, calcium, total suspended solids (TSS) and total solids (TS).

Concentrations of solids, nutrients, ions and their variations for the sampling periods for Catchment A, Sub-catchment B and Catchment C are shown in Figs. 4.10 to 4.18. Generally, higher concentrations of most parameters were observed after Catchment A and Sub-catchment B were logged and clear-felled compared with control Catchment C. With the removal and burning of vegetation and extensive soil disturbance, effects on water quality were expected.

Owing to the fortnightly sampling, there was difficulty in obtaining samples to cover an adequate range of concentrations with streamflow discharges. Loads were therefore computed using rating curves for the selected parameters in order to improve interpretation of data. Individual values obtained for the calibration and transition periods were plotted separately against stream discharge; relationships between parameters and discharges were fitted by eye to facilitate data extrapolation to monthly loads.

Mean monthly discharge was used to determine monthly loads for the various parameters. Based on these, and for comparative purposes, loads were expressed in kg/ha/month. Results for the three catchments are illustrated in Fig. 4.19 to 4.27. A pattern of change resulting from catchment development could be detected from the load diagrams for most of the parameters.

TSS and TS in Catchment B were higher after logging and clear felling (Figs. 4.19 and 4.20) due to accelerated soil erosion. However, as sampling did not cover the full range of high flows, suspended solids could have been underestimated. In contrast, suspended sediment was found to be considerably higher (refer Section 4.4).

Similarly, TSS and TS computed for Catchment A after logging and clear felling in October 1982 were higher than those for Sub-catchments B and C. The relatively lower loads for Sub-catchment B can be largely attributed to the soil types and

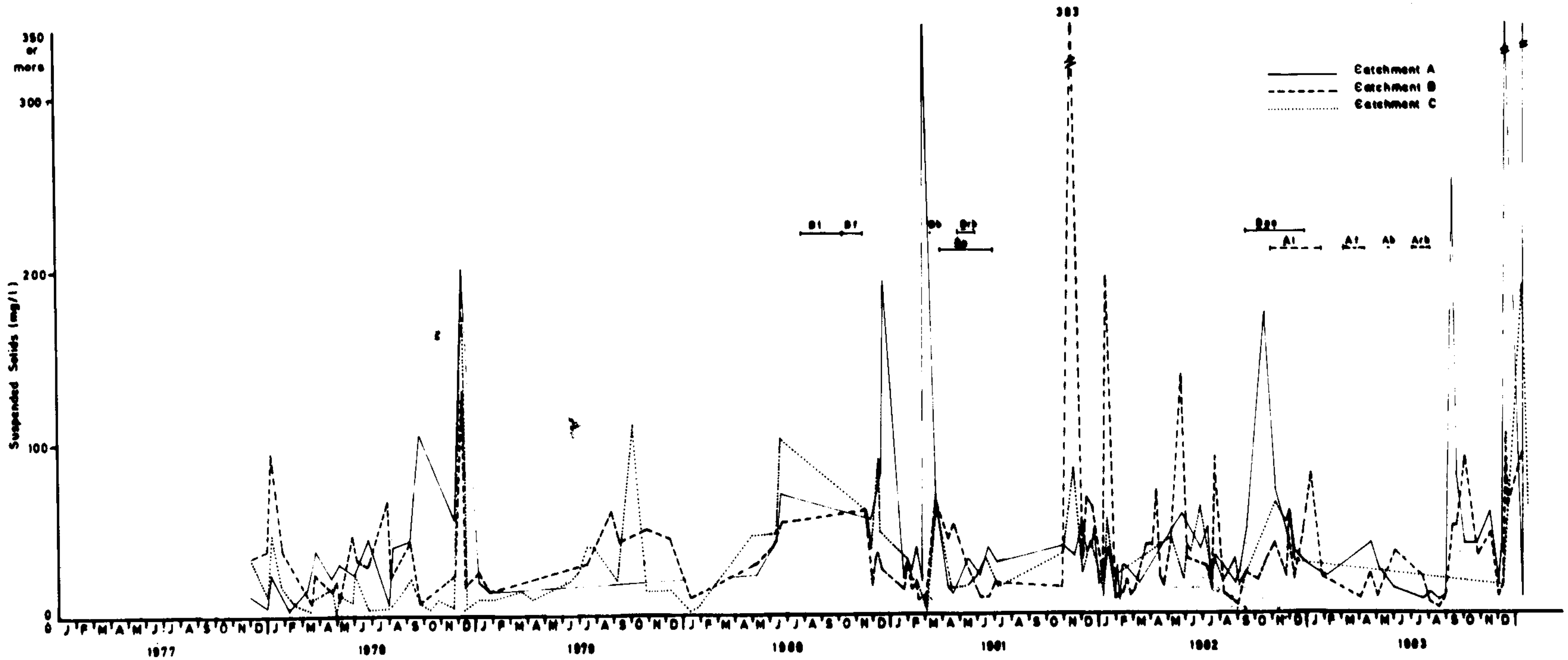


FIGURE 4.10 SUSPENDED SOLIDS CONCENTRATIONS IN CATCHMENTS A, B AND C

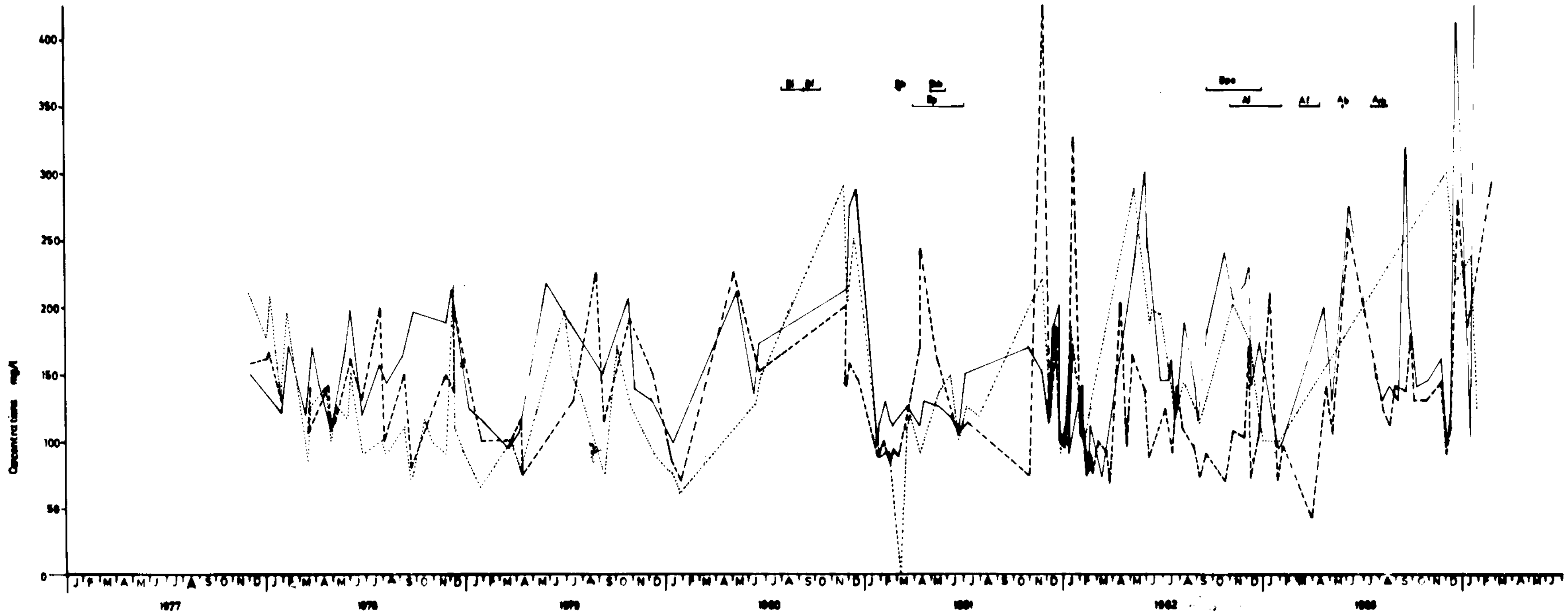


FIGURE 4.11 TOTAL SOLIDS CONCENTRATIONS IN CATCHMENTS A, B AND C

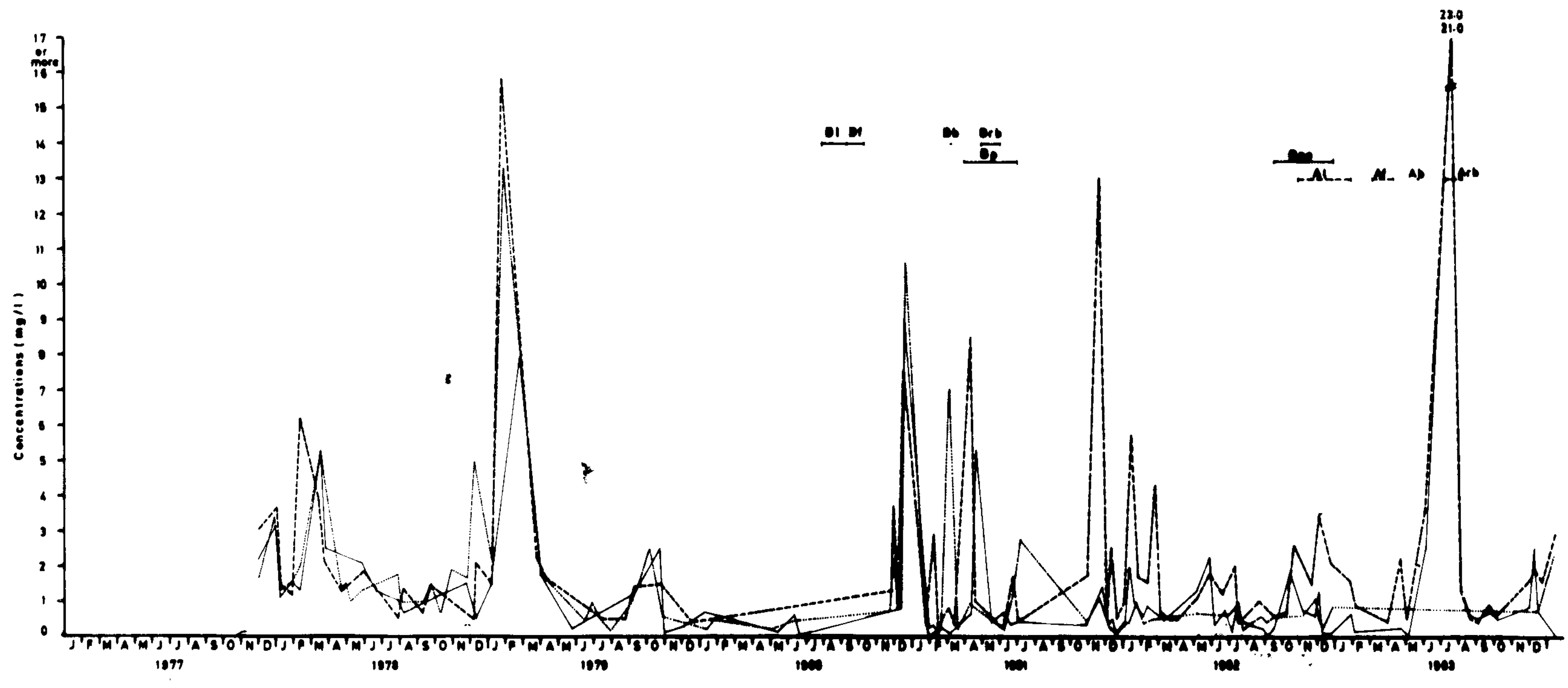


FIGURE 4.12 NITRATE CONCENTRATIONS IN CATCHMENTS A, B AND C

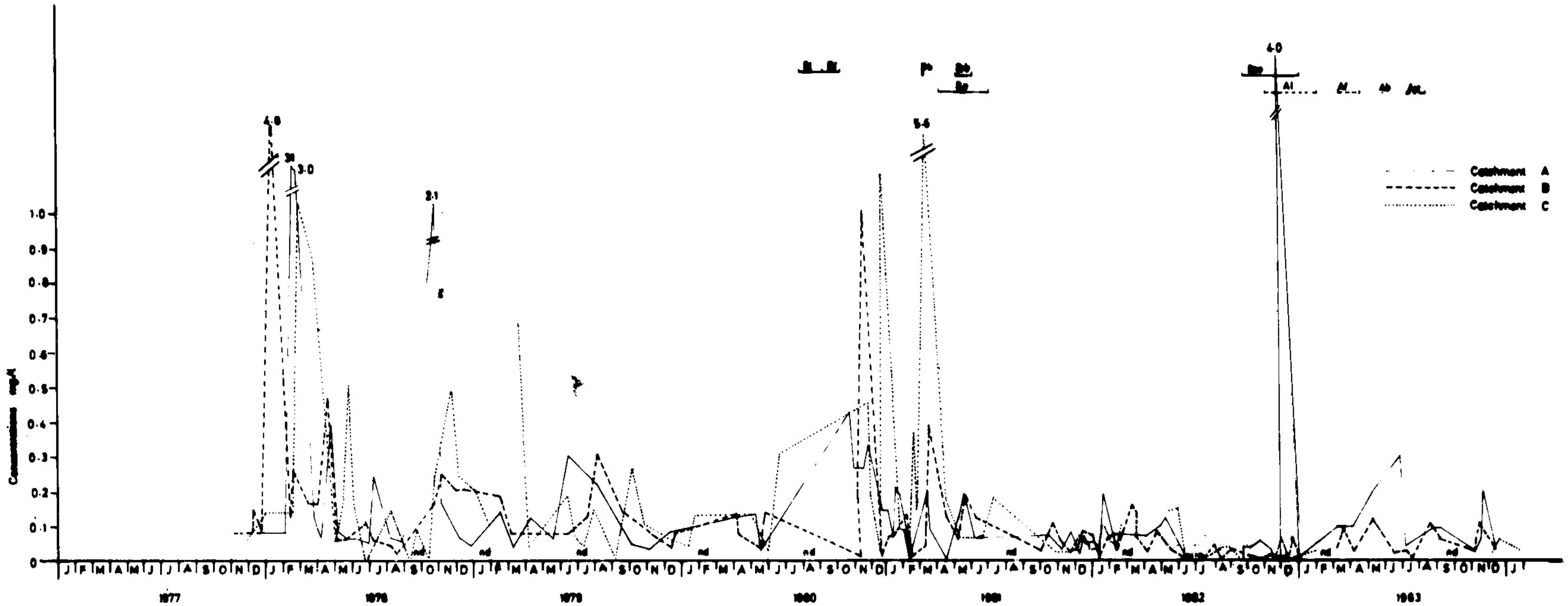


FIGURE 4.13 PHOSPHATE CONCENTRATIONS IN CATCHMENTS A, B AND C

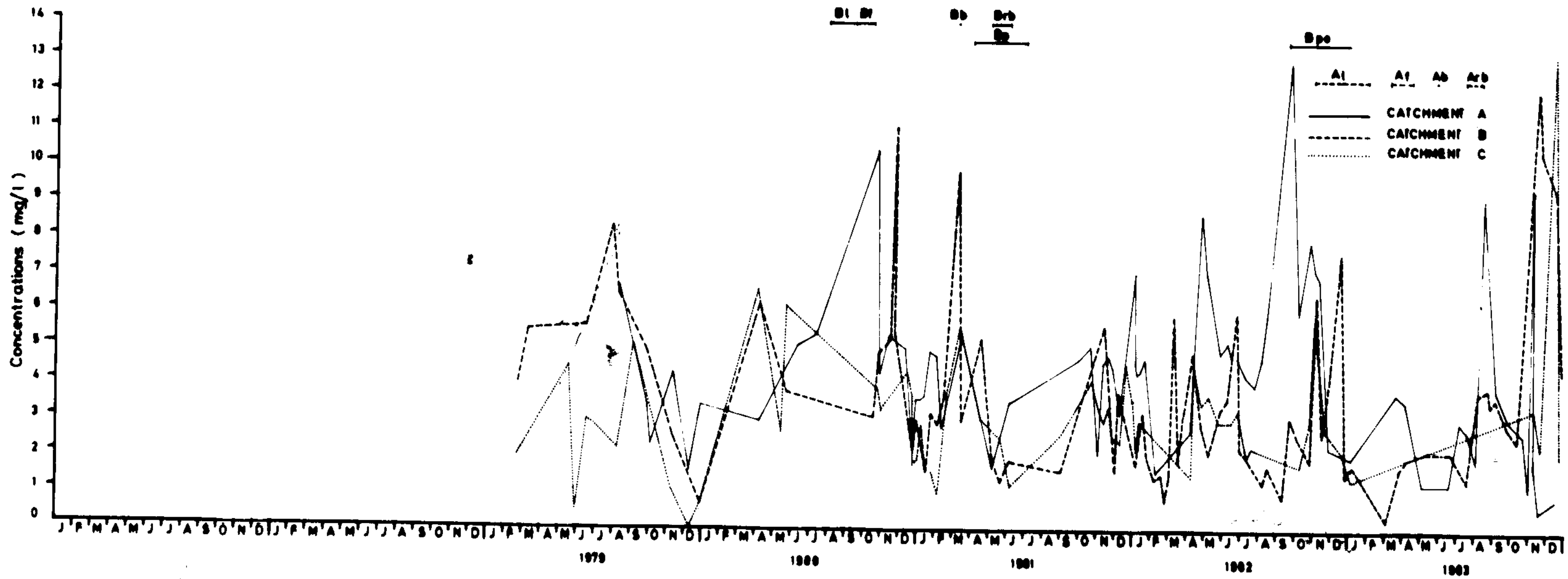


FIGURE 4.14 IRON CONCENTRATIONS IN CATCHMENTS A, B AND C

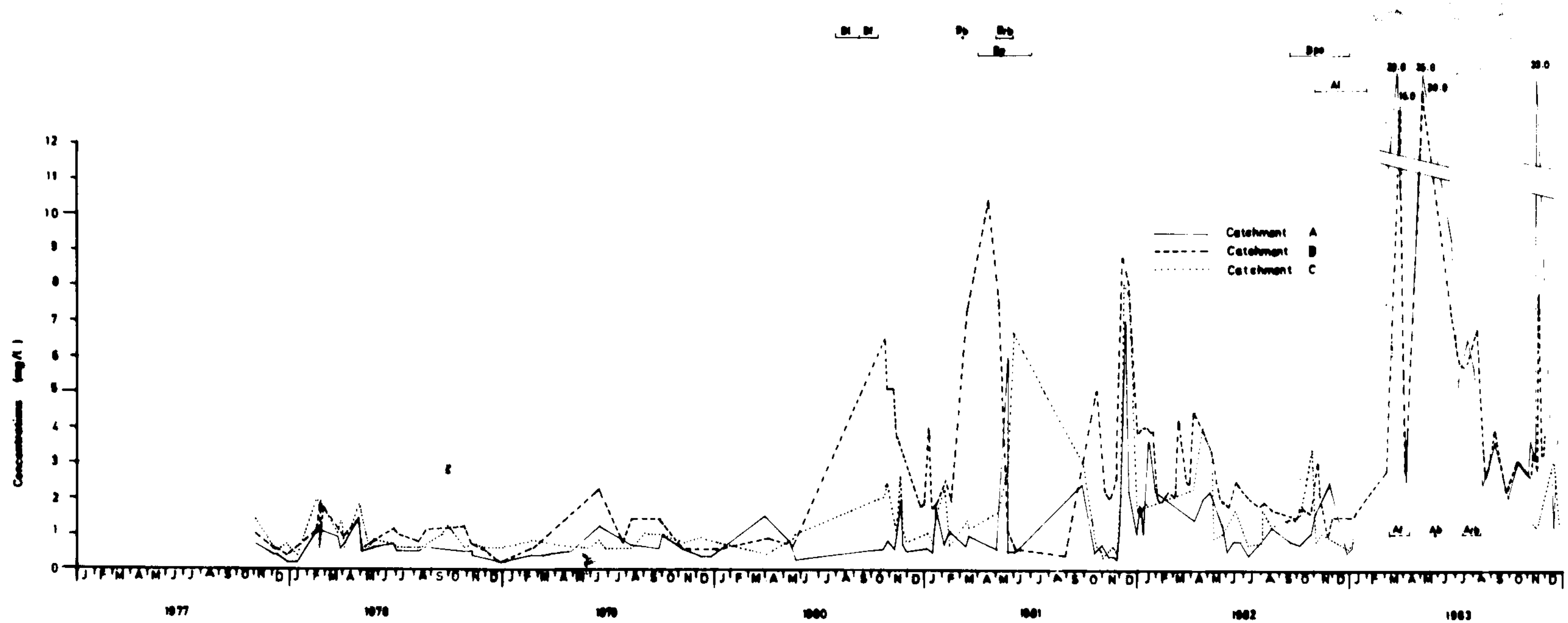


FIGURE 4.15 POTASSIUM CONCENTRATIONS IN CATCHMENTS A, B AND C

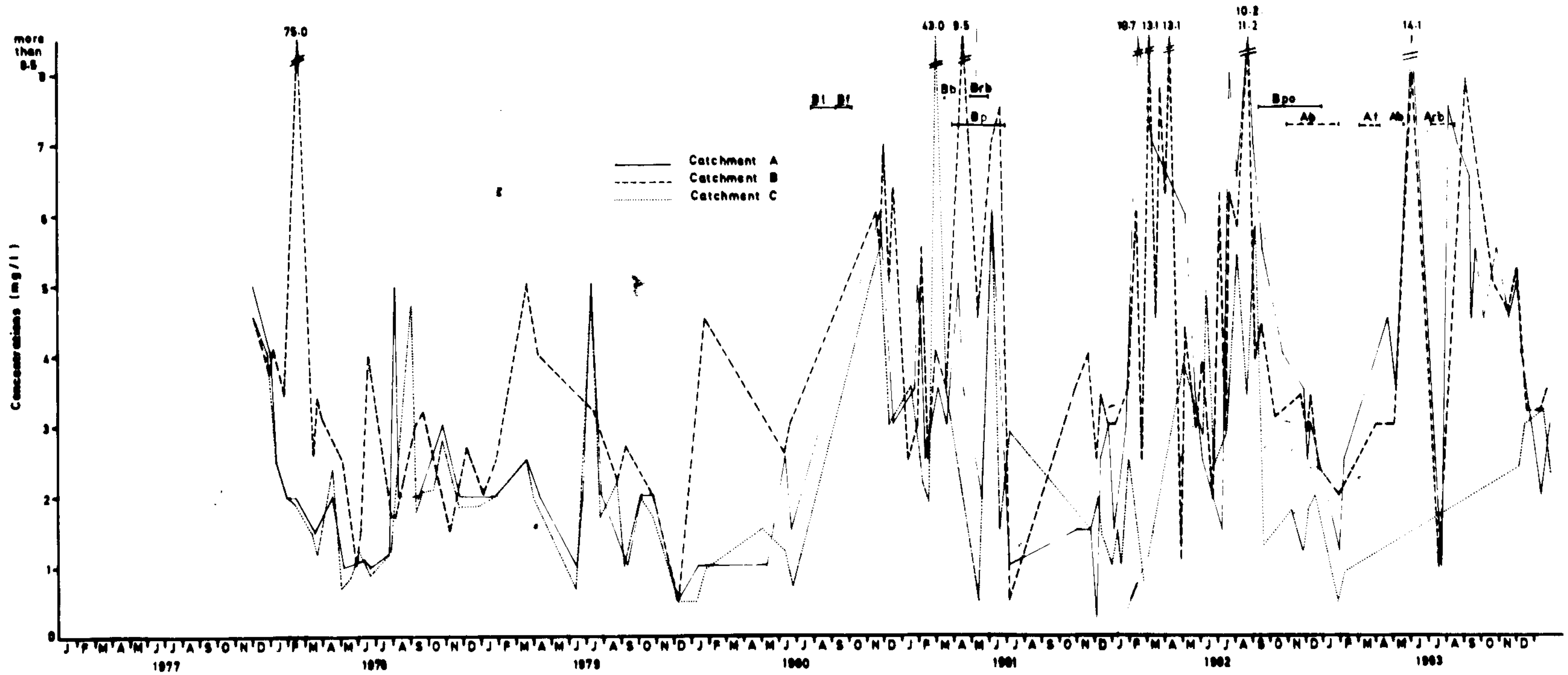


FIGURE 4.16 MAGNESIUM CONCENTRATIONS IN CATCHMENTS A, B AND C

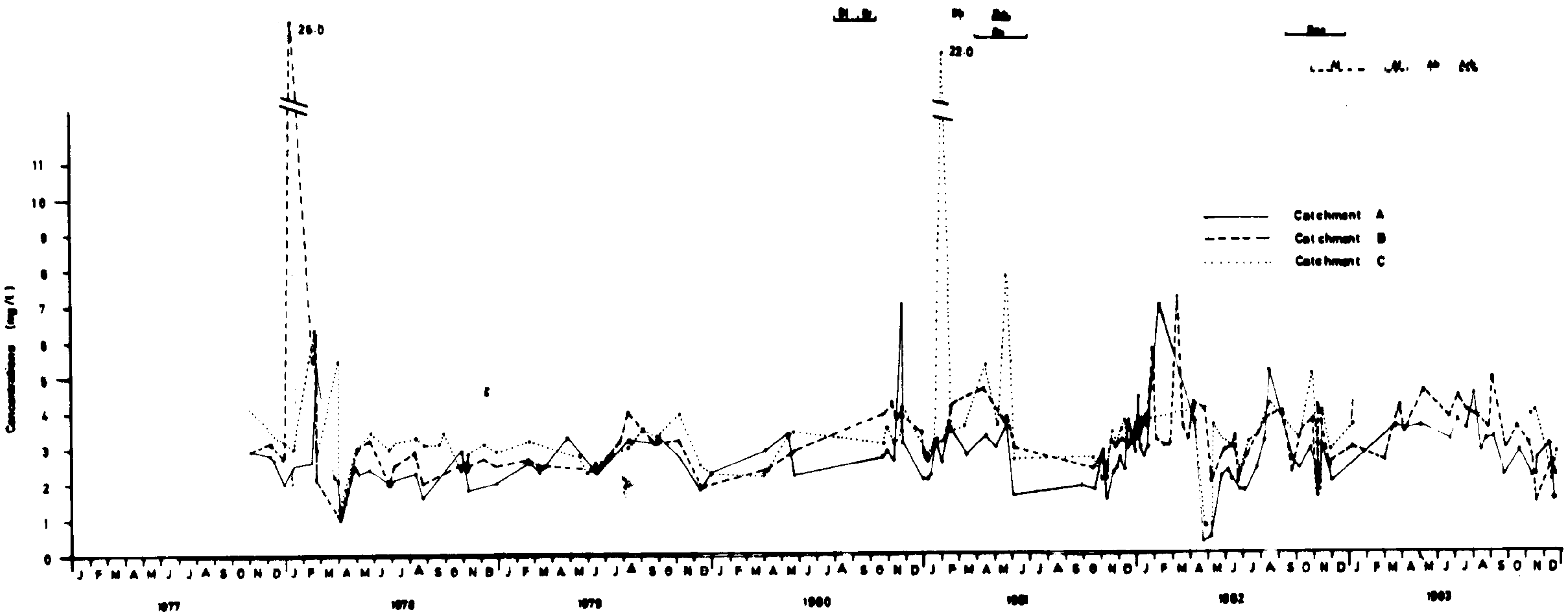


FIGURE 4.17 SODIUM CONCENTRATIONS IN CATCHMENTS A, B AND C

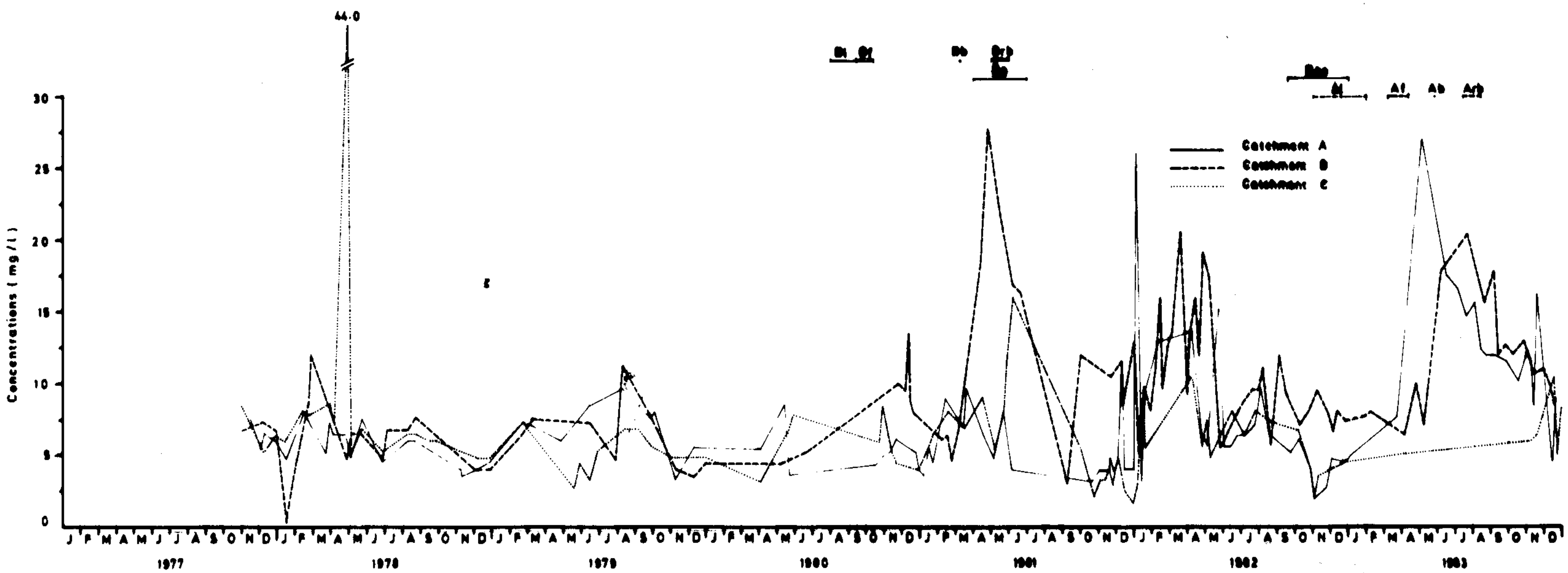


FIGURE 4.18 CALCIUM CONCENTRATIONS IN CATCHMENTS A, B AND C

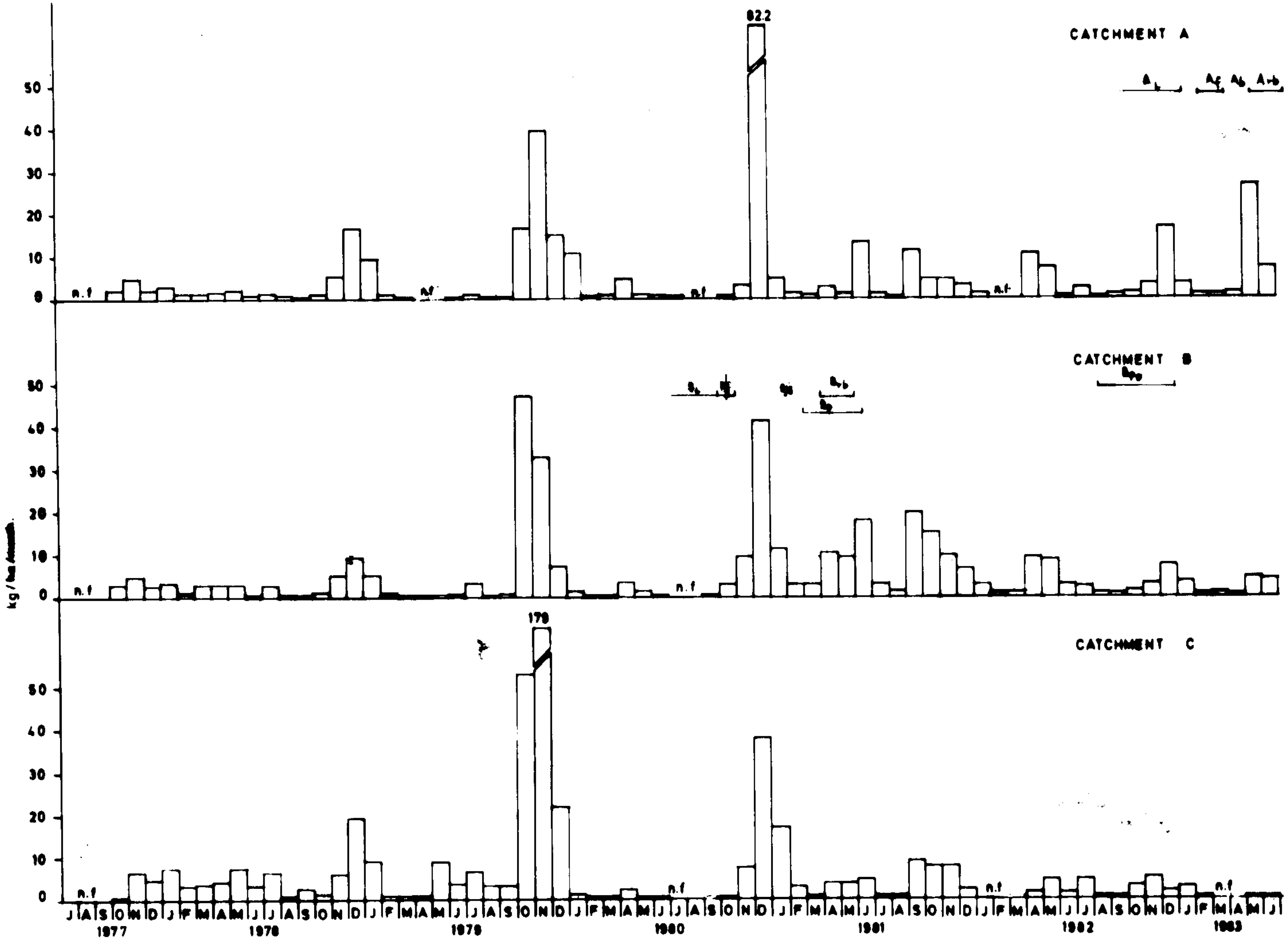


FIGURE 4.19 LOAD DISTRIBUTION OF TOTAL SUSPENDED SOLIDS IN CATCHMENTS A, B AND C

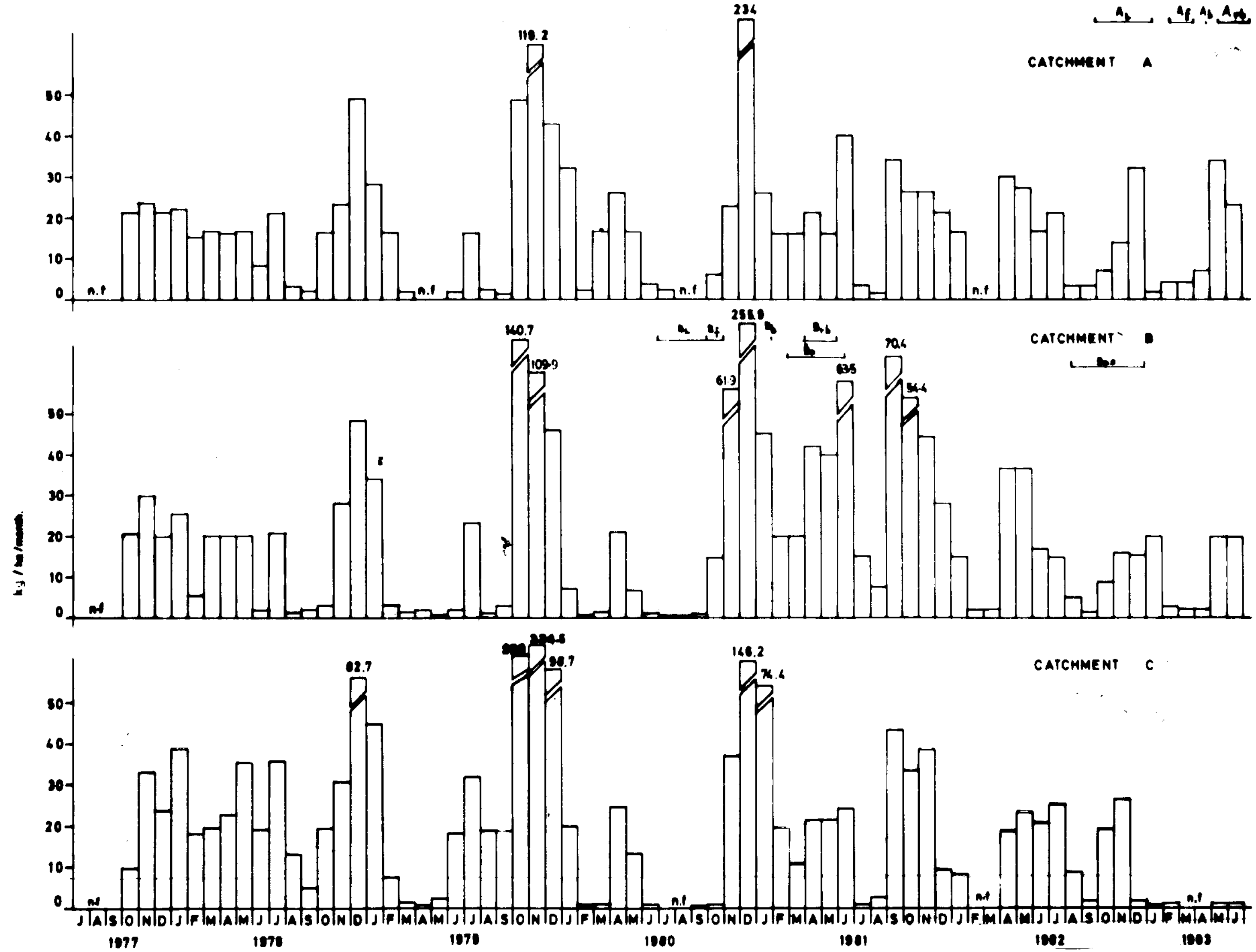


FIGURE 4.20 LOAD DISTRIBUTON OF TOTAL SOLIDS IN CATCHMENTS A, B AND C

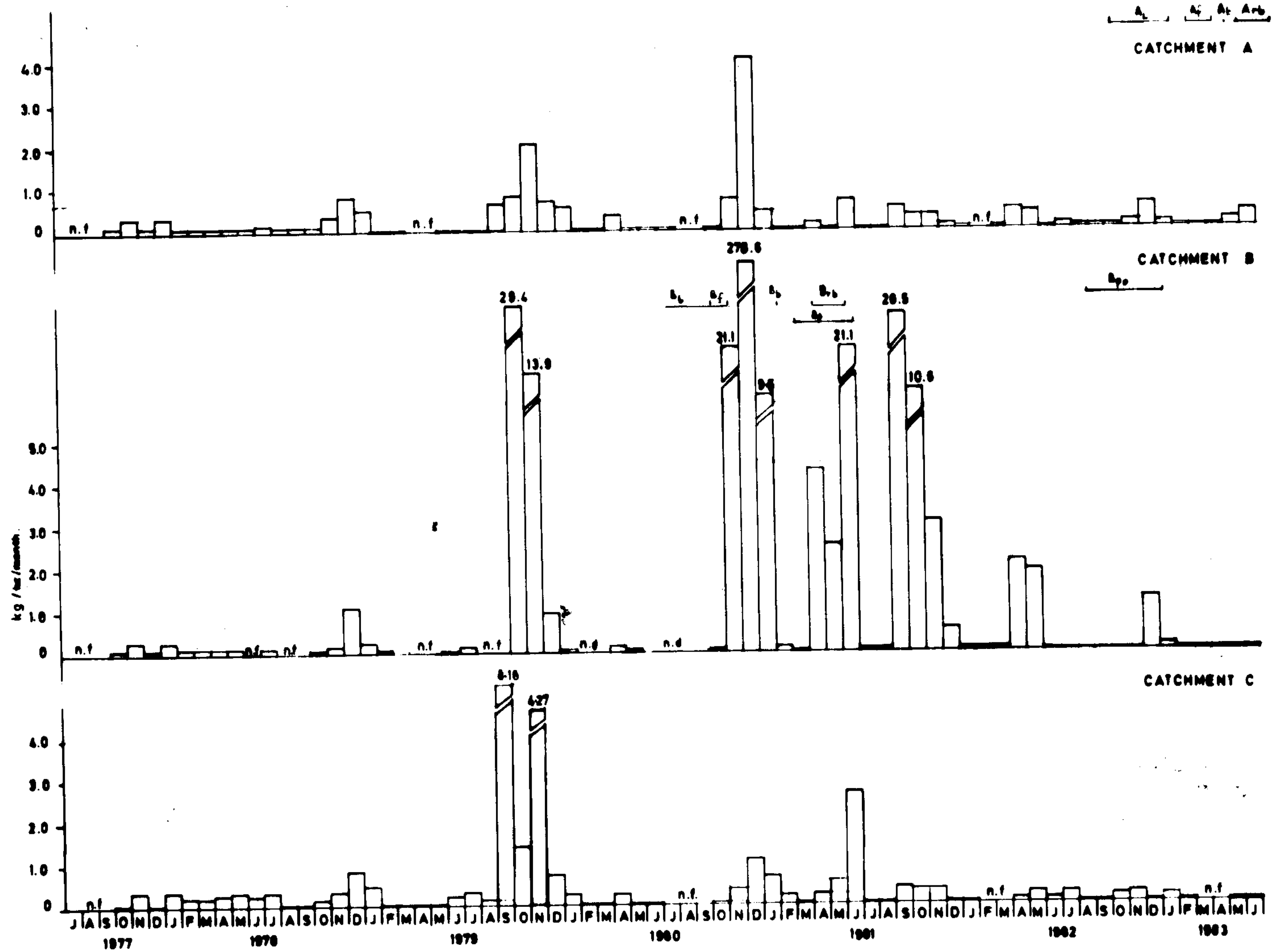


FIGURE 4.21 LOAD DISTRIBUTION OF NITRATES IN CATCHMENTS A, B AND C

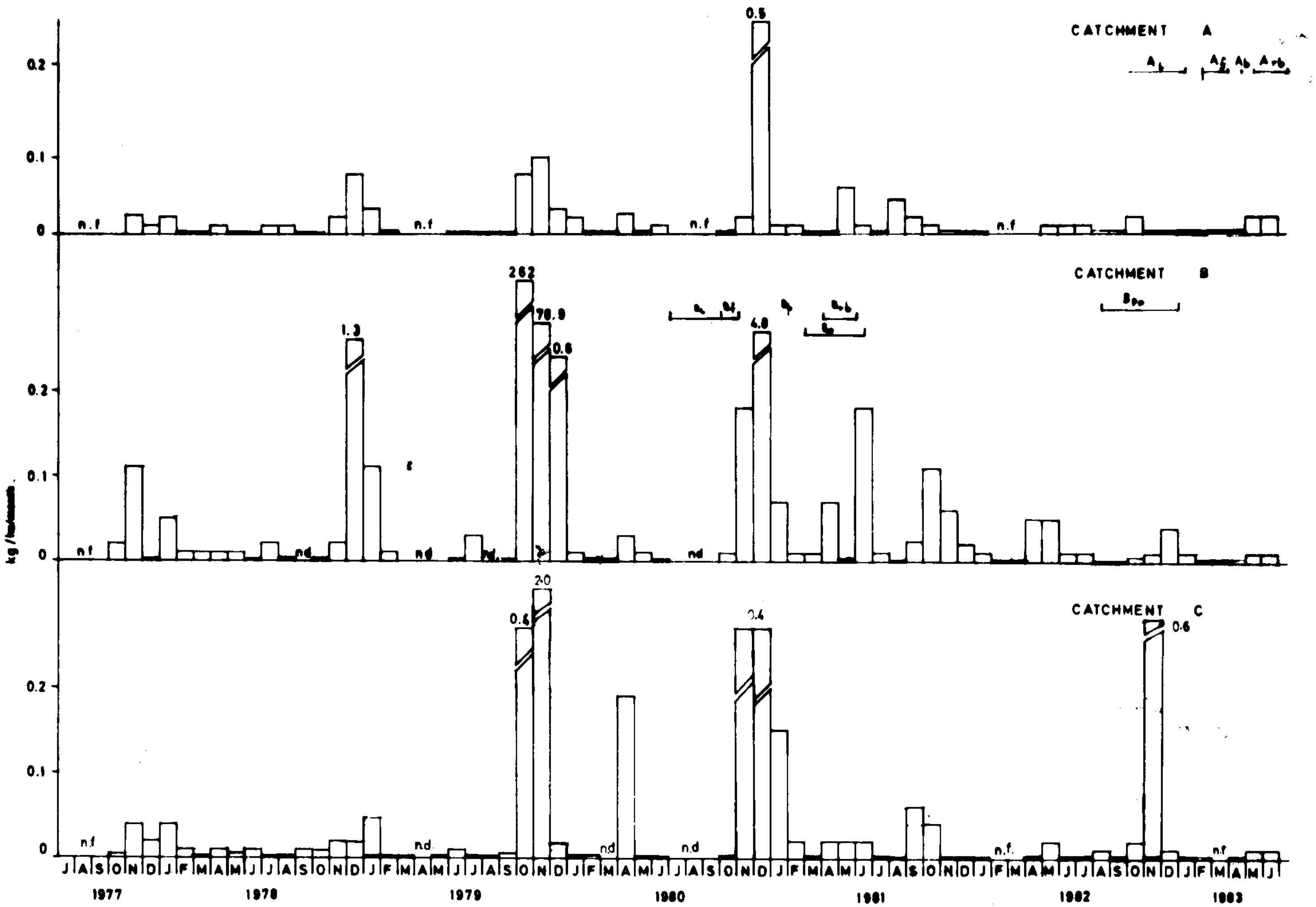


FIGURE 4.22 LOAD DISTRIBUTION OF PHOSPHATES IN CATCHMENTS A, B AND C

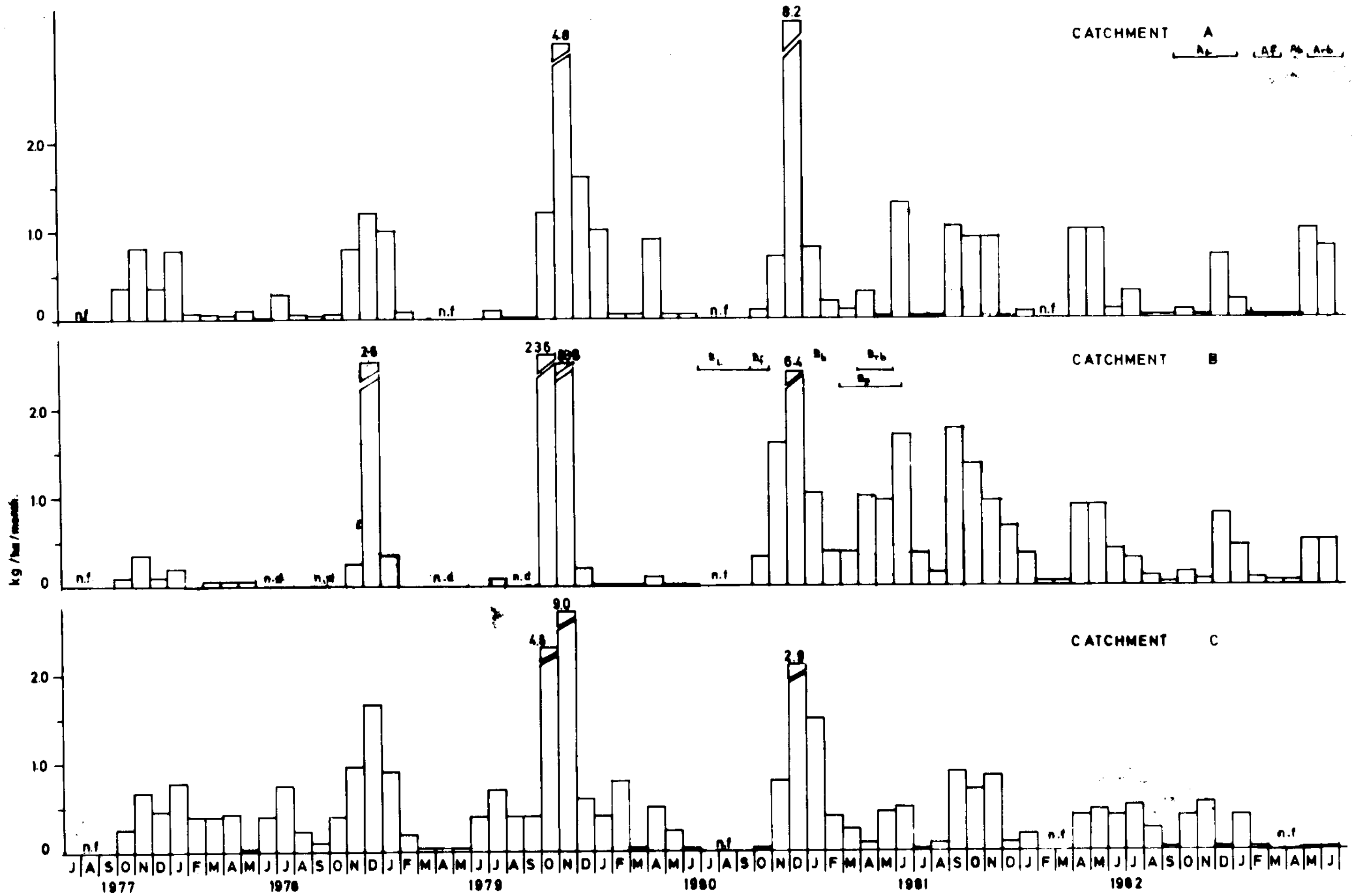


FIGURE 4.23 LOAD DISTRIBUTION OF IRON IN CATCHMENTS A, B AND C

Appendix 2 : Soil Profile Description.

Soil Pit. No 2 : Chat Series. (TYPIC PALEUDULT).

Topography	:	Undulating (5^{o})
Vegetation	:	Tertiary Jungle.
Parent Material	:	Iron-rich Shales.

Horizon Symbol	Horizon Depth.	Soil Profile Description.
Ah	0 - 3 cm.	Strong brown (7.5 YR 4/4); clay texture; very friable consistency; crumb structure; abundant pores; abundant fine root channels; distinct boundary.
B_{21}	3 - 71 cm.	Reddish Yellow (7.5 YR 6/8); fine sandy loam texture; friable to firm consistence; medium to moderate subangular blocky structures; many pores; patchy clayskins along few big root channels; few fine roots; distinct boundary; few ant nests present.
B_{22}	71 - 118 cm.	Yellowish red (5 YR 5/8); few faint mottlings; clay texture; friable consistence; fine moderate subangular blocky structures; few pores; patchy clayskins along few fine root channels; distinct boundary.
B_{23}	118 cm +	Yellow (10 YR 6/3); reddish (10 YR 4/8) plinthite and reddish yellow (7.5 YR 6/8) mottles; clay texture; friable consistence; medium moderate subangular blocky structure; few pores; few fine roots; few big channels; distinct boundary; variegated horizon with iron concretions.

Appendix 3 : Soil Profile Description.

Soil Pit. No 3 : Katong Series. (TROPEPTIC HAPLORTHOX)

Topography : Undulating (4^o)
Vegetation : Broad-leaf forest trees.
Parent Material : Quartz andesite.

Horizon Symbol	Horizon Depth	Soil Profile Description.
Ah	0 - 4 cm.	Dark brown (7.5 YR 4/4); clay texture; very friable consistence; crumb structure; abundant pores; abundant fine and big roots; abundant channels; indistinct boundary.
B_{21}	4 - 90 cm.	Strong brown (7.5 YR 5/6); clay texture; friable consistence; fine to medium subangular blocky structures; many pores; continuous clayskins; many big and small roots; few channels; distinct boundary; presence of termite nests at 5 - 15 cm depth.
B_{22}	90 cm +	Yellowish red (5 YR 5/8); yellow (10 YR 8/8) and brownish yellow (19 YR 6/6) mottling in streak form along voids; clay texture; friable consistence; fine to medium subangular blocked structures; many pores; continous clayskins; few big roots; few channels; diffuse boundary.

Appendix 4 : Soil Profile Description

Soil Pit. No 4 : Munchong Lateritic Phase (TROPEPTIC HAPLORTHOX)

Topography : Undulating (5°)
Vegetation : Tertiary Jungle.
Parent Material : Lateritic Shales.

Horizon Symbol	Horizon Depth.	Soil Profile Description.
Ah	0 - 4 cm	Dark brown (10 YR 4/3); clay texture; loose consistence; crumb structure; abundant pores; abundant roots; abundant channels; indistinct boundary.
B_{21}	4 - 50 cm	Strong brown (7.5 YR 5/8); clay texture; firm consistence; moderate to strong subangular blocky structures; many pores; patchy clayskins along root channels; few medium size roots; many channels; distinct boundary; few termite nests present.
B_{22cn}	50 - 95 cm	Strong brown (7.5 YR 5/8); clay texture; firm consistence; fine to moderate subangular blocky structures; few pores; few fine roots; distinct boundary; lateritic band composed of fine to large nodular and angular laterites.
B_{23t}	95 - 145 cm	Yellowish red (5 YR 5/8); brownish yellow (10 YR 6/6) mottlings; clay texture; firm consistence; fine to moderate subangular blocky structures; many patchy clayskins; distinct boundary.

Appendix 5 : Soil Profile Description.

Soil Pit. No. 5 : Munchong Series. (TROPEPTIC HAPLORTHOX)

Topography : Undulating (5^{o})
Vegetation : Tertiary Jungle.
Parent Material : Shale.

Horizon Symbol	Horizon Depth.	Soil profile Description.
Ah	0 - 2 cm.	Dark brown (7.5 YR 4/4); clay texture; loose consistence; crumb structure; abdundant pores; abundant fine and large roots; abundant channels; indistinct boundary; presence of abundant termite nests.
B_{21}	2 - 39 cm.	Strong brown (7.5 YR 5/6); clay texture; friable consistence; fine to medium subangular blocky structures; abundant pores; patchy clayskins; abundant fine and large roots; abundant channels; distinct boundary.
B_{22}	39 - 72 cm.	Strong brown (7.5 YR 5/8); clay texture; friable consistence; fine subangular blocky; many pores; many fine and medium roots; few channels; diffuse boundary.
B_{23}	72 - 130 cm.	Yellowish red (5 YR 5/8); clay texture; friable consistence; medium to moderate subangular blocky structure; patchy clayskins; few fine and medium roots; many fine iron concretions; distinct boundary.

Appendix 6 : Soil Profile Description.

<u>SoilPit.No</u> <u>6</u> : Munchong Lateritic Phase (TROPEPTIC HAPLORTHOX)

Topography : Rolling (8^o).
Vegetation : Tertiary Jungle.
parent Material : Lateritic Shales.

Horizon Symbol	Horizon Depth.	Soil Profile Description.
Ah	0 - 1 cm	Yellowish brown (10 YR 4.5/6); clay texture; friable consistence; crumb structure; abundant pores; abundant large roots; indistinct boundary.
B_{21}	1 - 33 cm.	Strong brown (7.5 YR 5/8); clay texture; friable to fine consistence; moderate subangular blocky structures; many pores; patchy clayskins along voids and root channels; many roots; many channels; few termite nests; diffuse boundary.
B_{22cn}	33 - 71 cm.	Strong brown (7.5 YR 5/8); clay texture; friable consistence; fine to moderate subangular blocky structure; few pores; few medium roots; few channels; abundant small and large iron concretions; distinct boundary.
B_{23cn}	71 cm +	Yellowish red (5 YR 5/8); clay texture; friable consistence; fine subangular blocky; few fine roots; big and small rods as well as slabs of iron concretions; diffuse boundary.

Appendix 7 : Soil Profile Description.

Soil Pit. No 7 : Segamat Series (HAPLIC ACRORTHOX).

Topography : Undulating (4^{o}).
Vegetation : Cocoa.
Parent Material : Andesite.

Horizon Symbol	Horizon Depth	Soil Profile Description.
AB	0 - 4 cm	Dark reddish brown (2.5 YR 3/4); heavy clay; moderate to weak, fine and medium subangular blocky and crumb; slightly sticky, slightly plastic; friable; common, fine and medium roots; diffuse smooth boundary.
B_{210x}	4 - 70 cm	Dark red (2.5 YR 3/6); heavy clay; moderate to weak, fine and medium subangular blocky; slightly sticky, slightly plastic, friable; many fine medium and coarse roots; diffuse smooth boundary.
B_{220x}	70 - 95 cm	Red (2.5 YR 4/6); heavy clay; moderate to weak, fine and medium subangular blocky; slightly sticky, slightly plastic; friable; common, fine and medium roots.

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