THE GOVERNMENT OF MALAYSIA
THE STATE OF SARAWAK

MIRI-BINTULU

REGIONAL PLANNING STUDY

SUPPORTING REPORT

No. 1

CLIMATE, HYDROLOGY AND LAND RESOURCES

—1974—

HUNTING TECHNICAL
SERVICES LTD. LONDON

HOFF AND OVERGAARD
COPENHAGEN

THE GOVERNMENTS OF MALAYSIA AND THE
STATE OF SARAWAK

MIRI BINTULU REGIONAL PLANNING STUDY

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No. 4

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C O N V E R S I O N S

ENGLISH AND METRIC EQUIVALENTS

Linear Measure:

1 inch	=	25.4 millimetres
	=	2.54 centimetres
1 foot (12 inches)	=	0.3048 metre
1 yard (3 feet)	=	0.9144 metre
1 chain (22 yards)	=	20.117 metres
1 mile (1 760 yards)	=	1.609 kilometres

Square Measure:

1 square inch	=	6.452 square centimetres
1 square foot	=	9.290 square decimetres
1 square yard	=	0.836 square metre
1 acre (4 840 sq. yards)	=	0.405 hectare
1 square mile (640 acres)	=	259.00 hectares

Cubic Measure:

1 cubic inch	=	16.387 cubic centimetres
1 cubic foot	=	0.028 cubic metre
1 cubic yard	=	0.765 cubic metre

Weights:

1 ounce (16 drams)	=	28.350 grammes
1 pound (16 ounces)	=	0.454 kilogram

Measure of Capacity:

1 pint	=	0.568 litre
1 quart	=	1.137 litres
1 gallon	=	4.546 litres

Velocities:

1 cubic foot per second or 1 cusec	=	0.028 cubic metre per second or cumecs
	=	28.31 cubic decimetres per second
1 gallon per hour	=	4.54 cubic decimetres per day
1 gallon per second	=	4.54 cubic decimetres per second

Temperature:

Fahrenheight	=	$9/5\ ^{o}C + 32$
Centigrade	=	$5/9\ (^{o}F - 32)$

PART I

CLIMATE AND HYDROLOGY

CHAPTER 1

1.1 INTRODUCTION

1.1.1 Terms of Reference

The scope of the water resources studies and therefore of the hydrological studies required for them is covered in the Terms of Reference (Schedule "A", Scope of Work), mainly under Phase II, para.24(5) which states:

> "Water Resources and Hydrology: The consultants will assess the long term requirements of water for urban, industrial and agricultural use, locate the possible sources of water supply and propose a phased schedule of investments. Detailed projects will be prepared for facilities required during the first six years of development with due regard to costs and longer term developments.
>
> The possible changes in the regime and discharges of rivers and their consequences as a result of use of water for various purposes, of discharge of waste water and of development activities in general including resulting ecological and environmental changes, will be studied. Necessary water management or conservancy measures should be indicated whenever flooding, silting and pollution in the lower reaches of the rivers are expected to increase beyond acceptable limits. Due weight must be given to the transport function of the rivers in this context".

In addition to this, para. 20(5) includes:

> "Transport: The consultants will project future air, land and water transport requirements, internal and external, consistent with overall development".

para. 24(2) includes:

> "Consideration should be given to the possible introduction of drainage and irrigation facilities within the semi-detailed master plan area".

and para. 24(4) includes:

> "Hydrogeological conditions are not encouraging in terms of underground water supply prospects, so that no significant input of geological expertise is necessary to meet the objectives of the regional study. Technical advice on these matters can be provided by staff of the Geological Survey when required by the Consultants".

1.1.2 Field Work

Field data collection finished at the end of October, 1973 because later records could not be used in the studies. All field installations and other hydrological equipment were handed over to the Government in November, 1973.

ment was made because of its advantages in data processing and computing facilities.

The two main aims of the field programme were:-

(a) to collect information on the flow characteristics and chemical quality of the surface waters likely to be needed as sources for water supply;

(b) to collect climatological data for the assessment of crop water and drainage requirements at a site representative of the areas which might be developed.

These represented subjects in which the existing information was limited, and yet which appeared most likely to feature in the detailed projects during the first years of development. Furthermore, they were considered to be within the limit of detailed supervision which could be exercised by one man (the Counterpart Hydrologist).

Field investigations of the changes in river flow and regime which might follow the development of the Study Area were impracticable with the manpower allocated. Other field investigations which it was originally hoped to carry out, such as suspended sediment sampling and surveys of flood levels proved to be impractical, as the workload of the main programme fully occupied the available staff.

1.1.3 Division of Hydrological Studies

The hydrological studies which have been carried out are of two kinds:-

(a) studies of the general hydrological characteristics of the Study Area as a background for other work;

(b) studies related to particular projects.

The general hydrology and climate of the Study Area in addition to providing a background for development affect the overall plans, particularly the choice of appropriate agricultural developments. Project hydrological studies concern the specific topics included in the Terms of Reference.

In accordance with the division of the hydrological studies, this chapter has two main sections. A brief third section contains recommendations for future climatological and hydrological data collection. Much of the detailed material is presented in the form of appendices, including summaries of all the data collected during the field work.

1.2 THE REGIONAL SETTING

1.2.1 The Land

The Fourth Division of Sarawak lies between the South China Sea and the Penambo range, which forms the border with Kalimantan (Indonesian Borneo). It contains the basins of the Batang Baram, the second river of Sarawak after the Rajang, together with the Batang Kemena and smaller rivers draining directly to the sea.

The Study Area covers some 5 800 square miles (15 000 square kilometres) of the Fourth Division and lies between latitudes 3°00' and 4°35' north and longitudes 113°00' and 114°40' east. On the north and east it is bounded by the Batang Baram, and on the south by the Batang Kemena. Just over half lies in the basins of these two rivers, the remaining central portion being drained by smaller rivers (see Figure 1.1).

The northern and central parts of the Study Area are lowlands, forming part of an extensive sedimentary basin which includes almost the whole of the Third, Fourth and Fifth Divisions as well as Brunei (Liecthi, P., 1960). Swamp or near-swamp conditions prevail over large areas, particularly in the lower portion of the Baram basin. Elevations in the south are higher, a ridge immediately to the north of the Batang Kemena rising gradually from the sea to reach a maximum of 4 330 feet at Bukit Dulit close to where the Sungai Tinjar enters the Study Area. Much higher relief occurs in the part of the Baram basin which lies outside the Study Area, reaching to 7 950 feet at Gunong Murud.

The geology of the Study Area is dominated by soft, fine-grained sedimentary rocks of very variable composition with occasional limestone remnants, such as Bukit Subis. They have low permeability and, in common with the widespread non-accreting alluvial soils derived from them, a low resistance to erosion (see Section 1.4.6).

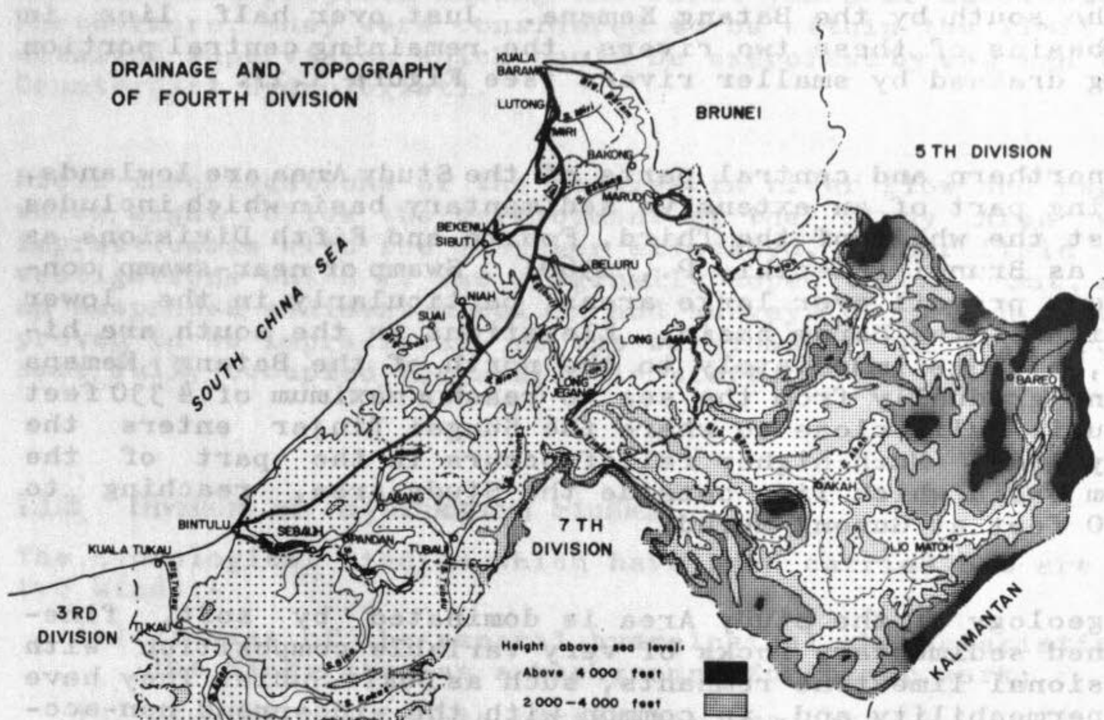
Except in the swamp areas, and on the poorer soils where patches of heath (Kerangas) forest occur, the natural vegetation of most of the Study Area is Mixed Dipterocarp Forest. Under undisturbed conditions the continuous leaf canopy and surface litter of this forest protect the soil from the direct and destructive impact of rain and solar radiation.

1.2.2 Regional Climate

The climate of Sarawak is monsoonal in the sense that there are distinct seasonal shifts in the prevailing winds in which one persistent circulation system is replaced by a reverse and equally persistent system (Ramage, C.S., 1971). In Sarawak, the two winds and the seasons over which they persist, are known as the north-east monsoon (locally called the "landas")

FIGURE 1.1

DRAINAGE AND TOPOGRAPHY OF FOURTH DIVISION



and the south monsoon. The south monsoon is less vigorous than the north-east monsoon.

On the basis of this circulation pattern four seasons can be distinguished:-

(a) the north-east monsoon ("landas"), usually established by January and remaining dominant through February and March;

(b) an inter-monsoon period of weaker circulation during which the boundary between the retreating north-east airstream and the advancing southerly airstream moves slowly and erratically northward over Borneo;

(c) the south monsoon, which persists from around May until September;

(d) a second inter-monsoon period during which the airstream boundary passes back across Borneo in a southerly direction.

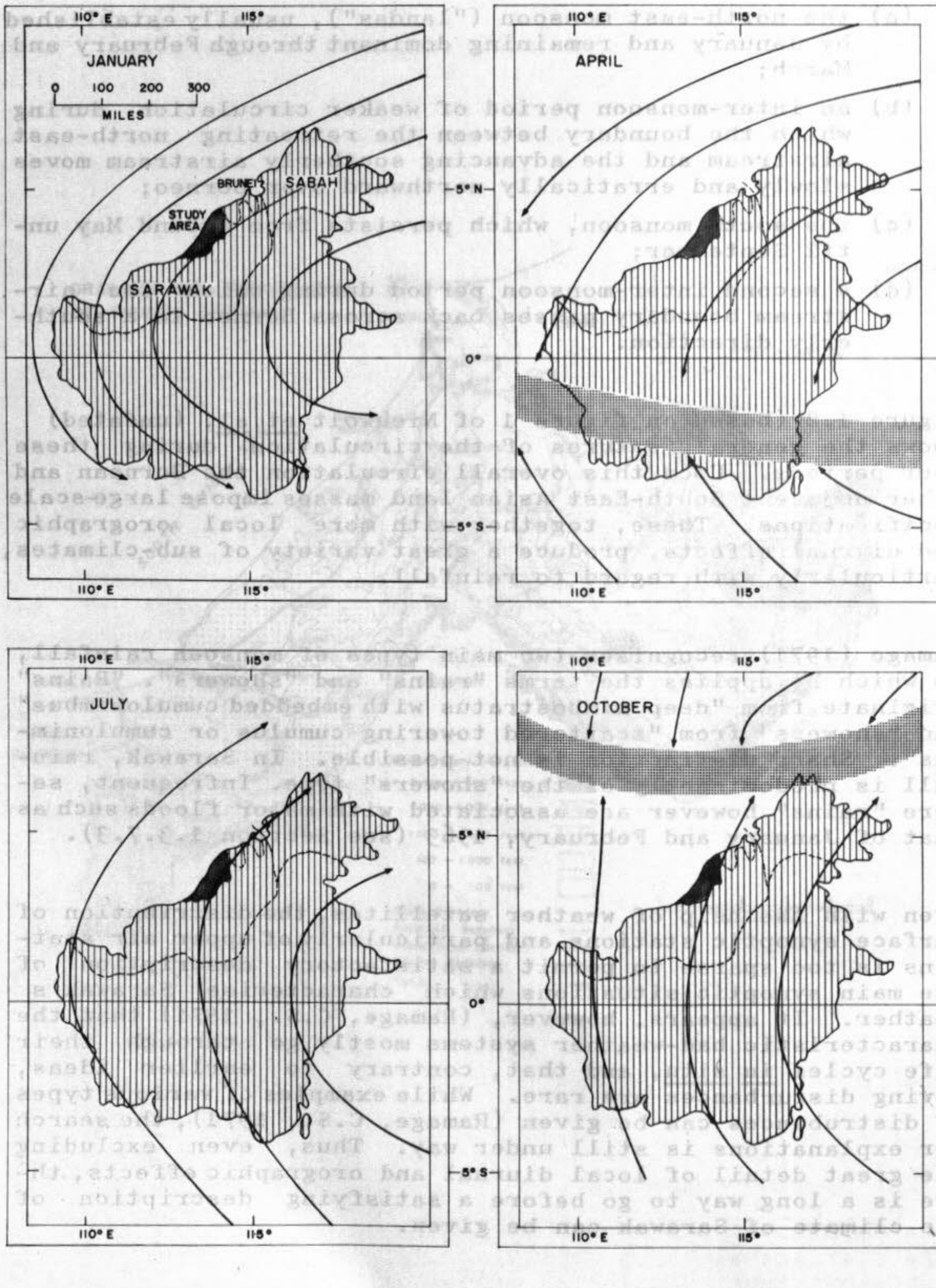
Figure 1.2 (based on figure 1 of Nieuwolt _et al_, (undated) shows the general features of the circulation during these four periods. Upon this overall circulation the Bornean and other adjacent South-East Asian land masses impose large-scale modifications. These, together with more local orographic and diurnal effects, produce a great variety of sub-climates, particularly with regard to rainfall.

Ramage (1971) recognises two main types of monsoon rainfall, to which he applies the terms "rains" and "showers". "Rains" originate from "deep nimbostratus with embedded cumulonimbus" and "showers" from "scattered towering cumulus or cumulonimbus". Sharp distinction is not possible. In Sarawak, rainfall is predominantly of the "showers" type. Infrequent, severe "rains" however are associated with major floods such as that of January and February, 1963 (see Section 1.3.7.3).

Even with the help of weather satellites, the distribution of surface synoptic stations and particularly of upper air stations is too sparse to permit a satisfactory description of the main synoptic situations which characterise Sarawak's weather. It appears, however, (Ramage, C.S., 1971) that the characteristic bad-weather systems mostly go through their life cycles _in situ_, and that, contrary to earlier ideas, moving disturbances are rare. While examples of various types of distrubances can be given (Ramage, C.S., 1971), the search for explanations is still under way. Thus, even excluding the great detail of local diurnal and orographic effects, there is a long way to go before a satisfying description of the climate of Sarawak can be given.

FIGURE 1.2

SURFACE WINDS AND AIR STREAM BOUNDARIES



1.3 GENERAL HYDROLOGICAL STUDIES

1.3.1 Outline

At the start of the Study, considering the available data and the additional data which could reasonably be collected, it was envisaged that the hydrological studies would consist mainly of those needed for water supply and irrigation projects. Other topics would be treated in a more general way. However, following the initial broad assessment of land capability, it became apparent that there was little scope for irrigation projects, and that detailed hydrological work would consequently be confined to water supply schemes.

A climate station at Kabuloh had by then been established and a considerable amount of work done on rainfall and evaporation; directed mainly towards the assessment of crop water requirements. Although no final irrigation studies were carried out, the information on rainfall and evaporation is presented. Also included as background information are estimates of mean river flows and discussions of the historic flood and drought.

As all these studies depended upon the nature and extent of the basic data available, before describing the results it is appropriate to outline the existing and Study Area hydrological networks and data.

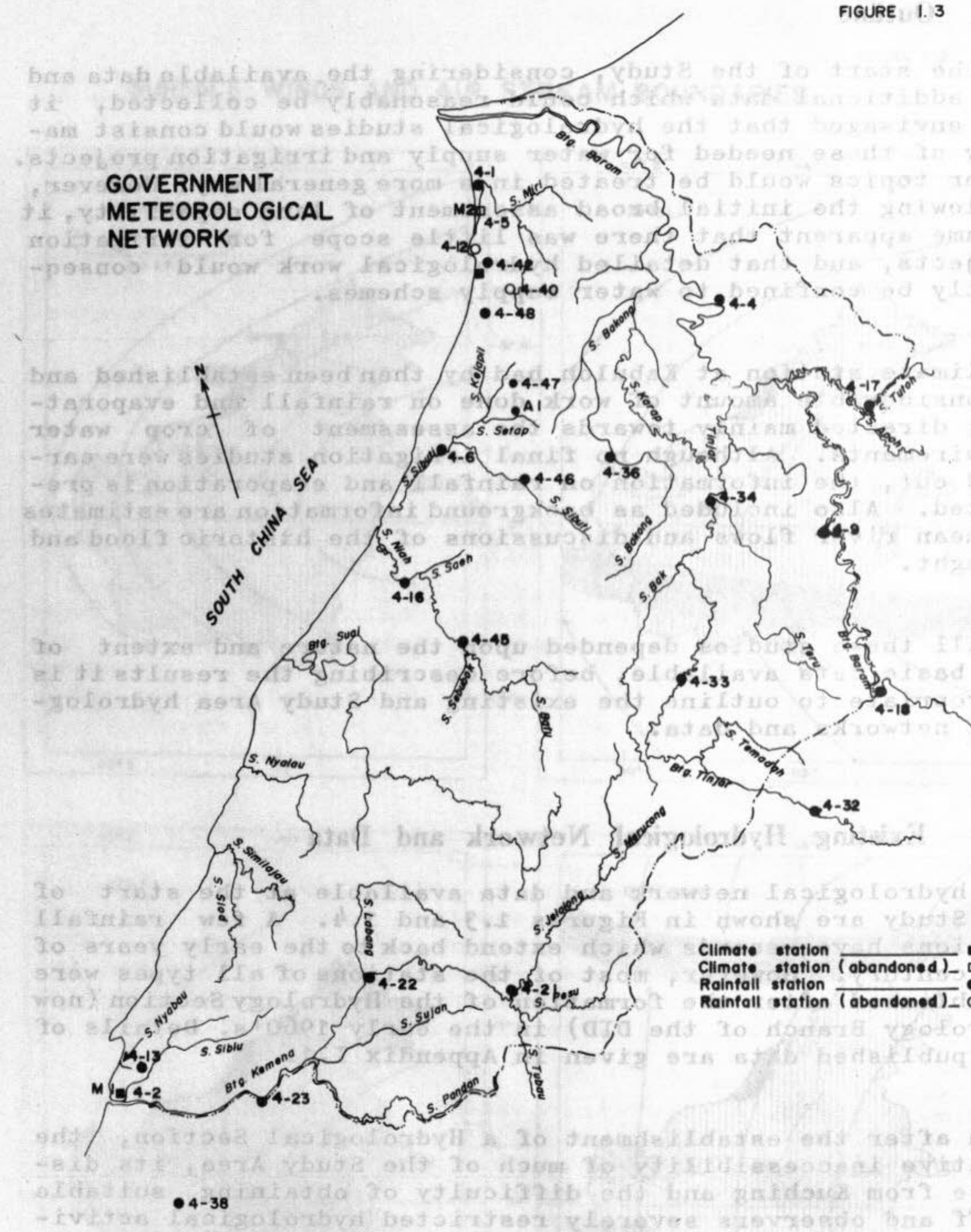
1.3.2 Existing Hydrological Network and Data

The hydrological network and data available at the start of the Study are shown in Figures 1.3 and 1.4. A few rainfall stations have records which extend back to the early years of the century. However, most of the stations of all types were established after the formation of the Hydrology Section (now Hydrology Branch of the DID) in the early 1960's. Details of the published data are given in Appendix I.1.

Even after the establishment of a Hydrological Section, the relative inaccessibility of much of the Study Area, its distance from Kuching and the difficulty of obtaining suitable staff and observers severely restricted hydrological activities. However, the completion of the Miri-Bintulu road early in the Study period, and the provision of a Counterpart Hydrologist posted to the Study Office in Miri, allowed an important amount of hydrological field work to be carried out to supplement the existing data.

At the start of the investigations there were 11 river gauging stations, 2 climatological stations, and 23 rainfall stations in operation in the Study Area.

FIGURE 1.3



1.3.3 Hydrological Network and Data

The initial appraisal showed that further data on stream flows and evaporation field work were required in order to provide an adequate basis for studying possible water development schemes. The stations established and information on their records are shown in Figure 1.5.

FIGURE 1.3

BAR CHART OF RAINFALL AND CLIMATOLOGICAL RECORDS

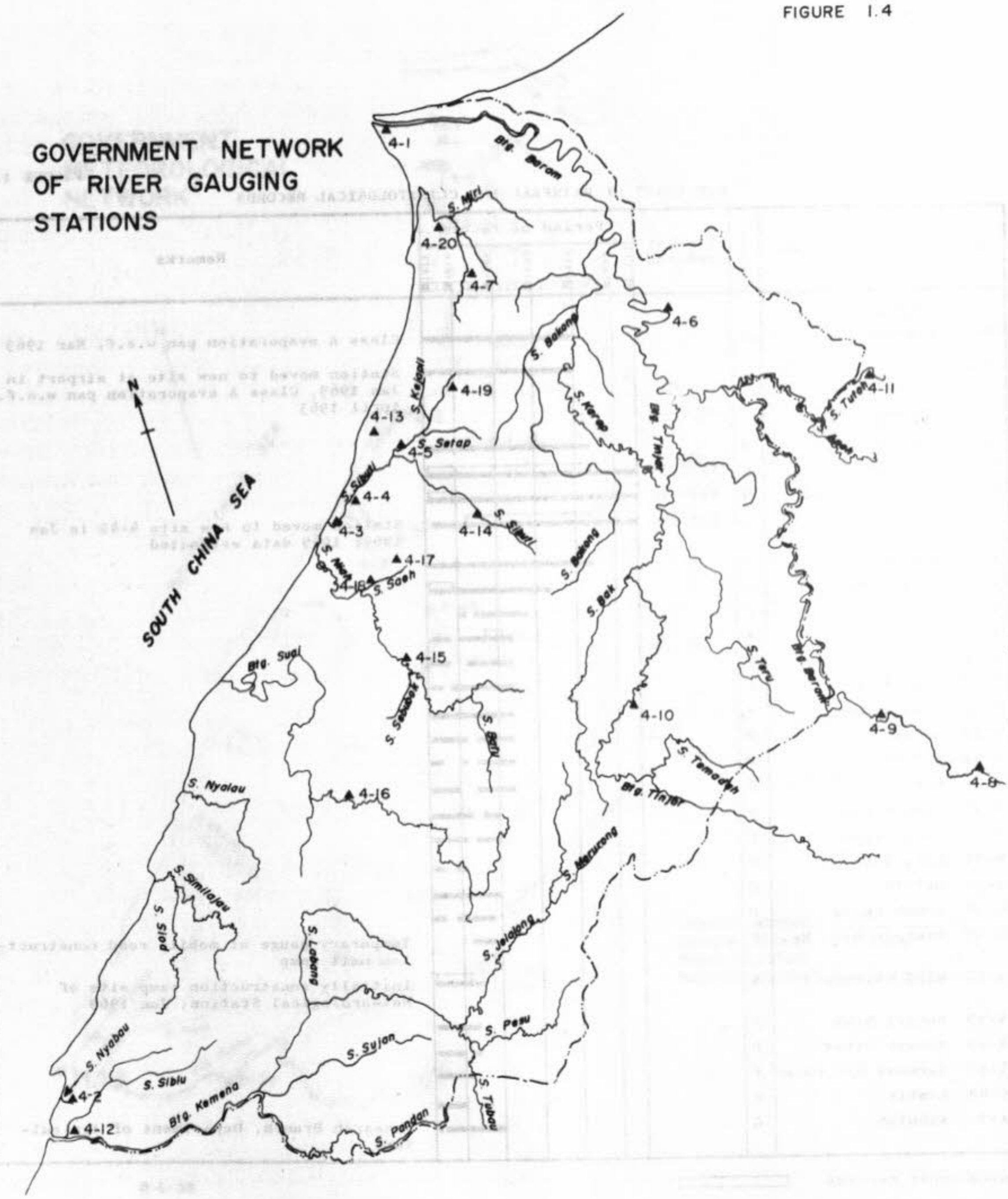
No.	Station	Consistency	Earlier records	Period of record (1947, 1950, 1955, 1960, 1965, 1970, 1973)	Remarks
	Climate				
M-1	Bintulu				Class A evaporation pan w.e.f. Mar 1963
M-2	Miri				Station moved to new site at airport in Jan 1969, Class A evaporation pan w.e.f. April 1963
	Rainfall				
4-1	Lutong	G			
4-2	Bintulu	G	1915-39		
4-4	Marudi	G	1914-40		
4-5	Miri	G	1917-40		Station moved to new site 4-42 in Jan 1969; 1969 data estimated
4-6	Bekenu	F			
4-9	Long Lama	P			
4-12	Tanjong Lobang	G			
4-13	Nyabau	F			
4-16	Niah	P			
4-17	Long Panai	F			
4-18	Long Pilah	F			
4-21	Tubau	P			
4-22	Labang	F			
4-23	Sebauh	F			
4-32	Long Sabing	P			
4-33	Long Jegan	F			
4-34	Long Teru	F			
4-36	Beluru	G			
4-38	Rumah Luang	P			
4-40	Bintulu Miri Mg.	F			Temporary gauge at mobile road construction unit camp
4-42	Miri (Airport)	G			Initially construction camp site of Meteorological Station, Jan 1969
4-45	Sungai Niah	P			
4-46	Sungai Sibuti	P			
4-47	Sarawak Oil Palm	F			
4-48	Lambir	F			
A-1	Kabuloh	G			Research Branch, Department of Agriculture

Autographic records

Notes: 1. Climatological data are published in the Annual Climatological Summaries of the Malayan Meteorological Service. Rainfall data are published in the Dept. of Civil Aviation (1958) and from July 1962 in the Sarawak Hydrological Yearbooks. Unpublished data are on file at DID Headquarters, Kuching.

2. Consistency of rainfall records assessed by double-mass plots; G = Good; F = Fair; P = Poor

FIGURE 1.4



The two existing climatological stations at Miri and Bintulu are near the coast, and their records are probably not representative of conditions in the main areas of existing and likely future agricultural development. Therefore a climatological station was established inland, at Kabuloh. The choice of locations was limited by the availability of resident observers and sites of suitable exposure. The best location was at the Agricultural Experimental Station at Kabu-

FIGURE 1.4

BAR CHARTS OF RIVER RECORDS

River and station	No.	Drainage area (Square mile)	Gauge type	Period of record 1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	Remarks
Batang Baram at Kuala Baram	4-1	8 673	R(W)											P
Sungai Nyabau at Nyabau dam	4-2	0.17	R(W)											Small dam for Bintulu water supply. Dam raised in 1968
Sungai Sibuti at Kelulit	4-3		R(W)											D
Sungai Sibuti at Rancha Rancha	4-4		R(W)											D
Sungai Sibuti at Satap	4-5		R(W)											D
Batang Baram at Marudi	4-6		R(W)											New recorder station w.e.f. 24-12-70
Sungai Liku	4-7	26	R(W)											Some rough estimates of minimum flows for new Miri supply intake W
Batang Baram at Liu Matu	4-8	1 015	S											Rating not yet fully developed H
Batang Baram at Long Pilah	4-9	3 732	S											Rated section u/s of main gauge H
Batang Tinjar at Long Jegan	4-10	923	S											H
Batang Tutoh at Long Terawan	4-11	1 248	S											H
Sungai Sibiu	4-12	60	S											Discharge record prepared by Study W
Sungai Opak	4-13		S											D
Sungai Sibuti	4-14	67.5	S											Gauge height record intermittent D
Sungai Niah	4-15	310	S											Gauge height record unreliable B
Sungai Suai	4-16	219	S											Spot discharge measurements only B
Sungai Saeh Merah	4-17		S											D
Sungai Saeh Puteh	4-18		S											D
Sungai Nusah at Kuala Nusah	4-19		S											D

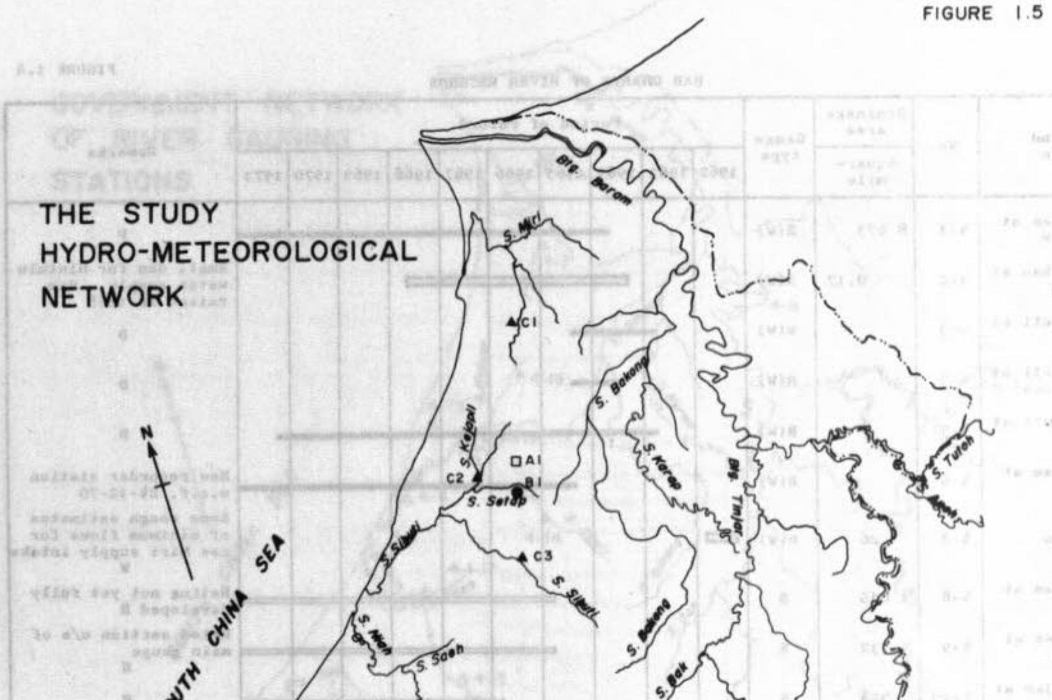
Legend:
- W.L. recorder (tidal)
- W.L. recorder (unrated)
- Staff gauge (rated)
- Staff gauge (unrated)
- Weekly recorder R(W)
- Staff gauge S

P = Port investigation
D = Drainage investigation
H = Hydroelectric investigation
W = Water supply investigation
B = Bridge investigation

Note: Many records contain gaps which are not detailed here.

Source: All stations operated by the Drainage and Irrigation Department. Information from Sarawak Hydrological Yearbook.

FIGURE 1.5



loh. Details of the instrumentation and records are given in Appendix I.2.

Six rain gauges were established, mostly in the area between the Sungai Niah and Bintulu along the most recently completed section of the Miri-Bintulu road. Their purpose was to pro-

FIGURE 1.5

BAR CHART OF STUDY CLIMATOLOGICAL, RAINFALL AND FLOW RECORDS

No.	Location	Type of gauge	1972 O	1972 N	1972 D	1973 J	1973 F	1973 M	1973 A	1973 M	1973 J	1973 J	1973 A	1973 S	1973 O	Remarks
	Climate															
A1	Kabuloh		—	—	—	—	—	—	—	—	—	—	—	—	—	See Appendix I.3 for details of meteorological instruments.
	Rainfall															
B1	Soil loss experiment	S				—	—	—	—	—	—	—	—	—	—	Gauge read periodically by CDC staff
B2	Rumah Mamat	S				—	—	—	—	—	—	—	—	—	—	Observer: Sebie ak Achoi
		R							—	—	—	—	—	—	—	
B3	Mile 34 Bintulu-Miri	R							—	—	—	—	—	—	—	With check gauge serviced by MBP staff
B4	Mile 24 Bintulu-Miri	S				—	—	—	—	—	—	—	—	—	—	Read weekly by MBP staff
B5	Mile 8 - Road Camp	D				—	—	—	—	—	—	—	—	—	—	Observer: Yuseff Hj. Salleh
B6	Mile 6 - Treatment Works site	D				—	—	—	—	—	—	—	—	—	—	W.e.f. totalisator check gauge installed, Observer Siong King Hing
A1	Kabuloh	R	—	—	—	—	—	—	—	—	—	—	—	—	—	Read by staff of Agricultural Research Station
	Riverflow															
C1	Sungai Liku	R		—	—	—	—	—	—	—	—	—	—	—	—	With 2x daily staff gauge read by Lambir Waterworks staff
C2	Sungai Kejapil	R		—	—	—	—	—	—	—	—	—	—	—	—	No local gauge reader
C3	Sungai Sibuti	R		—	—	—	—	—	—	—	—	—	—	—	—	No local gauge reader
C4	Sungai Niah	R			—	—	—	—	—	—	—	—	—	—	—	With 2x daily staff gauge readings by DID observer
C5	Sungai Suai	R			—	—	—	—	—	—	—	—	—	—	—	With 2x daily staff gauge readings by Sebie ak Achoi
C6	Sungai Sibiu	R			—	—	—	—	—	—	—	—	—	—	—	With 2x daily staff gauge by DID observer

Key: S = Storage gauge
D = Daily gauge
R = Autographic recorder (all pressure-bulb type except C1 which was float-operated)

vide some information in an area where none was available and for comparison with the previous streamflow measurements. The Study rainfall stations were of various types, depending mainly upon the availability of observers, and ranged from autographic gauges with daily check gauges, to totalising gauges read at weekly intervals. Data from these rainfall stations are given in the tables of Appendix I.3.

Six river gauging stations were established on the smaller rivers in the Study Area along the line of access provided by the Miri-Bintulu road. The number of these stations was governed by the amount of work which could be done by a single gauging team based on Miri. All the stations were equipped with water level recorders. Details of the stations, and of the records obtained, are given in Appendix I.4.

In conjunction with the stream gauging, regular water samples were taken at Study gauging stations and submitted to the Government Analytical Laboratory at Kuching for chemical analyses. The results are given in Appendix I.5.

Following the completion of the field work at the end of October, 1973 all the hydrological equipment and installations were handed over to the Government. The Drainage and Irrigation Department took over the river gauging and rainfall stations with the river gauging and rainfall equipment, and the Research Branch of the Department of Agriculture took over the climate station at Kabuloh, and its associated instruments and spares.

1.3.4 Climate - General

The temperature and humidity regime observed in the Study Area is typical of lowland equatorial climates. The mean annual temperature is about 26°C (79°F) and there is little seasonal variation. Figures 1.6 and 1.7 illustrate the monthly and diurnal regimes and show that the main temperature and humidity variations are diurnal.

1.3.5 Evaporation

A detailed discussion of evaporation is given in Appendix I.6. The conclusion is that over the priority development areas along the Miri-Bintulu road potential evaporation as indicated by the Penman open water evaporation estimate is 1 700 mm per year (67 inches per year). Table 1.1 shows the estimated monthly values.

FIGURE 1.6

MONTHLY TEMPERATURE REGIME

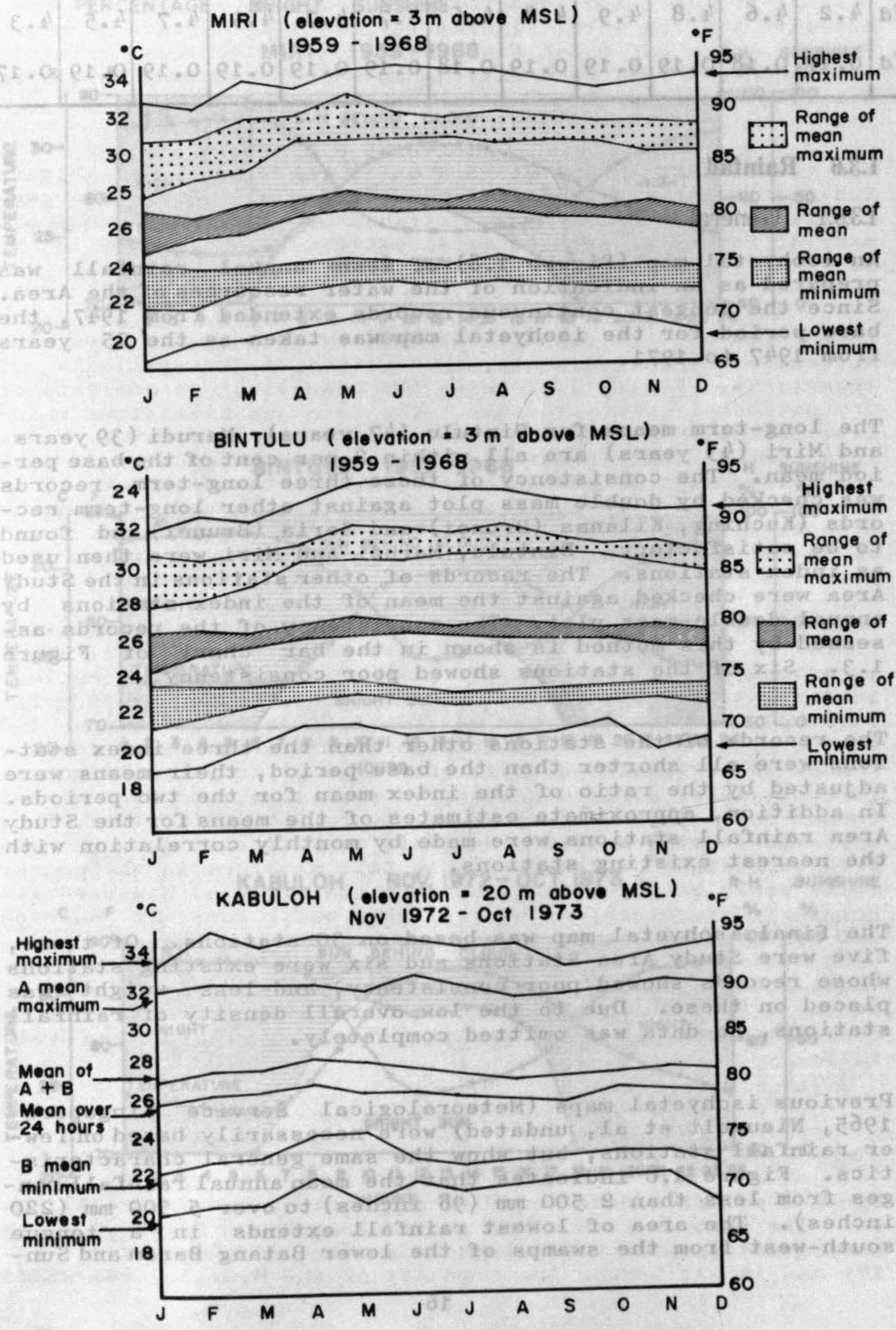


TABLE 1.1 ESTIMATED PENMAN OPEN WATER EVAPORATION

	J	F	M	A	M	J	J	A	S	O	N	D	Y
mm/d	4.2	4.6	4.8	4.9	4.8	4.6	4.7	4.7	4.9	4.7	4.5	4.3	4
in/d	0.17	0.18	0.19	0.19	0.19	0.18	0.19	0.19	0.19	0.19	0.19	0.17	0

1.3.6 Rainfall

1.3.6.1 General

An isohyetal map (Figure 1.8) of mean annual rainfall was prepared as an indication of the water resources of the Area. Since the longest continuous records extended from 1947, the base period for the isohyetal map was taken as the 25 years from 1947 to 1971.

The long-term means for Bintulu (47 years), Marudi (39 years and Miri (43 years) are all within 2 per cent of the base period mean. The consistency of these three long-term records was checked by double mass plot against other long-term records (Kuching, Kilanas (Brunei) and Seria (Brunei) and found to be satisfactory. Bintulu, Marudi and Miri were then used as index stations. The records of other stations in the Study Area were checked against the mean of the index stations by annual double-mass plot. The consistency of the records assessed by this method is shown in the bar chart of Figure 1.3. Six of the stations showed poor consistency.

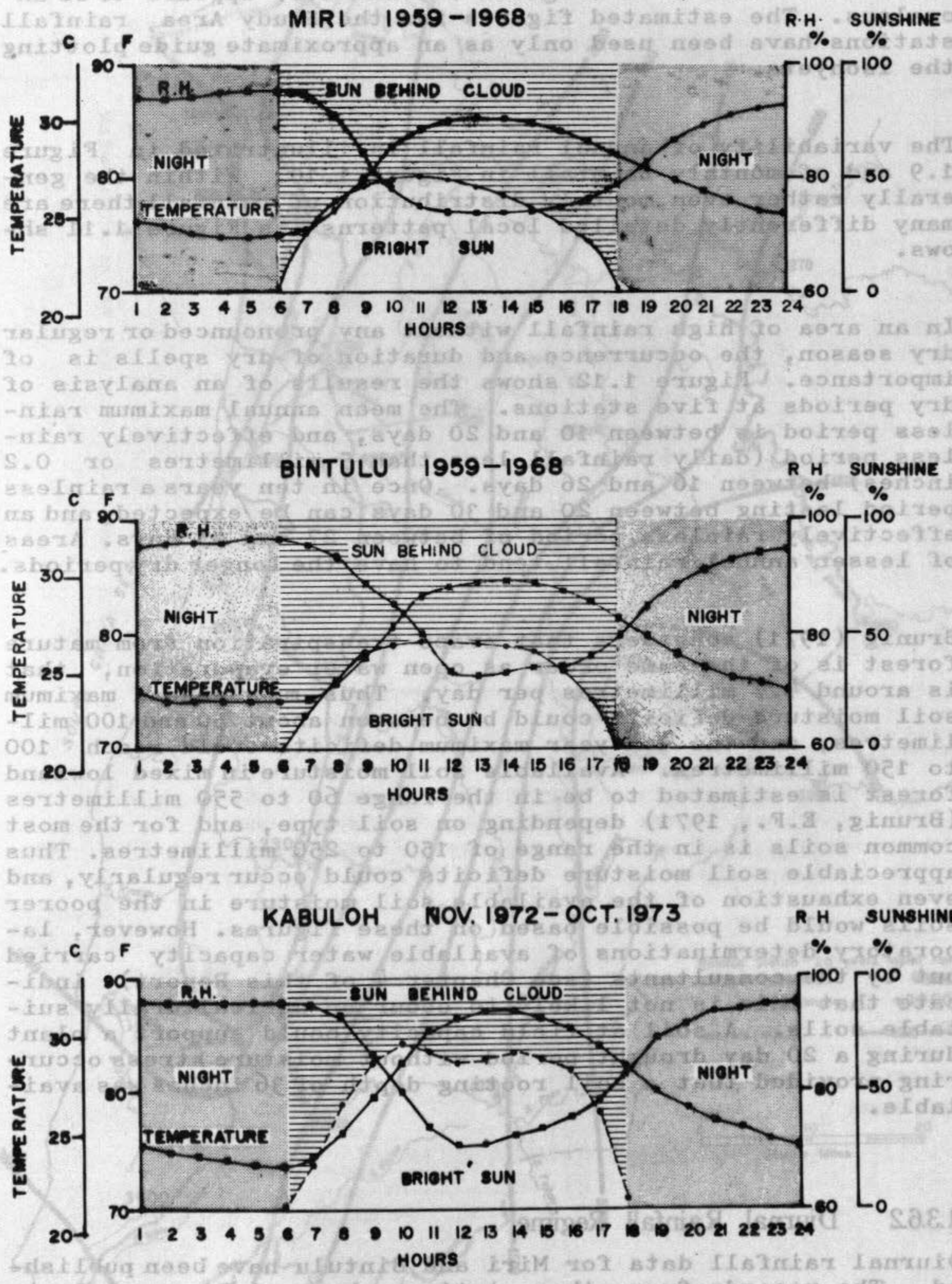
The records of the stations other than the three index stations were all shorter than the base period, their means were adjusted by the ratio of the index mean for the two periods. In addition, approximate estimates of the means for the Study Area rainfall stations were made by monthly correlation with the nearest existing stations.

The final isohyetal map was based on 30 stations. Of these, five were Study Area Stations and six were existing stations whose records showed poor consistency, and less weight was placed on these. Due to the low overall density of rainfall stations, no data was omitted completely.

Previous isohyetal maps (Meteorological Service Singapore 1965, Nieuwolt et al, undated) were necessarily based on fewer rainfall stations, but show the same general characteristics. Figure 1.8 indicates that the mean annual rainfall ranges from less than 2 500 mm (98 inches) to over 5 500 mm (220 inches). The area of lowest rainfall extends in a tongue south-west from the swamps of the lower Batang Baram and Sun-

FIGURE 1.7

DIURNAL VARIATION IN TEMPERATURE, RELATIVE HUMIDITY AND PERCENTAGE BRIGHT SUNSHINE



gai Bakong across the middle of the Sibuti, Niah and Suai basins. The area of highest rainfall lies along the south eastern edge of the Study Area where the Batang Baram and Batang Tinjar emerge from the highlands of the interior. The main rainfall gradient is thus perpendicular to the coast, falling at first and then rising steeply. The rainfall measured at station 4-46 (Figures 1.3 and 1.8) appears to be anomalous. The estimated figures for the Study Area rainfall stations have been used only as an approximate guide plotting the isohyets.

The variability of annual rainfall is illustrated in Figure 1.9 and of monthly rainfall in Figure 1.10. Within the generally rather even monthly distribution of rainfall there are many differently detailed local patterns as Figure 1.11 shows.

In an area of high rainfall without any pronounced or regular dry season, the occurrence and duration of dry spells is of importance. Figure 1.12 shows the results of an analysis of dry periods at five stations. The mean annual maximum rainless period is between 10 and 20 days, and effectively rainless period (daily rainfall less than 5 millimetres or 0.2 inches) between 16 and 26 days. Once in ten years a rainless period lasting between 20 and 30 days can be expected, and an effectively rainless period of between 27 and 45 days. Areas of lesser annual rainfall tend to have the longer dry periods.

Brunig (1971) considers that evapo-transpiration from mature forest is of the same order as open water evaporation, that is around 4.7 millimetres per day. Thus, mean annual maximum soil moisture deficits could be between about 50 and 100 millimetres, and the ten year maximum deficits could reach 100 to 150 millimetres. Available soil moisture in mixed lowland forest is estimated to be in the range 60 to 550 millimetres (Brunig, E.F., 1971) depending on soil type, and for the most common soils is in the range of 150 to 250 millimetres. Thus appreciable soil moisture deficits could occur regularly, and even exhaustion of the available soil moisture in the poorer soils would be possible based on these figures. However, laboratory determinations of available water capacity carried out by the consultants (see Chapter 4 of this Report) indicate that this is not likely to occur on agriculturally suitable soils. A soil at field capacity could support a plant during a 20 day drought period without moisture stress occurring provided that a soil rooting depth of 36 inches was available.

1.3.6.2 Diurnal Rainfall Regime

Diurnal rainfall data for Miri and Bintulu have been published. The records from other stations shown on Figure 1.3 as having autographic rain gauge data have not been analysed fully and it was beyond the capacity of the hydrological staff

FIGURE 1.8

MEAN ANNUAL ISOHYETAL MAP 1947-1971 (25 YEARS)

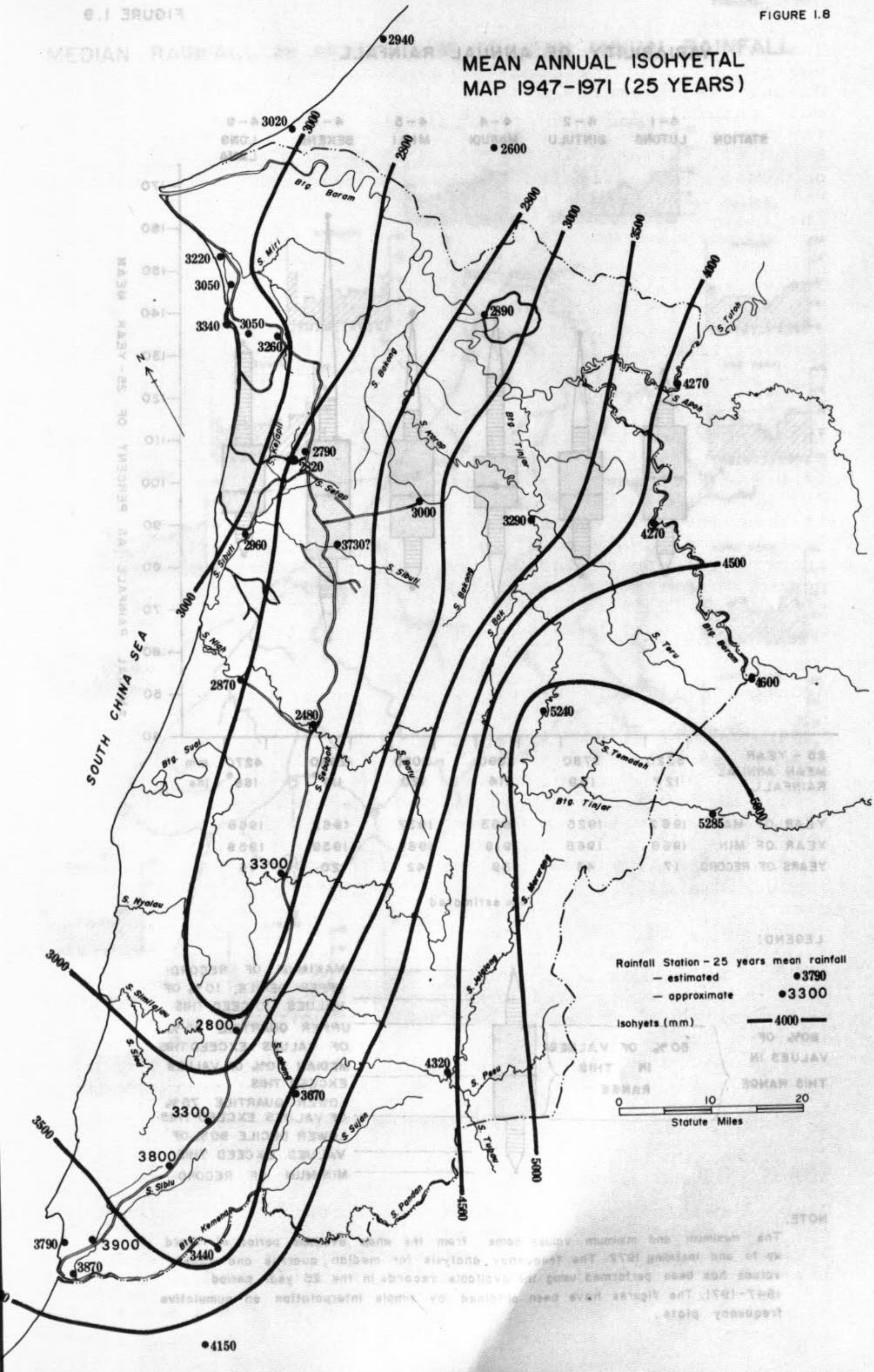
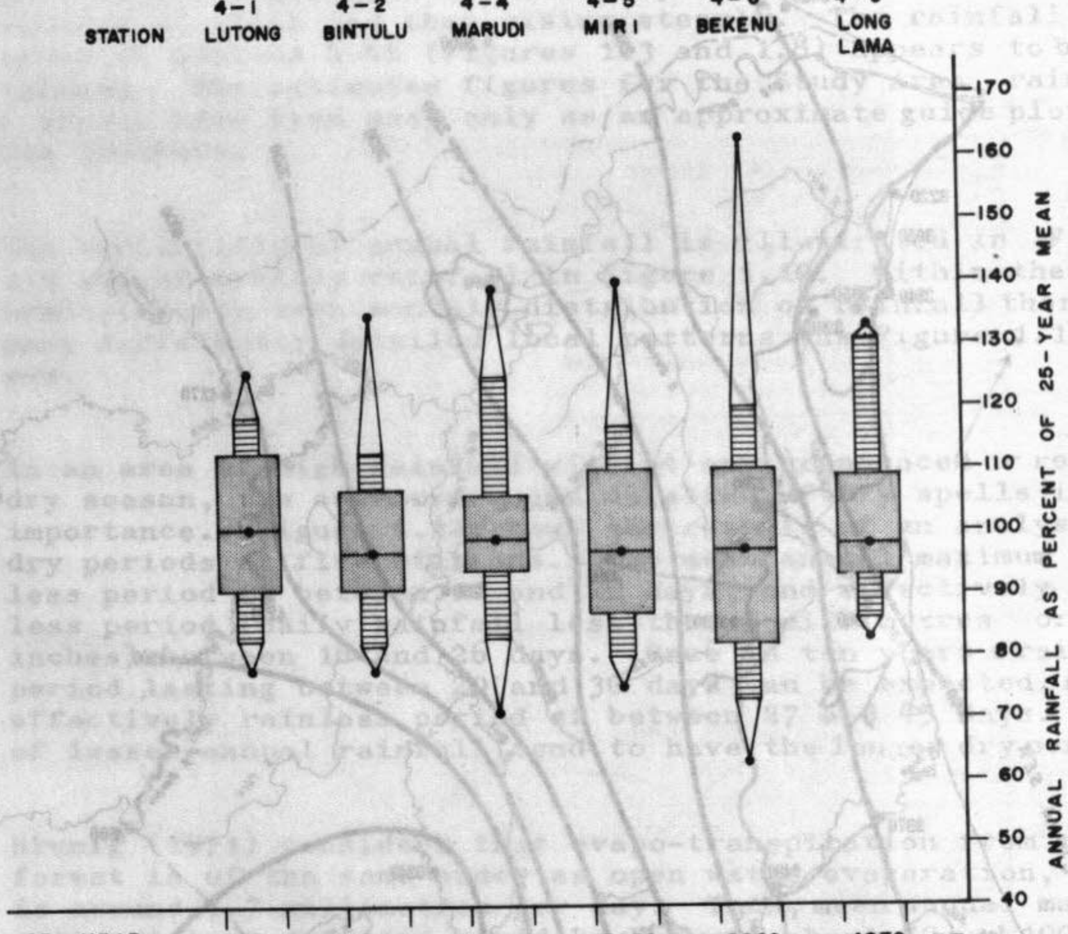


FIGURE 1.9

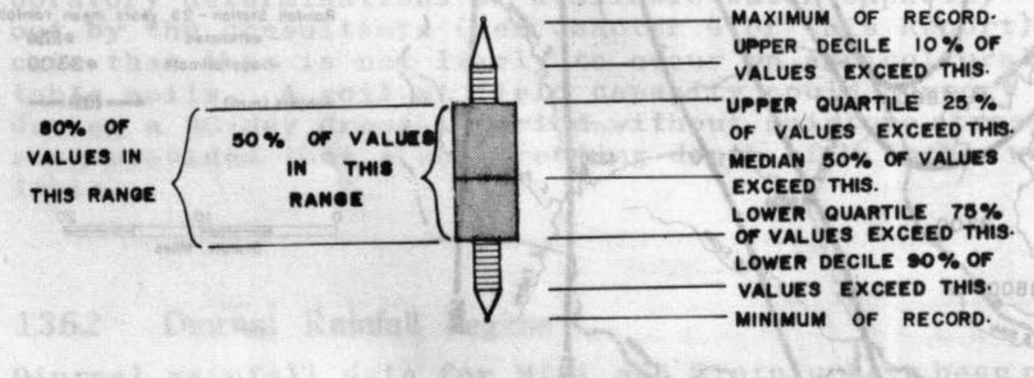
VARIABILITY OF ANNUAL RAINFALL



	LUTONG	BINTULU	MARUDI	MIRI	BEKENU	LONG LAMA	
25 - YEAR MEAN ANNUAL RAINFALL	3320	3780	2890	3050	2960*	4270*	mm
	127	149	114	120	117*	168*	Ins
YEAR OF MAX.	1962	1925	1963	1937	1962	1966	
YEAR OF MIN.	1968	1965	1919	1961	1959	1959	
YEARS OF RECORD	17	43	39	42	20	15	

* = estimated

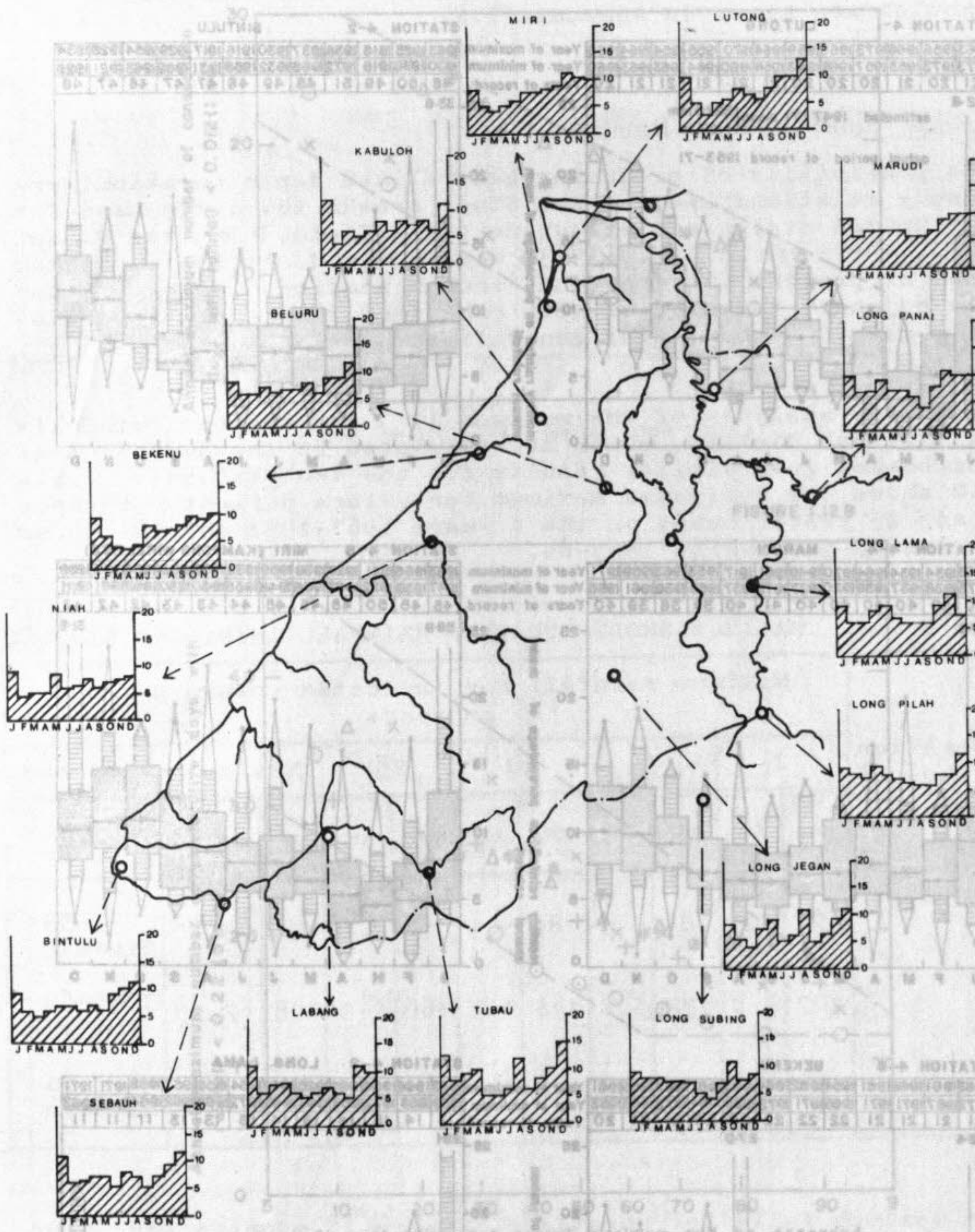
LEGEND:



NOTE:

The maximum and minimum values come from the whole available period of record up to and including 1972. The frequency analysis for median, quartile and decile values has been performed using the available records in the 25 year period 1947-1971. The figures have been obtained by simple interpolation on cumulative frequency plots.

MEDIAN RAINFALL AS PERCENTAGE OF MEAN ANNUAL RAINFALL



Based on analysis of all available monthly totals in the period 1947-1971.

FIGURE 1.11

VARIABILITY OF MONTHLY RAINFALL

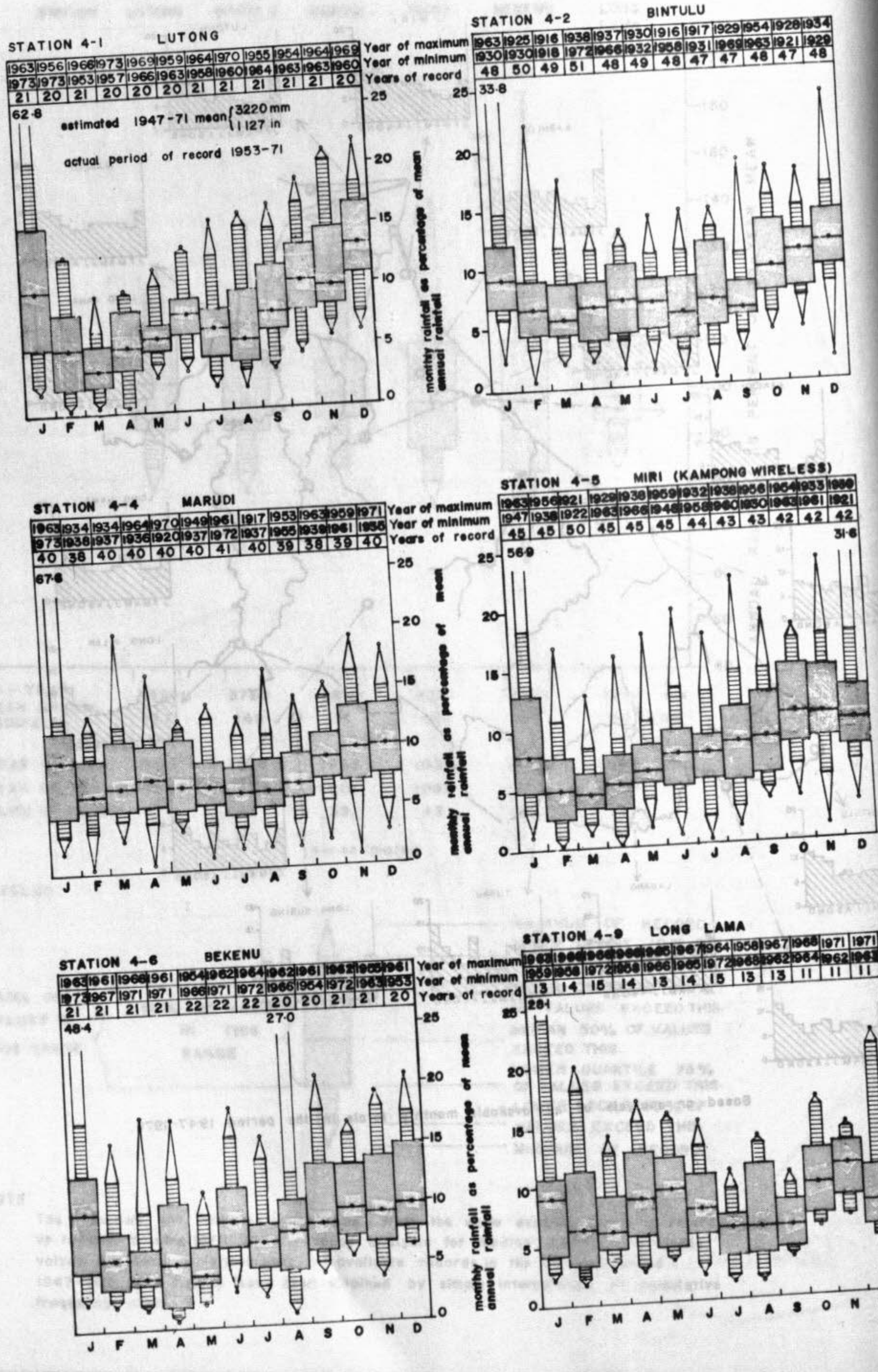
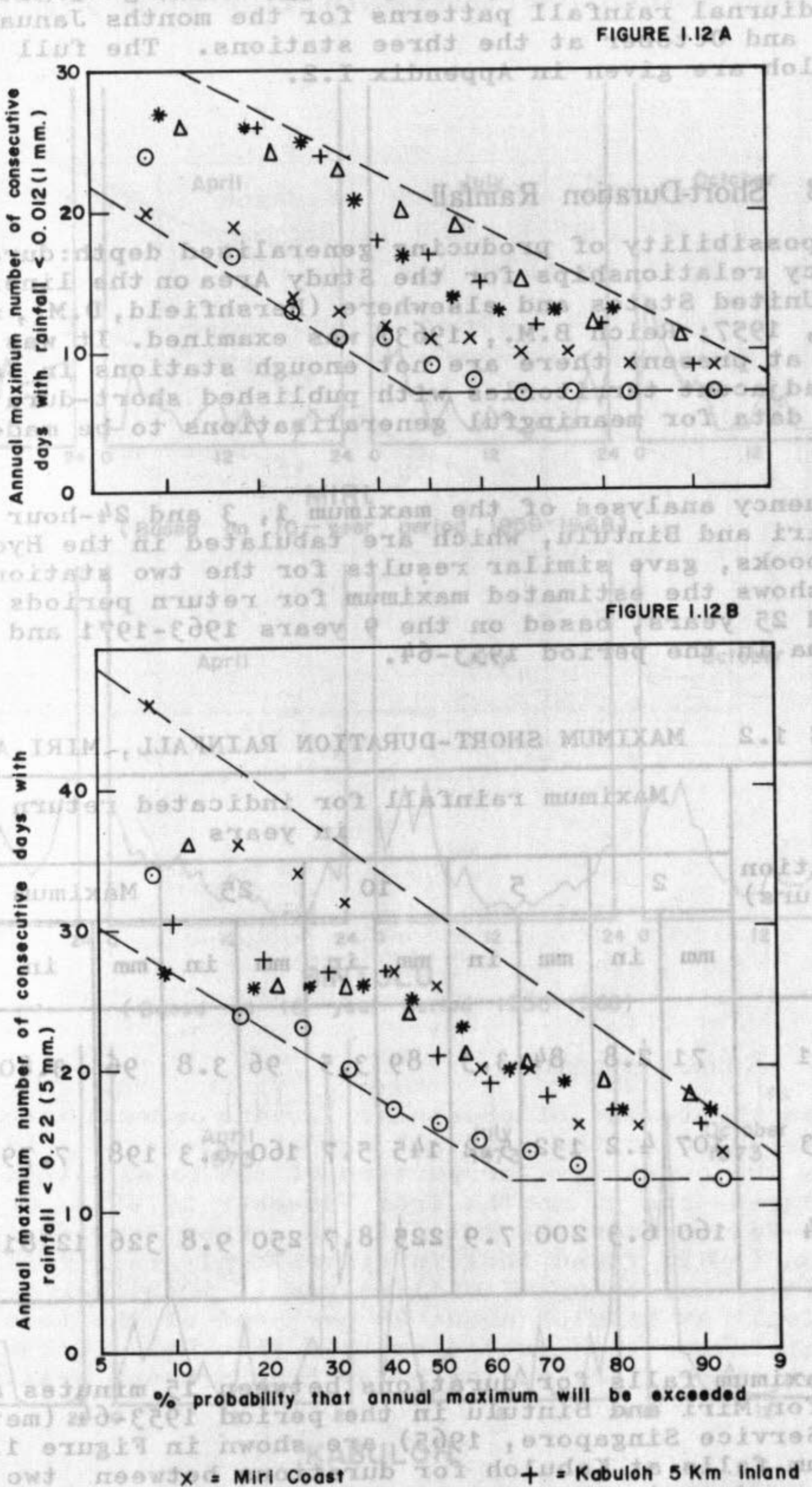


FIGURE 1.12

OCCURRENCE OF DRY PERIODS



NOTES. Based on daily rainfall records in the period 1963 to 1973 except for Kabuloh where observations started in 1965.

to undertake this work. The autographic data from the climate station at Kabuloh have been analysed. Figure 1.13 compares the diurnal rainfall patterns for the months January, April, July and October at the three stations. The full data for Kabuloh are given in Appendix I.2.

1.3.6.3 Short-Duration Rainfall

The possibility of producing generalised depth:duration:frequency relationships for the Study Area on the lines used for the United States and elsewhere (Hershfield, D.M., and Wilson, W.T., 1957; Reich B.M., 1963) was examined. It was concluded that at present there are not enough stations in Sarawak and the adjacent territories with published short-duration rainfall data for meaningful generalisations to be made.

Frequency analyses of the maximum 1, 3 and 24-hour rainfalls at Miri and Bintulu, which are tabulated in the Hydrological Yearbooks, gave similar results for the two stations. Table 1.2 shows the estimated maximum for return periods of between 2 and 25 years, based on the 9 years 1963-1971 and the known maxima in the period 1953-64.

TABLE 1.2 MAXIMUM SHORT-DURATION RAINFALL, MIRI AND BINTULU

Duration (hours)	Maximum rainfall for indicated return period in years										
	2		5		10		25		Maximum of record		
	mm	in	mm	in	mm	in	mm	in	mm	in	Date and place
1	71	2.8	84	3.3	89	3.5	96	3.8	96	3.80	2-2-54 Bintulu
3	107	4.2	132	5.2	145	5.7	160	6.3	198	7.79	12-1-63 Miri
24	160	6.3	200	7.9	225	8.7	250	9.8	326	12.81	8-2-71 Bintulu

The maximum falls for durations between 15 minutes and four days for Miri and Bintulu in the period 1953-64 (meteorological Service Singapore, 1965) are shown in Figure 1.14. The maximum falls at Kabuloh for durations between two minutes and four days in the period October 1972 to October 1973 (13 months) are also shown. The monthly maxima for Kabuloh are given in Appendix Table I.2.16.

FIGURE 1.13

DIURNAL RAINFALL DISTRIBUTION

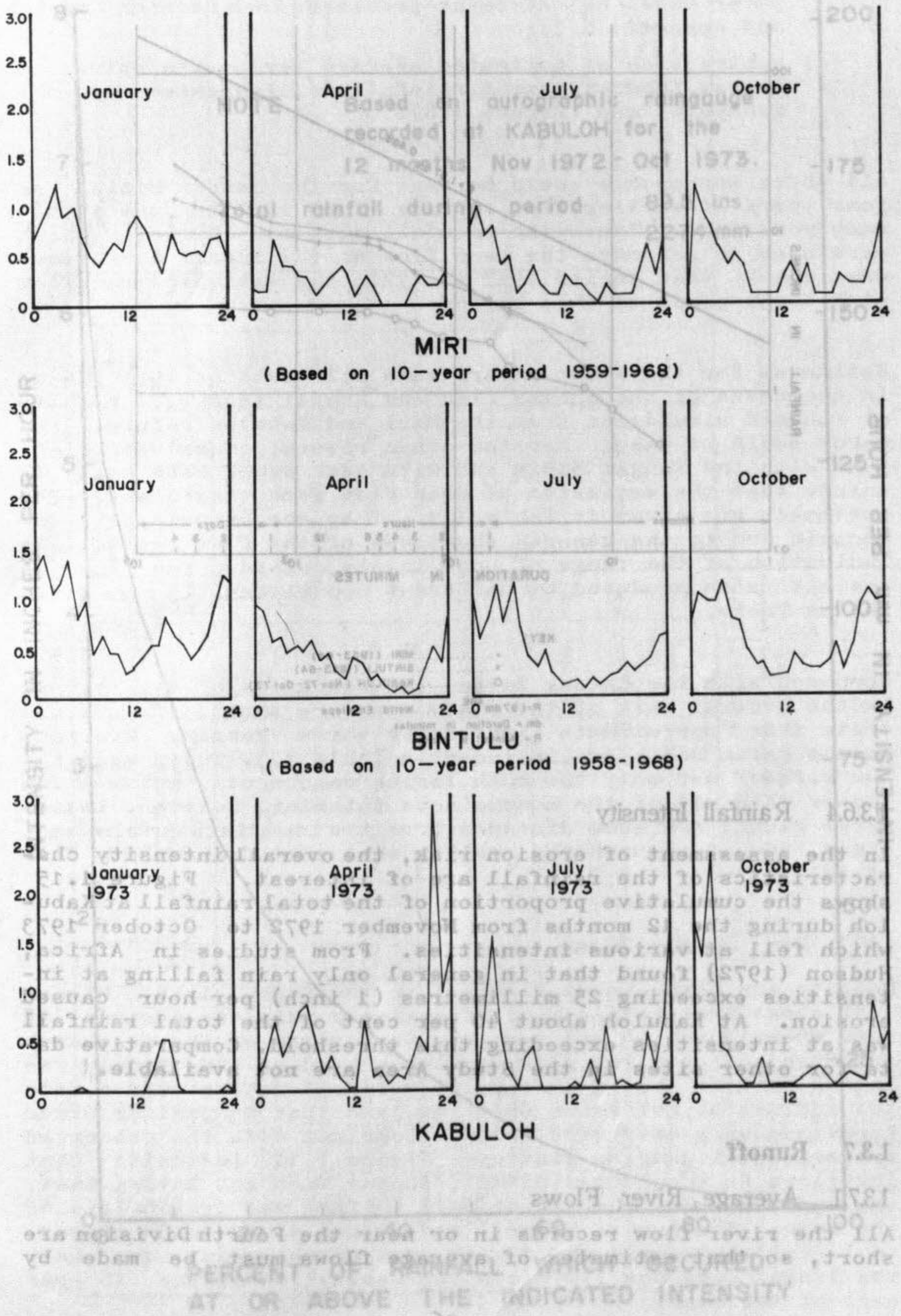
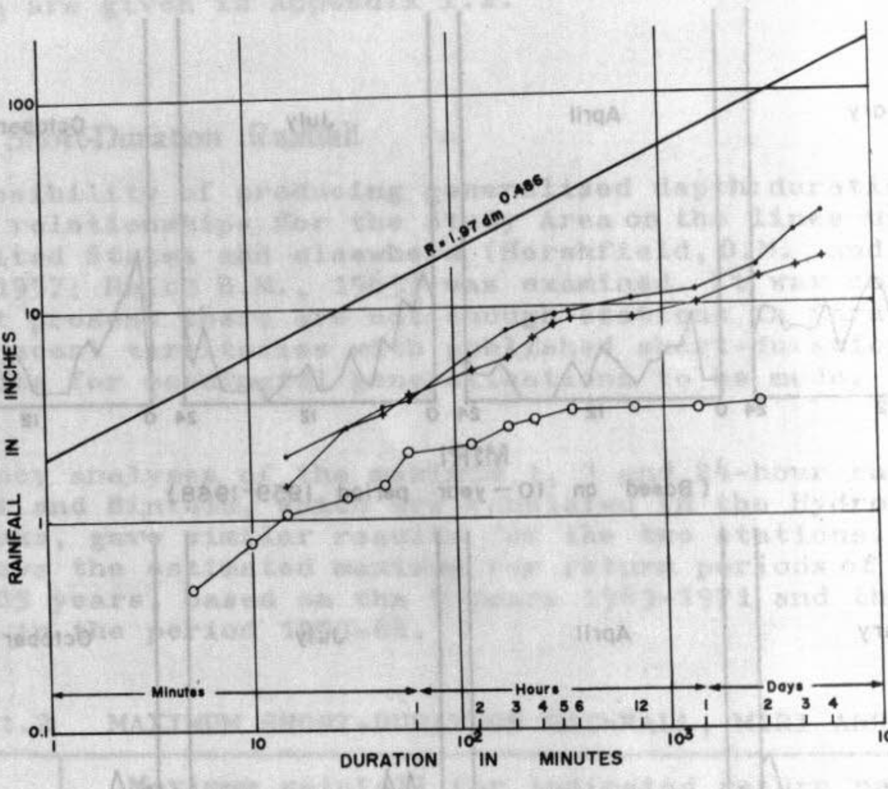


FIGURE 1.14

MAXIMUM RECORDED RAINFALL FOR VARIOUS DURATIONS



1.3.6.4 Rainfall Intensity

In the assessment of erosion risk, the overall intensity characteristics of the rainfall are of interest. Figure 1.15 shows the cumulative proportion of the total rainfall at Kabuloh during the 12 months from November 1972 to October 1973 which fell at various intensities. From studies in Africa, Hudson (1972) found that in general only rain falling at intensities exceeding 25 millimetres (1 inch) per hour caused erosion. At Kabuloh about 40 per cent of the total rainfall was at intensities exceeding this threshold. Comparative data for other sites in the Study Area are not available.

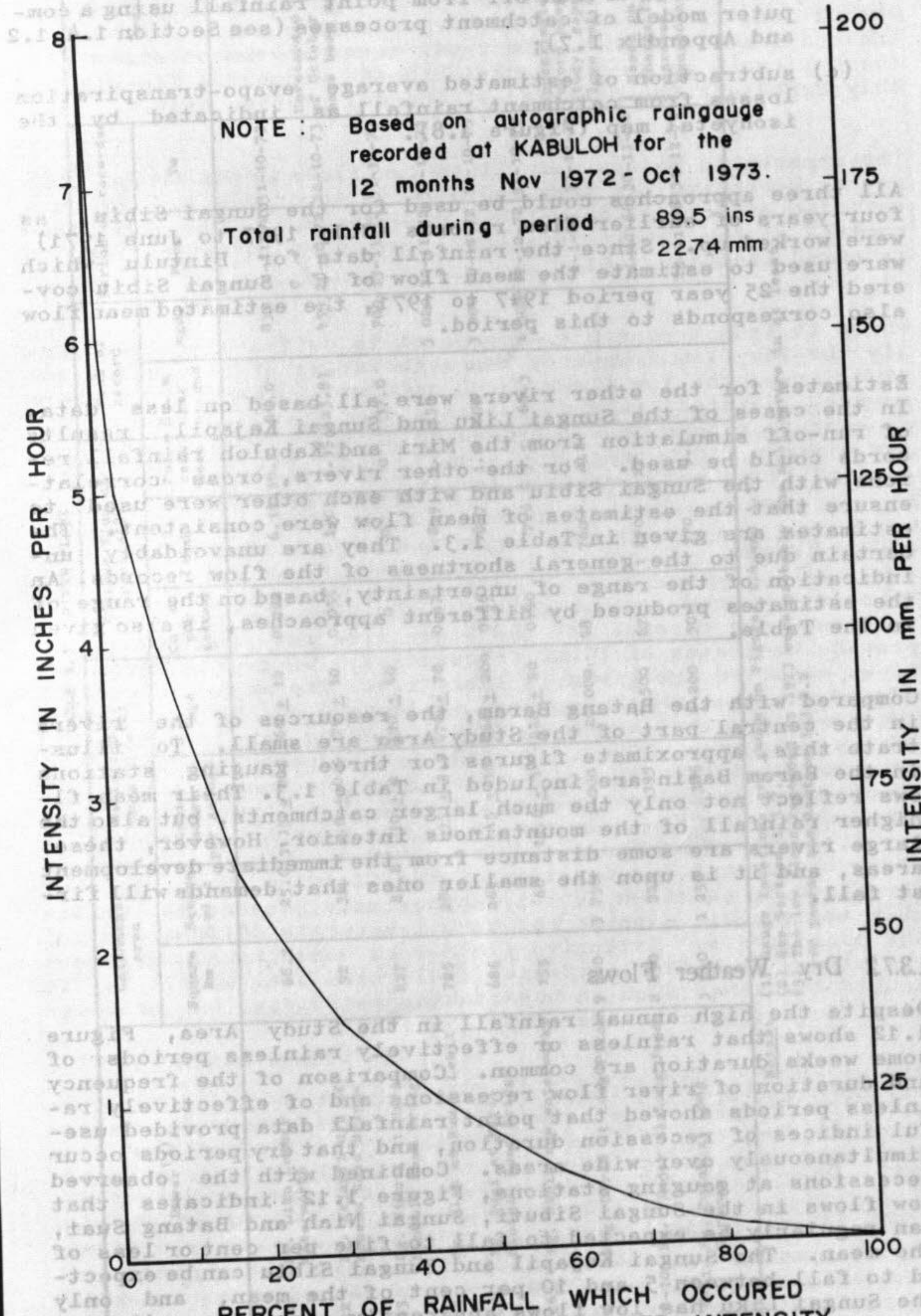
1.3.7 Runoff

1.3.7.1 Average River Flows

All the river flow records in or near the Fourth Division are short, so that estimates of average flows must be made by

FIGURE 1.15

RAINFALL INTENSITY DISTRIBUTION AT KABULOH



comparison with longer rainfall records. Three such approaches have been used:-

(a) direct annual rainfall: run-off correlation;

(b) simulation of run-off from point rainfall using a computer model of catchment processes (see Section 1.4.1.2 and Appendix I.7);

(c) subtraction of estimated average evapo-transpiration losses from catchment rainfall as indicated by the isohyetal map (Figure 1.8).

All three approaches could be used for the Sungai Sibiu, as four years of earlier flow records (July 1967 to June 1971) were worked up. Since the rainfall data for Bintulu which were used to estimate the mean flow of the Sungai Sibiu covered the 25 year period 1947 to 1971, the estimated mean flow also corresponds to this period.

Estimates for the other rivers were all based on less data. In the cases of the Sungai Liku and Sungai Kejapil, results of run-off simulation from the Miri and Kabuloh rainfall records could be used. For the other rivers, cross correlations with the Sungai Sibiu and with each other were used to ensure that the estimates of mean flow were consistent. The estimates are given in Table 1.3. They are unavoidably uncertain due to the general shortness of the flow records. An indication of the range of uncertainty, based on the range of the estimates produced by different approaches, is also given in the Table.

Compared with the Batang Baram, the resources of the rivers in the central part of the Study Area are small. To illustrate this, approximate figures for three gauging stations in the Baram Basin are included in Table 1.3. Their mean flows reflect not only the much larger catchments, but also the higher rainfall of the mountainous interior. However, these large rivers are some distance from the immediate development areas, and it is upon the smaller ones that demands will first fall.

1.3.7.2 Dry Weather Flows

Despite the high annual rainfall in the Study Area, Figure 1.12 shows that rainless or effectively rainless periods of some weeks duration are common. Comparison of the frequency and duration of river flow recessions and of effectively rainless periods showed that point rainfall data provided useful indices of recession duration, and that dry periods occur simultaneously over wide areas. Combined with the observed recessions at gauging stations, Figure 1.12 indicates that low flows in the Sungai Sibuti, Sungai Niah and Batang Suai, can regularly be expected to fall to five per cent or less of the mean. The Sungai Kejapil and Sungai Sibiu can be expected to fall between 5 and 10 per cent of the mean, and only the Sungai Liku has low flows apparently exceeding 10 per cent of the mean.

TABLE 1.3 RIVER FLOWS

	River[1]	Catchment area		Estimated mean flow[2]		Minimum flow of record[3]			Peak of record		Period of records		Remarks
		Square km	Square mile	Cubic metre per second	mgd	Cu. m per second	mgd	Per cent mean	Cu. m per second	mgd	From	To	
C1	Sg. Liku Lambir Waterworks	66.2	25.6	3.15 ± 0.5	60 ± 10	0.322	6.14	10.2	44.0	835	1-11-72	31-10-73	Unrecorded peak at end of October 1973 may have been maximum
C2	Sg. Kejapil d/s of Bekenu Road Bridge	92	35	4.0 ± 0.5	76 ± 10	0.054	1.03	1.35	(23.8)	453	20-10-72	22-10-73	
C3	Sg. Sibuti at Miri-Bintulu Road Bridge	227	87.8	10 ± 2	190 ± 40	0	0	0	37.0	700	13-11-72	31-10-73	
C4	Sg. Niah at Rumah Lebit	725	280	35 ± 3.5	670 ± 70	0.47	8.9	1.3	159	3 020	20-11-72	31-10-73	
C5	Sg. Suai at Miri-Bintulu Road Bridge	686	265	45 ± 10	860 ± 200	0.46	8.7	1.0	205	3 900	19-12-72	31-10-73	
C6	Sg. Sibiu new waterworks	155	60	11.6 ± 1	220 ± 20	0.40	7.6	3.5	68.3	1 300	17-12-72	31-10-73	Approximate daily flow record prepared by the Study; gaps and high flows not estimated
4-9	Btg. Baram at Long Pilah	9 660	3 730	1 000	20 000	48	760	4.8	-	-	1-1-66	31-12-71	
4-10	Sg. Tinjar at Long Jegan	2 490	923	395	7 500	67	1 270	17	-	-	1-12-66	30-11-71	Based on daily discharge figures in Sarawak Hydrological Yearbooks
4-11	Sg. Tutoh at Long Terawan	3 240	1 250	326	6 200	30	570	9.2	-	-	25-11-66	31-12-71	

__Notes:__
(1) Gauge locations are shown on Figures 1.4 and 1.5.
(2) See Section 1.3.7.1
(3) The low flows recorded in 1973 were probably the most severe in at least 20 years, see Section 1.3.7.2

The Sungai Liku, Sungai Kejapil and Sungai Sibiu probably owe their better maintained low flows to the relatively higher relief of their catchments, which permits the drainage of small amounts of ground water. Although the Sungai Niah and Batang Suai have areas of higher relief in their catchments, these are small relative to their total catchment sizes. In these rivers, as in the Sungai Sibuti, recession flows probably represent the drainage of channel storage only.

The apparently better maintained low flows in the Sungai Liku may be deceptive, as they could be in error due to the undetected effects of downstream swamp areas on the low flow control at the gauging station. Continued investigation is required (Section 1.5).

While it is not possible at present to estimate satisfactorily the low flow frequency characteristics of rivers in the Study Area, the low flows which occurred in early 1973 were severe. Rainfall records indicate that the 1973 drought had an average return period exceeding 20 years. Table 1.3 shows the minimum flows recorded in 1973, and Table 1.4 the durations of flows below various levels.

1.3.7.3 Floods

No notable floods occurred during the period of field investigations, and records for the Study Area are too short to provide estimates of flood frequencies. However, the maximum flows observed are given in Table 1.3. The major flood of memory was that which occurred in January and February 1963. The known physical aspects of the flooding have been reported (Jeeps and Gates, 1964). No detailed hydrological or meteorological investigations of this flood are known, nor was it practicable to undertake these during this Study. The 1963 floods were particularly severe in the Fourth Division. Figure 1.16 (based on Jeeps and Gates, 1964, Figures 2 and 3) shows the extent and duration of the flooding. The extent of the flooding as shown is only approximate because the available topographic maps do not permit accurate delineation of the peak levels. Extensive field work would have been required before peak flow estimates could have been made. It is doubtful whether such an undertaking would now be practicable, more than a decade after the event.

Information on flood flows is generally scarce, and it is not possible to assess the recurrence interval of the floods recorded during the field work (Table 1.3). Information from local residents indicates that over-bank flows lasting from a few days to one or two weeks are regular occurrences along the lower reaches of most rivers. The daily flow records computed on the Study for the Sungai Sibiu for the years 1967 to 1971 (Appendix I.1, Table I.1.3) indicate a mean annual maximum daily discharge of 470 litres per second per square kilometre (43 cusecs per square mile) and a five-year maximum of 1 300 litres per second per square kilometre (110 cusecs per square mile).

TABLE 1.4 DURATION OF LOW FLOWS IN 1973

Flow as per cent of mean	Number of days flow was below indicated level					
	Sungai Liku	Sungai Kejapil	Sungai Sibuti	Sungai Niah	Batang Suai	Sungai Sibiu
10	0	88	69	52	51	30
8	0	80	67	40	45	23
6	0	73	65	31	40	9
4	0	70	56	29	15	3
2	0	18	51	15	2	0
1	0	0	50	0	0	0

1.3.7.4 Water Quality

Samples of raw river water were taken at each of six Study Area river gauging stations. Chemical analyses were carried out by the Government Analytical Laboratory in Kuching. The results of the analyses are given in Appendix I.5. All the waters are basically similar, being agressive, soft and of poor organic quality. They have high colour and turbidity. All the waters sampled can however readily be treated to provide potable supplies (Supporting Report Number 6). The quality of the water in the Sungai Liku is marginally better than the others.

As field work progressed, regular sampling of suspended sediment load became less important as the possible need for impounding schemes for water supply purposes diminished. In view of the heavy work-load of the field staff sediment sampling was not undertaken. This aspect of water quality will need thorough investigations in the future if impounding schemes are proposed.

1.4 HYDROLOGICAL STUDIES

1.4.1 Water Supply Schemes

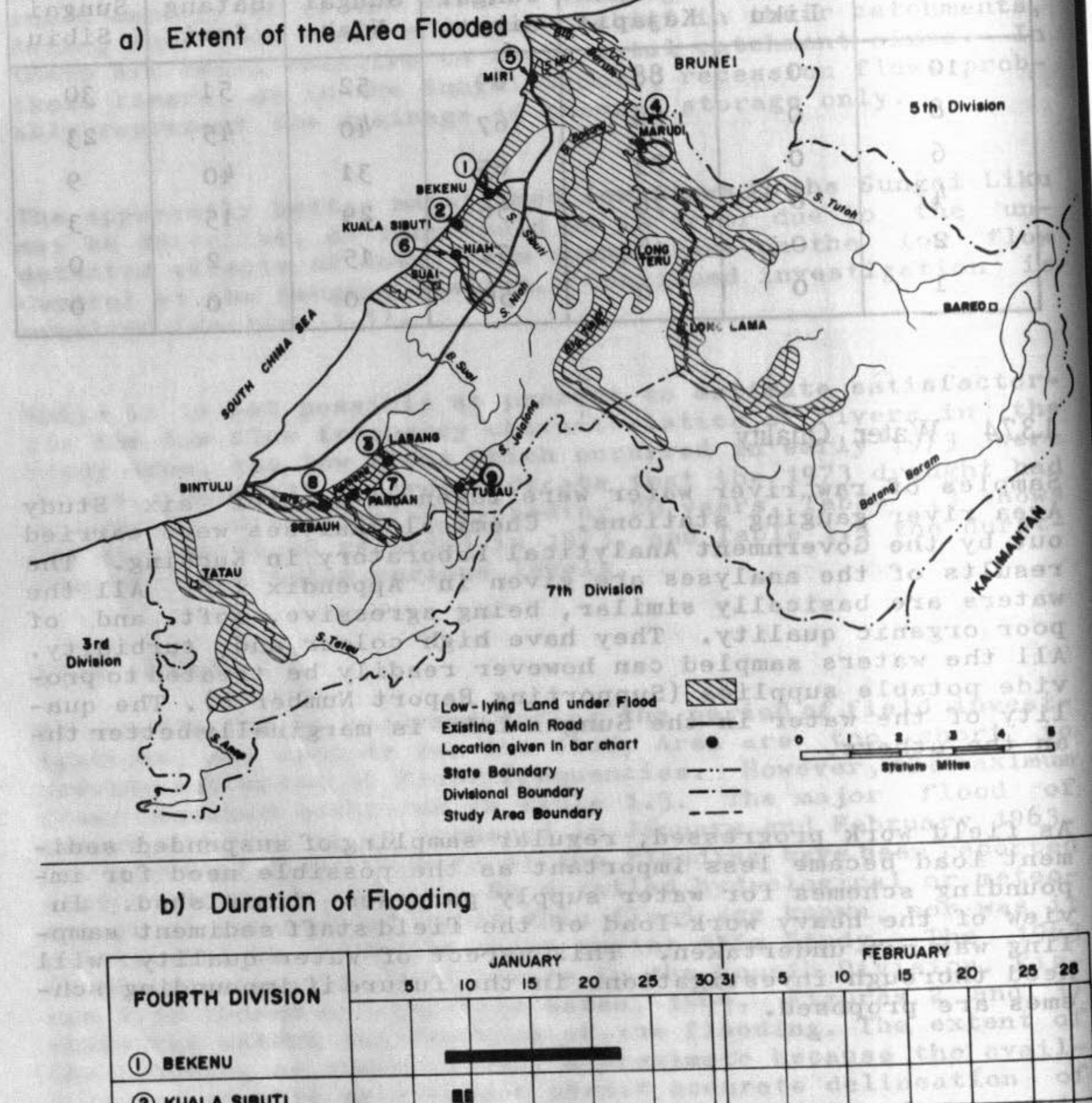
1.4.1.1 Run-of-river Schemes

Excluding the very small reservoir at Nyabau near Bintulu, all existing or planned water supply schemes in the Study Area are direct abstraction run-of-river schemes. Details of the water supply schemes are given in Supporting Report Number 5. Abstractions from the large rivers are not at present restricted by the available low flows, nor are they likely to be restricted in the near future. Abstractions from the smaller rivers may eventually be restricted.

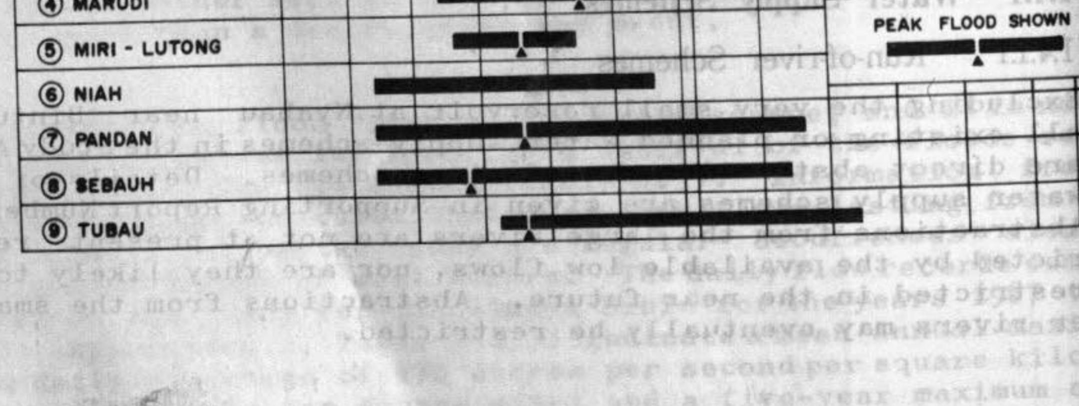
FIGURE 1·16

EXTENT AND DURATION OF THE 1963 FLOODS IN THE FOURTH DIVISION

a) Extent of the Area Flooded



b) Duration of Flooding



Dry weather flows in the smaller rivers have been discussed in Section 1.3.7.2 above. As the low flows which occurred in 1973 were of a return period estimated to exceed 20 years, they were considered suitable as first estimates of the available yields. Table 1.5 shows the proposed run-of-river schemes, estimated demands and, where appropriate, the 1973 minimum flow. It also shows the estimated average minimum flows, which have been assessed as described in Section 1.3.7.2.

1.4.1.2 Impounding Schemes

It was anticipated at the start of the Study that for some water supplies impounding schemes might be necessary, particularly in those areas where the catchments were liable to be developed extensively. In the absence of long-term run-off records, or of any run-off records which could successfully be correlated with long-term rainfall records on a monthly basis, a simple computer catchment model was used to simulate monthly run-off from rainfall. The model is described in Appendix I.7.

As no specific sites for possible impounding schemes were identified during the Study, the basic results of the yield/storage analyses are given here in dimensionless form. Figure 1.17a shows yield/storage curves for a 20 year return period derived from the synthetic monthly run-off series for four rainfall records (Miri, Kabuloh, Berakas and Bintulu). The rainfall stations were selected as having reasonably long and consistent records, and as representing a range of mean annual rainfall typical of the main areas of development.

Two curves are shown for each station, curve A representing relatively good infiltration and soil moisture capacity, and curve B poor infiltration and soil moisture capacity (see Appendix I.7). Differences between the A and B curves are generally small. Differences between stations are greater, and indicate that relatively less storage is needed in the wetter areas. Being based on point rainfall data, the curves of Figure 1.17 apply to small catchments only (up to say 10 square kilometres or 4 square miles). Thus they do not apply to any of the gauged catchments in the Study Area.

Although this Report does not recommend the construction of impounding schemes in the immediate development period, the results of the yield studies give an indication of their potential. To apply the curves, a first estimate of mean annual run-off can be made using the isohyetal map (Figure 1.8). Average evapo-transpiration losses are 50 per cent of rainfall up to a maximum loss of 1 700 millimetres per year. This estimation of losses is based on the results of the run-off simulation studies which indicated that, in the dryer areas, evapo-transpiration is reduced below the potential rate by the regular occurrence of periods of soil moisture stress (see also Section 1.3.6.1).

TABLE 1.5 PROPOSED RUN-OF-RIVER WATER SUPPLIES

Places served	Scheme reference	Source	Catchment area		Estimated 1990 demand mgd	1973 minimum flow(1) mgd	Estimated average annual minimum flow(2) mgd	Remarks
			Square km	Square mile				
Miri/Lutong/Kuala Baram	PU-18	Sg. Liku	66.2	25.6	3.9	6.1	8	
Bintulu/Kidurong	PU-19	Sg. Sibiu	155	60	3.0	7.6	18	River subject to tidal backwater at low flows
Bekenu/North Lambir Subis	PU-16	Sg. Kejapil	90	34	0.27	1.0	3	Yield may be affected by upstream abstractions, which are small at present and by plantation development
Niah-Suai	PU-1	Sg. Niah	730	280	3.1	8.9	20	River subject to tidal backwater at low flows
South Sawai Area - Sebanah	PU-3							
South Lambir Subis Village + Factory	PU-15							
Niah and Batu Niah towns	PU-17							
Ulu Kemena Area	PU-23	Btg. Kemena	NA	NA	0.5	-	-	Minimum flow large in relation to demand
Sebauh	PU-24	Sg. Sebangat	±8	±3	0.06	-	0.4	Flow measurements should be made if scheme further investigated
Long Lama	PU-21	Btg. Baram	±10 000	±4 000	0.3	-	-	Minimum flow large in relation to demand
Marudi	PU-20	Btg. Baram	±16 000	±6 000	0.25	-	-	River tidal, flow does not reverse
Beluru	PU-22	Sg. Bakong	±650	±250	0.08	-	-	River tidal, flow reverse. Water quality requires investigations

Notes: (1) Daily flows given in Appendix I.4

FIGURE 1.17

SYNTHETIC YIELD STORAGE CURVES

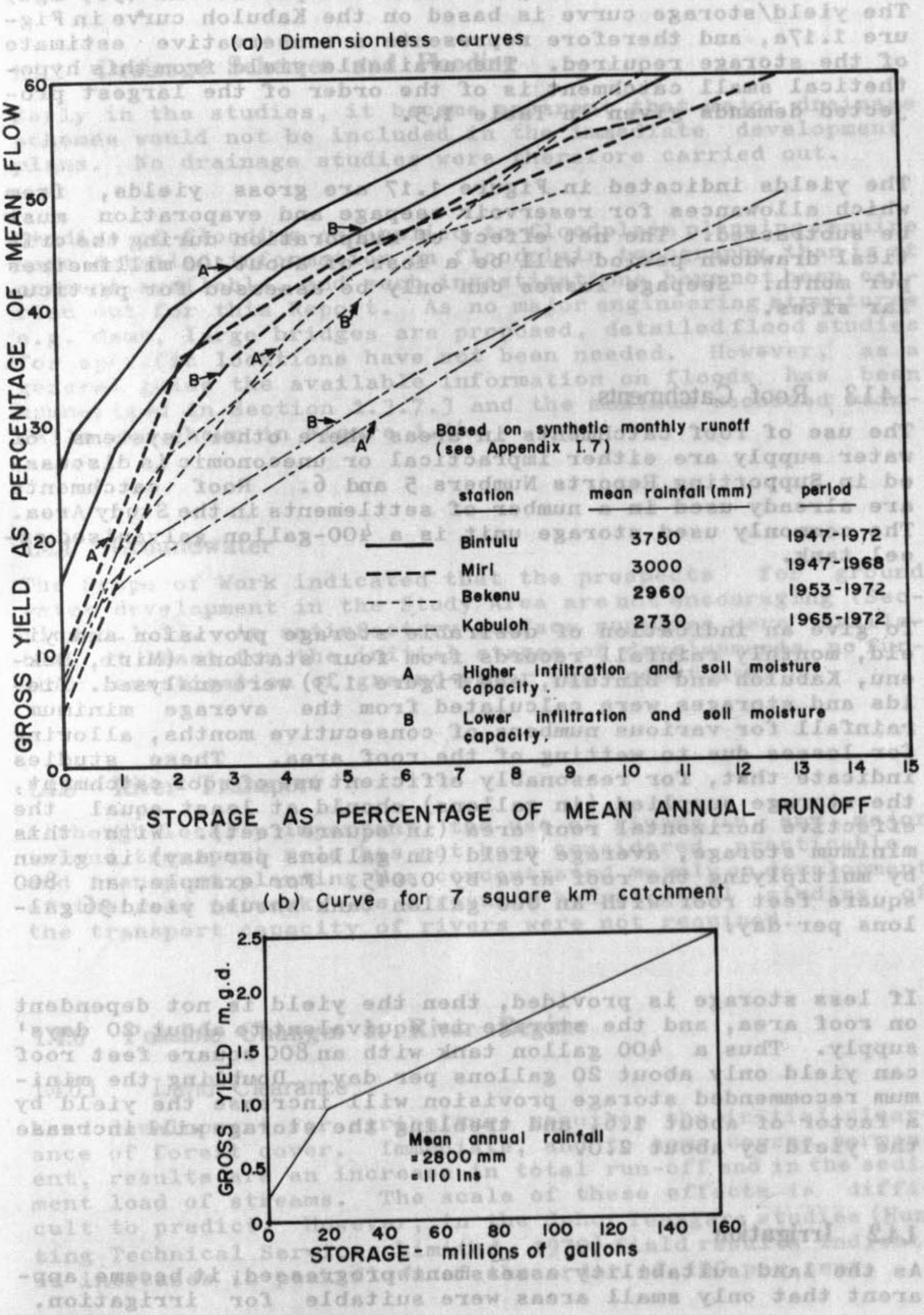


Figure 1.17 shows a yield/storage curve for a hypothetical 7 square kilometre (2.7 square mile) catchment in an area of 2 800 millimetres (110 inches) mean annual rainfall. The estimated mean annual run-off is 1 400 millimetres (55 inches) which is equivalent to 0.31 cubic metre per second (5.9 mgd). The yield/storage curve is based on the Kabuloh curve in Figure 1.17a, and therefore represents a conservative estimate of the storage required. The available yield from this hypothetical small catchment is of the order of the largest projected demands given in Table 1.5.

The yields indicated in Figure 1.17 are gross yields, from which allowances for reservoir seepage and evaporation must be subtracted. The net effect of evaporation during the critical drawdown period will be a loss of about 100 millimetres per month. Seepage losses can only be assessed for particular sites.

1.4.1.3 Roof Catchments

The use of roof catchments in areas where other systems of water supply are either impractical or uneconomic is discussed in Supporting Reports Numbers 5 and 6. Roof catchments are already used in a number of settlements in the Study Area. The commonly used storage unit is a 400-gallon galvanised steel tank.

To give an indication of desirable storage provision and yield, monthly rainfall records from four stations (Miri, Bekenu, Kabuloh and Bintulu, see Figure 1.3) were analysed. Yields and storages were calculated from the average minimum rainfall for various numbers of consecutive months, allowing for losses due to wetting of the roof area. These studies indicate that, for reasonably efficient use of roof catchment, the storage supplied (in gallons) should at least equal the effective horizontal roof area (in square feet). With this minimum storage, average yield (in gallons per day) is given by multiplying the roof area by 0.045. For example, an 800 square feet roof with an 800 gallon tank should yield 36 gallons per day.

If less storage is provided, then the yield is not dependent on roof area, and the storage is equivalent to about 20 days' supply. Thus a 400 gallon tank with an 800 square feet roof can yield only about 20 gallons per day. Doubling the minimum recommended storage provision will increase the yield by a factor of about 1.6, and trebling the storage will increase the yield by about 2.0.

1.4.2 Irrigation

As the land suitability assessment progressed, it became apparent that only small areas were suitable for irrigation.

Consequently no detailed studies of crop water and irrigation requirements were carried out. However, the evaporation data presented in Appendix I.6 are sufficient to enable crop water requirements to be assessed if needed in the future.

1.4.3 Drainage Schemes and Flooding

Early in the studies, it became apparent that major drainage schemes would not be included in the immediate development plans. No drainage studies were therefore carried out.

Studies of flooding as applied to floodplain planning require more detailed information on floodplain topography than is at present available, and such investigations have not been carried out for this Report. As no major engineering structures e.g. dams, large bridges are proposed, detailed flood studies for specific locations have not been needed. However, as a general guide the available information on floods has been summarised in Section 1.3.7.3 and the maximum recorded rainfalls are shown in Figure 1.14.

1.4.4 Groundwater

The Scope of Work indicated that the prospects for ground water development in the Study Area are not encouraging (Section 1.1.1). As satisfactory surface supplies were available, at least for the initial stages of developments, no further investigation of ground-water was undertaken.

1.4.5 River Transport

Although locally important, the use of rivers in any major inland transport role has not been considered practicable, and transport planning has concentrated mainly on development of the road network. As a result, hydrological studies of the transport capacity of rivers were not required.

1.4.6 Possible Changes in River Regime

1.4.6.1 Land Clearance

Land development for agriculture requires the initial clearance of forest cover. Immediate, and to some degree permanent, results are an increase in total run-off and in the sediment load of streams. The scale of these effects is difficult to predict. However, in the Johor Tenggara studies (Hunting Technical Services Limited, 1970) field results indicated increases in peak flows of the order of 100 per cent.

Coupled with increased floods is decreased infiltration to groundwater and a tendency for low flows to decrease due to smaller groundwater contribution. Comparisons in the Johor Tenggara area indicated low flows from developed areas as little as 30 per cent of flows from equivalent jungle covered areas. However, as low flows in the lowland catchments of the Study Area have little groundwater contribution under normal conditions, development may not have so much influence.

Quantitative information on sediment run-off in the Study Area is not at present available, nor was it practicable to monitor it on a meaningful scale. In the Johor Tenggara investigation (Hunting Technical Services Limited, 1970) approximate sediment run-off rates were varied between 100 and 300 tons per square mile per year, the higher figures being associated with developed areas. Figures of the same order have been quoted for other Peninsular Malaysian catchments (Douglas, I., 1968).

Measures which can be taken to mitigate the effects of altering the ground cover, such as the early establishment of cover crops, contouring etc., are now widely adopted. Nevertheless, the sediment run-off from developed areas may remain twice or more that of a comparable area of undisturbed forest. Planning for areas downstream of agricultural developments must allow for this.

1.4.6.2 Roads and Tracks

Provision of access is an important part of overall development. The consequences of road construction in the Study Area are similar to those of land clearance, but on a smaller scale and in a more concentrated form. Construction standards should aim towards the most rapid possible stabilisation of cuttings and embankments; so that zones of accelerated erosion do not remain after construction has been completed.

1.4.6.3 Timber Extraction

The main damage caused by timber extraction arises through poor standards of access track construction and skid trail alignment. The consequences are increased sediment run-off and even the initiation of gulley type erosion of hill slopes.

1.4.6.4 Pollution

Increasing development brings with it the risk of pollution by effluent from villages, towns and factories, as well as by excess agricultural chemicals. The questions of effluent and waste disposal are discussed in Supporting Reports Numbers 5 and 6.

The use of artificial fertilisers can lead to a marked increase in the nutrient concentrations of water draining from the fertilised areas. Also, the use of certain types of persistent poisons for weed and pest control can lead to accumulation of poison in various food chains. Both effects can lead to serious disruption of the local river ecology and may possibly become a danger to the human population. Measures to avoid trouble are suggested in Section 1.5.

1.5 RECOMMENDATIONS FOR FUTURE CLIMATOLOGICAL AND HYDROLOGICAL FIELD WORK

1.5.1 General

The hydrological network for the Study Area was designed primarily for short-term operation. Rapid and easy installation of equipment was necessary to ensure the maximum period of effective data collection. In consequence, many of the stations are not, in their present form, suitable for long-term operation, nor would they all be needed as part of the permanent network. Table 1.6 summarises the situation. The basic recommendations in this table are the same as were made during earlier correspondence with Government over the handover of these field stations.

1.5.2 Climatological Stations

The equipment and layout of the climatological station at Kabuloh is suitable for long-term operation, and it is recommended that this station be kept in operation.

1.5.3 Rainfall Stations

Where the Study rainfall stations are at sites where suitable observers are available (B2, B5 and B6, see Figure 1.5) it is recommended that they be kept in operation. It is also recommended that the proportion of autographic gauges be increased, as it is the short-duration rainfall characteristics which are least well documented.

1.5.4 Streamflow Stations

It is recommended that streamgauging continue on all the smaller rivers which are or are likely to be used for water supply. Where practicable, gauging stations should be combined with water supply intakes. All stations should be equipped with water level recorders. Rivers which should continue to be gauged are the Sungai Liku, Sungai Kejapil, Sungai Niah, and Sungai Sibiu, in addition to the existing Government network. New permanent gauges will be needed to replace stations C2, C4 and C6 (see Figure 1.5 and Table 1.6).

TABLE 1.6 STATUS OF STUDY CLIMATOLOGICAL AND HYDROLOGICAL STATIONS WITH RECOMMENDATIONS

Station	State as handed over to Government	Recommendations
A. CLIMATE		
A1 Kabuloh	Equipped with maximum, minimum, dry-bulb thermometers and thermo-hygrograph in screen; sunshine records; radiation integrator; anemometer, class A evaporation pan; autographic and standard rain gauges. Requires resident observer.	That observations be continued by the staff of the Agricultural Experimental Station.
B. RAINFALL		
B1 Mile 28, Miri	Storage rain gauge installed in association with a soil loss experiment. Read by staff of Sarawak Oil Palms Berhad.	That the gauge be removed.
B2 Rumah Mamat	Daily autographic rain gauge with check gauge. Gauges serviced by local observer.	That the autographic gauge be removed as the observer finds operation difficult. That the standard gauge remain as part of DID network.
B3 Mile 34, Bintulu	Daily recording rain gauge serviced weekly by Study staff. No local observer.	That the gauge be removed.
B4 Mile 24, Bintulu	Weekly storage gauge read by Study staff. No local observer.	That the gauge be removed.
B5 Mile 18, Bintulu	Standard daily gauge at PWD road camp.	That the gauge be incorporated into the DID network.
B6 Mile 6½, Bintulu	Standard daily gauge at new treatment works site.	That the gauge be incorporated into the DID network.
C. STREAMFLOW		
C1 Sungai Liku at Lambir Waterworks	Float operated, weekly water level recorder with permanent stilling well.	That the station be incorporated into the DID network with PWD co-operation in changing the recorder charts.
C2 Sungai Kejapil downstream of Bekenu Road Bridge	Recorder installation damaged by flood in October 1973 and subsequently removed.	That a new permanent station be established in conjunction with the proposed water supply intake.
C3 Sungai Sibuti at Miri-Bintulu Road Bridge	Weekly pressure bulb recorder.	That the recorder be removed and the station closed.
C4 Sungai Niah at Rumah Lebih	Weekly pressure bulb recorder. Site subject to tidal backwater at low flows. Daily staff gauge readings by DID observer.	That a new premanent gauging station with stilling well and float-operator recorder be established upstream free of tidal influences as part of the DID network.
C5 Sungai Suai upstream of Miri-Bintulu Road Bridge	Weekly pressure bulb recorder. Site subject to tidal backwater at low flows. Daily staff gauge readings be local observer.	That the recorder be removed. That staff gauge readings continue.
C6 Sungai Sibiu at new waterworks	Weekly pressure bulb recorder. Site subject to tidal backwater at low flows. Daily staff gauge readings by DID observer.	That a new permanent gauging station with stilling well and float operator recorder be established upstream free of tidal influences as part of the DID network.

Note: Station locations are shown on Figure 1.5.

1.5.5 Water Quality

It is recommended that routine chemical analysis be made of raw water samples from gauging stations. The analysis results should be published together with the other basic hydrological data. Samples from rivers draining areas of concentrated population, agricultural development or industry should also be analysed to monitor the level of pollution and to detect any dangerous increase. Water samples can readily be taken by gauging teams as part of routine operations. Experience during the Study shows that the Government Analytical Laboratory can accept the additional work load.

PART II

LAND RESOURCES

SUMMARY

The Study Area covered about 3.5 mn acres. Of this area 2.2 mn acres were excluded as offering only very limited agricultural development opportunity. The choice was made mainly on the basis of existing information and the study of the aerial photographs. The remaining area was subjected to a Detailed Reconnaissance or Broad Transect Survey, as a result of which the most promising lands were selected for more intensive study at a detailed or semi-detailed level. The area selected at this stage comprised a number of blocks totalling 112 000 acres; within this area the aim was to select 50 000 acres for early development.

The main determinants of land quality and its suitability for cropping in the setting of Miri-Bintulu are soil quality, land slope and liability to flooding - the latter hazard being mainly confined to the lands of the river floodplains. The land capability maps are therefore a synthesis of the information given on the soil maps and the terrain maps combined with knowledge of the geomorphology of the area.

The land suitable for agriculture is classified in six Classes, I to VI in descending order of merit, which is accompanied by an increasingly restricted range of suitable crops and increasing cost of development. The land class numeral is followed by suffixed letters which indicate the nature of the deficiency or difficulty which has determined the land class.

On the soil maps the units are the soil families or series in common use by the Soil Survey Division. The effective rooting depth for crops is of paramount importance in assessing the suitability of soils for crops, and an indication of this depth appears on the soil maps.

The main soils of the region have been formed on sedimentary rocks, ranging from sandstones to shales, and including some limestone occurrences. The landscape is dominated by severe dissection, steep sided hills and river floodplains. The steep hills and river floodplains are accompanied respectively by erosion hazards and liability to severe flooding, each of which impose restrictions on agricultural development.

The soil on the slopes is susceptible to erosion, and in surface run-off and by soil creep, material is constantly moving down-slope, accumulating on the river floodplains or passing beyond them to the sea. Even under a climatic regime which allows rapid rock weathering the consequence of erosion is that the upland soils are shallow, and combined with their slope are suitable for only a limited range of crops, most of which are trees. The high rainfall leaches the soils of

much of their nutrient contents, and the soils are of fertility, and sustained cropping will require the use fertilisers.

The removal of the natural vegetation will accelerate the pr cesses of leaching and erosion, and will require conserva ion measures on all but the gentlest slopes. Such measur will add considerably to the cost of development and the d fficulties of management. As indicated above, in the valle there are areas where soil material is accumulating and whi are without erosion hazards, although they are subject t river flooding which is virtually uncontrollable.

In the 1.5 mn acres of the Broad Transect Survey a total 590 000 acres was mapped as suitable for agriculture, th is 60 per cent of the area was considered to be unsuitabl In the suitable category the principal land class componen were:-

Land Class	Acres
IIIw	42 000
IVe	80 000
IVw	44 000
Ve	147 000
VIe	109 000

The statement below sets out the crops most suitable for th listed main land classes.

Land Class	Crop suitabilities
IIIw	Rice, grasses, tree crops such as rubber, tea oil palms, coconuts and forests
IVe	Grasses, permanent fruit trees, oil palms, cof fee, cashew nuts, rubber, tea, coconuts and for ests of various types
IVw	Rice, grasses, sago and forest reserves
Ve	Oil palms, coffee, cashew nuts, fruit trees, rub ber, forest plantations and forest reserves
VIe	Rubber, tea, cashew nuts and fruit trees, coco- nuts, forest plantations and forest reserves

There are smaller areas of higher land classes, including 6 000 acres of Class I land with virtually no deficiencies, and some 3 000 acres of Class IIw which is subject to infre- quent flooding of short duration. The principal land classes also have marginal suitability for a number of other crops.

As would be expected the area selected for more detailed sur- vey had a higher proportion of suitable land viz. 72 per cent The principal constituents were:-

Land Class	Acres
IIw & IIIw	9 000
IVe	20 000
IVs	7 000
Ve	19 000
VIe	11 000

The composition of the suitable land classes has changed slightly from that of the Broad Transect Survey findings and the range of suitable crops is not significantly changed.

The most promising area for development so far as proportions of suitable land is concerned is the Sungai Karabungan Area where 18 500 acres out of a total of 19 600 acres were found to be suitable for agriculture, although the largest proportion is suitable for grasses only. In this area around 6 000 acres is suitable for a wider range of crops.

CHAPTER 2

INTRODUCTION

2.1 THE STUDY APPROACH

In accordance with the Scope of Work rubber and oil palms are expected to become the main crops in the Study Area, but the possibilities for crop diversification have also been fully explored. The Scope of Work continues to say that "Forest exploitation will be the second major activity based on permanent forest reserves and timber cleared from land scheduled for future agricultural development".

With these directions in mind the soil studies in the Area were carried out in the following stages:-

(a) a stereoscopic aerial photo analysis of the entire Study Area amounting to more than 3.5 mn acres of land, supplemented by relevant physical resource data, which resulted in a broad zonation of land possibly suitable, and land unsuitable, for agricultural development;

(b) based on the findings mentioned in (a) above, an area was selected for soil studies at a broad transect level. This Detailed Reconnaissance Soil Survey gathered sufficient data to prepare land resource maps at a scale of 1:100 000. These maps form the basis for what the Scope of Work describes as a semi-detailed master plan and cover approximately 250 000 acres;

(c) based on the results of the Broad Transect Soil Survey and other relevant information areas were selected for a soil survey at a semi-detailed level. Such areas were as far as possible located on land where timber extraction was completed or apart from salvage operations near completion. A sufficiently large area was selected to locate a 50 000 acre development project for the period 1975-1980.

Thus, in accordance with the Scope of Work, soil and terrain classification followed by land evaluation has been carried out in two stages of the Study viz. a broad transect soil survey (b) and a semi-detailed soil survey (c).

The original intention under the Scope of Work was that a Soil Suitability Map would be prepared for the Broad Transect Soil Survey and the Semi-Detailed Soil Survey areas. These maps would be based on the existing Soil Suitability Classification (Wong, I.F.T., 1970). However, in agreement with the Soil Survey Division of the Department of Agriculture, Sarawak, this was discarded and a modified system of Land Capability Classification was developed. The system adopted for the Study has been based partly on "The Classification and Evaluation of Land in Sarawak" (Andriesse, J.P., 1966). This departure from this intention was necessitated by Government's wish for crop diversification. The land evaluation procedures are described in detail in Chapter 5 of this Report.

The terminology and classification of soils and terrain is that in general use by the Soil Survey Division. Because of established land evaluation criteria some terrain and soil classification parameters have been modified.

Terrain classes in this Study range over five degrees in each class. With classes 1 to 5 inclusive regarded as suitable for agriculture, the steep-land boundary has been placed at 25 degrees, which is the maximum in Terrain Class 5.

The soil classification used in this Study is that issued by the Soil Survey Division, Department of Agriculture, Sarawak as Technical Paper No.3. "A Draft Reclassification of Soils in Central and North Sarawak" (Scott, I.M., 1973). There is need to emphasise that this soil classification system assumes: "that many, if not most of the definitions adopted will be further refined and more basic alterations in approach may also prove necessary. Such amendments can best be made, however, following the practical application of the system in the field, and the classification is tendered in its present form with that in view." (Scott, I.M., 1973, page i). There is therefore again a need to emphasise that the definitions of a large number of the soils mentioned in this classification have been tested in the Study Area. And some changes have been proposed.

Prior to 1972 the Study Area had been covered by a variety of soil surveys, ranging from reconnaissance to semi-detailed. Most of these surveys had been reported on (Dames, T.W.G. and Sutton, C.D., 1959; Wall, J.R.D., 1961-1967; Ahmad Haji Ebon 1967-1968; and Lim, C.P., 1970-1972) by the Soil Survey Division of the Department of Agriculture, Sarawak. A wealth of data was drawn from these earlier reports and maps, especially during the Zonation Plan period and the Broad Transect Soil Survey.

The following sections of this chapter describe the methodology employed in this Study to classify, map and evaluate the soils in the Study Area.

2.2 SOIL SURVEY METHODS

2.2.1 The Zonation Plan

The first stage of the Study consisted of a systematic stereoscopic study of the air photographs at a scale of 1:25 000 for which a comprehensive legend was established. This legend, which is discussed in more detail in Appendix VII, formed the basis for the elimination of land which was considered unsuitable for agricultural development.

This category of land generally included both terrain with average slopes in excess of 25 degrees and peat swamps. The latter have been excluded as land having no agricultural development potential on the basis of its inherent characteristics. The peats in the extensive swamps of the Study Area are characterised by their very low degree of humification, high acidity and very high loss on ignition. Where certain agricultural crops have been successfully grown on such land in Peninsular Malaysia, at least the degree of humification has been considerably higher. However, so far research on the use of the type of peat found in the Fourth Division has been of low priority. Research has not shown a satisfactory, large scale method of developing the peats of the Baram and the Suai-Niah Areas for agriculture.

During this Zonation Plan period a considerable number of spot checks in the field were carried out. Doubtful photo-interpretation units were verified as to their actual terrain and soil characteristics, and where necessary corrections on the final zoning of land resources carried out. Also discussions with the Soil Correlator were held and familiarisation trips made to standardise soil survey methods and to acquaint the soils team with the major soil types found in the Study Area.

2.2.2 The Broad Transect Soil Survey

Based on the results of the first stage of the Study, described above (Para. 2.1) an area of 633 000 acres was initially selected. This area was roughly located south of the Sungai Niah and north of Labang (Figure 2.1). Due to existing population concentrations it became clear that areas, east of the Lambir-Subis Development Area, and near Labang and Tubau along the Batang Kemena had to be included. Therefore the total area studied at the Broad Transect Level amounted to 1 530 000 acres.

Soil survey sample areas (Figure 2.1) were selected on the basis of the aerial-photo interpretation, the general geology of the Study Area and the soil reconnaissance data available. As speed in this type of study was in this case an important factor, the ease of access to these sample areas was an added and became an important factor in deciding on the location of such areas.

The Sungai Karabungan Area, originally regarded and studied as a sample area, but subsequently treated as part of the

Semi-Detailed Soil Survey Area, was selected as a sample area with the following considerations in mind:-

(a) it was known since the commencement of the Study that the Kabuloh Family soils occur in limited areas along the north western corner of the Sungai Tangit Oil Palm Scheme, which is located close to the eastern boundary of the Sungai Karabungan Area. The Soils Team in discussions with the Sarawak Land Development Board came to the conclusion that these soils due to their limited depth and other adverse characteristics are undesirable for oil palm cultivation, and more detailed studies were necessary before alternative uses for these soils could be made.

(b) during the Zonation Plan period the Study had some preliminary ideas concerning the development of grazing land for beef cattle and it was thought that these soils were well suited for this purpose.

The study of sample areas is an important stage in the survey and land evaluation of any area regardless of its size. It is particularly crucial to ensure correlation and standardisation of soil survey methods and classification within the Soils Team. During the survey of these sample areas all soil survey procedures were studied by the combined Soils Team from the Soil Survey Division and the Consultants. A large number of soil profiles were also studied and classified in the field by the combined team.

The total number of sites examined in the sample areas including the Sungai Karabungan Area is listed below:-

TABLE 2.1 DETAILED TO SEMI-DETAILED SURVEY AREAS

Area	Location	Area surveyed	Number of Bores	Number of Pits	Total observation sites
		acres			
Sample Area A	Mile 68, Miri-Bintulu Road	5 200	278	12	290
Sample Area B	Mile 51, Miri-Bintulu Road	4 800	312	13	325
Sample Area C	South east of Rumah Gindi on Batang Suai	4 950	326	13	339
Sungai Karabungan Area	East of Sungai Tangit SLDB Scheme	19 963	1 089	20	1 109

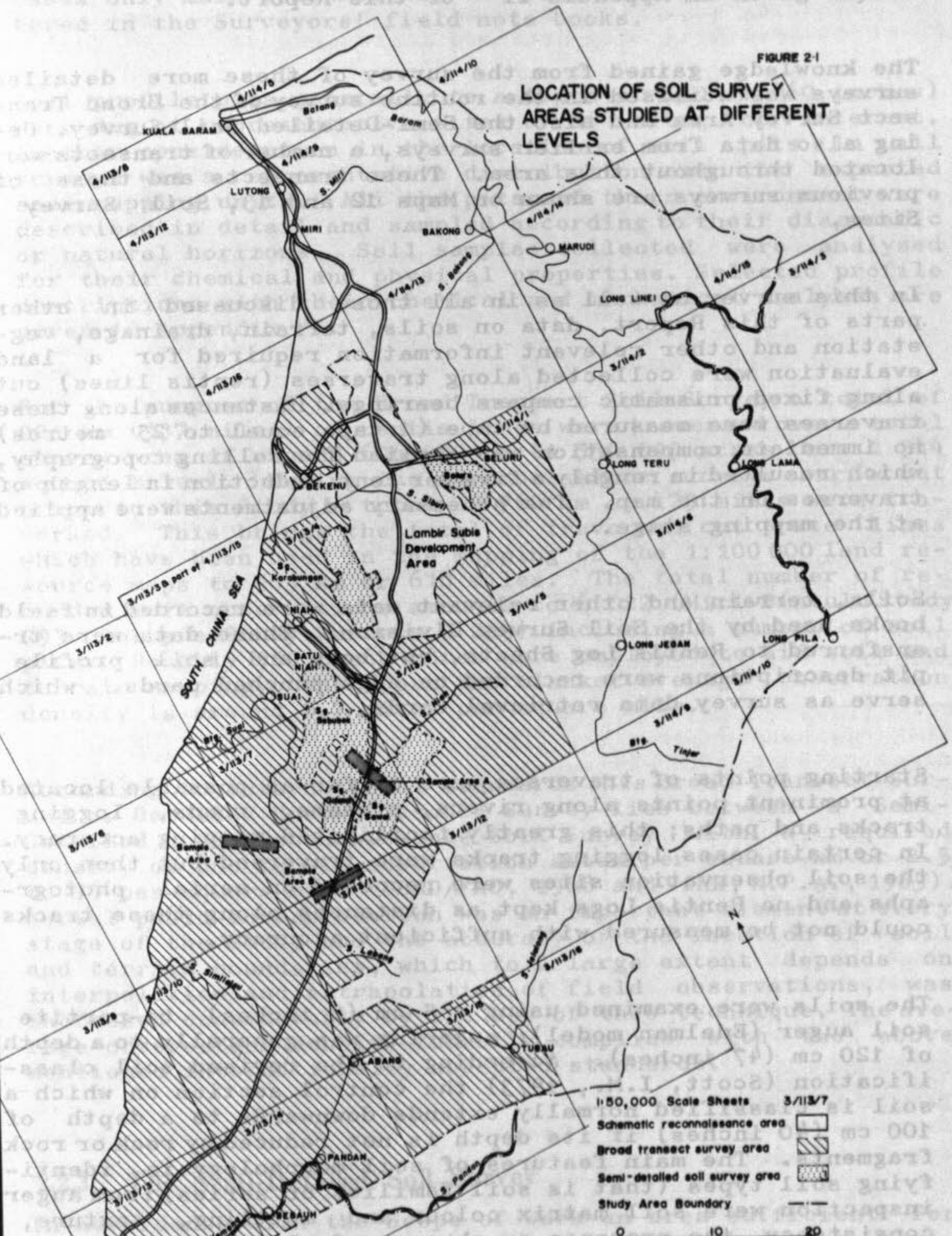


FIGURE 2-1

LOCATION OF SOIL SURVEY AREAS STUDIED AT DIFFERENT LEVELS

A more detailed description of the areas mentioned in Table 2.1 is given in Appendix II of this Report.

The knowledge gained from the survey of these more detailed surveys was utilised in the routine survey of the Broad Transect Survey Area and also the Semi-Detailed Soil Survey. Using also data from earlier surveys, a number of transects were located throughout this area. These transects and those of previous surveys are shown on Maps 12 and 13, Soil Survey Sites.

In this survey as well as in all those discussed in other parts of this Report, data on soils, terrain, drainage, vegetation and other relevant information required for a land evaluation were collected along traverses (rentis lines) cut along fixed prismatic compass bearings. Distances along these traverses were measured by tape (1 tape equal to 25 metres) no immediate compensation was applied for rolling topography, which resulted in roughly a five per cent reduction in length of traverses on the map. The necessary adjustments were applied at the mapping stage.

Soils, terrain and other relevant data were recorded in field books used by the Soil Survey Division. These data were transferred to Rentis Log Sheets, but bore and soil profile pit descriptions were recorded on edge punched cards, which serve as survey data retrieval cards.

Starting points of traverses were as far as possible located at prominent points along rivers, streams, roads, logging tracks and paths; this greatly facilitated mapping accuracy. In certain cases logging tracks were traversed but then only the soil observation sites were recorded on aerial photographs and no Rentis Logs kept as distances along these tracks could not be measured with sufficient accuracy.

The soils were examined using a 5 cm (2 inches) bi-partite soil auger (Edelman model); augering was generally to a depth of 120 cm (47 inches). According to the revised soil classification (Scott, I.M., 1973) the control section on which a soil is classified normally extends downwards to a depth of 100 cm (40 inches) if its depth is not reduced by rock or rock fragments. The main features of soil morphology in identifying soil types (that is soil families or series) from auger inspection were soil matrix colour and mottling, texture, consistency, the presence or absence of lateritic concretions, minerals, rock and rock fragments. Soil, terrain and other relevant data were supplemented by observations along road cuttings stream and river banks. Field procedures for the broad transect soil survey were to auger at intervals of not more than 225 metres (735 feet) or whenever a change of soil type was apparent or suspected. Supplementary observations or check bores were made where required. No full descriptions of these observations have been recorded; in most cases only main features and the soil classification were entered in the Surveyors' field note books.

Soil profile pits generally to a depth of 150 cm (60 inches) were dug at representative sites or at sites of interest. Another consideration in the location of soil pits in all surveys was a representative distribution over the expected soil mapping units. All the pits and their environment were described in detail and sampled according to their diagnostic or natural horizons. Soil samples collected were analysed for their chemical and physical properties. Selected profile descriptions with their chemical and mechanical analyses are given in Appendix VI.

For the purpose of the Broad Transect Soil Survey a total of 221 km (137 miles) of rentis lines were traversed over a total survey area of around 606 000 ha (1 530 000 acres or 2 344 square miles). During the reconnaissance surveys carried out prior to this Study a total of 762 km or 473 miles were traversed. This brings the total of traversed cut trace lines which have been used in the mapping of the 1:100 000 land resource maps to 983 km or 610 miles. The total number of recorded soil observations amounts to 6 022 (Miri-Bintulu Study 793 plus pre-Study Surveys 5 229) including a number of soil pits. Roughly 350 check bores were employed to aid soil and terrain mapping. Therefore the blanket average observation density is around 2.7 sites per square mile.

According to international standards this Broad Transect Survey or Detailed Reconnaissance Survey lies between a Semi-Detailed and a Reconnaissance Soil Survey with a required density of one to six observation sites per square km or 2.5 to 15 per square mile (IBRD/FAO, 1968 and Vink, A.P.A., 1963). Aerial photo-interpretation was an important element at every stage of the Study and the accuracy of the location of soil and terrain boundaries, which to a large extent depends on interpolation and extrapolation of field observations, was increased considerably by the use of this technique. The average observation density formally complies with the above mentioned internationally accepted standards.

2.2.3 The Semi-Detailed Soil Survey

In accordance with the Scope of Work an area sufficient for the development of 50 000 acres net was surveyed at a semi-detailed level. To achieve this net acreage experience has shown that approximately twice the required acreage should be surveyed. This target was achieved by the inclusion of the Sungai Karabungan Area, an area which was studied as a sample area and is discussed in detail in Appendix II.

The following criteria were used in the selection of area to be covered by a Semi-Detailed Soil Survey:-

(a) areas were selected from land assessed as suitable fo agricultural development as shown on Maps 14 and 15 Land Capability, scale 1:100 000.

(b) the distance between selected areas was kept as shor as possible, so as to simplify planning, implementat ion and management.

(c) ease of access and close proximity to existing roads

(d) selected areas were as far as possible located on Stat Land, but excluding unlogged or unlicensed Forest Re serves. This was because such areas would have impose an unacceptable delay in development.

The Beluru Area mentioned in Table 2.2 and which lies east of the Lambir-Subis Development Area was selected because of its proximity to the above development scheme and the considera- ble concentration of farmers in the area. Including the Sun- gai Karabungan Area the areas selected for a semi-detailed soil survey are listed below and shown on Figure 2.1 and on Maps 12 and 13, Soil Survey Sites.

TABLE 2.2 SEMI-DETAILED SURVEY AREAS
(ACREAGES AND OBSERVATION DENSITIES)

Location	Area surveyed	Recorded number of observations		Total number of recorded observation sites*	Average observation density acres per site	
	acres	Bores	Pits		Excluding check bores	Including check bores
Sebubok-Sawai Detailed Plan Area						
Sungai Galasah Area	14 728	310	32	334	44	22
Sungai Sawai Area	29 654	605	70	666	45	22
Sungai Sebubok Area	34 249	814	97	818	42	21
Total	78 631	1 729	199	1 818	43	22
Beluru and Sungai Karabungan Detailed Plan Areas						
Beluru Area	12 869	234	26	256	50	25
Sungai Karabungan	19 963	1 089	20	1 109	18	14**
Total	32 832	1 323	46	1 365	Figures not compatible	
Total Semi-Detailed Survey Area	111 463	3 052	245	3 183	Figures not compatible	

Notes: * Total number of recorded observation sites excludes those sites on which an auger bore was followed by a soil profile pit on the same site, thus number of bores plus number of pits is not equal to the total number of observation sites.

** Sungai Karabungan, 277 check bores added to obtain average observa- tion density, acres per site.

As shown on Maps 12 and 13, Soil Survey Sites, in each of the Survey Areas one or more base lines were cut utilising prominent land marks which could easily and with reasonable accuracy be recognised in the field. These base lines formed the spines for the rentis system. All trace lines were cut at fixed compass bearings, and distances along these lines measured with the standard 25 m tape. Here too no allowance was made for rolling topography. As required by the Scope of Work the distance between cut trace lines is 600 m (1 969 feet). The Scope of Work also stated that the distance between trace lines should not be more than 400 m (1 312 feet). Such a detail was however not mapable at the available publishing scale. Furthermore it was found that most alluvial valleys in the area selected for the Detailed Soil Survey were generally less than 250 m (820 feet) wide and therefore from a practical soil survey point of view and time availability too narrow for a more detailed survey.

In this survey the field procedure was to auger whenever a change of soil type (in this case soil family or series) was apparent or suspected. Consequently the maximum distance between observations was less than 125 m (410 feet). Many supplementary observations or check bores were made. In the Semi-Detailed Soil Survey Areas, the total number of check bores is equal to the total number of recorded observation sites.

The soils and terrain mapping of the Sebubok-Sawai Detailed Plan Area is based on one observation site per 22 acres (Table 2.2). This observation density complies with internationally accepted standards, which requires for a Semi-Detailed Soil Survey not less than one observation per 30 to 60 acres (IBRD/FAO, 1968), or according to Vink (1963) one observation site per 122 acres with the aid of aerial photo interpretation or one observation site per 14 acres without the use of aerial photo interpretation. As this procedure has been used throughout the study, it can be concluded that the observation density obtained is well within the limits set for Semi-Detailed Soil Surveys. It must be emphasised again that both the Broad Transect and Semi-Detailed Soil Surveys have been conducted on a rentis layout.

The examination of terrain and soil features has been conducted using the same procedures as those described in Section 2.2 of this Chapter.

2.3 MAP COMPILATION

2.3.1 Aerial Photographs

The Study Area has a complete aerial photographic coverage at a scale of 1:25 000 taken during the period 1963 to 1971. These photographs were used in the study of the Zonation Plan, and also during the first part of the Broad Transect Survey.

Good quality 1972 aerial photographic coverage at a scale of 1:25 000 for the southern part of the Study Area was available for the post-field aerial photo-interpretation of the Broad Transect Survey and for the entire Semi-Detailed Soil Survey. It was unfortunate that, due to adverse weather conditions and other commitments, the Lands and Survey Department, Sarawak were unable to deliver aerial photographic coverage at a scale of 1:10 000 of the Sebubok-Sawai Detailed Plan Area in time for the mapping of Terrain and Soils maps of the Semi-Detailed Soil Survey Areas.

2.3.2 The Zonation Plan

The aerial photo interpretation of the Study Area at a scale of 1:25 000 was compiled on to 1:25 000 print laydowns or uncontrolled air photo mosaics. These were reduced by photographic processes to 1:50 000, after which compilation on the 1:50 000 Topographic Maps, Series T735 followed. The aerial photo interpretation maps at the above scale were then fair drawn on stable base materials, so that dyeline prints can be made when required for future use.

To allow production of the Zonation Plan Map (Hunting Technical Services Limited and Hoff and Overgaard, 1972) the aerial photo interpretation maps at 1:50 000 scale covering the Study Area were generalised and areas considered as possibly suitable for agricultural development delineated. These were then plotted by pantograph on to the 1:250 000 base map for which Topographic maps Series T503 were used.

2.3.3 Sample Areas

The terrain and soils data of Sample Areas A, B and C plotted on 1:10 000 aerial photographs were compiled on to 1:25 000 machine plotted topographic maps. This compilation was carried out with the aid of a Zeiss-Aero Sketchmaster. The 1:25 000 base map was rescribed and certain topographic details such as roads, tracks and streams added where adequate field information had been collected and could be verified with recent large scale photographs.

Detailed information on the terrain and soils pattern is shown on Maps 1 and 2 respectively. The rentis layout of these survey areas and the location of the soil profile pits is given on Map 3.

Sample Areas A, B and C were specifically surveyed for the study of soil classification, soil pattern and soil properties, and soil and terrain interrelationships. A land evaluation map was regarded as irrelevant to this part of the

Study, because the size of these areas are rather small.

The mapping of the Sungai Karabungan Area was carried out in the same way as the Sample Areas described above but as 1:10 000 machine plot topographic maps were available this area was mapped at a final scale of 1:20 000.

As discussed in Section 2.2 of this Volume the study of this Sample Area was conducted with future agricultural development in mind. The evaluation of the land is shown on Map 7, Land Capability. This map has been produced from the Terrain (Map 4) and the Soils (Map 5) maps at the same scale viz. 1:20 000. Map 6, Soil Survey Sites, gives a record of the location of rentis lines and sampled soil pits.

The soil series has been used as far as possible as the mapping unit of the above areas. In cases where this mapping unit proved to be too detailed the family, family intergrade or family complex was employed, that is MERIT Family, BEKENU-KAPIT Family intergrade or BIJAT/SEDUAU Family complex. Mapping of the Sample Areas was carried out during the same period as the revision of the Soil Classification for North and Central Sarawak. Certain minor soil criteria given on the Sample Area maps are somewhat different from those recorded on the soils map covering the Semi-Detailed Survey Area (Map 17).

Soil depth phases are recorded as part of the soil annotations for example Bk.zcl.4: Bekenu Series, silty clay loam, 75 to 100 cm deep. These soil depth phases are agricultural and not pedological depths and have been chosen to allow for land evaluation of the land, in which available rooting depth for agricultural crops is an important criterion (see Chapter 5, Land Evaluation). In contrast the Sungai Karabungan soil map has four depth phases (0 to 50 cm, 50 to 75 cm, 75 to 100 cm, more than 100 cm), while Sample Areas A, B and C have been mapped with five soil depth classes viz. 0 to 50 cm, 50 to 60 cm, 60 to 75 cm, 75 to 100 cm and more than 100 cm. Depth class 2 (50 to 75 cm, Sungai Karabungan Area) was found to be too wide for oil palms, and this class was therefore split into two: 50 to 60 cm and 60 to 75 cm.

The mapping of Terrain and Soils of the Sungai Karabungan Area has been carried out by the Soil Survey Division in cooperation with the Consultant Land Classifiers. Detailed descriptions concerning this Area are given in Appendix II.4 of this Report.

2.3.4 The Broad Transect Soil Survey

All relevant data obtained during this survey and previous schematic reconnaissance surveys, supplemented with post-field aerial photo-interpretation were compiled on to the 1:25 000 air photographs. This information was then plotted on to the 1:50 000 Series T735 topographic maps by the use of the Sketchmaster. The resulting Soils and Terrain maps were then photographically reduced by a factor of two and compiled on to 1:100 000 topographic base maps. These base maps have been produced from the standard 1:50 000 Series T735 Topographic Sheets by recompilation and re-draughting. Maps 8 and 9 and Maps 10 and 11, respectively Terrain and Soils maps, give details of the terrain and soils pattern of the area studied.

There is a need here to emphasise that the choice of the publishing scale for land resource maps cannot be made on an arbitrary basis, but is governed by the aim and purpose of the survey and the density of observation (Section 2.2 The Broad Transect Soil Survey), because at some stage during the pre-feasibility study or the project implementation international agencies might be involved. The observation density is 2.7 sites per square mile (around one site per square km) and was considered sufficient to publish the resource maps for this survey at a scale of 1:100 000 (Vink, 1963 and IBRD/FAO, 1968). Apart from technical considerations, there are also some practical advantages to the scale of 1:100 000. In soil mapping one square cm is considered a basic mapping unit, and at a scale of 1:100 000 this equals one square km (100 ha or 247 acres).

The Land Capability maps (Maps 14 and 15) of this survey area have been compiled from the Terrain and Soils maps using the same mapping scale.

Maps 12 and 13, Soil Survey Sites, show all the trace lines traversed and used in the mapping of this survey area. These maps also provide information on the location of Survey Areas studied at other levels of soil survey, and the location of soil profile pits. Those which have been sampled by this study have been allocated their appropriate map grid reference according to map Series T735.

2.3.5 The Semi-Detailed Soil Survey

Due to weather conditions during flying and other circumstances outside the control of the Land and Survey Department, the 1:10 000 aerial photographs covering this survey area were not delivered in time for the post-field aerial photo-interpretation. The 1:25 000, 1972 photographs were therefore used instead to locate the rentis system and soil observation sites and subsequently plot the terrain and soil data. For each of the four survey areas, viz. Sungai Galasah, Sungai Sawai, Sungai Sebubok and Beluru (Figure 2.1) the 1:25 000 aerial photos were assembled to form a print laydown. All information contained on these print laydowns was then compiled onto stable drawing film. The resulting terrain and soil maps, including all available topographic detail, were then reduced to a scale of 1:50 000. These reductions were compiled onto the standard 1:50 000 topographic map. (See Maps 16, 17 and 18). During this process it was found that slight scale differences occurred between the reduced maps and the 1:50 000 base map. This acceptable discrepancy was mainly caused by the fact that aerial photographs being seldom true to scale; slight scale differences are particularly noticeable between runs of photographs. Furthermore ground control points were limited.

The mapping unit in this survey is the soil series, but soil families have been mapped where subdivisions of families into series was not catered for in the present soil classification system.

Map 19, Land Capability, has been compiled from the Soils and Terrain maps at the same mapping scale of 1:50 000.

2.3.6 Accuracy of Mapping

Limitations to the accuracy of mapping at a given publishing scale arise from a variety of factors, of which the following need to be mentioned:-

- the accuracy of the base maps;
- the plotting of the cut trace lines on the topographic base;
- the accuracy of the extrapolation and/or interpolation of terrain and soil boundaries between observation sites within the trace lines and of this information between traversed trace lines. This depends on the level of survey detail.

(a) in this Study the accuracy of the base maps must be accepted as an unalterable fact;

(b) the location of the traversed trace lines has in all cases initially been plotted on the aerial photographs, either at 1:10 000 or 1:25 000 scale, and then transferred to the topographic base by means of photographic reduction or by Sketchmaster. Field verification has been possible by comparison of the course of the rentis with the description given in the Rentis Logs;

(c) the major complication in locating soil boundaries stems from the fact that the areas are often heterogeneous and in most cases do not have exact boundaries but have a gradual transition. Certain areas in between two trace lines could be overlooked because of the grid pattern of survey. In general, however the knowledge of the physiography of the area as revealed to a large extent by systematic aerial photo-interpretation, is a sufficiently reliable guide for the location of boundaries at a given publishing scale. Details concerning the procedures used and a discussion of the aerial photo-interpretation and its legend appear in Appendix VII.

2.3.7 Soil Annotation and Colours of Mapping Units of the Published Maps

2.3.7.1 Introduction

A brief explanation of the system for soil annotations and colours of mapping units is required to be able to understand fully the soil maps accompanying this Report.

The system followed for annotating soil mapping units is that in general use by the Soil Survey Division, Department of Agricultural, Sarawak, consisting of a three-letter coding of soil family names. On certain published maps the Division used a combination of a one and two-letter system of annotation (Andriesse, J.P., 1972). In the Study it was found advantageous to use a two-letter annotation. The system was discussed and agreed upon by the Soil Survey Division.

The colour scheme selected for the soil mapping units is that in general use by the Soil Survey Division. However the Anderson Family was changed to a grey tone colour on the maps published by this Study.

2.3.7.2 Soil Mapping Unit Annotations

Soil annotations at the family level are indicated by capital letters (BK = Bekenu Family). At the series level a combination of capital and lower case letters is used (Bk = Bekenu Series).

Intergrades between soil families, which in the Soil Classification System are regarded as proper families, are denoted by a hyphen (-) between the intergrading families (BK-KP = Bekenu-Kapit Family Intergrade). Complexes of two families are indicated by an oblique (/) between these families, with the dominant family occupying first place (BK/KP = Bekenu/Kapit Family Complex). It must be emphasised that complexes of more than two families have not been used in this Study.

A complex of a family and a family intergrade, for instance BK.3/BK-KP.1, has been mapped frequently at the 1:100 000 scale maps. In the soils legend such a complex is always indicated as a complex of the first (BK = Bekenu Family) and the last named family (KP = Kapit Family).

A complex of soil series is indicated by an oblique (/) between the letter symbols (Mr.c.4/Jk.c.4) with the dominant series awarded first place in the complex.

2.3.7.3 Soil Mapping Unit Colours

Each soil family, family intergrade or family complex has been allocated its standard colour which is that in use by the Soil Survey Division. These colours resemble certain of the mapping unit's main features. Bottom land and alluvial soils are in the green and blue hues of the colour spectrum and upland soils in the yellow, brown and red hues.

At the series level, the colours are those of the family to which the series belong. Series separation within each family is achieved by employing grey tone dot or pattern screens. These screens are related to the dominant texture for the series. Fine regular dots or patterns for heavy textures such as clays and silts and coarse regular dots or patterns for light textured soils, loams and sands. Grey tone screens used for series intergrades or complexes follow the same texture pattern as that for the series; fine dots for heavy and coarse for light textures, but the grey tone screens chosen have irregular dots or patterns.

The 1:50 000 soil map of the Semi-Detailed Soil Survey Areas shows mapping units where a series is mapped in complex with a family intergrade e.g. Bk.zl.3/BK-KP.1. Bekenu series belongs to the Bekenu Family, and the colour used for the above mapping unit is that for the first and last named family complex, that is BK/KP. The series is identified by the use of a grey tone screen e.g. for Bk, which is the same screen as that employed for identifying the Bekenu Series when it is mapped on its own.

2.4 PHYSICAL AND CHEMICAL ANALYSES

The following analysis were carried out by the Environmental Chemistry Laboratory of Hunting Technical Services Limited, in England:-

A. Full series analysis

(i) Particle size

	millimetres
Very coarse and coarse sand	2 - 0.50
Medium sand	0.50 - 0.25
Fine sand	0.25 - 0.10
Very fine sand	0.10 - 0.05
Silt	0.05 - 0.002
Clay	less than 0.002

(ii) pH, soil-water suspension, 1 : 2.5

(iii) pH, soil-potassium chloride suspension, 1 : 2.5

(iv) Easily soluble potassium (acetic acid extraction)

(v) Easily soluble phosphorus (Bray and Kurtz, 1945)

(vi) Total available (6 NHCl soluble) phosphorus, potassium, calcium, magnesium

(vii) Cation exchange capacity (CEC)

(viii) Exchangeable cations: sodium, potassium, calcium, magnesium

(ix) Base saturation.

B. Top two horizons of all series analysis:-

Organic carbon and total nitrogen.

C. On representative samples:-

(i) Trace elements; total copper, zinc, manganese

(ii) Silica - sesquioxide ratio

(iii) Clay minerals

(iv) Free iron oxide

(v) Analysis of fine clay fraction

(vi) Water dispersible clay

(vii) Soil permeability

(viii) Available water capacity. Soil moisture held at tensions of 0, 1/10, 1/3, 1 and 15 atomosphere; bulk density.

Details of the methods and results of the analyses listed above are discussed in Appendices III, IV, V and VI.

It must be noted that a number of analyses have been carried out to be able to place soils in a certain family or series, results used for that purpose have not been tabulated in this Report.

CHAPTER 3

PHYSICAL FACTORS

3.1 GEOLOGY

The Study Area is formed exclusively of sedimentary rocks deposited in the North-west Borneo Geosyncline, and consists of almost complete successions of sandstone and shale, with limestone lenses. There is little lithological variation, and strata of varying ages are almost indistinguishable in the field.

Oldest rocks within the Area are the Main Geosynclinal Formation of the Setap Shale, Sibuti, Tangap and Nyalau Formations, believed to be of Miocene age. Younger formations are the Lambir and Belait Formations of Mio-Pliocene age. The younger deposits are represented by Quaternary terrace and alluvial deposits.

The older formation comprise a great thickness of mainly argillaceous strata: the Nyalau formation comprises a rather more sandy facies which is contemporaneous with the argillaceous formations. The Mio-Pliocene Belait and Lambir Formations are predominantly arenaceous strata which overlie the Setap Shale, Sibuti and Nyalau formations in synclinal basins. Alluvial terrace deposits overlie older strata in places particularly along certain coastal sections and along the inland margins of the present day deltaic areas. The approximate areas and location of the various formations is shown in Figure 3.1.

The Setap Shale Formation is a thick succession of shale with subordinate sandstone, and a few lenses of Limestone. It occupies large areas between the Batang Baram and Batang Tinjar, and to the north-east of the middle and lower section of the Sungai Niah. South-west of this river, the formation becomes increasingly interfingered by strata of the Nyalau Formation, and gives way to the Nyalau Formation south of the Sungai Semilajau. The shale is typically silty and clayey, occasionally very fine sandy, and is moderately soft and well-bedded; but hard, nodular shale does occur in some places. In the valley of the Sungai Niah, more arenaceous beds occur near the top of the formation containing, locally, sandy marlstone and calcareous sandstone. The formation is moderately folded in the Niah-Suai area, but more intense folding occurs to the east in the Tinjar and Baram areas. The dip of the strata appears to be mainly between 20 to 40 degrees in the Niah-Suai area, but is much nearer the vertical in the Tinjar-Baram area.

The Tangap Formation, is a calcareous formation within the Setap Shale Formation, and includes the Subis Limestone member which forms Gunong Subis. The Tangap Formation comprises calcareous shale, marl, greenish claystone and occasional beds of limestone, with some non-calcareous shales and sandy beds. The formation is gently folded, with dips of between 5 and 20 degrees.

The Sibuti Formation is composed of shale with some marl and lenses of limestone, but the calcareous occurrences are less frequent than in the Tangap Formation. The formation is moderately folded with dips in the same range as the Setap Shale Formation.

The Nyalau Formation is mainly arenaceous, but shale intercalations are common. South of the Batang Suai, the formation appears to consist mainly of fine grained sandstones and sandy shales with coarser grained sandstones increasing south of Sungai Similajau. In the area of the Batang Suai headwaters the formation largely consists of fine grained massive sandstones giving rise to well marked ridges with dip and scarp topography. The formation shows gentle to moderately steep dips.

The Belait Formation consists of massive, thick beds of sandstone with subordinate shale. This formation forms some of the highest land within the Study Area, Bukit Selikan (2 633 feet), Bukit Sekewa (2 278 feet) and the Dulit Range (between 3 000 and 4 200 feet). In the Dulit Range and immediately west of the Batang Tinjar, the sandstone is comparatively coarse, but becomes rather argillaceous west of the Sungai Niah headwaters.

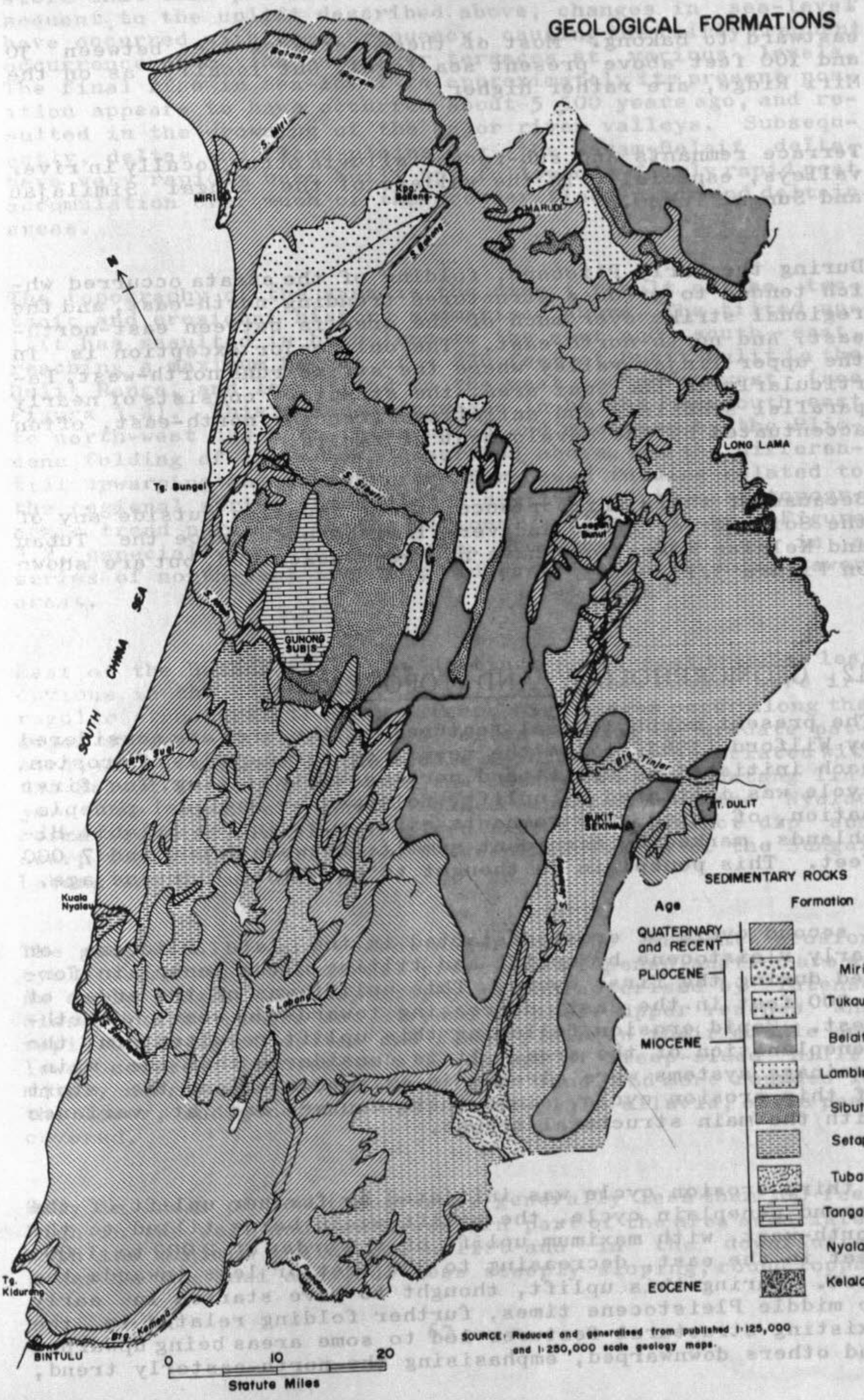
The Lambir Formation is of limited extent within the Study Area, and the main occurrences are in the Bakong area, the Lambir hills and east of Marudi. The formation consists of sandstones and shales with calcareous sandstone and limestone. The sandstone is medium to fine grained, but occasionally coarse near the top of the succession in the Lambir hills, and in the Marudi area. The Lambir Formation is generally gently folded.

Two further formations of limited extent are confined to the Lambir hills and the Miri Ridge. The Miri Formation is predominantly arenaceous in its upper part, but numerous shale-sandstone alternations occur. The Tukau Formation is composed largely of sand and poorly consolidated sandstone alternating with clay.

Terrace remnants occur in several places. The main areas are south of Tanjong Kidurong, north-east and south of Kuala Nyalau, the Marudi area and the largest continuous area stretching north along the coast from Tanjong Bungai to Miri, then

FIGURE 3·1

GEOLOGICAL FORMATIONS



eastward to Bakong. Most of these terraces lie between 30 and 100 feet above present sea-level, but locally, as on the Miri Ridge, are rather higher.

Terrace remnants and sub-recent alluvia occur locally in river valleys, especially in the valleys of the Sungai Similajau and Sungai Tukau.

During the early Pliocene, folding of the strata occurred which tended to produce structures trending north-east, and the regional strike over much of the area is between east-north-east, and north-north-east. The only major exception is in the upper Tinjar valley where the strike runs north-west. Particularly in the Suai area, the structur consists of nearly parallel synclines and anticlines trendi g north-east, often accentuated by the development of faults.

Because of their unimportance, their location outside any of the Soil Survey Areas and very limited occurrence the Tubau and Kelalan Formations have not been described, but are shown on Figure 3.1.

3.2 GEOMORPHOLOGY AND TOPOGRAPHY

The present morphological features of the area are considered by Wilford (1961) to be the result of three cycles of erosion, each initiated by uplift and northwesterly tilting. The first cycle was initiated by uplift, followed by regional peneplanation, of which only remnants exist e.g. in the Kelabit Highlands, marked by accordant summits between 6 000 and 7 000 feet. This peneplain is thought to be of late Pliocene age.

A second cycle of erosion started in the late Pliocene or early Pleistocene by uplift and tilting of the peneplain formed during the first cycle. This uplift was of the order of 4 000 feet in the east, decreasing towards the west and north-west. Rapid erosion following this uplift resulted in the peneplanation of the area. It is considered that the main drainage systems were already in existence before the start of this erosion cycle, since their courses are at variance with the main structural trends.

A third erosion cycle was initiated by further uplift of the second peneplain cycle, the uplift again being tilted to the north-west, with maximum uplift of the order of 2 000 to 3 000 feet in the east, decreasing to 300 feet or less towards the west. During this uplift, thought to have started in early to middle Pleistocene times, further folding related to the existing structural features led to some areas being upwarped and others downwarped, emphasising the north-easterly trend, and variations in height between structural units. It is possible that this process is still active at the present. Subsequent to the uplift described above, changes in sea-level have occurred with some frequency, causing the fairly frequent occurrence of marine and river terraces at various levels. The final rise in sea-level to approximately its present position appears to have occurred about 5 500 years ago, and resulted in the drowning of the major river valleys. Subsequently, deltas and flood-plains e.g. the Baram-Belait delta, have very rapidly been built up, followed by fairly rapid peat accumulation over much of the broader flood-plain and deltaic areas.

The topography of the area is the direct result of the tectonic and erosional history summarised above. The tilted uplift has resulted in high land to the east and south-east, reaching a maximum height of 4 230 feet at Bukit Dulit in the Dulit Range, and lower land to the west and north-west (see Figure 3.2). This general decrease in height from south-east to north-west has been interrupted and modified by the Pliocene folding of the strata described above, and the differential upwarping and downwarping of renewed folding related to the regional strike, producing a distinct north-east topographic trend parallel to the regional strike as shown in Figure 3.2, especially in the Suai area. This has resulted in a series of north-east trending ridges with intervening lower areas.

East of the Batang Suai, the distinct north-east trend is less obvious in the topography, largely due to the rather more irregular structural trends. Steep, high ridges occur along the edges of geological synclines, often forming an arcuate pattern, with lower land in the middle as for example associated with the Belait Formation between the Batang Suai and Batang Tinjar. The relatively gently folded sandstones of the Nyalau Formation have, in places, given rise to a distinct dip and scarp topography well shown between headwaters of the Sungai Labang and Batang Suai.

The geologically very recent nature of the present erosion cycle means that the normal processes of peneplanation are at an early stage. The topography is characterised by intense dissection by rivers and streams in their upper reaches and rapid build-up of deltas and flood-plain in their middle and lower courses, leading to a landscape of steep-sided hills, mainly narrow crested in the higher land, and more rounded in the lower, and generally wet, flood-plain alluvia, often peat covered.

Only in areas of low topography, generally less than 300 feet high in the west and north-western part of the area associated with the minimum geological uplift and in the downfaulted zones in the Suai area, do less steeply sloping, round topped

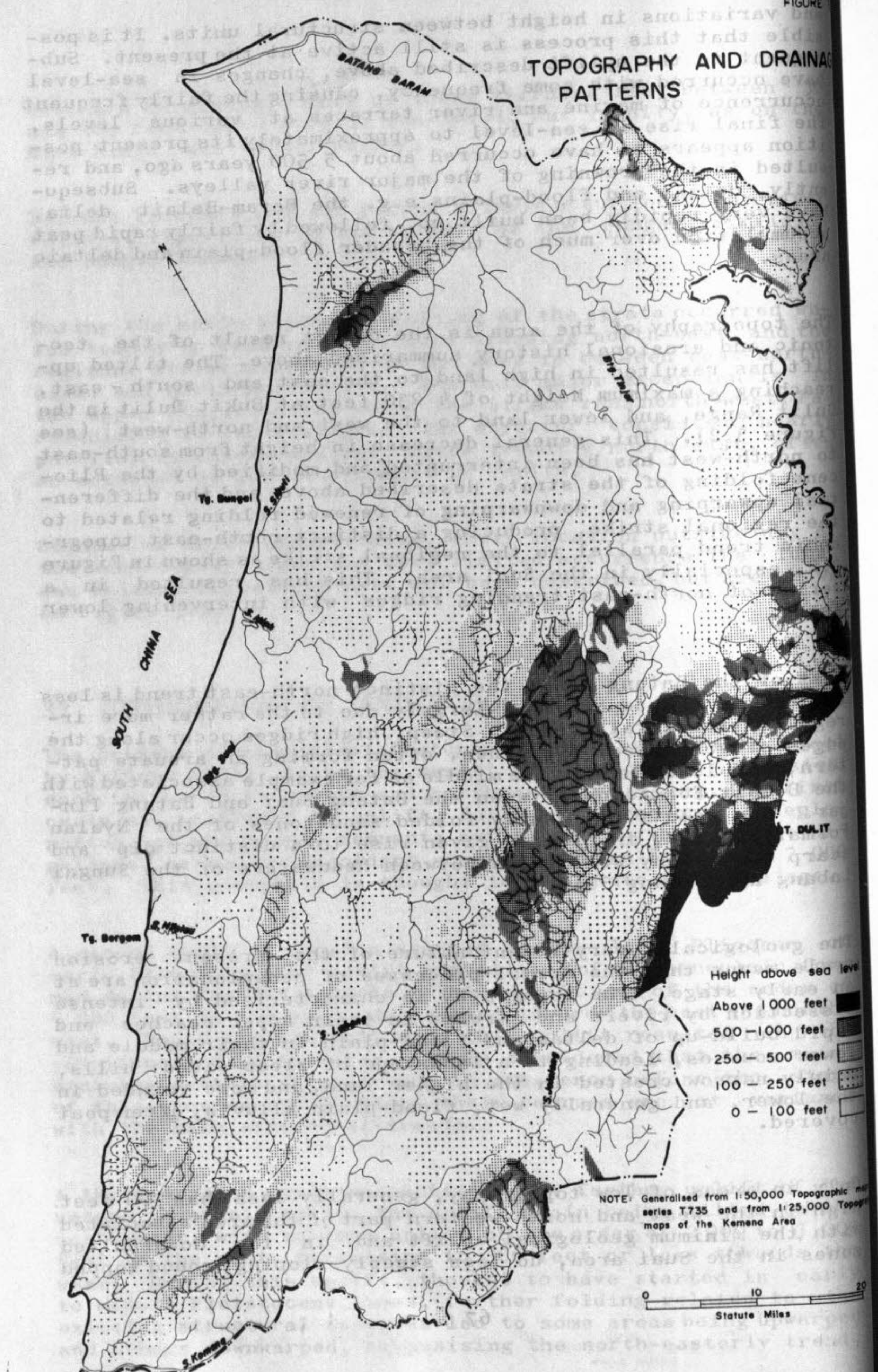


FIGURE
TOPOGRAPHY AND DRAINAG
PATTERNS
BATANG BARAM
SOUTH CHINA SEA
Tg. Sungei
Tg. Bergam
S. Kemena
T. DULIT
Height above sea level
Above 1000 feet
500 – 1000 feet
250 – 500 feet
100 – 250 feet
0 – 100 feet
NOTE: Generalised from 1:50,000 Topographic
series T735 and from 1:25,000 Topogr
maps of the Kemena Area
0
10
20
Statute Miles

hills occur. In these areas dissection is less severe, and the topography has assumed a rather more mature outline. However, in certain of these low lying areas, a secondary dissection cycle seems to have been initiated, perhaps by slight local uplift, resulting in steepening of the hill-slopes, and fairly deep incision of the streams. Examples of this can be found in part of the Niah Forest Reserve and the northern section of the Similajau Forest Reserve. The gentlest non-alluvial topography appears to be associated with downwarped areas of gently folded rocks with very low dips. Here, dissection is slight and significant areas of low slope, often less than 5 degrees occur. One such area is associated with the Tangap Formation in the Sungai Karabungan Area.

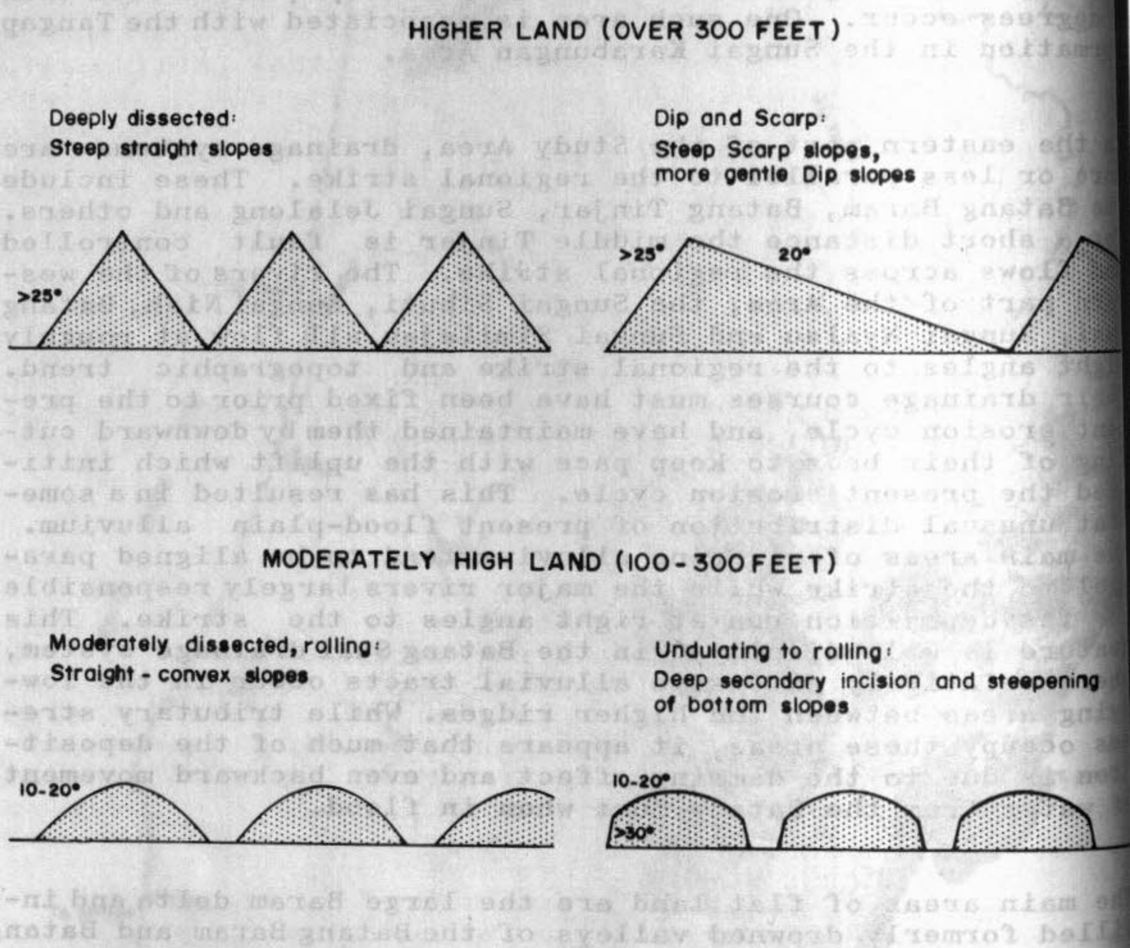
In the eastern part of the Study Area, drainage systems are more or less parallel to the regional strike. These include the Batang Baram, Batang Tinjar, Sungai Jelalong and others. For a short distance the middle Tinjar is fault controlled and flows across the regional strike. The rivers of the western part of the Area, the Sungai Sibuti, Sungai Niah, Batang Suai, Sungai Nyalau and Sungai Similajau all flow at roughly right angles to the regional strike and topographic trend. Their drainage courses must have been fixed prior to the present erosion cycle, and have maintained them by downward cutting of their beds to keep pace with the uplift which initiated the present erosion cycle. This has resulted in a somewhat unusual distribution of present flood-plain alluvium. The main areas of riverine alluvium tend to be aligned parallel to the strike while the major rivers largely responsible for its deposition run at right angles to the strike. This feature is well displayed in the Batang Suai drainage system, where relatively extensive alluvial tracts occur in the low-lying areas between the higher ridges. While tributary streams occupy these areas, it appears that much of the deposition is due to the damming effect and even backward movement of water from the Batang Suai when in flood.

The main areas of flat land are the large Baram delta and infilled formerly drowned valleys of the Batang Baram and Batang Tinjar, and the wide coastal swamp between Tanjong Bungai and Tanjong Borgam. Deep peat forms the surface deposit over most of these areas.

The shape of the slopes within the Study Area is relatively simple (Figure 3.3). The intense dissection within the higher land (in most cases anything over 300 feet) has resulted in steep (more than 25 degrees) slopes with a straight outline with sharp or very narrow convex crests, and immature topographic form. Lower areas are more mature with slopes in the range 10 to 25 degrees and largely within 10 to 20 degrees, and a convex-straight outline. Where overall heights are less than 100 feet, and mainly less than 45 feet, a larger percentage of the slope is convex in outline, with short-straight sections and, occasionally, a very narrow concave foot-slope.

FIGURE 3.3

DIAGRAMMATIC ILLUSTRATION OF MAIN SLOPE FEATURES



More commonly, secondary stream incision has over-steepened the bottom part of the slope. Where this incision is considerable as in the Niah and Similajau examples described above, incised valley sides may account for up to 30 per cent of the slope length from crest to crest. Some examples of cross-sections of actual areas are given in the Sample Area descriptions in Appendix II.

A common slope pattern in higher areas of massive, relatively gently dipping sandstone is the dip and scarp outline, with short, steep scarp slopes and long much more gentle dip slopes parallel to the rock dip. Where these form an almost continuous succession, often arcuate in outline, they form cuesta topography. This is commonly associated with the uptilted edges of geological synclines e.g. along the north-western edge of the valley of the Sungai Jelalong.

In summation, the present topographical features are typical of an immature or sub-mature geological erosion stage. Geological weathering is rapid, with a hot humid environment acting on relatively soft easily eroded parent rock, with the resulting severe dissection, steep sided hills and rapid build up of river flood-plains. It is a landscape which presents considerable problems to agricultural development.

3.3 CLIMATE

The main elements of the climate have been detailed in Chapter 1; only the features affecting the soil forming environment will be summarised here. Rainfall is heavy with average annual totals varying from about 100 inches in the Baram delta to 200 inches in the middle Baram and Tinjar areas. More important is the fact that this rainfall is spread reasonably uniformly throughout the year. On average no month has less than four inches, and in most areas except coastal ones, the minimum monthly average is in excess of six inches. Thus the area lies within a climatic zone characterised by a lack of any true dry season. Mohr and Van Baren (1959) have devised a classification which groups rainfall regimes according to the number of dry and wet months, a dry month being one in which less than 60 mm (2.4 inches) of rain falls, a wet month having more than 100 mm (4 inches). Within the Study Area, no location has an average monthly rainfall of less than four inches. Therefore, all parts of the area fall within Mohr and Van Baren's Group I, defined as areas in which "there will be a surplus of rain above evaporation during practically the whole twelve months of the year." While this is true of long term average for any month, there can and do occasionally occur periods of drought in any month of the year. Nevertheless, as far as the soil environment is concerned, the Study Area is one having a continuously wet climate.

Temperatures are uniformly high with little seasonal or diurnal variation, while humidity is also uniformly high, variation being largely diurnal as an inverse function of temperatures with little change in actual vapour content.

Monthly variation in average evaporation values is small, wi lowest average values in January and highest in May as derived from Class A pan evaporation measurements. These indicate maximum average values of 5.17 mm (0.20 inch) and minimum values of 3.9 mm (0.15 inch) per day. These values ar derived from coastal station records (see Appendix I.1) an because of the limitations of the technique the data shoul be used with caution. Inland values are likely to be lower by about 20 mm per year for every 10 km distance from the coas Comparison with the average monthly rainfall totals shows tha seldom does evapo-transpiration exceed the incoming rainfal While this statement is true of long term averages, there will certainly be short term periods of drought when evapotranspiration will considerably exceed rainfall.

3.4 VEGETATION

The prevailing conditions of uniformly high rainfall and temperature coupled with year long fairly high radiation intensity provides the ideal environment for luxurious vegetativ growth. The natural climax vegetation is tropical rain forest, clothing all undisturbed areas with a dense vegetativ cover. Thus the constant alterations in the landscape due t normal, inevitable geological erosion, the weathering of rock and the formation of soil occur under this dense vegetativ cover. The whole environment is an equilibrium, in which th natural vegetation is an important component, and readily responding to the other factors affecting that environment. Removal or alteration of the natural vegetation upsets the equilibrium, usually in an undesirable direction, by for exampl accelerating erosion, affecting the removal and distribution o plant nutrients, altering characteristics of water movemen in the soil, affecting run-off and causing changes in the soil climate.

The nature of the vegetative cover does not differ much over a wide variety of soils; generally the climatic factor tends to be of over-riding importance. The main differences arise between aerobic and non-aerobic soils, with special vegetation associations occurring on deep peats and swamp forest associations on poorly drained alluvia. Rather stunted, thin Kerangas Forest occurs on highly leached infertile terrace sands. Within the hill Dipterocarp Forest large variations in quality have been noted. In some cases these are related to particularly shallow soils, and poor quality hill Dipter ocarp Forest has generally been noted in areas of low, fairly gently undulating terrain with an average height of less than 30 feet above local alluvial level. Whether there is a true correlation between these poor forest areas and areas of low relief or whether the occurrence is purely accidental is not known, and even if there is a correlation, no reasonable cause can be indicated. Other areas of poor quality forest have been noted where no unusual soil or terrain characteristics occur.

CHAPTER 4

SOILS

4.1 SOIL GENESIS

A soil is the product of the interaction of parent material, climate, topography and organisms (including man) proceding over a period of time. In the Study Area, the absolute time scale during which the soil forming process has been active is relatively short. As indicated in previous sections, the landscape is young in the geological time scale, and there are no extensive old land forms. However, the age of a soil is not normally measured in terms of the length of time during which active formation has proceded undisturbed, but rather in terms of the stage of development the soil has reached. If a given set of conditions is maintained a stage will be reached when further alteration of the soil body will be slight and occur only very slowly. Such a soil is considered to have reached an advanced stage of maturity. Under conditions of intense weathering a soil will reach maturity in a shorter time than where weathering is much less intense. A primary factor in speed of weathering is climate, although parent material plays a part. The uniformly hot, humid environment of the Area provides ideal conditions for rapid weathering.

Within the Study Area there is little variation in the parent rock on which the weathering process is active. As indicated in the previous section, all rocks are sedimentary in origin with little lithological variation. Fine textured rocks predominate since even the sandstones are mainly fine grained, and are often argillaceous. The weathering and alteration of rocks depends largely on their exposure to air and moisture and the products of the decay of organic matter. The rate at which the weathering process procedes depends both on the physical and chemical properties of rock. In rocks which are well jointed or which have a high proportion of other planes of weakness, or are permeable, penetration by moisture and air is rapid and weathering procedes correspondingly rapidly. The generally fine textured sedimentary rocks of the Study Area are not very permeable, and since many are no more than moderately folded with few significant planes of weakness, the weathering process is largely confined to a fairly massive, compact surface. Even in the prevailing environment of potentially rapid weathering, that is hot, humid conditions with an abundance of rapidly decaying organic matter, the breakdown of the rocks is not very fast by wet tropical standards. There are variations within areas of essentially similar rocks: where folding is fairly severe and dips are steep, weathering occurs rather more rapidly than in gently folded areas of low dip. Extreme slowness of rock weathering within the area is best seen in the low, very gently folded, almost horizontally dipping strata of the Tangap Shale Formation. Weathering associated with these rocks is further complicated by their calcareous nature, and the tendency for a perched water

table to occur above the relatively impermeable rock, redu
ing the supply of oxygen and curtailing the oxidation proce
Very slow weathering has also been noted associated with ha
nodular shales of very low permeability. On the whole, t

ronment and the removal of soil by erosion is rapid. The inevitable result is shallow soils; in a high percentage of all auger and pit sites examined, partially weathered rock which retains much of its original shape and nature and is easily recognisable for what it is, occurs within three feet and a very high percentage within four feet. Apart from limiting the depth of the soil, the factor of rapid wastage conspires to limit the degree of development or the maturity of the soil body. Even in the intense weathering environment which obtains in this area, the time scale available between initial rock weathering and the final removal of soil by erosion is too short to allow advanced development. Easily soluble products are quickly removed, but the predominantly high silt contents, lack of friability, low content of water stable clay, the presence of 2 : 1 lattice clays (illite) and relatively low contents of oxides (e.g. gibbsite and goethite) indicate an intermediate stage of soil formation.

The luxuriant vegetation and the intense micro and macro faunal activity contribute to soil formation by providing large amounts of dead vegetative matter which is very rapidly broken down to provide a considerable supply of organic acids in the soil leaching solution. No figures are available for the Study Area but it has been calculated (D'Hoore, 1953) that equatorial forests of the former Belgian Congo produce 12 tons of dry matter per hectare per year (0.4 ton per acre). Under Sarawak conditions, the amounts will be of the same order. In spite of this large annual supply of organic matter, its mineralisation is so rapid that only the top 2 to 12 cm (1 to 5 inches) shows any appreciable darkening, and this is more generally confined to the top three inches. Apart from providing organic acids which greatly strengthen the leaching solution, vegetation and organisms also play an important role in facilitating the entry into, and transmission through the soil body of water, especially in fine textured soils. Permeability tests on small soil cores reveal that, in the absence of root channels and insect tunnels, the permeability of fine textured soils is as low as 0.004 cm per hour.

In summary the soils of the Study Area are the natural result of the interaction between a climate characterised by uniformly high temperatures and an excess of rainfall over evaporation providing a strong leaching environment on rocks sedimentary in origin, predominantly rather fine textured and relatively resistant to chemical weathering but offering limited resistance to erosion by running water. This interaction takes place in a geomorphologically young landscape of intense dissection and steep slopes resulting in the rapid erosion and removal of weathering products. The net result is generally rather shallow, moderately weathered, highly leached soils, with high contents of very fine sand, silt and clay. It must be concluded therefore that this material is not an ideal medium for crop growth and production, and requires special treatmemt and managerial practices such as the application of fertilisers and erosion control.

The foregoing section has been largely concerned with the development of hill soils, where, under aerobic conditions, weathering is largely by processes of hydration and oxidation.

Within the large areas of alluvial deposits, soil forming processes are different. Many of these deposits are permanently saturated, and fresh material is constantly being added to the surface. As has been indicated previously, the time factor is important in soil development, and for many of the alluvial soils the rate of deposition is so rapid that some of them are no older than the date of the previous flood. Very little time has been available for any soil development. Where the soils are permanently saturated, anaerobic conditions exist and little chemical alteration is possible in comparison with the activity in soils which are at least intermittently aerobic. Secondly, in permanently saturated soil, little leaching is possible, unless the groundwater is flowing steadily, so that soluble products normally absent in well drained soils are present. Alluvial soils in this Area are very immature, with very little evidence of weathering. In very poorly drained areas, the anaerobic conditions greatly reduce the faunal activity which normally breaks down organic matter, and the process is confined to anaerobic species. Their activity depends on a ready supply of inorganic nutrients, which are generally low in this area. Thus, the rapid accumulation of peat deposits is favoured.

Soil formation in parent materials of the main terrace deposits is also rather simple. The parent material is almost pure silica sand, so virtually no weathering occurs within the deposit. Soil formation is restricted to the deposition of organic matter, with some iron humus compounds within the deposit, mainly from groundwater. In many cases this soil formation is no longer active, because no groundwater exists within the present profile, and the soil may be considered largely fossil.

4.2 SOIL CLASSIFICATION

Soil classification is the grouping of soils into units according to certain observable or measurable properties. Most commonly, the properties shown are those which result from or affect soil genesis, such that the classification should, as far as possible, be a natural one which reflects the interaction of the many factors involved in soil formation. At the highest level of classification, the properties considered are genetic ones while more detailed characteristics are used in progressively lower categories, including those used as mapping units.

In this Study, the higher levels of classification have not been formally recognised or named: sufficient information to allow this to be done is not yet available, and the whole process of classification is under review at the moment, the eventual aim being to allow full classification of Sarawak soils within the terms and definitions of the United States Department of Agriculture Soil Classification, (A Comprehensive System, Seventh Approximation and its Supplements Soil Survey Staff, 1960 and 1967). Information available from this Study is sufficient only to indicate the likely placement of the soils in the higher categories.

Basically, the Seventh Approximation Soil Classification divides all known soils into ten orders based largely on the presence or absence of certain diagnostic sub-surface horizons. The features of these diagnostic horizons are those arising from the genesis of the soil. In Sarawak, only three diagnostic horizons which occur in humid environment are of interest. Such horizons can result from the movement downwards and deposition of the soluble and insoluble products of weathering, or can be the result of weathering in situ with little effect from re-deposition. Evidence from soil profiles would indicate that the character of the sub-soils appears to depend little on movement and deposition within the soil. Soluble salts are largely leached out of the soil, and there is no evidence that the movement of clay in the soil has led to its deposition in the sub-soil. This latter fact is of importance because previously the soils of this area have been considered as Red Yellow Podzolics, a group of soils characterised by clay deposition in some sub-soil horizon. Certainly nearly all hill soils show a clay increase with depth, and this increase in the coarser textured soils is sufficient to meet the quantitative requirements for an argillic horizon. However, no true clay skins have been noted in the soil profiles and limited information from thin section analysis indicates the absence of orientated clay (Scott, priv. comm., 1973). The major peds do show a pale coloured skin especially in the Merit family soils. The nature of this is not fully known, but may represent gleying of the ped faces. During heavy rain there is considerable water movement along major structural planes in fine textured soils, and commonly in a freshly dug soil profile pit there is free water on the larger ped faces.

The major chemical characteristics are those of a heavily leached but only partially weathered soil. Generally, the cation exchange capacity (CEC) is about 25 to 30 me/100 g clay. This value is quite high compared with the upper limit of 16 me/100 g clay set for oxic horizons in the Seventh Approximation (1967). Therefore, the upland soils certainly would not qualify as soils containing an oxic horizon. Preliminary clay mineral analysis indicates that 2:1 lattice clay is a minor but important constituent of the clay fraction, and there is a significant content of weatherable material in the sense used in the Seventh Approximation. Further, none of the soils, except for the special case of terrace sands, show any of the characteristics of a spodic horizon. Almost by elimination, the sub-soil characteristics of the upland soils are those of a cambic horizon. The main features of the cambic horizon are the result of weathering in situ rather than from additions of mineral material: thus the clay increase shown in the Merit and Bekenu families from B/C, C horizons to the true B horizons is due to the progressive weathering of the soil parent material rather than to additions of clay derived and mechanically transported from overlying horizons. However, upland soils do show a considerable increase in the clay content from A to B horizons. This would indicate that clay is lost from the A horizons, but, as explained above, does not accumulate in the sub-soil: therefore, there must be net loss of clay from the soil body. The mechanics of this are uncertain, but lateral loss and transport of clay must be effective during heavy rain. It has also been reported however, that clear cutans have been observed on thin sections collected from a Merit family profile in Central Sarawak (Scott, priv. comm., 1973). This would point at a certain movement of clay down the profile. A shifting process by soil fauna like termites and ants may also play a part together with mixing of the upper part of the soil in tree fall. In a few profiles there is some evidence that clay may be moved through the soil profile into the underlying weathering rock, particularly where it is broken up. The significance of this is difficult to judge. It may be that the prevailing moist or wet soil environment favours the transport of clay rather than its deposition. The soil may seldom be dry enough to encourage clay moved in suspension to adhere to ped faces and pore walls. Further, there is some indication that sub-soil porosity is generally low. As noted above, water movement, especially in the finer textured sub-soils, appears to be largely confined to fine cracks separating the major, coarse soil aggregates and along root channels.

In terms of the Seventh Approximation Classification, the residual upland soils merit inclusion in the Inceptisol order since they have a cambic horizon and lack, on present evidence, any other diagnostic horizons such as spodic, argillic or oxic horizons. Further arrangement of the soils within this order should await more detailed study with the specific aim of establishing a higher order classification.

This study has limited itself to the classification of soils into units at family and series levels to allow mapping and final interpretation of the soils in terms of their agricultural potential. The accreting alluvial soils are immature and all are likely to come within the definitions of the Entisol order. Other soils which have sub-soil horizons with very dark colours and relatively high organic matter contents may come within the Spodosol Order, but at present there is insufficient data to indicate that these organic horizons are definitely spodic in nature. In cases where the dark coloured horizon lies at considerable depth (more than 100 cm or 40 inches), these soils may reasonably be considered as Entisols. Pallid soils within the Study Area are comparatively rare, and there is insufficient data to establish their relationship to other upland soils.

4.3 PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOIL UNITS

4.3.1 Introduction

In this section the main physical and chemical properties of the various families and series are described. In fact, the chemical characteristics are described for the family, rather than individual series, in most cases because there are no significant chemical differences between series within one family. Further, in most families one series tends to be dominant: for example the Merit and Bekenu series are highly dominant in the Merit and Bekenu families respectively.

The classification of the soils within the Study Area is that devised by the Soil Survey Division, Sarawak (Scott, 1973), and is a classification at family, series and phase level. The reasons for the lack of classification at higher levels has been explained in the previous section.

In the first instance, soils are divided into two broad groups, accreting and non-accreting soils. The former includes all soils forming within the present flood-plains of rivers and streams and coastal alluvia. They are basically soils to which additions of parent material are constantly being made. The latter group includes all soils which are or have formed in situations above present flood-levels and which do not receive additions of material on their surfaces other than organic matter from normal vegetative decay. A third broad group includes organic soils; these are defined as having more than 30 per cent organic matter if the mineral fraction consists of more than 50 per cent clay, more than 20 per cent organic matter if the mineral fraction has no clay, and some proportional intermediate value of organic matter if the clay fraction is intermediate.

Within these three broad groups, further division is made on other features of the control section, primarily texture and colour. The control section is defined as that part of the soil profile between 10 cm (4 inches) and 100 cm (40 inches), or to a lithic or paralithic contact, whichever is the shallower. Depth to a lithic or paralithic contact is also a diagnostic feature at this level of classification, the division between very shallow or skeletal soils and others being set at 25 cm (10 inches). Division within the accreting soils is based on the electric-conductivity to separate riverine from marine alluvia, with further division between gley and non-gley soils and those occupying intermediate drainage positions. Divisions within non-accreting soils is made between pallid and non-pallid soils, the former being defined as soils having colour values of more than 5 and chromas of less than 3 according to the Munsell Colour notation as to the dominant matrix colour of the control section. Special recognition is made of soils with pallid upper horizons, and dark coloured sub-soil horizons within the control depth having colour values of 5 or less and chromas of less than 5. The dark coloured definition is intended to correspond to a spodic horizon where other classifying criteria are lacking. Sub-division is made between dark horizons which are soft and those which are hard enough to prevent penetration by a normal soil auger. Separation between soils derived from calcareous or non-calcareous parent material is achieved by setting a limit of pH 6 measured in some sub-soil horizon below 75 cm (30 inches), or immediately above a lithic or paralithic contact if shallower than 45 cm.

The major units of classification and mapping within the groups summarised very briefly above are soil families. These are based on a number of characteristics of which textural groupings are one of the most important. These groups are of the normal soil textural classes with one major difference: for the purposes of the family textural groupings the very fine sand fraction is considered as silt. These textural groups are:-

(1) Sands

Sands; loamy sands coarser than loamy very fine sand.

(2) Coarse loams

Sandy loam, light loam, light silt loam and silt in which the sand is mainly fine or coarser and the clay content is less than 18 per cent.

(3) Fine loams

(Where the sand is mainly fine or coarser) sandy clay loam; heavy loam, heavy silt loam, light clay loam, light silty clay loam: clay content 18 to 35 per cent.

(4) Coarse silts

(Where the sand is mainly very fine sand) loamy very fine sand, sandy loam, loam, silt loam, silt: clay content less than 18 per cent.

(5) Fine silts

(Where sand is mainly very fine sand) sandy loam, loam, silt loam, clay loam, silty clay loam, sandy clay loam: clay content 18 to 35 per cent.

(6) Clays

Sandy clay, clay loam, silty clay loam, silty clay, clay: clay content more than 35 per cent.

The main physical and chemical properties of the soils identified during the course of this Study are described below.

4.3.2 Merit Family

Soils of this group are the single most important group in the Study Area. They occupy 30 per cent of the Broad Transect Soil Survey Area and 54 per cent of the Semi-Detailed

Soil Survey Area. They are mainly non-accreting residual soils formed from shales and, occasionally, very fine grained sandstones. A very minor component of the family is the Lupar series in which the parent material is fine textured old alluvial material. The two major series within the family are the Merit and Jakar series, differentiated on colour. The Merit series has a hue of 10YR or yellower in some part of the control section (100 cm or 40 inches) above 50 cm (20 inches), while the Jakar series is redder than 10YR throughout the control section. The basic criteria for the family are that the weighted average texture of the control section below the Ah horizon or 10 cm (4 inches) whichever is the deeper be fine, that is it should contain more than 35 per cent clay and that the matrix colours should not be pallid. Table 4.1 shows the main features of the particle size distribution.

TABLE 4.1 AVERAGE PARTICLE SIZE ANALYSIS VALUES (PER CENT) FOR THE MERIT FAMILY

Horizon No. of samples in brackets	Clay	Silt	Very fine sand	Other sand
Ah (48)	21	39	19	21
Ae (78)	33	45	13	9
B1 (60)	39	41	12	8
B21 (80)	46	37	10	7
B22 (58)	47	34	9	10
B3 (38)	43	35	9	13
B/C & C (26)	40	40	8	12

The Merit family has a loam or silt loam Ah horizon about 5 cm (2 inches) deep on average, overlying clay loam sub-surface horizons which in turn overlie clay textured sub-soil B horizons. Where partially weathered parent material horizons occur, the texture decreases to light clay or clay loam, occasionally silty clay loam. Silt contents are high throughout, with minimum values in the B horizons and only very small amounts of fractions coarser than very fine sand occur: these are highest in the lower sub-soil horizons and this increase is largely due to iron-cemented particles. The organic carbon content of the Ah horizon averages out at 3.8 per cent, and considerably darkens the horizon. It is a horizon of intense faunal and bacteriological activity and in most cases is composed largely of faecal pellets imparting a moderately to strongly developed crumb structure and very friable consis ence. The horizon has a very high root density of mainly fi feeding roots, but also contains shallow laterals. Porosi is high, and the presence of this horizon is obviously ve important in its effect on the infiltration properties of t soil. On steep slopes, the Ah horizon is often either abse altogether, or is no deeper than about one and a half cm half an inch. On such sites, surface wash appears to be t high to allow the persistence of any depth of layer with si gnificant amounts of organic matter. It is likely that lo of the Ah horizon may greatly decrease the infiltration water into the soil and thus increase the run-off with atte dant increased erosion hazard. In this respect the leaf li ter is also important. It is seldom more than two leaves th ick and more usually is only of single leaf deep, but pla a part in decreasing the splash effect of water droplets.

Underlying the Ah horizon, or at the surface if this is abse the Ae horizon is mainly of clay loam, occasionally silty cl ay loam texture. The organic matter content decreases shar ly in this horizon and has little effect on soil structur This is weak to moderate, medium or coarse subangular bloc and the consistence is friable to firm. The horizon is ge erally well rooted with moderate porosity, and faunal activ ty is usually high with numerous tunnels as a result of an and termite activity. This activity considerably aids th movement of water, very much higher permeability values bei obtained from small core permeability tests where faunal act ivity is high than where it is absent. Faunal activity ma also have considerable effect in sorting and mixing the soi in this horizon.

In most profiles there is a horizon, designated B1, which ha properties intermediate between the overlying A horizon an the underlying B horizons. The colour is usually either sli ghtly more red and has higher chroma than the Ae horizon. Th structure is both more strongly developed and coarser th the overlying Ae horizon. Most commonly the structure is mod erate, coarse subangular blocky with a pale surface visib on some of the peds. As explained in the foregoing secti the exact nature of this pale surface to the peds is not know but it is important to note that they are in general not cl skins. The consistence is firm, occasionally very firm, an the porosity is low. Evidence of faunal activity is usual present, but at a much lower intensity than in the overlyi Ae. The intensity of rooting is less than in the Ae horizon

Maximum clay contents occur in the B2 horizons where the te ture is clay, occasionally silty clay and rarely heavy cl loam. As has been explained, it is not thought that this cl increase is due to clay derived from the overlying horizon The maximum clay content is due to weathering <u>in situ</u> and t accompanying net loss of clay from the surface and sub-surfa horizons. The B horizons are the most strongly coloured w ere there is a colour increase with depth, but frequently colour alters little with depth and an increase in chroma of two units often represents the maximum colour change from A to B horizons. In many profiles the significance of colour variation is rather vague. Evidence is insufficient at the moment to indicate whether differences in colour are due to minor differences in the parent material or to differences in the weathering environment. Colour differences do not appear to correlate with any significant variation in measureable physical or chemical characteristics. Soil structure in the B horizons is usually both most strongly and most coarsely developed. In many profiles a degree of coarse prismatic structure occurs, most easily seen in the profile after it has been left open for a time and has dried out a little. Water movement appears to be concentrated along these coarse structural planes, and the aggregates are invariably pale surfaced. The main structural aggregate is a coarse angular, less commonly subangular blocky, the peds are moderately to strongly developed. In some profiles a subsidiary structure of medium to fine rather wedge shaped peds occurs. These units are incomplete in that they are not separated from neighbouring peds at all points on their circumference. The significance or reason for this kind of ped is not at present known. Consistence in B horizons is firm to very firm and porosity very low. There is generally a very low level of faunal activity in comparison with overlying horizons and water movement within peds is rather restricted. Measurements of small core permeability indicate that permeability may frequently be less than 0.005 cm per hour, and water movement in the horizon depends heavily on the fine cracks separating the major peds. Root density in B horizons is very low, and the generally high compaction and low porosity does not provide a very satisfactory environment for root development.

In a very high percentage of all soils of the Merit family there are iron concretions present in the B horizons. The upper boundary of these concretions is nearly always abrupt and forms an obvious layer in the soil profile. Nevertheless, these concretionary layers do not appear to constitute a separate genetic horizon, since they can and do occur at any level in the B horizons and occasionally in the A. They appear to be largely a residue of rock weathering. Many exposures show the presence of iron concretions along cleavage planes of little altered rock. In some cases they are probably geological, but in most they appear to have derived from a previous weathering cycle interrupted by the uplift which initiated the present rock and soil weathering cycle. The concentration of these concretions into distinct layers is probably largely the result of slow colluvial processes on the generally steeply sloping landscape, although sorting by faunal activity may also have been an important factor. In many bottom slope positions these concretions occur on the surface and scattered throughout the profile, and it is likely that in such cases the soil is of largely colluvial derivation. The upper boundary, as noted, is usually clearly defined, and lies at an angle roughly parallel to the ground slope. The concretions themselves are usually only moderately hard and can be broken in the fingers. Many show the impress of the original parent material and are often described as iron cemented parent material. Others are less obvious in this respect, and have a soft earthy centre. Less commonly, the concretions are distinctly pipe-like. The density of concretions is highly variable, but can reach as much as 80 per cent by volume of the horizon. In concentrations greater than 50 per cent the concretionary horizon is strongly limiting to rooting and the concretionary layer usually defines the effective rooting depth. In a few cases, very high densities have been seen to provide a barrier to water penetration due to the very close packing of the concretions, the fine interstitial material and the complete lack of discernible structure. The base of the concretionary layer is usually the soil parent material, but occasionally the density of the concretions decreases fairly abruptly and a B horizon with a low concretionary density occurs. In most cases the depth of soil weathering and the effective depth of the soil from the point of view of plant rooting are very different. This creates some problems in deciding the limits for depth phases: ideally in a soil classification these should refer to the depth of the solum, the depth of soil development. However, in the conditions in the Study Area these would seldom be the same as the effective rooting depth and since the end result of the Study is a land capability assessment, depth phases have been used as effective depth. Obviously it is possible to indicate both parameters, but to do so greatly complicates the mapping procedure: for practical reasons this has been avoided.

In the Merit family, about 25 to 30 per cent of all profiles examined show sub-soil horizons in which the nature of the original parent material is obvious although generally heavily weathered. These constitute the C and B/C horizons, the latter tending to be mixtures of partially weathered rock and well weathered soil material occurring as discrete patches in the same horizon. Colour is much paler in these horizons than in the overlying B horizons, frequently being grey. When the parent rock is well weathered, there is little structure and the horizon is very compact; roots seldom penetrate into it. In some cases the B/C and C horizons retain the original rock structure and tongues of an overlying horizon penetrate into the underlying rock, parts of which show cementation by iron oxides. More rarely, the B horizons abruptly overlie a C horizon of little altered parent rock which retains the hardness of the original rock. This occurs most frequently when the shale parent rock is little folded and gently dipping, and there is a lack of planes of weakness along which water and air can penetrate to institute weathering: thus the weathering process is confined to the surface of the rock. In some nodular shales the weathering process also appears to be slow, and core boulders are common in such cases. Between the B2 horizons and the B/C and C horizons described above, there is commonly a horizon, designated B3, which has most of the characteristics of B2 horizons except that colour is often rather paler, small pieces of weathered shale are present and the clay content is lower. This horizon is more closely related to the B2 horizons, but contains properties of the underlying C and B/C horizons. Structure is usually weaker than in the overlying B2, consistence is very firm and the horizon commonly, but by no means invariably, contains the highest concentration of iron concretions.

There is a basic relationship between slope and effective soil depth within the Study Area. As indicated in the Sample Area descriptions in Appendix II, effective depth decreases with increasing slope. Further, on steeper slopes, generally those steeper than 25 degrees and with slope lengths greater than 50 metres, effective depth varies with position on the slope. The minimum depth occurs on bottom slopes and maximum depth on the upper third; consequently, mapping of soil depth is complex even at fairly large scales of mapping.

The average chemical characteristics of the Merit family are summarised in Table 4.2. Exchangeable cations are highest in the Ah and lowest in the B horizons, but overall values are extremely low. Values tend to increase somewhat in B/C and C horizons because of the more active release from rock weathering. Total cations on the other hand are lowest in the Ah horizon and increase steadily with depth. Total calcium is an exception, the highest levels occurring in the Ah and Ae, with only very low levels in the rest of the profile. This, and the distribution of the exchangeable cations, illustrates the very efficient concentration of available nutrients in

TABLE 4.2 AVERAGE CHEMICAL CHARACTERISTICS FOR THE MERIT FAMILY

Horizon No. of samples in brackets	pH soil/water 1:2.5	Exchangeable cations me/100 g soil			Total nutrients mg/100 g soil				CEC me/100 g soil	Per cent base saturation
		Ca	Mg	K	Ca	Mg	K	P		
Ah (90)	4.6	0.9	0.7	0.3	20	127	129	42	17.2	12.1
Ae (159)	4.8	0.3	0.3	0.1	6	162	163	24	13.6	5.0
B1 (118)	5.0	0.1	0.1	0.1	3	169	177	18	12.4	3.5
B21 (138)	5.1	0.1	0.1	0.1	2	200	215	20	12.5	3.3
B22 (118)	5.1	0.1	0.1	0.1	2	211	237	21	12.0	3.7
B3 (69)	5.3	0.2	0.3	0.1	3	231	233	21	12.5	4.3
B/C & C (43)	5.2	0.1	0.5	0.2	3	276	278	23	12.8	8.1

the vegetation and the surface few inches of the soil. The values for total cations are quite high and indicate the relatively immature stage of weathering of the present soil, while the very low exchangeable values are to be expected in heavily leached soils derived from parent materials relatively low in weatherable minerals. This is emphasised by the very low percentage base saturation, particularly in the B horizons. The relatively much higher value in the Ah horizon emphasises the degree to which available nutrients are concentrated here. Apart from the Ah horizon, the cation exchange capacity (CEC) is very uniform throughout the profile in spite of the range in clay content revealed in Table 4.1. The lower clay values in the A horizons, particularly in the Ah, might be expected to yield somewhat lower CEC values; but this is more than made up for by the higher organic content of these horizons. The pH values increase gradually with depth, the A horizons being strongly acid.

Apart from the micro-nutrients described above, micro-minerals are also important in plant growth. The table below shows average values for soils of the Merit family.

TABLE 4.3 AVERAGE PROFILE TRACE ELEMENT LEVELS (P.P.M.)

Cu	Mn	Zn
10	68	45

These average values indicate that micro-nutrients levels are low but probably adequate. However, considerable variation occurs, and in many cases the micro-nutrient levels are rather marginal. These levels could become critical when fertilisers are applied and the whole nutrient balance is changed. In general, there is some relationship between micro-nutrient levels and levels of total cations, higher levels of the former occurring when levels of the latter are high. In this connection, these levels appear to have some definite geographical distribution, and it is tentatively suggested that low general levels of both macro and micro-nutrients are associated with areas of poor primary forest. Examples are Sample Area B, parts of Similajau Forest Reserve and the Kemena Area. Here nutrient levels are very low, and the forest quality is generally very poor. There is also a possibility that this effect may relate to some extent to soil families. This is further discussed in Sections 3.5 and 3.16.

A very minor series within the Merit family is the Lupar series which includes fine textured soils derived from old alluvial deposits. These soils are very difficult to distinguish in the field from other soils in the Merit family since their physical properties are very similar to the Merit and Jakar series. They are usually distinguished by general topographic features and by the presence in some of a horizon of rounded quartz gravel and, occasionally, an obvious discontinuity between the alluvial material and the older surface on which it was deposited. However, the limited laboratory data would indicate that these soils are extremely low in plant nutrients, a fact to some extent not inconsistent with the poor quality forest they support.

4.3.3 Bekenu Family

Soils of this family are largely derived from residual parent material, and occupy 20 per cent of the Broad Transect Soil Survey Area and 3 per cent of the Semi-Detailed Soil Survey Area. The main source parent rock of this family is very fine grained sandstones and rather sandy and silty shales. Very small areas of Bekenu soils are derived from old alluvial material, and have been tentatively included in a separate series, the Tukau series. The main series are the Bekenu and the Sarikei series, differentiated on colour in the same way as the Merit and Jakar series in the Merit family. The basic criterion for the Bekenu family is that colour should not be so pale as to qualify as a pallid soil, and that the average texture of the control section should be fine or coarse silty. Most Bekenu soils are, in fact, fine silty. Clay content increases gradually from A to B horizons and decreases in the B and C horizons. Bekenu family soils contain similar silt contents to Merit family soils, but have almost double the very fine sand content. The content of coarser sand fractions is also much higher. The main features of the particle size distribution are given in Table 4.4.

TABLE 4.4 AVERAGE PARTICLE SIZE ANALYSIS VALUES (PER CENT) FOR THE BEKENU FAMILY

Horizon No. of samples in brackets	Clay	Silt	Very fine sand	Other sand
Ah (29)	12	37	30	21
Ae (41)	20	40	24	16
B1 (30)	25	37	24	14
B21 (40)	29	32	22	17
B22 (28)	29	36	20	15
B3 (15)	31	34	17	18
B/C & C (7)	22	45	20	13

The Ah horizons have an average organic carbon content of 4.6 per cent. Texture is normally a light loam and the structure is moderate medium crumb with very friable consistence. This horizon is on average 5 cm (2 inches) deep and seldom exceeds 10 cm (4 inches) so that, although it is frequent and persistent under natural vegetation, it can be quickly lost when land is cleared and cultivated. The importance of the Ah horizon in water movement has already been discussed in the section on Merit family soils.

Underlying the Ah horizon is the Ae horizon, containing considerably more clay than the Ah. The texture of this horizon is generally a heavy loam or silt loam, occasionally heavy fine sandy loam. Structure is moderate medium subangular blocky and consistence is friable; rather more so than in the case in the Merit family. Porosity is high, and faunal activity usually considerable. The horizon is well rooted.

The B horizons are marked by an increase in texture with light clay loam, very fine sandy clay loam and silty clay loam being the most common textures. Occasionally the texture in deep soils may reach heavy clay loam or even light clay, but the average clay content of the control section must not exceed 35 per cent. Structure is rather more strongly developed and the peds are coarser than in the Ae. The most commonly occurring structural designation is moderate, occasionally strong coarse subangular blocky, with firm consistence. Porosity is moderate to low. The B horizons of the Bekenu family soils are, on the whole, less compact than those of the Merit family and structure rather less strongly developed and aggrates smaller in size. Evidence of a prismatic or near prismatic aggregation is less obvious in Bekenu soils, and the formation of a distinct surface to the individual peds is less marked. Water movement through the B horizon is more rapid than in Merit family soils, and appears to be less concentrated along specific structural planes. In general, the horizon is a better rooting medium than in soils of the above mentioned family. Concretionary iron layers are as common in the Bekenu family as they are in the Merit family, and are the main feature limiting effective root depth. The nature of these concretionary layers is the same as in the Merit family.

The lower horizons of the Bekenu family profile are the B/C and C horizons and are marked by the presence of identifiable rock material. Within the normal depths described in a soil pit, these horizons occur less commonly in the Bekenu family than in the Merit family - in about 16 to 18 per cent of cases in the former as opposed to 25 to 30 per cent in the latter. This may indicate a greater depth of weathering in the Bekenu family related to the greater permeability of the parent rock. The texture of the B/C and C horizons is generally a very fine sandy or silty clay loam, occasionally light clay loam. Structure is generally weakly expressed, and may be limited to the structure inherited from the weathering parent rock. Consistence is usually very firm, but is largely a function of the degree of weathering in the horizon. In some cases, the C horizon may be relatively little altered parent rock. Whatever the degree of compaction, rooting in the horizon is usually very sparse or absent altogether. As in the case of the Merit family, there is often present a horizon transitional from B2 to B/C and C horizons in which the characteristics are usually more akin to the B2, but include some characteristics of the underlying B/C and C horizons. Most commonly it contains the greatest volume of iron concretions.

TABLE 4.5 AVERAGE CHEMICAL CHARACTERISTICS FOR THE BEKENU FAMILY

Horizon No. of samples in brackets	pH soil/water	Exchangeable cations me/100 g			Total nutrients mg/100 g soil				CEC me/100 g soil	Per cent base saturation
		Ca	Mg	K	Ca	Mg	K	P		
Ah (29)	4.8	0.9	0.5	0.3	32	58	57	40	14.5	11.9
Ae (42)	5.0	0.1	0.1	0.1	3	75	62	20	9.4	3.7
B1 (32)	5.1	<0.1	<0.1	0.1	1	92	74	15	8.1	2.9
B21 (41)	5.2	0.1	<0.1	0.1	1	97	88	15	8.6	3.0
B22 (29)	5.2	0.1	<0.1	0.1	2	106	103	14	8.2	3.5
B3 (16)	5.4	0.2	0.1	0.1	4	113	122	19	9.3	5.0
B/C & C (8)	5.3	<0.1	0.1	0.1	2	108	112	17	9.0	3.1

The main chemical characteristics of the Bekenu family are given in Table 4.5. This shows a distribution very similar to that for the Merit family, but lower levels of both exchangeable and total cations except for levels of total calcium, which are similarly very low in both families. The average levels of total cations is about half that of the Merit family. Cation exchange capacity is considerably lower than for the Merit family, but shows the same relationship between horizons. The lower levels are related to the lower clay contents as shown in Table 4.5. Base saturation are very similar in the two families except that the increased percentage base saturation of B/C and C horizons in the Merit family is not paralleled in the Bekenu family. Possibly this reflects the higher permeability of these horizons in the Bekenu family and the consequent greater degree of leaching.

The effect of the lower fertility levels of the Bekenu family is difficult to determine. One feature is the even higher concentration of exchangeable cations in the Ah horizon in the Bekenu family than in the Merit family. The main areas of Bekenu soils, as for example, the Similajau Forest Reserve area are generally areas of poor primary forest cover. Therefore, it is suggested very tentatively that there may be a correlation between forest quality and inherent soil fertility. It should be pointed out that areas of very shallow Bekenu family soils (where the depth of the solum is shallow) are excluded from this generalisation: they and the Bekenu-Kapit family intergrade characterised by having C horizons at shallow depth can have relatively high inherent fertility levels largely due to their extreme immaturity. These soils are commonly found on high, steeply sloping areas and have a forest quality that is often quite high, suggesting a possible divergence in the kind of land suitable for forestry on the one hand and agriculture on the other, where no external input of fertility is considered. There does appear to be a case that the areas most suitable for agriculture in terms of topography may be the areas which have the lowest potential for forestry. The evidence for this in this Study is admittedly very vague, incomplete and imprecise; but is worthy of further study, particularly where there is, or may arise, competition between forestry and agriculture for land.

The importance of inherent fertility levels in the agricultural development of Bekenu family soils is relatively limited and fertiliser inputs will be necessary to achieve optimum yields, but the need for fertility balance should again be stressed. The level of leaching losses of applied fertilisers may be slightly higher in the Bekenu family than in Merit family because of the higher permeability of the former.

The average levels of micro-nutrients in the Bekenu family are shown below.

TABLE 4.6 AVERAGE PROFILE TRACE ELEMENT LEVELS (P.P.M.) FOR THE BEKENU FAMILY

Cu	Mn	Zn
5	21	18

These values are much lower than in the Merit family, and micro-nutrient deficiencies are a distinct possibility especially where manurial treatments may upset the existing rather delicate nutrient balance. The zinc levels are particularly low. However, all levels are near the critical point where deficiency symptoms could be expected.

In general, the Bekenu family is more favourable for plant growth in terms of its physical properties than is the Merit family, but rather less so in chemical characteristics.

The two main series within the Bekenu family are the Sarikei and Bekenu series. The latter is by far the more important; but, apart from the colour difference which separates them, there do not appear to be any differences in their physical and chemical characteristics. A very minor soil, the Tukau series, is developed from old alluvial material. No laboratory data are available for this series, but it is likely that nutrient levels will be lower than for the other two series.

4.3.4 Nyalau Family

Only very limited areas are occupied by soils of this family within the Broad Transect Soil Survey Area and the Semi-Detailed Soil Survey Area, the figures being 6 per cent and 0.3 per cent respectively. They have formed from medium and fine grained sandstones and contain more sand than do either the Bekenu and Merit families, particularly in the grade sizes coarser than very fine sand, as shown in Table 4.7. A minor component of the family is soils with similar textural characteristics formed in old alluvial parent material. These are soils of the Sabangang series. All other soils of the family are included in the Nyalau series. The clay percentage distribution is very similar to that of the Bekenu family, but as mentioned above, the sand and silt distribution is very different. Like the other two families described, clay content increases with depth and reaches a maximum in the lower B horizons. Colour is often very uniform throughout the profile, there being no change in hue with depth, and only minor chroma changes.

TABLE 4.7 AVERAGE PARTICLE SIZE ANALYSIS VALUES (PER CENT) FOR THE NYALAU FAMILY

Horizon No. of samples in brackets	Clay	Silt	Very fine sand	Other sand
Ah (4)	13	26	19	52
Ae (5)	20	19	17	44
B1 (4)	24	21	12	43
B21 (5)	28	20	9	43
B22 (5)	32	18	10	40
B3 / B/C & C	Insufficient data			

The Ah horizon is dark coloured due to its relatively high organic matter content. The usual texture of this horizon is light sandy loam, occasionally loam, with a weak to moderate crumb structure and very friable consistence. As with all Ah horizons, there is a high density of fine feeding roots and intense faunal activity.

The underlying Ae horizon is sandy loam, loam or, occasionally, a sandy clay loam in texture. The horizon is weakly structured and friable to very friable. Porosity is high and the horizon is usually very well rooted with a high degree of faunal activity. The permeability of this horizon is high.

Underlying the Ae horizon, the B1 horizon is transitional to the true B2 horizons and is marked by an increase in clay content. The usual texture is sandy clay loam. Structure is weakly developed, and the units are rather coarser than in the Ae horizon. Consistency is friable and the porosity is high with fairly high permeability. The horizon is generally well rooted.

The B2 horizons are marked by a further increase in the clay content and, occasionally, a slight reddening of the colour. The usual texture is sandy clay loam, but may reach sandy clay in the deeper profiles. However, the fine textures do not usually occur within 100 cm (40 inches) of the surface. The structure is weak to moderately coarse blocky with friable to firm consistence. The pale coloured surface skin on individual peds which is so obvious in the Merit family is only very weakly expressed in the Nyalau family. The B2 horizons of the Nyalau family contain a higher root density than in either the Merit or Bekenu families and the Nyalau family appears to present little impediment to root development in the subsoil horizons. The porosity of the B2 horizons is moderate, and sub-soil permeability is probably quite high. As in the Bekenu and Merit families, iron concretions occur in the B2 horizons, but are usually less dense than in these two families and do not so frequently present a barrier to rooting. Nyalau soils are generally the most deeply weathered of the residual soils, probably as a result of the greater permeability of the parent rock and consequently its more rapid weathering.

The deep sub-soil B/C and C horizons are usually below the depth of normal soil inspection. Where they have been seen they are coarser than the overlying B2 horizons and are generally lacking in structure. They are much less compact than in Bekenu and Merit families soils.

The chemical characteristics of the family shown in Table 4.8 are very similar to those of the Bekenu family except for rather lower values of exchangeable potassium and lower CEC,

TABLE 4.8 AVERAGE CHEMICAL CHARACTERISTICS FOR THE NYALAU FAMILY

Horizon No. of samples in brackets	pH soil/water	Exchangeable cations me/100 g soil			Total nutrients mg/100 g soil				CEC me/100 g soil	Per cent base saturation
		Ca	Mg	K	Ca	Mg	K	P		
Ah (4)	4.8	0.2	0.3	0.1	4	55	55	40	10	7
Ae (5)	4.9	<0.1	<0.1	0.1	1	69	64	21	6	3
B1 (4)	4.9	0.1	0	<0.1	2	71	48	11	6	2
B21 (5)	5.0	0.1	<0.1	<0.1	2	95	94	12	6	4
B22 (5)	5.1	0.1	0	<0.1	2	107	110	13	6	4
B3, B/C & C	Insufficient data									

although the clay content is very similar in the two families. The family is poorly supplied with plant nutrients, but this may to some extent be overcome by the deeper rooting possible in this family. The leaching losses of applied fertiliser are likely to be very high because of the high permeability and low CEC. Response to fertiliser may well be greater in this family than in the other two, but optimum results from fertiliser may require more frequent, smaller applications than in the case of the other families, particularly the Merit family. The limited information available on micro-nutrient levels indicates that Nyalau soils are very deficient in this respect with copper and zinc less than 5 and 10 p.p.m. respectively. With values as low as these, micro-nutrients may well limit the response to applied fertiliser.

4.3.5 Peninjau Family

Soils of this family have formed in medium and coarse grained sandstones of rather low coherence and with a very low content of weatherable material.

Soils of this family have been described only in one small area south-west of Beluru in this Study. They are also reorted as occurring in the Lambir Hills (Wall, 1965c). In the Beluru area they are very deep, friable, featureless soils of loamy medium and fine sand texture and yellowish brown colour throughout. They are confined to very steep-sided, isolated ridges of Lambir formation. There is little evidence of horizonation, and they must be strongly leached to considerable depths. The associated vegetation is a rather light, open poor quality primary forest, and frequent periods of some moisture stress must occur. The soil has, probably, very low levels of plant nutrients.

4.3.6 Kapit Family

Soils in which the parent material occurs within 25 cm (10 inches) of the soil surface are considered shallow or skeletal soils. The parent material may be little-altered, compact rock, or more heavily weathered rock in which the original compaction has been sufficiently reduced to allow the material to be penetrated by an auger. In the first case the shallow soil is considered to belong the Meluan family; in the second to the Kapit family. The first is of rare occurrence within the areas studied. The second occurs more frequently, but seldom occupies discrete areas of any size: usually, it occurs as a complex with soils of either the Bekenu or Merit families or with the Kabuloh family. This latter family will be described in a later section.

The Kapit family occurs most frequently in high, very steeply sloping land, where the soil wastage due to natural geological erosion is more rapid than the renewal of soil by weathering. Rarely, Kapit family soils are found in areas of low relief associated with very compact shale parent material which appears to weather very slowly. Kapit family soils are very simple profiles with only a shallow A horizon overlying the C horizon. The texture of the A horizon is rather variable, depending on the nature of the parent material, but is mainly very fine sandy or silty clay loam to clay loam. Obviously the depth of soil available to plant roots is very limited. The C horizon, although physically penetrateable by roots, does not provide a good root medium, probably due to the lack of easily available nutrients in the horizon. Total cations are high because of the immature nature of the soil, and exchangeable levels are also rather higher than in the more mature soils. Insufficient data are available to provide meaningful average values, but one profile description with the relevant laboratory analyses is given in Appendix VI.

4.3.7 Merit-Kapit and Bekenu-Kapit Family Intergrades

More common than the very shallow soils just described are soils in which the lithic or paralithic contact occurs within 50 cm (20 inches) of the surface. In this Study, the dense concretionary layer occurring in many soils has been considered to be a paralithic contact. Soils in which the weathered parent rock C horizon or the dense concretionary layer occurs within 50 cm (20 inches) of the surface are considered as occupying an intergrade position between the Kapit family described above and the deeper soils of the Bekenu or Merit families. Thus they are the Bekenu-Kapit and Merit-Kapit family intergrades, separated on the basis of texture in the same way as the Merit and Bekenu families. These soils are characterised by the lack of a true B2 horizon, and the presence only of the transitional B1, and B3 horizons. Textures are very variable, ranging from very fine sandy clay loam to clay and relate mainly to the parent material, but also to the degree of weathering. Because of this variability, no attempt has been made to give average textures.

The Merit-Kapit and Bekenu-Kapit family intergrades are characterised by an A3, B, B3, B/C and C type profile. The Ah horizon is frequently absent or less than half an inch in depth and appears to be related to the steep slopes and consequently high degree of sheet wash associated with these intergrade soils. The efficient depth is by definition in this Study limited to depth of less than 50 cm (20 inches). Soil structure is usually weak, coarse blocky with a fairly high root density. In many cases, iron concretions occur throughout this depth and are found at the soil surface.

The average chemical characteristics of these intergrade family soils are given in Table 4.9. These show that the levels

TABLE 4.9 AVERAGE CHEMICAL CHARACTERISTICS FOR THE BEKENU-KAPIT AND MERIT-KAPIT FAMILY INTERGRADES

Horizon No. of samples in brackets	pH soil/water	Exchangeable cations me/100 g soil			Total nutrients mg/100 g soil				CEC me/100 g soil	Per cent base saturation
		Ca	Mg	K	Ca	Mg	K	P		
Ah (3)	4.7	0.9	1.1	0.4	21	173	154	37	16.9	18.2
Ae (8)	4.8	0.3	0.3	0.2	8	144	164	26	13.9	7.2
B1 (7)	4.9	0.1	0.2	0.1	2	198	209	23	13.5	4.2
B3 (10)	5.1	0.1	0.3	0.1	3	222	231	28	12.0	5.1
B/C & C (7)	5.3	0.1	0.4	0.1	3	269	234	21	13.2	5.9

of total cations are very similar to the Merit family, but that their exchangeable values are slightly higher, as is the base saturation percentage. The levels of exchangeable magnesium are significantly higher than in any of the families so far described with a calcium : magnesium ratio of less than one in nearly all horizons. Micro-nutrient levels are available for only one profile, but this would indicate that the levels are relatively high and that no deficiency is likely. On the whole, the main limiting factor of these intergrade soils is their shallow depth.

4.3.8 Kabuloh Family

4.3.8.1 Introduction

Soils of this family are derived from calcareous parent material of residual origin. Apart from this feature, their main common characteristic is that at some depth below 75 cm (30 inches) they have a horizon with a pH in excess of 6. Another feature of Kabuloh family soils is that they have a base saturation which is much higher than for any other residual family. The individual series within the family differ from each other markedly in both physical and chemical characteristics, and will be described separately. The area occupied by soils of the Kabuloh family is restricted to an area north-east and south-west of the limestone hills of Gunong Subis in the Sebubok and Sungai Karabungan Survey Areas. Within these areas they occupy 9 and 2.9 per cent respectively, but only less than half a per cent of the Broad Transect Soil Survey Area as a whole.

4.3.8.2 Kabuloh Series

The Kabuloh series soils are generally shallow and derived from calcareous shales. They differ from the other residual soils in that they are immature, with an Ah, Ae, B3, C profile sequence and no true B2 horizon. In this way the series is related to the Bekenu-Kapit and Merit-Kapit family intergrades as immature soils. The main difference is that the Kabuloh series must, by definition, be deeper than 50 cm (20 inches) to a lithic or paralithic contact, and it is calcareous. Texture is rather variable, but is mainly clay loam on clay. Within the control section, the average clay content is more than 35 per cent. Average particle size analysis data are given in Table 4.10.

The Ah horizon is usually very dark coloured with a high content of organic matter and a high carbon:nitrogen ratio relative to the other major residual series. The horizon has a well developed crumb structure with a friable consistence. On these calcareous soils the organic matter is rather less well humified and mineralised than in the non-calcareous soils. The horizon is well rooted with high faunal activity.

TABLE 4.10 AVERAGE PARTICLE SIZE ANALYSIS VALUES (PER CENT) FOR THE KABULOH SERIES

Horizon No. of samples in brackets	Clay	Silt	Very fine sand	Other sand
Ah (6)	24	48	20	8
Ae (4)	32	51	14	3
B3 (5)	41	42	15	2
C (6)	40	42	17	0

The underlying Ae horizon is pale coloured, the major hue being 2.5Y. This rather olive colour is a feature of the series, and is common to all horizons. The structure is weakly developed blocky with a firm consistence and rather low porosity. The texture is most commonly clay loam. In the field, the permeability of this horizon appears to be low, and the texture appears finer than the laboratory data show it to be.

The underlying B3 horizon is transitional in character between a B2 and C horizons. It is usually clay loam or clay in texture, the clay content being high in a few cases. Structure is very weakly developed blocky to massive with a very firm consistence and low porosity. Permeability appears to be very restricted, and rooting is not very well developed in this horizon. Commonly, this horizon contains hard, nodular manganese concretions up to 5 mm in diameter.

The lower C horizon is usually pale coloured clay or clay loam, very compact and massive with very low porosity. Rooting is frequently absent in this horizon. As in the B3 horizon, there are manganese concretions present in some of the soils. It is thought that these concretions are the result of the present weathering cycle unlike the iron concretions of the residual soils described in the foregoing sections. Their presence may be an indication of the frequently waterlogged condition of these soils.

A feature of the Kabuloh series is the frequency with which the soil rests abruptly on unaltered parent rock. The actual primary weathering zone appears to be very narrow. This is likely to result from the very compact, impermeable nature of the parent rock, its generally gentle dip and lack of structural planes of weakness at a high angle to the soil surface. This leads in many cases to the formation of a perched water table during heavy rain and frequent saturation of the overlying soil.

TABLE 4.11 AVERAGE CHEMICAL CHARACTERISTICS FOR THE KABULOH SERIES

Horizon No. of samples in brackets	pH soil/water	Exchangeable cations me/100 g soil			Total nutrients mg/100 g soil				CEC me/100 g soil	Per cent base saturation
		Ca	Mg	K	Ca	Mg	K	P		
Ah (6)	6.2	23.4	2.0	0.4	547	389	144	43	15.9	85.1
Ae (4)	5.8	11.0	1.2	0.2	205	294	108	19	13.4	72.6
B3 (5)	6.5	19.2	0.8	0.2	334	520	190	20	15.6	100
C6 (6)	7.5	29.1	1.0	0.1	533	622	231	19	15.7	100

The main chemical characteristics are summarised in Table 4.11. This shows a very different picture to the other residual soils. Base saturation is very high, due largely to the relatively high levels of exchangeable calcium. Levels of exchangeable magnesium are also higher than in the other residual soils, but of a much lower order than calcium. Exchangeable potassium is not much different. Thus the nutrient ratios are very differnt in the Kabuloh series. Calcium : magnesium ratios are high and increase with depth. The high base saturation percentage, and particularly the very high levels of exchangeable calcium, are characteristics which are uncommon in soils of a potentially highly leaching environment. Therefore, these soils must be considered immature, the rate of weathering slow. The soils fall into two broad categories, those occurring on steep slopes where the combination of slow weathering and relatively rapid wastage ensures that soil formation is incomplete and those on gentle slopes where wastage is slow, but weathering also very slow due to the nature of the parent rock already described. The poor permeability ensures slow removal of the soluble weathering products and the frequent occurrence of a perched water table may lead to secondary enrichment of the soil by products from the weathering zone. The levels of total cations are rather varied. Total calcium and magnesium are very much higher than in the Merit, Bekenu or Nyalau families, but potassium and phosphorus are little different from levels found in the Merit family. The other major characteristic which sets the Kabuloh series apart from the other residual soils is the much higher pH found in all horizons.

The micro-nutrient levels found in this series are shown below.

TABLE 4.12 AVERAGE PROFILE TRACE ELEMENT LEVELS (P.P.M.)

Cu	Mn	Zn
20	267	122

These are very much higher than for any other soil so far considered, and deficiency in this respect does not appear likely. However, in these relatively high pH soils, the possibility of unavailability of iron should be considered, especially since iron levels are relatively low.

4.38.3 Karabungan Series

The general physical properties of the Karabungan series soils are very similar to soils of the Merit family, and they can be difficult to distinguish in the field. However, the calcareous nature of the parent material can normally be determined by a simple acid test because, in nearly all cases, the C horizon occurs within normal inspection depth in these soils. The soil colour covers the same range as the Merit family and the rather pale olive colours associated with Kabuloh series are restricted to the B/C and C horizons and occasionally to the B3 horizon. The Karabungan series appears to represent a more mature expression of soil formation from calcareous parent material. It is a soil with an Ah, Ae, B2, C horizon sequence. It is a soil with a high average profile clay content, and is the finest textured of the residual soils as shown in Table 4.13. This is a reflection of the generally fine nature of the parent material. Karabungan soils occur on sloping topography at gradients between the very steep and very gentle categories characteristic of the Kabuloh series.

TABLE 4.13 AVERAGE PARTICLE SIZE ANALYSIS VALUES (PER CENT) FOR THE KARABUNGAN SERIES

Horizon No. of samples in brackets	Clay	Silt	Very fine sand	Other sand
Ah (10)	24	49	22	5
Ae (8)	38	47	12	3
B1	Insufficient data			
B21 (6)	55	35	8	2
B22 (6)	50	39	9	2
B3 (6)	47	41	6	6
B/C & C (10)	46	41	10	3

The Ah horizon has the characteristics common to all Ah horizons, a high organic matter content, well developed crumb structure and friable consistence with high root density. Texture is normally heavy loam or silt loam.

The Ae horizon is heavy clay loam, occasionally light clay texture. Colour is nearly always of 10YR hue and in this respect the series most closely resembles the Merit series of the Merit family. Soil structure is moderate medium to coarse subangular blocky with moderate porosity. The horizon is generally well rooted with high faunal activity.

Transitional horizons between A and B2 are mainly absent in this series, and the A2 horizon is directly underlain by B2. The latter has a high clay content (over 50 per cent on average). Commonly, the colour of the B2 horizons are stronger and redder than the overlying A3. Soil structure is moderately to strongly developed and is usually very coarse blocky. Evidence of a coarse prismatic structure is also present, particularly where soil pits have dried out. Pale coloured skins on individual peds are very common and well developed, and, as in the Merit family soils, water movement appears to be largely between peds: movement within peds is very restricted. The horizon is very compact with low porosity, and somewhat restricts rooting. Concretions are less common in the B2 horizons of this series than in most other soils. Manganese or manganese/iron concretions occur in some profiles, but more commonly the manganese occurs as soft patches and coatings on small sections of ped faces. Manganese coating on small parent material fragments is also common. Iron concretions like those in the Merit, Bekenu and Nyalau family soils are usually lacking, and the prevalance of manganese either as coatings or concretions can help to differentiate this series from the Merit family soils, although some of the last mentioned soils can show similar evidence of manganese.

The B3 horizon is usually slightly less red than the B2 horizons with a slightly lower clay content and less well developed structure. When concretions are present, the greatest volume is usually in this horizon. Parent rock fragments are usually present.

The B/C and C horizons are often the same colour as the soils of the Kabuloh series. They are very compact, weakly structured or massive, and have a very low porosity. They restrict rooting and usually define the lower limit of effective depth in this series. An abrupt transition from soil to unaltered rock is much less common than in the Kabuloh series, but abrupt transitions do occur.

The average chemical characteristics shown in Table 4.14 indicate that the Karabungan series occupies a position inter-

TABLE 4.14 AVERAGE CHEMICAL CHARACTERISTICS FOR THE KARABUNGAN SERIES

Horizon No. of samples in brackets	pH soil/water	Exchangeable cations me/100 g soil			Total nutrients mg/100 g soil				CEC me/100 g soil	Per cent base saturation
		Ca	Mg	K	Ca	Mg	K	P		
Ah (12)	5.5	9.4	2.6	0.4	161	187	92	36	21.1	54.8
Ae (15)	5.1	2.2	0.8	0.2	38	337	182	26	15.0	18.8
B1	Insufficient data									
B21 (10)	5.8	3.2	2.3	0.2	20	321	250	25	15.8	21.4
B22 (6)	6.5	1.7	0.8	0.2	43	309	252	25	15.0	21.6
B3 (7)	5.7	2.4	2.1	0.2	35	413	281	23	14.5	31.2
B/C & C (15)	6.7	13.9	1.4	0.2	785	334	147	19	17.8	80.1

mediate between the Kabuloh and Merit family soils. Levels of both total and exchangeable cations are considerably higher than in the Merit family as is base saturation, but are very much lower than in the Kabuloh series, except in the B/C and C horizons, where the calcareous nature of the parent material becomes obvious. The base saturation percentage would appear to be a reasonable feature to distinguish between the Karabungan series and the physically very similar Merit series within the Study Area, but the present level of 35 per cent suggested in the Draft Reclassification of Soils in Central and North Sarawak (Scott, 1973) is too high. While this is acceptable in the Kabuloh series, a limit of 15 or 20 per cent might be more appropriate for the Kabuloh family as a whole. In the Study Area, the base saturation of the Merit family soils is very low, and is very unlikely to approach either of these levels. Whether these limits would fit the soils in Sarawak as a whole will have to await detailed information from other areas. The levels of micro-nutrients from the limited information available are adequate for plant growth.

4.3.8.4 Tangap Series

The Tangap series is developed in calcareous sedimentary material, possibly calcareous marl. It has been encountered only in the Sungai Karabungan Area and is of limited extent. It is a deeply weathered soil, parent material being encountered only at depths below 60 inches in soil pits. Thus, although for the present included in the Kabuloh family, it does not meet the requirement of having a pH of 6 or more in all horizons below a depth of 75 cm (30 inches). However, as a soil unit it does possess other characteristics which are not found in other soils. It has distinctly red B2 horizons of very fine texture with an increasing degree of white mottling with depth until the lowest C horizons are pallid with prominent red mottling. Some Merit family soils do exhibit considerable mottling in their deeper sub-soils due to a fluctuating water table, but they do not show the near white matrix colours of great depth seen in soils of the Tangap series. The series is found on low, very gently undulating topography, often associated with the Kabuloh series. The parent material would seem to be very easily weathered.

The main feature of the soils is their great depth of fine textured material, the B2 horizons often extending beyond 150 cm (60 inches). The soils are weakly and coarsely structured with very low porosity, and their internal drainage is poor. However, the heavy sub-soil mottling and very pale matrix colour would not appear to be due to impeded drainage, and it may be that mottling did occur in the presence of a fluctuating water table, which has since lowered. In any case, these series do appear to exhibit in their variegation some of the characteristics often associated with soil formation in humid climates. The very compact nature of the sub-soil is not ideal for tree crops, although it is difficult to judge to what extent yields might be affected. There is no distinct limiting horizon as is the case with most hill soils. Manganese concretions are common in the sub-soil, but they are not dense enough to limit rooting.

Average particle size analysis values and chemical characteristics are given in Tables 4.15 and 4.16. Because analysis from only three profiles is available these figures are given as a broad guide only. They indicate that base saturation percentages are higher than for Merit soils and lower than in the Karabungan series. There would be some problem, on the evidence available, of including these soils in the Kabuloh family as at present defined. Nevertheless, they are significantly different from the Merit family which is the only other family into which they could be included on the present definitions, and they are known to be associated with calcareous parent rock. The pH is likely to reach 6 only at great depth. Some revision of the definitions of the Kabuloh family may be required.

4.3.9 Kayan Family

Soils of this family are of riverine alluvium derivation and occupy very small tracts in the Study Area. They mainly occur within the valley of Sungai Tukau and some sections of

TABLE 4.15 AVERAGE PARTICLE SIZE ANALYSIS VALUES (PER CENT) FOR THE TANGAP SERIES

Horizon No. of samples in brackets	Clay	Silt	Very fine sand	Other sand
Ah (2)	19	47	26	8
Ae (3)	35	48	13	4
B21 (3)	54	31	9	6
B22 (3)	59	30	8	3
B/C & C (2)	58	30	8	4

TABLE 4.16 AVERAGE CHEMICAL CHARACTERISTICS FOR THE TANGAP SERIES

Horizon No. of samples in brackets	pH soil/water	Exchangeable cations me/100 g soil			Total nutrients mg/100 g soil				CEC me/100 g soil	Per cent base saturation
		Ca	Mg	K	Ca	Mg	K	P		
Ah (2)	5.7	5.2	1.1	0.4	121	183	83	48	21.3	34.6
Ae (3)	5.1	1.4	0.4	0.2	24	224	136	30	13.6	13.8
B21 (3)	5.4	1.6	0.2	0.1	15	299	194	30	13.4	12.0
B22 (3)	5.5	2.8	0.3	0.2	32	356	210	30	13.8	20.2
B/C & C (2)	5.6	5.2	0.5	0.3	42	257	150	19	15.6	30.6

the Sungai Similajau in the Similajau Forest Reserve. They are commonly associated with Bemang family soils. Kayan family soils are deep, very friable, almost structureless sands and loamy sands with a low content of very fine sand. The colour is 10YR or yellower throughout, and only one series (the Kayan series) has been recognised. No chemical analyses are available for these soils, but their nutrient status is likely to be low, and their agricultural suitability is limited by their low retention capacity of both water and nutrients. Incorporation of organic matter would considerably alleviate both, and they are likely to be useful for vegetables, and certain fruit crops.

4.3.10 Bemang Family

These soils occur more widely than those of the Kayan family. They are found on the highest parts of the levees of larger rivers, and in the middle and upper sections of smaller streams, mainly those draining fine sandstone and sandy shale areas, and are often associated with non-accreting soils of the Bekenu family. Two series are recognised, the Bemang series consisting of deep, rather friable and weakly structured fine silty soils, with only rarely a more shallow variant in some narrow valleys where the alluvium overlies partially weathered shale at shallow depths. In most cases the profile is uniform in both colour and texture, and there is little obvious horizonation. Rather coarser soils of coarse loam texture are included in the Similajau series of the Bemang family. Here again the soils are deep, friable and weakly structured, but horizonation due to depositional layers is more commonly found in this series than in the Bemang series. Soil colour in both series is generally 10YR or yellower, and they are soils with little profile development. The agricultural potential of the Bemang family soils is high, and they are suitable for a wide range of crops, but are subject to occasional flooding. Although the family has a widespread occurrence throughout the Study Area, individual units are seldom of any size, and development of these soils separately will rarely be possible. The average chemical and physical characteristics are shown in the tables below.

TABLE 4.17 AVERAGE PARTICLE SIZE ANALYSIS VALUES (PER CENT) FOR THE BEMANG FAMILY

Horizon No. of samples in brackets	Clay	Silt	Very fine sand	Other sand
Ah (8)	18	44	25	13
Other horizons (9)	29	42	16	13

TABLE 4.18 AVERAGE CHEMICAL CHARACTERISTICS FOR THE BEMANG FAMILY

Horizon No. of samples in brackets	pH soil/water	Exchangeable cations me/100 g soil			Total nutrients mg/100 g soils				CEC me/100 g soil	Per cent base saturation
		Ca	Mg	K	Ca	Mg	K	P		
Ah (9)	4.7	2.2	1.1	0.2	58	140	128	41	13.4	26.6
Other horizons (12)	5.0	0.1	0.3	0.1	3	169	171	16	10.5	5.8

"Other Horizons" in the above tables are the weighted average values for all horizons other than the Ah horizon. Compared to the Bekenu family, which is the non-accreting soil most similar to the Bemang family, the texture is very similar. However, the alluvial soil has slightly higher total exchangeable bases than the residual soil, particularly of exchangeable magnesium. Total cations are considerably higher except for calcium. Levels of micro-nutrients are higher. The one set of analyses available shows values of 10, 105 and 54 for copper, manganese and zinc respectively, so that deficiency in these elements is not expected.

4.3.11 Seduau Family

Of the well drained accreting soils, the Seduau family is the most widespread. The major part of the levees of larger streams and many of the smaller streams are occupied by soils of this family which are characterised by a clayey texture, and contain more than 35 per cent clay. In common with other well-drained alluvial soils they show little horizonation, but are more compact than either the Kayan or Bemang family soils. Structure is usually better developed and is medium or coarse blocky. Like soils of the Bemang family, these are suitable for a wide range of crops, but again seldom occupy individual areas of any size, because their occurrence is limited to levees and some smaller well drained valley units.

Data from only two profiles are available. These indicate that the base saturation percentage is higher than in the Merit family, and that exchangeable magnesium is the major exchangeable cation. Total cations are very similar for the two families. Generally the nutrient status of soils of the Seduau family is rather better than of many residual soils.

4.3.12 Pakan Family

These are poorly drained alluvial soils of riverine origin. They fall within the textural groups coarse and fine loamy and coarse and fine silty. These are strongly gleyed, permanently or nearly permanently saturated soils with little discernible profile development. Some textural variation occurs within the control section, but this is rarely strongly contrasting. Such variation as does occur is largely due to depositional differences.

Within the Pakan family, two series are recognised, again defined in terms of texture. The dominant series is the Pakan series with a control section texture of fine silt. Coarse silts and coarse and fine loams are included in the Dangkar series, which does not occur in large enough units to be mappable within the Semi-Detailed Soil Survey Area. No laboratory data are available for this family.

4.3.13 Bijat Family

The major family within the poorly drained riverine alluvia is the Bijat family, characterised by a clayey texture, containing more than 35 per cent clay. These are largely permanently saturated soils with little or no horizonation. They are structureless and mainly unripened, with little inherent cohesion. It is difficult to extract these soils with an Edelman auger, because they appear to break down to a semi-fluid state when penetrated by the auger. There seems no doubt that major physical changes occur when these soils are drained. The effect of permanently lowering the water table on unripened soils was not examined within the Study Area, but experience from elsewhere suggests that the gradual compaction of such soils on drainage can lead to the development of an uneven micro-relief which would pose some problems in for example field levelling for wet land rice cultivation.

Two series are recognised within the Bijat family, the Sebandi series with 25 cm (10 inches) or less of an organic, peaty surface horizon, and the Bijat family without a surface peaty horizon. Analysis from only one profile is available. This indicates that the level of exchangeable bases is rather higher than for most well-drained soils as is the percentage base saturation. The pH is lower throughout the profile, and lacks the tendency to increase with depth common to better drained soils. Levels of total cations are moderate. In this example organic carbon content is high, the highest value occurring in the sub-surface horizon and yielding a high carbon:nitrogen ratio. This indicates the lower degree of mineralisation in a mainly anaerobic environment.

4.3.14 Bemang-Pakan Family Intergrade

The Bemang-Pakan intergrade of medium textured soils occurs widely in smaller drainage valleys. The actual drainage conditions included within the family intergrade vary considerably from moderately, through imperfectly, to poorly drained. The physical characteristics of these soils are likewise rather varied. The less poorly drained members are deep, fairly friable with weak, occasionally moderately developed blocky structure. Mottling is well developed, and the degree of gleying increases with depth. Like the well drained Bemang family, these soils provide a good rooting medium. The less well drained Bemang-Pakan family intergrade is more massive, but nevertheless still reasonably friable. The rooting depth is largely a function of water table depth, which, although highly variable over the year, is usually within the control depth.

This family intergrade is a group of soils which possesses considerable agricultural potential, providing the necessary drainage amelioration can be achieved. Their major disadvantage lies in a proneness to flooding of variable severity and duration which could make control both difficult and costly. It is this latter feature which could be the main limiting factor to annual and semi-perennial crops. Only towards the poorly drained limit of the intergrade will tree crops be seriously affected. Average chemical and physical characteristics of this intergrade family are given below.

TABLE 4.19 AVERAGE PARTICLE SIZE ANALYSIS VALUES (PER CENT) FOR THE BEMANG-PAKAN FAMILY INTERGRADE

Horizon No. of samples in brackets	Clay	Silt	Very fine sand	Other sand
Ah (3)	16	47	26	11
Rest (6)	26	45	22	7

TABLE 4.20 AVERAGE CHEMICAL CHARACTERISTICS FOR THE BEMANG-PAKAN FAMILY INTERGRADE

Horizon No. of samples in brackets	pH soil/water	Exchangeable cations me/100 g soil			Total nutrients mg/100 g soil				CEC me/100 g soil	Per cent base saturation
		Ca	Mg	K	Ca	Mg	K	P		
Ah (3)	4.5	0.7	0.6	0.2	15	117	121	48	14.4	11.4
Rest (6)	5.2	<0.1	0.2	0.1	2	127	140	14	8.5	5.8

4.3.15 Seduau-Bijat Family Intergrade

The soils of this family intergrade are the fine textured equivalents of the Bemang-Pakan family intergrade. They are generally more strongly and coarsely structured than the Bemang-Pakan family intergrade soils and considerably more compact, but are still deep soils providing a good rooting medium except where limited by a near permanent water table at depth. Like the Bemang-Pakan family intergrade, frequent if short-lived flooding is a major limitation to agriculture. This intergrade comprises the largest and most commonly occurring group of alluvial soils within the survey areas.

TABLE 4.21 AVERAGE PARTICLE SIZE ANALYSIS VALUES (PER CENT) FOR THE SEDUAU-BIJAT FAMILY INTERGRADE

Horizon No. of samples in brackets	Clay	Silt	Very fine sand	Other sand
Ah (3)	21	46	26	7
Rest (6)	47	38	9	6

TABLE 4.22 AVERAGE CHEMICAL CHARACTERISTICS FOR THE SEDUAU-BIJAT FAMILY INTERGRADE

Horizon No. of samples in brackets	pH soil/water	Exchangeable cations me/100 g soil			Total nutrients mg/100 g soil				CEC me/100 g soil	Per cent base saturation
		Ca	Mg	K	Ca	Mg	K	P		
Ah (4)	4.8	1.4	1.0	0.3	71	155	108	52	13.1	23.1
Rest (6)	5.0	0.1	0.5	0.1	2	183	171	14	10.0	8.4

The above average chemical characteristics show a relatively high base saturation percentage due largely to exchangeable magnesium. The latter, compared to the residual soils, appears to be a feature of most alluvial soils in the Area. Within the Seduau-Bijat family intergrade, the chemical characteristics vary with the drainage status of the soil, the poorer drained members showing higher exchangeable values than the better drained soils. This is probably due to differential leaching.

4.3.15.1 Hydrologic and Textural Sequences of Riverine Alluvium

The whole spectrum of riverine alluvial soils forms a distinct hydrologic sequence of soils and, to a lesser extent, a textural sequence in most river and stream valleys. The hydrologic sequence runs at right angles to the river or stream and consists of increasing gleying and progressively higher water tables as one procedes from the levee position to back swamp position. Similarly, a much less obvious textural gradient can be detected along the same axis. Some diagramatic sections are shown in Figure 4.1.

In broader valleys the drainage sequence is extended to include a rapid transition from very poorly drained mineral soils to increasing peat accumulation. Only in the larger river valleys is it possible to map these sequences as separate units even at the field mapping scale of 1:25 000 employed in the Semi-Detailed Soil Survey Area. Usually, the sequence must be indicated by the family or family intergrade or by a complex where no one unit predominates, and the valley unit is mapped accordingly. But it should be remembered that smaller though significant areas of the well and very poorly drained units will almost always occur.

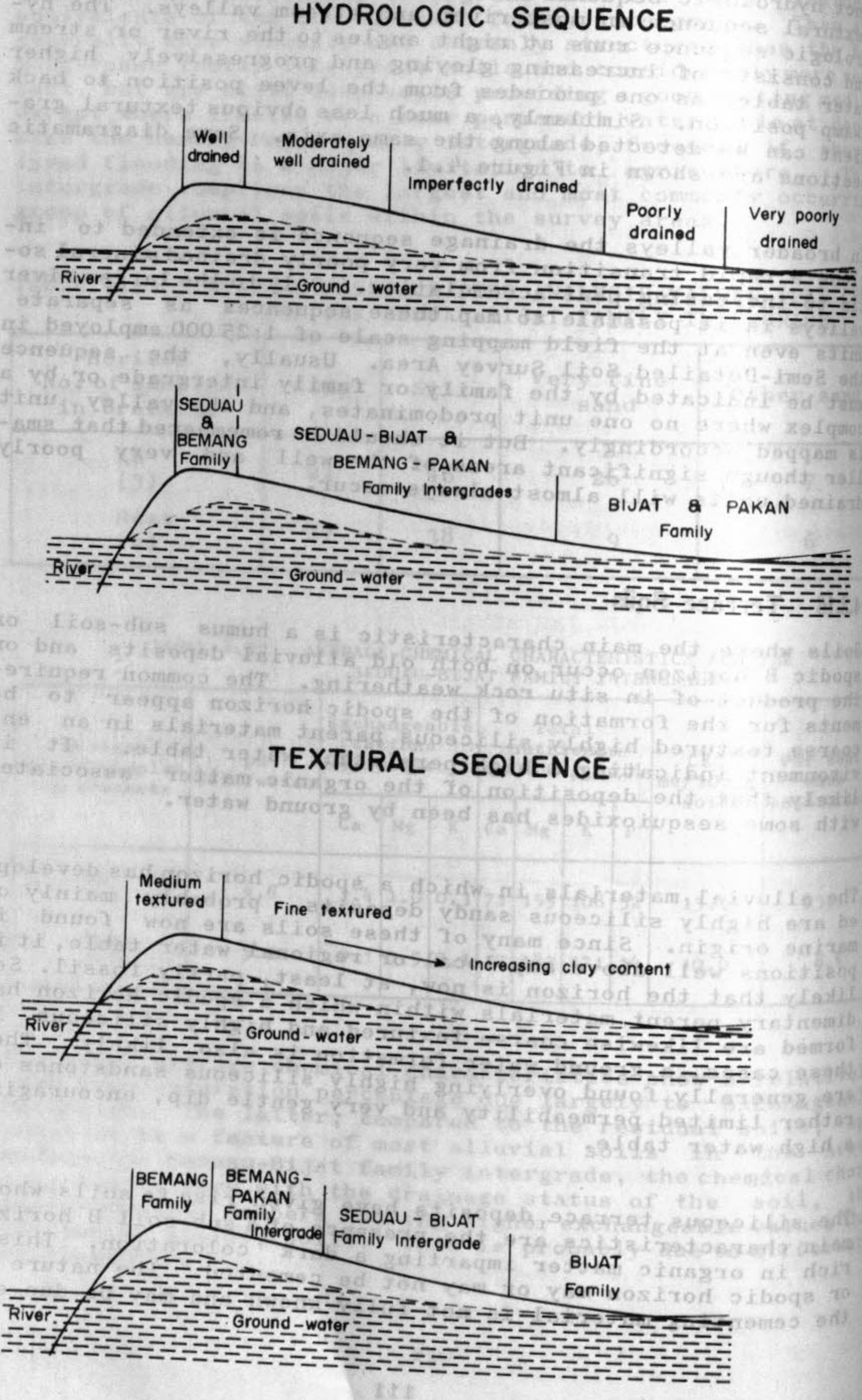
4.3.16 Terrace Soils

Soils where the main characteristic is a humus sub-soil or spodic B horizon occur on both old alluvial deposits and on the product of in situ rock weathering. The common requirements for the formation of the spodic horizon appear to be coarse textured highly siliceous parent materials in an environment indicating a high persistent water table. It is likely that the deposition of the organic matter associated with some sesquioxides has been by ground water.

The alluvial materials in which a spodic horizon has developed are highly siliceous sandy deposits, probably mainly of marine origin. Since many of these soils are now found in positions well above any local or regional water table, it is likely that the horizon is now, at least, partly fossil. Sedimentary parent materials within which a spodic horizon has formed are likewise coarse textured and highly siliceous. In these cases, a ground water formation is also likely. They are generally found overlying highly siliceous sandstones of rather limited permeability and very gentle dip, encouraging a high water table.

The siliceous terrace deposits have given rise to soils whose main characteristics are the presence of a sub-soil B horizon rich in organic matter imparting a dark coloration. This B or spodic horizon may or may not be cemented. The nature of the cementing material is not fully known and may be due en-

FIGURE 4·1


HYDROLOGIC SEQUENCE
Well drained
Moderately well drained
Imperfectly drained
Poorly drained
Very poorly drained
River
Ground - water
SEDUAU & BEMANG Family
SEDUAU - BIJAT & BEMANG - PAKAN Family Intergrades
BIJAT & PAKAN Family
River
Ground - water
TEXTURAL SEQUENCE
Medium textured
Fine textured
Increasing clay content
River
Ground - water
BEMANG Family
BEMANG - PAKAN Family Intergrade
SEDUAU - BIJAT Family Intergrade
BIJAT Family
River
Ground - water

tirely to humus or to humus sesquioxide compounds, more likely the latter. In the classification, a division is made at family level between those soils possessing a cemented spodic horizon and those without.

4.3.16.1 Miri Family

Soils with a cemented spodic horizon are included in the Miri family, and the alluvially derived members in the Miri series. Typically the series shows a bleached, nearly white sub-surface horizon overlying a very dark, hard, cemented sub-soil horizon, which in turn usually overlies a pale coloured deeper sub-soil. Occasionally, the dark horizon may overlie an older, weathered residual soil or even partially weathered rock, where the alluvial deposit is shallow. The cemented spodic horizon is impermeable to water, and a perched water table frequently occurs after heavy rain in the larger units dominated by very gentle slopes. Occasionally this perched water table may be sufficiently persistent for shallow peat formation at the surface. Humus accumulation at the surface also occurs in better drained situations due to very slow breakdown of organic matter in soils with extremely low nutrient levels and correspondingly low faunal activity. However, this occurs only under undisturbed Kerangas Forest conditions. Once this forest cover has been removed, regeneration appears to be confined to a scrub type vegetation which does not supply sufficient organic debris to maintain a humus layer. The layer gradually disappears, and bleached sand occurs at the surface. Miri series soils are characterised in the Study Area by very high contents of fine and very fine sand, and very low contents of clay and coarser sand. Generally, these soils provide a very poor medium for plant growth with almost negligible inherent fertility and very low capacities for water and nutrient retention, apart from problems of depth and waterlogging associated with the impermeable spodic horizon.

Soils of residual derivation with a cemented spodic horizon, have not been described during this Study, but are known to occur within the area. They are similar to the Miri series and are included in the Bako series. The main difference is that the size of the sand fraction is more variable.

4.3.16.2 Silantek Family

Soils with uncemented spodic horizons are included in the Silantek family. The Buso series includes such soils developed in parent material of alluvial origin. Apart from the permeable nature of the spodic horizon, the Buso soils are essentially similar to those of the Miri series. The main difference is that the spodic horizon is a barrier neither to water nor root penetration, and Buso soils are generally well to excessively drained. However, their agricultural potential is little better than the Miri soils. Their main residual equivalents are soils of the Silantek series. These soils occur in similar situations as the Bako series and the two series generally occur together. No explanation can be advanced as to why the spodic horizon is cemented in some places and not in others. Miri and Buso series soils occur side by side in identical parent materials of the same age; differences may be due to slight variations in the nature of the humus and sesquioxides deposited in the sub-soil from the ground water. Analyses for one Miri and one Buso series soil are available, and are given in Appendix VI.

4.3.17 Soils with Pallid Horizons

The soils of this group have a very limited occurrence within the Study Area. They have a wide range of textures developed in variable parent materials, but possess the common property of pale colours throughout the control section. They are characterised by very low levels of sesquioxides; in most cases this may be a factor of local parent materials very low in iron, but a few may have resulted from conditions favouring the loss of oxides from the profile.

4.3.17.1 Tika Family

Pallid soils coarser than loamy very fine sand are included in this family. In the Study Area, only the Bintulu series of this family has been identified. This is developed in highly siliceous terrace materials and occurs in association with Miri and Silantek family soils. The Bintulu series is in fact mainly a very deep Miri family soil in which the spodic horizon occurs well below the control depth. In other words, they are soils with a very thick A horizon. These soils have been called giant Podzols. The justification for considering these soils as a separate family is that, because the spodic horizon lies well below the control depth, it will not be possible to identify it during a soil survey from auger or pit inspection.

4.3.18 Other Soils

Alluvial soils of marine origin have not been investigated during this Study. They have been described and mapped during previous reconnaissance surveys. In this Study it has only been possible to reclassify existing data in terms of the new Draft Reclassification (Scott, 1973) and to make some revision of distribution from detailed examination of the aerial photographs.

During the preliminary studies to choose areas for the Broad Transect Soil Survey areas of organic soils were largely excluded. Therefore, little examination was made of these soils, and no chemical data are available. During the Broad Transect Soil Survey, sufficient checks were made to determine the boundaries of areas of organic soils where ground information was previously lacking, but most of the mapped areas are the result of information from previous reconnaissance studies and examination of the aerial photographs.

4.4 AVAILABLE WATER-HOLDING CAPACITY (A.W.C.)

In Appendix IV, the percentage of moisture held at various pressures is given in Table IV.1. These are expressed in terms of percentages by weight. It is generally more convenient to express these values on a percentage/volume basis or in terms of depth of water per unit depth of soil, this is effected by multiplying by the bulk density. In determining the total amount of available water it is customary to use that amount of water held by the soil between field capacity and wilting point. These essentially field values are approximated in the laboratory by suction pressures. The pressure of 15 atmospheres is accepted as a reasonable approximation of the wilting point. Field capacity is generally equated with a pressure of 1/10 or 1/3 atmospheres, the highest value commonly being considered the best approximation of field capacity in fine textured soils. However, the low 1/10 atmosphere value is being increasingly used in many different soils, and this is the value that has been adopted in this Study. Therefore, the total available water is the difference between the water held at 1/10 and 15 atmospheres. In the table below, the total amounts of available water expressed in inches per inch of soil depth are, given as profile averages for some of the major families.

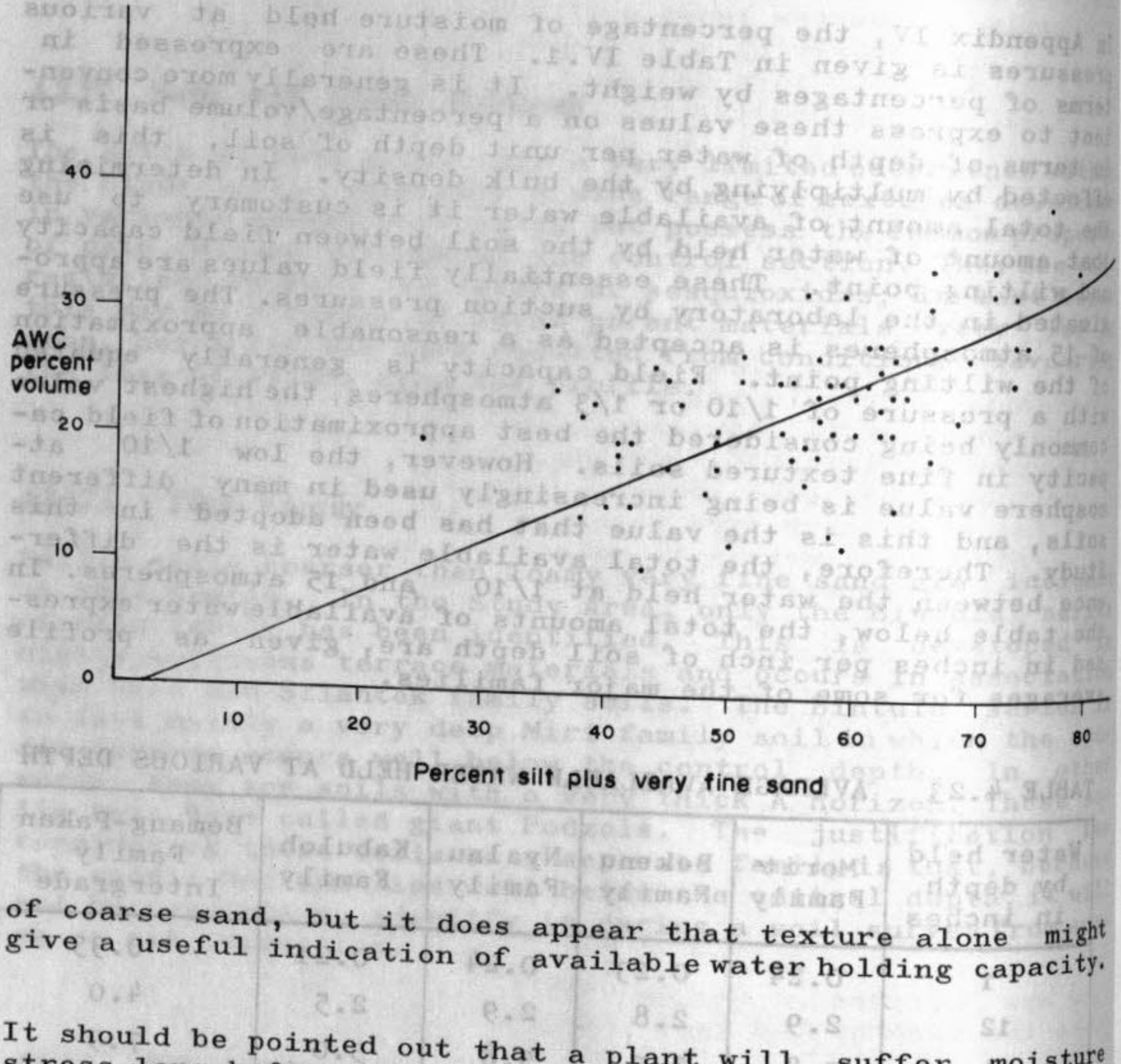
TABLE 4.23 AVERAGE AVAILABLE WATER HELD AT VARIOUS DEPTH

Water held by depth in inches	Merit Family	Bekenu Family	Nyalau Family	Kabuloh Family	Bemang-Pakan Family Intergrade
1	0.24	0.23	0.24	0.21	0.33
12	2.9	2.8	2.9	2.5	4.0
24	5.8	5.5	5.8	5.0	7.9
36	8.6	8.3	8.6	7.6	11.9

These figures indicate that relatively large amounts of water are held by the soils in the Study Area, with little difference between the families, although their textures vary considerably. The main feature all these soils have in common is a high content of very fine sand and silt, and Figure 4.2 shows a fairly strong positive relationship between silt and very fine sand content and available water holding capacity. The full significance of this relationship is restricted because of the lack of information on soils with a high content

FIGURE 4.2

THE RELATIONSHIP BETWEEN AVAILABLE WATER CAPACITY (AWC) AND SILT PLUS VERY FINE SAND CONTENT
(Excluding horizons containing concretions)



of coarse sand, but it does appear that texture alone might give a useful indication of available water holding capacity.

It should be pointed out that a plant will suffer moisture stress long before the actual wilting point is reached, and that yields will be affected at lower suction levels. More important is the amount of readily available moisture. This is rather difficult to define and will vary from plant to plant; but, generally, it is considered that depletion to about 50 per cent of the total water held can occur before undue stress occurs. Thus the amount of readily available water held by a Merit family soil is about 0.12 inch per inch of soil, or 4.3 inches for a three-foot soil depth. This is a high value, and indicates that water stored in the soil would be capable of enabling the plant to survive considerable periods of drought without undue water stress. If daily potential evapo-transpiration is of the order of 0.2 inches per day (probable a high value for this area), then a soil at field capacity could support a plant during a 20 day drought without moisture stress occurring, provided that a rooting depth of 36 inches was available. Obviously, as soil depth decreases, the amount of easily available water also decreases. A further factor which is important in relation to the amount of water available to plants is the presence of iron concretions in the soil. The measured available water holding capacity values confirm that the presence of iron concretions markedly depresses the available water holding capacity. For example the average available water in inches per inch for Merit family soils containing iron concretions is 0.16 compared to 0.24 for soils without these concretions. This lower figure is derived from soils containing between 10 and 30 per cent of iron concretions by volume from field estimates. The actual volume of iron concretions in the small cores on which the AWC determinations were made was not determined. However, it appears that AWC is reduced by a percentage slightly larger than the percentage of concretions by volume. If a given horizon contains 30 per cent by volume of iron concretions, then the AWC to be expected from the soil texture should be reduced by at least 30 per cent.

In short, tree crops are likely to suffer from water stress only where soil depth is very restricted or where the soil contains large amounts of concretions. This fact may be of particular importance in relation to cocoa which appears to be very sensitive to moisture stress. In the Study Area, the high value of AWC per unit depth and the lack of frequent prolonged drought periods is likely to allow successful production on shallower soils than those usually recommended.

4.5 EROSION

4.5.1 Introduction

Perhaps the best examples of erosion or soil wastage have been recorded in the United States of America. Bennett (1955) estimated in 1947 that in that country 282 mn acres of agricultural land had been ruined or seriously damaged by accelerated erosion. A further 775 mn acres of agricultural and forest land had been affected by erosion or were susceptible to erosion processes if incorrectly used. The author adds that large tracts of this land could have been protected and that the damage was not done maliciously, but was entirely due to ignorance. It may be correct to assume that erosion in Sarawak would be unlikely to reach such serious proportions, but it is important to realise that this country has limited land resources. Millions of acres are either mountainous, consist of deep peat, suffer from seawater intrusion or have other agriculturally adverse conditions.

Chapter 4, Section 1, discusses in detail the reasons for the occurrence of large areas of shallow soils within the Study Area. In this Section it is sufficient to summarise the more important factors which may have an effect on the erodibility or vulnerability of the soil to erosion.

The generally rather shallow, highly leached soils are the product of a weathering process, acting on parent rock which is sedimentary in origin and predominantly fine textured. Due to factors explained in this Chapter the permeability is low and therefore run-off could, under unfavourable conditions, be high.

Within the Study Area, erosion is almost entirely due to water. The nature and degree of erosion which occurs is a function of many variables, primarily rainfall duration and intensity, slope angle and length, vegetative cover, soil factors and human disturbance. The average annual rainfall varies from about 90 to nearly 200 inches with frequent storms of high intensity. Under these conditions, the potential for erosion is considerable. One of the major effects of rainfall in erosion is the dispersive and splash effect of the raindrops. The energy released by the impact of the raindrop breaks down the soil aggregates and brings the finer soil particles into suspension in the rainwater. Under the effect of gravity on a slope, this will result in soil being moved downhill. This movement is enhanced by surface run-off which preferentially removes clay and silt. A further effect of rainfall impact is to seal pore space with dispersed soil material decreasing infiltration and thus increasing run-off. Under certain conditions, on steeper slopes, mass movement of soil occurs. This catastrophic form of erosion is caused by lubrication of the soil profile by excess water. An example of this type of erosion is discussed in Section 5.3.

The angle and length of slope is an important factor in determining the amount of erosion that will occur. It has been found by many workers that for a given soil and rainfall, erosion increases with the angle and length of slope. Recently completed experiments at the National College of Agricultural Engineering at Silsoe (England), which are part of the Road Research Laboratory studies on road embankments, have shown that erosion is directly proportionate to the slope angle up to the extreme slope of 75 degrees. It has been concluded that soil loss increases with the increase of the angle of slope (Hudson, Priv. Comm., 1974).

The Study Area is characterised by steep slopes, but the intensity of dissection is such that slope length is not great except in the higher areas.

Good vegetative cover has a considerable effect in reducing erosion. This is achieved in several ways; by intercepting and reducing the impact of raindrops on the soil surface, by decreasing the velocity of run-off, the direct and indirect stabilising effect of roots and the encouragement of bacteriological activity with its effect on soil structure and porosity.

4.5.2 The Soil Erodibility

Various soil factors effect the erodibility of the soil. Wischmeier (1971) has used four soil factors to determine the erodibility factor of a soil - a textural factor dependant on the content of silt plus very fine sand and medium and coarse sand, soil organic matter, soil structure and permeability. From these factors a nomograph has been constructed which will allow the erodibility factor of any soil to be determined. This factor is used by several workers to calculate soil loss under a given situation, which includes rainfall, land use and crop and land management (Hudson, 1971).

The erodibility of a number of widely occurring soils in the Study Area has been calculated using Wischmeier's method; but these figures should be regarded as tentative, as this method has not yet been conclusively tested under Sarawak conditions. Using the average particle size analyses values of four soil families and average organic matter content (= organic carbon x 1.72), the erodibility is indicated below. The figures used in the computation of Table 4.24 are those given in Tables 4.1, 4.2, 4.4, 4.5, 4.7, 4.8, 4.10 and 4.11.

TABLE 4.24 APPROXIMATE AVERAGE ERODIBILITY FOR THE MERIT, BEKENU, NYALAU AND KABULOH FAMILIES (AFTER WISCHMEIER, JOHNSON AND CROSS, 1971)

Soil profile horizon	Erodibility factor			
	Merit Family	Bekenu Family	Nyalau Family	Kabuloh Family
Ah	0.15	0.23	0.22	0.22
Ae	0.45	0.48	0.33	0.34
B1	0.37	0.46	0.41	-
B2	0.37	0.43	0.46	0.37
B3	0.34	0.39	-	0.36
B/C	0.34	0.54	-	0.35

In the above table the low erodibility of the Ah horizon is demonstrated and emphasises the erosion-reducing characteristics of this surface horizon. Once this horizon is removed, the exposed underlying soil is highly erodible, particularly in the case of the Merit and Bekenu families soils. The latter family would appear to be the soil with the lowest resistance to erosion of the major upland soils. As will be explained later in this section, all the soils in the Study Area have a high erodibility factor and the need for conservation measures must be emphasised.

4.5.3 Erosion Created by Environmental Imbalance

Human interference in the natural balance is normally a positive factor in increasing erosion, as mentioned in Section 5.1. This imbalance is mainly created by destroying the natural vegetation and replacing it by crops, which have less effect in maintaining soil stability.

Within the Study Area evidence of erosion is widespread. Under natural primary forest the rate is fairly slow, but is nonetheless significant, and increases with increasing angle of slope (Hudson, 1971). Below 25 degrees erosion is primarily by splash and surface wash but above 25 degrees mass movement becomes increasingly important as shown by the frequent occurrences of slip terracettes and soil slips. Above a slope of 25 degrees soil depth is usually very limited. Relationships between slope and soil depth are discussed in Appendix II. Considerable field evidence has been collected of the above forms of soil wastage. Some examples have been reported in The Zonation Plan (Hunting Technical Services Limited and Hoff and Overgaard, 1972). Catastrophic forms of erosion have occurred and still occur in the Lambir hills, where land with slopes in excess of 20 degrees on mainly Nyalau family soils have been planted to rubber. This soil is derived from poorly consolidated rock with frequently alternating bands of sandstone and shale. This leads to a situation where soil permeability decreases very rapidly with depth, tending to produce a slip plain on which the upper part of the soil can move when saturated with water. Aerial photographic evidence has shown that about 10 per cent of the area has been ruined by land slips on such terrain. Less obvious, but nevertheless serious, erosion forms have been observed along Sungai Tru near Rumah Belulok. In this location field observations showed that in a period of about five years the depth of a Merit family soil was decreased by 12 to 16 inches on a slope of 29 degrees. This is equivalent to a soil loss of around 450 tons per acre per year, which is 100 times greater than the maximum acceptable natural loss. Other evidence can be observed along roadside cuttings where slumping of the cuts, even at low angles of repose, are common.

From the erosion point of view, the most hazardous form of agriculture at present widely practised in the Study Area is pepper growing. The pepper vines are planted at a fairly wide intervals up and down the slope and are clean weeded so that there is a considerable area of bare soil exposed to the direct impact of rain and run-off. When this practice is carried out, as it frequently is, on steep slopes, the rate of soil loss is disturbingly high, as shown in Table 4.25.

Another form of cultivation conducive to serious soil losses is the shifting cultivation of dry land rice, especially wh-

TABLE 4.25 SOIL LOSS AT DIFFERENT ANGLES OF SLOPE

Trial number	Location and Map Reference 1:50 000	Slope in degrees (per cent)	Crop and/or ground cover	Soil loss per plot tons*/acre/year (tons m./ha/year)	Mean soil loss tons*/acre/year (tons m./ha/year)
A1	Bukit Peninjau SOB 3/113/16 PJ422 498	35 (70)	2 years old oil palm, cover crop sprayed	6.07 (15)	4.04 (10)
A2				2.02 (5)	
B1	do	24 (49)	do	9.30 (23)	19.23 (47.5)
B2				29.15 (72)	
C1	do	21 (38.3)	do	1.62 (4)	1.82 (4.5)
C2				2.02 (5)	
D1	Junction Miri-Bintulu Road/Niah Road PJ185 121	33 (65)	Lallang and scrub	1.82 (4.5)	1.82 (4.5)
D2		31 (60)	1 year old pepper	43.30 (107)	43.23 (107)

Note * 1 ton = 2 000 pounds

ere the intervening fallow periods are short (Nye and Greenland, 1960). There is considerable evidence within the areas studied that fallow periods are shorter than they should be for soil recovery and decreasing. Most of the fallow examined was less than eight years old and considerable areas less than five years. Serious erosion has frequently been observed in these areas as indicated by the frequent occurrence of shallow soils under shifting cultivation as compared with the average depth under primary forest.

On the above evidence it can be concluded that control measures are necessary to counteract the forces of erosion acting on a soil that has limited resistance to surface wash and other forms of erosion and for the proper use of important land resources.

As has been explained above, the best erosion control is a dense forest cover, either primary or secondary. Run-off is slowed down and percolation of rain water increased due to the litter layer and the permeability of the underlying top soil, which has a relatively high humus content. The closed forest canopy also reduces the impact of rain on the forest floor.

4.5.4 Erosion Trials

In The Zonation Plan (Hunting Technical Services Limited and Hoff and Overgaard, 1972) it was recommended that the upper gradient limit for cultivation under Sarawak conditions be placed at 25 degrees (46.5 per cent). This limit was chosen on the basis of field observations carried out during the Zonation Plan period, supported by experience from other countries. Furthermore, soil studies carried out in the Sample Areas (Appendix II) indicate that a large percentage of the land above 25 degrees has a soil depth of less than 24 inches. On such land terracing and platforming are more likely to increase the chance of accelerated erosion and soil slip than reduce it. For example, a six-foot bench terrace cut in a 25 degree slope requires a soil depth of over 30 inches to be effective.

Simple erosion trials were carried out on different slopes subjected to different agricultural practices. Figure 4.3 gives the location of these trials. Three pairs of plots of ten by one metre were located under one year old oil palm. One single trial of ten by one metre was sited in recently planted pepper interplanted with chillies, yams and onions, and one single trial on two months old natural regrowth, mainly consisting of lallang and low scrub, which efforded a reasonable cover. Details of these trials are given in Table 4.25.

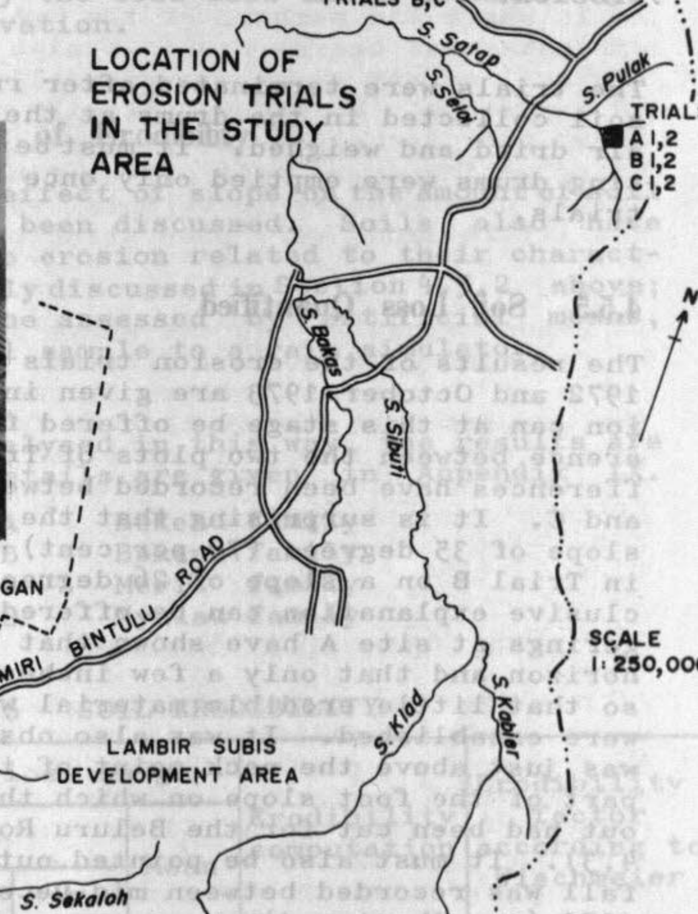
The object of these simple tests was to assess the soil loss on a range of slopes and to determine more accurately the up-

FIGURE 4.3

TRIAL A

TRIALS B,C

TRIAL C



TRIALS BI and B2

TRIAL A

per slope limit for agriculture under conditions prevailing in the Study Area. Trials A, B and C were treated bi-monthly with a weedicide to test the soil loss on bare soil surfaces. The reason for this rather unnatural treatment in a hot humid climate is that to a certain extent such a surface will exist under older plantings of rubber and oil palm when the tree crowns have closed and the cover crop has receded. Also tree-base erosion (especially noticeable in rubber) resulting in a form of pedestal erosion, will increase.

Trial D2 situated in a one year old pepper garden was treated in exactly the same way as the surrounding garden. Trial D1 was left untreated to assess the effect of young regrowth on erosion.

The trials were terminated after running for one year. The soil collected in the drums at the bottom of each plot was air dried and weighed. It must be emphasised that the collecting drums were emptied only once during the course of the trials.

4.5.5 Soil Loss Quantified

The results of the erosion trials carried out between October 1972 and October 1973 are given in Table 4.25. No explanation can at this stage be offered for the considerable difference between the two plots of Trial B, however, no such differences have been recorded between the plots of Trials A and C. It is surprising that the soil loss of Trial A on a slope of 35 degrees (70 per cent) is considerably lower than in Trial B on a slope of 26 degrees (49 per cent). No conclusive explanation can be offered for this result. But augerings at site A have shown that the profile has lost its A horizon and that only a few inches of the B horizon are left, so that little erodible material was available when the trials were established. It was also observed that the trial site was just above the neck point of this 35 degree slope; also part of the foot slope on which this experiment was carried out had been cut for the Beluru Road alignment (see Figure 4.3). It must also be pointed out that practically no rainfall was recorded between mid-December, 1972 and mid-March, 1973 (see Chapter 1).

The soil loss of Trial D2 was considerable: at a loss of 43.23 tons per acre per year, it was eight times higher than the allowable limit (Hudson, 1972) of five tons per acre per year. This demonstrates clearly that pepper cultivation practices are overdue for a change and that the use of terraces and cover crops, involving a different planting density and pattern, should be seriously considered.

Trials B and C also showed that erosion on slopes in excess of 25 degrees is unacceptable, and the soil loss on a 21 degree slope are susceptible of control. It is demonstrated in the above trials that erosion hazards on slopes greater than 25 degrees are in the long run unacceptable and that this slope therefore is recommended as the upper limit for agricultural development.

It must be emphasised that the above conclusions are based on trials which have been operated for one year and must therefore be regarded as tentative. However, these trials and evidence reported in Chapters 3 and 4 and Appendix II are sufficiently convincing to accept the upper limit of 25 degrees for agricultural development in Sarawak. It is also recommended that these erosion trials are continued for a number of years and that trials under different environmental conditions than those so far studied are undertaken. It would for instance be valuable to study the soil loss under natural vegetation and shifting cultivation.

4.5.6 Laboratory Assessment of Erodibility

In the above section the effect of slope on the amount of soil lost from the profile has been discussed. Soils also have inherent susceptibility to erosion related to their characteristics. These were briefly discussed in Section 4.5.2 above; but erodibility can also be assessed by artificial means, that is by exposing a soil sample to a rain simulator.

Four soil samples were analysed in this way, the results are given in Table 4.26 and details are given in Appendix IX.

Sample A	Bekenu family
Sample B	Bekenu family
Sample C	Merit family
Sample D	Nyalau family

TABLE 4.26 SOIL ERODIBILITY

Soil type	Measured soil loss in gm					Erodibility computation	Erodibility factor according to Wischmeier
	Replications				Mean		
	1	2	3	4			
Sample A Bekenu family	47.15	48.00	50.25	50.20	48.90	207	0.21
Sample B Bekenu family	51.00	45.55	48.22	44.00	47.19	184	0.18
Sample C Merit family	50.00	53.10	58.95	60.67	55.68	260	0.26
Sample D Nyalau family	21.00	23.70	25.40	24.23	23.58	24	0.02

To measure directly the erosion under standardised laboratory rainfall conditions a modified Morin-type rainfall simulator (Hudson, Priv. Comm., 1973 and Morin et al, 1967) was used. The rainfall intensity simulated was at a rate of 95 mm (3.8 inches) per hour for a duration of 30 minutes.

The mean measured soil loss suggests that the Nyalau family sample has the lowest erodibility, although the organic matter is low and sand content high. These factors seem to have been offset by the good structure and good permeability of this soil. The erodibility factor for this Nyalau family soil is much lower (0.02) than that given in Table 4.24, where the Ah horizon has an erodibility factor of 0.22. The reason for this is that Sample D above has been collected in the Lambir Hills where the members of the Nyalau family contain a high percentage of coarse sand. Nyalau family soils occurring in the soil survey areas are generally derived from a fine grained sandstone. Both Bekenu family soils have high silt contents, poor structure and permeability. This accounts for them being at the upper half of the range in Figure 4.4. The Merit family soil appears to be moist vulnerable to erosion. It has little sand, very poor structure and low permeability.

It needs emphasis that the above erodibility results should be regarded only as an indication of the vulnerability to erosion of the tested soils. It should also be remembered that the samples have been collected from one single horizon in four different locations as shown in Appendix IX. Firm conclusions cannot therefore be drawn at this stage and further studies are recommended.

4.5.7 Soil Conservation Measures

It has been emphasised in the above sections that soil loss under certain conditions is high, and it has been concluded that the upper gradient limit for agricultural development should be 25 degrees. However at slopes of less than 25 degrees soil losses can still be considerable and therefore control measures should be enforced. These measures consist of contour cultivation and planting, the use of cover crops, platforming and terracing. Table 4.27 is meant to be a guide for erosion control measures in future development and agricultural improvement schemes.

FIGURE 4.4

RELATIONSHIP BETWEEN COMPUTED ERODIBILITY AND MEASURED SOIL LOSS

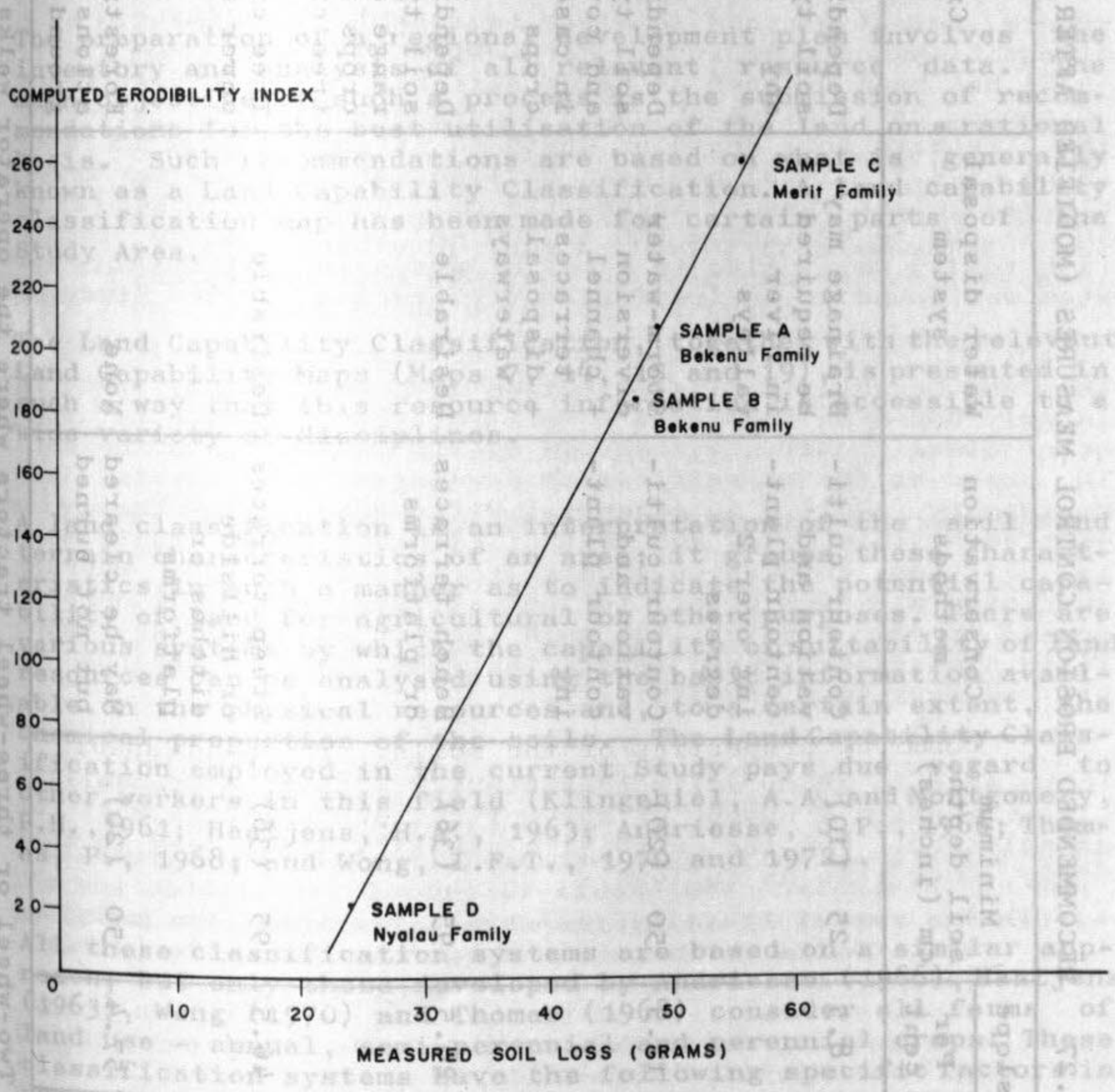


TABLE 4.27 RECOMMENDED EROSION CONTROL MEASURES (MODIFIED AFTER HUDSON, PRIV. COMM. 1973)

Maximum slope		Minimum soil depth cm (inches)	Conservation methods	Water disposal system	Crops	Cultivation machinery (not construction)
Degrees	Per cent					
5	8.5	25 (10)	Contour cultivation and contour planting over 2 degrees	Drainage may be required in river valleys	Depending on soil type - any	any
10	17.5	50 (20)	Contour cultivation and contour planting	Storm-water diversion + channel terraces + disposal waterways	Depending on soil type - any and cover crops in case of tree crops	any
15	26.5	95 (36)	Bench terraces or platforms	Desirable	Depending on soil type wide range and cover crops in case of tree crops	4-wheel tractor
25	46.5	95 (36)	Steep terraces or hillside ditches or platforms	Desirable	Tree crops with cover crop	Walking tractor*
30	57.4	50 (20)	May be cleared but not burned	None	Forestry plantations close ground cover	None

Note * Two-wheel or three-wheel tractors where the operator walks behind the vehicle.

CHAPTER 5
LAND EVALUATION

5.1 INTRODUCTION

The Scope of Work emphasises the importance of establishing a maximum diversified cropping pattern in the Study Area. Although traditional agriculture, especially shifting cultivation, should be modernised or phased out, such agricultural practices have been considered within the framework of land evaluation.

The preparation of a regional development plan involves the inventory and analysis of all relevant resource data. The main objective of such a process is the submission of recommendations for the best utilisation of the land on a rational basis. Such recommendations are based on what is generally known as a Land Capability Classification. A land capability classification map has been made for certain parts of the Study Area.

The Land Capability Classification, together with the relevant Land Capability Maps (Maps 7, 14, 15 and 19), is presented in such a way that this resource information is accessible to a wide variety of disciplines.

A land classification is an interpretation of the soil and terrain characteristics of an area; it groups these characteristics in such a manner as to indicate the potential capability of land for agricultural or other purposes. There are various systems by which the capability or suitability of land resources can be analysed using the basic information available on the physical resources and, to a certain extent, the chemical properties of the soils. The Land Capability Classification employed in the current Study pays due regard to other workers in this field (Klingebiel, A.A. and Montgomery, P.H., 1961; Haatjens, H.A., 1963; Andriesse, J.P., 1966; Thomas, P., 1968; and Wong, I.F.T., 1970 and 1972).

All these classification systems are based on a similar approach; but only those developed by Andriesse (1966), Haatjens (1963), Wong (1970) and Thomas (1968) consider all forms of land use - annual, semi-perennial and perennial crops. These classification systems have the following specific factors in common:-

(a) the soils are classed according to their permanent characteristics;

(b) the capability of a soil is better when a wider range of crops can be grown than that of a soil with a narrower range;

(c) the soils are grouped according to the severity of crop growth limiting factors;

(d) they are mainly directed to agriculture though to a certain extent also towards forestry.

The Scope of Work required that the Study ".... be guided as far as practicable...." by the Soil Suitability Classification standardised for Malaysia. This Soil Suitability Classification (Wong, I.F.T., 1970) does not claim to be a soil suitability classification for specific crops e.g. grasses, groundnuts, hill padi, cocoa, oil palm, rubber, etc., which require specific interpretations of the soil and terrain data. Although, certain refinements in the parameters have been applied since 1970 (Wong, I.F.T., 1972), it was considered impracticable to apply this system in its enirety to the Study. It was found that the range of a number of limitations to crop growth, were too broad to allow reasonable assessment of crop diversification prospects. For instance Class I (Wong, I.F.T., 1972) has been defined as being suitable for the widest range of crops, but a slope of up to 12 degrees has been allowed. The effective soil depth or depth to strongly compacted layer (Wong, I.F.T., 1972) has been divided into four rather broad classes: less than 10 inches (25 cm), 10 to 25 inches (25 to 50 cm), 20 to 40 inches (50 to 100 cm) and 40 to 50 inches (100 to 125 cm). Also in terms of drainage criteria this system was found to be insufficiently precise for the Study.

The Land Capability Classification adopted for this Study is largely based on Andriesse's work in 1966 and which is, like other classification systems in use in many parts of the world, based on the classification developed by Klingebiel and Montgomery (1961). An essential difference between the system adopted by this Study and that of Klingebiel and Montgomery is that these authors only cater for annual crops, whereas Andriesse's system caters for annual, semi-perennial and perennial crops. However, the main factors on which the capability classes are based remain the same, that is hazards of use and long term productivity.

To be able to group soils consistently within a capability classification a number of assumptions and criteria must be established. For the capability classification used in this Study, they were as follows:-

(1) The system is an interpretive classification based on the effects which soil and terrain characteristics (slope, soil texture, soil depth, effects of past erosion, permeability, water holding capacity and clay content) may have when used for the crop groups listed in Section 5.3, Table 5.9.

(2) The classification is based on permanent, unalterable soil and terrain characteristics. However in certain cases soils were upgraded where improvements were considered economically feasible e.g. in the case of Pendam-Mukah family intergrades.

(3) The soils are grouped into capability classes and subclasses according to their degree and number of limitations to use or risk of damage when used. Each cap-

ability subclass includes a number of different soil families and/or soil series.

(4) Most soils in Sarawak have a low to very low fertility level and the use of fertilisers is assumed to become a common practice under all types of management. Therefore, in determining the capability of the majority of soils the nutrient levels have been ignored, except in those cases where nutrient imbalance is serious as in the Miri, Silantek, Tika families and other similar sand soils.

(5) The capability classification is not a productivity rating.

(6) The level of management is not a criterion; but it is possible to assign each capability subclass to its appropriate management type, including small - holder development.

(7) The capability classification of certain soils will change if irrigation, drainage and reclamation measures are applied to such land. In these cases the basic resource maps will change as well. But the bunding of large tracts of land suffering from seawater intrusion has been regarded as uneconomical at present, unless high value crops can be found.

(8) Distance to markets and accessibility to development areas are not criteria for the capability groupings. Soils in remote areas have been classed solely according to limitations to use or risk of soil damage due to combinations of resource characteristics.

(9) It is expected that crop husbandry and management will advance, whereby certain crops now placed in a given capability class could in the future, with the application of new techniques or new variations, be upgraded to a higher class. These advances however would not alter the terms of each land capability subclass.

5.2 THE LAND CAPABILITY CLASSIFICATION SYSTEM

The adopted classification system identifies land in terms of its suitability for groups of crops (see Section 5.5) and includes wet land rice as well as sago and forest plantations.

As mentioned earlier, the land classification for this Study is largely based on system developed by Andriesse (1966); but the latter permits the use of slopes up to 35 degrees in the classes suitable for agricultural crops, whereas, for reasons discussed above (Section 5 of Chapter 4), slopes in excess of 25 degrees are excluded for agricultural development in the system adopted for the Study. The Miri-Bintulu classification has been designed to cater for the different levels of soil investigations employed in the Broad Transect and the Semi-Detailed Soil Surveys and is related to the particular conditions of terrain and soils that are encountered in the Study Area. The classification has seven main classes, as follows:-

Class I Land with no or few limitations to use; capable of supporting a wide range of climatically adapted annual, semi-perennial and perennial crops.

The soils in this class are deep (deeper than 100 cm/40 inches) well drained, and the land is mostly flat or nearly level with slopes of less then 3 degrees (5.5 per cent). No drainage, flood protection or erosion control measures are required.

Class II Land with slight to moderate limitations or hazards to use, but capable of supporting a wide range of climatically adapted annual, semi-perennial and perennial crops.

The soils in this class are deep (deeper than 100 cm/40 inches), with good or slightly restricted drainage, the land is flat to gently undulating with gradients of less than 5 degrees (8 to 9 per cent). If flooding occurs it is infrequent and of short duration. Some minor drainage, flood protection and erosion control measures may be required.

Class III Land with a number of minor, and one major, limitations or hazards to use; capable of supporting a restricted number of annual crops, but a wide range of semi-perennial and perennial crops.

The soils in this class are moderately deep to deep (deeper than 75 cm/30 inches). Drainage is imperfect or better. The land is flat to undulating with gradients of less than 10 degrees (17 to 18 per cent); flooding on flat land is infrequent and of short duration. Some minor flood protection and drainage and, on undulating land major erosion measures may be required.

Class IV Land with not more than two major and a number of minor limitations or hazards to use; capable of supporting a very restricted number of annual crops, and a moderate range of semi-perennial and perennial crops.

The soils in this class can be moderately shallow (deeper than 60 cm/24 inches). The hilly land in this class can have slopes to a maximum of 15 degrees (26.7 per cent). Flat alluvial land in this class is water-logged most of the time and flooding is common and of moderate duration. Flood protection and drainage measures required to improve this land to a standard suitable for dry land crops would be extensive and probably uneconomic. The undulating sloping land requires certain conservation measures.

Class V Land with two or more major, and a number of minor, limitations or hazards to use; capable of supporting a very restricted number of annual crops and a small range of semi-perennial and perennial crops.

The soils in this class can be shallow (deeper than 50 cm/20 inches). The hilly land in this class can have slopes of up to a maximum of 20 degrees (36.5 per cent). Flat alluvial land in this class is continuously water-logged and flooding frequent. Flood protection in this class may have to be such that it precludes the cultivation of most crops. Intensive erosion control measures are required on the steeper slopes, especially between 15 and 20 degrees (26.7 and 36.5 per cent).

Class VI Land with severe major limitations or hazards to use; capable of supporting a very restricted number of annual crops and a restricted range of perennial crops. Under certain conditions a potential exists for timber plantations.

The soils in this class can be shallow to very shallow (deeper than 25 cm/10 inches). The hilly land in this class can have slopes up to a maximum of 25 degrees (46.5 per cent), which is regarded as the upper limit of land suitable for agricultural development. Flat land is continuously water-logged and flooding excessive, which precludes this land from agricultural development. Intensive erosion control measures are required on slopes between 20 and 25 degrees (36.5 and 46.5 per cent).

Class VII Land unsuitable for most forms of agricultural development and mainly suitable for forest and wild life reserves, and forest under controlled exploitation.

Upland soils are shallow to very shallow and the terrain very steep and dissected.

Soils on flat alluvial land are very poorly drained and subject to continuous flooding.

5.3 THE CAPABILITY SUBCLASSES

5.3.1 The Delineation of Subclasses

To indicate the kind of limitation within a particular land capability class, Classes II to VII have been divided into specific subclasses according to factors affecting crop growth and soil conservation. It has been possible to limit the number of subclasses to a minimum, even for the Semi-Detailed Soil Survey Areas. The subclasses (or limiting factors to crop growth) are the mapping units on the Land Capability maps (Maps 7, 14, 15 and 19). The following subclasses have been distinguished:-

- erosion hazard limitions : suffix - e
- soil limitations within the rooting zone : suffix - s
- excess water or internal drainage limitations and flooding hazards : suffix - w
- soil and erosion hazard limitations : suffix - se
- soil, internal drainage limitations and flooding hazards : suffix - sw

Depending on the final mapping scale, the mapping units inevitably include a certain percentage of impurities, admixtures of another class. The percentage of impurities within a particular mapping unit is of course related to the level of survey: the Semi-Detailed Soil Survey has a lower percentage than the Broad Transect Survey. As has been explained in Chapter 2, Section 3, the land classes have been derived from the terrain and soil mapping units.

Table 5.1 gives the capability classes and subclasses of the system adopted for this Study, together with the criteria for crop growth limitations. The soil families and series appropriate to each subclass have been listed for those soils which occur within the boundaries of the Study Area. A list of crop groups suitable to each subclass has also been given; parentheses are used to indicate marginality. These crop groups are discussed in Section 5 below.

5.3.2 Subclass Criteria

A description of the subclasses, which play an important part in the final planning of an area, is required to appreciate the application of the Land Capability Classification in this Study.

Three basic groups of limitations on which the subclasses are based have been given in Section 3.1 above. The two complex subclasses mentioned are essentially combinations of the three basic groups. The parameters employed for each subclass are as follows.

5.3.2.1 Slope

Erosion is, as has been explained in Section 5 of Chapter 4, a serious hazard to the use of land in Sarawak and is the overriding limitation to agricultural productivity over large areas. The principal factor controlling liability to erosion is slope. It must be emphasised again that the present country-wide agricultural slope limit of 35 degrees has been discarded and the upper limit set at 25 degrees. But it has been assumed that adequate conservation measures will be used and

TABLE 5.1

LAND CAPABILITY CLASS I AND II

CLASS	I	II		
Sub-class	-	e	s	w
Soil FAMILY and/or Series in each Sub-class	BEMANG - Bemang SEDUAU - Seduau, Malang BEKENU - Bekenu, Sarikei	BEKENU - Bekenu, Sarikei MERIT - Merit, Jakar MERIT/BEKENU KABULOH - Karabungan, Tangap	BEMANG - Semilajau SARATOK - Saratok, Penipah NYALAU - Nyalau, Sabangang NYALAU/BEKENU MERIT/NYALAU	BEMANG - Bemang SEDUAU - Seduau, Malang
Maximum slope in degrees	3	5	3	3
Erosion hazard	Slight or absent	Slight	Slight or absent	Slight or absent
Effective soil depth cm (inches)	Deeper than 100 (40)	Deeper than 100 (40)	Deeper than 100 (40)	Deeper than 100 (40)
Drainage	Well	Well to moderately well	Well to moderately well	Well to moderately well
Flooding	None	None	None	Infrequent and of short duration
Texture groups	Loams, silts and clays no surface peat	Loams, silts and clays no surface peat	Loams, silts and clays no surface peat	Loams, silts and clays no surface peat
Crop groups	1 2 3 4 5 6 7 8 9 10 11 12 13 14 16	(1) (2) 3 4 5 6 7 8 (9) (10) 11 12 13 14 16 Marginal: 1 - slopes over 3 degrees unsuitable 2 - heavy clays (KB) unsuitable for groundnuts 9 - heavy clays (KB) unsuitable 10 - heavy clays (KB) unsuitable for citrus	(1) 2 (3) 4 5 6 7 8 9 10 11 12 13 14 16 Marginal: 1 - light textured soils unsuitable 3 - light textured soils unsuitable	1 (2) 3 (4) (5) 6 7 (8) (10) 11 12 13 14 16 Unsuitable for: Papaya 8 and Pepper 10: flooding Marginal: 2 - flooding 4 - flooding 5 - flooding 11 - flooding except oil palm and coffee

TABLE 5.1 (Cont'd)

LAND CAPABILITY CLASS III

Sub-class	e	s	w	se
Soil FAMILY and/or Series in each Sub-class	BEKENU - Bekenu, Sarikei MERIT - Merit, Jakar MERIT/BEKENU KABULOH - Karabungan, Tangap	BEKENU - Bekenu, Sarikei MERIT - Merit, Jakar MERIT/BEKENU KABULOH - Kabuloh, Karabungan, Tangap	BEMANG-PAKAN SEDUAU-BIJAT	SARATOK - Saratok, Penipah NYALAU - Nyalau, Sabangang NYALAU/BEKENU MERIT/NYALAU
Maximum slope in degrees	10	5	5	5
Erosion hazard	Moderate	Moderate	Slight	Moderate
Effective soil depth cm (inches)	Deeper than 100 (40)	Deeper than 75 (30)	Deeper than 100 (40)	Deeper than 100 (40)
Drainage	Very well to moderately well	Imperfect to very well	Imperfect	Imperfect to very well
Flooding	-	-	Infrequent and of short duration	-
Texture groups	Loams, silts and clays no surface peat	Loams, silts and clays no surface peat	Loams, silts and clays no surface peat	Loams, silts and clays no surface peat
Crop groups	(2) 3 (4) (5) 6 7 8 (9) (10) 11 12 13 14 16 Marginal: 2 - heavy texture (KB) unsuitable for groundnuts 4 - heavy texture (KB) unsuitable 5 - heavy texture (KB) unsuitable 9 - heavy texture (KB) unsuitable 10 - heavy texture (KB) unsuitable for citrus and pepper	(2) 3 (4) (5) 6 7 8 (9) (10) 11 12 13 14 16 Marginal: 2 - heavy texture (KB) unsuitable for groundnuts 4 - heavy texture (KB) unsuitable 5 - heavy texture (KB) unsuitable 9 - heavy texture (KB) unsuitable 10 - heavy texture (KB) unsuitable for citrus and pepper	1 3 (4) (5) 6 7 (8) (9) (10) (11) 12 13 14 16 Marginal: 4 - flooding 5 - flooding 8 - flooding, unsuitable for papaya 9 - flooding and heavy texture 10 - flooding, unsuitable for pepper 11 - flooding; except for oil palm and coffee	2 3 4 5 6 7 8 9 10 11 12 13 14 16

TABLE 5.1 (Cont'd)

LAND CAPABILITY CLASS IV

Sub-class	e	s	w	se
Soil FAMILY and/or Series in each Sub-class	BEKENU - Bekenu, Sarikei MERIT - Merit, Jakar MERIT/BEKENU KABULOH - Kabuloh, Karabungan, Tangap	BEKENU - Bekenu, Sarikei MERIT - Merit, Jakar MERIT/BEKENU KABULOH - Kabuloh, Karabungan, Tangap	BEMANG/BIJAT PAKAN - Pakan, Dangkar BIJAT - Bijat, Sebandi BIJAT/SEDUAU BIJAT-PENDAM PENDAM - Pendam (if reclamation feasible) PENDAM-MUKAH (if PENDAM reclaimable) MUKAH - (if peat less than 50 cm/20 inches), Mukah	SARATOK - Saratok, Penipah NYALAU - Nyalau, Sabangang NYALAU/BEKENU MERIT/NYALAU
Maximum slope in degrees	15	10	3	10
Erosion hazard	Moderate	Moderate	Slight or absent	Moderate
Effective soil depth cm (inches)	Deeper than 75 (30)	Deeper than 60 (24)	Deeper than 75 (30)	Deeper than 75 (30)
Drainage	Imperfect to very well	Imperfect to very well	Very poor and poor	Moderately well to very well
Flooding	-	-	Common and of moderate duration	-
Texture groups	Loams, silts and clays no surface peat	Loams, silts and clays no surface peat	Loams, silts and clays surface peat less than 50 cm (20 inches)	Loams, silts and clays no surface peat
Crop groups	(3) 6 7 8 (9) (10) 11 12 13 14 16 Marginal: 3 - heavy clays (KB) unsuitable 9 - heavy clays (KB) unsuitable 10 - heavy clays (KB) unsuitable for citrus and pepper	(2) (3) (4) (5) 6 7 8 (9) (10) 11 12 13 14 16 Marginal: 2 - heavy clays (KB) unsuitable for groundnuts, some vegetables require minimum soil depth of 75 cm (30 in) 3 - heavy clays (KB) unsuitable 4 - heavy clays (KB) unsuitable 5 - heavy clays (KB) unsuitable 9 - heavy clays (KB) unsuitable 10 - heavy clays (KB) unsuitable for citrus and pepper	1 6 15 16	2 3 4 5 6 7 8 9 10 11 12 13 14 16

TABLE 5.1 (Cont'd)

LAND CAPABILITY CLASS V

Sub-class	e	s	w	se	sw
Soil FAMILY and/or Series in each Sub-class	BEKENU - Bekenu, Sarikei MERIT - Merit, Jakar MERIT/BEKENU KABULOH - Kabuloh, Karabungan, Tangap	KAYAN - Kayan, Kabong, Belawai SILANTEK - Silantek, Tunggal, Buso, Grang KERAIT - Kerait, Ajoh KERAIT/BANDANG BEKENU - Bekenu, Sarikei MERIT - Merit, Jakar MERIT/BEKENU KABULOH - Kabuloh, Karabungan, Tangap	BEMANG/BIJAT BIJAT - Bijat, Sebandi BIJAT/MUKAH MUKAH - (if peat less than 50 cm/20 inches), Mukah	SARATOK - Saratok, Penipah SARATOK/KERAIT NYALAU - Nyalau, Sabangang NYALAU/SILANTEK NYALAU/BEKENU MERIT/NYALAU	KAYAN-TATAU KAYAN/BEMANG
Maximum slope in degrees	20	No limit	3	15	3
Erosion hazard	Severe	Moderate - severe	Slight or absent	Severe	Slight or absent
Effective soil depth cm (inches)	Deeper than 60 (24)	Deeper than 50 (20)	No limit	Deeper than 60 (24)	Deeper than 60 (24)
Drainage	-	Excessive to imperfect	Very poor	-	Very poor and excessive
Flooding	-	None	Frequent	None	Frequent
Texture groups	Loams, silts and clays no surface peat	Sands, loams, silts and clays no surface peat	Loams, silts and clays surface peat less than 50 cm (20 inches)	Loams, silts and clays no surface peat	Sands no surface peat
Crop groups	(6) (10) 11 12 13 14 16 Marginal: 6 - over 15 degrees only after trials 10 - heavy clays (KB) unsuitable for citrus and pepper	(6) (13) 14 16 Marginal: 6 - over 15 degrees only after successful trials; KY unsuitable 13 - over 25 degrees unsuitable	1 6 15 16	3 6 7 8 11 12 13 14 16	(13) (14) 16 Marginal: 13 - KY/TT unsuitable 14 - sands not suitable for certain tree species

TABLE 5.1 (Cont'd)

LAND CAPABILITY CLASS VI

Sub-class	e	s	se	sw
Soil FAMILY and/or Series in each Sub-class	BEKENU - Bekenu, Sarikei MERIT - Merit, Jakar MERIT/BEKENU KABULOH - Karabungan, Tangap, Kabuloh	MIRI - Miri, Bako SILANTEK/MIRI SILANTEK/TIKA TIKA - Tika, Bintulu BEKENU-KAPIT NYALAU-KAPIT MERIT-KAPIT KABULOH-KAPIT MUKAH - Mukah, Tekajong (peat more than 50 cm/20 inches)	SARATOK - Saratok, Penipah SARATOK/KERAIT PENINJAU - Peninjau NYALAU - Nyalau, Babangang NYALAU/PENINJAU NYALAU/SILANTEK NYALAU/BEKENU MERIT/NYALAU	NONOK - Nonok NONOK-TATAU TATAU - Plan, Tatau, Matu TATAU/MUKAH TATAU/IGAN BIJAT/ANDERSON I (inland peat) IGAN - Igan, Bruit IGAN/SILANTEK ANDERSON I/MUKAH (inland peat)
Maximum slope in degrees	25	No limit	20	-
Erosion hazard	Severe	-	Severe	Absent
Effective soil depth cm (inches)	Deeper than 60 (24)	Deeper than 25 (10)	Deeper than 60 (24)	No limit
Drainage	-	-	-	Very poor
Flooding	-	-	-	No limit
Texture groups	Silts and clays no surface peat	Sands, loams, silts and clays surface peat more than 50 cm (20 inches)	Loams, silts and clays no surface peat	Sands, loams, silts and clays surface peat less than 200 cm (80 inches)
Crop groups	(11) 12 13 14 16 Marginal: 11 - between 20 and 25 degrees	(1) (6) 9 16 Marginal: 1 - only on Mukah 6 - shallow soil, only after successful trials	(6) 11 12 13 14 16 Marginal: 6 - over 15 degrees only after trials	(6) 15 16 Marginal: 6 - only on BIJAT/ANDERSON I

TABLE 5.1 (Cont'd)

LAND CAPABILITY CLASS VII

Sub-class	e	s	w	se
Soil FAMILY and/or Series in each Sub-class	BEKENU - Bekenu, Sarikei MERIT - Merit, Jakar MERIT/BEKENU	BELAT - Belat BELAT-TATAU BELAT/ANDERSON BIJAT/ANDERSON II PENDAM - Pendam (if unreclaimable) PENDAM/RAJANG RAJANG - Rajang RAJANG-ANDERSON PENINJAU/MELUAN NYALAU/MELUAN NYALAU/KAPIT MELUAN - Meluan MELUAN/KAPIT MELUAN/ROCK KAPIT - Kapit KAPIT/MERIT IGAN/ANDERSON ANDERSON I, II & III ANDERSON II & III/MUKAH	NONOK - Nonok TATAU - Plan, Tatau, Matu PENDAM-MUKAH (if PENDAM unreclaimable) MUKAH - Mukah, Tekajong (peat more than 20 inches)	SILANTEK - Silantek, Tunggal, Buso, Grang SILANTEK/KERAIT SARATOK - Saratok, Penipah PENINJAU - Peninjau NYALAU - Nyalau, NYALAU/SILANTEK NYALAU/PENINJAU NYALAU/BEKENU MERIT/NYALAU IGAN/SILANTEK
Maximum slope in degrees	Over 25	-	3	Over 20
Erosion hazard	Severe	Severe on hill soils. None on valley soils.	Absent	Severe
Effective soil depth cm (inches)	No limit	Less than 25 (10)	No limit	No limit
Drainage	-	-	No limit	No limit
Flooding	-	-	No limit	No limit
Texture groups	Loams, silts and clays no surface peat	Sands, loams, silts and clays surface peat more than 100 cm (40 inches)	Sands, loams, silts and clays surface peat more than 50 cm (20 inches)	Sands, loams, silts and clays no surface peat
Crop groups	14 16	(14) 16	15 16	14 16

maintained, especially between 20 and 25 degrees (26.7 and 36.5 per cent). In this connection Hudson (1971) reports that in an experiment on the management of identical adjacent plots of maize, the loss of soil was 15 times greater on that which was badly managed.

Slope classes are as quoted on the Terrain maps (Maps 1, 4, 8, 9 and 16): 0 to 5 degrees, 6 to 10 degrees, 11 to 15 degrees, 16 to 20 degrees, 21 to 25 degrees, 26 to 30 degrees and over 30 degrees. But for land capability classification purposes the 0 to 5 degrees range has been split into 3 degrees maximum and 5 degrees maximum respectively to cover alluvial soils and residual soils on very gently sloping upland. Furthermore, no division is applied for slopes over 25 degrees. The following table gives the maximum permitted slope for each subclass.

TABLE 5.2 SLOPE AND LAND CLASSES

CLASS	Permitted slope in degrees	CLASS	Permitted slope in degrees	CLASS	Permitted slope in degrees
I	3	IVe	15	VIe	25
IIe	5	IVs	10	VIs	-
IIs	3	IVw	3	VIse	20
IIw	3	IVse	10	VIsw	-
IIIe	10	Ve	20	VIIe	over 25
IIIs	5	Vs	-	VIIs	-
IIIw	5	Vw	3	VIIw	3
IIIse	5	Vse	15	VIIse	over 20
		Vsw	3		

5.3.2.2 Soil

The criteria used in defining the soil families and series are to a large extent also used in designating land capability subclasses. A considerable number of land classes are therefore based on the family and series definitions as outlined in the Soil Classification (Scott, 1973). The descriptions of the families and their appropriate series are discussed in Chapter 4. But many soil families and series are sufficiently alike in use characteristics to make other criteria, such as drainage and slope, of more importance. In a few cases soil texture has been a limiting criterion, as for example in Subclass IIIse where the "s" signifies a coarse loam texture associated with the Saratok family and the Nyalau family when occurring pure or in complex with Merit or Bekenu families. An overriding factor in land use planning and land management is the effective rooting depth available to plants and this criteria is used for most soils. In Chapter 4, Section 1, it has been pointed out that, due to the weathering conditions of the parent rock and the rapid erosion, the resulting soil available to plant growth has a limited depth. It was found that a high percentage of observations had shallow soils.

It must be emphasised that the accepted criteria are based on minimum crop requirements. The following table gives the minimum effective soil depth within each subclass.

TABLE 5.3 EFFECTIVE SOIL DEPTH AND LAND CLASSES

CLASS	Permitted soil depth cm (inches)	CLASS	Permitted soil depth cm (inches)	CLASS	Permitted soil depth cm (inches)
I	100 (40)	IVe	75 (30)	VIe	60 (24)
IIe	100 (40)	IVs	60 (24)	VIs	25 (10)
IIs	100 (40)	IVw	75 (30)	VIse	60 (24)
IIw	100 (40)	IVse	75 (30)	VIsw	-
IIIe	100 (40)	Ve	60 (24)	VIIe	-
IIIs	75 (30)	Vs	50 (20)	VIIs	25 (10)
IIIw	100 (40)	Vw	-	VIIw	-
IIIse	100 (40)	Vse	60 (24)	VIIse	-
		Vsw	60 (24)		

5.3.2.3 Drainage and Flooding

The drainage classes used in this Study are those given in the Soil Survey Manual for Malayan Conditions (Leamy and Panton, 1966), which in turn are based on those given in Handbook 18 (Soil Survey Staff, 1951).

In a study of this type covering a limited period, it is only possible to make a broad assessment of the flood hazards, drawn largely from circumstantial evidence and inference.

As drainage and water-logging are inherent characteristics of many soil families, these soils fall easily in place in the framework of the classification. And, in general, drainage criteria for the different land classes apply to flat alluvial land; but in some cases they are also limiting factors in the residual soils.

The drainage and flooding criteria in each subclass are as follows.

TABLE 5.4 DRAINAGE AND FLOODING CRITERIA IN LAND CLASSES

CLASS	Drainage criteria	Flooding criteria
I	Well	None
IIe, IIs	Well to moderately well	None
IIw	as IIe, IIs	Infrequent and of short duration
IIIe	Very well to moderately well	-
IIIs, IIIse	Imperfect to very well	-
IIIw	Imperfect	Infrequent and of short duration
IVe, IVs	Imperfect to very well	-
IVse	Moderately well to very well	-
IVw	Very poor and poor	Common and of short duration
Ve, Vse	-	-
Vs	Excessive to imperfect	-
Vw	Very poor	Frequent
Vsw	Very poor or excessive	Frequent
VIe, VIs, VIse	-	-
VIsw	Very poor	-
VII	-	-

5.3.2.4 Other Criteria

Two other criteria not so far discussed are the texture groups and depth of surface peat. The former is a grouping of soil textures according to the Soil Classification (Scott, 1973). A discussion of these groupings is given in Chapter 4, Section 3. Surface peat, although an important factor in the capability classification, is not separated as an independent criterion, but has been included in soil limitations within the rooting zone: it is also a parameter in terms of the Soil Classification.

5.4 MAPPING AND DISTRIBUTION OF LAND CLASSES

5.4.1 Mapping Procedures of the Land Classes

As has been explained in Chapter 2, the land capability mapping units have been obtained by combining terrain and soil information under the strict system discussed in the above section and applying certain assumptions described in the Introduction to this Chapter.

The general procedures used in deciding the land capability mapping units need explanation. This is especially required for the Sungai Karabungan Area (Map 7). In this area soils occur which, although shallow, rest on very gentle slopes, that is the Kabuloh family soils. A number of characteristics of this soil, such as poor structure, compactness and low permeability, could make this soil a problematic medium for plant growth, especially as there is little agronomic information for such crops as pasture grasses and fodder. It will be shown that the Kabuloh family presents special problems in the Land Capability system, and it has been noted that this soil and other soils derived from calcareous shales or marl fit uneasily in the adopted Capability Classification.

North of the access road into the Sungai Karabungan Area a large unit of VIs (see Map 7) has been mapped. The constituents of this unit are very shallow soils of the Kapit and Merit families on terrain of Classes 3, 4, 5 and 6. But land class VIs can also consist of shallow Kabuloh family soils occurring over Terrain Classes 1, 2 and 3 as mapped in an area north of the headwaters of the Sungai Karabungan. In the first case this unit is unsuitable for all forms of agriculture and the area would best be left under forest. But in the second case a VIs unit is suitable (although marginally) for at least one crop that is grasses for grazing (crop group 6, Table 5.9). From the above discussion it can be concluded that when lands for grazing (crop group 6, grasses) and fodder crops (crop group 7) have to be identified, and if the soils resemble those of the Kabuloh family, then the Terrain, and possibly also the Soil, maps of the appropriate area must be consulted.

Table 5.5 shows the land classes suitable and marginally suitable for crop groups 6 and 7.

The Land Capability maps of the Broad Transect Survey Area (Maps 14 and 15) and the Semi-Detailed Soil Survey Area (Map 19), at scales of 1:100 000 and 1:50 000 respectively, have been mapped on the basis of the same principles as the Sungai Karabungan Area.

In the above survey areas the procedure was first to delineate all areas with slopes exceeding 25 degrees and those with slopes of less than 5 degrees. The latter indicated flat areas with alluvial deposits, but also areas with residual soils on slopes of less than 5 degrees. A further division was then made on the basis of the soil maps, and the appropriate capability subclass appended to each mapping unit. In areas with slopes of over 25 degrees the soil type was ignored and the unit labelled Class VIIe, indicating a serious erosion hazard. The remaining areas were classified using both terrain and soil information and guided by the parameters set out in the Land Capability Classification described above.

TABLE 5.5 SUITABILITY FOR CROP GROUPS 6 AND 7, SUNGAI KARABUNGAN AREA

Land CLASS	Suitable crop group	Remarks
I	6 + 7	-
IIw	6 + 7	-
IIIe	6 + 7	-
IVe	6 + 7	-
IVs	6 + 7	-
IVw	6	Selected grass species
Vw	6	Selected grass species
Ve	6	Between 15 and 20 degrees slopes, after trials
VIs	6	Marginal, trials required on slopes between 15 and 20 degrees

5.4.2 Land Assessment at Different Survey Levels

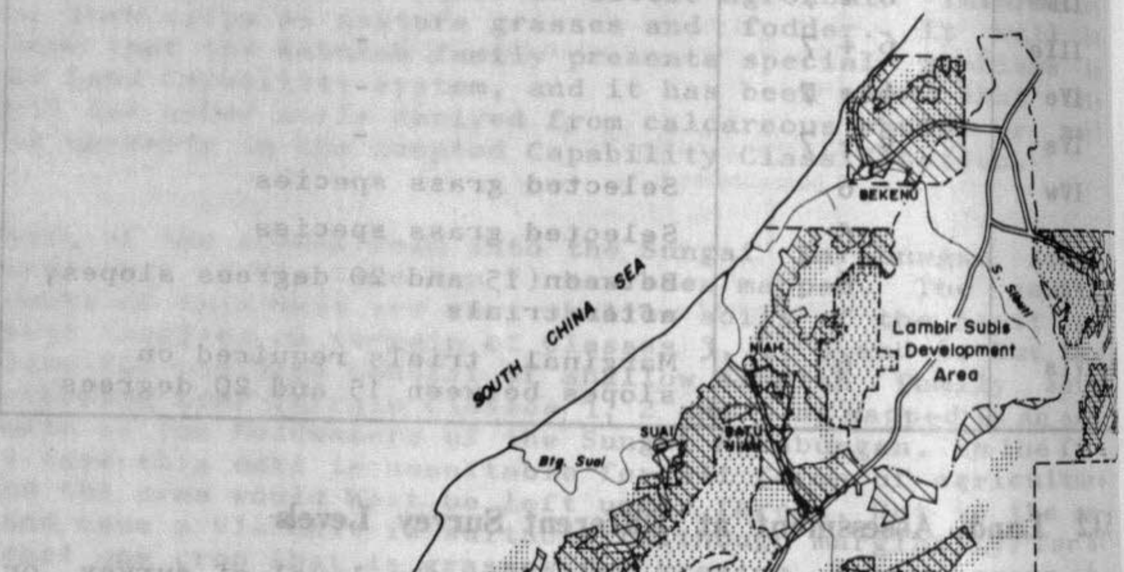
There is a close correlation between the level of survey or soil observation density and the use possibilities of the end product: the land capability maps. Every aim and objective requires its specific level of survey and scale of the final published map.

Appendix VIII gives a description of the procedures and results achieved during the Zonation Plan study. Figure VIII.1 of this Appendix shows the areas assessed as possibly suitable for agricultural development. These areas have been delineated on the bases of aerial photo-interpretation, earlier schematic reconnaissance soil surveys supplemented with quick field checks carried out in areas requiring clarification. It is clear therefore that conclusions drawn and planning executed on the basis of such scant information must be regarded as tentative, and more detailed soil and terrain investigation are essential before any plans for these areas can be drawn up.

Land assessed as suitable for agricultural development at the Broad Transect Soil Survey are shown in Figure 5.1 together with the land assessed as possibly suitable for agriculture in the Zonation Plan study. A comparison of these areas clearly indicates that at the more detailed survey level of the Broad Transect Survey considerable areas, previously assessed as suitable, had to be excluded. Information collected at the Broad Transect Soil Survey and presented in the form of Land Capability maps (Maps 14 and 15), can serve as a base for regional planning only in the broadest of terms. For example, because the main development areas are known, a plan for a long term trunk road network can be drawn up and certain new

FIGURE 5.1

A COMPARISON OF LAND EVALUATION AT TWO DIFFERENT SURVEY LEVELS



Limit of broad transect soil survey

Land assessed as possibly suitable for agriculture from schematic reconnaissance soil survey data supplemented with systematic aerial photo interpretation.

Land assessed as suitable for agriculture based on broad transect soil survey data supplemented with systematic aerial photo interpretation.

Areas surveyed at semi-detailed level.
(For comparision see Figure 5.2)

0 10 20
Statute Miles

population centres can be tentatively located, but they may have to be shifted in the light of later findings. It must also be emphasised that at this stage insufficient information is available to indicate acreage figures for the development blocks with any degree of accuracy.

It is only after more detailed surveys that a solid base for development planning can be offered. Figure 5.2 compares land evaluated at Broad Transect and Semi-Detailed Soil Survey levels. This figure demonstrates clearly that considerable tracts of land assessed as suitable for agricultural development at the Broad Transect Survey were found to be unsuitable at the Semi-Detailed level of soil survey. In this case the total reduction amounted to 30 per cent. For Beluru the figure was even higher - 50 per cent.

5.4.3 Distribution and Area of Land Classes

5.4.3.1 The Broad Transect Soil Survey Area

The distribution of the various land capability classes is illustrated on the Land Capability maps (Maps 14 and 15) at a scale of 1:100 000. The areas suitable for agricultural development on the basis of the assessment at this level of survey have been generalised on Figure 5.1.

The gross acreage covered by each subclass is listed in Table 5.6 a more detailed breakdown of the acreages mentioned below are given in Appendix VII.

The Land Capability maps covering this survey area show a typical alternating pattern of land assessed as suitable and unsuitable for agriculture. The largest concentrations of suitable land are situated between the Lambir-Subis Development Area and the Batang Suai in the Niah and Similajau Forest Reserves. Long tracts of suitable land continue into the southern part of the Similajau Forest Reserves. But these tracts become narrow and interrupted by unsuitable land, to such an extent that north-east of Bintulu the majority of the land is unsuitable for any agricultural development. Land suitable for market gardening is not available within a 10 to 15 miles radius from this town; but a long elongated stretch of Class I land occurs north-west and south-east of the Bintulu-Miri road, the total area amounting to 4 300 acres. No other sizeable areas of land suitable for annual and semi-perennial crops occur around Bintulu. The majority of the suitable land near this town can only be planted to perennial crops.

North of Sebauh, and along the Batang Kemena upstream from Labang as far as Tubau, narrow tracts of Class III land occur. Provided the intensity of flooding, which occurs along a river of this size, is not too serious, these areas could be used for the cultivation of annual and semi-perennial crops. The

FIGURE 5.2

A COMPARISON OF LAND EVALUATION AT BROAD TRANSECT AND SEMI-DETAILED SOIL SURVEY LEVELS

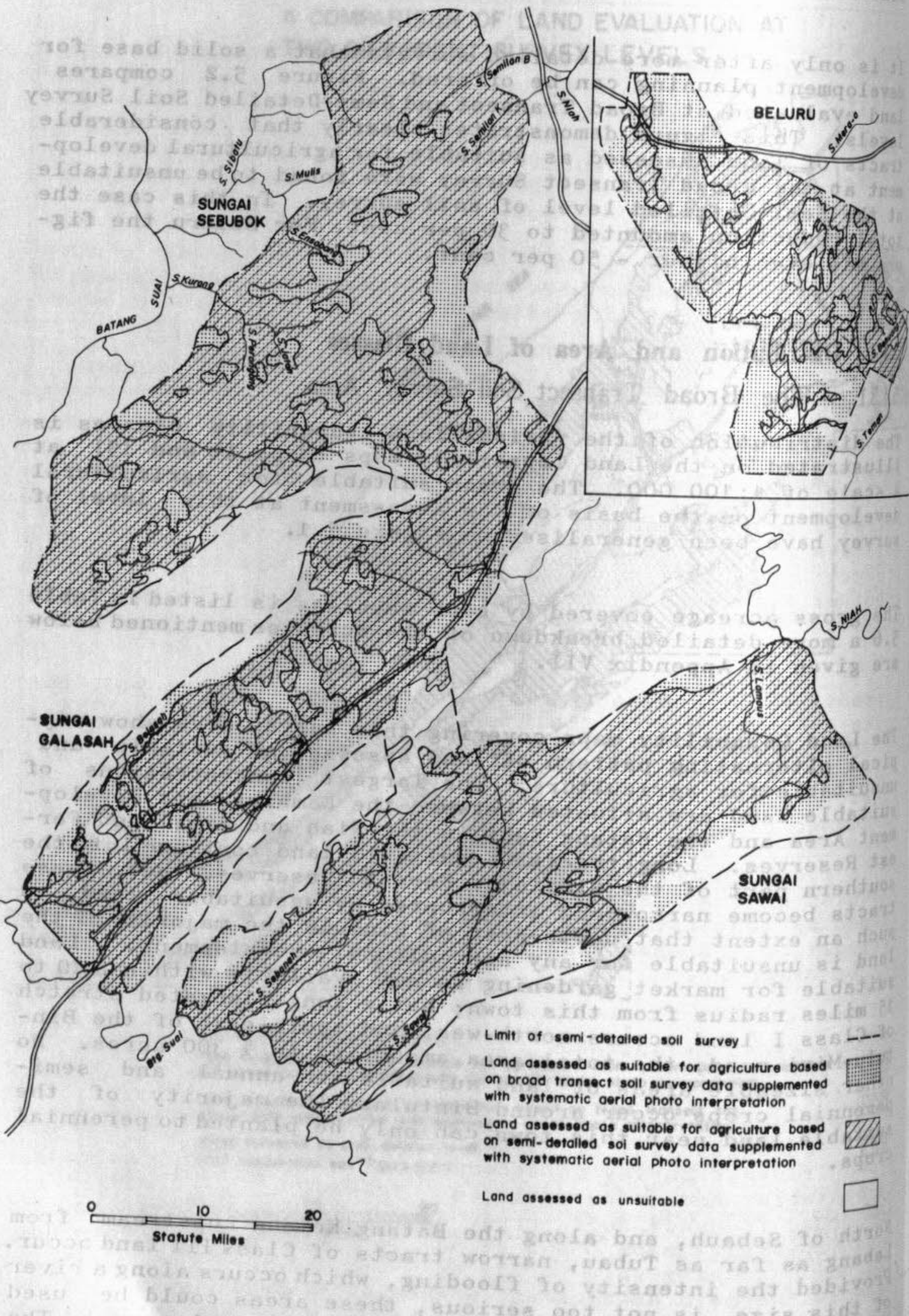


TABLE 5.6 GROSS AREA OF LAND CLASSES (TO THE NEAREST 100 ACRES)

Broad Transect Survey Area			
Land suitable for agriculture		Land unsuitable for agriculture	
CLASS	Area (acres)	CLASS	Area (acres)
I	6 700	Vs	47 500
I + IVe	500	Vs + VIIs	300
IIw	3 200	Vsw	5 600
IIw + Ve	900	VIse + VIsw	3 100
IIe + VIe	300	VIs	71 600
IIIw	41 600	VIsw	40 200
IIIe	100	VIIe	496 100
IIIe + IVw	600	VIIs	245 400
IIIe + IVe	200	VIIs + IVe	600
IIIw + IIIs	400	VIIs + IVs	1 300
IIIs + Ve	300	VIIse	28 700
IIIs + VIe	300		
IVe	79 600		
IVe + IIIw	1 100		
IVe + IVw	2 800		
IVe + IVs	600		
IVe + VIsw	100		
IVe + VIs	1 200		
IVw	43 700		
IVw + Ve	2 100		
IVw + Vs	1 700		
IVs	26 300		
IVs + I	400		
IVs + IIIw	2 700		
IVs + IVw	1 100		
IVse	2 200		
Ve	147 500		
Ve + I	1 600		
Ve + IVe	25 000		
Ve + IVs	1 600		
Ve + Vs	26 600		
Vw	20 800		
Vse	19 700		
Vs + VIe	1 600		
VIe	108 900		
VIse	15 700		
Total area suitable	589 700	Total area unsuitable	940 400
Total area mapped - 1 530 000 acres			

Note: Area includes Semi-Detailed Soil Survey Area, but excludes the Sungai Karabungan Area.

soil and terrain pattern between Labang and Tubau is complex and further, more detailed soil and terrain investigations are required before an accurate evaluation of the use possibilities can be given.

The area south-east of the Semi-Detailed Soil Survey Area and situated in the Sawai Protected Forest appears to be suitable for a wide range of perennial crops. But whether areas suitable for annual and perennial crops exist will have to be decided after a more detailed survey.

The area directly south of the Lambir-Subis Development Area, and east of the Miri-Bintulu Road has extensive units of Class Ve+Vs. At the 1:100 000 mapping scale these classes could not be separated. Class Vs has been regarded as unsuitable for all crops and only marginally suitable for grasses, coconut and cashew. Any definite cropping pattern for this area should therefore be based on more detailed soil surveys.

North of Bekenu (see inset,Map 14) large areas of IIIw, IVw and IVe occur. Most of the land around this town is occupied, but it is felt that other crops than those grown at present could be successfully cultivated.

Table 5.6 shows that, of a total mapped area of 1 530 000 acres, only about one-third of the survey area - 589 700 acres - has been assessed as suitable for agricultural development.

5.4.3.2 The Semi-Detailed Soil Survey Area

The Land Capability map (Map 7) of the Sungai Karabungan Area at a scale of 1:20 000 shows the distribution of the various land classes mapped. The linear pattern typical for the soils and terrain in the Study Area as a whole is also apparent in the land capability pattern of this area, which has been mapped at a much larger scale than the Broad Transect Survey Area.

The areas unsuitable for any agricultural development are concentrated in the north-west. Large areas of Kabuloh family soils are present, resulting in the widespread occurrence of Class VIs. As has been discussed in Section 4.1 of this Chapter, Capability Class VIs is regarded as marginally suitable for the development of pastures because land with slopes exceeding 15 degrees must be subjected to trials before such areas are cultivated. Similar trials should be carried out on land of Class Ve, which occurs extensively in this area.

Table 5.7 shows that 93 per cent (18 492 acres) is suitable for some form of agricultural development; but it must be emphasised again that about half of the area (3 400 acres) of Class VIs may prove to be unsuitable for grasses after the completion of necessary trials.

TABLE 5.7 GROSS AREA OF LAND CLASSES
(QUOTED TO THE NEAREST ACRE)

Sungai Karabungan Area					
CLASS	Land suitable for agriculture	Percentage	CLASS	Land unsuitable for agriculture	Percentage
I	331	2	Vs	332	2
IIw	2 062	10	VIIe	252	1
IIIe	483	2	VIIs	888	4
IVe	1 018	5			
IVs	2 739	14			
IVw	1 012	5			
Ve	3 317	17			
Vw	295	2			
VIe	368	2			
VIs	6 867	34			
Total	18 492	93	Total	1 472	7
Total area mapped 19 964 acres					

The capabilities of the Beluru Area, shown as an inset on Map 19, are considerably more limited than the Sungai Galasah, Sungai Sawai and Sungai Sebubok Areas. Of the total of 12 869 acres surveyed just under half of the area, or 6 422 acres, is suitable for agriculture. This land is concentrated in the centre of the Survey Area and consists mainly of Class IVe, 3 400 acres. An area of Class IVw dissects the above mentioned land class and amounts to about 1 000 acres. This land, consisting of Seduau-Bijat family intergrades, could possibly be utilised for a rice irrigation scheme.

Map 19, depicts the capabilities of the Sungai Galasah, Sungai Sawai and Sungai Sebubok Areas. The total area surveyed amounts to 78 631 acres, of which about two-thirds (55 017 acres) is suitable for a wide range of climatically adaptable crops. Land Classes IVe, Ve and VIe make up the bulk of the suitable land (see Table 5.8 and Appendix VII.2). They are only suitable for tree crops. An area of about 3 000 acres, consisting of Class IIIe and IIIw, could be used for cocoa; but it must be emphasised that, before this crop is cultivated on a large scale, information from a trial presently underway in the Sungai Tangit Scheme of the Sarawak Land Development Board should be analysed. Observations gathered so far show clearly that this crop will be subjected to less favourable conditions here than anywhere else.

TABLE 5.8 GROSS AREA OF LAND CLASSES
(QUOTED TO THE NEAREST ACRE)

SEMI-DETAILED SOIL SURVEY AREA (SUNGAI SEBUBOK,
SUNGAI SAWAI AND SUNGAI GALASAH AREAS)

CLASS	Land suitable for agriculture	Percentage of total	CLASS	Land unsuitable for agriculture	Percentage of total
I	-	-	Vs	3 370	3.70
IIw	2 314	2.50	VIs	4 469	4.90
IIIw	4 304	4.70	VIsw	229	0.30
IIIe	1 759	1.90	VIIe	19 857	21.70
IIIs	906	1.00	VIIs	2 136	2.30
IVw	1 976	2.20			
IVe	18 669	20.40			
IVs	4 431	4.80			
Vw	-	-			
Ve	16 052	17.50			
Vse	49	-.10			
VIe	10 691	11.70			
Ve+VIe	288	0.30			
Total	61 439	67.10	Total	30 061	32.90

Total area mapped - 91 500 acres

5.5 CROP GROUPS AND THEIR DEMANDS ON TERRAIN AND SOILS

5.5.1 Introduction

A Land Capability Classification for a particular region is not complete without a statement of the climatically adapted crops acceptable for each capability subclass. The decision as to whether a crop is acceptable for a certain environment is based on the minimum soils and terrain conditions under which that crop will give acceptable growth and yields. Each crop will only thrive within a certain range of physical and chemical soil conditions. Some crops are more tolerant of adverse conditions than others. For example oil palm and rubber can be grown under a wide range of terrain and soils conditions, but cocoa is more particular about its environment. If the soil criteria for certain crops are to be established then the tolerance range for each crop and group of crops with similar demands must be known.

5.5.2 Criteria for Climatically Adapted Crops

Table 5.9 sets out the range of acceptable soils and terrain criteria for a wide variety of crops. These

TABLE 5.9 RANGE OF ACCEPTABLE SOILS AND TERRAIN CRITERIA FOR CROP GROUPS WITH SIMILAR DEMANDS (ADAPTED FOR SARAWAK CONDITIONS FROM JOHOR TENGGARA REGIONAL MASTER PLAN)

Main group	Crops and crop groups	Soil and terrain criteria
Annual crops	1: Rice (wet land)	Slope: 0 to 3 degrees. Drainage: moderately well to very poorly. Flooding: frequent and protracted, provided controllable. Effective soil depth: deeper than 30 cm (12 inches). Soil texture: heavier than loam if water table higher; otherwise sandy clay loam and heavier. Depth of surface peat: less than 50 cm (20 inches) if well humified and with high base status, otherwise less than 30 cm (12 inches). Depth to acid sulphate layer: deeper than 50 cm (20 inches). Workability: surface stones and rocks less than 25 per cent; no submerged timbers in peat.
	2: Groundnuts, vegetables, tobacco	Slope: 0 to 5 degrees, with conservation to 10 degrees. Drainage: very well to moderately well. Flooding: none. Effective soil depth: deeper than 50 cm (20 inches), some vegetables require minimum of 75 cm (30 inches). Soil texture: excluding sands and heavy clays. Depth of surface peat: less than 50 cm (20 inches); some vegetables could thrive on a depth of over 120 cm (48 inches) provided peat is well humified and with acceptable base status. Depth to acid sulphate layer: deeper than 75 cm (30 inches). Workability: less than 25 per cent of surface stones and rocks.
	3: Rice (dry land)	Slope: 0 to 5 degrees, with conservation to 15 degrees. Drainage: well to imperfect. Flooding: not applicable. Effective soil depth: deeper than 60 cm (24 inches). Soil texture: heavier than loam, but excluding heavy clays. Depth of surface peat: not applicable. Depth to acid sulphate layer: not applicable. Workability: less than 25 per cent of surface stones and rocks. Note: Due to its lower yields and the accelerated erosion hazard, this type of rice cultivation should gradually be phased out, and the acreage of wet land rice increased.
	4: Tapioca, yams, sweet potatoes, ginger, turmeric	Slope: 0 to 5 degrees, with conservation to 10 degrees. Drainage: very well to imperfect. Flooding: none. Effective soil depth: deeper than 60 cm (24 inches). Soil texture: excluding sands and heavy clays. Depth of surface peat: less than 50 cm (20 inches) if peat well humified and with high base status over 50 cm (20 inches). Depth to acid sulphate layer: deeper than 75 cm (30 inches). Workability: less than 25 per cent of surface stones and rocks.
	5: Pulses, soya beans, maize, sorghum, chillies	Slope: 0 to 5 degrees, with conservation to 10 degrees. Drainage: very well to imperfect. Flooding: none. Effective soil depth: deeper than 50 cm (20 inches). Soil texture: excluding loamy sand and lighter textures, and heavy clays. Depth of surface peat: less than 50 cm (20 inches). Depth to acid sulphate layer: deeper than 75 cm (30 inches). Workability: less than 25 per cent of surface stones and rocks.
Semi-perennial crops	6: Grasses (pasture)	Slope: 0 to 15 degrees, to 20 degrees only after successful trials. Drainage: no restrictions as a wide range of adaptable grass species could be available. Flooding: infrequent and of short duration, but could be frequent in certain topographic positions. Effective soil depth: deeper than 50 cm (20 inches). Soil texture: no restrictions as a wide range of adaptable grass species could be available. Depth of surface peat: less than 50 cm (20 inches). Depth to acid sulphate layer: deeper than 50 cm (20 inches). Workability: less than 50 per cent of surface stones and rocks.
	7: Grasses (fodder), lemon grass(1), citronella grass(2), vetiver grass(3)	Slope: 0 to 5 degrees, with conservation to 15 degrees. Drainage: very well to imperfect. Flooding: infrequent and of short duration. Effective soil depth: deeper than 50 cm (20 inches). Soil texture: excluding loamy sand and lighter textures. For vetiver grass heavy clays excluded. Depth of surface peat: less than 25 cm (10 inches). Depth to acid sulphate layer: deeper than 50 cm (20 inches). Workability: less than 25 per cent of surface stones and rocks. Note: (1) *Andropogon nardus* L. var. *flexuosus* Hack. (2) *Andropogon nardus* L. var. *genuinus* Hack. (3) *Andropogon zizanoides* Urban
	8: Banana, sugar cane, ramie, papaya	Slope: 0 to 10 degrees, with conservation to 15 degrees. Drainage: very well to moderately well. Flooding: none for ramie and papaya; infrequent and of short duration for banana and sugar cane. Effective soil depth: deeper than 60 cm (24 inches).

TABLE 5.9 (cont'd)

Main group	Crops and crop groups	Soil and terrain criteria
Semi-perennial crops	8: (cont'd)	Soil texture: excluding loamy sand and lighter textures. Depth of surface peat: less than 25 cm (10 inches). Depth to acid sulphate layer: deeper than 75 cm (30 inches). Workability: less than 25 per cent of surface stones and rocks.
	9: Pineapple	Slope: 0 to 10 degrees. Drainage: very well to imperfect. Flooding: none. Effective soil depth: deeper than 25 cm (10 inches) if well drained. Soil texture: excluding medium and coarse sand and heavy clays. Depth of surface peat: deep peats allowed if drained, well humified and with high base status. Depth to acid sulphate layer: deeper than 50 cm (20 inches). Workability: less than 25 per cent of surface stones and rocks, few submerged timbers in peat.
Perennial crops	10: Cocoa, pepper, citrus, avocado (Persea americana), mangosteen (Garoinia mangostana), mango (Mangifera indica)	Slope: 0 to 25 degrees, above 10 degrees with conservation. Drainage: well and moderately well. Flooding: none for pepper, but infrequent and of short duration for cocoa, citrus, avocado, mangosteen and mango. Effective soil depth: deeper than 75 cm (30 inches). Soil texture: excluding loamy sand and lighter textures. Citrus, light textured soils and clay soils excluded. For pepper; heavy clays, such as Kabuloh family soils exeluded. Depth of surface peat: less than 50 cm (20 inches). Depth to acid sulphate layer: deeper than 100 cm (40 inches). Workability: less than 25 per cent of surface stones and rocks.
	11: Oil palm, Coffee (Robusta and Libarica), arecanut, rambutan, nutmeg, cloves, cinnamon	Slope: 0 to 25 degrees, above 10 degrees with conservation; due to managerial demands oil palm is regarded as marginal on slopes between 20 and 25 degrees, there are however no adverse effects to growth or yield. Drainage: well and moderately well. Flooding: none, for oil palm flooding up to one week would be acceptable, but coffee for shorter periods. Effective soil depth: deeper than 60 cm (24 inches). Soil texture: excluding sandy loam and lighter textures. Depth of surface peat: less than 50 cm (20 inches). Depth to acid sulphate layer: deeper than 100 cm (40 inches). Workability: less than 50 per cent of surface stones and rocks.
	12: Rubber, tea, Brazil nut, guava, durian, anatto (Bixa orellana)	Slope: 0 to 25 degrees, above 10 degrees with conservation. Drainage: very well to imperfect. Flooding: infrequent and of short duration. Effective soil depth: deeper than 60 cm (24 inches). Soil texture: excluding sandy loam and lighter textures. Depth of surface peat: less than 75 cm (30 inches) for rubber and tea 100 cm (40 inches), provided peat is well humified and with acceptable base status. Depth to acid sulphate layer: deeper than 100 cm (40 inches). Workability: less than 50 per cent of surface stones and rocks.
	13: Coconut, cashew nut	Slope: 0 to 25 degrees, above 10 degrees with conservation. Drainage: very well to imperfect. Flooding: infrequent and of short duration. Effective soil depth: deeper than 50 cm (20 inches). Soil texture: no restriction. Depth of surface peat: less than 75 cm, deeper if peat well humified and of acceptable base status. Depth to acid sulphate layer: deeper than 75 cm (30 inches). Workability: less than 50 per cent of surface stones and rocks.
Forest	14: Illipe nut (Enkabang rusa, Shorea stenoptera, Burck, var.), bamboo, forest plantations, forest under controlled exploitation with regeneration	Slope: 0 to 30 degrees. Drainage: very well to imperfect. Flooding: infrequent. Effective soil depth: deeper than 50 cm (20 inches). Soil texture: no restriction but for sand and loamy sand suitable tree species would have to be selected. Depth of surface peat: no restriction for Shorea alba; Mixed Dipterocarp Forest less than 200 cm (80 inches); bamboo and illipe nut less than 75 cm (30 inches). Depth of acid sulphate layer: deeper than 100 cm (40 inches), not applicable to mangrove species. Workability: not applicable.
	15: Sago	Slope: 0 to 5 degrees. Drainage: poor and very poor. Flooding: no restrictions. Effective soil depth: deeper than 50 cm (20 inches). Soil texture: excluding loamy sand and lighter. Depth of surface peat: less than 50 cm (20 inches). Depth to acid sulphate layer: deeper than 50 cm (20 inches). Workability: not applicable.
	16: Forest and other reserves	No restrictions.

criteria have been set at the lowest level of acceptability: that is where crops can still maintain an acceptable level of yield. The table has been simplified by grouping crops with similar demands on terrain and soils. Crop groups with the same growing period have also been combined.

The terrain and soil conditions listed in the Table have been adapted to the less favourable environmental conditions in Sarawak and it must be stressed again that many of the criteria would reflect marginal conditions to plant growth and crop yield in other parts of South East Asia. For instance a slope of up to 10 degrees for the cultivation of groundnuts, vegetables and tobacco can hardly be called a generous criterion, nor is a soil depth of 75 cm (30 inches) for cocoa, pepper and citrus. The consequence of the lowering of the soils and terrain criteria is that a greater demand will be placed on management practices.

The criteria used are those for soils in their natural state; therefore human interference has been ignored. The range of crops listed in Table 5.9 has been selected on the basis of their climatic adaptability with no consideration for their economic feasibility. It is not claimed that all the climatically adaptable crops have been included in the Table.

APPENDIX I

APPENDIX I

TABULATED CLIMATOLOGICAL AND HYDROLOGICAL DATA

I.1 EXISTING CLIMATOLOGICAL AND HYDROLOGICAL DATA

General Climate

Selected climatological elements are published by the Malaysian Meteorological Service in the form of an Annual Climatological Summary. These elements are listed in Table I.1.1. During the Study, Summaries were available for the years up to and including 1968. The Malaysian Meteorological Service also prepares monthly abstracts in a less detailed format. These contain the elements which are listed in Table I.1.2. During the hydrological studies, these monthly abstracts were available for the months up to and including October 1973.

Rainfall

Monthly rainfall totals for the period up to 1957 have been published (Department of Civil Aviation, 1958). The Hydrology Branch now acts as a central pool for all Sarawak rainfall data. With effect from July 1962 daily rainfall figures for most stations have been regularly published in the Hydrological Yearbooks of the Drainage and Irrigation Department. At present this series covers the period up to December, 1971. Later figures have been made available when requested.

For the years between 1957 and 1962 the only published rainfall data is that for Meteorological Stations. However, the records for this period are available at the Headquarters of the Drainage and Irrigation Department in Kuching. Also all available monthly figures for stations in the Study Area were assembled on the Study office files.

There are at present few autographic rain gauges in Sarawak. Reasonably long-term records are available for the meteorological stations at Miri and Bintulu. Maximum rainfalls for variable durations in the period 1953-1964 have been published (Meteorological Service Singapore, 1965) but the individual annual maxima for this period are not available. Since July 1962, annual maxima 1, 3 and 24 hour rainfall for Miri and Bintulu have been published in the Sarawak Hydrological Yearbooks.

As indicated in Figure 1.3, intermittent autographic data are available for Marudi, Long Lama and Nyabau, but the incomplete nature of these records reduces their value.

Evaporation

The standard evaporation instrument in Sarawak is the American Class A evaporation pan. With the co-operation of the Meteorological Service, the Hydrological Section installed Class

TABLE I.1.1 ELEMENTS PUBLISHED IN THE ANNUAL CLIMATOLOGICAL SUMMARIES OF THE MALAYSIAN METEOROLOGICAL SERVICE

Pressure

Monthly mean 07 hours pressure

Temperature

Monthly mean 08, 14 and 20 hours, mean for 24 hours
Monthly mean maximum and minimum
Monthly highest maximum and date
Monthly lowest minimum and date
Monthly mean hourly temperature from autographic records
Monthly number of days with temperature in various ranges

Relative humidity

Monthly mean 08, 14 and 20 hours, mean for 24 hours
Monthly mean hourly relative humidity from autographic records

Rainfall

Monthly total
Greatest day's fall in month and date
Number of days in month rainfall exceeded .01, 0.5 and 2.0 inches
Number of rain days in month
Monthly totals of rain by hours as registered by autographic rain gauge

Cloud

Monthly mean cloud in oktas at 08, 14 and 20 hours

Sunshine

Monthly mean sunshine duration
Monthly mean hourly sunshine duration

Wind

Monthly percentage frequency and mean velocity of wind from the various directions
Monthly number of hours with wind speed in various ranges

General weather

Monthly number of days with hail, thunder, fog, overcast or blue sky

TABLE I.1.2 ELEMENTS PUBLISHED IN THE MONTHLY ABSTRACTS OF THE MALAYSIAN METEOROLOGICAL SERVICE

Pressure

Daily mean pressure

Temperature

Daily maximum, mean and minimum temperature

Relative humidity

Daily mean relative humidity

Rainfall

Daily total

Sunshine

Daily total

Wind

Daily mean speed
Speed and direction of highest gust each day

Evaporation

Monthly total Class A pan evaporation (if available)

Note: Daily mean values of temperature and relative humidity are based on 24 hourly values from autographic records.

A evaporation pans at Miri and Bintulu meteorological stations in April and March 1963 respectively. In the Fourth Division, but outside the Study Area, a pan was operated at Long Akah (April-June 1963) and more recently at Bario (September 1971) but these records are at present too short to be of value. Daily records from the Hydrological Section stations are published in the Hydrological Yearbooks.

Rivers

The locations of Government river gauging stations in the Fourth Division, and the type and extent of their records are shown in Figure 1.4. At the outset, following the establishment of the Hydrological Sections, it was intended to collect hydrological data for all general development needs (1962/63

Hydrological Yearbooks, Introduction). The overall plan behind the hydrological network was however not elaborated. It appears that most of the stations were essentially single purpose. With the separate creation of the State Drainage and Irrigation Departments in January 1967, new stations after that date tended to be more exclusively orientated towards Drainage and Irrigation projects.

The main headings under which river gauging stations have been operated are summarised below. These are not based on any official plan, but represent the Study's assessment. These headings are also noted in the bar chart of Figure 1.4.

(a) Drainage Studies

Eight of the nineteen stations shown in Figure 1.4 are essentially connected with drainage schemes. They are concentrated in the lower Sungai Sibuti (Paya Selanyau Scheme) and lower Sungai Niah basins. They are all unrated stations, recording levels only, and many are tidal. Records from these stations will have been used in Departmental studies of the drainage schemes in those areas, but have not been used in the Consultants' studies.

(b) Bridge Site Investigations

Gauges 4-14, 4-15 and 4-16 were established on the Sungai Sibuti, Sungai Niah and Batang Suai near the proposed crossing points of the Miri-Bintulu road. The main purpose of these guages was to provide flood level information for the eventual design of permanent bridges over these rivers. This was also part of the purpose of the gauge on the Sungai Sibiu (4-12).

(c) Port Investigations

The main purpose of the tide gauge at Kuala Baram (4-1) was the hydraulic investigations of the Kuala Baram area as part of the investigation of the possibility of establishing a deep water port at Kuala Baram.

(d) Hydro-electric Investigations

A preliminary study of hydro-electric potential in Sarawak (Snowy Mountains Authority, 1962) identified a number of potentially feasible hydro-electric developments on the major rivers of Sarawak including the Batang Baram. Following from this, gauging stations were established on the Batang Baram and its tributaries, the Batang Tinjar and Sungai Tutoh. In due course, these records will be invaluable. However, major hydro-electric schemes do not enter into development programmes in the period covered by this report, and the records from the stations in the Baram basins have been used as background information only in the present studies.

(e) Water Supply Investigations

This area of investigation has been perhaps worst served by the existing hydrological network, although at the present level of development this has not been of great consequence. Other than on the large rivers where quantity is not a problem, discharge measurements have in the past been made at four stations (4-12, 4-14, 4-15 and 4-16). However, at two stations (4-14 and 4-15) the gauge height record proved insufficiently reliable to be used, and at 4-16 there was no continuous gauge height record. It was therefore possible for the Study to construct a daily discharge record only for station 4-12 on the Sungai Sibiu. At the other stations effectively only spot discharge measurements were available.

Daily gauge height and, where available, discharge figures are published in the Sarawak Hydrological Yearbooks. Records for the Sungai Sibiu (station 4-12, Figure 1.4), which were worked up by the Study, are given in Tables I.1.3 and I.1.4 and the rating curve used shown in Figure I.1.1. The flows are based on published daily gauge heights.

TABLE I.1.3 SUNGAI SIBIU AT MILE 6, DISCHARGE MEASUREMENTS MADE FROM 20-12-66 TO 18-8-68

Measurement No.	Date	Gauge height	Discharge	Cross-section	Mean velocity	Defining rating curve No.
		Feet	Cusecs	Square feet	Feet per second	
1	20-12-66	13.65	1 360	574	2.37	1
2	21-12-66	15.5	1 590	708	2.25	1
3	21-12-66	15.42	1 580	733	2.15	1
4	21-12-66	15.30	1 530	669	2.29	1
5	11-3-67	13.0	1 300	570	1.99	1
6	11-3-67	13.15	1 330	559	2.38	1
7	12-3-67	14.05	979	645	1.52	1
8	12-3-67	13.85	1 600	618	2.58	1
9	12-3-67	13.50	1 030	619	1.67	1
10	13-3-67	13.20	1 360	596	2.29	1
11	13-3-67	13.12	1 370	585	2.34	1
12	17-8-68	6.1	302	218	1.39	1
13	17-8-68	6.0	290	214	1.35	1
14	17-8-68	5.9	264	212	1.25	1
15	18-8-68	5.6	216	199	1.09	1
16	18-8-68	5.5	232	194	1.20	1

Note: Measurements made by Hydrology Branch, Drainage and Irrigation Department; data from file at DID Headquarters, Kuching.

TABLE I.1.4.1

SUNGAI SIBIU
MEAN DAILY DISCHARGE IN CUSECS - 1967

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	996			196	185	162	159	147	132	720	352	1 062
2	1 110			159	741	150	153	138	123	317	263	734
3	982			132	867	138	141	132	117	337	468	357
4	727			141	322	138	138	122	107	400	372	221
5	1 712			389	206	129	130	129	112	337	241	1 078
6	657		478	221	159	127	125	138	120	254	462	1 734
7				159	150	189	117	122	127	213	259	2 044
8	127			293	150	416	127	122	112	175	292	2 316
9	1 204			272	246	217	117	127	107	221	217	1 756
10	1 110			185	196	162	115	132	102	213	192	389
11			1 380	144	168	162	112	125	182	217	225	203
12			1 204	127	150	144	115	141	162	203	206	182
13			1 186	229	138	853	636	156	112	192	178	138
14			327	282	144	1 778	590	127	112	272	221	122
15	433		250	199	1 450	815	484	110	444	389	927	138
16	1 778		203	150	532	292	2 215	102	875	250	1 070	153
17	3 025		221	156	233	277	2 499	107	378	196	520	150
18	4 798		433	564	182	282	1 756	217	196	182	450	210
19	6 650		444	1 249	1 240	1 530	422	456	322	153	734	1 480
20	5 075		217	657	890	2 433	225	225	196	153	456	713
21	3 410		196	259	890	2 008	1 054	352	213	153	264	551
22	1 231		203	203	263	2 303	671	282	264	159	233	526
23	2 277		210	199	770	808	372	203	372	203	221	1 054
24	2 381		171	292	433	273	273	165	221	246	214	508
25	1 668		147	185	270	237	214	168	178	203	264	307
26	162		138	182	671	221	200	182	357	185	357	217
27			138	178	454	221	185	159	974	196	362	544
28			130	185	272	225	171	127	706	210	720	332
29	935		127	210	221	200	185	135	337	502	450	508
30	1 440		138	203	189	185	192	129	837	416	337	322
31	1 267		175		168		171	138		189		277
Total cusecs days				8 000	12 950	17 075	14 064	5 115	9 434	8 056	11 864	20 326
Mean cusecs				267	418	569	454	165	314	260	395	656
Mean cumecs				7.55	11.8	16.1	12.8	4.67	8.88	7.35	11.1	18.6
Mean m.g.d.				144	225	306	244	88.8	169	140	213	353
Runoff mm				126	204	268	221	81	149	127	237	320
Runoff in				4.96	8.03	10.58	8.72	3.17	5.85	4.99	9.35	12.60
Peak cumecs				35.4	35.1	68.9	70.8	12.9	27.6	20.4	30.3	65.6

Catchment area = 155 sq. km = 60 sq. miles

TABLE I.1.4.2

SUNGAI SIBIU
MEAN DAILY DISCHARGE IN CUSECS - 1968

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	241	132	99	422	1 249	342	297	147	217	268	3 180	141
2	1 178	114	95	603	1 430	217	237	135	199	217	2 843	153
3	433	272	91	307	609	1 857	225	122	225	159	2 008	127
4	422	272	81	192	268	1 603	241	141	210	250	551	159
5	770	210	95	268	178	496	590	383	175	538	450	433
6	450	144	91	217	162	383	411	357	168	292	1 880	229
7	263	165	109	153	144	307	268	1 054	182	317	1 712	1 195
8	233	327	109	307	141	433	217	636	171	1 480	1 400	577
9	192	178	109	362	159	1 734	175	570	168	990	332	259
10	213	127	127	225	217	912	165	711	117	741	302	213
11	182	147	117	162	159	378	245	272	93	538	175	1 675
12	159	127	89	229	1 054	322	322	168	427	478	144	699
13	153	127	99	206	1 006	337	268	168	433	427	127	347
14	153	123	81	210	692	272	245	287	347	427	122	1 152
15	272	127	119	307	245	268	175	1 086	259	400	129	352
16	800	112	95	357	456	2 068	141	741	233	456	127	282
17	1 030	104	87	282	322	852	117	254	297	268	210	282
18	332	102	129	233	245	367	171	199	427	444	342	422
19	317	102	357	203	171	250	373	192	357	302	229	570
20	245	97	159	664	210	199	1 613	168	317	168	307	484
21	217	91	177	307	159	178	1 635	147	259	122	268	411
22	165	107	664	206	127	189	982	127	317	490	307	741
23	153	99	692	400	117	159	570	95	259	1 070	394	1 332
24	150	97	777	182	119	122	196	112	282	1 144	713	1 400
25	144	407	520	150	196	112	217	162	153	1 679	342	1 390
26	144	93	670	132	657	112	203	192	189	1 880	250	596
27	132	164	1 915	199	1 520	156	150	150	259	490	175	307
28	135	153	1 800	389	1 592	127	206	119	347	383	156	241
29	122	150	1 778	785	1 961	127	153	122	352	141	138	225
30	124		250	741	1 550	394	162	124	302	2 355	122	860
31	114		225		727		153	122		2 567		643
Total cusecs days	9 638	4 110	11 706	9 400	17 842	15 273	11 123	8 963	7 741	22 081	19 435	17 897
Mean cusecs	311	142	378	313	576	509	359	289	258	712	648	577
Mean cumecs	8.80	4.02	10.7	8.86	16.3	14.4	10.2	8.18	7.30	20.1	18.3	16.3
Mean m.g.d.	167	76.4	203	168	310	274	193	155	139	383	349	310
Runoff mm	152	65	184	148	281	241	175	141	122	348	306	282
Runoff in	5.97	2.55	7.26	5.83	11.06	9.47	6.89	5.56	4.80	13.69	12.05	11.09
Peak cumecs	33.4	11.5	54.2	22.2	55.5	58.6	46.3	30.8	12.3	72.7	90.0	47.4

Catchment area = 155 sq. km = 60 sq. miles

TABLE I.1.4.3

SUNGAI SIBIU
MEAN DAILY DISCHARGE IN CUSECS - 1969

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	416	141	389	378	830	119	206	83	2 594	185	400	852
2	342	129	254	178	422	124	150	129	990	570	241	395
3	400	147	127	156	720	138	233	138	272	182	629	958
4	785	104	119	127	416	292	192	93	268	175	362	734
5	762	87	112	119	189	225	203	83	203	199	241	400
6	322	77	99	117	138	237	210	75	185	250	427	1 285
7	206	69	97	144	135	245	217	83	272	1 086	792	1 070
8	182	67	97	127	122	210	297	77	221	570	1 490	734
9	175	71	95	217	570	147	590	91	171	438	2 080	438
10	165	162	105	263	1 204	221	250	91	144	532	1 846	636
11	122	122	129	245	282	199	643	85	132	1 222	860	590
12	462	317	860	168	882	182	538	127	124	538	1 276	974
13	1 603	520	590	150	1 712	317	342	132	124	307	905	1 285
14	927	322	317	138	1 054	192	213	119	119	332	657	1 984
15	332	229	312	122	229	297	312	144	114	268	1 361	1 943
16	337	159	250	132	189	2 394	268	150	199	259	1 470	1 624
17	347	122	233	117	156	2 580	438	203	175	287	1 152	438
18	210	124	196	544	196	1 811	282	144	150	229	643	352
19	182	135	127	629	165	596	272	405	119	217	462	322
20	162	852	122	352	185	272	583	400	114	383	367	456
21	138	1 186	104	217	259	225	650	250	114	259	307	1 490
22	124	292	129	770	254	189	357	830	322	678	254	2 634
23	93	210	185	713	196	185	210	383	307	427	317	1 624
24	77	182	199	312	185	162	147	389	259	337	263	557
25	95	153	250	297	165	141	127	551	250	233	263	1 520
26	112	129	400	254	438	135	114	490	263	196	287	1 490
27	241	132	277	196	347	124	112	317	268	192	282	875
28	450	1 135	770	352	250	141	107	352	272	196	297	720
29	268		263	168	153	156	225	1 571	210	389	411	450
30	117		175	643	141	124	89	2 621	192	2 164	762	307
31	138		144		129		81	2 394		860		570
Total cusecs days	10 292	7 375	7 526	8 345	12 313	12 380	8 658	13 000	9 147	14 160	21 104	29 713
Mean cusecs	332	263	243	278	379	413	279	419	305	457	703	958
Mean cumecs	9.40	7.44	6.88	7.88	10.7	11.7	7.20	11.9	8.63	12.9	19.9	27.1
Mean M.G.D.	179	141	131	150	204	222	150	225	164	246	378	515
Runoff mm	162	116	118	131	194	195	136	205	144	223	332	469
Runoff in	6.38	4.57	4.66	5.17	7.63	7.67	5.37	8.06	5.67	8.78	13.08	18.47
Peak cumecs	45.4	33.6	24.4	21.8	48.5	73.1	18.4	74.2	73.5	61.3	58.9	74.6

Catchment area = 155 sq. km = 60 sq. miles

TABLE I.1.4.4

SUNGAI SIBIU
MEAN DAILY DISCHARGE IN CUSECS - 1970

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	807	297	114	213	292	2 621	1 440	347	168	317	254	292
2	383	272	112	213	508	2 553	1 323	203	478	203	221	468
3	277	233	112	292	302	2 056	564	168	474	210	225	1 231
4	2 092	372	117	196	322	2 290	394	225	292	233	468	845
5	2 164	1 078	119	207	213	2 189	422	178	213	372	272	405
6	950	1 915	119	250	189	2 368	287	185	317	1 258	282	456
7	692	1 380	394	822	175	2 420	268	974	217	882	520	405
8	643	557	438	367	168	685	225	1 267	233	596	822	367
9	998	277	422	277	564	327	213	950	367	427	322	277
10	622	245	292	282	685	241	213	352	416	433	287	245
11	332	217	237	830	297	206	192	890	237	636	438	213
12	400	210	210	1 592	189	175	159	1 078	277	583	367	192
13	332	203	178	1 332	185	168	156	713	277	433	327	221
14	317	192	196	1 520	171	153	156	508	207	616	327	221
15	1 078	171	942	1 480	175	144	159	897	277	272	307	206
16	1 361	194	622	807	162	141	150	438	1 582	229	322	213
17	622	150	250	367	150	182	144	609	462	213	678	352
18	332	147	307	259	138	213	159	912	268	671	468	357
19	322	144	263	912	206	210	150	636	217	927	287	622
20	307	144	192	1 603	144	138	327	337	203	762	400	496
21	297	132	322	2 056	182	117	352	241	196	337	792	450
22	807	124	416	1 903	182	112	287	185	203	217	1 380	317
23	770	122	312	1 144	168	109	196	185	777	905	1 723	268
24	400	114	189	713	389	109	203	182	867	867	650	225
25	322	119	150	468	378	112	196	178	342	268	307	1 869
26	292	114	111	462	217	210	168	153	217	225	456	1 857
27	416	114	221	302	400	966	317	750	203	468	468	1 204
28	378	119	416	287	526	1 118	217	150	189	462	352	748
29	312		770	352	282	282	297	259	182	462	302	367
30	259		307	254	807	229	277	165	182	287	282	263
31	245		206		734		196	182		389		734
Total cusecs days	19 529	9 306	9 116	21 762	9 500	22 844	9 807	13 897	10 540	15 160	14 306	16 386
Mean cusecs	630	332	294	725	306	761	316	448	351	489	477	529
Mean cumecs	17.8	9.40	8.32	20.5	8.66	21.5	8.94	12.7	9.93	13.8	13.5	15.0
Mean M.G.D.	339	179	158	390	165	409	170	241	189	263	257	285
Runoff mm	307	146	144	343	150	360	154	219	166	239	225	258
Runoff in	12.10	5.76	5.65	13.49	5.89	14.16	6.08	8.61	6.53	9.40	8.87	10.16
Peak cumecs	61.3	54.2	26.7	58.2	22.8	74.2	37.5	35.9	44.8	35.6	48.8	52.9

Catchment area = 155 sq. km = 60 sq. miles

TABLE I.1.4.5

SUNGAI SIBIU
MEAN DAILY DISCHARGE IN CUSECS - 1971

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1 701	720	317	178	135	322				206	1 022	656
2	1 380	1 450	307	958	132	199				203	383	544
3	1 294	1 657	292	622	132	807				229	282	458
4	1 118	1 440	268	389	141	422				411	245	389
5	603	792	225	664	171	302				352	237	1 528
6	416	1 046	237	444	141	196				277	367	1 440
7	433	1 892	221	352	196	692				196	456	603
8	394	2 008	210	213	168	347				162	1 603	347
9	389	5 561	199	302	156	241				144	1 603	322
10	352	5 417	206	400	147	357				138	882	1 144
11	302	3 768	168	433	141	322				135	484	1 249
12	263	1 915	150	268	138	199				182	352	882
13	664	577	141	250	138	182				532	287	526
14	302	394	144	175	144	171				508	245	433
15	254	347	147	168	138	199				263	282	394
16	217	1 361	150	159	132	282				250	603	383
17	206	912	150	153	132	263				241	400	1 249
18	185	800	150	156	129	317				233	327	875
19	178	734	156	150	127	221				213	394	557
20	175	727	144	153	127	178				221	603	1 846
21	171	590	144	147	124	175				250	748	2 446
22	206	544	147	150	127	165				312	1 213	966
23	178	478	233	153	129	141				450	1 010	557
24	175	357	272	156	132	135				347	882	1 592
25	576	1 285	302	236	138	138				372	762	1 213
26	1 276	1 267	277	206	162	138				629	2 316	450
27	2 394	800	259	153	203	144				762	2 008	277
28	2 486	378	210	144	287	144				1 062	1 490	250
29	2 607		199	132	272	159				692	882	411
30	1 972		182	132	259	150				383	875	1 222
31	1 938		182		189					1 430		1 240
Total cusecs days	24 755	39 217	6 389	8 196	4 887	7 708				11 785	23 310	26 419
Mean cusecs	799	1 401	206	273	158	257				380	777	852
Mean cumecs	22.6	39.6	5.83	7.73	4.47	7.27				10.8	22.0	24.1
Mean M.G.D.	430	754	111	147	85	138				204	418	458
Runoff mm	389	615	101	129	77	121				185	367	416
Runoff in	15.3	24.2	3.96	5.08	3.03	4.78				7.30	14.45	16.37
Peak cumecs	73.8	157	8.98	27.1	8.13	22.9				40.5	65.6	69.3

Catchment area = 155 sq. km = 60 sq. miles

SUNGAI SIBIU — STATION 4-12
RATING CURVE No. I (PERIOD 1966–1971)

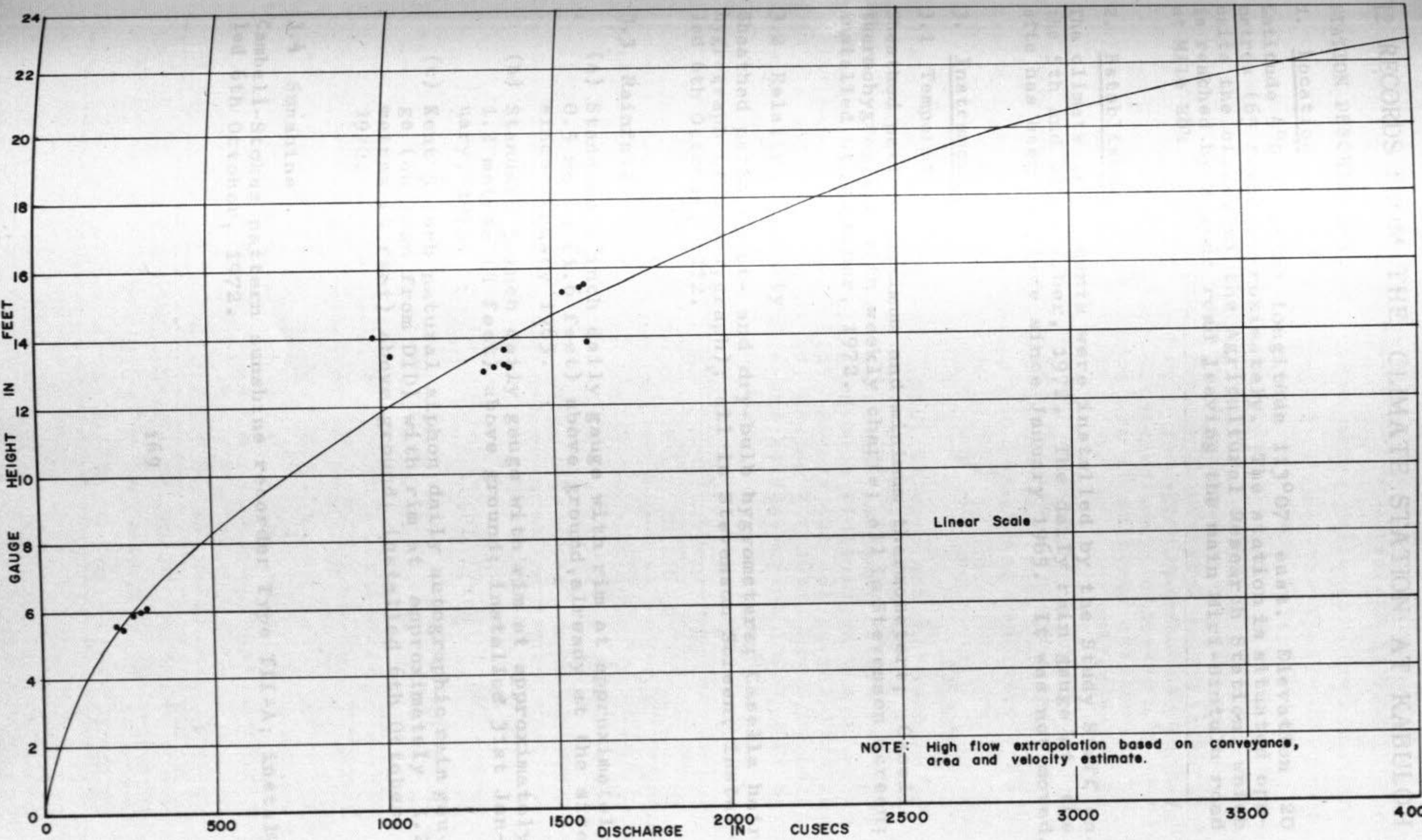


FIGURE I.I.I

12 RECORDS FROM THE CLIMATE STATION AT KABULOH

STATION DESCRIPTION

1. Location

Latitude 4°07' north; longitude 113°07' east. Elevation 20 metres (65 feet) approximately. The station is situated opposite the office of the Agricultural Research Station, which is reached by a spur road leaving the main Miri-Bintulu road at Mile 28½.

2. Establishment

The climate instruments were installed by the Study Staff on the 5th and 6th October, 1972. The daily rain gauge at the site has been in place since January 1965. It was not moved.

3. Instruments

3.1 Temperature

Sheathed pattern maximum and minimum thermometers; Casella thermohygrograph with weekly charts; all in Stevenson Screen; installed 6th October, 1972.

3.2 Relative Humidity

Sheathed pattern wet- and dry-bulb hygrometers; Casella hair hygrograph (thermohygraph); all in Stevenson Screen; installed 6th October, 1972.

3.3 Rainfall

(a) Standard 5 inch daily gauge with rim at approximately 0.5 metre (1.6 feet) above ground, already at the site since January 1965.

(b) Standard 5 inch daily gauge with rim at approximately 1.2 metres (4 feet) above ground; installed 31st January, 1973.

(c) Kent 5 inch natural siphon daily autographic rain gauge (on loan from DID) with rim at approximately 1.2 metres (4 feet) above ground; installed 6th October, 1972.

3.4 Sunshine

Cambell-Stokes pattern sunshine recorder Type III-A; installed 6th October, 1972.

3.5 Incoming Radiation

RIMCO-CSIRO integrating pyranometer; installed 6th October, 1972.

3.6 Wind

Munro cup-counter anemometer type IM119 reading in kilometres cup axis set at 2 metres (6.6 feet) above ground level; installed 6th October, 1972.

3.7 Evaporation

American Class A evaporation pen (locally manufactured) with hook gauge and still-well; standard exposure; installed 6th October, 1972.

4. Exposure

The exposure at the site is good. The Experimental Station provides a wide area clear of tall trees, particularly to the east and west. Sunshine and radiation records are not affected by any appreciable screening of the horizon. The nearest building is the two storey office of the Experimental Station which is about 7.5 metres (25 feet) high, and 4.0 metres (130 feet) north-east of the climate station enclosure.

TABLE I.2.1 CLIMATOLOGICAL SUMMARY

Detail	1972		1973										Total	Mean	Extreme
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct			
Mean air temperature at 0800 °C	25.3	24.5	24.3	24.2	24.5	25.2	24.5	25.1	24.4	24.4	24.8	24.7	-	24.7	-
Mean air temperature over 24 hours °C	26.3	26.1	26.0	26.4	26.5	26.9	26.3	26.4	26.1	25.9	25.8	26.4	-	26.3	-
Mean maximum temperature A °C	32.1	32.0	32.0	32.4	32.3	32.3	31.9	32.7	32.1	31.4	31.5	31.8	-	32.0	-
Mean minimum temperature B °C	22.9	22.5	22.2	22.8	23.0	24.1	24.2	22.7	22.4	22.5	22.8	22.9	-	22.9	-
Mean of A and B °C	27.5	27.3	27.1	27.6	27.7	28.2	28.1	27.7	27.3	27.0	27.1	27.3	-	27.5	-
Highest maximum °C	33.8	34.2	33.4	35.2	34.3	34.9	34.7	34.6	34.2	34.3	33.1	33.3	-	-	35.2
Date	14	31	18	23	10	14	19	16/17	21	27	16	15	-	-	Feb 23
Lowest minimum °C	21.8	20.2	20.0	20.5	20.5	21.9	20.5	21.5	21.0	21.3	21.5	21.5	-	-	20.0
Date	30	30	28	5	3	11	11	12	7	26	4	4	-	-	Jan 28
Mean relative humidity at 0800 %	90	93	94	94	93	94	94	94	94	94	93	88	-	93	-
Mean relative humidity over 24 hours %	88	88	86	86	86	87	88	87	86	86	87	87	-	87	-
Mean vapour pressure over 24 hours mb	29.9	29.6	28.5	29.1	29.5	30.7	29.8	29.7	29.1	28.7	28.7	29.8	-	29.4	-
Mean saturation deficit over 24 hours mb	4.73	4.77	5.46	5.73	5.63	5.11	4.77	5.22	5.49	5.33	4.99	4.99	-	5.18	-
Mean daily wind run at 2 m km	77.4	70.4	75.1	88.0	94.5	89.3	83.2	77.2	79.6	80.4	91.0	90.9	-	83.0	-
Total rainfall (0800-0800) mm	204	170	37	15	79	325	279	285	254	178	177	271	2 274	189	-
Greatest day's fall mm	42	64	18	9	16	59	54	43	41	48	48	84	-	-	84
Date	5	9	7	8	17	15	6	5	31	24	7	28	-	-	Oct 28
Class A pan evaporation mm/day	4.84	4.73	4.74	5.25	4.73	4.75	4.54	4.30	4.50	4.22	4.79	4.72	1 705	4.67	-
Mean daily sunshine duration hours/day	7.29	7.24	6.97	6.13	4.88	5.80	6.54	6.70	6.79	5.51	5.01	6.18	-	6.25	-
Mean daily global radiation cals/cm²/day	422	430	413	407	396	430	427	429	425	419	427	438	-	422	-
Penman open water evaporation mm/day	4.63	4.69	4.53	4.67	4.72	5.04	4.82	4.84	4.79	4.82	4.95	5.01	-		

1.3 THE STUDY RAINFALL STATIONS AND RECORDS

INTRODUCTION

The locations of the Study rain gauges, the types of gauge and periods of record are shown in Figure 1.5. Details of short-duration rainfall at Kabuloh have been given in Figures 1.14 and 1.15 and in Table 1.2.16. This Appendix gives monthly rainfall at the other six rainfall stations and daily rainfall at four of them. Daily totals are not available for the storage gauges C1 and C4. The monthly totals for these storage gauges have where necessary been adjusted to true months by comparison with totals at adjacent stations.

On the completion of the field work and data reduction, all original gauge readings and autographic rain gauge charts were handed over to the Drainage and Irrigation Department, Kuching.

TABLE I.3.1

STUDY RAINFALL STATION - RUMAH MAMAT
(DAILY TOTALS IN mm)

Latitude: 3°33' north Longitude: 113°38' east Elevation: 20 m

Day	1972 Oct	1972 Nov	1972 Dec	1973 Jan	1973 Feb	1973 Mar	1973 Apr	1973 May	1973 Jun	1973 Jul	1973 Aug	1973 Sep	1973 Oct
1					-	-	0.8	-	12.4	-	5.8	7.1	-
2					0.5	-	38.1	-	10.3	2.5	11.2	-	62.0
3					-	-	10.4	26.4	47.8	17.3	22.6	14.3	5.1
4					-	-	10.7	11.0	-	15.2	-	-	3.3
5					-	-	10.9	15.2	48.3	-	-	4.8	-
6					-	82.3	-	46.9	12.5	0.8	-	14.6	-
7					5.3	-	48.0	9.4	-	13.7	6.9	21.9	-
8					2.8	-	-	-	5.3	31.2	3.8	5.3	-
9					4.3	-	1.0	11.7	5.8	-	59.2	4.1	0.8
10					-	-	32.0	1.8	74.4	-	-	17.3	9.9
11					-	-	15.2	15.4	-	-	1.5	33.0	-
12					-	9.1	0.3	-	-	-	-	0.8	-
13					1.0	4.1	-	8.9	-	-	1.3	-	14.2
14					-	1.3	21.6	3.8	-	8.6	1.0	1.3	1.8
15					-	15.7	8.6	3.8	-	-	3.3	11.4	-
16					25.9	1.3	6.3	-	-	15.8	-	2.4	10.9
17					-	50.5	17.8	28.8	-	-	0.4	2.7	5.1
18				Installed 19th	-	-	7.3	-	3.6	-	9.3	0.8	50.5
19				-	36.1	-	25.4	-	-	-	0.9	3.8	10.9
20				-	1.8	29.2	10.6	33.5	-	-	-	39.5	1.5
21				-	0.5	17.5	3.3	-	15.0	-	2.5	4.6	35.6
22				-	24.9	-	2.0	7.6	-	-	-	19.1	72.6
23				-	10.2	-	16.6	35.1	7.4	-	29.2	-	16.3
24				-	5.6	9.1	-	-	12.0	1.0	16.8	57.4	19.6
25				-	-	-	5.6	15.0	-	2.3	-	0.3	29.7
26				-	12.4	-	27.7	-	6.4	3.3	-	8.4	21.6
27				-	-	-	16.8	5.8	18.3	4.8	-	8.6	4.3
28				7.6	-	-	1.7	11.9	-	14.7	4.6	9.7	-
29				-		4.3	50.0	17.4	60.5	12.9	-	3.2	-
30				-		-	1.0	7.0	6.4	25.2	48.3	-	-
31				-		1.5		3.8		4.3	10.4		65.3
Total					131.3	225.9	389.7	320.3	346.4	170.3	239.0	296.4	441.0

TABLE I.3.2

STUDY RAINFALL STATION - MILE 34, BINTULU
(DAILY TOTALS IN mm)

Latitude: 3°23' north Longitude: 113°27' east Elevation: 80 m

Day	1972			1973									
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1								3.6	3.8	0.3	4.4	-	
2								-	7.0	2.0	3.8	10.3	
3								17.2	60.6	14.2	-	5.7	
4								23.0	-	23.0	1.7	0.3	
5							Installed 5th	31.9	11.7	-	50.9	15.6	
6							-	110.0	57.4	-	31.4	41.9	
7							77.7	1.4	2.3	-	9.1	1.3	
8							-	0.2	-	-	0.9	30.8	
9							5.4	37.8	-	4.7	53.6	1.1	
10							13.1	23.1	49.8	38.7	0.1	0.7	
11							15.1	-	27.8	-	4.8	43.1	
12							6.9	-	1.3	-	-	18.5	
13							-	2.0	-	-	2.2	7.2	
14							6.9	6.0	-	5.0	-	0.9	
15							3.5	12.3	-	-	-	11.5	
16							29.0	-	-	1.6	0.5	5.4	
17							18.6	4.1	-	-	5.0	0.7	
18							15.5	1.6	8.1	0.5	12.0	18.2	
19							17.2	0.9	-	-	0.5	29.1	
20							24.7	2.9	-	41.2	-	7.0	
21							-	6.9	30.5	-	-	10.2	
22							5.9	2.9	4.5	-	-	5.6	
23							23.0	-	11.0	0.5	6.0	1.0	
24							70.8	16.9	-	1.6	25.7	19.4	
25							2.3	0.3	20.5	2.9	-	1.4	
26							-	-	4.5	-	-	7.6	
27							-	3.7	41.3	5.0	0.8	7.0	
28							4.4	3.8	2.8	52.7	3.9	6.7	
29							-	5.2	38.3	6.2	0.4	-	
30							36.3	4.0	18.4	19.9	34.8	-	
31								10.7		5.8	8.1		
Total							-	332.4	401.6	225.8	260.6	308.6	

TABLE I.3.3

STUDY RAINFALL STATION - MILE 18, BINTULU
(DAILY TOTALS IN mm)

Latitude: 3 15' north Longitude: 113 16' east Elevation: 30 m

Day	1972 Oct	1972 Nov	1972 Dec	1973 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1					-	15.5	33.3	-	-	34.3	6.4	31.8	-
2					-	-	-	-	25.4	29.2	3.8	-	7.6
3					-	-	5.3	-	7.6	16.5	3.3	-	19.1
4					23.6	-	26.4	55.1	2.3	-	14.2	12.7	38.1
5					-	14.5	-	5.1	2.0	-	-	28.7	8.9
6					-	26.2	-	27.4	48.3	-	-	25.4	-
7					-	-	6.4	58.9	20.3	-	42.9	7.1	-
8					0.5	-	38.1	21.6	6.4	-	2.8	1.3	9.4
9					-	38.6	22.4	15.5	-	42.7	5.3	12.7	-
10					-	-	9.7	4.1	63.5	-	35.8	2.5	-
11					-	-	3.3	3.6	76.2	-	-	10.9	3.0
12					-	-	17.8	-	1.8	-	-	25.4	-
13					-	38.1	-	-	-	-	2.3	-	-
14					-	-	-	14.0	-	-	-	-	12.7
15					18.5	7.6	63.5	4.3	-	-	-	12.7	12.7
16					22.9	9.9	29.2	2.0	-	-	-	27.4	-
17					0.5	31.8	-	-	-	10.7	-	25.4	19.6
18					1.5	-	5.1	9.1	-	-	2.3	1.5	-
19				Installed 20th	3.6	23.9	4.1	-	16.8	2.3	30.7	1.8	30.5
20				-	28.7	34.3	20.3	-	-	46.7	-	3.8	25.4
21				-	-	28.4	2.8	4.3	-	-	-	1.3	5.1
22				0.5	-	-	11.4	19.1	-	-	-	3.8	17.3
23				-	-	-	30.0	11.4	33.0	-	-	52.6	25.4
24				-	35.8	-	3.0	-	-	-	26.9	2.5	24.9
25				-	6.1	-	-	2.5	7.4	41.7	3.8	-	58.4
26				-	8.1	-	3.3	-	-	-	-	9.4	19.6
27				-	-	-	-	0.8	11.9	29.2	-	11.7	8.6
28				-	-	-	12.7	5.6	15.5	4.6	-	4.8	71.1
29				3.3		1.5	-	4.8	7.9	25.4	12.4	3.6	25.4
30				-		-	35.3	1.5	12.7	13.4	-	-	8.6
31				-		-		-		45.2	-		3.0
Total					149.8	270.3	383.4	270.7	359.0	341.9	192.9	320.8	454.4

TABLE I.3.4

STUDY RAINFALL STATION - MILE 6, BINTULU
(DAILY TOTALS IN mm)

Latitude: 3 14' north Longitude: 113 09' east Elevation: 30 m

Day	1972 Oct	1972 Nov	1972 Dec	1973 Jan	1973 Feb	1973 Mar	1973 Apr	1973 May	1973 Jun	1973 Jul	1973 Aug	1973 Sep	1973 Oct
1					-	-	24.6	-	-	42.9	33.5	-	10.7
2					-	-	8.9	17.3	45.2	-	15.2	-	-
3					-	-	-	-	15.5	-	26.7	-	-
4					28.7	-	42.7	45.2	5.8	21.8	21.3	15.7	2.5
5					-	-	-	15.5	-	12.4	2.3	66.3	-
6					-	34.0	10.9	-	8.1	-	-	45.2	-
7					1.8	47.2	68.8	23.1	15.2	-	5.1	8.6	7.4
8					0.3	-	-	-	25.9	-	-	22.6	-
9					-	25.9	34.8	5.6	4.1	52.8	2.3	-	-
10					-	15.2	-	18.3	50.3	-	-	-	-
11					-	7.9	-	-	42.4	-	20.3	-	-
12					-	-	31.2	12.4	-	-	-	47.2	-
13					-	80.5	15.0	-	-	-	-	-	-
14					47.0	6.1	37.6	9.6	-	15.5	15.2	-	5.8
15					-	53.1	50.0	31.8	-	48.3	-	-	-
16					-	17.3	46.0	-	-	-	-	42.7	26.9
17					6.6	40.9	-	-	5.6	-	-	-	-
18					42.9	59.9	-	6.1	-	75.7	-	-	-
19				Installed 20th	-	18.3	42.4	4.1	-	-	26.9	35.3	
20				-	-	-	16.3	-	40.6	-	-	33.8	
21				1.3	24.4	-	8.1	-	11.7	27.9	-	-	104.4
22				-	-	68.1	-	-	-	-	-	-	
23				-	5.8	-	-	41.1	-	-	-	40.6	
24				-	-	-	17.5	-	-	-	26.9	20.3	
25				-	21.8	2.3	-	-	-	-	-	-	26.9
26				-	7.4	8.1	7.9	16.3	-	17.8	-	-	24.9
27				-	15.5	40.9	-	-	-	-	-	26.9	26.9
28				-	-	-	25.9	5.6	12.7	-	-	24.9	31.5
29				-		-	-	-	-	11.2	-	-	-
30				-		5.3	47.2	24.4	-	26.9	27.6	-	-
31				-		3.8		-		-	37.3		5.3
Total					202.2	534.8	535.8	276.4	283.1	353.2	260.6	430.1	273.2

I.3 THE STUDY RIVER GAUGING STATIONS AND RECORDS

INTRODUCTION

This Appendix contains the records from the Study river gauging stations. The station locations are shown on Figure 1.5. For each station a brief description is given, followed by a table summarising the available discharge measurements and a figure showing the rating curve of curves used. Finally there is a table of daily mean discharge.

All the stations were equipped with water-level recorders, and the daily discharge figures are based on three - hourly mean gauge heights. The reason for this sub-division is that five out of the six instruments were pressure-bulb recorders with a circular chart. For three-hourly periods the time-base of the charts can be taken as linear, which facilitates the reading of mean gauge height.

The base gauge at each station was a staff gauge, and where practicable all recorder traces were corrected so as to agree with staff gauge observations.

Flows for periods when recorders malfunctioned were calculated from staff gauge observations, when available, or were estimated using rainfall data, comparison with adjacent stations and recession curves. It was not possible however to estimate the missing flows for Sungai Kejapil in October 1973 as a large flood occurred towards the end of the month which damaged the installation. The station was not re-opened following this flood as the end of the field work period had been reached.

DESCRIPTION OF RIVER GAUGING STATION

Name: Sungai Liku at Lambir Waterworks

Location: Station C1 on Figure 1.5

Latitude: 4°18' north   Longitude: 114°02' east

Catchment area: 66.2 square kilometres
25.6 square miles

The gauge is at the intake of the Lambir Waterworks. The turnoff to the waterworks is at 8¾ mile Miri-Bintulu Road.

Establishment:

Water level recorder installed by Study staff on 1st November, 1972.

Gauges:

(a) Staff gauge range 34 to 54 feet, part of PWD intake equipment;

(b) Lea float operated weekly water level recorder on loan to the Study from DID. Chart zero set to 34 feet on staff gauge.

History:

No previous flow records. The station was operated by the Study from 1st November, 1972 to 31st October, 1973. During November 1973 it was handed over to the DID.

Channel and control:

The channel bed is sandy and banks steep. Channel alignment appears reasonably stable. Control is channel. It is possible that at very low flows there are backwater effects from swamp areas downstream, though the evidence is at present indecisive. Over-bank flow starts at gauge height 44 feet.

Discharge measurements:

Discharge measurements were made by current meter at a section 180 metres (600 feet) upstream of the gauge. Wading measurements at low and medium flows, boat measurements at high flows.

Regulation and diversion:

The waterworks intake at the gauge abstracts between 50 and 100 l/s (1 and 2 mgd). There are no upstream diversions or regulation. The rating applies to the net flow downstream of the intake and daily discharges are subsequently corrected for abstraction. Daily discharge figures represent natural gross flow.

Accuracy:

Flows up to 6 cumecs (110 mgd) are fair, though there is some uncertainty about very low flows. Further measurements are needed at levels below 36 feet. The high flow rating is tentative being based on a single measurement.

Co-operation:

Daily staff gauge observations and raw water abstraction data were provided by the PWD.

TABLE I.4.1

SUNGAI LIKU AT LAMBIR WATERWORKS
DISCHARGE MEASUREMENTS MADE BY STUDY STAFF FROM 6-11-72 TO 8-10-73

Measurement No.	Date	Gauge height	Discharge (as measured)	Net discharge	Surface width	Cross-section	Mean velocity	No. of vertical sections	Defining rating curve No.
		Metre	Cumecs	Cumecs	Metre	Square metre	Metre per second		
1	6-11-72	37.23	2.07	2.01	11.7	7.98	0.260	21	1
2	21-12-72	36.25	0.934	0.864	10.2	4.74	0.197	19	1
3	30-12-72	36.10	0.779	0.679	10.0	4.05	0.192	18	1
4	9-1-73	36.00	0.714	0.644	10.0	3.84	0.186	17	1
5	13-1-73	35.80	0.515	0.445	9.0	3.14	0.164	16	1
6	26-1-73	35.50	0.389	0.319	9.0	2.51	0.155	15	1
7	2-2-73	35.40	0.369	0.289	9.0	2.37	0.156	15	1
8	9-2-73	35.50	0.394	0.313	9.5	2.62	0.150	15	1
9	6-4-73	37.80	2.27	2.19	12.3	9.57	0.237	19	1
10	11-4-73	43.25	23.4	23.3	16.8	34.2	0.683	10	1
11	28-4-73	39.25	6.12	6.03	13.5	15.8	0.388	26	1
12	4-5-73	37.75	2.78	2.70	12.0	9.08	0.306	23	1
13	25-5-73	36.85	1.43	1.34	11.3	5.79	0.248	21	1
14	31-5-73	37.10	1.57	1.49	12.0	6.58	0.239	21	2
15	8-6-73	37.30	1.84	1.75	11.5	7.19	0.255	22	2
16	22-6-73	36.40	0.823	0.728	10.0	4.05	0.203	19	2
17	10-7-73	37.33	1.838	1.77	11.5	7.05	0.261	21	2
18	10-7-73	37.30	1.756	1.68	11.5	7.12	0.247	21	2
19	17-7-73	36.45	0.787	0.699	10.0	4.41	0.179	19	2
20	24-7-73	36.15	0.561	0.482	8.0	3.91	0.144	16	2
21	2-8-73	38.05	2.25	2.15	13.5	10.0	0.225	24	2
22	8-8-73	38.40	4.44	4.34	13.0	12.7	0.349	12	2
23	13-8-73	38.36	3.02	2.94	12.5	10.8	0.279	24	2
24	24-8-73	36.18	0.641	0.550	9.0	4.39	0.146	16	2
25	27-8-73	36.16	0.650	0.549	9.9	3.23	0.202	19	2
26	10-9-73	38.60	4.14	4.05	13.5	13.4	0.309	26	2
27	17-9-73	37.25	1.58	1.49	12.0	6.99	0.226	22	2
28	24-9-73	36.70	0.914	0.832	10.8	4.89	0.186	20	2
29	1-10-73	36.48	0.758	0.663	10.4	4.35	0.174	19	2
30	8-10-73	37.00	1.16	1.07					2

Note: Due to rounding of figures for publication the calculation of discharge from the quoted area and velocity may not agree exactly with the discharge figure above.

TABLE I.4.2

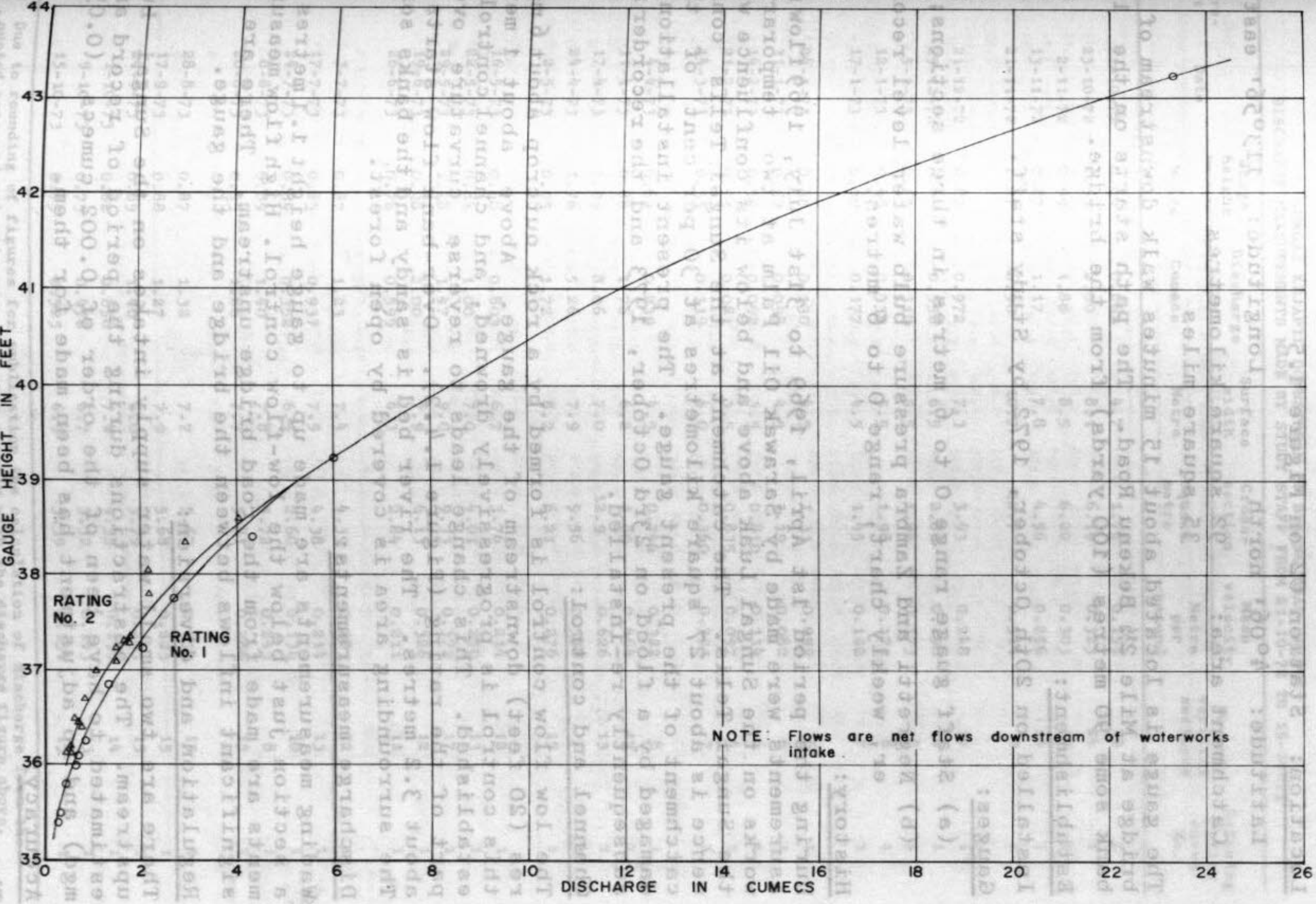
SUNGAI LIKU AT LAMBIR WATERWORKS
MEAN DAILY DISCHARGE IN CUMECS FROM 1-11-72 TO 31-10-73

Day	1972			1973									
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1		1.17	3.03	1.82	0.355	0.333	0.526	1.81	1.31	1.40	4.19	1.07	2.44
2		1.19	11.0	1.61	0.366	0.333	1.23	1.33	7.90	3.24	3.27	0.945	2.30
3		0.957	6.74	1.03	0.375	0.330	1.04	2.66	23.6	2.32	1.62	0.877	2.35
4		0.765	5.56	0.820	0.373	0.439	0.680	3.90	13.8	11.8	2.51	1.64	3.01
5		0.687	2.41	0.717	0.371	0.941	11.1	2.74	3.30	7.53	2.25	0.987	6.29
6		1.50	1.67	0.679	0.364	0.407	3.49	9.55	3.13	5.21	1.00	0.809	4.38
7		1.43	1.42	0.673	0.390	0.366	1.77	16.2	2.32	3.27	0.927	5.67	3.69
8		0.911	1.44	0.802	0.387	0.368	1.83	3.04	1.93	2.03	3.46	29.4	2.85
9		0.764	7.30	0.713	0.392	0.354	1.34	1.91	1.78	2.30	3.10	18.9	2.57
10		0.671	6.95	0.612	0.386	0.342	1.12	2.01	1.43	2.08	1.93	5.02	3.65
11		0.729	2.77	0.575	0.368	0.340	14.0	2.12	4.43	1.49	1.41	2.84	3.29
12		1.34	1.94	0.538	0.348	0.337	6.71	1.82	3.66	1.21	12.8	2.18	2.67
13		1.03	1.45	0.516	0.362	0.338	2.47	1.23	1.93	1.05	5.51	1.71	2.56
14		0.866	1.27	0.516	0.371	0.348	1.81	1.03	1.45	0.951	1.97	1.62	2.46
15		0.779	1.12	0.522	0.359	0.341	2.46	0.954	1.18	0.983	1.29	2.40	2.68
16		0.855	1.00	0.522	0.422	0.343	34.6	0.894	1.05	1.07	1.01	3.15	2.31
17		0.792	0.964	0.493	0.898	1.47	9.78	0.807	0.911	0.827	0.873	1.88	2.42
18		1.71	0.877	0.473	0.488	6.02	25.9	0.737	1.22	0.816	1.65	1.49	2.21
19		1.88	1.20	0.452	0.398	1.87	6.21	1.34	1.42	0.733	1.28	1.27	2.29
20		2.19	1.49	0.456	0.375	1.07	3.41	2.15	1.01	0.680	0.968	1.93	2.46
21		3.56	0.944	0.454	0.366	0.776	2.45	1.47	0.825	0.664	0.849	1.27	2.07
22		4.21	0.965	0.448	0.357	2.27	1.96	1.57	0.755	0.594	0.765	1.09	2.19
23		3.46	0.848	0.430	0.352	1.59	2.63	1.03	0.783	0.597	0.707	1.11	2.14
24		1.63	0.828	0.409	0.333	0.900	2.26	0.859	0.786	0.624	0.643	1.05	4.29
25		3.59	1.65	0.403	0.340	0.710	1.84	1.01	1.06	0.682	0.826	0.964	4.17
26		15.1	2.63	0.383	0.334	0.985	2.09	1.30	7.57	0.648	0.790	0.889	5.39
27		3.15	1.16	0.380	0.333	0.644	4.57	7.84	5.31	0.602	0.647	0.851	8.74
28		2.42	0.905	0.376	0.337	0.670	6.46	5.28	2.04	0.542	0.577	1.09	22.4
29		1.54	0.798	0.367		1.09	2.47	1.91	1.50	0.538	0.540	0.978	8.76
30		2.39	0.790	0.365		0.770	1.96	1.34	1.44	0.819	0.514	1.09	8.95
31			0.711	0.364		0.612		1.48		0.752	0.755		17.5
Total cumecs days		63.27	73.83	18.91	10.90	27.71	160.2	83.32	100.8	58.05	60.63	96.17	145.5
Mean cumecs		2.11	2.38	0.610	0.389	0.894	5.34	2.69	3.36	1.87	1.95	3.21	4.69
Mean M.G.D.		40.1	45.2	11.6	7.39	17.0	101	51.1	63.8	35.5	37.1	61.0	89.1
Runoff mm		82.6	96.3	24.7	14.2	36.2	209	109	132	75.7	79.1	126	190
Runoff in		3.3	3.8	0.97	0.56	1.43	8.2	4.3	5.2	3.0	3.1	5.0	7.5
Peak cumecs		22.4	16.5	3.01	1.32	9.36	44.0	30.1	32.2	(20.0)	(20.0)	41.0	43.9

Catchment area = 66.2 sq. km = 25.6 sq. miles

FIGURE I.4.1

SUNGAI LIKU AT LAMBIR WATERWORKS
RATING CURVES (PERIOD NOVEMBER 1972 — OCTOBER 1973)



DESCRIPTION OF RIVER GAUGING STATION

Name: Sungai Kejapil downstream of Bekenu road bridge

Location: Station C2 on Figure 1.5

Latitude: 4°06' north Longitude: 113°56' east

Catchment area: 92 square kilometres
35 square miles

The gauge is located about 15 minutes walk downstream of the bridge at Mile 2½ Bekenu Road. The path starts on the left bank some 90 metres (100 yards) from the bridge.

Establishment:

Installed on 20th October, 1972 by Study staff.

Gauges:

(a) Staff guage range 0 to 6 metres in three sections;

(b) Negretti and Zambra pressure bulb water level recorder, weekly chart, range 0 to 6 metres.

History:

During the period 1st April, 1969 to 31st July, 1969 flow measurements were made by Sarawak Oil Palm at two temporary works on the Sungai Luak above and below its confluence with the Sungai Telis. The catchment at the Sungai Telis confluence is about 27 square kilometres at 30 per cent of the catchment of the present gauge. The present installation was damaged by a flood on 23rd October, 1973 and the recorder not subsequently re-installed.

Channel and control:

The low flow control is formed by a rock outcrop about 6 metres (20 feet) downstream of the gauge. Above about 1 metre this control is progressively drowned, and channel control is established. This change leads to reverse curvature over part of the rating (Figure I.4.2). Over-bank flow starts at about 3.2 metres. The river bed is sandy and the banks soft. The surrounding area is covered by open forest.

Discharge measurements:

Wading measurements are made up to gauge height 1.1 metres at a section just below the low-flow control. High flow measurements are made from the road bridge upstream. There are no significant inflows between the bridge and the gauge.

Regulation and diversion:

There are two small water supply intakes on the Sungai Luak upstream. The abstractions during the period of record are estimated to have been of the order of 0.002 cumecs (0.05 mgd) and no adjustment has been made for them.

Accuracy:

The accuracy of flows up to 2 cumecs (38 mgd) is good. Higher flows are approximate only.

Co-operation:

No local observer.

TABLE I.4.3

SUNGAI KEJAPIL DOWNSTREAM OF BEKENU ROAD BRIDGE
DISCHARGE MEASUREMENTS MADE BY STUDY STAFF FROM 21-10-72 TO 15-10-73

Measurement No.	Date	Gauge height	Discharge	Surface width	Cross-section	Mean velocity	No. of vertical sections	Defining rating curve No.
		Metre	Cumecs	Metre	Square metre	Metre per second		
1	21-10-72	0.64	0.267	4.7	1.76	0.151	19	1
2	23-10-72	0.95	2.00	8.1	6.19	0.323	24	1
3	2-11-72	0.99	1.88	8.5	6.20	0.303	17	1
4	13-11-72	0.87	1.17	7.8	4.56	0.256	16	1
5	21-11-72	2.07	6.90	10.7	12.7	0.544	9	1
6	21-12-72	0.82	0.972	7.3	3.93	0.248	14	1
7	29-12-72	0.75	0.556	6.5	2.80	0.198	12	1
8	5-1-73	0.65	0.318	5.5	1.84	0.173	8	1
9	12-1-73	0.68	0.339	5.5	1.98	0.171	8	1
10	17-1-73	0.60	0.177	4.5	1.45	0.122	7	1
11	24-1-73	0.56	0.130	4.5	1.31	0.099	6	1
12	31-1-73	0.52	0.098	4.3	1.19	0.082	6	1
13	14-2-73	0.52	0.092	3.5	0.810	0.114	6	1
14	21-2-73	0.51	0.081	3.5	0.835	0.097	5	1
15	14-3-73	0.55	0.119	4.0	0.360	0.331	7	1
16	4-4-73	0.63	0.239	4.5	0.744	0.322	8	1
17	11-4-73	0.88	1.76	6.2	3.80	0.464	12	1
18	17-4-73	1.99	8.06	7.0	12.9	0.626	13	1
19	24-4-73	1.76	5.26	7.9	9.56	0.550	7	1
20	2-5-73	0.95	1.72	8.2	6.21	0.276	15	1
21	16-5-73	0.80	0.803	6.7	3.76	0.214	12	1
22	22-5-73	0.84	1.00	7.0	4.01	0.250	13	1
23	29-5-73	1.28	3.47	9.0	9.33	0.372	17	1
24	19-6-73	0.98	2.00	7.9	6.13	0.326	12	1
25	26-6-73	0.76	0.599	6.3	2.84	0.211	11	1
26	3-7-73	0.87	1.23	7.4	4.39	0.281	12	1
27	17-7-73	0.83	0.937	7.5	4.38	0.214	13	1
28	24-7-73	0.69	0.352	6.5	2.60	0.136	10	1
29	8-8-73	0.89	1.40	7.8	5.72	0.243	8	1
30	20-8-73	0.93	1.66	7.7	5.81	0.286	15	1
31	28-8-73	0.87	1.32	7.7	5.62	0.235	15	1
32	17-9-73	0.88	1.27	7.9	5.68	0.223	15	1
33	24-9-73	0.89	1.40	8.0	5.79	0.241	15	1
34	1-10-73	0.82	0.858	7.4	4.35	0.199	14	1
35	9-10-73	0.73	0.476	6.7	3.32	0.143	13	1
36	15-10-73	0.75	0.525	6.9	3.39	0.154	13	1

Note: Due to rounding of figures for publication the calculation of discharge from the quoted area and velocity may not agree exactly with the discharge figure above.

TABLE I.4.4

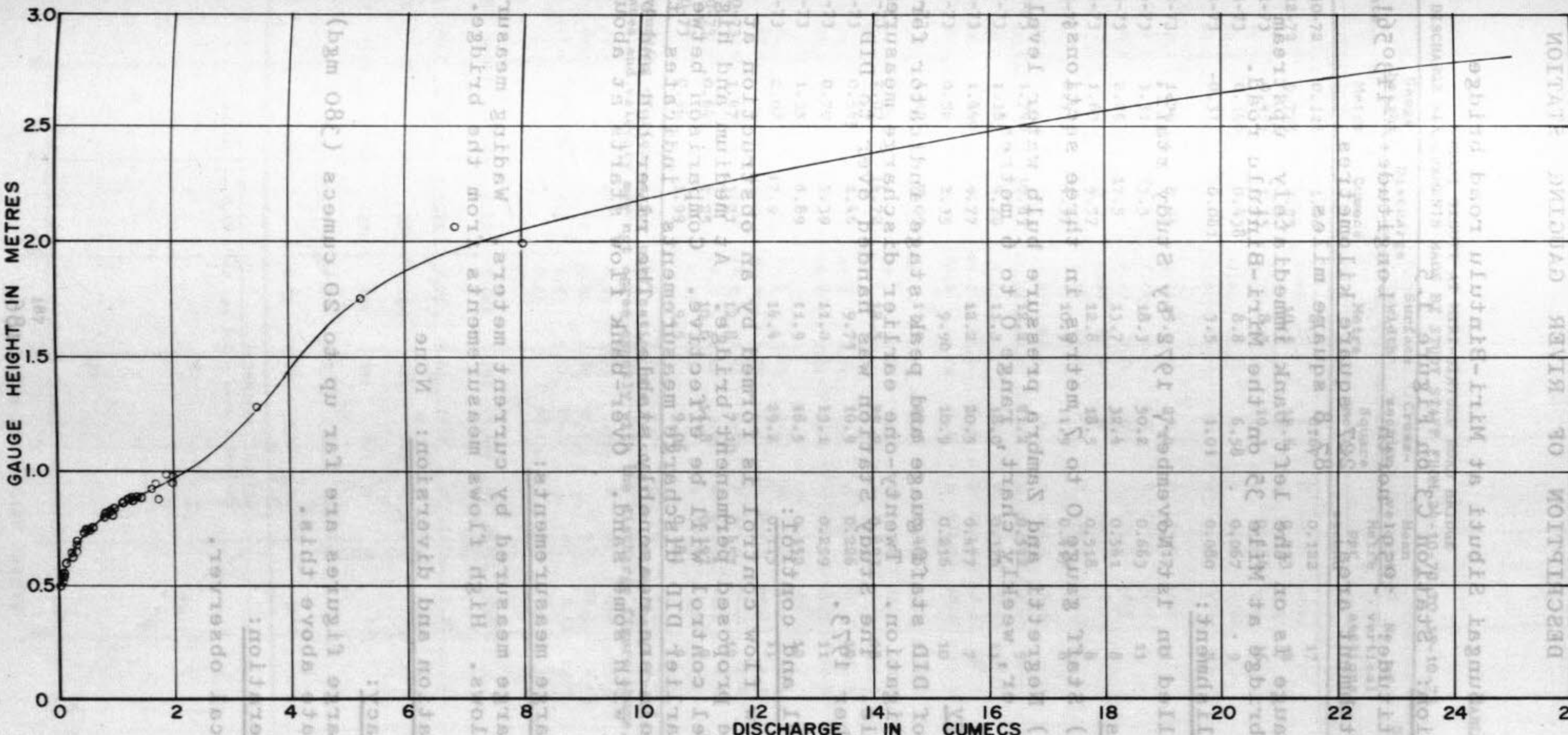
SUNGAI KEJAPIL D/S OF BEKENU ROAD BRIDGE
MEAN DAILY DISCHARGE IN CUMECS FROM 20-10-72 TO 22-10-73

Day	1972			1973									
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1		3.43	10.0*	0.409	0.093	0.061	0.102	3.09	2.58	1.21	3.79	14.3	0.86
2		2.23	15.0*	0.396	0.093	0.056	0.108	2.00	4.41	1.13	4.40	5.33	0.64
3		0.963	13.0*	0.396	0.093	0.054	0.403	1.16	10.0	1.27	3.51	3.38	0.51
4		0.627	10.0*	0.367	0.101	0.058	0.313	0.910	19.3	3.27	2.16	3.32	0.59
5		0.529	15.0*	0.295	0.102	0.084	0.931	2.99	14.5	6.62	1.29	3.41	0.54
6		2.58	9.0*	0.275	0.102	0.073	1.67	5.12	9.01	4.71	0.994	2.35	0.49
7		7.15	5.0*	1.10	0.102	0.069	0.806	12.5	8.86	3.70	0.916	2.69	0.49
8		2.0*	2.5*	1.21	0.202	0.064	0.454	11.9	9.33	2.53	1.69	9.98	0.49
9		1.21	2.0*	0.853	0.233	0.058	0.322	5.46	10.3	4.93	3.80	21.6	0.47
10		0.843	10.0*	0.508	0.211	0.061	0.246	3.37	8.51	9.84	4.01	21.7	1.65
11		1.02	15.0*	0.393	0.166	0.061	1.62	2.70	12.2	4.02	3.75	12.8	2.42
12		1.37	20.0*	0.350	0.108	0.058	5.99	1.86	21.2	2.42	5.80	5.47	1.03
13		1.49	10.0*	0.251	0.097	0.079	3.35	1.28	19.0*	1.45	13.4	3.72	0.67
14		0.986	6.0*	0.206	0.093	0.098	1.18	0.925	15.0*	1.09	4.85	2.73	0.60
15		0.817	3.0*	0.186	0.087	0.123	0.659	0.858	11.0*	0.881	2.82	2.23	0.561
16		0.750	1.9*	0.177	0.076	0.119	4.73	0.803	8.0*	0.821	1.89	1.77	0.527
17		0.750	1.4*	0.177	0.092	0.111	7.54	0.663	4.5*	0.943	1.42	1.33	0.506
18		6.03	1.0*	0.162	0.110	0.115	12.3	0.511	3.0*	0.969	2.05	1.21	0.413
19		10.4	0.9*	0.146	0.119	0.288	18.5	0.492	2.00	1.08	2.41	1.11	0.534
20	0.253	15.3	1.1*	0.141	0.104	0.200	12.5	1.2*	1.37	0.797	1.77	0.999	1.236
21	0.229	10.7	0.859	0.134	0.087	0.147	7.0*	1.0*	0.943	0.687	1.43	3.31	0.714
22	0.316	6.12	2.18	0.130	0.073	0.129	3.5*	0.9*	0.964	0.573	1.25	2.60	0.566
23	1.37	5.54	1.27	0.130	0.069	0.343	8.0*	0.777	0.845	0.409	0.911	1.96	
24	1.48	3.55	0.895	0.130	0.063	0.277	4.80	0.720	0.839	0.377	0.945	1.39	
25	0.564	2.41	0.687	0.118	0.061	0.158	3.40	0.573	0.650	0.307	2.44	1.02	
26	0.339	12.7	1.97	0.109	0.061	0.117	3.21	1.94	0.589	0.879	3.52	0.859	
27	0.321	15.9	1.20	0.102	0.061	0.097	2.64	1.81	1.58	0.952	1.91	0.650	
28	0.433	8.0*	0.695	0.100	0.061	0.093	2.49	2.97	1.01	2.54	1.16	1.85	
29	0.378	4.0*	0.549	0.093		0.087	2.03	3.43	0.615	2.55	0.799	2.08	
30	0.321	3.0*	0.510	0.093		0.094	1.67	4.41	0.640	4.09	0.489	1.22	
31	0.386		0.479	0.093		0.111		3.30		4.63	7.98		
Total cumecs days		132.4	163.1	9.23	2.82	3.54	112.5	81.6	202.5	71.7	89.4	138.4	
Mean cumecs		4.41	5.26	0.300	0.101	0.114	3.75	2.63	6.75	2.31	2.88	4.61	
Mean M.G.D.		39.7	47.3	2.70	0.91	0.99	33.8	23.7	60.8	30.8	25.9	41.5	
Runoff mm		124	153	8.7	2.6	3.3	106	76.6	190	67.3	83.9	130	
Runoff in		4.9	6.0	0.34	0.10	0.13	4.1	3.0	7.5	2.6	3.3	5.1	
Peak cumecs				1.71	0.370	0.555				12.0	15.5	23.8	

Note: * estimated

Catchement area = 92 sq. km = 35 sq. miles

SUNGAI KEJAPIL DOWNSTREAM OF BĘKENU ROAD BRIDGE
RATING CURVE (PERIOD OCTOBER 1972 — OCTOBER 1973)



NOTE: Reverse curvature is due to drowning of the low flow control and change to channel control. High flow rating estimated from velocity and area.

FIGURE I.4.2

DESCRIPTION OF RIVER GAUGING STATION

Name: Sungai Sibuti at Miri-Bintulu road bridge

Location: Station C3 on Figure 1.5

Latitude: 3°59' north Longitude: 113°56' east

Catchment area: 227 square kilometres
87.8 square miles

The gauge is on the left bank immediately upstream of the road bridge at Mile 35 on the Miri-Bintulu road.

Establishment:

Installed on 1st November, 1972 by Study staff.

Gauges:

(a) Staff gauge 0 to 7 metres in three sections;

(b) Negretti and Zambra pressure bulb water level recorder, weekly chart, range 0 to 6 metres.

History:

Site of DID staff guage and peak stage indicator for bridge investigation. Twenty-one earlier discharge measurements available. The Study Station was handed over to DID during November 1973.

Channel and control:

The low flow control is formed by an obstruction at the site of the proposed permanent bridge. At medium and high flows channel control will be effective. Comparison between Study and earlier DID discharge measurements indicates that the controls are reasonably stable. The river bed and banks are muddy with some sand. Over-bank flow starts at about 6 metres.

Discharge measurements:

Discharge measured by current meters. Wading measurements at low flows. High flows measurements from the bridge.

Regulation and diversion: None

Accuracy:

Discharge figures are far up to 20 cumecs (380 mgd) and approximate above this.

Co-operation:

No local observer.

TABLE I.4.5

SUNGAI SIBUTI AT MIRI-BINTULU ROAD BRIDGE
DISCHARGE MEASUREMENTS MADE BY STUDY STAFF FROM 24-10-72 TO 19-10-73

Measurement No.	Date	Gauge height	Discharge	Surface width	Cross-section	Mean velocity	No. of vertical sections	Defining rating curve No.
		Metre	Cumecs	Metre	Square metre	Metre per second		
1	24-10-72	0.326	1.06	8.5	8.67	0.122	17	1
2	29-12-72	0.725	2.95	10.5	12.6	0.233	18	1
3	4-1-73	0.455	1.15	8.5	10.1	0.114	16	1
4	12-1-73	0.140	0.438	8.8	6.58	0.067	9	1
5	26-1-73	-0.31	0.081	3.5	1.01	0.080	5	1
6	21-3-73	1.72	8.64	15.9	27.2	0.317	11	1
7	18-4-73	3.31	33.3	18.3	50.2	0.663	11	1
8	26-4-73	2.29	17.5	13.7	32.4	0.541	8	1
9	11-5-73	1.65	9.57	12.8	18.5	0.518	8	1
10	17-5-73	0.935	4.97	10.9	11.9	0.417	8	1
11	25-5-73	1.740	10.83	12.2	21.2	0.512	9	1
12	15-7-73	1.185	6.78	11.3	18.0	0.376	11	1
13	29-6-73	1.440	9.77	12.2	20.5	0.477	7	2
14	20-7-73	0.56	2.35	9.90	10.9	0.216	10	2
15	3-8-73	1.19	7.09	11.0	17.5	0.406	11	2
16	10-8-73	2.02	14.72	12.5	29.9	0.493	13	2
17	17-8-73	0.565	2.46	9.75	10.9	0.226	10	2
18	29-8-73	0.70	3.39	11.0	13.1	0.259	11	2
19	12-9-73	1.35	8.89	11.9	18.5	0.152	12	2
20	28-9-73	2.07	17.9	14.4	29.2	0.115	11	2
21	4-10-73	1.47	3.21	12.8	7.10	0.457	12	2
22	11-10-73	0.64	3.25	10.0	11.8	0.197	9	2
23	19-10-73	0.36	1.99	9.5	9.06	0.181	9	2

Note: Due to rounding of figures for publication the calculation of discharge from the quoted area and velocity may not agree exactly with the discharge figure above.

TABLE 1.4.6

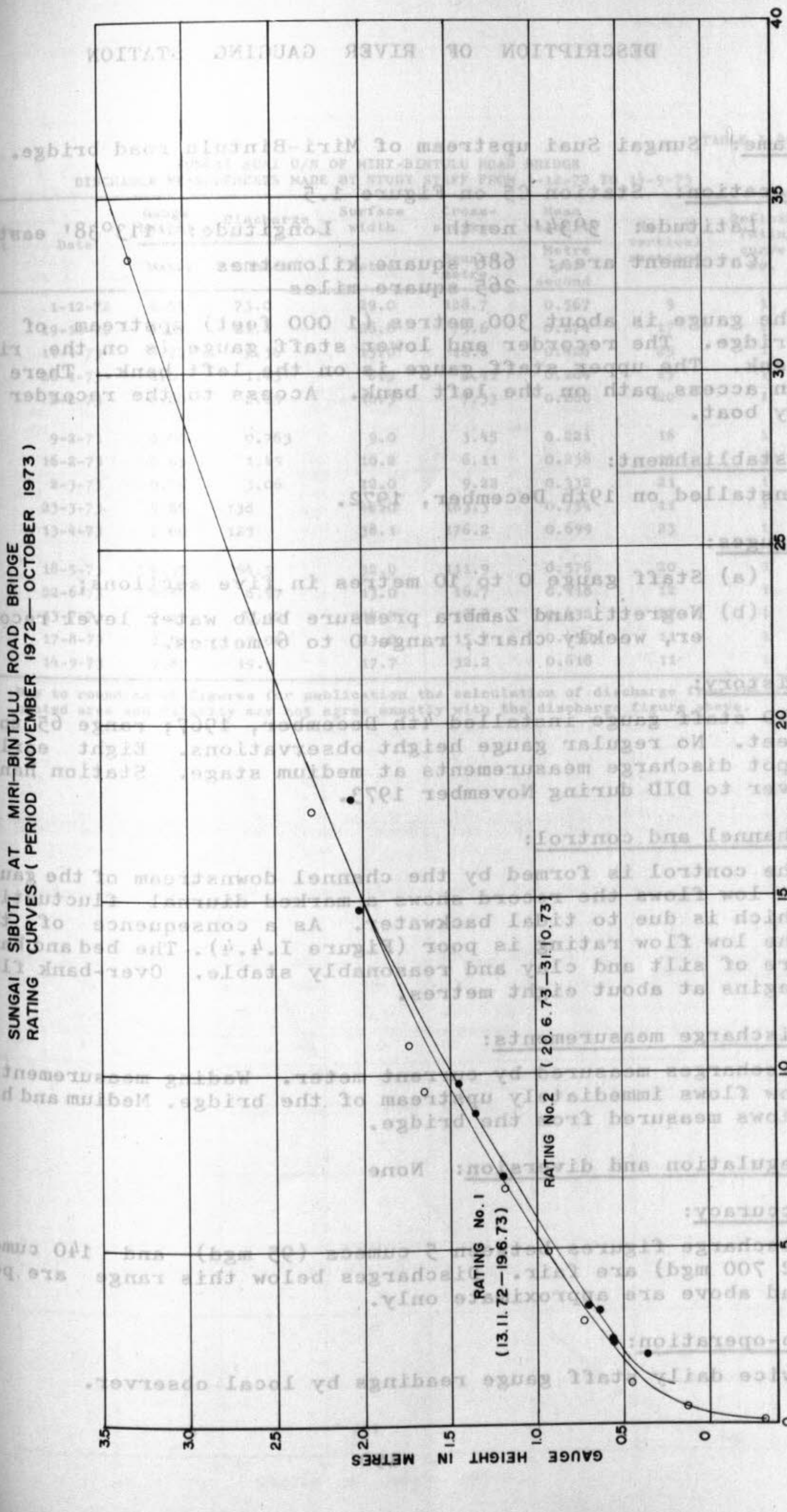
SUNGAI SIBUTI AT MIRI-BINTULU ROAD BRIDGE
MEAN DAILY DISCHARGE IN CUMECS FROM 13-11-72 TO 31-10-73

Day	1972 Oct	1972 Nov	1972 Dec	1973 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1			11.0	1.20	0	0	2.66	21.1	30.0*	4.91	28.3	25.1	14.3
2			13.5	1.24	0	0	2.49	19.1	25.0*	3.76	15.0	15.6	10.0
3			30.8	2.22	0	0	7.33	13.8	35.0*	3.33	7.53	8.69	7.60
4			28.7	1.48	0	0	5.25	14.4	40.0*	5.83	4.92	9.93	10.0
5			14.3	1.08	0	0	7.77	16.8	35.0*	13.0	3.61	11.9	11.2
6			7.63	0.786	0	0	17.2	16.0	27.0*	20.2	2.84	8.68	10.5
7			5.38	0.603	0	0	21.1	15.5	35.0*	24.3	2.30	6.25	10.1
8			5.47	0.540	0	0	14.0	14.8	28.9	19.0	8.04	27.7	7.33
9			11.7	0.503	0	0	8.18	14.3	26.5	22.7	24.2	34.7	5.29
10			33.1	0.487	0	0	5.99	12.2	22.2	26.6	17.1	27.8	3.92
11			34.6	0.490	0	0	9.40	10.7	21.9	18.1	9.95	14.2	3.19
12			27.1	0.495	0	0	9.48	12.0	21.0	9.57	7.36	9.15	3.32
13		5.48	25.1	0.581	0	0	9.24	13.7	16.8	6.09	7.30	9.36	2.59
14		7.70	15.8	0.537	0	3.47	8.32	9.79	11.0	4.34	5.80	8.56	2.76
15		8.40	8.86	0.460	0	5.16	22.2	8.04	7.80	3.47	3.99	5.57	3.10
16		6.68	5.98	0.403	0	16.3	73.3	6.58	5.65	2.91	2.89	5.04	2.63
17		6.26	4.40	0.356	0	16.7	27.2	5.03	4.68	3.09	2.31	8.60	1.83
18		6.10	3.09	0.337	0	16.6	32.6	4.37	3.50	5.28	3.19	15.4	1.40
19		5.66	2.30	0.321	0	23.4	34.6	4.72	3.12	3.45	6.21	11.6	1.39
20		8.66	2.22	0.080	0	19.5	33.1	4.27	5.61	2.20	6.52	7.64	2.33
21		23.4	1.75	0.216	0	12.8	32.5	3.09	3.47	1.64	4.94	5.26	4.03
22		28.1	1.26	0.179	0	15.5	28.2	4.28	3.68	1.19	12.73	3.95	3.29
23		26.3	2.22	0.152	0	25.2	17.7	5.81	11.2	1.03	9.64	8.58	2.19
24		22.8	5.92	0.094	0	19.5	12.7	7.63	8.35	1.22	6.13	9.09	4.51
25		17.9	15.5	0.055	0	13.8	9.85	11.5	6.38	1.15	5.82	5.09	13.7
26		35.9	15.8	0	0	20.9	15.4	8.75	5.36	0.795	9.27	3.84	14.7
27		37.2	12.1	0	0	19.7	25.6	12.3	4.81	0.717	6.76	3.35	17.0
28		21.4	6.57	0	0	14.7	24.7	22.0	9.24	3.72	4.61	11.9	30.1
29		10.0	3.60	0		9.77	20.3	26.3	11.5	15.4	3.28	22.1	35.2
30		7.09	23.2	0		5.87	17.3	35.9	6.74	32.1	2.30	19.7	35.3
31			1.65	0		3.86		35.9		.35.1	15.1		31.0
Total cumecs days			380.6	13.50	0	262.7	505.7	410.7	486.4	296.2	250.0	364.3	305.8
Mean cumecs			12.3	0.43	0	8.47	16.9	13.2	16.2	9.55	8.06	12.1	9.86
Mean M.G.D.			234	8.17	0	161	321	251	308	181	153	230	187
Runoff mm			145	5	0	100	192	156	185	112	95	138	116
Runoff in			5.7	0.20	0	3.9	7.6	6.1	7.3	4.4	3.7	5.4	4.6
Peak cumecs			36.4	2.54	0	25.7	34.8	37.0		36.1	31.6	35.8	35.6

Note: * estimated

Catchment area = 227 sq. km = 87.8 sq. miles

FIGURE I.4.3


SUNGAI SIBUTI AT MIRI–BINTULU ROAD BRIDGE
RATING CURVES (PERIOD NOVEMBER 1972 — OCTOBER 1973)
RATING No. 1
(13.11.72—19.6.73)
RATING No.2
(20.6.73—31.10.73)
DISCHARGE IN CUMECS
0
5
10
15
20
25
30
35
40
GAUGE HEIGHT IN METRES
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

DESCRIPTION OF RIVER GAUGING STATION

Name: Sungai Suai upstream of Miri-Bintulu road bridge.

Location: Station C5 on Figure 1.5

Latitude: 3°34' north Longitude: 113°38' east

Catchment area: 686 square kilometres
265 square miles

The gauge is about 300 metres (1 000 feet) upstream of the bridge. The recorder and lower staff gauge is on the right bank. The upper staff gauge is on the left bank. There is an access path on the left bank. Access to the recorder is by boat.

Establishment:

Installed on 19th December, 1972.

Gauges:

(a) Staff gauge 0 to 10 metres in five sections;

(b) Negretti and Zambra pressure bulb water level recorder, weekly chart, range 0 to 6 metres.

History:

DID staff gauge installed 4th December, 1967; range 65 to 97 feet. No regular gauge height observations. Eight earlier spot discharge measurements at medium stage. Station handed over to DID during November 1973.

Channel and control:

The control is formed by the channel downstream of the gauge. At low flows the record shows a marked diurnal fluctuation which is due to tidal backwater. As a consequence of this the low flow rating is poor (Figure I.4.4). The bed and banks are of silt and clay and reasonably stable. Over-bank flood begins at about eight metres.

Discharge measurements:

Discharges measured by current meter. Wading measurements at low flows immediately upstream of the bridge. Medium and high flows measured from the bridge.

Regulation and diversion: None

Accuracy:

Discharge figures between 5 cumecs (95 mgd) and 140 cumecs (2 700 mgd) are fair. Discharges below this range are poor and above are approximate only.

Co-operation:

Twice daily staff gauge readings by local observer.

TABLE I.4.7

SUNGAI SUAI U/S OF MIRI-BINTULU ROAD BRIDGE
DISCHARGE MEASUREMENTS MADE BY STUDY STAFF FROM 1-12-72 TO 14-9-73

Measurement No.	Date	Gauge height	Discharge	Surface width	Cross-section	Mean velocity	No. of vertical sections	Defining rating curve No.
		Metre	Cumecs	Metre	Square metre	Metre per second		
1	1-12-72	4.55	73.0	29.0	128.7	0.567	9	1
2	19-12-72	2.25	21.8	26.8	79.6	0.274	17	1
3	11-1-73	0.73	5.36	13.0	12.6	0.426	25	1
4	26-1-73	0.01	1.43	8.5	5.41	0.264	15	1
5	2-2-73	0.20	2.05	10.3	7.33	0.280	20	1
6	9-2-73	0.00	0.763	9.0	3.45	0.221	16	1
7	16-2-73	0.05	1.45	10.2	6.11	0.238	19	1
8	2-3-73	0.60	3.06	12.0	9.22	0.332	21	1
9	23-3-73	5.86	138	42.0	183.3	0.754	11	1
10	13-4-73	5.60	123	38.1	176.2	0.699	23	1
11	18-5-73	4.35	64.5	32.0	111.9	0.576	20	1
12	22-6-73	0.85	6.97	13.0	16.7	0.418	12	1
13	13-7-73	1.19	8.12	14.5	18.8	0.432	27	1
14	17-8-73	1.00	7.06	13.0	15.7	0.450	11	1
15	14-9-73	1.87	19.9	17.7	32.2	0.618	11	1

Note: Due to rounding of figures for publication the calculation of discharge from the quoted area and velocity may not agree exactly with the discharge figure above.

TABLE I.4.8

SUNGAI SUAI U/S OF MIRI-BINTULU ROAD BRIDGE
MEAN DAILY DISCHARGE IN CUMECS FROM 19-12-72 TO 31-10-73

Day	1972			1973									
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1				4.96	2.11	4.75	34.1	59.3$^+$	53.9$^+$	176$^+$	113	138	26.9
2				6.05	2.20	2.60	39.0	47.5$^+$	61.0$^+$	191$^+$	126	155	21.9
3				4.67	1.87	1.86	56.1$^+$	23.6$^+$	128$^+$	189$^+$	139	154	54.2
4				5.20	1.56	3.25	70.2$^+$	80.4	157$^+$	163$^+$	148	154	111
5				4.90	1.18	4.66	86.0$^+$	103	169$^+$	111$^+$	135	115	96.2
6				5.35	1.05	2.73	62.0$^+$	132	166$^+$	81.6	65.1	34.8	60.6
7				4.14	0.58	56.8	40.7$^+$	149	159$^+$	38.4	17.7	27.5	31.4
8				6.67	0.46	104	50.1$^+$	137	179$^+$	27.6	23.3	55.0	17.2
9				8.82	0.90	85.2	90.0$^+$	79.0	193$^+$	39.3	38.5$^+$	94.0	11.5
10				8.90	2.06	20.2	49.7$^+$	33.5	198$^+$	61.8	117$^+$	114	8.78
11				4.94	2.16	13.6	52.3$^+$	23.9	202$^+$	33.6	115$^+$	76.6	8.04
12				3.41	3.55	8.60	109$^+$	35.6	203$^+$	14.6	49.7$^+$	47.9	8.39
13				2.66	2.65	13.7	119$^+$	26.9	205$^+$	9.49	17.6$^+$	36.6	6.66
14				2.30	2.03	52.0	60.5$^+$	30.0	185$^+$	6.93	10.1$^+$	21.3	16.8
15				3.69	1.95	31.6	81.1$^+$	40.8	134$^+$	5.33	7.83$^+$	14.6	16.5
16				45.2	1.79	50.3	115$^+$	39.5	42.0$^+$	4.41	8.39$^+$	21.8	22.2
17				32.8	1.45	36.4	128$^+$	31.6	10.1$^+$	3.85	7.25	29.8	10.9
18				10.4	1.32	76.9	127$^+$	57.3	5.95$^+$	3.49	5.05	23.1	6.97$^+$
19			25.6	5.46	1.09	119	121$^+$	86.3	14.3$^+$	3.14	5.09	13.7	42.4$^+$
20			14.5	4.04	1.99	118	139$^+$	54.5	18.6$^+$	2.83	6.25	21.7	77.7$^+$
21			35.3	3.13	2.28	73.0	137$^+$	26.5	8.56$^+$	2.21	6.87	52.8	114$^+$
22			82.7	2.58	2.33	107	87.4$^+$	29.5	7.41	1.79	4.98	53.5	119$^+$
23			69.4	2.16	2.21	118	50.2$^+$	33.0	20.0	1.79	3.82	49.9	103$^+$
24			46.2	1.71	2.66	82.6	38.1$^+$	71.6	15.8	3.24	4.80	44.7	98.8$^+$
25			53.1	1.43	18.9	29.4	26.3$^+$	117$^+$	16.2	2.60	18.2	91.1	132.5$^+$
26			44.6	1.29	10.5	16.8	42.3$^+$	78.9$^+$	14.3	6.83	17.0	122	167$^+$
27			19.6	1.24	8.00	18.5	41.6$^+$	46.5$^+$	37.1	4.65	7.93	68.4	178$^+$
28			19.8	1.30	7.92	34.3	65.8$^+$	42.5$^+$	60.8	3.63	4.73	45.4	191$^+$
29			14.3	1.42		28.8	42.9$^+$	59.3$^+$	101	7.31	3.69	63.3	183$^+$
30			9.10	1.47		21.7	39.1$^+$	85.1$^+$	134	40.6	3.90	45.4	158$^+$
31			6.28	1.64		29.5		86.7$^+$		76.5	67.2		105$^+$
Total cumecs days				193.9	88.78	1 366.2	2 201.3	1 947.4	2 899.4	1 317.2	1 298.7	1 985.8	2 203.6
Mean cumecs				6.25	3.17	44.1	73.4	62.8	96.7	42.5	41.9	66.2	71.1
Mean M.G.D.				119	60.2	838	1 395	1 193	1 837	808	796	1 258	1 351
Runoff mm				24.4	11.2	172	277	245	365	166	164	250	278
Runoff in				0.96	0.44	6.8	10.9	9.6	14.4	6.5	6.5	9.8	10.9
Peak cumecs				52.8	22.7	127	141	149	205	193	149	155	(193)

Note: + Based on 2x daily staff gauge observations

Catchment area = 686 sq. km = 265 sq. miles

SUNGAI SUAI UPSTREAM OF MIRI BINTULU ROAD BRIDGE
RATING CURVE (PERIOD DECEMBER 1972 — OCTOBER 1973)

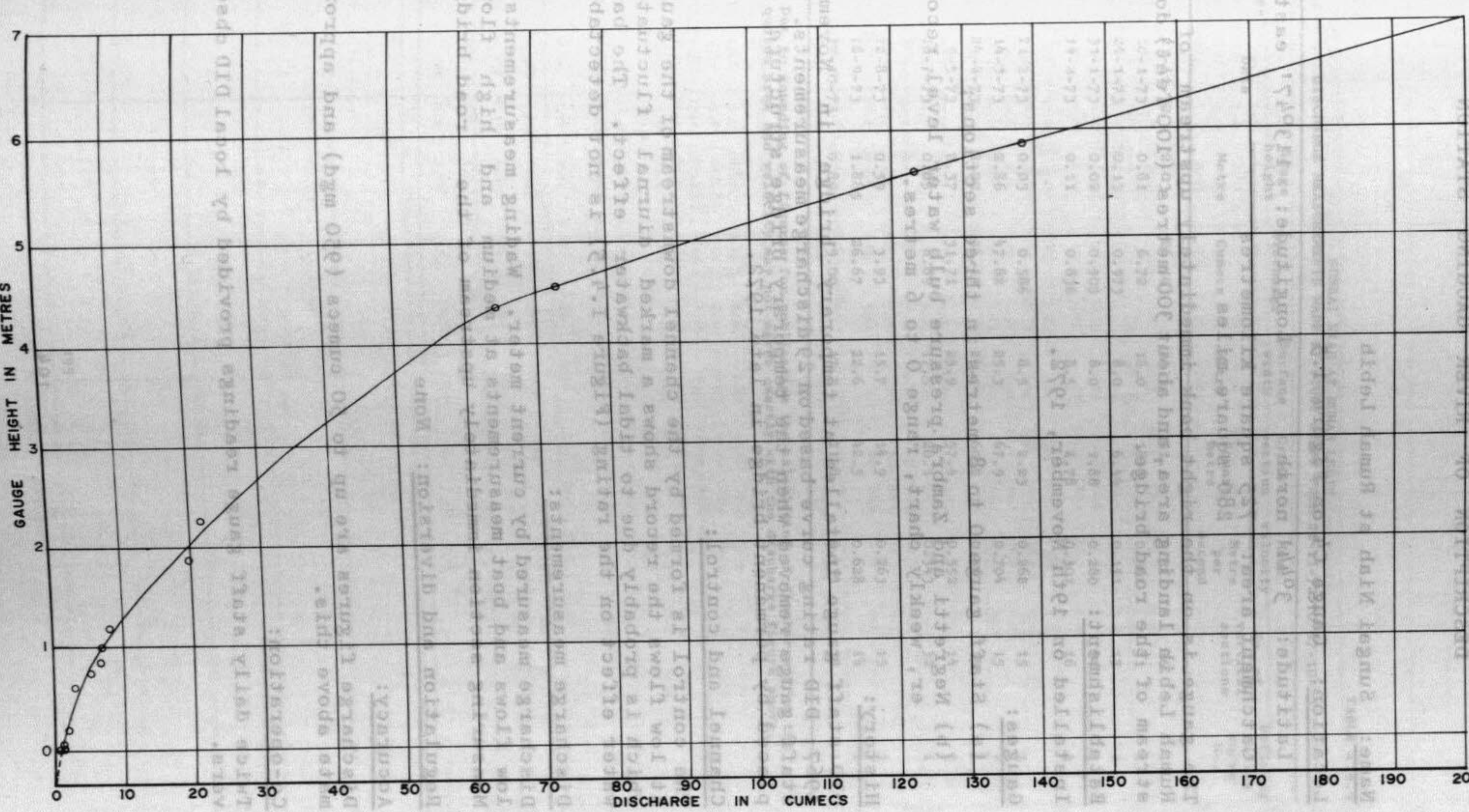


FIGURE I.4.4

DESCRIPTION OF RIVER GAUGING STATION

Name: Sungai Niah at Rumah Lebih

Location: Gauge C4 on Figure 1.5

Latitude: 3°44' north Longitude: 113°47' east

Catchment area: 725 square kilometres
280 square miles

The gauge is on the right bank immediately upstream of the Rumah Lebih landing area, and about 300 metres (100 feet) downstream of the road bridge.

Establishment:

Installed on 19th November, 1972.

Gauges:

(a) Staff gauge 0 to 8 metres in three sections;

(b) Negretti and Zambra pressure bulb water level recorder, weekly chart, range 0 to 6 metres.

History:

DID staff gauge installed at temporary bridge in November 1967; DID rating curve based on 29 discharge measurements. DID staff gauge removed when the temporary bridge structure replaced by permanent bridge in late 1972.

Channel and control:

The control is formed by the channel downstream of the gauge. At low flows the record shows a marked diurnal fluctuation which is probably due to tidal backwater effect. The backwater effect on the rating (Figure I.4.5) is not detectable.

Discharge measurements:

Discharge measured by current meter. Wading measurements at low flows and boat measurements at medium and high flows. Measuring section immediately upstream of the road bridge.

Regulation and diversion: None

Accuracy:

Discharge figures are up to 50 cumecs (950 mgd) and approximate above this.

Co-operation:

Twice daily staff gauge readings provided by local DID observers.

TABLE I.4.9

SUNGAI NIAH AT RUMAH LEBIH
DISCHARGE MEASUREMENTS MADE BY STUDY STAFF FROM 21-11-72 TO 17-10-73

Measurement No.	Date	Gauge height Metre	Discharge Cumecs	Surface width Metre	Cross-section Square metre	Mean velocity Metre per second	No. of vertical sections	Defining rating curve No.
1	21-11-72	2.03	26.10	24.1	51.1	0.511	16	1
2	10-1-73	0.81	6.72	16.0	18.6	0.362	31	1
3	24-1-73	0.13	0.973	8.0	6.44	0.151	15	1
4	31-1-73	0.02	0.503	8.0	1.88	0.280	14	1
5	14-2-73	0.11	0.836	8.5	2.78	0.301	16	1
6	21-2-73	0.03	0.586	8.5	2.23	0.262	15	1
7	14-3-73	2.86	47.82	25.3	67.9	0.704	15	1
8	24-4-73	2.22	34.12	24.1	60.2	0.567	15	1
9	9-5-73	2.37	31.71	25.9	57.4	0.552	14	1
10	18-7-73	0.85	6.89	17.5	20.1	0.343	32	1
11	22-8-73	0.59	3.93	15.7	14.9	0.263	15	1
12	18-9-73	1.885	26.67	22.6	42.5	0.628	14	1
13	17-10-73	0.89	9.00	17.7	21.8	0.413	19	1

Note: Due to rounding of figures for publication the calculation of discharge from the quoted area and velocity may not agree exactly with the discharge figure above.

TABLE I.4.10

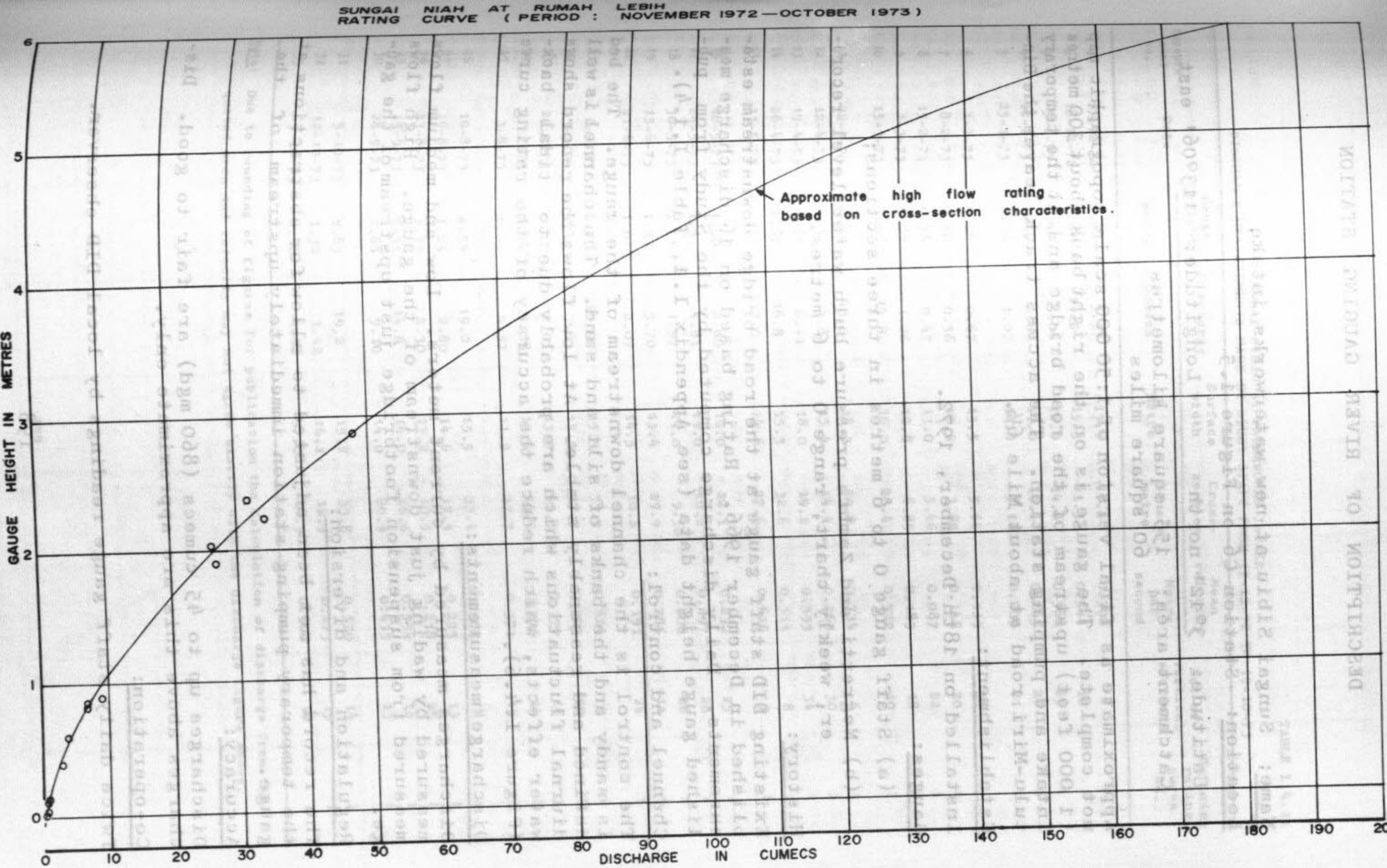
SUNGAI NIAH AT RUMAH LEBIH
MEAN DAILY DISCHARGE IN CUMECS FROM 20-11-72 TO 31-10-73

Day	1972			1973									
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
1			41.4	3.94	0.59	2.65	5.41	36.1	78.5	62.8	57.7	101	20.8
2			33.1	3.12	0.62	1.86	6.32	24.7	71.2	46.8	56.7	98.1	13.0
3			36.1	2.73	0.66	1.53	19.5	23.8	95.4	22.9	49.6	70.7	27.9
4			80.9	2.91	0.65	1.22	13.3	100+	136	20.0	37.1	65.3	61.3
5			48.4	7.08	0.59	1.01	7.37	110+	130	43.1	36.4	48.1	38.7
6			16.6	3.66	0.53	0.94	7.27	82.0+	125	54.1	14.1	18.3	26.0
7			22.6	2.59	0.47	8.67	9.76	107+	117	31.6	6.73	12.9	17.3
8			24.6	4.38	0.50	32.2	19.9	92.0+	119	26.7	7.06	32.5	10.7
9			36.9	8.19	2.26	10.7	40.2	33.0	119	44.6	16.2	44.5	7.81
10			62.9	6.67	3.18	4.64	15.3	49.0+	107	84.0	28.3	32.5	6.66
11			38.5	3.83	2.02	10.1	38.7	76.0+	67.5	64.0	47.7	17.7	9.14
12			49.3	2.62	1.62	4.29	92.7	67.0+	50.3	18.1	17.8	28.6	7.42
13			60.2	2.01	1.24	8.03	92.9	76.0+	28.0	10.8	8.46	34.9	4.79
14			53.9	1.68	1.01	42.3	50.4	61.0+	14.7	7.86	5.94	15.1	4.03
15			44.4	1.42	0.85	24.1	75.5	67.0+	9.90	6.25	4.74	10.1	13.3
16			21.0+	15.2	0.78	27.2	82.3	72.0+	7.57	5.01	4.40	11.5	19.6
17			11.0+	11.4	0.69	18.3	67.2	30.0+	5.78	4.07	3.80	17.5	9.78
18			8.0+	4.46	0.63	79.9	65.4	16.6	4.43	5.82	5.01	23.6	8.35
19			6.0+	2.87	0.60	108	78.2	15.1	3.63	4.25	3.46	13.7	10.4
20		31.4	5.0+	2.15	0.56	120	103	11.6	10.8	2.94	6.23	8.78	43.3
21		27.5	27.0+	1.67	0.60	74.5	101	9.18	5.85	2.45	6.60	11.2	36.8
22		44.7	90.0+	1.39	0.79	74.8	60.2	10.2	20.1	2.05	4.26	14.5	14.1
23		80.7	105+	1.23	3.02	94.8	42.1	31.8	64.8	2.06	3.49	45.3	8.85
24		84.1	128+	1.06	19.7	60.7	30.7	39.5	30.5	1.85	2.94	29.2	47.6
25		50.3	140+	0.87	40.0	67.6	37.6	21.9	23.7	1.86	3.56	47.6	113
26		67.9	128+	0.77	13.7	42.3	48.1	24.8	14.9	5.40	19.6	43.5	133
27		89.1	61.0+	0.69	4.72	18.2	63.6	22.8	29.1	2.88	8.11	18.7	155
28		62.4	15.0+	0.67	3.82	17.6	43.9	63.4	62.7	2.98	4.11	14.3	154
29		29.7	9.34	0.66		9.16	29.5	67.2	74.1	7.18	3.25	21.7	129
30		21.4	6.77	0.65		6.44	22.1	107	51.6	17.3	10.3	34.9	65.9
31			5.33	0.62		6.29		113		45.3	55.2		29.4+
Total cumecs days			1 416.2	103.2	106.4	980.0	1 369.4	1 660.7	1 678.1	657.0	538.8	986.1	1 247.1
Mean cumecs			45.7	3.33	3.80	31.6	45.6	53.6	55.9	21.2	17.4	32.9	40.2
Mean M.G.D.			868	63.3	72.2	600	866	1 018	1 062	403	331	625	764
Runoff mm			169	12.3	12.7	117	163	198	200	78.2	64.0	117	148
Runoff in			6.6	4.8	0.50	4.6	6.4	7.8	7.9	3.1	2.5	4.6	5.8
Peak cumecs				25.0	48.1	123	110	(116)	139	87.2	90.4	103	159

Note: + Based on 2x daily staff gauge observations

Catchment area = 725 sq. km = 280 sq. miles

FIGURE I.4.5


SUNGAI NIAH AT RUMAH LEBIH
RATING CURVE (PERIOD : NOVEMBER 1972 — OCTOBER 1973)
Approximate high flow rating based on cross-section characteristics.
GAUGE HEIGHT IN METRES
DISCHARGE IN CUMECS
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200

DESCRIPTION OF RIVER GAUGING STATION

Name: Sungai Sibiu at new waterworks intake

Location: Station C6 on Figure 1.5

Latitude: 3°12' north Longitude: 113°06' east

Catchment area: 155 square kilometres
60 square miles

Approximate as final version of 1:50 000 scale topographic map not complete. The gauge is on the right bank about 300 metres (1 000 feet) upstream of the road bridge and at the temporary intake and pumping station. The access track leaves the Bintulu-Miri road at about Mile 6½.

Establishment:

Installed on 18th December, 1972.

Gauges:

(a) Staff gauge 0 to 6 metres in three sections;

(b) Negretti and Zambra pressure bulb water level recorder, weekly chart, range 0 to 6 metres.

History:

Existing DID staff gauge at the road bridge downstream established in December 1966. Rating based on 16 discharge measurements. Daily discharge computed by the Study from published gauge height data (see Appendix I.1, Table I.1.4).

Channel and control:

The control is the channel downstream of the gauge. The bed is sandy and the banks of silt and sand. The channel is well defined and reasonably stable. At low flows the record shows diurnal fluctuations which are probably due to tidal backwater effects, which reduce the accuracy of the rating curve (Figure I.4.6).

Discharge measurements:

Discharges measured by current meters. Low and medium flows measured by wading just downstream of the gauge. High flows measured from suspension footbridge just upstream of the gauge.

Regulation and diversion:

The record has not been adjusted to allow for abstractions at the temporary pumping station immediately upstream of the gauge.

Accuracy:

Discharges up to 45 cumecs (860 mgd) are fair to good. Discharges above this are approximate only.

Co-operation:

Twice daily staff gauge readings by local DID observer.

TABLE I.4.11

SUNGAI SIBIU AT WATERWORKS INTAKE
DISCHARGE MEASUREMENTS MADE BY STUDY STAFF FROM 17-12-72 TO 19-10-73

Measure-ment No.	Date	Gauge height	Discharge	Surface width	Cross-section	Mean velocity	No. of vertical sections	Defining rating curve No.
		metre	Cumecs	Metre	Square metre	Metre per second		
1	17-12-72	1.40	3.37	13.4	11.2	0.302	8	1
2	18-12-72	2.07	11.5	15.3	21.3	0.541	10	1
3	5-1-73	1.47	5.06	16.0	14.0	0.361	29	1
4	12-1-73	1.12	2.69	14.0	10.1	0.265	27	1
5	25-1-73	0.78	1.07	14.0	5.11	0.209	21	1
6	1-2-73	0.76	0.67	13.5	5.64	0.119	24	1
7	8-2-73	0.60	0.56	12.3	3.82	0.148	20	1
8	15-2-73	0.76	0.47	13.0	5.46	0.087	22	1
9	1-3-73	0.87	1.26	12.8	6.89	0.183	18	1
10	15-3-73	2.46	14.8	16.0	28.4	0.522	10	1
11	22-3-73	4.13	43.9	18.3	59.8	0.734	6	1
12	12-4-73	1.35	3.83	15.4	14.4	0.265	30	1
13	19-4-73	1.69	6.41	18.0	19.2	0.335	34	1
14	26-4-73	2.67	16.8	15.5	32.6	0.514	8	1
15	11-5-73	2.58	17.0	14.6	27.6	0.616	9	1
16	18-5-73	1.20	2.80	14.0	12.1	0.232	25	1
17	24-5-73	1.51	4.81	14.0	16.2	0.297	26	1
18	30-5-73	1.01	1.97	14.0	9.50	0.206	26	1
19	15-6-73	1.53	5.70	13.4	19.9	0.286	11	1
20	21-6-73	1.07	2.07	14.5	10.8	0.191	24	1
21	6-7-73	2.79	20.90	15.3	33.5	0.624	9	1
22	13-7-73	1.47	3,83	15.5	17.2	0.222	12	1
23	20.7073	1.17	2.01	13.5	11.3	0.177	14	1
24	27-7-73	1.44	4.58	12.5	16.6	0.276	12	1
25	3-8-73	1.64	6.57	11.9	17.7	0.371	12	1
26	10-8-73	2.59	19.0	15.5	33.4	0.568	8	1
27	16-8-73	1.25	2.80	14.6	12.4	0.225	13	1
28	23-8-73	1.13	2.30	13.2	10.5	0.218	25	1
29	14-9-73	2.31	14.8	14.0	26.6	0.554	14	1
30	28-9-73	1.88	9.10	14.0	20.9	0.435	13	1
31	5-10-73	2.83	19.2	15.2	33.8	0.570	14	1
32	12-10-73	1.32	3.42	16.1	12.5	0.273	15	1
33	9-10-73	1.46	4.48	17.0	14.9	0.300	14	1

Note: Due to rounding of figures for publication the calculation of discharge from the quoted area and velocity may not agree exactly with the discharge figure above.

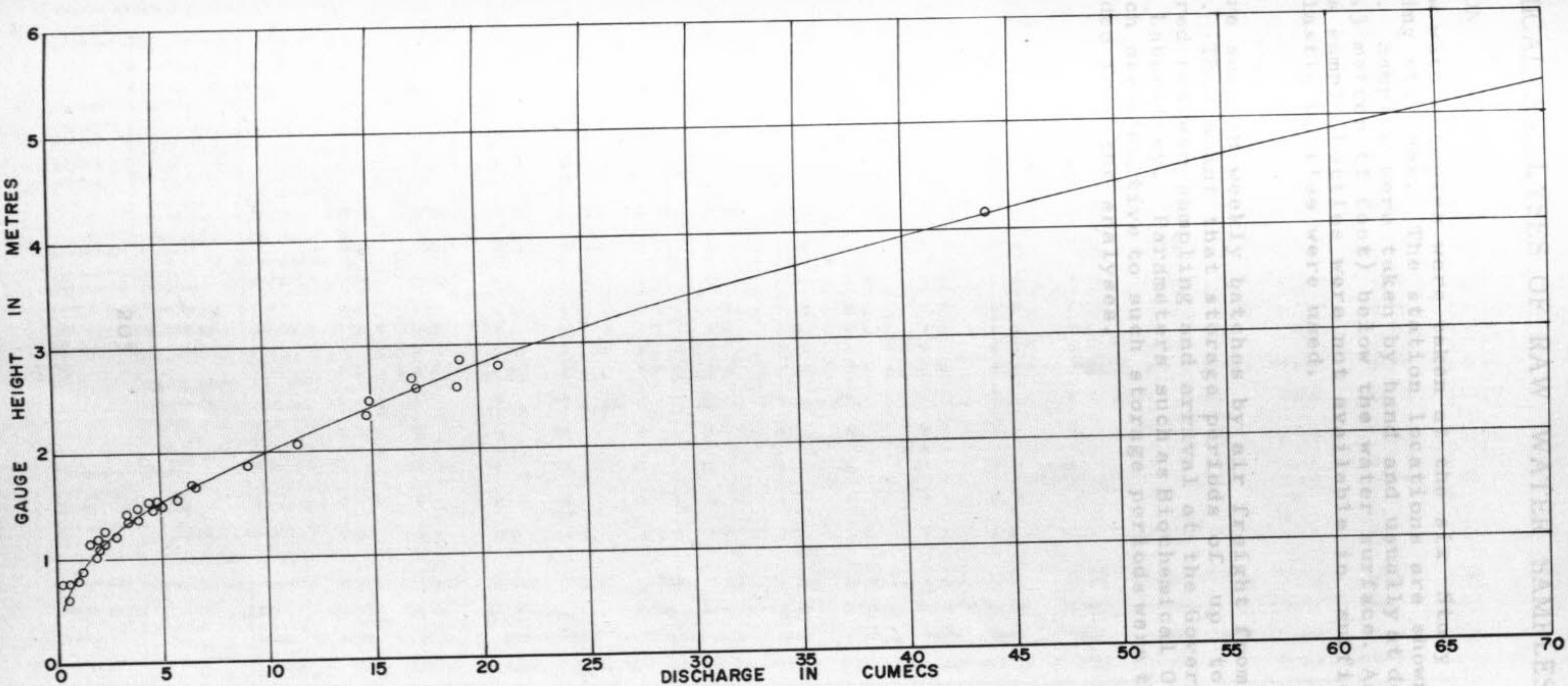
SUNGAI SIBIU AT WATERWORKS INTAKE
MEAN DAILY DISCHARGE IN CUMECS FROM 17-12-72 TO 31-10-73

Day	1972 Oct	1972 Nov	1972 Dec	1973 Jan	1973 Feb	1973 Mar	1973 Apr	1973 May	1973 Jun	1973 Jul	1973 Aug	1973 Sep	1973 Oct
1				14.0	0.83	1.28	6.19	19.3	2.55	18.1	30.6	13.3	3.18
2				25.5	0.76	0.98	12.7	7.95	1.42	18.3+	11.6	18.1	2.95
3				14.8	0.78	0.90	4.73	4.76	5.74	9.80+	6.17	15.9	8.16
4				6.28	0.69	0.85	3.61	22.5	4.77	20.5+	7.67	25.2	25.4
5				4.53	0.59	0.62	32.1	17.1	4.57	24.6+	9.69	8.01	19.3
6				4.18	0.62	0.95	14.2	16.7	3.22	16.1+	5.03	5.98	5.34
7				6.30	0.54	9.17	4.65	41.6	18.8	9.16	8.64	30.2	4.25
8				15.6	0.46	5.48	50.3	38.4	22.7	6.30	14.8	32.2	6.83
9				5.59	0.40	2.29	38.3	28.4	13.2	46.9	8.54	19.1	3.63
10				3.38	0.40	9.77	8.15	12.7	25.8	35.4	16.5	11.4	8.31
11				2.61	0.44	3.63	6.27	16.9	63.6	8.76	22.8	9.39	5.75
12				2.20	0.60	1.88	3.90	9.18	67.7	5.29	8.87	26.3	3.36
13				2.04	0.75	21.1	3.85	5.39	56.4	4.04	5.23	17.6	2.83
14				1.97	0.81	17.9	4.84	3.86	18.9	3.27	3.82	11.7	3.83
15				2.47	0.73	9.66	7.24	4.16	4.82	3.11	3.18	21.7	4.68
16				3.88	0.67	16.9	20.4	4.71	3.54	3.12	2.88	22.7	5.36
17			3.75	2.91	0.76	6.57	26.8	2.97	2.98	4.55	3.16	11.6	3.71
18			3.36	2.14	1.38	11.3	21.6	2.68	2.55	4.20	4.36	6.80	3.66
19			3.10	1.80	1.05	10.4	7.04	3.09	3.63	3.13	9.45	5.17	5.20
20			2.95	1.67	0.72	7.09	7.95	2.33	2.97	2.48	9.29	11.2	16.5
21			2.57	1.47	1.50	38.7	8.20	2.35	2.15	11.6	4.32	10.7	25.3
22			2.74	1.28	2.96	44.0	16.7	2.27	5.06	13.9	2.88	4.93	11.9
23			21.2	1.13	1.78	36.8	24.5	5.01	18.5	4.46	2.45	22.1	17.3
24			21.9	1.06	1.09	16.2	19.5	4.98	7.56	2.97	3.09	22.6	29.5
25			29.4	0.93	5.04	4.77	6.75	3.11	3.28	5.68	12.3	8.18	54.8
26			36.7	0.80	3.99	3.19	14.2	2.61	2.78	4.31	4.77	6.63	44.5
27			24.6	0.74	2.95	2.91	7.53	2.16	2.93	6.95	2.83	10.7	58.9
28			11.3	0.75	1.95	3.22	5.53	2.43	2.97	11.7	2.86	8.77	60.9
29			4.99	0.72		3.78	4.66	2.18	19.5	17.1	2.15	5.33	49.3
30			3.43	0.80		2.03	11.4	1.94	22.1	19.5	4.04	3.93	24.9
31			2.90	0.86		1.75		2.15		25.9	18.7		8.1
Total cumecs days				134.3	35.24	296.1	403.8	295.9	416.6	366.3	252.1	427.2	528.7
Mean cumecs				4.33	1.26	9.55	13.5	9.55	13.9	11.8	8.13	14.2	17.1
Mean M.G.D.				82.3	23.9	181	257	181	264	224	154	270	325
Runoff mm				74.8	19.6	165	225	165	232	204	140	238	294
Runoff in				2.9	7.7	6.5	8.9	6.5	9.1	8.0	5.5	9.4	11.6
Peak cumecs				26.2	7.45	46.9	65.1	45.0	68.3	54.4	34.0	37.4	65.3

Note: + Based on 2x daily staff gauge observations
Catchment area = 155 sq. km = 60 sq. miles

FIGURE I.4.6

SUNGAI SIBIU AT WATERWORKS INTAKE
RATING CURVE (PERIOD: DECEMBER 1972 — OCTOBER 1973)



15 CHEMICAL ANALYSES OF RAW WATER SAMPLES

INTRODUCTION

Regular raw water samples were taken at the six Study Area river gauging stations. The station locations are shown on Figure 1.5. Samples were taken by hand and usually at depths of about 0.3 metres (1 foot) below the water surface. As suitable glass sample bottles were not available in sufficient numbers, plastic bottles were used.

Samples were sent in weekly batches by air freight from Miri to Kuching. This meant that storage periods of up to one week occurred between sampling and arrival at the Government Analytical Laboratory. Parameters such as Biochemical Oxygen Demand which are sensitive to such storage periods were therefore excluded from the analyses.

TABLE I.5.1 SUMMARY OF CHEMICAL ANALYSES - SUNGAI LIKU AT LAMBIR WATERWORKS

Date	31-12-72	21-12-72	6-1-73	13-1-73	9-1-73	26-1-73	2-2-73	9-2-73	2-3-73	11-3-73	4-5-73	11-5-73	31-5-73	8-6-73	10-7-73	21-9-73	24-9-73
Time	1000	1500	1000	1020	1233	1520	1705	1600	1740	1650	1645	1650	1630	1640	1600	1630	1530
Gauge height (feet)	16.10	36.25	36.0	35.80	36.00	35.50	35.40	35.50	35.30	35.30	37.70	37.30	37.10	37.30	37.3	36.8	36.70
Discharge (cumecs)	0.695	0.817	0.615	0.464	0.615	0.316	0.289	0.316	0.263	0.263	2.64	1.70	1.40	1.70	1.70	1.04	0.92
Carbon dioxide (as CO_2)	4.2	4.2	5.4	5.4	1.8	2.0	4.0	1.4	2.4	4.2	9.4	10.0	13.8	11.2	7.6	6.6	3.2
Total alkalinity (as $CaCO_3$)	6	4	6	6	8	8	8	6	8	8	2	-	Abs	10	12	3	6
Hardness: Total (as $CaCO_3$)	15	15	14	16	20	17	17	18	18	21	15	15	22	16	13	10	15
Calcium (as $CaCO_3$)	8	7	6	7	10	8	7	8	8	10	7	7	12	9	9	6	7
Magnesium (as $CaCO_3$)	7	8	8	9	10	9	10	10	10	11	8	8	10	7	4	4	8
pH	5.5	5.1	5.5	5.6	5.3	6.0	6.0	6.0	6.0	5.9	4.9	4.4	4.4	5.3	5.2	5.0	5.1
Chlorides (as Cl)	4	5	4	5	5	4	6	5	5	6	4	5	8.5	7	4	3.0	3
Soluble iron (as Fe)	0.3	0.1	0.3	1.1	Tr	1.3	0.4	1.0	0.5	1.0	0.10	Abs	Tr	Tr	Abs	0.20	0.80
Total iron (as Fe)	1.4	1.6	0.5	2.5	0.4	1.7	0.5	1.15	0.8	1.25	0.90	2.60	1.50	1.40	1.60	1.40	2.00
Oxygen absorption ($KMnO_4$, 4 hrs)	1.45	1.55	1.75	0.8	1.95	1.1	0.9	1.00	1.15	0.8	2.45	2.05	2.15	5.80	3.10	1.90	1.75
Manganese: Total (as Mn)		0.09	0.07	0.12	0.16	0.11	0.12	0.14	0.11	0.12	0.16	0.14	0.19	0.14	0.14	0.09	0.11
Soluble (as Mn)		0.06	0.03	0.12	0.15	0.07	0.10	0.10	0.10	0.01	0.16	0.14	0.08	0.13	0.13	0.09	0.11
Sulphate (as SO_4)		15	15	19	23	15	15	18	17	19	23	19	44	20	8	12	1
Silica (as SiO_2)		6	7	9	9	6	5	6	4	9	7	4	8	4	3	1	1
Organic phosphate (as PO_4)		Tr	0.01	Tr	Tr	0.01	Tr	Tr	0.01	0.01	Tr	Tr	Tr	Tr	0.01	0.01	0.01
Solids: Total	30	37	67	61	72	60	50	43	63	84	36	59	56	62	63	47	29
Soluble	22	36	46	41	49	49	47	47	57	81	16	32	49	58	38	33	22
Suspended	8	1	21	20	23	11	3	6	6	3	20	27	7	4	25	14	7
Loss on ignition (suspended)	6.5		3	4	10	3	2	2	5	1	15	8	3	2	8	14	1
Colour Hazen Unit	35	25	120	110	5	70	15	30	40	40	5	10	5	5	5	20	20
Turbidity	11	19.5	20.5	21.5	16.5	14.5	14	13.5	11.0	8.0	14.5	15.5	14.5	24	15.5	12	16.5

TABLE I.5.2 SUMMARY OF CHEMICAL ANALYSES - SUNGAI KEJAPIL DOWNSTREAM OF BEKENU ROAD BRIDGE

Date	11-10-71	4-10-72	9-10-72	23-10-72	21-11-72	21-12-72	29-12-72	5-1-73	17-1-73	24-1-73	31-1-73	7-2-73
Time	1445	1430	1445	1630	1515	1220	1200	1520	1415	1530	1500	1320
Gauge height (feet)				0.95	2.08	0.81	0.75	0.65	0.60	0.56	0.52	0.53
Discharge (cumecs)				1.87	8.48	0.858	0.555	0.275	0.177	0.130	0.093	0.102
Carbon dioxide (as CO_2)	6.4	6.0	6.0	4.4	8.6	4.6	3.2	4.2	3.8	2.4	4.2	3.0
Total alkalinity (as $CaCO_3$)	20	12	20	18	14	16	20	20	26	26	26	26
Hardness: Total (as $CaCO_3$)	19	16	19	18	13	17	19	21	22	24	27	25
Calcium (as $CaCO_3$)	9	11	11	18	8	10	9	11	11	10	10	11
Magnesium (as $CaCO_3$)	10	5	8	0	5	7	10	10	11	14	17	14
pH	6.3	6.2	6.3	6.6	6.0	6.3	6.6	6.5	6.8	6.6	6.7	6.7
Chlorides (as Cl)	6	4	5	5	5	5	6	5	6	6	6	6
Soluble iron (as Fe)	2.50	1.20	3.0	2.5	0.8	1.80	2.50	1.40	2.00	1.20	0.50	1.25
Total iron (as Fe)	4.00	2.40	3.5	4.0	1.7	3.00	5.50	2.25	3.00	1.80	0.80	1.40
Oxygen absorption ($KMnO_4$, 4 hrs)	7.75	8.05	5.80	5.00	7.95	5.75	6.10	4.10	3.80	3.40	3.95	4.70
Manganese: Total (as Mn)						0.06			0.05	0.02	0.02	0.01
Soluble (as Mn)						0.01			0.02	0.02	0.01	Tr
Sulphate (as SO_4)						8			10	11	11	11
Silica (as SiO_2)						6			4	7	2	6
Organic phosphate (as PO_4)						Tr			0.01	0.03	0.01	Tr
Solids: Total	89	125	81	135	109	72	54	72	64	61	79	98
Soluble	63	61	53	59	58	64	39	66	47	57	64	58
Suspended	26	64	28	76	51	8	15	6	17	4	15	40
Loss on ignition (suspended)		11	2	14	3.2		35	5	10	3	10	9
Colour Hazen Unit	150	250	130	260	250	95	210	160	150	100	85	100
Turbidity	47.0	100	32.5	>100	>100	44.0	37.0	31.5	34.0	33.5	16.5	19.5

TABLE I.5.2 (cont'd)

Date	14-2-73	28-2-73	7-3-73	21-3-73	4-4-73	24-4-73	2-5-73	9-5-73	29-5-73	7-6-73	10-7-73	17-9-73	24-9-73
Time	1515	1510	1400	1240	1500	1630	1550	1500	1430	1450	1015	1233	1215
Gauge height (feet)	0.52	0.48	1.49	0.57	0.63	1.78	0.94		1.29	2.35	2.32	0.88	0.89
Discharge (cumecs)	0.093	0.061	4.17	0.141	0.233	5.40	1.79		3.56	13.3	12.6	1.32	1.40
Carbon dioxide (as CO_2)	2.4	7.2	3.4	4.0	4.0	8.6	2.0	2.0	9.6	8.4	2.8	2.6	3.6
Total alkalinity (as $CaCO_3$)	26	16	34	26	26	14	14	6	14	20	20	12	20
Hardness: Total (as $CaCO_3$)	24	14	30	29	28	28	38	9	29	23	20	12	26
Calcium (as $CaCO_3$)	12	6	13	18	13	14	23	5	16	14	15	4	14
Magnesium (as $CaCO_3$)	12	8	19	14	15	14	15	4	13	9	5	8	12
pH	6.9	6.7	7.2	6.8	6.9	5.9	6.2	6.5	6.3	6.0	6.0	6.5	6.9
Chlorides (as Cl)	6	3	8	7	7	7	6	3	6	6	5	2	3
Soluble iron (as Fe)	1.00	1.25	1.00	0.65	0.75	0.75	2.80	1.20	0.90	0.90	0.60	0.60	2.0
Total iron (as Fe)	1.50	1.50	1.05	1.75	1.25	1.25	4.80	1.40	1.50	1.50	1.20	2.00	3.0
Oxygen absorption ($KMnO_4$, 4 hrs)	4.45	5.50	5.05	5.0	5.40	8.30	11.70	6.20	10.35	8.20	7.10	6.45	9.15
Manganese: Total (as Mn)	0.03	0.02	0.05	0.05	0.03	0.11	0.04	0.06	0.06	0.15	0.08	0.09	0.07
Soluble (as Mn)	0.01	0.01	0.01	0.01	0.01	Tr	Abs	0.02	Abs	Abs	Abs	Abs	Abs
Sulphate (as SO_4)	13	5	11	14	19	23	26	12	21	13	11	8	15
Silica (as SiO_2)	1	13	15	9	9	9	1	9	10	6	2	9	3
Organic phosphate (as PO_4)	0.01	0.01	0.01	0.01	0.02	Tr	0.01	0.02	Abs	0.01	0.01	0.01	0.02
Solids: Total	77	95	106	111	106	116	125	89	98	115	95	100	70
Soluble	62	68	110	83	89	110	82	64	73	80	63	48	65
Suspended	15	27	6	83	17	6	43	25	25	35	32	52	5
Loss on ignition (suspended)	11	15	2	16	8	5	20	1	10	7	26	3	3
Colour Hazen Unit	70	200	100	70	90	120	250	60	125	150	100	85	130
Turbidity	14.5	43.0	14.5	15.5	21.5	30.5	45.5	23	38	41	42.0	60.5	29.5

TABLE I.5.3 SUMMARY OF CHEMICAL ANALYSES - SUNGAI SIBUTI AT MIRI-BINTULU ROAD BRIDGE

Date	4-10-72	24-10-72	29-12-72	4-1-73	26-1-73	2-2-73	9-2-73	16-2-73	2-3-73	21-3-73	5-4-73	26-4-73	11-5-73
Time	1405	1320	1445	1225	1340	1520	1845	1400	1520	1620	1330	1535	1550
Gauge height (feet)		0.366	0.73	0.45	-0.31	-0.46	-0.43	-0.40	-0.41	1.77	2.17	2.31	1.64
Discharge (cumecs)		1.06	3.33	1.45	0.05	0	0	0	0	12.3	17.2	19.0	10.9
Carbon dioxide (as CO_2)	7.2	5.0	3.6	7.0	3.4	8.8	4.4	2.2	5.6	6.2	6.0	6.0	4.4
Total alkalinity (as $CaCO_3$)	18	28	18	20	38	38	40	40	54	16	24	18	20
Hardness: Total (as $CaCO_3$)	16	10	18	19	29	30	33	32	42	26	28	16	19
Calcium (as $CaCO_3$)	10	9	13	8	16	16	16	15	21	14	16	8	12
Magnesium (as $CaCO_3$)	6	1	5	11	13	14	17	17	21	12	12	8	7
pH	6.3	6.4	6.6	6.4	6.6	6.6	6.7	7.0	6.9	6.1	6.5	6.2	6.9
Chlorides (as Cl)	4	3	5	3	3	5	5	4	5	8	6	5	4
Soluble iron (as Fe)	0.8	2.0	0.5	1.4	2.0	1.2	2.0	2.65	1.15	0.50	0.50	1.0	0.10
Total iron (as Fe)	1.4	3.0	1.1	1.8	4.5	1.7	2.5	3.40	2.50	1.75	1.00	2.25	2.00
Oxygen absorption ($KMnO_4$, 4 hrs)	11.15	7.85	5.85	6.6	5.9	6.35	6.2	6.55	6.05	8.20	8.15	9.10	14.65
Manganese: Total (as Mn)					0.12	0.10	0.11	0.16	0.30	0.16	0.03	0.12	0.25
Soluble (as Mn)					0.08	0.03	0.10	0.03	0.01	0.01	0.01	0.02	0101
Sulphate (as SO_4)					3	3	3	4	1	18	11	6	5
Silica (as SiO_2)					16	2	4	7	12	8	13	21	11
Organic phosphate (as PO_4)					0.01	0.02	0.01	0.01	0.01	0.01	0.02	Tr	0.01
Solids: Total	167	115	60	84	118	92	68	128	120	115	143	153	62
Soluble	76	94	23	30	96	70	52	94	75	85	120	86	50
Suspended	91	21	37	54	22	22	16	34	45	30	23	67	12
Loss on ignition (suspended)	9	2	8	26	15	7	9	6	11	19	8	22	2
Colour Hazen Unit	125	135	130	240	400	300	250	250	110	85	225	220	250
Turbidity	96	91	47.5	62.5	76.5	46.5	46.5	68.0	31.5	35.5	96.0	>100	57

TABLE I.5.3 (cont'd)

Date	31-5-73	8-6-73	13-6-73	15-6-73	13-7-73	21-9-73	25-9-73
Time	1230	1325	1415	1600	1550	1550	1330
Gauge height (feet)	3.54	3.54	2.10	1.19	1.05	0.95	0.95
Discharge (cumecs)	37.0	37.0	16.3	6.92	6.30	5.50	5.50
Carbon dioxide (as CO_2)	9.0	6.6	2.0	2.0	2.6	6.0	3.6
Total alkalinity (as $CaCO_3$)	12	20	20	32	34	18	20
Hardness: Total (as $CaCO_3$)	15	14	18	22	19	11	18
Calcium (as $CaCO_3$)	9	9	12	14	11	11	9
Magnesium (as $CaCO_3$)	6	5	6	8	8	0	9
pH	6.3	6.1	6.1	6.5	6.2	6.3	6.9
Chlorides (as Cl)	5	7	6	6	4	2	3
Soluble iron (as Fe)	0.75	0.70	1.20	1.00	2.00	1.40	1.50
Total iron (as Fe)	1.20	1.20	1.60	1.40	2.60	2.40	2.60
Oxygen absorption ($KMnO_4$, 4 hrs)	11.45	14.75	8.80	10.8	10.95	10.40	9.50
Manganese: Total (as Mn)	0.09	0.40	0.15	0.28	0.20	0.16	0.14
Soluble (as Mn)	0.01	0.01	0.02	0.02	0.01	Abs	0.02
Sulphate (as SO_4)	8	3	3	4	4	9	9
Silica (as SiO_2)	16	8	11	8	5	8	9
Organic phosphate (as PO_4)	0.01	Tr	0.01	0.01	0.01	0.01	0.01
Soluble: Total	117	78	107	116	113	110	490
Soluble	53	70	77	93	93	63	50
Suspended	64	8	30	23	20	47	440
Loss on ignition (suspended)	15	6	5	11	6	20	12
Colour Hazen Unit	225	200	130	200	210	175	225
Turbidity	67	54	43	53	54	48.5	66

TABLE I.5.4 SUMMARY OF CHEMICAL ANALYSES - SUNGAI NIAH AT RUMAH LEBIH

Date	19-9-72	27-10-72	21-11-72	17-1-73	24-1-73	31-1-73	7-2-73	14-2-73	28-2-73	7-3-73	21-3-73	6-4-73
Time	1445	1130	1120	1045	1145	1100	1100	1130	1200	1245	1400	1215
Gauge height (feet)	0.56	1.00	2.00	1.13	0.12	0.02	0	0.11	0.60	0.64	3.35	10.75
Discharge (cumecs)	3.68	9.10	26.5	11.1	0.90	0.53	0.47	0.86	4.05	4.47	61.5	5.75
Carbon dioxide (as CO_2)	4.2	4.8	5.8	4.0	2.0	5.4	3.0	4.6	6.4	7.6	10.4	4.8
Total alkalinity (as $CaCO_3$)	18	16	18	18	22	26	26	24	32	22	12	16
Hardness: Total (as $CaCO_3$)	14	10	12	10	16	20	20	14	28	13	12	12
Calcium (as $CaCO_3$)	8	5	7	3	7	7	8	7	12	6	5	5
Magnesium (as $CaCO_3$)	6	5	5	7	9	13	12	7	16	7	7	7
pH	6.7	6.4	6.2	6.0	6.4	6.6	6.6	6.4	6.2	6.2	5.7	6.3
Chlorides (as Cl)	5	3	4	4	3	3	3	4	7	6	6	4
Soluble iron (as Fe)	0.3	0.9	0.8	0.8	2.50	1.0	2.5	2.0	1.25	1.00	0.65	1.0
Total iron (as Fe)	0.9	2.0	1.4	1.6	4.0	1.2	2.75	2.25	1.75	2.00	1.65	1.25
Oxygen absorption ($KMnO_4$, 4 hrs)	5.25	4.15	4.8	5.25	4.25	4.75	4.90	5.55	5.15	4.95	5.60	5.20
Manganese: Total (as Mn)				0.05	0.02	0.05	0.01	0.03	0.04	0.07	0.08	Tr
Soluble (as Mn)				Abs	0.01	0.01	Tr	0.01	0.01	0.01	0.01	Tr
Sulphate (as SO_4)				4	2	3	4	4	9	12	6	5
Silica (as SiO_2)				5	8	3	2	4	12	14	8	9
Organic phosphate (as PO_4)				0.01	0.06	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Solids: Total	78	84	131	60	64	81	84	64	97	138	81	87
Soluble	37	37	38	20	49	59	42	56	81	81	56	65
Suspended	41	47	93	40	15	22	42	8	16	57	25	22
Loss on ignition (suspended)	38	6	2.4	4	6	11	6	5	5	15	11	13
Colour Hazen Unit	150	100	150	125	200	200	200	175	100	150	100	130
Turbidity	31.5	34.5	>100	72	30.5	26	27	21.5	16.5	100	33.5	46.5

TABLE I.5.4 (cont'd)

Date	24-4-73	2-5-73	9-5-73	29-5-73	5-6-73	13-6-73	20-6-73	11-7-73	18-9-73	20-9-73	27-9-73
Time	1430	1130	1330	1144	1240	1215	1530	1135	1300	1100	0820
Gauge height (feet)	2.20	1.85	2.23	3.23	5.35	1.96	1.27	3.85	1.89	0.95	1.64
Discharge (cumecs)	30.7	23.7	31.5	57.9	143	25.7	13.2	78.7	24.4	8.40	19.7
Carbon dioxide (as CO_2)	5.6	1.6	2.0	7.6	3.6	1.8	1.4	2.4	5.4	2.2	2.0
Total alkalinity (as $CaCO_3$)	14	12	12	10	18	18	14	16	24	14	14
Hardness: Total (as $CaCO_3$)	10	13	12	11	8.5	12	11	9	21	9	12
Calcium (as $CaCO_3$)	5	7	6	6	6	5	6	8	11	4	5
Magnesium (as $CaCO_3$)	5	6	6	5	2.5	7	5	1	10	5	7
pH	6.1	6.2	6.6	6.2	6.1	6.0	6.1	6.0	6.6	6.6	6.9
Chlorides (as Cl)	5	3	3	4.5	6	5	5	4	2	2	2
Soluble iron (as Fe)	0.75	0.60	0.40	0.50	0.40	0.80	1.00	0.40	2.00	0.80	0.80
Total iron (as Fe)	1.0	1.10	1.40	1.10	0.70	1.50	1.40	0.80	4.00	1.60	1.40
Oxygen absorption ($KMnO_4$, 4 hrs)	4.35	3.85	6.00	6.60	5.05	4.90	4.70	4.35	12.30	4.80	5.05
Manganese: Total (as Mn)	0.05	0.04	0.10	0.05	0.05	0.12	0.07	0.05	0.14	0.05	0.07
Soluble (as Mn)	Abs	Abs	Abs	0.01	Tr	Tr	Tr	Abs	Abs	Abs	Abs
Sulphate (as SO_4)	6	9	6	4	3	6	7	4	10	7	11
Silica (as SiO_2)	11	4	13	13	15	8	5	8	4	9	4
Organic phosphate (as PO_4)	Tr	0.01	0.01	Tr	Tr	0.01	0.01	0.01	0.01	0.15	0.01
Solids: Total	108	81	130	115	80	100	95	70	103	68	61
Soluble	74	18	30	36	60	32	49	39	76	49	39
Suspended	34	63	100	79	20	68	46	31	27	19	22
Loss on ignition (suspended)	9	3	21	14	11	12	13	15	19	13	11
Colour Hazen Unit	125	100	125	125	110	60	60	70	200	125	125
Turbidity	27.0	57	70	>100	>100	56.0	50.5	27.0	29.5	49.5	54

TABLE I.5.5 SUMMARY OF CHEMICAL ANALYSES - SUNGAI SUAI UPSTREAM OF MIRI-BINTULU ROAD BRIDGE

Date	19-9-72	28-10-72	1-12-72	17-12-72	4-1-73	20-1-73	25-1-73	1-2-73	8-2-73	15-2-73	1-3-73	16-3-73
Time	0930	1015	1820	1235	1415	1440	1245	1310	1330	1310	1315	1175
Gauge height (feet)		5.05	4.55	2.22	0.78	(0.58)	0.60	0.11	-0.25	0	0.65	3.96
Discharge (cumecs)		95.5	73.00	23.4	5.07	(3.77)	3.88	1.60	0.43	1.17	4.19	55.1
Carbon dioxide (as CO_2)	6.8	11.4	2.8	11	5.4	4.2	2.4	8.0	3.2	2.6	7.6	8.0
Total alkalinity (as $CaCO_3$)	12	12	8	6	14	16	16	18	26	22	14	12
Hardness: Total (as $CaCO_3$)	6	10	6	6	8	8	10	12	12	11	8	6
Calcium (as $CaCO_3$)	3	5	2	4	3	5	5	6	4	4	6	1
Magnesium (as $CaCO_3$)	3	5	4	2	5	3	5	6	8	7	2	5
pH	5.9	5.5	6.6	6.1	6.1	6.2	6.2	6.2	6.7	6.7	6.1	5.9
Chlorides (as Cl)	5	4	5	3	4	3	3	4	5	4	4	4
Soluble iron (as Fe)	0.6	0.25	0.5	0.5	2.25	0.9	1.4	0.9	2.5	2.5	1.0	0.50
Total iron (as Fe)	0.8	0.80	0.8	1.3	2.5	1.4	2.0	1.1	3.0	2.75	1.25	1.25
Oxygen absorption ($KMnO_4$, 4 hrs)	6.45	5.95	6.65	4.6	5.25	5.75	5.5	5.5	7.30	6.20	7.00	5.55
Manganese: Total (as Mn)				0.07		0.04	0.03	0.05	0.09	0.05	0.02	0.07
Soluble (as Mn)				0.06		0.01	Tr	Tr	0.02	0.01	0.01	0.02
Sulphate (as SO_4)				2		3	1	2	2	2	2	6
Silica (as SiO_2)				6		6	6	2	3	4	15	8
Organic phosphate (as PO_4)				Tr		0.01	0.02	0.01	0.01	0.01	0.01	0.01
Solids: Total	76	83	104	97	63	25	54	63	48	67	74	174
Soluble	55	28	24	36	29	21	50	40	41	61	47	67
Suspended	21	55	80	61	34	4	4	23	7	6	27	107
Loss on ignition (suspended)	17	4	5		5	8	3	14	6	5	15	20
Colour Hazen Unit	125	100	125	65	140	125	125	175	250	150	150	150
Turbidity	59.5	26.5	>100	61.5	28.0	35	23	28	28	20.5	36	>100

TABLE I.5.6 (cont'd)

Date	15-3-73	20-3-73	6-4-73	26-4-73	4-5-73	11-5-73	31-5-73	5-6-73	15-6-73	13-7-73	21-9-73	28-9-73
Time	1700	1245	0900	1130	0930	0835	1000	1030	0854	0925	0900	0830
Gauge height (feet)	2.48	4.12	2.31	2.67	3.10	2.58	1.17	3.11	1.53	1.45	2.07	1.89
Discharge (cumecs)	16.2	43.8	14.1	18.4	24.6	17.4	2.51	24.8	5.03	4.23	11.2	9.08
Carbon dioxide (as CO_2)	7.6	2.4	4.0	4.0	2.0	2.4	3.0	3.6	1.6	2.0	2.8	2.2
Total alkalinity (as $CaCO_3$)	20	10	12	12	10	6	14	18	12	18	8	10
Hardness: Total (as $CaCO_3$)	8	6	9	7	10	11	30	10	8	7	5	9
Calcium (as $CaCO_3$)	4	4	4	3	6	4	7	6	5	5	3	4
Magnesium ($caCO_3$)	4	2	5	4	4	7	23	4	3	2	2	5
pH	6.0	6.2	6.1	6.0	6.0	6.4	6.8	6.1	5.9	6.0	6.3	6.7
Chlorides (as Cl)	5	7	4	5	3	4	5	6	6	4	2	2.5
Soluble iron (as Fe)	0.20	0.40	0.25	0.50	0.30	0.90	1.00	0.40	0.60	0.60	0.40	0.50
Total iron (as Fe)	0.40	1.25	0.75	0.75	1.00	1.00	1.20	0.80	0.80	0.95	0.70	1.10
Oxygen absorption ($KMnO_4$, 4 hrs)	6.60	6.40	5.65	4.95	5.45	5.55	5.00	7.35	3.05	3.00	5.65	4.85
Manganese: Total (as Mn)	0.04	0.09	0.04	0.03	0.11	0.04	0.02	0.08	0.02	Tr	0.03	0.04
Soluble (as Mn)	0.01	0.01	0.01	Abs	Abs	Abs	Abs	Tr	Tr	Abs	Abs	Abs
Sulphate (as SO_4)	6	5	2	3	4	13	9	4	4	3	3	5
Silica (as SiO_2)	4	5	3	6	2	8	8	5	5	2	2	1
Organic phosphate (as PO_4)	0.01	0.01	0.02	0.01	0.01	0.01	Tr	Abs	Tr	0.01	0.01	0.01
Solids: Total	84	113	48	107	90	43	44	65	34	50	38	35
Soluble	67	38	39	52	12	16	28	41	30	42	18	20
Suspended	17	75	9	55	78	27	16	24	4	8	20	15
Loss on ignition (suspended)	5	25	5	1	4	1	3	11	3	5	4	6
Colour Hazen Unit	110	100	70	85	85	7	100	70	20	40	70	70
Turbidity	37	50.5	28	28	76.5	23	16.5	41.0	15.5	13.5	20.5	23

I.6 EVAPORATION STUDIES

GENERAL

Both evaporation pan data and climate data suitable for use with the various evaporation formulae are available in the Study Area. Although the American Class A evaporation pan has been recommended by the World Meteorological Organisation as a reference instrument, in practice it has many drawbacks. Some of these stem from a lack of appreciation of the need for strict adherence to the prescribed installation, operation and maintenance standards, and some from the basic unsuitability of the Class A pan in certain environments. In the Study Area, and indeed throughout much of South-east Asia, frequent intense rainfall causes water to splash out of the pan, and can lead to over-estimates of evaporation on rainy days. Systematic corrections cannot be made for splash nor for departures from standard operating procedures. Consequently the pan data must be used with caution. The hydrological studies have not made use of pan data, and they are presented here only for the sake of general comparison.

A more satisfactory basis for the estimation of evaporation is the combined energy balance and bulk aerodynamic equation first put forward by Penman (1947). Estimates using this approach were made for Miri, Bintulu and Kabuloh, and are described below.

CLASS A PAN EVAPORATION

There are nine complete calendar years of Class A pan data for Miri and Bintulu. For this period the annual totals are:-

Miri	1 800 millimetres (71 inches)
Bintulu	1 730 millimetres (68 inches)

In January 1969, the Meteorological station at Miri was moved some miles from Kampong Wireless to its present site at the Airport. Double-mass comparison with the Bintulu data does not show any changes in the Miri data corresponding to this move, so the series is considered to be homogeneous.

For the sake of comparison with the Penman evaporation estimates (see below) monthly average pan evaporation was computed for the six years 1967 to 1972. These figures are shown in Table I.6.1.

TABLE I.6.1 MONTHLY CLASS A PAN EVAPORATION IN MILLIMETRES PER DAY AND INCHES PER DAY (1967-72)

Month	Station			
	Miri		Bintulu	
	Millimetres	Inches	Millimetres	Inches
January	3.99	0.157	4.24	0.167
February	4.57	0.180	4.45	0.175
March	4.70	0.185	4.93	0.194
April	5.05	0.199	4.93	0.194
May	5.17	0.203	5.03	0.198
June	4.95	0.195	4.60	0.181
July	5.05	0.199	4.55	0.179
August	5.00	0.197	4.90	0.193
September	5.13	0.202	4.75	0.187
October	4.98	0.196	4.55	0.179
November	4.49	0.177	4.34	0.171
December	4.19	0.165	4.29	0.169
Year	4.77	0.188	4.62	0.182

Pan evaporation observations were started at Kabuloh during October 1972 (Appendix I.3, Table I.3.8). Table I.6.2 compares the pan evaporation at all three stations.

During the twelve month period covered by Table I.6.2, the pan evaporation totals at Miri and Bintulu were 104 per cent and 93 per cent of their respective nine year means. The total for Kabuloh is therefore probably within five per cent of the mean.

THE PENMAN OPEN WATER EVAPORATION ESTIMATE

General

The Penman equation may be written in general form as:

$$E_o = H_A - H_B + E_A$$

where $$H_A = \frac{\Delta}{\Delta+\gamma} \cdot R_A\,(a_1 + a_2 n/N)(1 - r) \qquad (1)$$

$$H_B = \frac{\Delta}{\Delta+\gamma} \cdot T_A{}^4(a_3 - a_4 . e_d{}^{1/2})(a_5 + a_6 n/N) \qquad (2)$$

$$E_A = \frac{\gamma}{\Delta+\gamma} \cdot a_7(a_8 + a_9 . U_2)(e_a - e_d) \qquad (3)$$

TABLE I.6.2 CLASS A PAN EVAPORATION IN MILLIMETRES PER DAY, NOVEMBER 1972 TO OCTOBER 1973

Month	Station		
	Miri	Kabuloh	Bintulu
<u>1972</u>			
November	4.90	4.27	3.94
December	5.19	4.37	4.33
<u>1973</u>			
January	5.09	4.74	3.89
February	5.57	5.25	4.59
March	5.23	4.73	5.64
April	5.61	4.76	4.45
May	5.08	4.54	4.42
June	5.20	4.30	4.79
July	5.32	4.49	4.60
August	5.01	4.32	4.41
September	4.58	4.79	4.07
October	4.92	4.72	4.30
Year	5.14	4.60	4.38

The climatic parameters and fixed constants are described in Table I.6.3. The parameters a_1 to a_9 are empirical constants.

The Penman equation was originally derived from experimental data obtained at the Rothamstead Experimental Station in England. Before it can be applied with confidence elsewhere, two general questions have to be answered:

(a) Do the empirical constants a_1 to a_9 vary significantly from place to place?

(b) Does the way in which the climate parameters are measured and their means calculated significantly affect the answer?

Despite the widespread application of the Penman equation, fully satisfactory answers to these questions are not available. It was therefore necessary to investigate them before using the Penman equation in the Study Area.

The Empirical Constants

In the equatorial region, with little variation of daily mean temperature and vapour pressure, and with generally low windspeeds, the largest element of the Penman formula is equation one, the incoming solar energy term. The values of the constants a_1 and a have been evaluated for many locations and found to vary considerably. It was therefore decided to investigate their values in the Study Area, and to equip the climate station at Kabuloh with a radiation integrator as we-

TABLE I.6.3 TERMS OF THE PENMAN EQUATION

Term	Description	Units used	Remarks
Δ	Slope of the saturation vapour pressure curve at mean air temperature T_A	mb/^oC	Obtained from tables.
γ	Psychrometric constant for aspirated conditions at given ambient pressure	mb/^oC	γ = 0.667 mb/^oC for Study Area.
R_A	Theoretical vertical radiation in absence of an atmosphere	mm/day	Radiation in cal/cm^2/day obtained from tables is converted to equivalent by dividing by the latent heat of evaporation. In the Study Area (mean temperature 28^{o}C) latent heat of evaporation taken as 58.3 cal/mm
R_I	Measured incoming radiation	mm/day	If available, R_I is substituted for R_A $(a_1 + a_2n/N)$ in equation 1. See also remarks for R_A.
n	Observed sunshine	hr/day	Measured by Campbell-Stokes pattern sunshine recorder.
N	Maximum theoretically possible hours of sunshine	hr/day	Obtained from tables.
$\cdot T_A^4$	Black body radiation at mean air temperature	mm/day	Radiation from tables converted to equivalent evaporation as for R_A.
ld	Mean vapour pressure	mb	
U_2	Mean wind run at 2 metres above ground	km/day	
(la - ld)	Mean saturation deficit	mb	

ll as a sunshine recorder (instrument details and daily records are given in Appendix I.2).

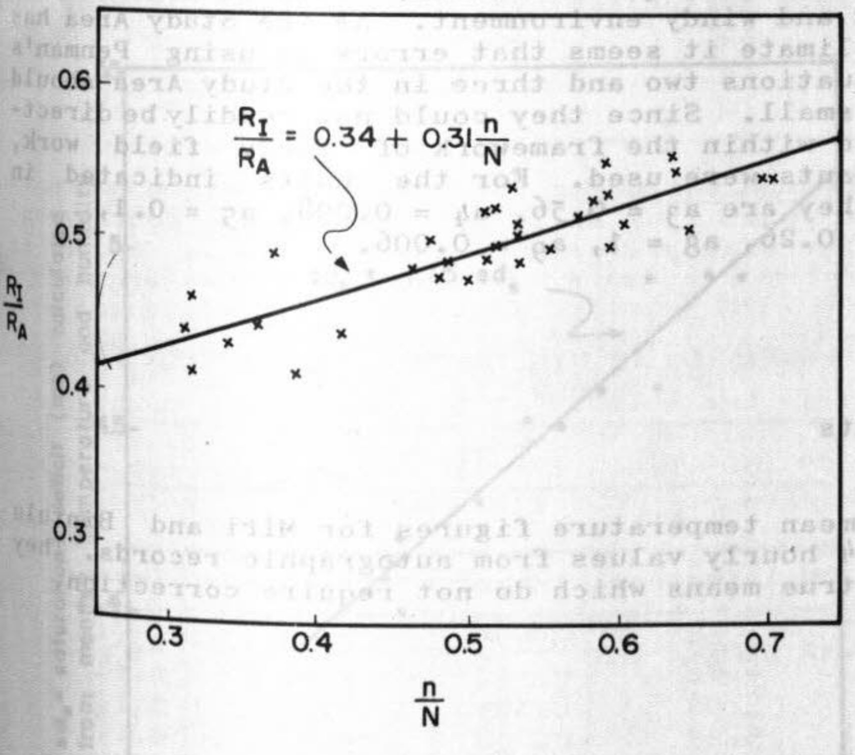
Based on averages for "ten-day" periods (1st to 10th, 11th to 20th and 21st to end of each month), a regression analysis was carried out. The results are shown in Figure I.6.1. The least squares regression equation for estimating RI/RA was:

$$RI/RA = 0.34 + 0.31\ n/N$$

This equation was used to estimate incoming radiation at Miri and Bintulu. The values of the constants are appreciably different to those obtained at other equatorial stations, as Table I.6.4 shows and support the need for local verification.

FIGURE I.6.1

CORRELATION BETWEEN RADIATION AND SUNSHINE AT KABULOH



Note: Based on 10-day averages for the period Nov. 1972 - Sept. 1973

R_I = Measured incoming radiation

R_A = Theoretical vertical radiation in absence of an atmosphere

n = Observed sunshine

N = Maximum theoretically possible hours of sunshine

TABLE I.6.4 COMPARISON OF VALUES OF COEFFICIENTS a_1 AND a_2

Station	Latitude	a_1	a_2	Source
Kabuloh	4°07' north	0.34	0.31	Miri-Bintulu Study
Singapore (Paya Lebar)	1°21' north	0.25	0.47	Chia (1969)
Singapore (University)	1°19' north	0.23	0.46	Chia (1969)
Kuala Lumpur	3°07' north	0.24	0.41	Miri-Bintulu Study from unpublished data

The validity of equation two, estimating the net outgoing longwave radiation, has been less often investigated. Fitzpatrick and Stern (1965) found that the coefficients in Penman's version of equation two did not suit a dry monsoonal environment in Western Australia except during warm wet periods. The same authors conclude that Penman's version of the bulk aerodynamic term (equation three) could be seriously in error in a dry and windy environment. As the Study Area has a warm humid climate it seems that errors in using Penman's versions of equations two and three in the Study Area should be relatively small. Since they could not readily be directly investigated within the framework of Study field work, Penman's constants were used. For the units indicated in Table I.6.3, they are $a_3 = 0.56$, $a_4 = 0.008$, $a_5 = 0.1$, $a_6 = 0.9$, $a_7 = 0.26$, $a_8 = 1$, $a_9 = 0.006$.

Climate Elements

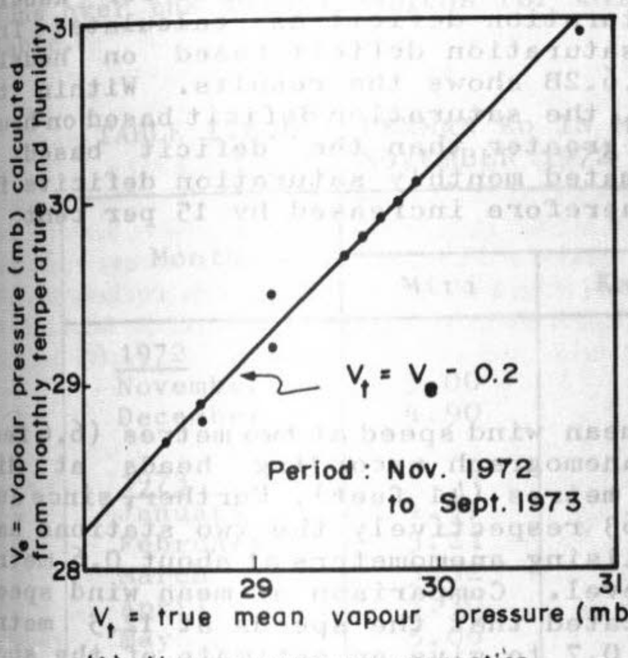
Temperature

The published mean temperature figures for Miri and Bintulu are based on 24 hourly values from autographic records. They are therefore true means which do not require correction.

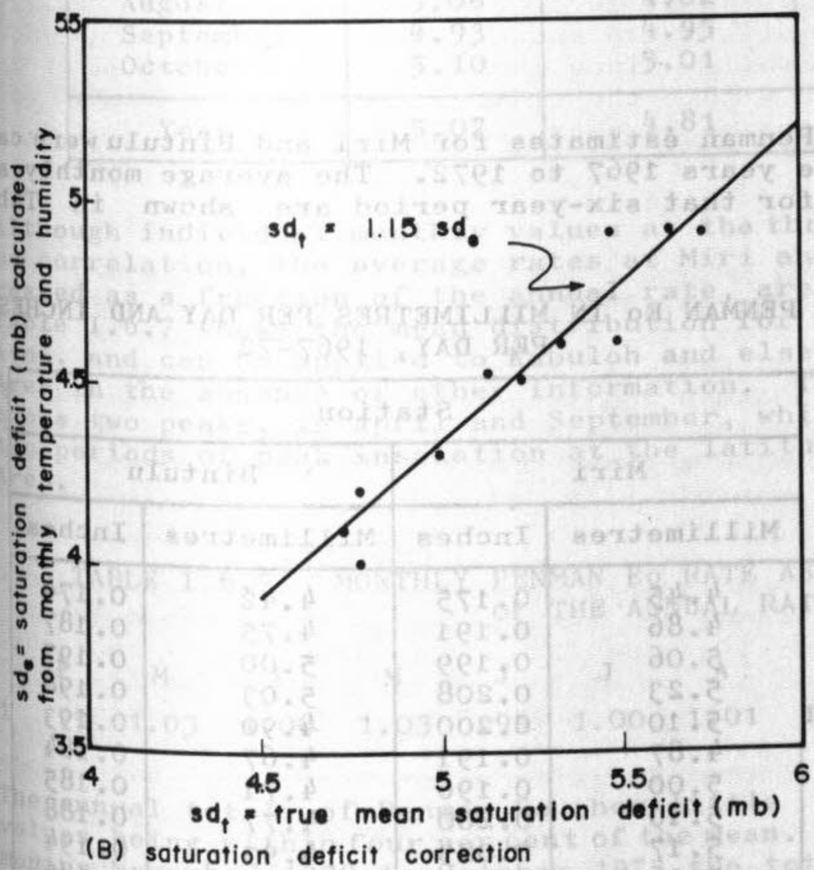
Vapour Pressure

For Miri and Bintulu it was necessary to calculate mean vapour pressure from mean temperature and relative humidity, as vapour pressure figures are not published. Using data from Kabuloh, for which hourly figures of vapour pressure were calculated from thermohygrograph data, the true monthly mean vapour pressure was compared with the mean calculated from monthly mean temperature and relative humidity. Figure I.6.2A shows that the systematic difference is very small. The reason for this is that there is little diurnal variation of vapour pressure.

FIGURE I.6.2



(A) Vapour pressure correction



(B) saturation deficit correction

Saturation Deficit

Mean figures for saturation deficit are needed for equation four. Again for Miri and Bintulu it was necessary to calculate the monthly mean saturation deficit from monthly mean air temperature and relative humidity. Records for Kabuloh were used to compare saturation deficit as calculated from monthly data with mean saturation deficit based on hourly calculations. Figure I.6.2B shows the results. Within the sensitivity of the data, the saturation deficit based on hourly data was 15 per cent greater than the deficit based on monthly data. The estimated monthly saturation deficits for Miri and Bintulu were therefore increased by 15 per cent to allow for this.

Wind

Equation four requires mean wind speed at two metres (6.6 feet) above the ground. The anemograph recording heads at Miri and Bintulu are at 12.5 metres (41 feet). Further, since August 1964 and October 1963 respectively the two stations have been equipped with totalising anemometers at about 0.6 metre (two feet) above ground level. Comparison of mean wind speeds at the two heights indicated that the speeds at 12.5 metres should be multiplied by 0.7 to give an estimate of the speed at two metres. This factor was used for Miri and Bintulu.

Results

Final monthly Penman estimates for Miri and Bintulu were calculated for the years 1967 to 1972. The average monthly and annual values for that six-year period are shown in Table I.6.5.

TABLE I.6.5 PENMAN Eo IN MILLIMETRES PER DAY AND INCHES PER DAY, 1967-72

Month	Station			
	Miri		Bintulu	
	Millimetres	Inches	Millimetres	Inches
January	4.45	0.175	4.42	0.174
February	4.86	0.191	4.75	0.187
March	5.06	0.199	5.00	0.197
April	5.23	0.208	5.03	0.198
May	5.10	0.200	4.90	0.193
June	4.87	0.191	4.67	0.184
July	5.00	0.196	4.71	0.185
August	5.10	0.200	4.77	0.188
September	5.17	0.023	4.93	0.194
October	5.06	0.199	4.81	0.189
November	4.77	0.187	4.60	0.181
December	4.55	0.179	4.39	0.173
Year	4.94	0.194	4.75	0.187

Table I.6.6 compares the Penman estimates for the three stations over the twelve months for which Kabuloh data are available.

TABLE I.6.6 PENMAN Eo IN MILLIMETRES PER DAY, NOVEMBER 1972 TO OCTOBER 1973

Month	Station		
	Miri	Kabuloh	Bintulu
1972			
November	5.00	4.63	4.80
December	4.90	4.75	4.68
1973			
January	4.97	4.66	4.71
February	5.21	4.67	5.11
March	5.32	4.72	5.03
April	5.30	5.04	5.00
May	5.06	4.82	4.90
June	5.03	4.84	4.90
July	5.00	4.79	4.90
August	5.06	4.82	4.90
September	4.93	4.95	4.77
October	5.10	5.01	5.00
Year	5.07	4.81	4.89

Although individual monthly values at the three stations have no correlation, the average rates at Miri and Bintulu, expressed as a fraction of the annual rate, are very similar. Table I.6.7 shows the mean distribution for these two stations, and can be applied to Kabuloh and elsewhere in the Study Area in the absence of other information. The distribution shows two peaks, in April and September, which correspond to the periods of peak insolation at the latitude of the Study Area.

TABLE I.6.7 MONTHLY PENMAN Eo RATE AS A FRACTION OF THE ANNUAL RATE

J	F	M	A	M	J	J	A	S	O	N	D
.91	.99	1.03	1.06	1.03	.99	1.00	1.01	1.05	1.01	.97	.92

The annual totals of Penman Eo show little variation, all values being within four per cent of the mean. For the twelve months November 1972 to October 1973 the totals for both Miri and Bintulu were three per cent greater than their six year means. Allowing for this, the estimated six year mean for Kabuloh is 1 710 millimetres.

Differences in annual Penman Eo between the three sites are of the order of six per cent. Bintulu, with higher rainfall and less insolation, has a smaller Eo than Miri. Kabuloh, with less rainfall than Bintulu, nevertheless shows a slightly smaller Eo. This difference may not be significant, but equally may be an indication of decreasing Eo with distance from the coast. Such a decrease has been observed in the lowlands of West Malaysia (Nieuwolt, 1965; Wycherly, 1966). However, the data at present available do not define these variations from the Study Area in such a way as to permit reliable estimation for places without direct observations. For the present it appears that the total for Kabuloh may be most representative of the Study Area as a whole, which is therefore taken as 1 700 millimetres per year or 4.65 millimetres per day.

I7 COMPUTER RUNOFF MODEL

INTRODUCTION

In order to be able to estimate the yield/storage characteristics of possible impounding schemes without long-term run-off data, it was necessary to simulate monthly run-off from rainfall. The simple catchment model described by Haan (1972) appeared adaptable to small catchments in the Study Area. This model operates on rainfall and potential evapo-transpiration. As proposed by Haan it uses daily input data and in fact operates on an even shorter time scale by using standardised diurnal distributions to represent the average intensity of precipitation.

In adapting the model, it was decided to use monthly rainfall and monthly Penman open water evaporation as basic inputs. While it would reduce the accuracy of the resultant monthly run-off estimates, this approach was necessary because much of the long-term rainfall data was in the form of monthly totals only and also to reduce to a minimum the time needed to adapt the model.

MODEL OUTLINE

The model outline in the form finally used is shown in Figure I.7.1. It consists of three parts:-

(a) Surface

At the surface a proportion of the incoming precipitation is intercepted by the forest canopy. Following the findings of Brunig (1971), Kenworthy (1969) and Low (1972) interception was taken as 35 per cent of rainfall. The intercepted rainfall satisfied part of the evaporation demand. Of the remaining 65 per cent of rainfall, a variable proportion was considered to run directly off into surface water channels, and the remainder to enter the upper soil storage.

(b) Upper soil storage

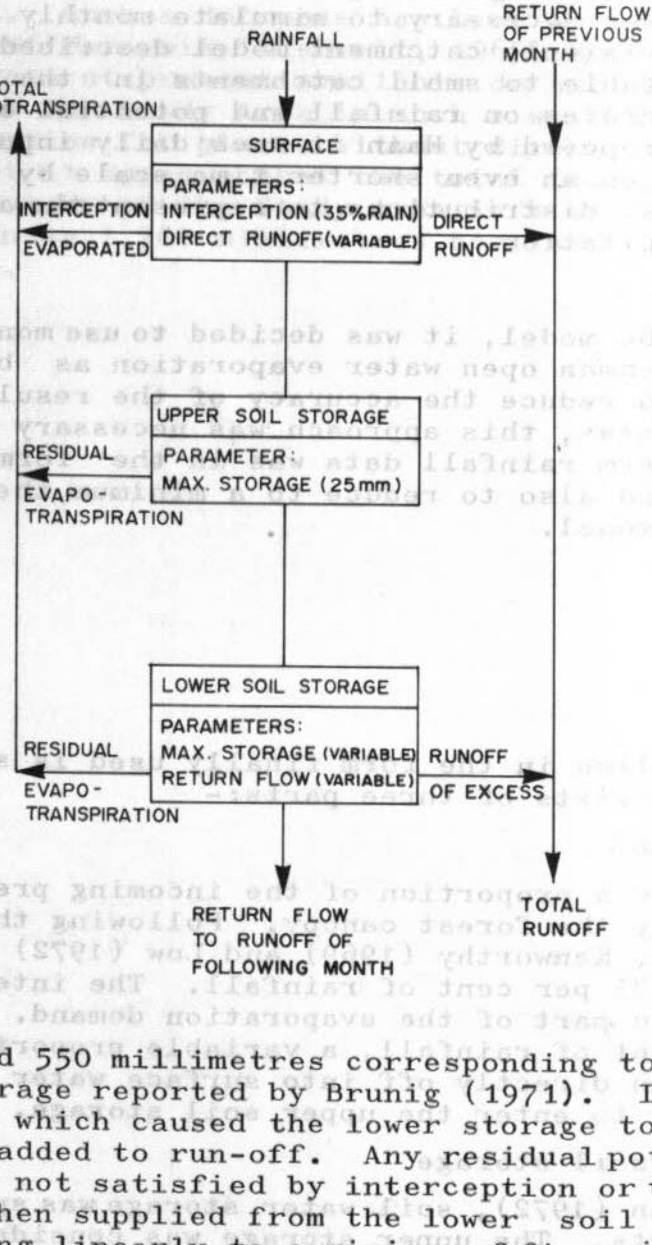
Following Haan (1972), soil water storage was split into upper and lower parts. The upper storage was considered to have a capacity of 25 millimetres. Infiltration first filled this storage and any excess became inflow to the lower soil storage. Residual potential evapo-transpiration was supplied freely from the upper storage, to the 25 millimetres limit on its capacity, and the storage adjusted accordingly.

(c) Lower soil storage

The lower soil storage had a variable maximum capacity. It was not considered that appreciable storage existed below the root zone, and so the limit of the lower soil storage was set

FIGURE 1.7.1

RUNOFF MODEL OUTLINE



between 50 and 550 millimetres corresponding to the range of root zone storage reported by Brunig (1971). Inflow from the upper storage which caused the lower storage to exceed its capacity was added to run-off. Any residual potential evapotranspiration not satisfied by interception or the upper soil storage was then supplied from the lower soil storage at a rate decreasing linearly to a minimum of five millimetres per month depending on the state of the lower storage. Finally a variable proportion of the remaining storage was considered to contribute to run-off in the following month.

Altogether the catchment model has three parameters whose values can be varied to represent different types of catchment. As with all such simplified run-off models, these parameters correspond only approximately to actual physical characteristics. However, this is sufficient for some degree of reasoned judgement to be used in selecting parameters values.

OPTIMISING MODEL PARAMETERS

For most cases, values of the three parameters would have to be selected by using judgement. However, the programme was so written that if short periods of comparable rainfall and run-off data were available, optimum values of the three parameters could be found automatically so as to minimise the overall cumulative error in the estimated run-off values. This optimisation procedure was possible for an eight month period of record for the Sungai Sibiu (station C6, Figure 1.5).

Three of the Study rainfall stations (B4, B5 and B6 on Figure 1.5) together with Bintulu (4-2 on Figure 1.3) gave an indication of monthly catchment rainfall over the months February to September 1973. For seven out of these eight months the simulation procedure produced estimates, after optimising the three variable parameters, which were within 15 per cent of the observed value. The error in the first month was greater than this, probably through the influence of the initial soil moisture status which had to be estimated. The performance of the model with Sungai Sibiu data, of which the rainfall could only be considered an approximation to catchment rainfall, was encouraging. The optimised parameter values were 70 per cent for direct run-off of residual rainfall after subtraction of interception losses, 300 millimetres maximum water storage in the lower layer and 40 per cent of the net lower storage appearing as run-off the following month.

SIMULATION FROM LONGER RAINFALL RECORDS

There were no other catchments for which even approximate areal rainfall figures were available. For the yield/storage studies four rainfall records were chosen as being representative of the main development areas (4-2, 4-5, 4-6 and A-1 in Figure 1.3). The consistency of these records had been checked and found to be good, or fair in the case of 4-6 (see Chapter 1, Section 1.3.6.1).

Of the many possible combinations of the three variable model parameters which could have been used, two combinations were selected so as to represent fairly extreme cases. The values are given in Table I.7.1.

Both sets of parameters in Table I.7.1 are intended to represent forested conditions with a well developed canopy. The poorer soil gives a generally more rapid catchment response and more frequent appearance of soil moisture deficits. In consequence, particularly in the drier areas, run-off is increased and actual evapo-transpiration depressed below the potential rate. Table I.7.2 summarises the variations in actual evapo-transpiration rates, deduced from simulated run-off.

TABLE I.7.1 PARAMETER VALUES USED IN RUN-OFF SIMULATION

Parameter	Poor soil		Good soil	
	Value	Remarks	Value	Remarks
Direct run-off fraction	70%	Soil with low infiltration capacity	50%	Soil with moderate infiltration capacity
Maximum lower soil water storage	75 mm	Shallow soil	325 mm	Deep soil (for tropical forest)
Return flow from lower soil water storage	70%	Rapid drainage due to impermeable under layer	30%	Slower drainage from deeper profile

TABLE I.7.2 EFFECT OF SOIL CONDITION ON EVAPO-TRANSPIRATION

Station	Period	Mean annual rainfall (mm)	Soil condition	Mean annual loss as percentage Penman Eo
4-2 Bintulu	1947-1955 1958-1972	3 750	Good Poor	98 91
4-5 Miri	1947-1968	3 000	Good Poor	88 78
4-6 Bekenu	1953-1972	2 950	Good Poor	88 78
A-1 Kabuloh	1965-1972	2 730	Good Poor	87 76

Note: Soil condition refers to Table I.7.1.

As Figure 1.17 has shown, the differences in average losses are not of great significance when yield/storage relations are considered. The reason for this is that the greater losses from catchments with deeper soils are offset by better maintained low flows. Within the Study Area, most catchments could be expected to fall somewhere between the poor soil and good soil conditions of Table I.7.1. Catchments in the unulating middle areas of the river basins would tend to have the poorer conditions, and those in the Lambir hills or hills south of the Sungai Suai (Figure 1.1) to have the better conditions.

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APPENDIX II

APPENDIX II

SAMPLE AREAS

II.1 SAMPLE AREA A

II.1.1 Location

The area (5 200 acres) is located at mile 68 of Miri-Bintulu road and runs roughly north-south on either side of the road for a distance of nearly 10 kilometres (6.2 miles).

II.1.2 Survey Density

Soil Survey within the area was conducted along parallel rentis lines cut at 400 metres (1 300 feet) intervals for a distance of slightly over 2 kilometres (1.2 miles), and linked at either end by lines cut for a distance of just under 10 kilometres. Auger inspection was carried out with full recorded descriptions at an average interval of 200 metres (650 feet) along the rentis lines, with further check bores where necessary. A total of 290 sites was recorded including 12 fully sampled soil pits, giving an average density of one site per 18 acres; but, including the check bores, the density of observation is rather greater than this.

II.1.3 Geology

The 1:250 000 scale geological map (Baram-Suai Area accompanying Memoir No. 13 Haile, 1962) indicates that the northern two-thirds of the area is covered by deposits of the Nyalau and Setap Shale Formation, the latter predominating. Setap Shale Formation is described by Haile (1962), as "blue grey silty and clayey shale, occasionally sandy, well bedded, moderately soft and lignitic in some bands, but hard and nodular in others". Within the Sample Area, the shale was seen to be predominantly of a very fine sandy, to silty texture. In the areas with a higher elevation, fine grained sandstone occurs on the hill tops in places, and appears to be the eroded remnant of an upper sandy bed; a similar occurrence is described for the Setap Shale Formation in the valley of the Sungai Niah.

The subordinate areas of Nyalau Formation are not really recognisably different from the the Setap Shale. The formation is described as grading into the Setap Shale Formation, and is mostly fine grained.

The southern third of the Sample Area is shown on the Geological map as alluvium, but was found in the field to consist of very low, undulating hills, with only very subordinate alluvium.

II.1.4 Topography

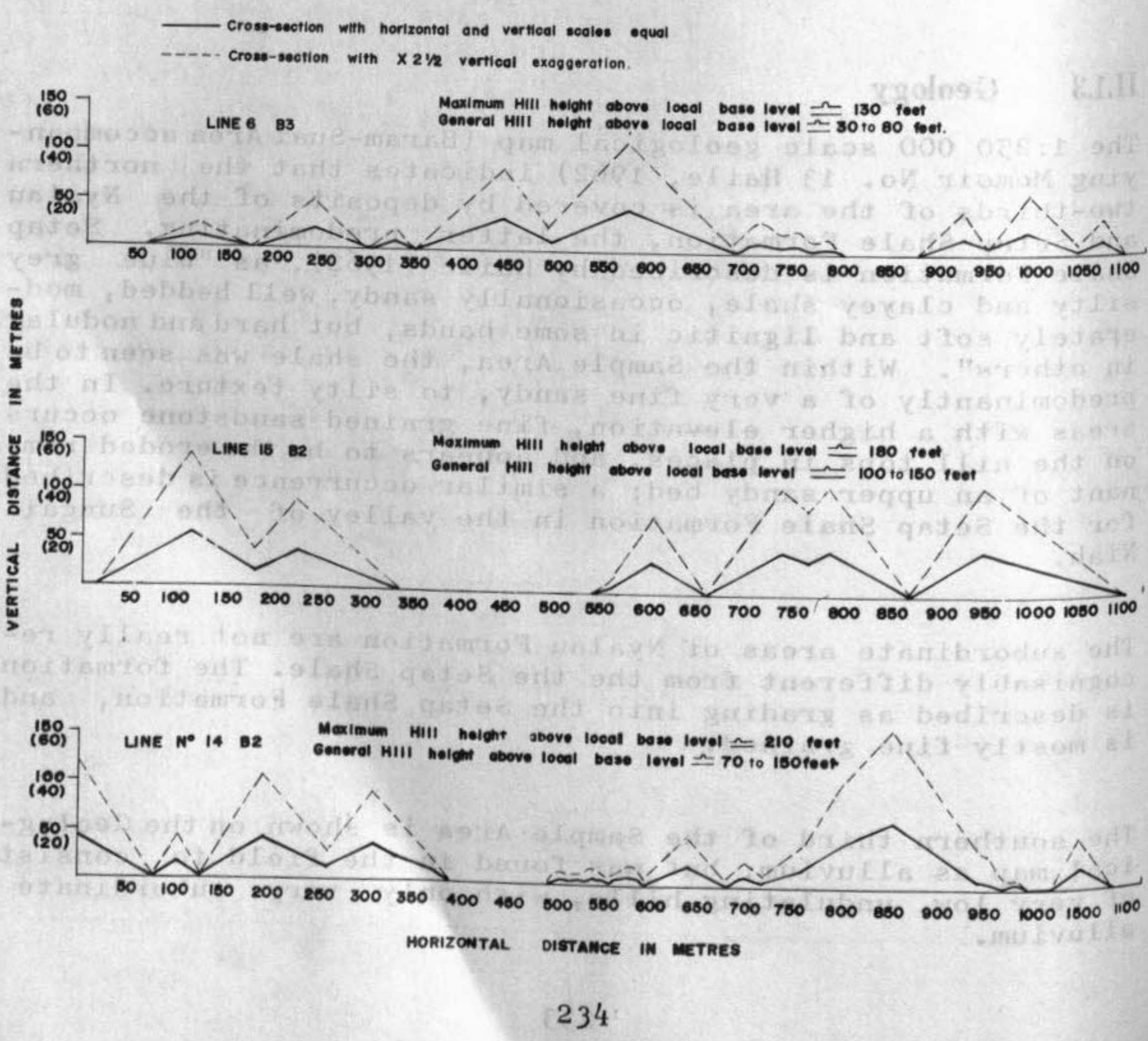
The area has a general north-east to south-west trend imposed by the geology. The highest hills, up to 200 feet above local alluvium level, occur across the middle portion of the area, and are mapped on the aerial photo-interpretation map as B2. Slopes are mainly within the range 20 to 35 degrees, with occasional slopes of 40 degrees coinciding with the occurrence of the remnant sandstone beds. Subsequent erosion of the original north-east to south-west trend has given rise to a series of short, well marked ridges at right angles to this direction, with more or less equal slopes.

The northern third of the area (aerial photo-interpretation (API) unit B3) is lower, many of the hills being less than 75 feet high, with slopes mainly in the range 5 to 15 degrees. Hills tend to have convex tops with no particular alignment.

The southern third (API unit B3/B4) is very low and undulating, less than 50 feet in height, and with slopes generally in the range 5 to 10 degrees. Cross sections of typical API Units are shown in Figure II.1.1.

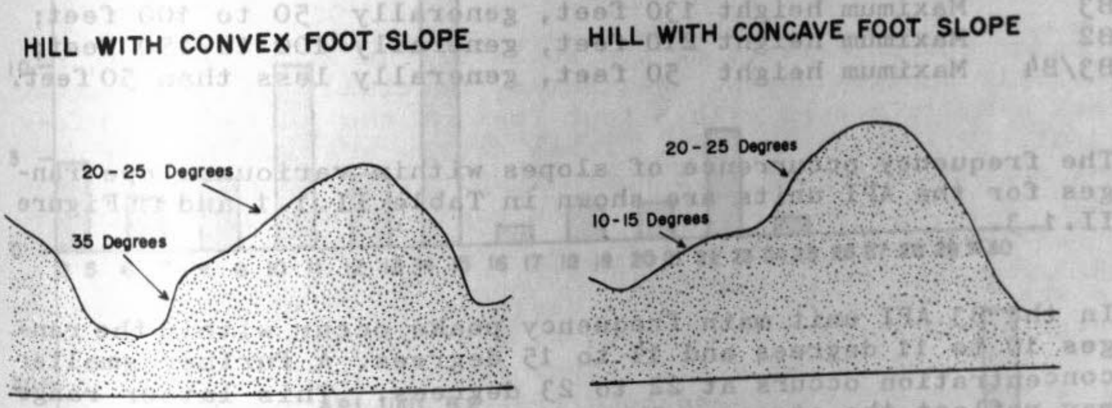
FIGURE II.1.1

TOPOGRAPHIC CROSS SECTIONS



Drainage lines in the area, except in the southern third, are deeply incised, usually into the parent rock, and only the few larger streams like the Sungai Sebubok have significant alluvium. In most cases slopes increase on the valley edges, but, occasionally, decrease and become concave. These latter occurrences appear to be associated with colluvial material which has partially infilled the valley, and in which the stream is too weak to remove it. These two common shapes are shown in Figure II.1.2. Actively eroding valley heads are common throughout the area except in the low, undulating southern third of this area.

FIGURE II.1.2



Apart from the geological erosion associated with headwater regression, other erosion features are common on all steeper slopes, particularly on slopes of more than 25 degrees. The most common evidence is in slip terracettes and exposed tree roots, and in the soil depth itself. Also, the common occurrence of weakly sorted colluvial material at the bottom of steep slopes is further evidence of fairly intense sheet erosion. Soil slips have also been noted, but these do not appear to be a common feature in the area.

TABLE II.1.1 PERCENTAGE OF SITES IN VARIOUS SLOPE RANGES BY API UNITS

Slope range	Percentage of sites API Units		
	B3	B2	B3/B4
0 - 5	12.5	0	20.6
6 - 10	25.0	1	39.6
11 - 15	35.9	3	25.3
16 - 20	9.3	16	12.6
21 - 25	14.0	32	1.5
26 - 30	3.0	35	0
More than 30	0	13	0

From Table II.1.1 it can be concluded that:-

In B3	73 per cent of all sites are less than 15 degrees;
In B2	80 per cent of all sites are more than 20 degrees, 48 per cent more than 25 degrees, and 60 per cent equal to or greater than 24 degrees;
In B3/B4	85 per cent of all sites are less than 15 degrees, 60 per cent less than 10 degrees.

Main slope range in B3 is 11 to 15 degrees;
Main slope range in B2 is 21 to 30 degrees;
Main slope range in B3/B4 is 6 to 10 degrees.

Hill heights are as follows:

B3	Maximum height 130 feet, generally 50 to 100 feet;
B2	Maximum height 210 feet, generally 100 to 150 feet;
B3/B4	Maximum height 50 feet, generally less than 50 feet.

The frequency occurrence of slopes within various slope ranges for the API units are shown in Table II.1.1 and in Figure II.1.3.

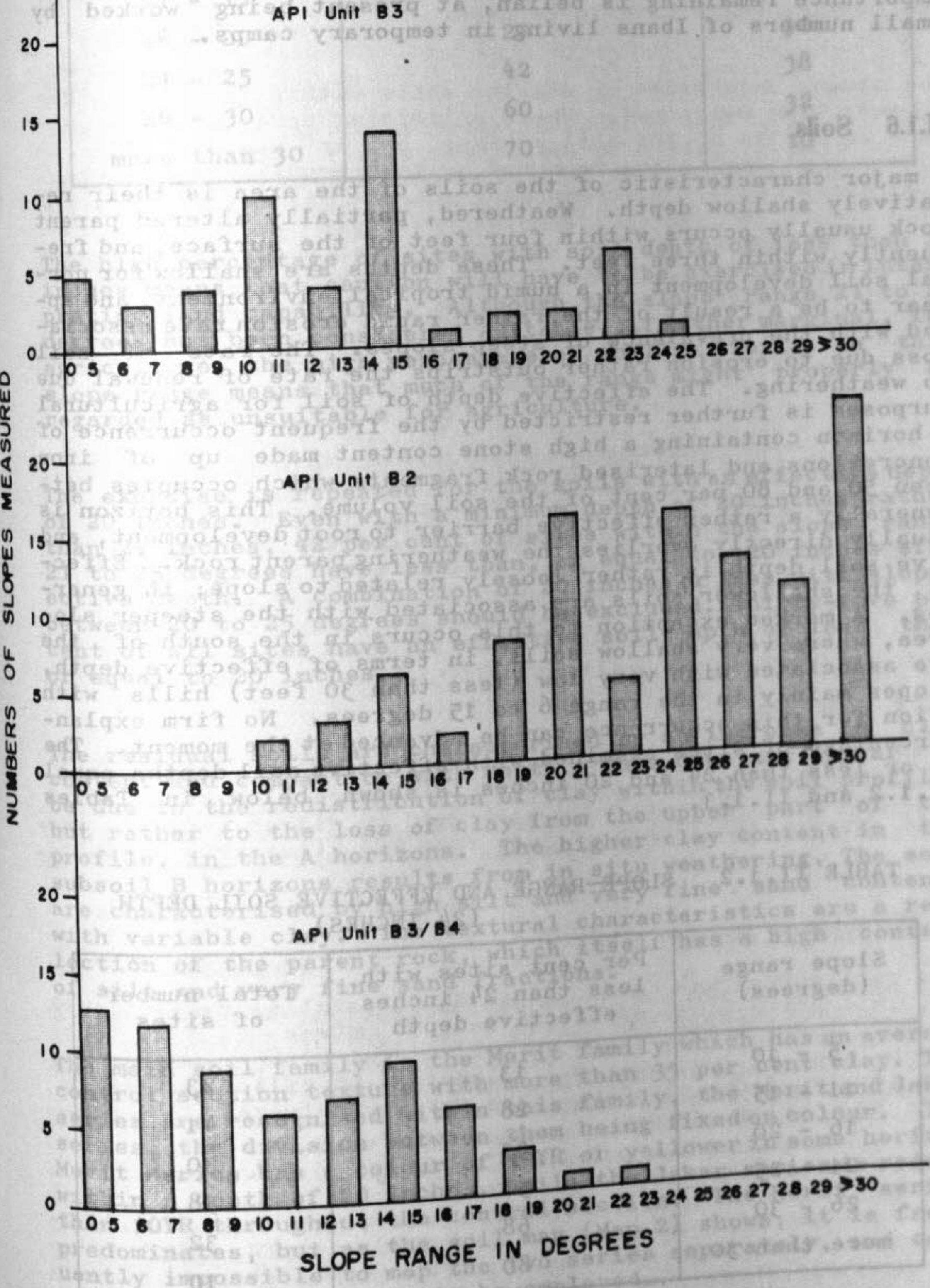
In the B3 API unit main frequency peaks occur within the ranges 10 to 11 degrees and 14 to 15 degrees. A further smaller concentration occurs at 22 to 23 degrees. This latter range may reflect the steeper slopes associated with valley and headwater erosion imposed on low hills. The former ranges appear to be the normal slopes for the sub-mature topography of the B3 API unit, where a subsequent erosion cycle is either absent or limited.

Within the B2 unit, a frequency peak occurs in the slope range 20 to 21 degrees; further concentrations occur at 24 to 25 degrees and more than, or equal to, 30 degrees. It is thought that the 20 to 21 degrees and 24 to 25 degrees concentrations represent the lower hills within the unit, which are less affected by active valley and valley head erosion. The maximum concentration at more than or equal to 30 degrees probably represents the heavily dissected, immature topography of the higher hills, where valley incision and headwater regression are particularly active. Thus the B2 unit may include two topographic types, the gentler slopes within the 20 to 21 degrees and 24 to 25 degree ranges, which are associated with sub-mature topography, and the steep (more than or equal to 30 degrees slopes) associated with immature topography.

The B3/B4 unit represents a mixture of mature and sub-mature topography, the former including the ranges 0 to 5 degrees, 6 to 7 degrees and 8 to 9 degrees which together make up 51 per cent of all slopes, and the latter represented by the slight concentration in the range 14 to 15 degrees, and some 33 per cent of all slopes in the range 12 to 17 degrees.

FIGURE II.1.3

SLOPE ANALYSIS



II.1.5 Vegetation

The area is covered by logged Hill Dipterocarp Forest. Timber extraction from small pockets previously unfelled was in progress during the course of the survey, but was nearly complete. General timber quality appears to have been good except on the steepest areas with shallow soils, and in the southern part of the area where very shallow soils occur on low gently undulating hills. The only species of economic importance remaining is belian, at present being worked by small numbers of Ibans living in temporary camps.

II.1.6 Soils

A major characteristic of the soils of the area is their relatively shallow depth. Weathered, partially altered parent rock usually occurs within four feet of the surface, and frequently within three feet. These depths are shallow for normal soil development in a humid tropical environment, and appear to be a result of the rather rapid erosion rate associated with the prevalence of steep slopes. The rate of soil loss due to erosion rather outstrips the rate of renewal due to weathering. The effective depth of soil for agricultural purposes is further restricted by the frequent occurrence of a horizon containing a high stone content made up of iron concretions and laterised rock fragments which occupies between 50 and 80 per cent of the soil volume. This horizon is generally a rather effective barrier to root development, and usually directly overlies the weathering parent rock. Effective soil depth is rather loosely related to slope; in general, the shallower soils are associated with the steeper slopes. A marked exception to this occurs in the south of the area, where very shallow soils, in terms of effective depth, are associated with very low (less than 30 feet) hills with slopes mainly in the range 6 to 15 degrees. No firm explanation for this occurrence can be advanced at the moment. The percentage of sites examined with effective soil depths equal to or less than 24 and 20 inches is shown below in Tables II.1.2 and II.1.3.

TABLE II.1.2 SLOPE RANGE AND EFFECTIVE SOIL DEPTH (24 INCHES)

Slope range (degrees)	Per cent sites with less than 24 inches effective depth	Total number of sites
5 - 10	13	23
11 - 15	28	41
16 - 20	33	30
21 - 25	58	38
26 - 30	68	32
more than 30	80	10

TABLE II.1.3 SLOPE RANGE AND EFFECTIVE SOIL DEPTH (20 inches)

Slope range (degrees)	Per cent sites with effective depth 20 inches	Number of sites
6 - 10	9	23
11 - 15	22	41
16 - 20	27	30
21 - 25	42	38
26 - 30	60	32
more than 30	70	10

The high percentage of sites with soil depth of less than 24 inches means that caution will have to be exercised in interpreting land capability. Although the slope range 21 to 25 degrees has been considered suitable, if rather marginal, for agriculture, the high percentage of shallow soils in this slope range means that much of the range might properly be regarded as unsuitable for agriculture.

The exercise is repeated for the soils with an effective depth of 20 inches. Even with a minimum depth of 20 inches rather than 24 inches, 42 per cent of sites within the slope range 21 to 25 degrees have less than, or equal to, 20 inches effective depth. A combination of 20 inches or less with slopes between 20 to 25 degrees should be excluded. Thirty-five per cent of all sites have an effective soil depth of less than or equal to 20 inches.

The residual soils are characterised by an increase in clay content and compaction with depth. This does not appear to be due to the redistribution of clay within the soil profile, but rather to the loss of clay from the upper part of the profile, in the A horizons. The higher clay content in the subsoil B horizons results from <u>in situ</u> weathering. The soils are characterised by high silt and <u>very</u> fine sand contents with variable clay. The textural characteristics are a reflection of the parent rock, which itself has a high content of silt and very fine sand fractions.

The main soil family is the Merit family which has an average control section texture with more than 35 per cent clay. Two series are recognised within this family, the Merit and Jakar series, the division between them being fixed on colour. The Merit series has a colour of 10YR or yellower in some horizon within a depth of 20 inches, while the Jakar series is redder than 10YR throughout the control section. The Merit series predominates, but as the soil map (Map 2) shows, it is frequently impossible to map the two series separately, and complex mapping units have to be employed.

Soils of the Bekenu family are found overlying rocks with a particularly high content of silt and very fine sand. The average clay content of the control section is less than 35 per cent, but the combined values of silt and very fine sand ensure textures of coarse and fine silty. Soils of this family, which occupy a smaller area than the Merit family, are divided into two series on the same colour basis as the Merit family soils. As in the Merit family, it is difficult to separate the two series at a field mapping scale of 1:10 000, and complex units have to be used.

The common occurrence of shallow soils within this area has already been mentioned. Where a limiting horizon occurs within 20 inches of the soil surface, but is deeper than 10 inches, such soils are regarded as intergrades between skeletal soils and the corresponding non-skeletal family. The main intergrade family is the Bekenu-Kapit family intergrade, which has the textural characteristics of the Bekenu family but has a limiting horizon within 20 inches of the surface. This limiting horizon may be either a B/C or C horizon or a layer of dense concretions. The Merit-Kapit family intergrade also occurs, but occupies a much smaller area than the Bekenu-Kapit family intergrade.

Alluvial, accreting mineral soils occur within the sample area, but the individual units are too small to map. Soil families recognised are the Seduau and Bijat families and the Seduau-Bijat family intergrades. Very small areas of the Bemang family also occur.

II.2 SAMPLE AREA B

II.2.1 Location

Sample Area B, covering 4 800 acres, is located at Mile 51 on the Bintulu-Miri road, some seven miles south of the Sungai Suai bridge. The area runs east-west on either side of the road for a total length of just over 9.5 kilometres (6 miles).

II.2.2 Survey Density

The soil survey was conducted along 26 parallel rentis lines cut in a north-south direction and 400 metres (1 300 feet) apart. These rentis lines were linked at either end by two cross-lines of just over 9.5 kilometres (6 miles) in length. The length of the parallel lines was approximately 2 kilometres (1.2 miles) each.

The terrain was continuously recorded along each of these cut lines and detailed soil descriptions from auger borings recorded at an average interval of 200 metres (650 feet). In addition 13 soil pits were dug at representative sites to allow detailed sampling of the soil for a wide range of analyses. A total of 325 sites was recorded in this Sample Area, giving an overall survey density of one recorded observation site per 15 acres.

II.2.3 Geology

Rocks of the Setap Shale Formation occupy the greater part of the area, with a very small area of Nyalau Formation in the extreme north-west, according to the 1:250 000 scale Geological Map accompanying Geological Survey Memoir 13 (Haile, 1962). The Setap Shale Formation is described as consisting largely of shale with subordinate sandstone. Much very fine sandy and silty shale does occur, but there are also large areas of fine and medium grained sandstone; it is not known whether the latter represents a greater extent of the Nyalau Formation than shown on the Geological Map or simply a sandstone member of the Setap Shale.

The Geological Map indicates that large areas of alluvium occur at either end of the area. In the western end, true alluvium does not cover large areas and is limited to stream valleys. Most of the area indicated as alluvium is in fact occupied by undulating terrain composed of very low hills generally less then 30 feet high. In the eastern part of the area, alluvium covers a significant area, associated with the Sungai Dulang and Sungai Laham, but intervening areas are occupied by very low, undulating terrain.

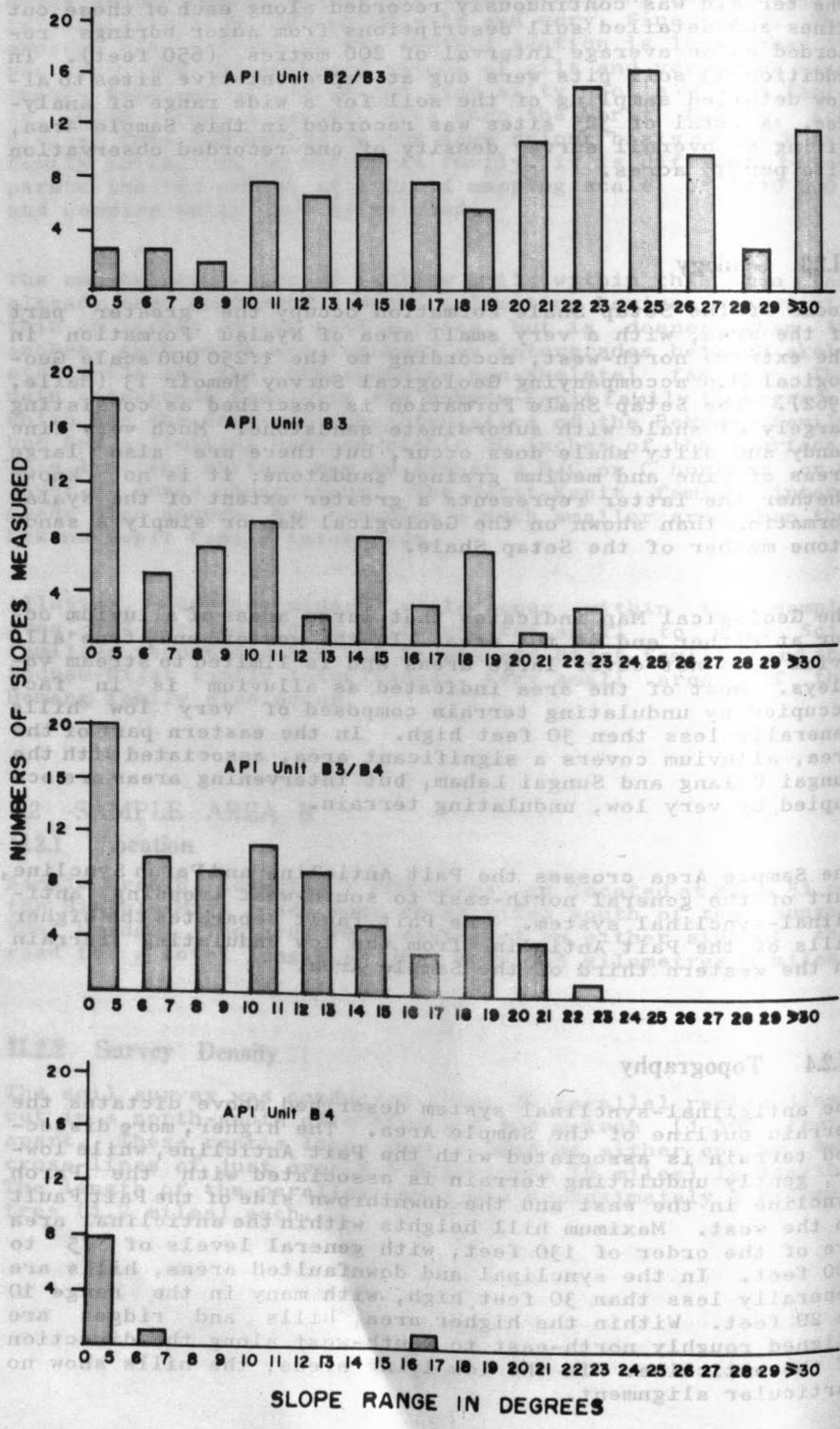
The Sample Area crosses the Pait Anticline and Paroh Syncline, part of the general north-east to south-west trending anticlinal-synclinal system. The Pait fault separates the higher hills of the Pait Anticline from the low undulating terrain in the western third of the Sample Area.

II.2.4 Topography

The anticlinal-synclinal system described above dictates the terrain outline of the Sample Area. The higher, more dissected terrain is associated with the Pait Anticline, while lower, gently undulating terrain is associated with the Paroh Syncline in the east and the downthrown side of the Pait Fault on the west. Maximum hill heights within the anticlinal area are of the order of 130 feet, with general levels of 75 to 100 feet. In the synclinal and downfaulted areas, hills are generally less than 30 feet high, with many in the range 10 to 20 feet. Within the higher area, hills and ridges are aligned roughly north-east to south-west along the direction of the anticline. In the low lying areas, the hills show no particular alignment.

FIGURE II.2.1

SLOPE ANALYSIS



During the preliminary aerial photo-interpretation, the area was divided into four API units. API unit B2/B3 roughly coincides with the Pait Anticline, while units B3 and B3/B4 correspond to the Paroh Syncline and the downfaulted area east of the Pait Fault respectively. The fourth API unit B4 occupies only a small area in the north-east associated with the alluvium of the Sungai Laham. Active dissection of the higher land of the B2/B3 unit is frequently seen, particularly in headwater regression of small streams. The lower areas appear to have reached a much more advanced stage of landscape maturity, with no active dissection.

The following table shows the slope distribution within the various API units. Within the B2/B3 unit, 49 per cent of all sites measured have slopes in excess of 20 degrees and 21 per cent have slopes exceeding 25 degrees. Only 5.5 per cent of sites have slopes exceeding 20 degrees in the B3 unit with figures of one per cent and nil for units B3/B4 and B4 respectively. Within units B3/B4 and B4 slopes of 10 degrees or less predominate, the percentages being 77 per cent and 86 per cent respectively.

Figure II.2.1 shows the frequency distribution of measured
sites within narrow slope ranges for the API units. The dis-
tribution within unit B2/B3 is fairly uniform, but peaks do
occur in the ranges 10 to 11 degrees, 14 to 15 degrees and 22
to 25 degrees. Within the B3 unit, the peaks are at 0 to 5
degrees, 10 to 11 degrees and 14 to 15 degrees. The 0 to 5
degrees peak in the B3 unit reflects the low, gently undulat-
ing nature of much of the unit in this area. The peaks at 10
to 11 degrees and 14 to 15 degrees in both the B3 and B2/B3
units appear to represent the fairly mature topography of the
lower hills. The 22 to 25 degrees peak and the secondary pe-
ak at 30 degrees, or greater in the B2/B3 unit, represent the
rather immature topography of the higher areas, and more clo-
sely resemble the normal B2 unit. The unit B3/B4 shows a
similar slope distribution to the B3 unit, but with a very
much higher percentage of gentle slopes. The B4 unit reflects
its alluvial nature; nearly all slopes are less than 5 deg-
rees. Typical cross-sections through the various units are
shown in Figure II.2.2.

II.2.5 Vegetation

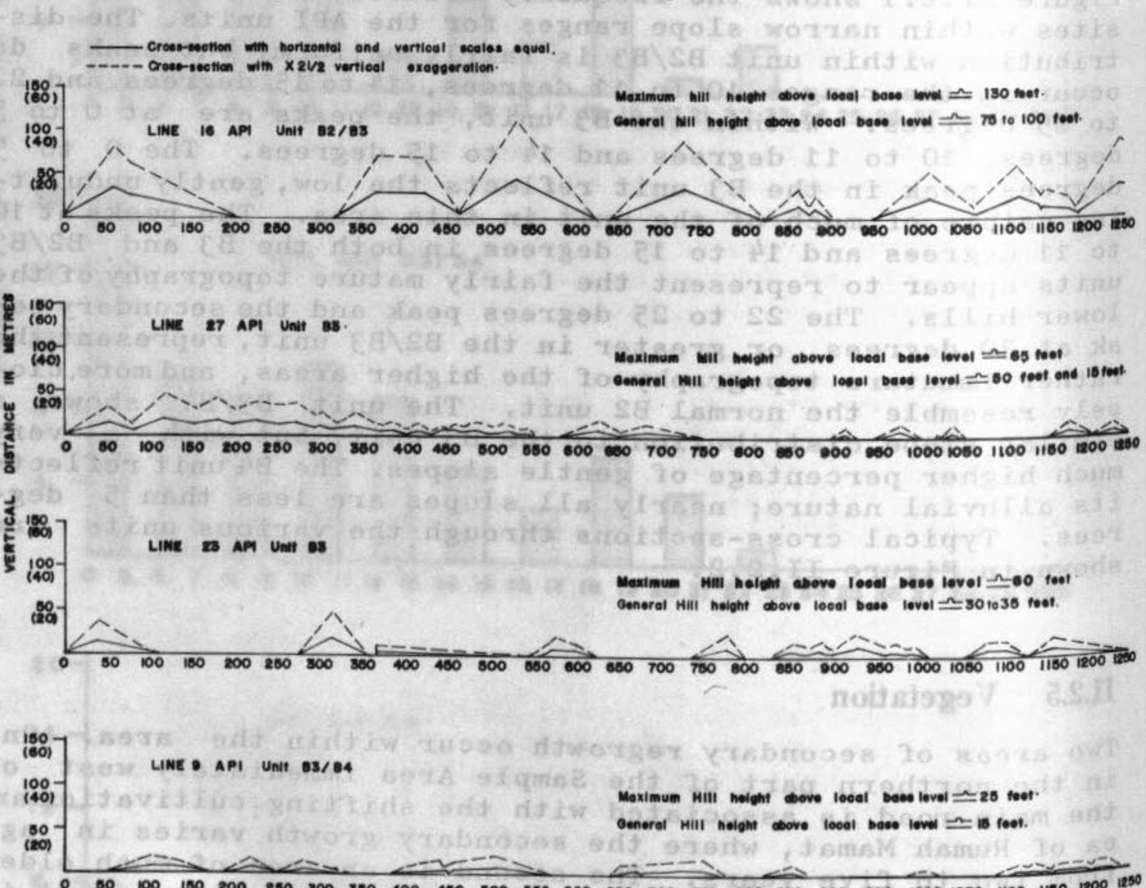
Two areas of secondary regrowth occur within the area. One
in the northern part of the Sample Area immediately west of
the main road is associated with the shifting cultivation ar-
ea of Rumah Mamat, where the secondary growth varies in age
from two to five years. The second is an area of much older
secondary regrowth mixed with some much older trees. It is
difficult to judge the age of the secondary, but it is prob-
ably at least 20 years old. It is an area remote from any
known longhouse, and there is no evidence that it was ever
cleared for cultivation. It is possible that the forest was
severely damaged during a freak storm.

TABLE II.2.1 PERCENTAGE OF MEASURED SITES FALLING WITHIN VARIOUS SLOPE RANGES BY API UNITS

Slope range in degrees	Percentage of measured sites			
	API unit B4	API unit B3/B4	API unit B3	API unit B2/B3
0 - 5	71.4	43.5	24.3	0.9
6 - 10	14.3	33.3	33.8	12.4
11 - 15	0	11.1	20.3	15.9
16 - 20	14.3	11.1	16.2	22.1
21 - 25	0	1.0	4.1	27.4
26 - 30	0	0	1.3	18.6
over 30	0	0	0	2.7
Total	100.0	100.0	100.0	100.0

FIGURE II.2.2

TOPOGRAPHIC CROSS SECTIONS



The rest of the area is covered by Hill Dipterocarp Forest; apart from a small area of swamp forest in the eastern edge of the area. About one-third of the forest area has been logged within the past 18 months. The unlogged forest represents the poorest quality forest so far encountered. There are virtually no large trees and an apparently low density of economic species. There is considerable evidence of a high frequency of tree fall, particularly east of the main road, very often associated with shallow soils; but there is only a slight correlation between soil and forest quality, which does not explain the overall very poor quality of the forest. The only important species recorded with any frequency is belian, associated with low hills and alluvium, and meranti, usually of small girth, found on the higher hills of the B2/B3 unit. There is some, rather vague, evidence that the poorest forest occurs on the shallowest soils. The relationship between soils and forest quality is something about which very little appears to be known, but, if such a relationship does exist, it is of considerable importance for the proper allocation of land use.'

II.2.6 Soils

The soils of this area fall into three broad groups, residual, alluvial and organic. Residual soils occupy the greater part of the area and have developed more or less in situ from the weathering of the parent rock. There is some evidence that some of the characteristics of these soils may be due to a previous soil weathering cycle when the conditions were somewhat different from the present. The very frequent occurrence of a dense stony layer largely composed of iron concretions and iron-cemented rock fragments may indicate a stage when soil formation was associated with a fluctuating water table, a condition required for the formation of such features. These conditions do not exist for hill soils at the present, but could have existed prior to the geological uplift that initiated the present weathering cycle.

Other important characteristics like texture are largely determined by the nature of the parent material. Fine textured shales give rise to fine textured soils, sandy shales and fine grained sandstones to medium textured soils and coarse textured soils are derived from coarser grained sandstones. Further, in nearly all the residual soils there is a textural gradient, textures becoming finer with depth. Based on the textural characteristics, the residual soils are divided into three groups based on the average texture of the control section. The three groups are fine, coarse and fine silty and loamy as defined below.

Clayey	Fine and coarse silty	Coarse and fine loamy
Clay, clay loam and silty clay loam (with more than 35 per cent clay), silty clay, fine sandy clay	Clay loam and silty clay loam (with less than 35 per cent clay), very fine sandy loam, silt loam, very fine sandy clay loam, loam (with less than 15 per cent medium and coarse sand) very fine sandy loam and silt loam.	Sandy loam, medium and coarse sandy clay loam, loam (with more than 15 per cent medium and coarse sand), light clay loam.

These fine, medium and coarse textured groups define the Merit, Bekenu and Nyalau families respectively.

Within the Merit and Bekenu families two series each are recognised based on colour. Soils with colours of 10YR or yellower within 20 inches of the surface are included in the Merit and Bekenu series, and redder than 10YR throughout the control section are included in the Jakar and Sarikei series. Only one series, the Nyalau series, has been recognised within the Nyalau family.

The Jakar series is of much more common occurrence in this area than in Sample Area A, especially in the eastern half of the area. The Bekenu and Sarikei series occur largely in the western part, while the Nyalau series is confined to two small areas of medium and fine grained sandstone. Intergrade families are recognised where a limiting horizon occurs within 20 inches of the surface, but deeper than 10 inches. These are the Merit-Kapit and Bekenu-Kapit family intergrades. The depth phases shown on the soil map (Map 2) are indications of the effective depth for plant rooting.

Alluvial soils are divided into three broad groups on the basis of their internal drainage characteristics as revealed by matrix colours and the presence or absence of mottling. The well drained group of soils, characterised by yellowish or reddish colours and very little mottling, are divided into families on the basis of the control section texture. Fine textured soils containing more than 35 per cent clay are included in the Seduau family, loamy and silty soils in the Bemang family. No coarse textured alluvial soils occur in this Sample Area. Very poorly drained soils have pale matrix colours and very little reddish mottling. Family division is made on the same textural basis as the well drained group. Fine textured soils are included in the Bijat family and loams and silts in the Pakan family. No coarse textured poorly drained alluvial soils occur. Intermediate drainage categories are covered by family intergrades - the fine textured members in the Seduau-Bijat family intergrade and the loams and silts in the Bemang-Pakan family intergrade.

The alluvial soils occupy rather larger areas, and represent soils of relatively high potential, provided certain existing restrictions can be removed such as poor drainage and the tendency to flash flooding.

Organic soils are the product of the accumulation of organic debris under anaerobic conditions, which limit the rate of breakdown and oxidation of organic matter so that the constant replenishment of debris is much faster than its breakdown, thus allowing considerable depths to accumulate. These organic soils are characterised by their very low humification, very high water content and high wood content. They are included in the Anderson family when the peat is deeper than 40 inches. Within this Sample Area, only two small areas of Anderson family soils have been identified, occupying very poorly drained valleys.

The residual soils of the Merit, Bekenu and Nyalau families are the dominant soils of the area. One of the major characteristics of these soils is the presence of the concretionary layer described above. This layer is usually thicker than 12 inches and is an effective barrier to root development. Thus, the depth of soil available to plant roots is limited to the soil overlying this layer. This effective soil depth is related to slope, particularly on hills higher than 50 feet, but significant areas of very shallow soils do occur on very low hills with gentle slopes. However, shallow soil depths occur more commonly on the steeper slopes. The percentage of sites examined with effective depths of 24 and 20 inches or less are given in Table II.2.2.

TABLE II.2.2 SLOPE RANGE AND EFFECTIVE SOIL DEPTH

Slope range in degrees	Percentage of sites 24 inches effective depth	Percentage of sites 20 inches effective depth
0 - 5	13.4	10.4
6 - 10	34.2	16.4
11 - 15	29.5	20.5
16 - 20	20.4	10.2
21 - 25	31.4	25.7
26 - 30	59.1	50.0
more than 30	66.6	66.6

II.3 SAMPLE AREA C

II.3.1 Location

This Sample Area, covering some 4 950 acres, is located 4 kilometres (2.5 miles) south-west of Rumah Gindi on the Sungai Suai, and runs approximately 9.0 kilometres (5.6 miles) in a north-westerly direction from the Sungai Sebatang to the head-waters of the Sungai Derais. The area is bisected by the Sungai Po, which flows into the Sungai Suai at Rumah Gindi.

II.3.2 Survey Density

The Area was surveyed by means of 26 rentis lines cut at intervals of 400 metres (1 300 feet) on a bearing of 214 degrees. The rentis lines were linked at either end by a cut line 10 kilometres (6.2 miles) in length. The length of the cross rentis lines varied from 2 kilometres (1.2 miles) at the south-eastern end of the area to 2.4 kilometres (1.3 miles) at the north-western end. The lines were cut with compass and chain only, resulting in approximately a five per cent reduction in length on the map due to the rolling topography.

The survey was conducted along these cut lines, auger inspection being conducted at an average interval of 200 metres (650 feet). A total of 339 sites was described, of which 13 were soil pits fully sampled for a wide range of analyses including available water holding capacity and subsoil permeability. This coverage gave an overall survey density of one observation site per 15 acres.

II.3.3 Geology

Two Formations are represented within the Sample Area, the Setap Shale Formation and the Nyalau Formation. Lithologically, there is not much variation between the two formations. Both contain arenaceous and argillaceous members, but generally the Nyalau Formation is rather more sandy than the Setap Shale. The area lies between the predominantly Nyalau Formation area south of the Sungai Similajau and the largely argillaceous Setap Shale, Sibuti and Tangap Formations to the north, giving rise to a fairly complicated interfingering of the Nyalau and Setap Shale Formations.

Within the Sample Area, the Nyalau Formation appears to consist largely of fine grained sandstone; but coarser grained sandstones occur locally, usually as remnants on hill tops, where they are associated with distinct dip and scarp topography, the upper scarp face being marked by cliffs up to 25 feet high. Within this formation, one small outcrop of limestone has been identified, but the area occupied by this is small. The area occupied by the Nyalau Formation appears to be larger than indicated on the 1:250 000 Geological Map of the Suai-Baram area (Haile, 1962).

The Setap Shale Formation occupies the greater part of the Sample Area. In most cases the formation consists of a rather sandy shale with only small areas of truly argillaceous sediments. This may be a reflection of its occurrence between predominantly argillaceous and arenaceous areas.

A third geological type occurs within the area. This is the Jerudong Terrace Material, significant areas of which are shown on the Geological Map as occurring outside the Sample Area. The area of this deposit within the Sample Area is small, and appears to be the highly eroded remnants of a formerly more extensive area. Certainly the deposit is very shallow and rests uncomformably on the older weathered rock. The deposit is described by Haile (1962) in Memoir 13 as an "unbedded, pure white, medium grained sand". Part of the deposit in the Sample Area fits this description, but the greater part is a finer textured, yellowish brown material containing distinct layers or stonelines of very rounded quartz pebbles.

The area lies within the general north-east to south-west trending anticlinal-synclinal system. Most of the area is synclinal in nature, but in the extreme south-east impinges on the edge of a much higher ridge of which the highest point is at 740 feet.

II.3.4 Topography

The north-east to south-west geological trend appears to have had less effect on the topography than in other areas. In the extreme south-east, ridges are aligned parallel to this trend, but the only other distinct alignment of hills is an arcuate pattern in the centre of the area perhaps related to the Batang Syncline. Apart from these two cases, the pattern of hills and ridges is rather haphazard. The maximum hill heights are about 150 feet in the extreme south-east and 130 feet elsewhere, with more general levels between 60 to 80 feet.

During the aerial photo-interpretation carried out for The Zonation Plan, most of the area was mapped in the B3 and B2/B3 API units. As shown in Table II.3.1, within the B2/B3 unit, slopes are very variable, but tend to be steep, with 32 per cent of all sites examined greater than 20 degrees and 18 per cent greater than 25 degrees. The comparative figures for the B3 unit are 13 per cent and 7 per cent respectively. Small areas of the B2 unit also occur, but are too small to allow meaningful analysis; most of the slopes lie in the 25 to 35 degrees range.

TABLE II.3.1 PERCENTAGE OF MEASURED SITES FALLING WITHIN VARIOUS SLOPE RANGES BY API UNITS

Slope range in degrees	Percentage of measured sites	
	API Unit B2/B3	API Unit B3
0 - 5	7.7	10.9
6 - 10	23.0	32.0
11 - 15	19.2	21.8
16 - 20	18.3	20.2
21 - 25	13.5	7.6
26 - 30	15.4	5.9
more than 30	2.9	0.8

A feature of this area is the very active present erosion cycle associated with valley head regression and incision of the upper reaches of small streams. This has had a considerable effect in increasing the gradient of slopes, especially when associated with low hills, and has resulted in much less favourable terrain than might have been expected from examination of the aerial photographs. Some of the badly dissected low hills cannot be identified at even 1;10 000 scale, due to the very small size of individual valley-hill-valley units and the blanketing effect of the forest canopy. The high degree of dissection appears to be due to the fact that much of the area is a low-level watershed between several drainage systems.

Figure II.3.1 shows the frequency occurrence of measured sites within narrow slope ranges. In API unit B3 main peaks are recorded within the ranges 8 to 13 degrees and 20 to 21 degrees, the former relating largely to the more mature topography within the unit, while the latter is related to the secondary incision cycle described above. Within the B2/B3 unit the spread is much more uniform, illustrating the more complex nature of this unit. However, the frequency distribution does show similarities with the B3 unit, with peaks in the ranges 8 to 13 degrees and 20 to 23 degrees. The much higher occurrence of slopes equal to or greater than 24 degrees reflects those parts of the unit with characteristics more akin to the B2 unit. Line 25 in Figure II.3.2 shows this mixture of B2 and B3 type units. Line 19 is more like B3 in height and general outline, but has been subjected to severe incision by streams, giving a higher percentage of steep slopes than is normal for B3. Line 17 is a rather special case, illustrating scarp and dip topography, with alternating steep and relatively gentle slopes. Figure II.3.3 shows typical cross-sections within the API unit B3.

FIGURE II. 3.1

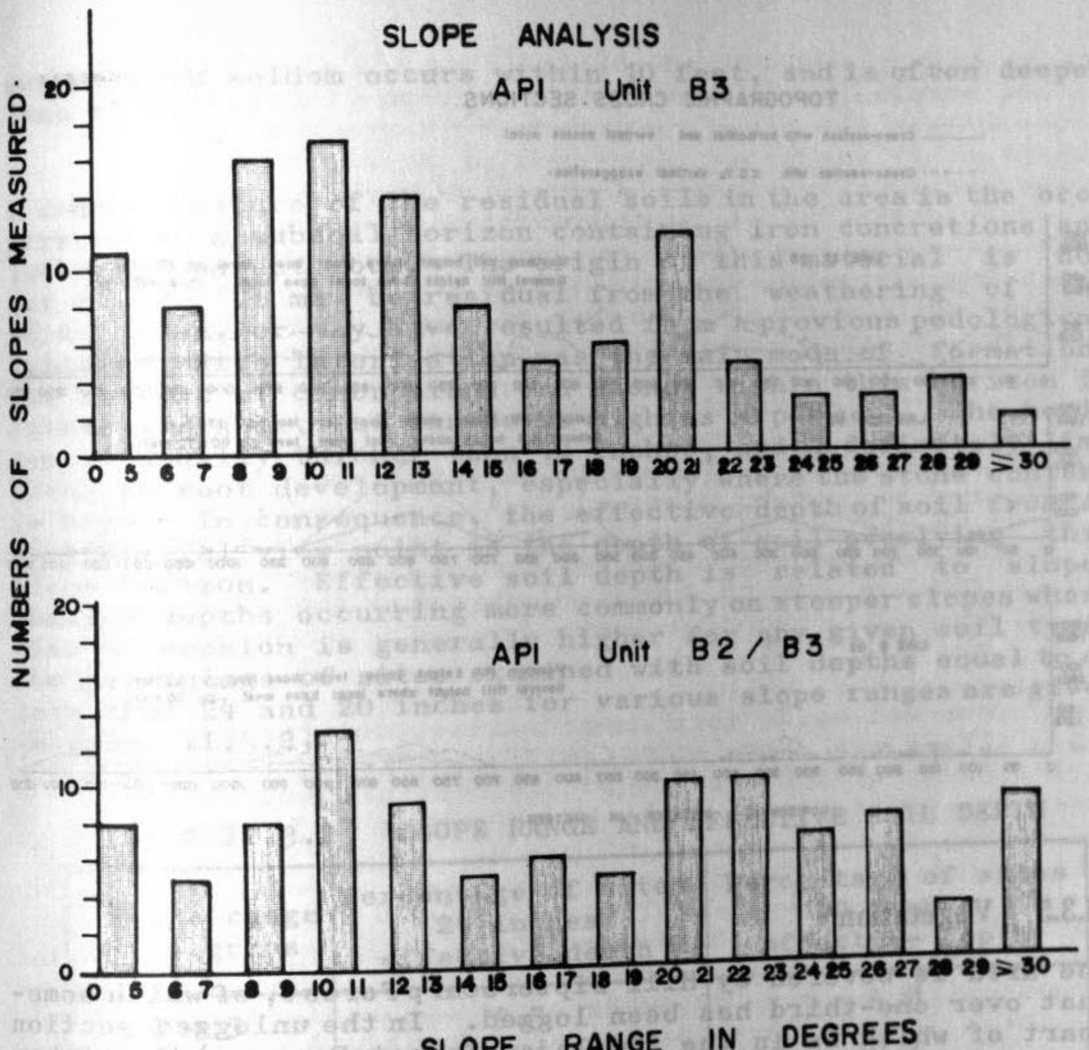
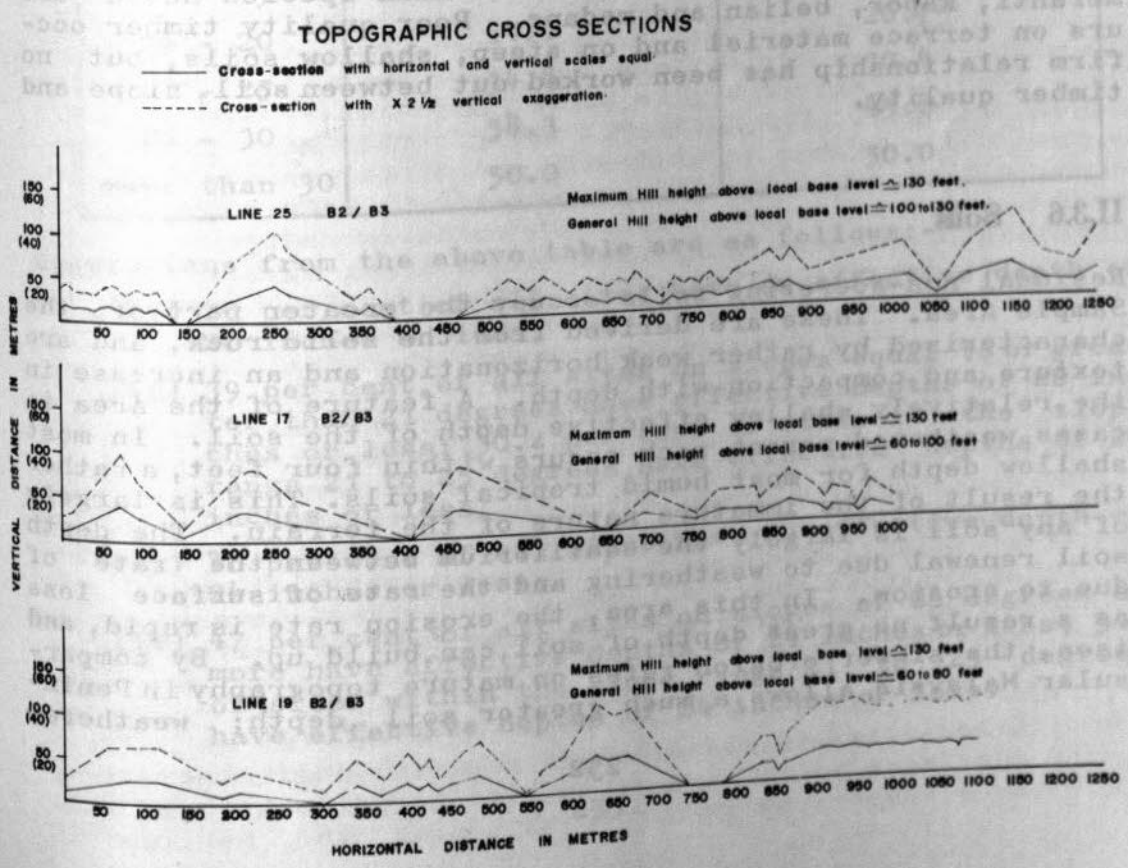
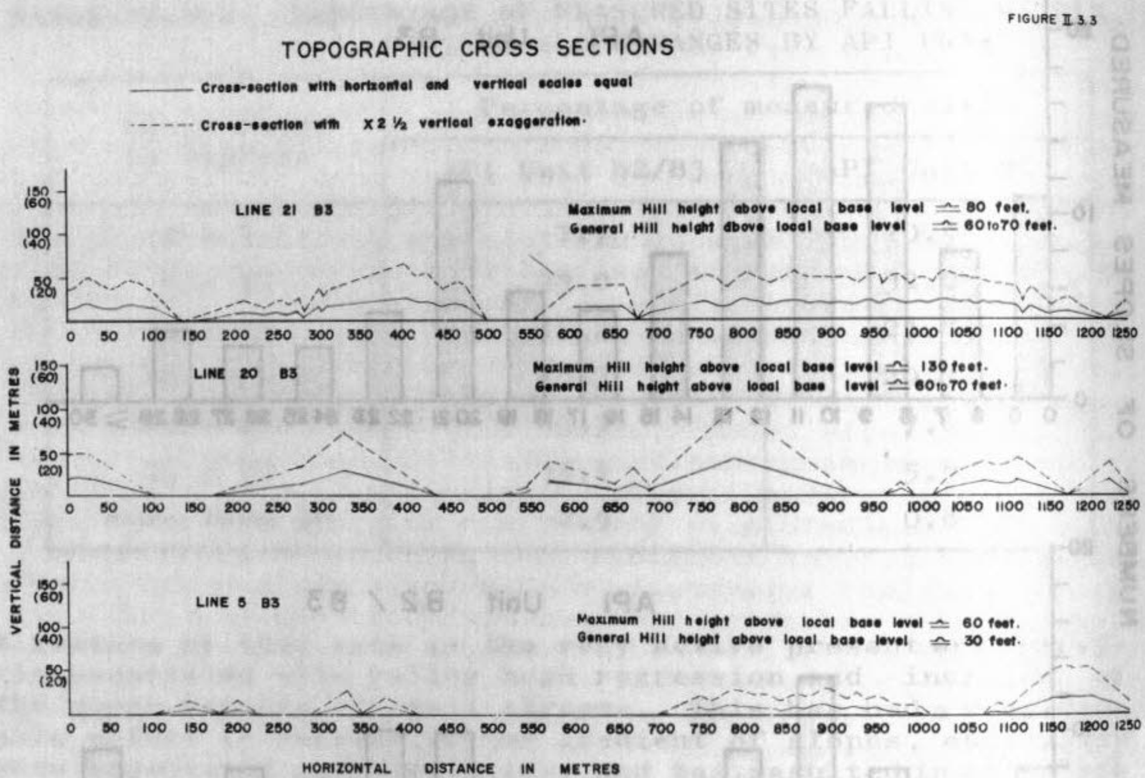


FIGURE II 3.2





II.3.5 Vegetation

The area is covered by Hill Dipterocarp Forest, of which somewhat over one-third has been logged. In the unlogged section (part of which is in the Similajau Forest Reserve) the timber is of good quality both in terms of size and frequency of economically important species. The main species noted are meranti, kapor, belian and medang. Poor quality timber occurs on terrace material and on steep, shallow soils, but no firm relationship has been worked out between soil, slope and timber quality.

II.3.6 Soils

Residual non-accreting soils occupy the greater part of the Sample Area. These are derived from the solid rock, and are characterised by rather weak horizonation and an increase in texture and compaction with depth. A feature of the area is the relatively shallow effective depth of the soil. In most cases weathered parent rock occurs within four feet, a rather shallow depth for most humid tropical soils. This is largely the result of the immature nature of the terrain. The depth of any soil is largely the equilibrium between the rate of soil renewal due to weathering and the rate of surface loss due to erosion. In this area, the erosion rate is rapid, and as a result no great depth of soil can build up. By comparison, the slower erosion rates on mature topography in Peninsular Malaysia allows a much greater soil depth; weathered parent rock seldom occurs within 10 feet, and is often deeper than this.

A common feature of the residual soils in the area is the occurrence of a subsoil horizon containing iron concretions and laterised parent rock. The origin of this material is not yet clear. It may be residual from the weathering of the parent rock, or may have resulted from a previous pedological cycle in which laterisation was the main mode of formation. The content of concretions and stones within this horizon is rather variable, but can be as high as 80 per cent. The horizon is usually thicker than 12 inches, and is definitely limiting to root development, especially where the stone content is high. In consequence, the effective depth of soil from an agricultural view point is the depth of soil overlying this stony horizon. Effective soil depth is related to slope, shallow depths occurring more commonly on steeper slopes where rate of erosion is generally higher for any given soil type. The percentage of sites examined with soil depths equal to or less than 24 and 20 inches for various slope ranges are given in Table II.3.2.

TABLE II.3.2 SLOPE RANGE AND EFFECTIVE SOIL DEPTH

Slope range in degrees	Percentage of sites 24 inches effective depth	Percentage of sites 20 inches effective depth
0 - 5	9.5	4.8
6 - 10	20.3	10.1
11 - 15	18.6	11.6
16 - 20	44.4	26.7
21 - 25	34.8	30.4
26 - 30	58.3	45.8
more than 30	50.0	50.0

Conclusions from the above table are as follows:-

(i) 20 per cent of all sites have an effective depth of 20 inches or less;

(ii) 39 per cent of all sites on slopes equal to or greater than 21 degrees have effective depths of 20 inches or less; 30.2 per cent of sites in the slope range 21 to 25 degrees have effective depths of 20 inches or less;

(iii) 30 per cent of all sites have an effective depth of 24 inches or less;

(iv) 47 per cent of all sites on slopes of 21 degrees or more have effective depths of 24 inches or less; 34.8 of sites within the slope range 21 to 25 degrees have effective depths of 24 inches or less.

Rather surprising is the high percentage (20 per cent) of sites within the slope range 6 to 10 degrees with effective depths of 24 inches or less; most of these sites are in footslope areas below steeper slopes, and have possibly been affected by colluviation, with resulting concentration of concretions and stones into thick stone lines. Of importance in assessing agricultural potential is the high percentage of shallow soils within the rather marginal slope range 21 to 25 degrees. Erosion within this slope range is relatively rapid under natural, undistrubed forest, and will almost inevitably be accelerated under agricultural usage, unless very specific erosion control measures like properly designed bench terraces are taken. Therefore, any soil which at the outset is of inadequate or very marginal depth for economic crop production, should not be considered for agricultural production on these steep slopes. The prevalence of shallow soils on slopes steeper than 25 degrees emphasises the inadvisibility of cultivation on such slopes.

These residual soils have been divided into rather broad groups. There are three main families differentiated largely on the basis of the texture of the control section. Soil textures are divided into three broad groups as shown in Appendix II.2.

These textural groups together define the Merit, Bekenu and Nyalau families. Within the Sample Area, the Merit family predominates. A fourth family occurs sporadically in areas too small to map; this is the Kapit family, occurring on the steeper slopes, and characterised by shallow depth to weathering rock (10 inches or less) and generally stony nature.

The soil families are divided into series on the basis of colour and the nature of the parent material, whether residual or alluvial. The Merit and Jakar series are residually derived soils of the Merit family and differ in colour, the former having a hue of 10YR or yellower in some part of the profile above 20 inches, while the latter is redder than 10YR throughout. Similarly, the Bekenu family is divided into the Bekenu and Sarikei series, the former being the less red of the two. Within the residually derived soils of the Nyalau family, only one series is recognised, the Nyalau series. Within the Merit and Nyalau families two further series are recognised developed in old alluvial parent material. The Lupar series is similar in all physical characteristics to the Merit series except that it frequently contains a layer of rounded quartz pebbles, which betrays the alluvial nature of the parent material. Occasionally the bi-sequent nature of the profile is obvious, with the old alluvial material overlying residual material. Similarly, the Sabangang series is similar to the Nyalau series except for the features mentioned above.

Some limited areas of old alluvial material characterised by highly quartzose sands have given rise to soils with a distinct humus subsoil horizon. In this area, the horizon is not cemented, and the soil belongs to the Buso series of the Silantek family.

Accreting alluvial soils are separated into drainage categories and further divided into families on the basis of the average texture of the control section. Well drained soils of fine texture, that is containing more than 35 per cent clay, are included in the Seduau family, while those of loamy and silty texture are in the Bemang family. No coarse textured well drained alluvial soils occur. Very poorly drained soils are divided into families on the same textural basis as the well drained soils to give the Bijat soils which are fine textured, and Bemang soils which are medium textured.

Intermediate drainage features are covered by family intergrades giving the Seduau-Bijat family intergrade and the Bemang-Pakan family intergrade respectively for fine and medium textures.

II.4 SUNGAI KARABUNGAN SAMPLE AREA

II.4.1 Introduction

Field work on this Sample Area was carried out by the Soil Survey Division of the Department of Agriculture, Sarawak in co-operation with the Consultant Land Classifiers. The compilation and mapping of the Soils and Terrain maps (Maps 4 and 5) has been the responsibility of the Soil Survey Division as was the compilation of this Appendix.

In 1972, the Sarawak Land Development Board intended to expand its oil palm area westward of its planted Ladang Dua Area at Sungai Tangit but examination of a previously published Soil map and Report (Lim, 1970) indicated that a large percentage of this area (Ladang Lima) consists of soils derived from calcareous shale parent material. Apart from the lack of agronomic data to show the growth response of oil palm on this soil type, these calcareous soils are severely restricted by the very shallow rooting depth, as a large percentage of these soils were found to rest not on soft weathered parent material as is the case with most non-calcareous shale derived soils, but on indurated shale bed rock.

At this time, the National Livestock Corporation also requested the Department of Agriculture to identify and investigate in detail an area of around 5 000 acres for the purpose of establishing the first large scale cattle production centre in the State. One area upstream from Bintulu along the Sungai Sebungan was surveyed at a semi-detailed level in early 1972 but was abandoned due to access and other difficulties. Because the Sungai Karabungan Area was regarded as unsuitable for oil palm it was subsequently earmarked for cattle production, as this area not only has the advantage of better access but the whole area has an aggregate of about 20 000 acres of State Land where the forest had been logged and was thus available for immediate development, as soon as soil survey of the area has proved its suitability for its intended purpose.

II.4.2 Location

The surveyed area lies approximately 40 to 50 miles south-west of Miri. It is sited approximately five to two miles in a north-south direction from the Miri-Bintulu main road and access into the area is provided by a reasonably good timber road from Mile 41 of the Miri-Bintulu Road which continues north-westward towards the Sibuti River and southward almost bisecting the whole length of the surveyed area. Towards the south, another gravelled timber road extends westward into the Survey Area but only fails to link up with the north-south timber road by a gap of about two miles.

II.4.3 Survey Density

As mentioned in Chapter 2, Section 2, the surveyed area was also covered in the aerial photo-interpretation during the Zonation Plan study (Appendix VIII). The land types identified were relied upon, partly as a guide to the nature of the terrain to be encountered but more important, as this area formed the first of the four sample areas studied jointly by the Sarawak Soil Survey Team and the Consultant Soil Scientists, it provided the testing ground for the accuracy of the air photo interpretation, standardisation of soil mapping techniques and soil correlation amongst members of both teams.

The method employed in the field survey is one adopted as standard practice by the Soil Survey Division. This involves the cutting of a base line (rentis) from an easily identified point both on topographic maps and air photographs. The starting point for the base rentis was the western end of the timber road which extends from Mile 47 of the Miri-Bintulu Road. This rentis was cut at a bearing of 270 degrees until it met the edge of shifting cultivation. Along this base line, cut lines perpendicular to it were cut at fixed intervals of 400 metres along fixed compass bearings (see Map 6). No compensations were made for reduction of rentis length due to slope, but for a large part of the area, except for the northern and southern parts, the slopes were not sufficiently steep to offset the horizontal distance too severely. Moreover, the area is criss-crossed by a large number of timber tracks which serve to rectify any minor deviations of distances and bearings of these cutlines. Along each cut line, the data on soils, terrain, drainage, vegetation and other relevant information required for land evaluation were collected. The soils were examined at intervals of 200 metres; at each point the soils were described in detail down to depths of 100 to 200 centimetres or to the surface of the indurated bedrock, whichever is shallower. Between this interval check bores also examined the change, if any, of soils between bores of fixed intervals of 200 metres. In the Sungai Karabungan Area it was found at the early stage of the survey that there was considerable difficulty in identifying and differentiating soils formed from the calcareous shale from the more widespread and common hill soils formed from non-calcareous shale parent material. In soil augerings where the soil parent material shale, or shale fragments, could be obtained these were tested with hydrochloric acid for immediate confirmation of lime reaction and hence enabled classification of the soils within the family of calcareous soils. In cases where this procedure could not be followed due to the unavailability of weathering parent material and ambiguity arose as to its position in the classification system, small samples of subsoil were collected and forwarded to the Agricultural Department's Research Laboratory at Semongok for pH determinations. The total number of soils determined for pH in this way was 415. Results of the pH values were later used in classification of the specific soil bores and in mapping.

II.4.4 Geology

The area is built up of two formations - the Tangap Formation and the Subis Formation, both of Miocene age. The Tangap Formation comprises calcareous shale, marl and greenish claystone. The formation is gently folded, dips of 5 to 10 degrees are most common although Haile (1962) has noted folding up to 20 degrees as also usual. Within the survey area, this calcareous shale occurs as almost horizontally bedded silty shale, and intercalations of limestone are uncommon in the central part of the area but to the south-west in Ulu Sungai Tangap which is probably grading into the lower part of the formation, pinacles of coral-algal limestone are found exposed on the surface.

Calcareous marl as evidenced from the soil distribution pattern, appears to occur mainly in the central part of the Survey Area. Here, despite the rapid surface erosion by streams and tributaries of the Sungai Karabungan, rapid soil weathering as shown by the comparatively deeper soils formed from this type of parent material than from bedded calcareous shale elsewhere, has nevertheless kept pace with erosion and surface soil removal. In the south small intercalations of non-calcareous Sibuti Formation shale with Tangap Formation has resulted in patches of non-calcareous soils in an area of predominantly calcareous soils.

The calcareous Tangap Formation pitches north-eastward and is overlain by the Sibuti Formation which is composed dominantly of shale with minor but impersistent lenses of siltstone and sandstone; no single sandstone bed is reported to be continuous over a large area. From this shale formation the steep and dissected hills in the north and north-east part of the survey area are formed.

II.4.5 Topography

The Survey Area forms the watershed between two main river systems, the Sungai Niah to the south and the Sungai Sibuti to the north. From this watershed small tributaries radiate north, west and southward into the main rivers and the only sizeable streams encountered in this area are the Sungai Karabungan which flows south and then westward into the Sungai Niah and Sungai Separoh in the north which in turn flows into the Sungai Sibuti. A large part of the area, particularly the central area, is therefore devoid of any reliable stream which can be depended upon for water supply. The Sungai Separoh probably lies too far to the north to have any contribution to the area while the location of the tributaries of the Sungai Saeh to the west are too peripheral to have any significance either. The only large stream in the whole area can be counted on for water supply is the Sungai Karabungan. It is most important that some consideration be given to make the best use of the water from this stream, with some provisions to protect the unnecessary contamination following development of the Area and measures to protect against accelerated erosion hazards.

The terrain of the area reflects the two important geological factors, the contrasting lithologies and the regional strike. The two lithologic units, calcareous shale which includes marl, and non-calcareous shale which also includes subordinate sandstone give rise to marked difference in landforms. The area in the north and extreme south are formed from non-calcareous shale. In areas where the shale beds are strongly dipping, with dips exceeding 40 degrees, the hills are steeply sloping and rise to over 300 feet. Three fairly massive blocks of steep hills are present in the area, two in the northern half, from which the Sungai Karabungan and Sungai Separoh originate, and one block in the south-west. In the extreme northern part, active erosion and secondary dissection by the headwaters of Sungai Separoh has reduced the area to undulating low hills where summits are aligned almost at right angles to the original strike.

In the central part of the area where calcareous shale and marl predominate, the landform comprises low hills in which the absolute amplitude rarely exceeds 100 feet. The lower relief is due mainly to the chemically more erodible calcareous shale under the acidic weathering environment. However, there are few fairly extensive terrace-like surfaces of 50 to 100 feet rising above the local alluvial level which still retain the original strike; these surfaces are characterised by steep scarps with exposed shale beds and large boulders are commonly found at the lower slopes. Valleys separating these surfaces are mostly dry and marked by sink holes, indicating that subterranean drainage is active. Marl is found associated with calcareous shale mainly in the eastern part of the central area. The topography comprises undulating low hills which are seldom more than 50 feet above the alluvium; hill slopes are gentle and merge into poorly drained colluvium and alluvium.

In the south, intercalations of non-calcareous shale with calcareous shale have produced more steeply sloping and higher hills amongst gently sloping low hills and more extensive and broad river alluvium associated with the Sungai Karabungan and Sungai Tangap. In the south-west, patches of crystalline coral limestone, being more resistant than calcareous shale, remain as rugged pinacles on the surface.

Figures II.4.1 and II.4.2 are sections plotted from slope measurements collected from the field. These sections attempt to present the landform diagrammatically in some parts of the area. Figure II.4.1 (lines D15 and D16 from west to east) shows the steeply sloping and dissected hills formed from strongly dipping shale and sandstone in parts of the northern area; while Base Line A from west to east shows the characteristic topography formed from calcareous shale and marl in the central part of the area; hills are all less than 100 feet above local alluvium and the slopes are long and gentle, with eastern scarp slopes and gentle dip slopes grading into alluvium. Figure II.4.2 (lines B7 and B8 from west to east) shows that the topography of the south consists of steeper hills as compared to the central part, with extensive tracts of flat alluvium towards the east formed by Sungai Karabungan.

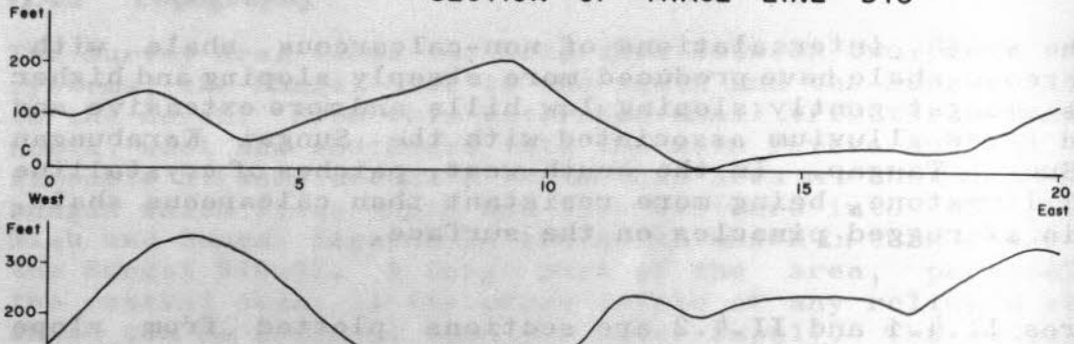
The terrain data collected also help to confirm the accuracy of the land type identification from air photograph interpretation. Examples of trace lines are given to show this in Table II.4.1.

TABLE II.4.1 API UNITS OF ELEVEN TRACE LINES

Trace line	Length	API unit	Percentage of trace line	
	Metres		Less than 25^{o}	Over 25^{o}
Base Line A	6 825	B3	99	1
A15	2 225	B3	100	0
A16	4 825	B3	93	7
A26	3 500	B3	93	7
A31	2 500	B3	100	0
B1	2 250	B3	97	3
B9	2 250	B3	100	0
C6	1 975	B3	95	5
B15	1 450	B2	58	42
D8	1 425	B2	49	51
D13	1 175	B1	17	83

From these random sections it is possible to conclude that air photo-interpretation of land type B3 has 97 per cent of the terrain with slope below 25 degrees and only 3 per cent with slopes in excess of 25 degrees. This confirms the hypothesis that B3 land type is almost entirely suitable for agri-

SECTION OF TRACE LINE D15



SECTION OF TRACE LINE D16

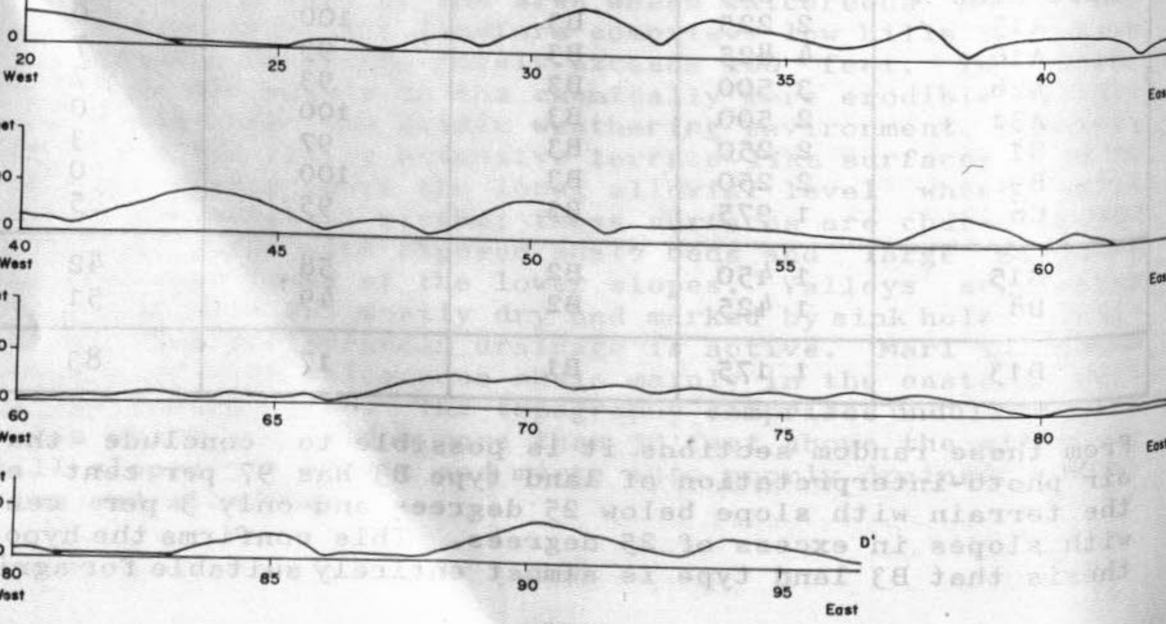
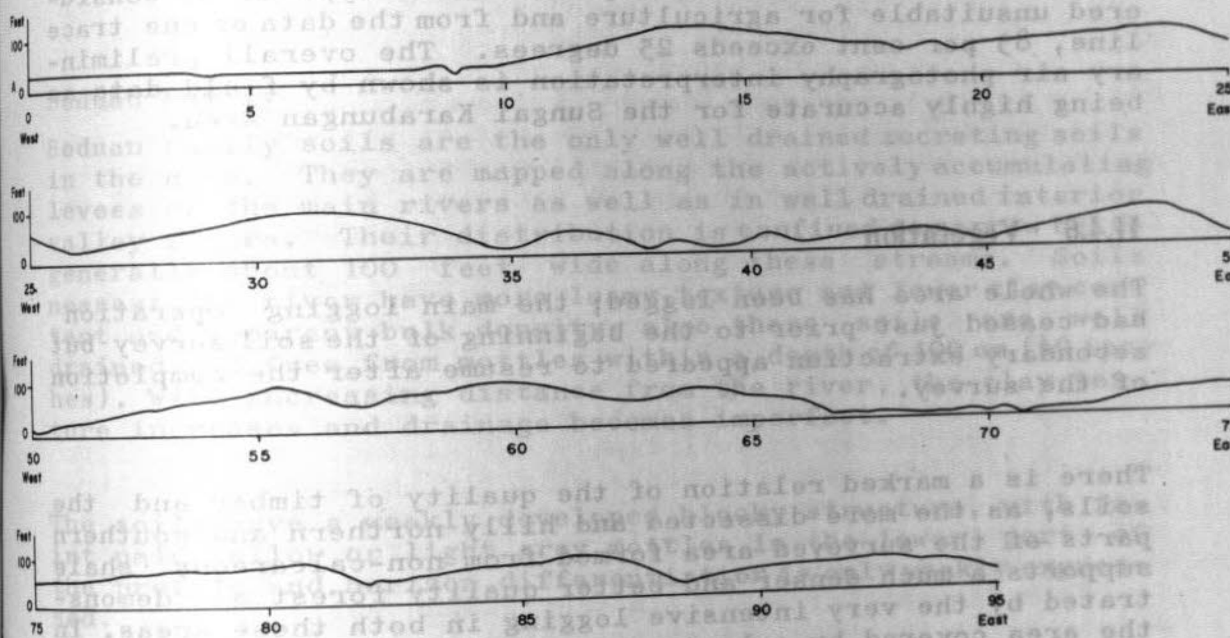
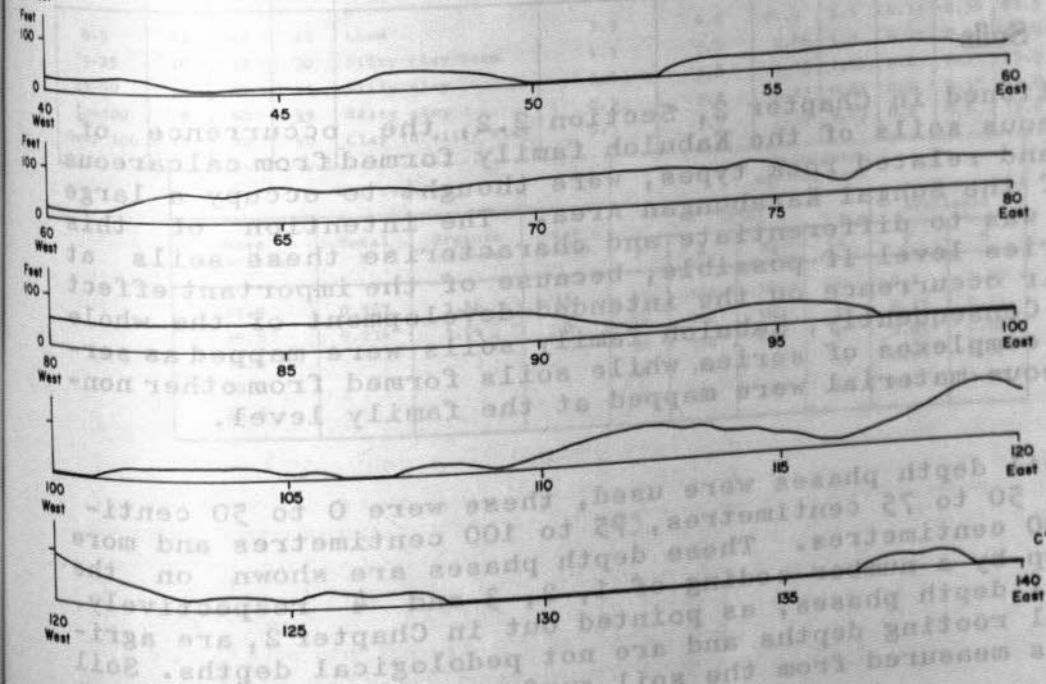


FIGURE II.4.2

SECTION OF BASE LINE A FROM TAPE 255 TO 195



SECTION OF TRACE LINES B7 AND B8



culture on topographical criteria. Land type B2 is considered as marginal or unsuitable for agriculture and the field data show that only 53 per cent has slopes less than 25 degrees and 47 per cent exceeds 25 degrees. Land type B1 is considered unsuitable for agriculture and from the data of one trace line, 83 per cent exceeds 25 degrees. The overall preliminary air photography interpretation is shown by field data as being highly accurate for the Sungai Karabungan Area.

II.4.6 Vegetation

The whole area has been logged; the main logging operation had ceased just prior to the beginning of the soil survey but secondary extraction appeared to resume after the completion of the survey.

There is a marked relation of the quality of timber and the soils, as the more dissected and hilly northern and southern parts of the surveyed area formed from non-calcareous shale supports a much denser and better quality forest as demonstrated by the very intensive logging in both these areas. In the area covered by calcareous soils, trees are relatively small, with few good quality timber species, mainly characterised by very small trees and abundant creepers associated with lianas. Consequently, little of this forest has been logged.

There is evidence of rapid encroachment of the primary forest on the northern, western and southern edges of the survey area by shifting cultivation. No attempt is made in the Report to determine the area of land affected in recent years in this manner.

II.4.7 Soils

As mentioned in Chapter 2, Section 2.2, the occurrence of calcareous soils of the Kabuloh family formed from calcareous shale and related rock types, were thought to occupy a large part of the Sungai Karabungan Area. The intention of this survey was to differentiate and characterise these soils at the series level if possible, because of the important effect of their occurrence on the intended development of the whole area. Consequently, Kabuloh family soils were mapped as series or complexes of series while soils formed from other non-calcareous material were mapped at the family level.

Four soil depth phases were used, these were 0 to 50 centimetres, 50 to 75 centimetres, 75 to 100 centimetres and more than 100 centimetres. These depth phases are shown on the soil map by a number coding of 1, 2, 3 and 4 respectively. The soil depth phases, as pointed out in Chapter 2, are agricultural rooting depths and are not pedological depths. Soil depth is measured from the soil surface to the upper surface of the lithic or paralithic horizon as defined in the revised soil classification for soils in Central and North Sarawak (Scott, I.M., 1973).

Seduau Family

Seduau family soils are the only well drained accreting soils in the area. They are mapped along the actively accumulating levees of the main rivers as well as in well drained interior valley floors. Their distribution is confined to narrow belts generally about 100 feet wide along these streams. Soils nearest the river have more loamy texture and lower clay content and apparent bulk density; also these soils are well drained and free from mottles within a depth of 100 cm (40 inches). With increasing distance from the river, the clay texture increases and drainage becomes imperfect.

The soils have a weakly developed blocky structure, with faint pale yellow or light grey mottles in the lower part of the profile and horizon differentiation is only weakly expressed.

The average particle size analysis from four profiles is shown in Table II.4.2. Sand, mainly as very fine sand fraction, is highest in the Ah horizon. Silt content throughout the profiles is 40 per cent or higher, while clay increases regularly with depth. The average texture is a light silty clay.

TABLE II.4.2 AVERAGE CHEMICAL AND MECHANICAL ANALYSES OF FOUR PROFILES OF SEDUAU FAMILY

Depth (cm)	Particle size analyses per cent			Texture	pH soil/water 1 : 2.5	pH soil/KCl 1 : 2.5	Exchangeable cations me/100g soil					
	Sand	Silt	Clay				Ca	Mg	Na	K	CEC	CEC/clay
0-5	31	47	22	Loam	5.5	4.6	14.4	2.1	0.15	0.38	21.5	98
5-25	18	52	30	Silty clay loam	4.9	3.9	2.88	4.0	0.15	0.2	15.9	53
25-50	12	48	41	Silty clay	5.1	3.8	1.15	1.05	0.2	0.15	15.9	39
50-100	9	42	49	Silty clay	5.3	3.9	1.23	0.85	0.2	0.15	15.0	31
Over 100	11	40	40	Clay to silty clay	5.3	3.9	2.38	0.85	0.2	0.2	15.5	31

Per cent				Nutrients mg/100g soil					
				Total				Available	
Base saturation	Total N	Organic carbon	C/N ratio	P	K	Mg	Ca	P	K
69.5	0.367	5.46	15	41	126	361	291	0.5	0.20
30.8	0.214	1.64	8	24	144	389	40	0.15	0.11
18.4				18	168	416	17	0.05	0.08
18.0				16	168	398	15	0.05	0.07
26.6				16	182	395	29	Nil	0.07

The average chemical characteristics for four profiles are given in Table II.4.2. pH figures are higher in the Ah horizon and lowest in the Ae horizon; thereafter the values remain almost constant at 5.1 to 5.3. These pH figures are slightly higher than those of Seduau soils elsewhere and the effect of calcium from the neighbouring calcareous hill land is the main cause. Carbon values are high in the Ah horizon but low in the Ae horizon, thereby giving a moderately high C/N value for the Ah and a lower value for Ae horizons. Calcium and magnesium are the two dominent exchangeable cations whose values are high in the Ah and Ae horizons. Exchangeable K is low in all horizons. The base saturation percentage and cation exchange capacity are highest in the Ah. Cation exchange capacity of clay exceeds 30 milliequivalents/100 grammes in all horizons and this is incompatible with the cation exchange capacity limit for clay of Seduau soils which has been fixed at 30 milliequivalents/100 grammes for Seduau family in the revised classification. If cation exchange capacity/clay is used as a parameter in soil family definition, then 30 milliequivalents/100 grammes appears slightly low and 35 milliequivalents/100 grammes could be used. The classification and mapping of this soil family was too advanced to permit changes but it poses the problem of either to raise the cation exchange capacity/clay limit of Seduau soils or to place Seduau soils in Sungai Karabungan area in another new family.

Reserve calcium is highest in the Ah and is caused by accreting calcareous material from the surrounding calcareous shale; reserve magnesium values are much higher than other alluvial soils like the Bijat family or residual soils like the Merit family but are comparable to those for Kabuloh family though not as high. Reserve phosphorus and potassium values are low.

Bijat Family

Bijat family soils are poorly drained clay formed from accreting parent material. These soils are coloured light grey to grey, clay content being more than 35 per cent. Strong brown or reddish yellow mottles are common within the control section. The Bijat family comprises two series, the Bijat series which is without any surface peat and is the dominant soil in the mapping unit, and the Sebandi series which has a maximum thickness of 25 cm (10 inches) of muck overlying clay. over Sebandi series is only a minor component within the mapping unit. Bijat soils are massive, structureless and firm in the moist state. In the Sungai Karabungan area, Bijat soils occur in poorly drained sites of interior valleys, particularly in the northern part, in colluvial sites and in small basin swamps notably in the lower part of Sungai Karabungan. The acreage mapped is 1 056 or five per cent of the survey area.

Two Bijat pit profiles were sampled and analysed. The average particle size analysis and the chemical properties are shown in Table II.4.3. The texture is shown by analysis to consist of clay, with a marked increased in clay content from

TABLE II.4.3 AVERAGE CHEMICAL AND MECHANICAL ANALYSES OF TWO PROFILES OF BIJAT FAMILY

Horizon	Particle size analyses per cent			Texture	pH soil/water 1 : 2.5	pH soil/KCl 1 : 2.5	Exchangeable cations me/100g soil					
	Sand	Silt	Clay				Ca	Mg	Na	K	CEC	CEC/clay
Ah	32	42	26	Loam	5.3	4.3	4.2	2.0	Nil	0.4	11.5	44
Ae	10	42	48	Silty clay	5.8	4.3	2.9	2.1	Nil	0.3	10.7	22
B1	5	25	70	Clay	5.2	3.5	0.8	3.6	0.2	0.3	11.1	16
B2	6	19	75	Clay	4.9	3.5	4.6	2.4	0.3	0.2	11.5	15
C	12	22	66	Clay	5.2	3.6	4.2	2.7	0.5	0.1	11.3	18

Per cent				Nutrients mg/100g soil							
				Total*				Total**			
Base saturation	Total N	Organic carbon	C/N ratio	P	K	Mg	Ca	P	K	Mg	Ca
58	0.55	4.23	9	25	17	33	42	53	126	181	701
50				5	20	36	23	35	149	196	476
44				5	21	39	6	22	179	213	301
65				3	18	35	3	33	112	161	301
67				3	17	36	3				

Notes * Profile from non-calcareous site
** Profile from calcareous site

48 per cent to 71 per cent within 25 cm (10 inches) depth.

The chemical data show a very variable level of exchangeable calcium, total calcium, magnesium and potassium between the two profiles. The Bijat family sampled from a non-calcareous site shows that the pH values and calcium levels are similar to those in Bijat soils from other areas, being characterised by low pH and low exchangeable calcium but magnesium values are much higher than those for normal Bijat soils. The Bijat family sampled from a site strongly influenced by calcareous parent material is characterised by slightly higher pH values, high exchangeable and total calcium levels. The levels of total calcium, magnesium and potassium are five to ten times higher than those from a non-calcareous site. The evidence of the analysis clearly shows the chemical differences of Bijat soils are attributed to the different environments of the surrounding area which forms the source of parent material for Bijat soils. These calcareous Bijat soils resemble those formed from alluvium in limestone areas in West Sarawak such as the Paya Megok series. Total levels of phosphorus are low in all Bijat soils though they are somewhat higher in calcium-rich soils. Values of total sodium, available phosphorus and potassium are low in all Bijat soils.

Bijat and Seduau Family Complex

This mapping unit occupies only a small area (144 acres) and is mapped in alluvium behind well drained levees of the lower Sungai Karabungan where imperfect and poorly drained heavy textured soils of Seduau and Bijat families occur in complex associations.

Bekenu Family

Bekenu soils are formed from very fine grained sandstone or silty shale parent materials. These soils occupy a very small percentage of the area (54 acres or 0.3 per cent) and are mapped on low hills in the northern part.

Bekenu soils have very fine sandy loam texture in the A horizon and are coloured dark yellowish brown. The soil is moist and friable, with crumbly structure. The B horizon has very fine sandy clay loam, clay loam or silty clay loam texture and is coloured uniformly 10YR, colour increase is rarely more than 2.5 units with depth, and the soil has a weak, coarse subangular blocky structure and is moist and firm in consistency. The maximum colour increase extends beyond the B horizon and is best expressed in the B3 or BC horizon where weathering fragments of parent materials are found. Bekenu soils are less compact than Merit soils formed from very fine grained parent materials, and are all less than 75 cm (30 inches) deep overlying weathering parent material or the paralithic horizon.

Bekenu-Kapit Family Intergrade

Soils of Bekenu-Kapit family intergrade are formed from similar parent material as Bekenu soils but differ by having a lithic or paralithic contact within 50 cm (20 inches) from the surface. These soils are characterised by having a weakly developed B horizon and a weak coarse blocky structure. In a large number of these soils, the B horizon rests on a paralithic horizon of clay loam to clay mixed with soft weathering rock fragments. Iron concretions or compact stonelines are rare. Most of these soils contain coarse roots in the deeply weathered paralithic horizon.

No profile of these soils was sampled or analysed but the chemical characteristics are not expected to differ markedly from other residual soils like the Merit family. The acreage mapped is small, only 32 acres or 0.2 per cent of the survey area.

Merit Family

Soils of Merit family are formed from non-calcareous parent material which is comprised almost entirely of shale, with subordinate very fine grained sandstone and siltstone. Merit soils occupy 2 785 acres or 13.6 per cent of the survey area. These soils occur mainly in the northern parts where non-calcareous rock types predominate and occur only as small patches in the south where non-calcareous shale occurs intercalated with calcareous shale.

Merit family comprises three series and these have already been detailed in Chapter 3, Section 2. Although no attempt was made to map these soils at the series level both the Merit and the Jakar series were identified in the area. Merit series has hue of 10YR or yellower in some part of the control section above the first 50 cm (20 inches) while Jakar series has hue redder than 10YR throughout the control section. An examination of the Merit soils from bore descriptions may indicate the distribution of the two series; 45 per cent of the soils examined have hues of 10YR or yellower throughout the control section and thus qualify for the definition of Merit series and of the remainder 55 per cent have hues redder than 10YR in some part of the control section and most of these soils would qualify for the Jakar series.

Of the three depth phases mapped, the moderately shallow phase with depths of 50 to 75 cm (20 to 30 inches) occupies the largest area, with an acreage of 2 172 or 77 per cent of all Merit soils mapped. Most of these soils are found in the northern part and are associated with the Merit-Kapit family intergrade. The general relationship whereby the shallower soils are found on steeper slopes does not entirely apply to this area as 75 per cent of the moderately shallow soils occur on slopes of less than 25 degrees and only 25 per cent on steeper slopes. This is one of the most significant features of both the Merit soils and the Merit-Kapit family intergrades and the shallowness of these soils may in part be due to the rapid erosion and truncation carried out by the headwaters of Sungai Separoh and its tributaries.

Nearly all Merit soils have a thin Ah horizon which rarely exceeds five cm (two inches) but this is absent on steeper slopes as a result of slope wash. This horizon is generally coloured dark greyish brown with patchy faint dark brown and grey mottles due to surface gleying. This horizon is moist and friable, with crumbly structure and abundant organic matter and abruptly overlies the Ae horizon with a thickness ranging from five to 15 cm (six inches) and is coloured 10YR or redder. This Ae horizon has clay loam or fine sandy clay loam texture, weak medium blocky structure and firm consistence. On the lower slopes strongly weathered, moderately indurated residual rock fragments of colluvial origin are found admixed with the soil.

The transition from the A to the B horizon is expressed by an increase in texture from clay loam to clay though the actual thickness of this B1 horizon may be thin. The B2 horizon can be recognised by a fairly distinct clay increase, with a texture of clay or very fine sandy clay. This horizon has weak to moderate subangular blocky structure and is moist and firm while porosity is low. Some structural faces are stained brown or dark brown by organic matter leached from upper horizons. Root density is low and roots consist of fine rootlets and a few coarse tap roots. The B2 horizon merges either into a B3 or BC horizon, depending on the amount of weathered parent rock fragments present. But for the moderately shallow phase, weathered rock fragments of over 50 per cent of the volume are encountered within 75 cm (30 inches) depth.

These weathered rock fragments are soft and easily crushed to a clayey texture. In soils which show marked increases in hue with depth, the maximum hue is often reached in this horizon and represents the maximum illuviation of iron and the rock fragments show a greater degree of induration due to laterisation by iron as compared to those in the paler coloured soils. The BC horizon is compact and not easily augered but the material when augered is friable and dry. Deep cuttings and pits show that the boundary of the weathering material and the soil is highly irregular and the weathered zone may extend to depth of over 250 cm (100 inches) before the relatively unweathered dark grey shale is reached.

TABLE II.4.4 AVERAGE CHEMICAL AND MECHANICAL ANALYSES OF THREE PROFILES OF MERIT FAMILY

Horizon	Particle size analyses per cent			Texture	pH soil/water 1 : 2.5	pH soil/KCl 1 : 2.5	Exchangeable cations me/100g soil					
	Sand	Silt	Clay				Ca	Mg	Na	K	CEC	CEC/clay
Ah	28	48	24	Loam	4.6	3.6	0.9	1.3	0.2	0.4	11.3	47
Ae	16	50	34	Clay loam	4.9	3.8	0.2	0.5	0.2	0.2	10.9	32
B1	15	42	43	Silty clay	5.0	3.9	0.1	0.5	0.2	0.1	11.2	26
B2	19	35	46	Clay	5.0	3.9	0.1	0.3	0.2	0.2	11.2	24
B3	15	38	47	Clay	5.4	3.9	0.3	0.3	0.1	0.2	11.2	24
BC	12	42	46	Silty clay	5.5	4.0	0.1	0.6	0.1	0.2	11.2	23

Per cent				Nutrients mg/100g soil						
Base saturation	Total N	Organic carbon	C/N ratio	Total					Available	
				P	K	Mg	Ca	Mg/K	P	K
15.5	0.32	6.48	20	45	71	149	12	2.1	0.7	0.24
7.6	0.148	1.95	13	31	117	207	3	1.8	0.1	0.12
5.8				13	133	232	4	1.7	0.1	0.12
5.6				21	153	248	3	1.6	Nil	0.10
5.7				16	165	267	6	1.6	Nil	0.07
5.5				14	174	250	2	1.4	Nil	0.10

The average particle size analysis values of three profiles of Merit soils are shown on Table II.4.4. The Ah horizon has the highest content of sand fraction and sand content of the other horizons remains almost constant. Silt content exceeds 40 per cent in all horizons except the B2 and B3 horizons which reflects a high silt content in the parent material. There is a significant increase in clay content from the A to the B horizons but no single B horizon displays any distinct clay bulge. The average texture of Merit soils from the analysed profiles is a light clay or silty clay.

The average chemical characteristics are given in Table II.4.4. This shows that the Ah horizon has the highest carbon content but low nitrogen, hence giving a high C/N ratio for the Ah horizon and a medium ratio for the Ae horizon. The pH values for the A and the B1 horizons are similar to other Merit soils but those for the subsoil horizons are slightly higher by nearly half a unit than those of Merit soils in the Lambir-Subis area. All the exchangeable cations levels are low and comparable to other Merit soils. The cation exchange capacity values average 11 milliequivalents/100 grammes for two profiles and are comparable to values for average Merit soils in other areas but in one profile the average cation exchange capacity values are high throughout the profile and this also appears to correlate with the lower values for total potassium. However, the average cation exchange capacity values of clay still fall below the upper limit of 35 milliequivalents/100 grammes permitted for Merit soils. The values of base saturation percentage are no different from other Merit soils and these are low throughout the profile. The levels of total calcium for all profiles are low while those for magnesium and potassium show a gradual increase with depth, indicating that the release of these cations to the soil probably lies in the clay minerals associated with the weathered parent material and is less affected by factors like soil organic matter. Merit soils studied outside the survey area have a ratio of total magnesium to potassium of almost 1 : 1, but in the survey area, this ratio decreases from 2.1 to 1.4 from the Ah to the BC horizon. The ratio of magnesium to potassium is also related to the concentration of the extractant used and a comparison of the values of total magnesium and potassium obtained by using 8NHCl and concentrated HCl acid shows that the higher concentration of the extractant decreases the ratio from two to less than 0.5. Higher potassium values obtained from the stronger extractant suggests that a considerable amount of this is released from a breakdown of the clay lattice.

Merit-Kapit Family Intergrade

Soils of Merit-Kapit family intergrade are formed from similar parent material to the Merit family but differ only by their shallow depth, with a lithic or paralithic contact within 50 cm (20 inches) of the surface. The area mapped under this unit is 3 708 acres or 18.48 per cent, being the largest of all the soil mapping units in the survey area. Of these, over 50 per cent occur on slopes exceeding 15 degrees.

As with Bekenu-Kapit soils, the Merit-Kapit soils have a weakly developed B horizon and the Ah horizon is generally missing due to surface erosion. The BC horizon which occurs within 50 cm (20 inches) depth contains a matrix of clay and soft weathered fragments of weathered parent material. Stonelines of laterised parent material are a more persistent feature as compared to the Bekenu-Kapit soils and these are found to be more common on gentle slopes and on hills of lower amplitude. On the steeper slopes the BC horizon merges into deeply weathered and compact parent material which is difficult to auger. Nevertheless, the stonelines or weathered parent rock do not completely prevent many coarse roots extending into these horizons.

No profile of Merit-Kapit soils was sampled for analysis but chemical data for these soils elsewhere have indicated little difference from Merit soils. The main limitation of these soils is their shallow rooting depth.

Kabuloh Family

Kabuloh soils are formed from calcareous shale or marl and they were first identified and mapped at series level by Wall (1964) at the Kabuloh Agricultural Station. More recent semi-detailed soil surveys in the Lambir-Subis area have shown the more widespread occurrence of these soils and that they are agriculturally important to the development of the Lambir-Subis area (Lim, C.P., 1970). Because of the importance of Kabuloh soils in the Sungai Karabungan area, these soils have been studied in more detail than other soils in the area and hence soils of this family were mapped as far as possible at the series level.

Kabuloh soils are clay or silty clay in texture and chemical parameters have largely been relied upon to differentiate these soils from others with similar textures. Kabuloh soils have a pH of over 6.0 and exchangeable calcium of more than five milliequivalents in some horizons below a depth of 75 cm (30 inches) or immediately above a paralithic or lithic horizon if shallower than 75 cm (30 inches).

Three series were mapped; these are the Kabuloh, Karabungan and Tangap series. The first two series have field and chemical characteristics that are easily distinguished from other heavy textured soils derived from non-calcareous parent materials. The third series possesses physical properties which almost resemble a strongly coloured and variegated deep phase of the Jakar series but the chemical properties of the control section in most cases is no different from those of Merit soils except for the strongly calcareous nature of the parent material.

Kabuloh Series

Kabuloh series soils are formed from calcareous shale parent material, with clay or silty clay texture, hue 10YR or yellower, pH H_2O over 6.0, base saturation 100 per cent and exchangeable calcium over five milliequivalents throughout the control section. The hue and high base saturation are the most important characteristics which separate Kabuloh series from the other two series of the Kabuloh family.

Kabuloh series soils are mainly mapped in the central part of the area. Of the three phases mapped, the moderately shallow phase (50 to 75 cm/20 to 30 inches) occupies 1 194 acres or 71 per cent of the Kabuloh series soils. The moderately shallow phase is separated from the skeletal soils - Kabuloh-Kapit family intergrade by the minimum depth requirement of 50 cm (20 imetres overlying a lithic or paralithic contact. Examination of the bore descriptions shows that Kabuloh soils with 50 to 60 cm (24 inches) depth occupy 70 per cent of the area and the remainder of the area is covered by soils deeper than 60 cm (24 inches). These figures correlate with the relative area distribution of the depth phases mapped.

TABLE II.4.5 AVERAGE CHEMICAL AND MECHANICAL ANALYSES OF THREE PROFILES OF KABULOH FAMILY

Horizon	Particle size analyses per cent			Texture	pH soil/water 1 : 2.5	pH soil/KCl 1 : 2.5	Exchangeable cations me/100g soil					
	Sand	Silt	Clay				Ca	Mg	Na	K	CEC	CEC/clay
Ah	31	40	29	Clay loam	6.7	5.9	27.4	2.2	0.1	0.5	15.1	52
Ae	20	48	32	Clay loam	6.3	5.0	22.2	1.2	0.1	0.3	15.4	48
B	22	40	38	Clay loam	6.5	4.8	27.9	1.0	0.1	0.2	11.7	31
B3	12	48	40	Clay	8.4	7.0	30.9	1.2	0.1	0.2	11.2	28

Per cent				Nutrients mg/100g soil						
				Total					Available	
Base saturation	Total N	Organic carbon	C/N ratio	P	K	Mg	Ca	Mg/K	P	K
100	0.450	7.23	16	49	192	535	775	2.8	0.4	0.20
100	0.231	2.17	9	29	212	624	422	2.9	0.1	0.11
100				19	273	675	486	2.5	0.1	0.07
100				31	263	922	688	3.5	0.1	0.7

Table II.4.5 shows the average particle size analysis from four profiles of Kabuloh series. These soils have a silt content of 40 per cent or over for all horizons. The clay content of the B horizon averages 38 to 40 per cent which indicates a light clay texture.

The Ah horizon is coloured dark greyish brown, is moist and friable and has a crumb structure. The carbon content is high but the carbon : nitrogen ratio is comparable to that of the Ah horizon of Merit soils. This horizon is well rooted and usually contains abundant white ants and earthwroms.

The Ae horizon is generally thin, being less than 10 cm (4 inches) thick. This horizon is coloured 10YR or 2.5Y with a clay loam or silty clay loam texture, is moist and firm, with a weak to moderate subangular blocky structure. The soil is mottled with abundant fine black particles of organic matter or manganese. In many soils examined, there are abundant white ants within this horizon.

The change from the Ae horizon to the B horizon is abrupt and is difficult to distinguish clearly particularly by augering. The B horizon has a hue of 10YR or 2.5Y and differs little from the Ae horizon while the texture becomes heavier, with an average clay loam to clay texture. This horizon is moist, firm to very firm, with moderately well developed coarse angular blocky structure which improves to strong coarse prismatic upon drying. The very firm consistence experienced in field descriptions is caused by the low porosity as the texture shows an average clay content of only 40 per cent for this horizon. Rooting is poor and consists of few fine roots and occasional coarse roots. Like the Ae horizon, fine black organic matter or manganese is present dispersed throughout the horizon. In most Kabuloh soils, particularly the shallow phase, the B horizon changes abruptly into the BC horizon which consists of dark olive grey clay mixed with soft clayey shale. There is a marked increase in moisture content in the BC horizon, giving the soil a slightly soapy consistence. This BC horizon contains abundant soft black manganese nodules and the concentration is highest at the BC and C contact where coarse moderate indurated manganese nodules are deposited. The BC horizon has a weak blocky structure, tending towards massive with depth. Tree roots either stop or flatten at the lower part of this horizon, suggesting that there is a physical and chemical restriction to root development beyond this depth.

The average chemical characteristics are shown in Table II.4.5. All horizons have pH values of more than 6.0. Levels of exchangeable calcium are high and increase with depth and those for magnesium are moderately high in all horizons. The ratio of calcium to magnesium is also high and increases with depth. The high exchangeable calcium accounts for the very high base saturation values of 100 per cent for all four profiles examined and clearly differentiate Kabuloh series from the other two series of the Kabuloh family. Levels of exchangeable potassium and sodium are low and comparable to those of other residual soils. Levels of total calcium and magnesium are high. Although high levels of calcium tend to suppress the levels of potassium, total potassium levels are comparable to or higher than those of residual soils like the Merit family and are twice as high as those of the Karabungan and Tangap series. The ratio of magnesium to potassium increases from 2.8 in the Ah horizon to 3.5 in the B3 horizon, while the ratio for Merit soils decreases from 2.1 to 1.4 from the surface to the subsoil. Levels of available phosphorus and potassium are no different from those of other hill soils.

The physical and chemical properties of Kabuloh series are markedly different from other hill soils. Furthermore, these soils are characterised by their shallow rooting depth and in nearly all the moderately shallow phases mapped, over 80 per cent of the soils rest directly on relatively unweathered shale (lithic horizon) instead of grading onto strongly weathered parent material (paralithic horizon). The lithic horizon is impenetrable to rooting while the paralithic horizon of other residual hill soils provides a medium for some coarse tap roots. This impenetrable lithic horizon is one very serious limitation to the use of most of these soils. The absence of a deep weathering zone is attributed to the low permeability of the parent material, the absence of any fracture planes at a high angle to the soil surface, and the gentle dip of the shale beds. The active weathering parent rock is confined to a zone several inches thick, and is best observed after rainfall when a perched water table is formed at the soil-rock interface. Weathering of the calcareous shale is considered to operate by dissolution of the calcareous parent rock material by the slightly acidic soil solutions moving from the upper soil horizons.

The average profile trace element levels have been shown in Table 4.12 (page 100) and it is thought that the levels of copper, manganese and zinc are present in sufficient amounts. The unavailability of boron, copper, iron, zinc and manganese should be kept in mind in view of the high pH of these soils. Severe boron deficiency symptoms have been noted on isolated mature oil palms grown on moderately shallow Kabuloh series soils at the Kabuloh Agricultural Station. For pasture, for example, the pH of these soils should be kept not higher than 6.0.

Karabungan Series

The Karabungan series is formed from calcareous shale parent material similar to that of Kabuloh series. This series was first established in this area and the soils are differentiated from Kabuloh series by having a colour change of at least 2.5 units in some part of the control section and the values of base saturation and pH H_2O are lower than those of Kabuloh series.

The morphology of the upper part of a Karabungan profile resembles that of the Kabuloh series while the lower part resembles the Merit soils. However, the colour increase and the heavier textures of the B horizons are characteristic features of these soils. Moreover, the weathering parent material which is normally reached within the soil examination depth can be tested with dilute acid to confirm its calcareous origin.

Most Karabungan soils have an Ah horizon coloured dark yellowish brown, with a loamy texture, crumb structure and friable consistence. The organic matter content, as with most other residual soils, is high, giving a high carbon to nitrogen ratio.

Karabungan soils occupy 1 293 acres or 7.3 per cent of the survey area and of these 701 acres are moderately shallow (50 to 75 cm/20 to 30 inches), 525 acres are moderately deep (75 to 100 cm/30 to 40 inches) and only 67 acres are deep (over 100 cm/40 inches). These soils are mapped in the eastern and southern parts of the survey area and over 90 per cent of these soils occur on slopes of less than 20 degrees.

The Ae horizon is coloured 10YR or yellower and its hue resembles that of the Kabuloh series. The thickness of this horizon ranges from five to 15 cm two to six inches with clay loam or silty clay loam texture, moist to firm consistence and the structure is moderately well developed blocky. This horizon is well rooted and frequently contains abundant termites and coarse pores.

The transition from the Ae horizon to the B horizon is abrupt, being characterised by a marked change in colour from 10YR to 7.5Y or redder. The clay content, as shown in Table II.4.6, is over 50 per cent. This horizon has a firm to very firm consistence, with a coarse moderately developed blocky structure which improves to coarse prismatic on drying. Pale yellow mottles are common and become prominent with depth.

TABLE II.4.6 AVERAGE CHEMICAL AND MECHANICAL ANALYSES OF FOUR PROFILES OF KARABUNGAN SERIES

Horizon	Particle size analyses per cent			Texture	pH soil/water 1 : 2.5	pH soil/KCl 1 : 2.5	Exchangeable cations me/100g soil					
	Sand	Silt	Clay				Ca	Mg	Na	K	CEC	CEC/clay
Ah	36	42	22	Loam	5.8	4.9	13.4	2.9	0.1	0.6	27.6	100
Ae	20	46	34	Silty clay loam	5.2	3.9	6.1	1.7	0.1	0.3	18.0	52
B1	12	39	49	Clay	5.4	3.9	5.1	0.8	0.1	0.2	17.4	35
B2	10	33	57	Clay	5.8	4.0	9.1	0.8	0.1	0.2	18.3	32
B3	10	34	56	Clay	6.0	4.4	11.1	0.6	0.1	0.2	16.7	29
BC	10	37	53	Clay	6.3	4.8	18.0	0.8	Nil	0.2	21.8	41

Per cent				Nutrients mg/100g soil						
Base saturation	Total N	Organic carbon	C/N ratio	Total					Available	
				P	K	Mg	Ca	Mg/K	P	K
68.5	0.373	6.52	18	32	44	166	204	3.8	0.4	0.27
49.6	0.235	2.83	12	23	54	218	66	4.0	0.4	0.12
31.4				13	62	226	47	3.7	0.1	0.30
46.9				12	67	238	64	3.6	0.1	0.31
73.6				10	66	233	116	3.5	0.1	0.31
80.2				11	53	174	155	3.3	0.1	0.10

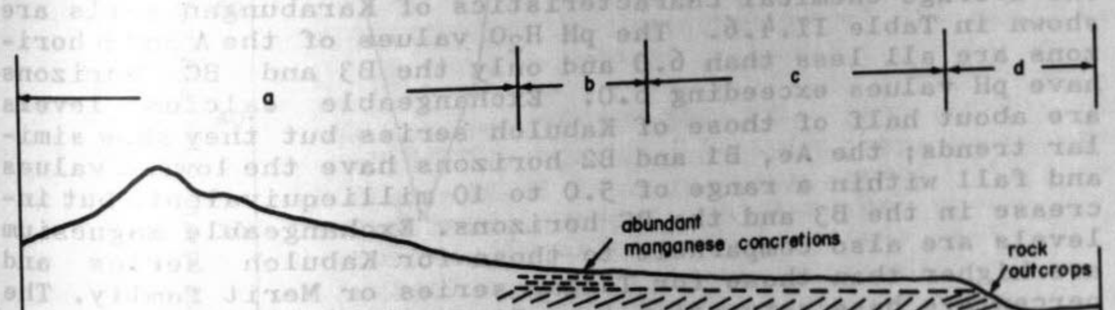
The B2 horizon generally merges into a deep B3 horizon with a matrix colour similar to the B2 horizon but with prominent pale coloured mottles. The average texture is also a heavy clay and consistence is firm to very firm. Structure is weak coarse blocky tending towards massive with depth.

The BC horizon has an average thickness of 50 cm (20 inches) which differs from the Kabuloh series where the BC horizon is almost absent. This horizon is coloured dark grey or light olive grey and clay is present admixed with dark grey soft clayey shale. The structure is massive, soft and soapy and after heavy rain a perched water table may form at the lower part of the horizon above the shale bedrock. This horizon is poorly rooted and the few fine roots present tend to flatten at the lower part of the horizon as in BC horizon of Kabuloh series indicating that marked changes in chemical characteristics and higher pH probably restrict root development. Soft manganese concretions are present in abundance in this horizon but like the Kabuloh series, stonelines or iron concretion are absent.

Karabungan soils were observed to be best developed on slopes ranging from 10 to 20 degrees. On slopes less than 10 degrees, Kabuloh series soils predominate. Thus on some of the fairly extensive terrace-like surfaces where there is a continuous gradation in slope from almost flat to steeply sloping, the Kabuloh to Karabungan series soil sequence relationship can be mapped as a soil catena as shown in Figure II.4.3.

FIGURE II. 4.3

KABULOH - KARABUNGAN SOIL SERIES DISTRIBUTION IN RELATION TO TOPOGRAPHY AND DRAINAGE



a : Karabungan series soils - moderately deep phase on slopes exceeding seven degrees.

b : Kabuloh series soils - imperfectly drained, gritty phase, at footslope with abundant manganese concretions throughout profile.

c : Kabuloh series soils - moderately well drained and moderately shallow phase on slopes less than seven degrees.

d : Alluvial / colluvial soils on valley floor.

The more intense weathering of the soils on the steeper slopes (10 to 20 degrees) has resulted in the greater depth of soil formation normally associated with the Karabungan series as compared to Kabuloh series soils on more gentle slopes (less than 10 degrees). On these more gentle slopes there is often a perched water table above the shale bed and which inhibits the differential mobilisation and oxidation of iron and manganese within the soil. This perched water table is similar to that formed above the humus pan of groundwater podzols. The BC horizon with this perched water is expected to be subjected to more anaerobic conditions and under the high pH prevailing in a weathering horizon, this favours the precipitation of manganese as stable oxides (probably as Mn (OH 2).

On sites where there is a wide fluctuation of water table and where lateral enrichment of manganese by seepage water occurs, the manganese hydroxide may oxidise successively to Mn_3O_4 and MnO_2 which is the stable phase over the whole pH range. This appears to be confirmed by the presence of shallow Kabuloh soils described at the lower footslope containing abundant well formed and indurated manganese concretions throughout the profile and also on the soil surface.

On slopes exceeding 10 degrees, the less frequent occurrence of a perched water table induces a more aerobic condition. Although the weathering horizon is still weakly reducing as shown by the presence of abundant soft manganese nodules in the BC horizon of Karabungan soils, the B horizons are generally well drained and oxidising conditions prevail. This oxidising condition coupled with the higher degree of maturity of soil development on steeper slopes, results in a varying degree of rubification or reddening caused by the presence of iron oxide.

The average chemical characteristics of Karabungan soils are shown in Table II.4.6. The pH H_2O values of the A and B horizons are all less than 6.0 and only the B3 and BC horizons have pH values exceeding 6.0. Exchangeable calcium levels are about half of those of Kabuloh series but they show similar trends; the Ae, B1 and B2 horizons have the lowest values and fall within a range of 5.0 to 10 milliequivalents but increase in the B3 and the BC horizons. Exchangeable magnesium levels are also comparable to those for Kabuloh series and are higher than those for Tangap series or Merit family. The percentage base saturation (see Figure II.4.4) is lowest in the B horizons, which are only 50 per cent saturated but values rapidly increase with depth to over 80 per cent. The average cation exchange capacity values are higher than those of Kabuloh and Tangap series by five milliequivalents. However, the cation exchange capacity/clay of all horizons are less than 35. Levels of total calcium show similar trends as Kabuloh series; the lowest levels are found in the B horizons and increase sharply with depth. The levels of total magnesium, potassium and phosphorus are lower than Kabuloh and Tangap series and the Merit family (see Figure II.4.5). The low potassium levels result in the high potassium : magnesium ratio for all horizons.

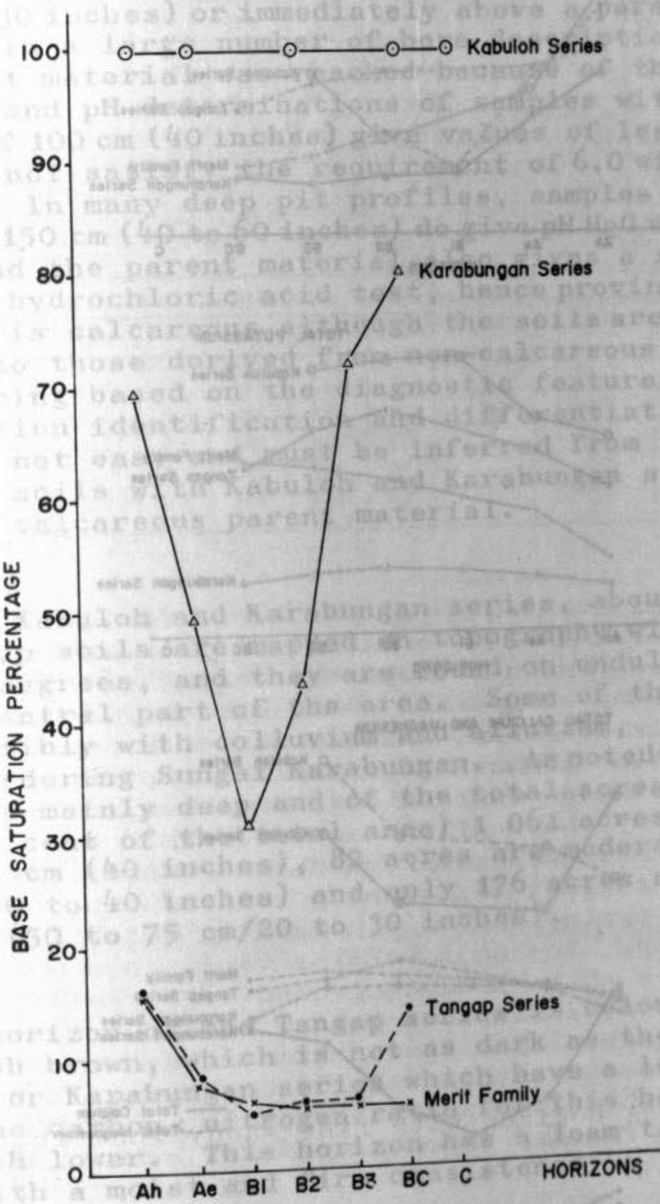
Tangap Series

The Tangap series is formed from calcareous, mainly marl, sedimentary parent material. This series was first established in this area as the result of the survey. These soils are characterised by their strong and variegated coloured subsoil, with hues of at least 2.5 units higher than 10YR; and their greater soil depths.

Chemical parameters are also used to differentiate these soils from other series of the Kabuloh family and Merit family soils.

FIGURE II.4.4

(a) AVERAGE VALUES OF PERCENTAGE BASE SATURATION



(b) AVERAGE pH H_2O VALUES

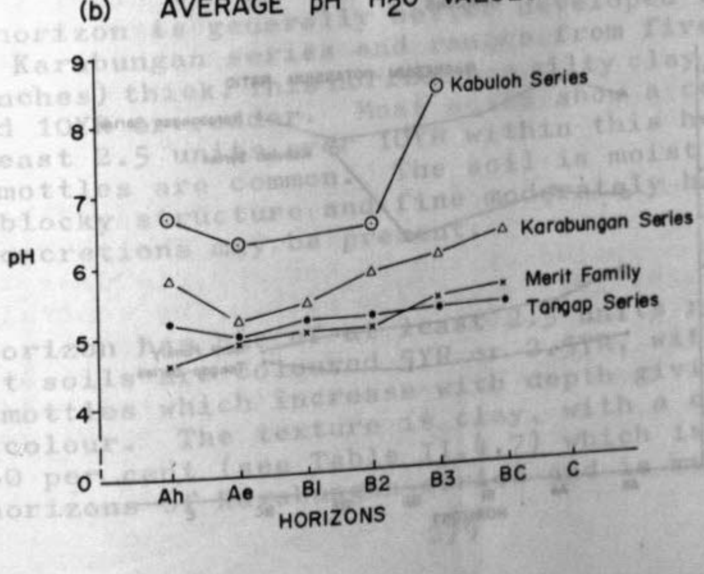
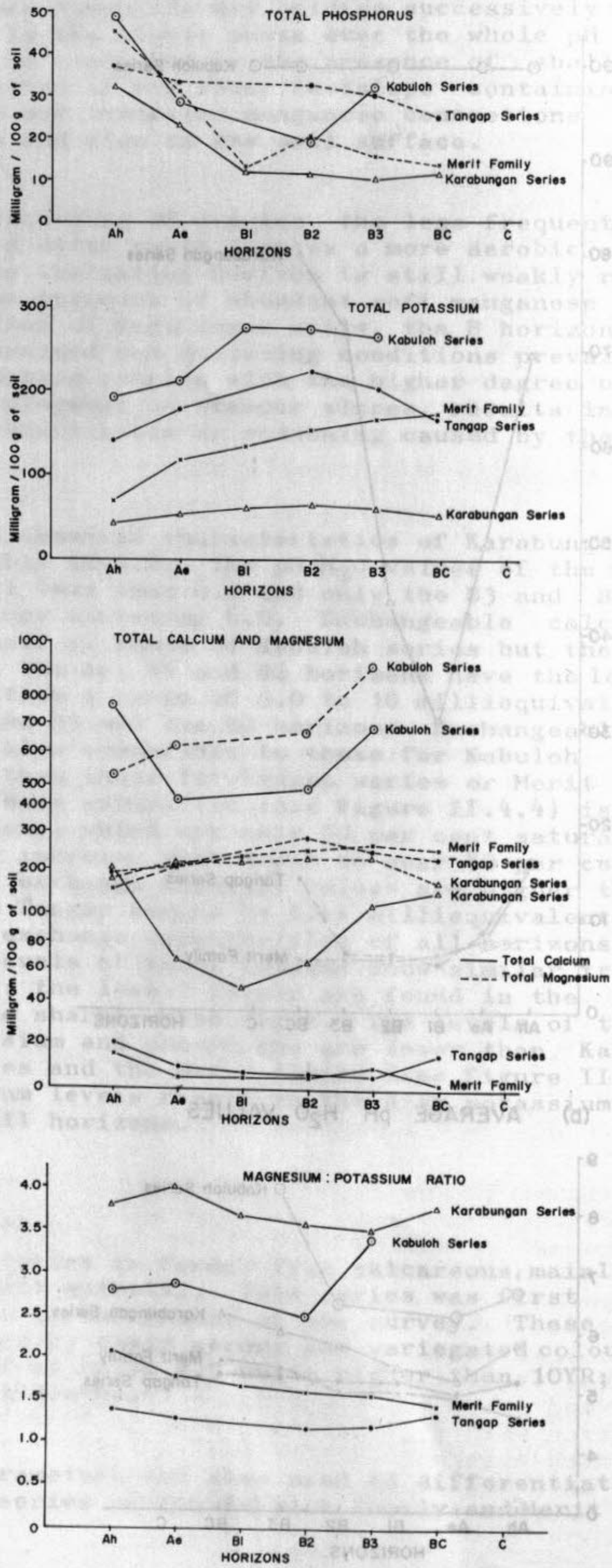


FIGURE II 4.5

AVERAGE CHEMICAL ANALYSES VALUES BY HORIZONS FOR DIFFERENT SOILS IN THE SUNGAI KARABUNGAN SAMPLE AREA



Tangap series is tentatively defined as having a pH H_2O of 6.0, base saturation over 35 per cent and exchangeable calcium of clay of more than five milliequivalents below a depth of 75 cm (30 inches) or immediately above a paralithic horizon. However, in a large number of bore descriptions, no weathering parent material was reached because of the great depth of the soil and pH determinations of samples within the control section of 100 cm (40 inches) give values of less than 6.0 and hence do not satisfy the requirement of 6.0 within the control section. In many deep pit profiles, samples taken at depths of 100 to 150 cm (40 to 60 inches) do give pH H_2O values of 6.0 and higher and the parent material also gives a strong reaction with the hydrochloric acid test, hence proving that the parent material is calcareous although the soils are morphologically similar to those derived from non-calcareous rock types. In soil mapping based on the diagnostic features within the control section identification and differentiation from other soils is not easy and must be inferred from the association of these soils with Kabuloh and Karabungan soils and the presence of calcareous parent material.

Like the Kabuloh and Karabungan series, about 80 per cent of the Tangap soils are mapped on topography with slopes of less than 20 degrees, and they are found on undulating low hills in the central part of the area. Some of the low hills merge imperceptibly with colluvium and alluvium, particularly in areas bordering Sungai Karabungan. As noted above, the Tangap soils are mainly deep and of the total acreage of 1 319 acres (6.4 per cent of the total area) 1 061 acres are deep (more than 100 cm (40 inches), 82 acres are moderately deep (75 to 100 cm/30 to 40 inches) and only 176 acres are moderately shallow (50 to 75 cm/20 to 30 inches).

The Ah horizon of the Tangap series is coloured brown or dark yellowish brown, which is not as dark as the Ah horizons of Kabuloh or Karabungan series which have a lower carbon content. The carbon : nitrogen ratio for this horizon is therefore much lower. This horizon has a loam to clay loam texture, with a moist and firm consistence, a crumb structure and is well rooted.

The Ae horizon is generally better developed than in the Kabuloh or Karabungan series and ranges from five to 15 cm (two to six inches) thick. This horizon has silty clay texture, and is coloured 10YR or redder. Most soils show a colour increase by at least 2.5 units over 10YR within this horizon and pale yellow mottles are common. The soil is moist and firm, with a weak blocky structure and fine moderately hard iron manganese concretions may be present.

The B horizon has hue of at least 2.5 units redder than 10YR and most soils are coloured 5YR or 2.5YR, with prominent pale yellow mottles which increase with depth giving a variegated matrix colour. The texture is clay, with a clay content of 50 to 60 per cent (see Table II.4.7) which is comparable to the B horizons of Karabungan series and is much higher than

TABLE II.4.7 AVERAGE CHEMICAL AND MECHANICAL ANALYSES OF THREE PROFILES OF TANGAP SERIES

Horizon	Particle size analyses per cent			Texture	pH soil/water 1 : 2.5	pH soil/KCl 1 : 2.5	Exchangeable cations me/100g soil					
	Sand	Silt	Clay				Ca	Mg	Na	K	CEC	CEC/clay
Ah	22	49	29	Clay loam	5.2	3.9	1.4	0.5	0.1	0.2	13.5	46
Ae	11	47	42	Silty clay	4.9	3.8	0.3	0.2	0.1	0.2	12.3	29
B2	10	34	57	Clay	5.2	4.0	0.2	0.1	0.1	0.2	11.5	20
B3	13	34	53	Clay	5.3	4.0	0.3	0.1	0.1	0.2	11.8	22
BC	10	36	54	Clay	5.3	4.0	0.9	0.2	0.1	0.2	11.8	22

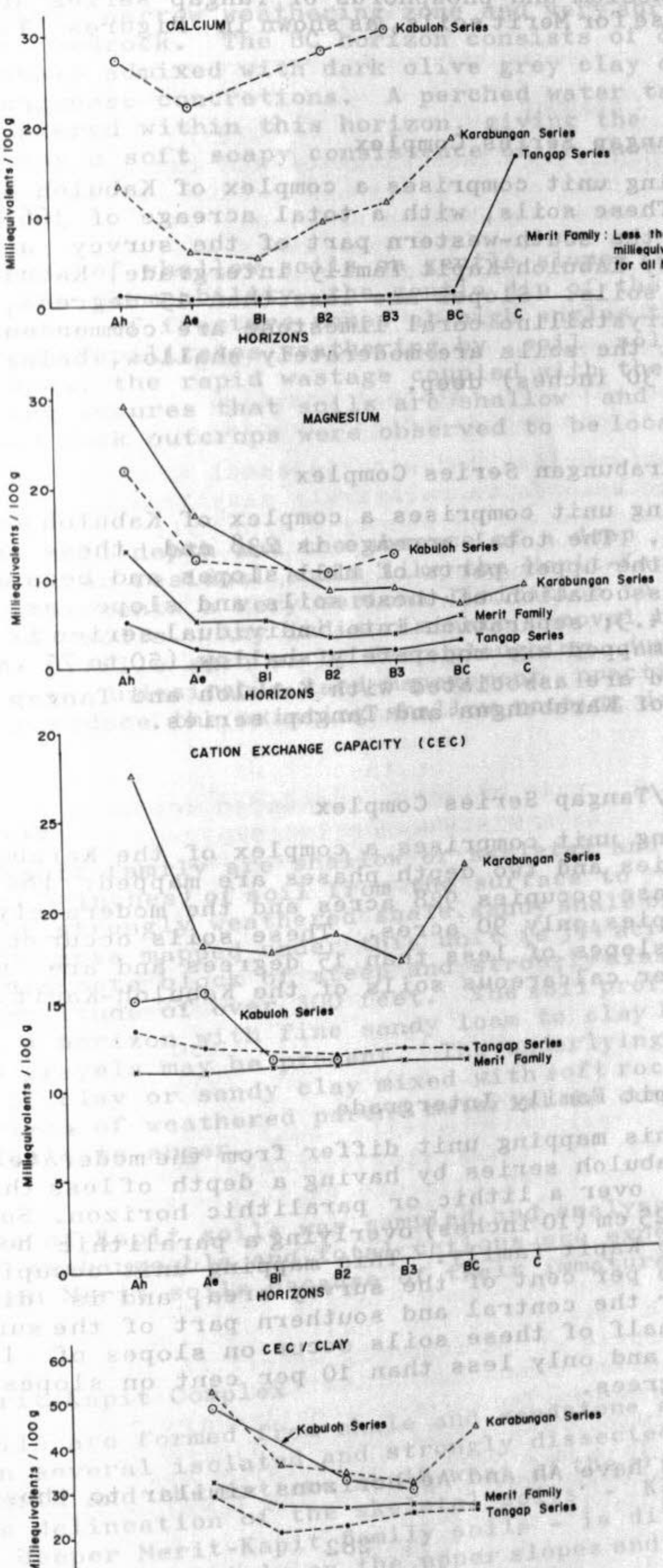
Per cent				Nutrients mg/100g soil						
Base saturation	Total N	Organic carbon	C/N ratio	Total					Available	
				P	K	Mg	Ca	Mg/K	P	K
16	0.201	2.59	13	37	137	186	20	1.4	0.1	0.12
8	0.116	0.97	8	33	175	222	6	1.3	Nil	0.08
5				33	222	283	4	1.3	Nil	0.09
6				30	204	245	4	1.2	Nil	0.11
14				25	169	231	11	1.4	Nil	0.13

the B horizons of Kabuloh series or Merit family. The structure is weak coarse blocky to massive. Iron-manganese concretions are also present, dispersed throughout the soil but not in concentrated stonelines as in some Merit family soils. Locally at colluvial sites, these concretions are found in large volumes which constitute a serious impedence to rooting. In more detailed mapping some of these soils could be mapped as a gritty phase of the series. The variegated or pallid subsoils and the well formed concretions present in varying amounts suggest that Tangap soils were probably formed in a weathering regime with a fluctuating water table which has since lowered. The soil forming conditions therefore approximate to those which produce ground water laterite which is characterised by a deep and pallid zone in the subsoil. The B horizons generally extends beyond the limits of the control section to merge with a deep B3 horizon with variegated colours of reddish yellow and pale yellow. The BC or weathering horizon is reached in most cases at a depth of 150 cm (60 inches).

Stonelines or laterised shale fragments are almost absent in most Tangap soils. This is one physical diagnostic feature which can be used to differentiate Tangap series from most Merit soils where stonelines or shale fragments commonly overlie firm weathering shale.

The average chemical characteristics of Tangap soils from four profiles are shown in Table II.4.7. The pH H_2O values of all horizons, including the BC horizon, is less than 6.0. The level of exchangeable calcium within the control section is less than five milliequivalents but rises to more than 10 milliequivalents in the C horizon (see Figure II.4.6) thus showing clearly that the parent material is calcareous. The percentage base saturations almost parallel those of Merit

AVERAGE CHEMICAL ANALYSES VALUES BY HORIZONS FOR DIFFERENT SOILS IN THE SUNGAI KARABUNGAN SAMPLE AREA



soils. Likewise, the cation exchange capacity, total calcium, magnesium and phosphorus of Tangap series are comparable to those for Merit soils, as shown in Figures II.4.5 and II.4.6.

Kabuloh/Tangap Series Complex

This mapping unit comprises a complex of Kabuloh and Tangap series. These soils, with a total acreage of 166 acres, are mapped in the south-western part of the survey area, being bordered by Kabuloh-Kapit family intergrade, Kabuloh series and Merit soils. Slopes are less than 15 degrees, and outcrops of crystalline coral limestone are common on the surface. All the soils are moderately shallow, being 50 to 75 cm (20 to 30 inches) deep.

Kabuloh/Karabungan Series Complex

This mapping unit comprises a complex of Kabuloh and Karabungan series. The total acreage is 238 and these soils are mapped on the upper parts of hill slopes and because of the intimate association of these soils and slope as shown in Figure II.4.3; separation into individual series is difficult. The soils mapped are moderately shallow (50 to 75 cm (20 to 30 inches) and are associated with Kabuloh and Tangap series and a complex of Karabungan and Tangap series.

Karabungan/Tangap Series Complex

This mapping unit comprises a complex of the Karabungan and Tangap series and two depth phases are mapped: the moderately deep phase occupies 928 acres and the moderately shallow phase occupies only 90 acres. These soils occur on low hills, mainly on slopes of less than 15 degrees and are surrounded by shallower calcareous soils of the Kabuloh-Kapit family intergrade.

Kabuloh-Kapit Family Intergrade

Soils of this mapping unit differ from the moderately shallow phase of Kabuloh series by having a depth of less than 50 cm (20 inches) over a lithic or paralithic horizon. Soils shallower than 25 cm (10 inches) overlying a paralithic horizon belong to the Kapit family. This mapping unit occupies 3 121 acres or 16 per cent of the survey area, and is distributed widely over the central and southern part of the survey area. More than half of these soils occur on slopes of less than 10 degrees and only less than 10 per cent on slopes greater than 20 degrees.

These soils have Ah and Ae horizons similar to those of the moderately shallow phase of Kabuloh series and they overlie a weak B horizon. Like the Kabuloh series they are characterised by their narrow weathering zone and very abrupt change from soil to bedrock. The BC horizon consists of dark grey weathered shale admixed with dark olive grey clay containing abundant manganese concretions. A perched water table is usually encountered within this horizon, giving the weathered shale and clay a soft soapy consistence as in Kabuloh series soils.

The occurrence of shallow soils on gentle slopes is accounted for by the low permeability, the gentle dip of the shale bed and the absence of fracture zones at high angles to the soil surface which facilitates weathering by soil solution. On steeper slopes, the rapid wastage coupled with the slow rate of weathering ensures that soils are shallow and immature. Boulders and rock outcrops were observed to be locally abundant.

The shallow soil depth and the absence of a deep weathering zone as in other residual soils like the Merit-Kapit family intergrade, presents a very serious limitation to the use of Kabuloh-Kapit soils. Any indiscriminate removal of the upper part of the profile such as by deep ploughing during land clearing or by undesirable land management practices could drastically reduce the existing shallow rooting depth.

Kapit Family

Soils of Kapit family are shallow or skeletal and have less than 25 cm (10 inches) of soil from the surface to the parent material of strongly weathered shale, sandy shale or fine sandstone. The area mapped under this unit is 344 acres and occupies one discrete block of steep and strongly dissected hills with an amplitude of over 300 feet. The soil profile consists of a thin A horizon with fine sandy loam to clay loam texture and shale gravels may be present. The underlying BC horizon consists of clay or sandy clay mixed with soft rock fragments. The C horizon of weathered parent material is compact, firm and difficult to auger.

No profile of Kapit soils was sampled and analysed but the levels of exchangeable and total cations are expected to be higher than Merit soils because of their immature nature.

Kapit/Merit-Kapit Complex

These soils are formed from shale and sandstone and they are mapped on several isolated and strongly dissected high hills in the north and the extreme south-west of the area. In these areas the delineation of the skeletal soils - Kapit family from the deeper Merit-Kapit family soils - is difficult. The deeper soils occur mainly on the upper slopes and hill summits and the skeletal soils occur on lower slopes where there is active erosion and soil removal. The acreage mapped is 408 or 2.0 per cent of the survey area.

II.4.8 Land Capability

The Land Capability Classification and the limits of the seven Land Classes have already been discussed in detail in Chapter 5. In the Sungai Karabungan area, all the seven classes were mapped. Three of the five subclasses distinguished in the classification for this area are:-

- Erosion hazard limitations .... e
- Soil limitation within the rooting zone ..... s
- Excess water or internal drainage limitations and flooding hazards .... w

The land for subclass "w" with internal drainage limitations and flooding hazards is relatively easy to map as this includes flat land formed by poorly drained alluvium or colluvium. However, subclasses "e" and "s" for erosion hazard and soil limitations have been found difficult to define. The arbitary limits of rooting depth of 60 centimetres (24 inches) is used as the minimum depth requirement for crop growth. Land in which the soils are deeper than 60 centimetres (24 inches) and with slope exceeding 10 degrees is classified according to the erosion hazard as shown in Table II.4.8.

TABLE II.4.8 LAND CLASSES DELINEATED ACCORDING TO SLOPE WITH MINIMUM ROOTING DEPTH OF 60 CM (24 INCHES)

Land class	Minimum soil depth cm (inches)	Slope degrees	Erosion hazard
IIe	100 (40)	< 5	Slight
IIIe	100 (40)	<10	Moderate
IVe	75 (30)	<15	Moderate
Ve	60 (24)	<20	Severe
VIe	60 (24)	<25	Severe
VIIe	No limit	Over 25	Severe

Table II.4.9 shows the land classes delineated by effective rooting depth because of the shallow rooting depth and the impermeable shale which commonly underlies the bulk of the calcareous soils. The classification strongly emphasises the minimal rooting depth of 60 centimetres (24 inches) and the erosion hazards of soils shallower than 100 centimetres (40 inches) on hill slopes. The minimum soil depth and the corresponding permitted slope for the erosion hazard ratings are shown in Table II.4.9.

TABLE II.4.9 LAND CLASSES DELINEATED ACCORDING TO SOIL DEPTH

Land class	Minimum soil depth cm (inches)	Slope degrees	Erosion hazard
IIs	Over 100 (40)	< 5	Slight
IIIs	Over 75 (30)	< 5	Moderate
IVs	Over 60 (24)	<10	Moderate
Vs	50 to 60 (20 to 24)	No limit	Moderate to severe
VIs	25 to 50 (10 to 20)	No limit	-
VIIs	<25 (<10)	No limit	Severe

(a) Land with slight erosion hazards

Land with less than five degrees slope and soils are deeper than 100 centimetres.

(b) Land with moderate erosion hazard

Land with slopes of less than 10 degrees and soil depth of at least 60 centimetres (24 inches) or land with slopes of less than 15 degrees but with soil depth greater than 75 centimetres (30 inches).

(c) Land with severe erosion hazard

Land with slopes more than 75 degrees and soil depth of less than 75 centimetres (30 inches).

Table II.4.10 shows the acreages of the land classes mapped. The dominant soil series or complexes of these series and families are also shown.

CLASS I

This land occupies 31 acres and comprises levee alluvium with a maximum slope of three degrees; soils are well drained, deeper than 100 centimetres (40 inches) with no flooding and with none or a slight erosion hazard. The soils are mapped as Seduau family and occur entirely in the upper valley of the Sungai Separoh in the northern part of this area.

CLASS II

Of the three subclasses e, s and w, only subclass w was mapped. Class IIw occupies 2 062 acres and comprises alluvial levees of up to three degrees as in Class I but the land is subject to infrequent flooding of short duration. The soils

TABLE II.4.10 LAND CAPABILITY CLASSES - SOILS AND ACREAGES

Terrain class	Soils Family or Series	Acreage	Percentage of area
I	Seduau	331	2
IIw	Seduau	2 062	10
IIIe	Merit, Karabungan, Tangap	483	2
IVe	Merit, Bekenu, Kabuloh, Karabungan, Tangap	1 018	5
IVs	Merit, Bekenu, Kabuloh, Karabungan, Tangap	2 739	14
IVw	Bijat, Seduau/Bijat	1 012	5
Ve	Merit, Bekenu, Kabuloh, Karabungan, Tangap	3 317	17
Vs	Merit, Bekenu, Kabuloh, Karabungan, Tangap	332	2
Vw	Bijat	295	2
VIe	Merit, Bekenu, Kabuloh, Karabungan, Tangap	368	2
VIs	Kabuloh-Kapit, Bekenu-Kapit, Merit-Kapit	6 867	34
VIIe	Merit	252	1
VIIs	Kapit, Merit/Kapit, Merit-Kapit	888	4
	Total	19 964	100

Note For more detailed inventory of the acreages of the mapping units refer to Appendix VII.3, Tables VII.3.1 to VII.3.3.

are well to moderately well drained clay and are deeper than 100 centimetres (40 inches). The area mapped lies in the middle part of Sungai Karabungan and the upper parts of its tributaries. Land of this class has a slight or no erosion hazard.

CLASS III

Of the four subclasses e, s, w and se, only one subclass, e, was mapped. Class IIIe comprises land with slopes of less than 10 degrees and the soils are over 100 centimetres (40 inches) deep, mainly on the Tangap soil series of the Kabuloh family. The area mapped totals 1 083 acres and occupies low hills in the upper Sungai Karabungan valley. The erosion hazard of this class is rated as moderate.

CLASS IV

This class has four subclasses: e, s, w and se as in Class III, three subclasses, e, s and w were mapped.

Class IVe

This class occupies 1 018 acres and comprises land with slopes up to 15 degrees and the soil depth is at least 75 centimetres (30 inches). Compared to class IIIe land, slopes are steeper and soils are shallower. The soils are almost entirely of the Merit family. The erosion hazard of this class is rated as severe.

Class IVs

This class occupies 2 739 acres and comprises land with slopes up to 10 degrees and the minimum soil depth is 60 centimetres (24 inches). The slope is greater and soil depth shallower than those for class IVe. Merit soils occupy only a small part of the area mapped, the rest being Kabuloh, Karabungan and Tangap series or complexes of these series which occur in the central and southern half of the survey area. The erosion hazard of this class is rated as moderate.

Class IVw

Land of this class occupies 1 012 acres and comprises poor or very poorly drained flat alluvium or interior valleys of the lower Sungai Karabungan which are subjected to frequent flooding of moderate duration. The soils are fine textured clay, deeper than 75 centimetres (30 inches) and they include Bijat family or a complex of Bijat and Seduau families.

CLASS V

This class has five subclasses: e, s, w, se and sw but only subclasses e and s were mapped.

Class Ve

Class Ve land has slopes up to 20 degrees and a minimum soil depth of 60 centimetres (24 inches). This subclass occupies 3 317 acres, the second largest unit after Class VIs. The soils comprise small areas of Merit family in the northern half but are mainly Kabuloh, Karabungan and Tangap series or their complexes in the southern part. The erosion hazard is rated as severe.

Class Vs

Class Vs land has no slope limit but the minimum soil depth is only 50 centimetres (20 inches). The area mapped is small, 332 acres, and the soils are mainly Karabungan series. The erosion hazard is rated as moderate to severe, depending on the slope.

Class Vw

This class of land occupies 295 acres and comprises very poorly drained flat alluvium and interior valleys which are subjected to frequent flooding. The soils are deep, fine textured clay of fine Bijat family.

CLASS VI

This class has four subclasses: e, s, se and sw but only two subclasses e and s were mapped.

Class VIe

This class occupies 368 acres and comprises land with slopes exceeding 25 degrees and minimum soil depth of 60 centimetres (24 inches). The soils consist mainly of Merit and Bekenu families. Because of the steep slopes, erosion hazard is rated as severe.

Class VIs

This class occupies 6 867 acres and comprises land with soils of 25 to 50 centimetres (10 to 20 inches) deep and because of the limitation of shallow soil depth, no slope limit applies to this class. This class includes large tracts of Kabuloh-Kapit and Merit-Kapit family intergrades and small areas of Bekenu-Kapit family intergrade. The Kabuloh-Kapit family intergrade occurs on terrain with slopes of less than 15 degrees but with careful management practice, some of this land can be used for pasture. On the other hand, the Merit-Kapit family intergrade occurs mainly on slopes steeper than 15 degrees and the shallow soils on these slopes rule out any possibility for agricultural use and the land is best left under forest. As Class VIs land occupies 34 per cent of the survey area, and much of this lies in the area considered for pasture development, the shallow Kabuloh soils on gentle slope must be distinguished from shallow Merit soils of this land class from the soil and terrain maps.

CLASS VII

This class has four subclasses: e, s, w and se but only subclasses e and s were mapped.

Class VIIe

This class occupies 252 acres and comprises land with slopes exceeding 25 degrees. The steep slopes preclude using this land for agriculture even if the soils are deeper than 25 centimetres (10 inches). The soils of this unit consist of Merit-Kapit family intergrades. The erosion hazard of this class is rated as severe.

Class VIIs

This class occupies 888 acres and comprises land in which the soils are shallower than 25 centimetres (10 inches) deep which is insufficient for crops even if these soils occur on gently sloping land. This unit includes some of the highest hills in the area and the soils are all classified as Kapit family. Land of this class is unsuitable for agricultural use and is best left under forest. The erosion hazard for this land class is rated as severe.

APPENDIX III

APPENDIX III

METHODS OF SOIL ANALYSES

III.1 FULL SERIES ANALYSIS

(i) Particle Size Analysis

40 g of soil were dispersed by shaking overnight with sodium hexameta phosphate/sodium carbonate solution. The suspension was then transferred to a one litre cylinder, made up to volume and mixed. A Bouyoucos hydrometer was used to take readings after the following settling times:-

(a) 46 seconds, to give silt plus clay content, that is the fractions 0.05 to 0.002 mm and less than 0.002 mm respectively;

(b) five hours, to give the clay content;

(c) total sand (fraction greater than 0.05 mm) content was obtained by subtracting the figure found in (a) from 100 per cent.

The samples were wet-sieved through a 100 micron sieve and the sand dried at 105°C. The dried samples were then put through a nest of sieves giving the fractions of 2 to 0.50 mm (2 000 to 500u), 0.50 to 0.25 mm (500 to 250u), 0.25 to 0.10 mm (250 to 100u) and 0.10 to 0.05 mm (100 to 50u). The fraction 100 to 50u was obtained by difference, using the value obtained from the Bouyoucos hydrometer.

(ii) pH Soil : Water Suspension, 1 : 2.5

A Pye Unicam model Universal was used for the pH determination; 50 ml of deionised water were added to 20 g of soil. The suspension was stirred and allowed to settle. After one hour the pH of the Supernatant liquid was measured.

(iii) pH Soil : Potassium Chloride, 1 : 2.5

0.5 ml of NKCl was then added to the above suspension (see (ii) above), stirred and allowed to settle. The pH of the supernatant liquid was then measured with a Pye pH meter mentioned under (ii) above.

(iv) Easily Soluble Potassium

4 g of soil were extracted by shaking with 20 ml of 0.5 N acetic acid for one hour. Potassium was determined by atomic absorption.

(v) Easily Soluble Phosphorus

This analysis has been adapted from the method of Bray and Kurtz (1945). 2 g of soil were extracted by shaking for one minute with Bray Z solution (0.03 N ammonium fluoride in 0.1 N hydrochloric acid). Phosphorus was determined on the extract by the molybdenum blue method.

(vi) Total Available (6NHCl soluble) Phosphorus, Potassium, Calcium and Magnesium

0.5 g of finely ground soil were weighed into a test tube and 2.5 ml of 8 N hydrochloric acid were added following by heating on an aluminium block at 95°C for two hours. 2.5 ml of deionised water were added and the contents of the test tube mixed, centrifuged and the clear supernatant liquid decanted into a clean test tube. Phosphorus was determined on this extract by the vanadate-molybdate method. Potassium, calcium and magnesium were determined by atomic absorption spectroscopy.

(vii) Cation Exchange Capacity (CEC)

4 g of soil were shaken twice with triethanolamine buffered barium chloride solution, pH 8.2 in order to replace all exchangeable cations with barium. Excess barium was removed by shaking with water. The sample was then shaken with a solution of magnesium sulphate of known concentration. This replaced the exchangeable barium by magnesium, at the same time removing barium from solution as barium sulphate. The magnesium remaining in solution was determined by titration with EDTA using Solochrome black 6B as indicator. The cation exchange capacity is calculated from the difference between the amount of magnesium added and the amount remaining in solution.

(viii) Exchangeable Cations - Sodium, Potassium, Calcium and Magnesium

4 g of soil were extracted by shaking with 20 ml of N ammonium acetate solution at pH 7.0 for one hour. Calcium and magnesium were determined by atomic absorption spectroscopy using strontium chloride as a releasing agent to overcome interference by aluminium or phosphate. Sodium and potassium were also determined using atomic absorption methods, utilising strontium chloride as an ionisation buffer.

(ix) Base Saturation

By calculation.

III.2 ANALYSES OF TOP TWO HORIZONS OF ALL SERIES ANALYSES

(i) Organic Carbon

A weighed sample of finely ground soil was digested with a known amount of potassium dichromate and concentrated sulphuric acid. A known amount of deionised water was added and an aliquot filtered off. The amount of Cr^{+++} in the filtrate was determined colorimetrically. In the calculation of the results, it was assumed that only 77 per cent of the organic carbon present had been oxidised.

(ii) Total Nitrogen

A weighed sample of finely ground soil was digested with concentrated sulphuric acid, potassium sulphate and selenium. After digestion the sample was made alkaline with caustic soda and the released ammonia was steam-distilled into boric acid containing a mixed indicator of bromocresol green/methyl red. The ammonia was then titrated against standard sulphuric acid.

III.3 ANALYSES OF REPRESENTATIVE SOIL PROFILES

(i) Trace Elements - Total Copper, Zinc and Manganese

A known weight of finely ground soil was digested with a concentrated nitric/perchloric acid mixture. The samples were evaporated to dryness and the residues leached with hydrochloric acid. Copper, zinc and manganese were measured in the acid leachate using atomic absorption techniques.

(ii) Silica-Sesquioxide Ratio

A weighed sample of finely ground soil was fused in a platinum crucible with sodium carbonate. The crucible containing the fused mass was then placed in an evaporating basin, covered with water and left overnight to soften. All the material was removed from the crucible and washed into a basin. The sample was then acidified with hydrochloric acid and the solution evaporated to dryness and baked. The residues were leached with 6 N hydrochloric acid and filtered. The residue in the filter paper (silica) was washed with dilute hydrochloric acid and deionised water, followed by ashing in a platinum crucible and weighed.

The filtrate was made alkaline with ammonia solution and the precipitated iron and aluminium hydroxides were filtered off, dried and ashed in a silica crucible, after which weighing followed.

(iii) Clay Minerals

A sample of 2 mm sieved soil was dispersed by shaking overnight with Calgon solution and the clay fraction separated off by differential centrifugation. Free iron oxide was removed by treatment with sodium dithionite and sodium citrate. After this pretreatment the sample was divided into two fractions. One fraction was saturated with potassium, whilst the other fraction was saturated with magnesium. X-ray diffraction was then carried out on the K and Mg saturated samples in order to identify the clay minerals present in the sample. Representative samples were also examined by Differential Thermal Analysis to verify the x-ray results.

(iv) Free Iron Oxide

A weighed quantity of finely ground soil was extracted by shaking overnight with sodium acetate buffer, pH 3.8 and sodium dithionite. Ferrous iron was determined in this extract colorimetrically by the thioglycollic acid method.

(v) Analysis of Fine Clay Fraction

100 g of soil were dispersed by shaking overnight with sodium hexametaphosphate/sodium carbonate solution. The suspension was then transferred to a one litre measuring cylinder, made up to volume and mixed. A Bouyoucos hydrometer was used to take readings after a settling time of seven days, giving the amount of fine clay remaining in suspension.

(vi) Water Dispersible Clay

100 g of soil were shaken with deionised water overnight. The suspension was transferred to a one litre cylinder, made up to volume and mixed. A Bouyoucos hydrometer was used to take readings after five hours, giving the amount of water dispersible clay.

(vii) Soil Permeability

Samples of undisturbed soil were collected in the field using a core sampling device described in the USDA Agriculture Handbook No. 60 (1954). The rate at which water was able to pass through these undisturbed cores was measured in a closed circuit system having a constant head of water, above and below the soil.

(viii) Available Water Capacity (AWC)

Soil moisture held at tensions of 0, 1/10, 1/3, 1 and 15 atmospheres and bulk density. Soil samples were collected in the field using the core sampler mentioned under III.3 (vii).

The dry weight of the undisturbed soil in the core was determined and the bulk density calculated.

Subsequently the cores were saturated with water, placed in a porous plate apparatus and subjected to pressures of 0, 1/10, 1/3 and 1 atmosphere. After each pressure stage the samples were removed and weighed to determine the moisture content at the above mentioned pressures.

The samples were then transferred to the high pressure chamber and the soil moisture content determined when in equilibrium at a pressure of 15 atmospheres.

APPENDIX IV

APPENDIX IV

SOIL MOISTURE DETERMINATIONS

IV.1 INTRODUCTION

Soil moisture can only be extracted by plants when the forces by which that moisture is held are lower than the tension in the plant tissues. Plants suffer moisture stress when moisture in the soil has been depleted due to low rainfall and evapo-transpiration and the remaining moisture unavailable to plants. High soil temperatures, which often occur on cultivated land deplete soil moisture reserves especially when the crop is in its early stages and the soil surface is bare.

Only a certain part of the moisture reserves within the soil are available to the plant. This range is called the "available water content" or available water capacity (AWC).

There are several methods to determine the AWC:-

(a) by laboratory determination using the porous plate and pressure membrane apparatus as used in this Study and described in Chapter 4, Section 4;

(b) by calculation on the basis of Salter and Williams' method (1967).

The AWC is defined as the moisture held by the soil between field capacity - the highest moisture content - and permanent wilting point - the lowest possible moisture content for plant growth.

In the laboratory these conditions are simulated by using tensions of 1/10, 1/3 and 15 atmosphere respectively. In this Study the 1/10 value has been used as an approximation for the field capacity. The moisture content is expressed on a dry basis; it is however more useful to know the moisture content by volume of the soil. This is calculated by the bulk density or apparent specific gravity. The bulk density is the weight of dry soil per unit volume and thus includes the space occupied by soil solids and the pore space in a particular volume of soil. The bulk densities of the soils studied range from 1.00 to 1.80. Obviously the higher values are generally found in the sandy soils.

Many research workers generally quote the following amounts of water remaining in the soil after wilting point has been reached:-

Sands approximately 0.5 inch per foot of soil
Loams approximately 1.5 inches per foot of soil
Clays approximately 2.5 inches per foot of soil

Table IV.1 lists the moisture holding characteristics of a number of selected profiles. Other profile characteristics are given in Appendix VI. In the above mentioned Table the following basic calculations have been used:-

(a) AWC by weight percentage = moisture held at 1/10 of an atmosphere minus moisture held at 15 atmosphere;

(b) AWC in volume per cent = AWC in weight per cent times BD;

(c) AWC in inches per soil horizon

$$= \frac{\text{AWC volume per cent x depth}}{100}$$

TABLE IV.1 MEASURED AVAILABLE WATER CAPACITY FOR SELECTED PROFILES

Soil Family or series	Site No.	Sample No.	Depth inches	Percentage moisture retention on dry weight basis at pressure					B.D. g/cc	AWC wt.	AWC vol.	AWC inches per horizon
				0 atm.	1/10 atm.	1/3 atm.	1 atm.	10 atm.		Per cent	Per cent	
Jk.fsc.4	A396	A0128	0-7½	43.5	32.1	29.3	27.8	11.6	1.22	20.5	25.0	1.9
		A0129	7½-16	27.5	23.4	21.8	20.8	13.3	1.34	10.1	13.5	1.1
		A0130	16-25	32.0	28.9	27.4	26.4	16.0	1.53	12.9	19.7	1.7
		A0131	25-36	29.7	24.8	23.2	21.6	13.4	1.79	11.4	20.4	2.2
Mr.c.5	B766	A0145	0-8	40.9	33.3	29.6	26.3	12.6	1.24	20.7	25.7	2.1
		A0146	8-15	40.7	28.6	27.4	26.6	16.8	1.48	11.8	17.5	1.2
		A0147	15-22	31.0	32.1	29.3	27.8	18.7	1.58	13.4	21.2	1.5
Mr.c.5	A456	A0166	0-21	46.6	40.3	38.5	36.9	29.6	1.40	10.7	15.0	3.2
Mr.c.4	A457	A0169	0-12	55.3	41.2	37.4	34.9	21.5	1.05	19.7	20.7	2.5
		A0170	12-23	38.1	33.1	31.5	30.4	25.5	1.44	7.6	10.9	1.2
		A0171	23-37	40.2	34.9	33.8	32.3	27.3	1.34	7.6	10.2	1.4
Mr.c.3	A488	A0185	0-8	38.0	34.1	31.7	30.4	16.0	1.38	18.1	25.0	2.0
		A0186	8-30	42.2	39.9	38.0	36.4	23.0	1.33	16.9	22.5	5.0
Mr.c.4	A489	A0188	0-10	54.2	51.2	47.4	45.4	23.2	1.25	28.0	35.0	3.5
		A0189	10-32	49.2	45.5	42.8	41.6	24.6	1.35	20.9	28.2	6.2
Mr.c.4	A149	A0191	0-11	33.9	29.7	26.8	25.0	10.4	1.46	19.3	28.2	3.1
		A0192	11-19	29.6	27.2	24.9	23.7	13.1	1.56	14.1	22.0	1.8
		A0193	19-35	30.5	27.6	25.6	24.5	14.0	1.58	13.6	21.5	3.4
Mr.c.4	B108	B0028	0-2	51.5	46.0	43.5	42.1	22.0	1.49	24.0	35.8	1.0
		B0029	2-10	45.0	40.9	39.0	37.6	24.4	1.50	16.5	24.8	2.0
		B0030	10-27	44.2	41.5	39.0	37.2	23.0	1.59	18.5	29.4	5.0
Mr.c.4	B004	B0033	0-1½	51.2	39.2	35.9	37.2	11.3	1.16	27.9	32.4	0.5
		B0034	1½-8	34.5	30.7	28.7	34.1	14.6	1.42	16.1	22.9	1.5
		B0035	8-22	37.7	31.5	29.8	27.0	17.0	1.51	14.5	21.9	3.1
Bk.zcl.5	B134	B0042	0-7	33.5	36.4	31.7	29.8	10.2	1.29	26.2	33.8	2.4
		B0043	7-19½	51.4	36.4	32.3	30.2	11.3	1.24	25.1	31.1	3.9
		B0044	19½-33	48.5	30.0	28.0	26.8	11.5	1.35	18.5	25.0	3.4
Mr.c.4	B178	B0046	½-8	46.4	39.7	37.1	34.9	19.7	1.33	20.0	26.6	2.0
		B0047	8-12	46.7	38.5	36.1	34.2	22.9	1.26	15.6	19.7	0.8
		B0048	12-33	42.3	37.0	35.0	31.3	22.5	1.40	14.5	20.3	4.3
KB-KP.1	B243	B0056	1-5½	57.5	50.1	47.0	44.0	22.2	1.40	27.9	39.1	1.8
		B0057	5½-23	52.8	47.8	44.8	42.3	22.3	1.49	25.5	38.0	6.7
Jk.zc.5	B247	B0067	0-5½	54.6	45.4	40.6	37.4	13.4	1.22	32.0	39.0	2.1
		B0068	5½-16	39.9	35.2	32.7	31.5	14.9	1.32	20.3	26.8	2.8
		B0069	16-27	35.3	33.6	31.9	30.8	16.8	1.60	16.8	26.9	3.0
		B0070	27-43	36.8	34.9	33.4	31.9	19.1	1.60	15.8	25.3	4.0
Bk.zcl.5	B403	B0089	½-12	44.7	35.7	31.0	28.0	8.8	1.23	26.9	33.1	3.8
		B0090	12-19½	31.8	28.0	25.1	23.1	9.8	1.45	18.2	26.4	2.0
		B0091	19½-35	28.3	26.3	24.6	22.8	11.7	1.56	14.6	22.8	3.5
Mr.c.4	B817	B0216	0-4½	43.8	35.4	32.7	30.9	21.4	1.23	14.0	17.2	0.8
		B0217	4½-15	37.2	33.3	31.3	30.1	21.2	1.47	12.1	17.8	1.9
		B0218	15-26	39.7	34.3	32.4	31.6	23.2	1.33	11.1	14.8	1.6
Bk.zl.4	B848	B0230	0-6	52.0	39.0	33.1	29.9	14.8	1.15	24.2	27.8	1.7
		B0231	6-15	56.6	36.0	31.2	28.5	14.7	1.21	21.3	25.8	2.3
		B0232	15-26	36.4	32.0	28.9	27.2	18.4	1.38	13.6	18.8	2.1

TABLE IV.1 (cont'd)

Soil Family or series	Site No.	Sample No.	Depth inches	Percentage moisture retention on dry weight basis at pressure					B.D. g/cc	AWC wt.	AWC vol.	AWC inches per horizon
				0 atm.	1/10 atm.	1/3 atm.	1 atm.	10 atm.		Per cent	Per cent	
Mr.c.4	B868	B0234	0-7	50.2	40.0	34.6	31.8	16.4	1.17	23.6	27.6	1.9
		B0235	7-18	42.3	35.0	31.9	29.6	19.9	1.28	15.1	19.3	2.1
		B0236	18-27	34.5	30.9	28.9	26.8	22.4	1.40	8.5	11.9	1.1
		B0237	27-39	36.3	32.9	30.8	29.0	23.1	1.48	9.8	14.5	1.7
Jk.c.3	B882	B0240	5-12	42.3	37.4	34.1	31.5	22.0	1.33	15.4	20.5	1.4
		B0241	12-18	37.7	33.8	31.7	29.9	24.6	1.34	9.2	12.3	0.7
		B0242	18-25	38.7	35.5	33.8	32.3	28.3	1.44	7.2	10.4	0.7
MR-KP.1	B933	B0262	0-4½	41.3	32.4	30.4	29.3	24.3	1.33	8.1	10.8	0.5
		B0263	4½-12	50.0	44.6	42.4	40.5	32.5	1.33	12.1	16.1	1.2
		B0264	12-24	49.4	43.1	41.5	39.4	32.8	1.18	10.3	12.2	1.5
Mr.c.4	B934	B0265	0-5	38.5	30.6	28.6	26.6	19.7	1.39	10.9	15.2	0.8
		B0266	5-16	36.3	29.7	28.2	26.7	21.5	1.40	8.2	11.5	1.3
		B0267	16-32	34.6	29.2	27.7	25.9	20.7	1.47	8.5	12.5	2.0
Kg.c.5	C549	C0003	4-8½	59.4	51.7	49.2	46.7	28.7	1.37	23.0	31.5	1.4
		C0004	8½-26	55.8	53.8	52.3	50.4	30.8	1.60	23.0	36.8	6.4
Kg.c.4	C108	C0036	4-8	46.5	43.3	41.5	40.1	25.4	1.58	17.9	28.3	1.1
		C0037	8-18	44.1	41.3	39.8	38.9	26.0	1.62	15.3	24.8	2.5
		C0038	18-28	47.3	41.1	39.4	37.8	28.2	1.50	12.9	19.4	1.9
Bk.zcl.5	D416	D0023	1½-8½	37.7	31.6	26.7	23.6	7.6	1.33	24.0	31.9	2.2
		D0024	8½-25	30.7	28.5	25.8	24.1	11.0	1.52	17.5	26.6	4.4
		D0025	25-45	30.9	27.2	25.9	24.3	12.9	1.50	14.3	21.5	4.3
Mr.c.2	D552	D0048	1½-6½	36.2	29.7	26.3	23.7	11.1	1.33	18.6	24.7	1.2
		D0049	6½-15	33.1	29.7	27.7	25.9	15.1	1.47	14.6	21.5	1.8
		D0050	15-36	30.2	27.2	26.1	24.8	15.2	1.57	12.0	18.8	3.9
Bm.zcl.5	D1012	D0214	0-16	51.4	37.8	34.8	33.1	12.5	1.26	25.3	31.9	5.1
		D0215	16-30	38.9	34.4	32.6	31.6	10.0	1.38	24.4	33.7	4.7
BM.5	D1035	D0236	3-25	44.9	31.2	24.4	22.1	11.5	1.23	19.7	24.2	5.3
		D0237	25-43	44.7	34.2	28.7	24.7	12.9	1.17	21.3	24.9	4.5
		D0238	43-54	34.8	28.1	25.5	23.4	11.9	1.30	16.2	21.1	2.3
		D0239	54-62	35.5	32.6	31.6	30.2	22.8	1.35	9.8	13.2	1.1
Tg.c.5	C488	E0009	2-9	39.7	37.5	35.4	33.4	18.1	1.42	19.4	27.5	2.0
		E0010	9-35	37.0	36.4	35.2	33.9	23.9	1.45	12.5	18.1	4.7
		E0011	35-61	37.2	35.3	33.9	32.6	23.0	1.48	12.3	18.2	4.7
	E346	E0033	2½-11	30.9	25.9	21.5	18.9	7.6	1.44	18.3	26.4	2.2
		E0034	11-26	27.9	25.3	22.6	20.8	9.8	1.58	15.5	24.5	3.7
		E0035	26-38	28.8	26.8	24.9	23.4	11.9	1.58	14.9	23.5	2.8
Mr.c.5	E442	E0050	0-6	54.6	43.2	37.2	34.6	11.8	1.08	31.4	33.9	2.0
		E0051	6-14	36.2	30.9	28.9	27.0	14.6	1.38	16.3	22.5	1.8
		E0052	14-23	35.2	31.9	30.4	29.4	16.9	1.60	15.0	24.0	2.2
		E0053	23-38	36.7	35.7	34.2	32.4	20.2	1.63	15.5	25.3	3.8
Mr.c.3	E030	E0154	0-6	41.0	33.3	28.9	25.6	14.4	1.29	18.9	24.4	1.5
		E0155	6-15	33.0	29.4	27.3	25.7	18.1	1.48	11.3	16.7	1.5
		E0156	15-23	35.9	32.7	31.0	29.2	21.2	1.43	11.5	16.4	1.3
Mr.c.5	F464	F0180	3-12	47.6	39.0	36.9	34.8	20.2	1.20	18.8	22.6	2.0
		F0181	12-39	40.6	37.2	35.4	34.4	22.2	1.34	15.0	20.1	5.4
		F0182	39-49	43.3	40.3	38.2	37.1	23.7	1.30	16.6	21.6	2.2

APPENDIX V

TABLE V.1 TRACE ELEMENTS

Sample No.	Element (ppm)		
	Cu	Mn	Zn
D0012	4	53	18
D0013	5	35	23
D0014	6	42	34
D0015	9	40	43
D0016	10	38	43
B0024	8	50	27
B0025	10	214	45
B0026	6	142	36
B0027	12	48	57
B0028	9	104	40
B0029	12	77	58
B0030	20	45	67
B0031	18	33	52
B0032	19	196	75
C0035	19	272	83
C0036	20	200	91
C0037	20	120	91
C0038	20	138	77
C0039	20	86	92
C0040	20	100	91
B0046	12	128	53
B0047	13	100	65
B0048	18	68	67
B0049	15	53	56
B0050	15	120	65
B0051	17	386	60
B0052	13	372	80
B0053	18	120	83
B0054	16	360	95
B0056	21	372	100
B0057	26	146	98
B0058	20	48	87
B0059	16	400	83
B0060	20	290	95
B0061	12	108	62
B0062	15	300	67
B0063	20	214	72
B0064	18	334	44
B0065	23	93	60
B0066	23	168	67
B0067	5	96	28
B0068	5	48	30
B0069	6	38	36
B0070	8	40	45
B0071	9	42	51
C0035	17	254	83
C0036	17	208	87
C0037	17	162	91
C0038	18	162	83
C0039	No sample		
C0099	5	26	10
C0100	4	16	10
C0101	4	16	13
C0111	6	62	21
C0112	6	53	24
C0113	6	45	24
C0114	8	68	23
A0026	3	14	8
A0027	4	20	14
A0028	4	26	20
A0029	5	26	22
A0030	5	30	23
A0031	6	35	25
B0089	4	18	15
B0090	4	18	15
B0091	4	18	19
B0092	5	16	22
B0093	8	16	25
B0094	9	18	27
E0032	3	20	8
E0033	3	16	9
E0034	4	20	16
E0035	4	20	15
E0036	6	26	20
B0046	13	#	51
B0047	16	#	65

Sample No.	Element (ppm)		
	Cu	Mn	Zn
B0048	18	#	65
B0049	18	#	60
B0050	18	#	62
B0051	17	#	60
B0052	16	#	75
B0053	18	#	83
B0054	20	#	86
B0055	23	#	87
B0056	23	#	95
B0057	26	#	100
B0058	21	#	83
B0059	37	#	160
B0060	18	#	77
B0062	18	#	67
B0063	20	#	72
B0064	20	#	65
B0065	26	#	67
B0066	27	#	83
A0066	6	6	10
A0067	4	8	16
A0068	5	10	26
A0087	4	10	8
A0088	5	8	13
A0089	6	10	13
A0091	6	10	19
A0092	5	10	16
A0093	6	10	25
B0127	7	18	18
B0128	6	14	25
B0129	7	14	33
D0077	4	8	8
D0078	6	8	11
D0079	4	14	16
B0161	9	14	22
B0162	7	16	27
B0163	9	24	40
B0164	13	20	58
B0177	10	14	11
B0178	9	18	12
B0179	9	16	18
B0180	11	12	20
B0181	12	12	17
B0186	16	26	37
B0187	12	28	44
B0188	16	45	65
B0189	8	30	53
B0190	17	32	47
B0211	8	61	26
B0212	7	95	28
B0213	7	110	32
B0214	12	61	50
B0215	15	152	80
A0109	9	39	44
A0110	11	45	53
A0111	14	129	24
A0112	14	50	74
A0124	2	24	32
A0125	8	24	39
A0126	8	14	44
A0127	9	16	49
D0176	6	26	13
D0177	8	14	28
D0178	6	12	29
D0179	7	14	34
D0180	9	26	37
D0181	9	35	33
E0072	7	18	40
E0073	8	18	47
E0074	10	18	71
E0075	10	22	74
E0076	12	32	68
E0077	11	16	42
F0041	6	37	30
F0042	6	22	37
F0043	9	18	47
F0044	10	16	50

Sample No.	Element (ppm)		
	Cu	Mn	Zn
F0045	12	28	58
F0089	6	26	26
F0090	7	39	34
F0091	9	43	37
F0092	10	97	42
F0093	11	75	53
B0230	4	29	17
B0231	3	20	15
B0232	3	31	20
B0233	5	53	37
B0234	4	27	22
B0235	4	31	25
B0236	7	41	37
B0237	8	50	43
B0238	8	59	41
B0239	5	43	28
B0240	7	55	32
B0241	8	77	41
B0242	11	70	55
B0243	12	90	53
B0262	14	630	74
B0263	13	530	77
B0264	16	182	84
B0272	29	87	34
B0273	11	117	44
B0275	12	151	65
B0280	9	47	34
B0281	13	45	48
B0282	14	45	51
B0283	15	50	48
B0284	4	39	23
B0285	7	63	34
B0286	9	89	43
B0287	9	104	38
A0166	13	345	71
A0167	15	1 675	84
A0169	7	84	34
A0170	9	53	46
A0171	12	61	60
A0173	12	325	77
A0174	12	285	77
A0175	11	109	84
A0185	8	35	38
A0186	12	43	60
A0187	13	59	55
A0188	9	100	65
A0189	11	102	80
A0190	13	265	88
A0191	3	20	20
A0192	3	20	23
A0193	4	23	31
A0194	5	20	38
E0154	4	131	41
E0155	5	91	51
E0156	7	89	65
E0157	7	104	65
E0158	8	174	60
E0159	10	265	74
E0199	8	84	48
E0200	10	154	55
E0201	12	96	65
E0202	15	123	74
E0203	18	285	84
E0204	9	590	50
E0205	8	405	53
E0206	11	500	65
F0169	7	385	30
F0170	9	188	43
F0171	12	134	55
F0172	12	68	51
F0173	11	185	57
F0220	4	115	36
F0221	3	107	44
F0222	8	43	57
F0023	9	31	57
F0224	10	29	55

Note: # Insufficient sample

V.2 CLAY MINERALS

V.2.1 Introduction

The analyses on clay minerals have been conducted by the Department of Biochemistry and Soil Science, University College of North Wales, at Bangor.

The following preliminary report on the clay mineralogy of the Study Area has been compiled by Dr. D.A. Jenkins of the above Department.

The analytical programme has involved 87 clay samples (2u esd) from 17 profiles. They have been examined by x-ray diffractometry on Philips equipment (PW 1011/1050/1352) using CuK_2 (Ni filtered + p.h.s.) generated at 40kV/20mA, a slit system of 1^o/1 mm/1^o, scanning speed of 1^o 2θ/minute and damping time of 2 seconds. Traces were obtained for pipetted slides of the following samples:-

(a) untreated (2 to 50^o 2θ);

(b) pretreated plus dithionite/citrate buffer and NaOCl and subsequently

- saturated + Mg^{+2}
- saturated + Mg^{+2}; treated + ethylene glycol;
- saturated + K^+
- saturated + K^+; heated to 300^oC, 500^oC, 550^oC or 600^oC.

On the basis of the relative peak heights obtained in these traces, the profiles may be grouped qualitatively according to their clay mineralogy into the five groups listed below.

(i) Profiles A432, A490, B403, B845, B882, D1034, D1077, E364, E442, E590, E710 and F465

Preliminary examination of the analyses indicates that these 12 profiles have a fairly similar clay mineralogy. This comprises Kaolinite (?) as a major constituent together with mica, chlorite, vermiculite and inter-stratified (12A^o) material, In general the vermiculite increases towards the surface at the expense of either chlorite, mica, or both, to become a minor or even a major component. The chlorite is generally heat unstable and is mostly a minor component although it is a major component in two profiles (B403 and E710). The mica varies from a trace to a minor component. Of the other detected minerals, quartz is mostly a constant minor constituent, although in one profile (B403) it is concentrated at the surface, and in another (A432) with depth. Goethite is present as a trace constituent throughout, increasing with depth in one profile (E710). Lepidocrocite is also a trace constituent except in B882 and B845 where it is absent; in three profiles (E364, E590 and E710) it increases with depth.

(ii) Profile C719

This profile bears similarities with those of group (i) in that kaolinite (?) is a major component and mica a minor constituent concentrated at depth; however, chlorite is absent and vermiculite increases to become a major component at the surface. Quartz is also a major component and the profile is note-worthy in that Lepidocrocite increases in abundance becoming a major component at the top; a trace of Geothite is also present.

(iii) Profiles E587 and F390

In these two profiles kaolinite (?) is a major constituent, but so also is a chlorite (heat stable at depth, becoming unstable towards the surface) and irregularly inter-stratified (12A°) material, whilst mica and vermiculite are absent (except for the top 2 cm of F390 where vermiculite is present). Goethite is a minor component, quartz a trace component, and lepidocrocite absent.

(iv) Profile C488

This profile is dominated by a well crystalline kaolinite with minor amounts of vermiculite developing in upper horizons at the expense of mica; chlorite is absent. Quartz is also a minor component, goethite increases with depth; lepidocrocite is a trace constituent.

(v) Profile D089

This profile is distinctive in that it is dominated by a montmorillonite and vermuculite, with mica, kaolinite (?) and quartz as minor constituents. Iron oxides are not detectable.

To complete the analytical programme, it is hoped to confirm the presence and nature of the kaolinite (?) (for example DMSO treatment) and to seek for such additional minerals as gibbsite and halloysite. Selected samples (nine) from four profiles have been subjected to DT analysis on Standata equipment; it is planned to complete similar analyses on samples from the remaining thirteen profiles.

APPENDIX VI

APPENDIX VI

SELECTED SOIL PROFILE DESCRIPTIONS

The following profile descriptions of a number of soil families, series and family intergrades have been selected because these profiles had been sampled for certain special reasons such as soil moisture determinations and other physical and chemical analyses and are representative of the families, series and family intergrades discussed in this Report.

Index to profiles described.

Sample Areas	Broad Transect Survey	Semi-Detailed Survey
B108	A225	B713
B247	A244	B714
B279	A259	B747
B403	A265	B890
C708	A280	B968
C719	B462	D920
C488	B586	D1091
C678	D630	E514
D089	D751	E587
	F071	E638
		E710
		E726
		F376
		F367
		F368
		F606

Site No.: B108

Map Reference: Sample Area A Line 22/Tape 64

Topography: Upper part of 20 degrees north facing convex slope

Parent Material: Shale

Soil Family/Series: MERIT/Merit

Vegetation: Logged primary

Drainage: Moderately well

Description for specified depth

0-2 inches

Yellowish brown (10YR 5/4); fine sandy clay loam; moist and friable; moderate organic matter content; moderate medium crumb structure; medium pores; abundant medium to fine roots. Smooth gradual boundary to:

2-10 inches

Yellowish brown (10YR 5/6); clay loam; moist and firm low organic matter content; moderate medium angular blocky structure; fine cracks; medium pores; many medium to large roots; few fine shale fragments. Smooth gradual boundary to:

10-27 inches

Brownish yellow and strong brown (10YR 6/8 to 7.5YR 5/8); many medium distinct grey (10YR 5/1) mottles; clay; moist and firm; low organic matter content; moderate coarse angular blocky structure; medium cracks; fine pores; many fine and medium roots; many fine shale fragments. Clear wavy boundary to:

27-34 inches

Brownish yellow and light brownish grey (10YR 6/6 and 10YR 6/2); many medium prominent red (2.5YR 5/6) mottles; clay; moist and very firm; few fine roots; many shale fragment. Abrupt wavy boundary to:

34-54 inches

Strongly weathered shale with some manganese and iron original structures still obvious.

54-62 inches

Very compact partly weathered shale, iron and manganese; clay skins on fragments.

CHEMICAL AND MECHANICAL ANALYSES

Site No. B108
Map Reference Sample Area A Line 22/Tape 64
Soil Family MERIT
Soil Series Merit

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
			Sand				Silt	Clay		
			2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ				
16218	B0028	0-2	0.5	0.8	13.3	24.4	35	26	4.6	3.7
16219	B0029	2-10	0.3	0.5	10.5	12.7	32	44	5.0	3.9
16220	B0030	10-27	4.0	0.8	6.0	11.2	24	54	5.2	4.0
16221	B0031	27-34	2.5	1.0	2.0	11.5	29	54	5.2	4.0
16222	B0032	34-54	5.3	2.3	3.0	10.4	40	39	5.4	3.9

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
0.4	0.9	0.2	0.3	22.1	0.260	3.78	14.6
0.1	0.5	0.2	0.2	18.5	0.140	1.46	10.4
0.1	0.3	0.2	0.1	17.3			
0.1	0.1	0.2	0.2	17.9			
0.1	0.8	0.3	0.2	18.3			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
27	56	137	4.3	0.3	0.16
17	92	230	1.6	0.2	0.11
17	81	194	2.1	0.2	0.07
9	114	247	1.1	0.2	0.07
12	89	288	1.1	0.2	0.09

Site No.: B247

Map Reference: Sample Area B Cut Trace Line 14/Tape 23

Topography: 20 degrees slope facing south

Parent Material: Shale

Soil Family/Series: MERIT/Jakar

Vegetation: Poor primary

Drainage: Moderately well

Description for specified depth

0-5½ inches

Yellowish brown (10YR 5/4 to 5/6); loam; moist and friable; moderate organic matter content; moderate medium subangular blocky structure; many medium pores; abundant fine and medium roots. Smooth gradual boundary to:

5½-16 inches

Reddish yellow (7.5YR 6/6); fine sandy clay loam to clay loam; moist and firm; low organic matter content; moderate medium and coarse subangular blocky structure; few fine cracks; many medium pores; abundant fine and medium roots. Smooth gradual boundary to:

16-27 inches

Reddish yellow (7.5YR 6/8); clay to clay loam; moist and firm; low organic matter content; moderate to strong coarse prismatic, and moderate coarse angular blocky structure; many medium cracks; few fine pores; few fine and large roots. Smooth clear boundary to:

60+ inches

Yellowish red (5YR 5/8); many medium distinct strong brown and yellow (7.5YR 5/6 and 10YR 7/6) mottles; clay; moist and very firm; low organic matter content; structureless; abundant iron stained shale fragments.

CHEMICAL AND MECHANICAL ANALYSES

Site No.	B247
Map Reference	Sample Area B, Cut Trace Line 14/Tape 23
Soil Family	MERIT
Soil Series	Jakar

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
			Sand				Silt	Clay		
			2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ				
18332	B0067	0-5½	Nil	0.3	0.3	16.4	60	23	4.8	3.8
18333	B0068	5½-16	0.3	0.5	0.5	13.7	55	30	4.9	3.9
18334	B0069	16-27	0.3	0.3	0.5	15.9	47	36	5.1	3.9
18335	B0070	27-43	0.5	0.3	0.5	13.7	44	41	5.2	4.0
18336	B0071	43-60	2.0	0.5	0.5	9.0	42	46	5.2	4.0

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
0.2	0.2	< 0.1	0.1	11.0	0.129	1.81	14.0
0.2	0.1	< 0.1	0.1	10.7	0.074	0.79	10.7
0.3	0.1	< 0.1	0.1	10.3			
0.1	< 0.1	< 0.1	0.1	10.4			
0.1	< 0.1	< 0.1	0.1	10.1			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
33	116	188	1	0.1	0.09
22	120	211	3	0.1	0.04
16	130	236	3	Nil	0.03
13	141	255	3	Nil	0.04
15	161	274	3	Nil	0.04

Site No.: B279

Map Reference: Sample Area B, Line 23/Tape 1

Topography: Mid-slope of 27 degrees east facing slope

Parent Material: Shale

Soil Family/Series: MERIT/Merit

Vegetation: Primary forest - logged recently

Drainage: Well drained

Description for specified depth

0-2 inches

Yellowish brown (10YR 5/4); loam; moist and friable; low organic matter content; weak crumb structure; many pores; abundant large roots; fine faunal activity - ants. Smooth diffuse boundary to:

2-11 inches

Yellowish brown (10YR 5/6); silt loam; moist and friable; low organic matter content; weak, medium subangular blocky structure; abundant fine pores; many roots; fine faunal activity. Diffuse smooth boundary to:

11-31 inches

Strong brown (7.5YR 5/8); few fine faint pale yellow (2.5Y 7/4) mottles; clay; moist and firm; weak, coarse subangular blocky structure; many fine pores; many medium roots; medium faunal activity - ants; silt skin cutans. Clear smooth boundary to:

31-51 inches

Strong brown to yellowish red (7.5YR 5/8 to 5YR 5/8); many medium distinct yellow (2.5Y 7/6) mottles; clay; moist and firm; compact, weak to moderate coarse subangular blocky structure; few fine pores; few fine roots. Abrupt smooth boundary to:

51-65 inches

Yellowish red (5YR 5/6); many medium distinct pale yellow (2.5Y 7/4) mottles; clay, plus many large soft pieces of shale; moist and firm; weak, coarse subangular blocky structure-compact; few fine roots. Diffuse smooth boundary to:

65-71+ inches

Red plus pale yellow and white (2.5YR 5/6 plus 2.5Y 7/4 and 2.4Y 8/0); clay, plus many soft silty shale fragments; moist and firm; structureless to weak coarse subangular blocky structure; few fine roots.

CHEMICAL AND MECHANICAL ANALYSES

Site No.	B279
Map Reference	Sample Area B Line 23/Tape 1
Soil Family	MERIT
Soil Series	Merit

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 – 500 µ	Sand 500 – 250 µ	Sand 250 – 100µ	Sand 100 — 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
18366	C0072	0-2	2.5	1.0	4.5	26.0	43	23	4.9	3.7
18367	C0073	2-11	0.3	0.5	4.0	9.2	46	40	4.9	4.0
18368	C0074	11-31	0.3	0.5	3.3	7.9	38	50	5.0	3.9
18369	C0075	31-51	0.8	1.0	2.8	4.4	38	53	5.2	4.0
18370	C0076	51-65	12.7	1.3	2.3	5.7	30	48	5.4	4.1
18371	C0077	65-74	4.5	0.5	3.5	8.5	35	48	5.3	4.0

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Percent: Organic Carbon	C/N Ratio
0.7	1.0	0.1	0.3	11.5	0.293	4.74	16.2
0.1	0.2	< 0.1	0.1	11.2	0.100	1.11	11.1
0.1	0.1	< 0.1	0.1	10.8			
0.1	0.1	< 0.1	0.1	8.9			
0.1	0.1	< 0.1	0.2	11.0			
0.2	0.1	< 0.1	0.2	11.3			

Nutrients: Milligrams / 100g of Soil — Total: P	Total: K	Total: Mg	Total: Ca	Available: P	Available: K
44	120	198	13	0.2	
20	161	258	3	0.1	
13	198	302	3	Nil	
12	214	314	3	Nil	
20	224	293	1	Nil	
16	242	298	1	Nil	

Site No.: B403

Map Reference: Sample Area C Cut Trace Line 18/Tape 8

Topography: Site on upper part of north-west facing 20 degrees slope

Parent Material: Sandy shale

Soil Family/Series: BEKENU/Bekenu

Vegetation: Logged primary

Drainage: Moderately well

Description for specified depth

0-½ inch

Dark brown (10YR 4/3); organic loam; moist and friable; high organic matter content; moderate fine crumb structure; large prominent pores; abundant fine and medium roots; termite activity. Smooth abrupt boundary to:

½-12 inches

Brownish yellow (10YR 6/6); light fine sandy loam; moist and friable; low organic matter content; weak to moderate medium angular blocky structure; large prominent pores; abundant medium and large roots; termite activity. Smooth clear boundary to:

12-19½ inches

Brownish yellow (10YR 6/8); few medium distinct grey (2.5Y 5/0) mottles; fine to medium sandy clay loam; moist and firm; low organic matter content; moderate coarse angular blocky structure; medium and large prominent pores; many medium and large roots; termite activity. Smooth clear boundary to:

19½-35 inches

Reddish yellow (7.5YR 6/6 to 6/8); few medium distinct grey (2.5Y 5/0) mottles; fine to medium sandy clay; moist and firm; low organic matter content; moderate, coarse angular blocky structure; fine coarse cracks; medium prominent pores; few fine and medium roots; termite activity. Smooth and clear boundary to:

35-45½ inches

Reddish yellow (5YR 6/8); many medium prominent grey (2.5Y 5/0) mottles; medium sandy clay to clay; moist and very firm; low organic matter content; weak to moderate coarse angular blocky structure; fine coarse cracks; fine and medium prominent pores; few fine and large roots. Smooth gradual boundary to:

45½-61 inches

Light red to reddish yellow (2.5YR 6/8 to 5YR 6/8); many medium prominent grey (2.5Y 5/0) mottles; medium sandy clay to clay; moist and very firm; low organic matter content; weak and moderate angular blocky structure; fine coarse cracks; fine and medium prominent pores. Wavy abrupt boundary to:

61-69+ inches

Light red to reddish yellow (2.5YR 6/8 to 5YR 6/8); many medium prominent grey (2.5Y 5/0) mottles; clay; moist and very firm, low organic matter content; fine prominent pores; abundant stones of sandy shale.

CHEMICAL AND MECHANICAL ANALYSES

Site No. B403
Map Reference Sample Area C, Cut Trace Line 18/Tape 8
Soil Family BEKENU
Soil Series Bekenu

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 — 500 µ	Sand 500 — 250 µ	Sand 250 — 100µ	Sand 100 — 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1 : 2.5
20193	B0089	½-12	0.3	0.5	17.5	23.7	43	15	4.7	3.9
20194	B0090	12-19½	0.4	0.9	19.2	19.5	42	18	4.8	3.9
20195	B0091	19½-35	0.3	0.5	17.8	18.4	40	23	5.0	4.0
20196	B0092	35-45½	0.4	0.6	15.1	18.9	37	28	5.1	4.0
20197	B0093	45½-61	0.8	0.3	9.8	19.1	37	33	5.1	4.0
20198	B0094	61-69	7.0	1.5	6.5	15.0	37	33	5.4	4.1

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Organic Carbon	C/N Ratio
0.1	0.1	< 0.1	0.1	9.3	0.242	1.38	5.7
0.1	0.1	0.1	0.1	9.3	0.113	0.78	6.9
0.1	0.1	< 0.1	< 0.1	9.0			
0.2	< 0.1	0.1	0.1	8.4			
0.2	< 0.1	0.1	0.1	8.6			
0.2	< 0.1	0.2	0.1	9.1			

Nutrients: Milligrams / 100g of Soil — Total: P	K	Mg	Ca	Available: P	K
23	54	61	2	0.1	0.05
17	49	64	1	Nil	0.03
14	56	70	Nil	Nil	0.02
16	75	86	Nil	0.1	0.03
23	104	103	Nil	Nil	0.04
31	117	96	Nil	Nil	0.05

Site No.: C708

Map Reference: Sample Area C Cut Trace Line 14/Tape 70

Topography: Site on 7 degrees slope facing south-west

Parent Material: Fine sandstone, fine sandy shale

Soil Family/Series: BEKENU/Bekenu

Vegetation: Unlogged primary forest

Drainage: Well drained

Description for specified depth

0-1½ inches

Very dark greyish brown (10YR 3/2); loam; moist and friable; high organic matter content; structureless to weak medium subangular blocky structure; few fine cracks; few fine pores; abundant medium roots; common faunal activity. Abrupt smooth boundary to:

1½-11 inches

Brownish yellow (10YR 6/6); fine sandy loam to fine sandy clay loam; moist and friable; low organic matter content; moderate coarse subangular blocky and crumb structures; many medium cracks; abundant medium pores; abundant medium and large roots; medium faunal activity. Clear smooth boundary to:

11-20 inches

Reddish yellow (7.5YR 6/3); few fine faint pale yellow (5Y 7/3) mottles; fine sandy clay loam; moist and firm; coarse moderate subangular blocky structure; abundant medium pores; abundant medium roots; fine faunal activity. Clear wavy boundary to:

20-38 inches

Reddish yellow (7.5YR 6/6); fine sandy clay loam to fine sandy clay with abundant moderately hard or hard platy reddish brown (5YR 4/3) gravel and stones; moist and friable; coarse weak subangular blocky structure; few medium cracks; few fine pores; many medium roots. Clear wavy boundary to:

38-56 inches

Strong brown (7.5YR 5/6); many fine distinct mottles - grey (10YR 6/1); fine sandy clay plus abundant soft sandy shale fragments; moist and firm; massive structure; few fine pores; few fine roots; abrupt smooth boundary to:

56+ inches

Strong brown (7.5YR 5/6); firm fine sand.

CHEMICAL AND MECHANICAL ANALYSES

Site No. C708

Map Reference Sample Area C, Cut Trace Line 14/Tape 70

Soil Family BEKENU

Soil Series Bekenu

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
			Sand				Silt	Clay		
			2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ				
20216	C0105	0-1½	2.0	0.4	1.3	46.3	46	4	4.6	3.4
20217	C0106	1½-11	0.3	0.2	1.6	19.9	59	19	4.7	3.7
20218	C0107	11-20	2.1	0.5	2.1	20.3	49	26	4.9	3.8
20219	C0108	20-38	6.4	1.3	3.1	17.2	43	29	5.2	3.9
20220	C0109	38-56	1.6	0.5	1.5	15.4	55	26	5.2	3.9
20221	C0110	56+	4.5	2.0	3.4	32.1	47	11	4.9	3.9

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
3.5	1.4	0.1	0.3	11.7	0.588	8.64	14.7
0.1	0.1	< 0.1	0.1	10.3	0.084	1.18	14.0
0.1	0.1	< 0.1	0.1	9.0			
0.1	0.1	< 0.1	0.2	9.6			
0.1	0.2	< 0.1	0.2	10.4			
0.2	0.5	< 0.1	0.2	8.8			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
45	58	54	130	0.4	0.20
20	78	61	2	0.1	0.06
			Nil	Nil	0.07
25	110	78	Nil	Nil	0.09
16	132	86	2	Nil	0.11
27	80	94	7	0.2	0.13

Site No.: C719

Map Reference: Sample Area C, BASE LINE A/Tape 337

Topography: Site on 30 degrees north-east facing slope of low hill

Parent Material: Sub-recent alluvium inferred from subrounded quartz gravels in subsoil, and a planed surface of shale

Soil Family/Series: MERIT/Lupar

Vegetation: Primary, unlogged, very few large timber trees

Drainage: Well drained

Description for specified depth

0-1½ inches

Dark brown (10YR 4/3); very fine sandy loam; moist and friable; low organic matter content; weak medium subangular blocky and crumb structure; many fine cracks, many fine pores; many large roots; fine faunal activity. Clear smooth boundary to:

1½-6 inches

Yellowish brown (10YR 5/6); few medium distinct light grey (7.5YR 7/0) mottles; medium sandy clay loam; moist and friable to firm; low organic matter content; medium coarse subangular blocky structure; many medium cracks; many fine pores; many medium roots; fine faunal activity. Clear wavy boundary to:

6-17 inches

Strong brown (7.5YR 5/6); few fine distinct light grey (5YR 7/2) mottles; medium sandy clay loam to medium sandy clay; moist and firm; moderate coarse subangular blocky structure; many large cracks; many fine pores; many fine roots. Clear smooth boundary to:

17-29 inches

Reddish brown plus strong brown (2.5YR 4/4 plus 7.5YR 5/6); many medium distinct light grey to pale yellow (5Y 7/2 to 7/3) mottles; fine sandy clay to clay, moist firm; weak coarse subangular blocky structure; many cracks; few fine pores; few fine roots; few rounded clear quartz fragments at lower depth; few medium and hard iron grits and gravels; distinct wavy boundary to:

29-42 inches

Yellowish red plus strong brown (5YR 5/6 plus 7.5YR 5/6); many medium distinct light brownish grey to light yellowish brown (2.5Y 6/3) mottles; fine sandy clay to clay; moist and firm; structureless to weak coarse subangular blocky and massive; few fine roots; few small rounded grits and gravel fragments; few round quartz gravels. Abrupt wavy boundary to:

42-55 inches

Grey (2.5Y 5/0); shale with yellowish brown (10YR 5.4); moderately weathered clay.

CHEMICAL AND MECHANICAL ANALYSES

Site No. C719
Map Reference Sample Area C BASE LINE A/Tape 337
Soil Family MERIT
Soil Series Lupar

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent — Sand 2000 – 500 µ	500 – 250 µ	250 – 100µ	100 — 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
20204	C0093	0-1½	3.0	6.8	26.3	18.9	32	13	4.3	3.5
20205	C0094	1½-6	2.5	6.1	25.7	10.7	32	23	4.7	3.8
20206	C0095	6-17	2.0	3.8	19.3	9.9	29	36	4.9	3.8
20207	C0096	17-29	3.8	3.6	13.5	11.1	25	43	5.1	3.9
20208	C0097	29-42	4.3	2.1	7.5	8.1	35	43	5.3	4.0
20209	C0098	42-55	0.3	0.1	0.3	21.3	60	18	3.8	3.8

Exchangeable Cations Milliequivalents / 100g of Soil — Ca	Mg	Na	K	C E C	Percent — Total N	Organic Carbon	C/N Ratio
0.4	1.0	< 0.1	0.4	10.9	0.267	4.08	15.3
0.1	0.2	< 0.1	0.1	9.2	0.081	0.85	10.5
0.1	0.1	< 0.1	0.1	11.0			
0.2	0.1	< 0.1	0.1				
0.1	0.1	< 0.1	0.1	10.9			
0.2	1.0	0.1	0.3	10.4			

Nutrients: Milligrams / 100g of Soil — Total P	K	Mg	Ca	Available P	K
40	80	66	10	0.6	0.23
22	88	75	1	0.1	0.07
19	134	124	1	0.1	0.07
23	154	142	1	Nil	0.08
33	161	154	1	Nil	0.10
30	123	365	2	8.0	0.19

Site No.: C488

Map Reference: Sungai Karabungan Sample Area Cut Trace Line BASE LINE A/Tape 78

Topography: Site on gentle hill crest, sloping 2 degrees east

Parent Material: Shale

Soil Family/Series: KABULOH/Karabungan

Vegetation: Extracted primary forest

Drainage: Imperfect

Description for specified depth

0-2 inches

Brown (10YR 5/3); loam; crumb structure; moist and friable; abundant fine and medium roots. Clear smooth boundary to:

2-9 inches

Yellowish brown (10YR 5/8); prominent fine and medium pale yellow to reddish yellow (2.5Y 7/4 to 7.5YR 7/6) mottles; clay; subangular blocky structure; moist and firm; many fine and medium roots; few magnesium and calcareous concretions. Clear wavy boundary to:

9-35 inches

Red (2.5YR 5/6) prominent fine and medium pale yellow to reddish yellow (2.5Y 7/4 to 7.5YR 7/6) mottles; clay; subangular blocky structure; moist and firm; few fine and small roots; few magnesium and calcareous concretions. Clear boundary to:

35-61 inches

Red (2.5YR 5/6) prominent pale yellow (2.5Y 7/4) mottles; clay; angular blocky structure; moist and firm; few manganese and calcareous concretions. Clear and wavy boundary to:

61-73 inches

Yellowish brown (10YR 5/4) prominent medium and coarse white to yellowish red (10YR 8/1 to 5YR 5/6) mottles; clay; angular blocky structure; moist and firm; few manganese and calcareous concretions. Clear and irregular boundary to:

73-84 inches

Grey (10YR 6/1); shale; moist and very firm; few manganese and calcareous concretions. Clear and wavy boundary to:

84-90 inches

Grey (10YR 6/1); clayey shale; moist and very firm.

CHEMICAL AND MECHANICAL ANALYSES

Site No. C488
Map Reference Sungai Karabungan Sample Area Cut Trace BASE LINE A/Tape 78
Soil Family KABULOH
Soil Series Karabungan

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 — 500 µ	Sand 500 — 250 µ	Sand 250 — 100µ	Sand 100 — 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
16293	E0008	0-2	1.5	1.3	1.3	24.9	48	23	5.3	4.0
16294	E0009	2-9	2.0	1.0	1.0	10.0	53	33	4.8	3.8
16295	E0010	9-35	3.0	1.3	1.5	6.2	35	53	5.1	4.0
16296	E0011	35-61	1.0	0.8	1.3	11.9	37	48	5.4	4.1
16297	E0012	61-73	1.8	1.5	1.5	7.2	38	50	5.3	4.0
16298	E0013	73-84	0.3	0.3	0.5	5.9	38	55	7.4	6.2
16299	E0014	84-90	0.8	1.0	2.5	7.7	48	40	8.5	7.8

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Organic Carbon	C/N Ratio
2.4	0.4	0.2	0.2	17.6	0.232	3.55	15.3
0.5	0.1	0.2	0.2	13.7	0.120	1.36	11.3
0.1	< 0.1	0.2	0.1	12.8			
0.3	< 0.1	0.2	0.1	12.5			
2.2	0.1	0.2	0.1	12.0			
6.5	0.4	0.2	0.1	9.8			
16.9	0.3	0.2	0.1	13.6			

Nutrients: Milligrams / 100g of Soil — Total: P	K	Mg	Ca	Available: P	K
39	40	61	28	0.1	0.07
36	49	70	5.9	0.1	0.06
46	81	109	2.6	Nil	0.07
42	77	82	3.8	Nil	0.07
36	67	72	17	Nil	0.10
31	56	61	80	0.1	0.15
23	35	75	5 121	0.2	0.09

Site No.: C678

Map Reference: Sungai Karabungan Sample Area Cut Trace Line 45/Tape 1

Topography: Site in low rise, mid slope 13 degrees to the south

Parent Material: Calcareous shale

Soil Family/Series: KABULOH/Tangap

Vegetation: Logged forest

Drainage: Well drained

Description for specified depth

0-1 inch

Dark greyish brown (10YR 4/2); loam; weak fine subangular blocky structure; moist/dry loose; few cracks; many fine pores; abundant large roots. Clear wavy boundary to:

1-4 inches

Yellowish brown (10YR 5/4); clay loam to clay; moderate medium subangular blocky structure; few fine cracks; many fine pores; abundant large roots. Clear smooth boundary to:

4-16 inches

Yellowish red (5YR 5/6); clay moist and firm to very firm; moderate coarse prismatic structure; few fine cracks; many medium pores; abundant large roots; patchy cutans on few peds, some pores. Clear smooth boundary to:

16-27 inches

Yellowish red (5YR 5/6); few fine faint pale yellow brown (2.5Y 7/4 to 10YR 5/6) mottles; clay; moist and firm; moderate coarse prismatic structure; few fine cracks; many medium pores; many fine roots; patchy cutans on few peds, some pores. Diffuse wavy boundary to:

27-39 inches

Yellowish red (5YR 5/6); few fine distinct pale yellow (2.5Y 7/4) mottles; clay; moist and firm to very firm; moderate medium angular blocky structure; few fine cracks; few fine pores; many fine roots. Clear wavy boundary to:

39-60 inches

Light yellowish brown (2.5Y 6/4); abundant coarse prominent red (2.5YR 5/6) mottles; clay; moist and firm to very firm; moderate medium angular blocky structure; few fine cracks; few fine pores; few fine roots. Diffuse wavy boundary to:

60-75 inches

Light olive grey (5Y 6/2); abundant coarse prominent; yellowish brown (10YR 5/6) mottles; clay and weathered shale; moist and firm to very firm; weak coarse subangular blocky structure; few fine cracks; few fine pores; few fine roots. Diffuse wavy boundary to:

75-90 inches

Yellowish brown plus grey (10YR 5/6 plus 5Y 6/1); clay plus soft shale; moist firm structureless; few soft manganese fragments; augered beyond 90 inches.

90-110 inches

Grey plus yellowish brown (5Y 6/1 plus 10YR 5/6); clay plus soft shale; moist firm; few soft black manganese concretions;

110+ inches

Dark grey (5Y 4/1); shale (not sampled).

CHEMICAL AND MECHANICAL ANALYSES

Site No. C678
Map Reference Sungai Karabungan Sample Area Cut Trace Line A5/Tape 1
Soil Family KABULOH
Soil Series Tangap

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
			Sand				Silt	Clay		
			2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ				
16272	C0041	0-1	2.0	2.5	3.0	34.5	40	18	6.1	5.1
16273	C0042	1-4	0.8	1.3	1.8	15.1	48	33	5.1	3.9
16274	C0043	4-16	0.3	0.8	1.3	14.6	35	48	5.2	3.8
16275	C0044	16-27	0.5	1.0	1.5	21.0	23	53	5.6	4.0
16276	C0045	27-39	0.8	1.3	1.8	15.4	27	56	5.8	4.2

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	C/N Ratio
7.6	1.4	0.2	0.5	31.9	0.330	7.40	22.4
3.1	1.1	0.2	0.2	18.9	0.200	4.32	21.6
2.3	0.4	0.2	0.2	20.8			
4.3	0.4	0.2	0.1	19.5			
8.0	0.6	0.2	0.1	18.8			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
36	62	256	200	0.3	0.28
25	81	328	51	0.1	0.11
13	110	399	20	Nil	0.09
11	123	438	39	Nil	0.09
12	110	428	89	0.1	0.09

Site No.: D089

Map Reference: Sungai Karabungan Cut Trace Line A4/Tape 16

Topography: Undulating

Parent Material: Calcareous shale

Soil Family/Series: KABULOH/Kabuloh

Vegetation: Logged primary

Drainage: Imperfect to poor

Description for specified depth

0-1½ inches

Dark greyish brown (10YR 4/2) fine sandy clay loam; moderate medium and fine crumb structure; moist and friable; many fine pores; many fine and medium roots; faunal activity. Smooth clear boundary to:

1½-5 inches

Olive brown to dark yellowish brown (2.5Y 4/4 to 10YR 4/4) clay to clay loam; moderate medium subangular blocky structure; moist and firm; many fine pores; many fine and medium roots; faunal activity. Smooth clear boundary to:

5-21 inches

Light olive brown (2.5Y 5/4 to 5/6); many, medium fine brown (10YR 4/4) mottles; clay, weak coarse angular blocky to weak coarse prismatic structure; moist very firm; few coarse cracks; few fine pores; few to many fine roots; faunal activity. Wavy abrupt boundary to:

21+ inches

Solid, grey rather flaggy calcareous very fine sandy shale.

CHEMICAL AND MECHANICAL ANALYSES

Site No.	D089
Map Reference	Sungai Karabungan Cut Trace Line A4/Tape 16
Soil Family	KABULOH
Soil Series	Kabuloh

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
			Sand				Silt	Clay		
			2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ				
18J11	B0058	0-1½	0.5	1.0	1.5	12.0	37	48	6.5	5.7
18J12	B0059	1½-5	1.0	1.0	0.8	17.2	47	33	6.1	4.9
18J13	B0060	5-21	0.5	0.5	0.5	13.5	40	45	6.2	4.5

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
26.6	2.6	0.1	0.5	11.5	0.510	8.12	15.9
21.6	1.8	0.1	0.2	23.0	0.266	2.67	10.0
24.4	2.0	0.1	0.2	11.4			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
47	198	532	781	0.3	0.30
31	224	618	406	0.1	0.11
20	291	789	438	Nil	0.08

<u>Site No.</u>: A225

<u>Map Reference</u>: Broad Transect Survey, Cut Trace Line R26/Tape 5

<u>Topography</u>: Site in back swamp of river valley

<u>Parent Material</u>: Alluvium

<u>Soil Family/Series</u>: BIJAT

<u>Vegetation</u>: Young secondary swamp forest

<u>Drainage</u>: Poor

<u>Description for specified depth</u>

3-0 inch

Humified litter

0-10 inches

Dark brown (10YR 4/3); few fine distinct reddish brown (5YR 5/3) mottles; very fine sandy clay loam; moist and very friable; medium faunal activity; high organic matter content; moderate medium subangular blocky structure; many medium and fine cracks; many large pores; abundant medium roots. Clear wavy boundary to:

10-21 inches

Very dark greyish brown (10YR 3/2); few fine distinct reddish brown (5YR 5/3) mottles; light clay loam; moist and friable; high organic matter content; fine faunal activity; weak medium subangular blocky structure; many fine cracks; many fine pores; many fine roots. Diffuse smooth boundary to:

21-32 inches

Greyish brown (10YR 5/2); few fine distinct reddish brown (5YR 5/3) mottles; clay loam to clay; moist and firm; low organic matter content; massive structure; few fine roots. Diffuse smooth boundary to:

32-49 inches

Greyish brown (10YR 5/2); clay; wet and sticky; massive structure.

CHEMICAL AND MECHANICAL ANALYSES

Site No. A225
Map Reference Broad Transect Survey, Cut Trace Line R26/Tape 5
Soil Family BIJAT
Soil Series

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent — Sand 2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
20125	A0054	0-10	Nil	Nil	0.3	25.7	50	24	4.8	3.7
20126	A0055	10-21	Nil	Nil	0.3	17.7	50	32	4.9	3.7
20127	A0056	21-32	Nil	Nil	0.3	20.7	50	29	5.0	3.4
20128	A0057	32-49	Nil	Nil	0.8	20.2	47	32	4.6	3.1

Exchangeable Cations Milliequivalents / 100g of Soil — Ca	Mg	Na	K	C E C	Percent — Total N	Organic Carbon	C/N Ratio
0.6	0.5	0.1	0.2	11.6	0.423	4.20	9.9
0.5	0.5	< 0.1	0.1	12.4	0.291	7.72	26.5
0.2	0.5	< 0.1	0.1	10.5	0.096	1.99	20.7
0.2	0.7	0.1	0.1	9.9	0.055	0.58	10.5

Nutrients: Milligrams / 100g of Soil — Total P	Total K	Total Mg	Total Ca	Available P	Available K
65	110	129	12	1.7	0.14
30	107	119	11	0.8	0.08
12	110	109	4	0.2	0.07
8	93	109	1	0.2	0.05

Site No.: A244

Map Reference: Broad Transect Survey, Cut Trace Line R13/Tape 81.5

Topography: Site on upper slope of low hill near flat summit, facing 3 degrees east

Parent Material: Sandstone

Soil Family/Series: BEKENU/Bekenu

Vegetation: Open poor primary forest

Drainage: Well drained

Description for specified depth

½-0 inch

Leaf litter; high organic matter content.

0-1 inch

Dark yellowish brown (10YR 4/4); light fine sand; moist very friable; high organic matter content; weak fine crumb structure; common medium cracks; abundant medium and large roots. Clear wavy boundary to:

1-8 inches

Yellowish brown (10YR 5/6); light fine sand; moist and friable; low organic matter content; weak medium subangular blocky structure; common fine to few fine cracks; many fine and medium pores; many medium and large roots. Diffuse smooth boundary to:

8-15 inches

Strong brown (7.5YR 5/8); few fine faint yellowish red (5YR 5/6) mottles; fine sandy clay loam; moist and friable; weak medium subangular blocky structure; common fine to few fine cracks; many fine and medium pores; many fine roots; few coarse hard sandstone fragments; laterised parent material. Clear irregular boundary to:

15-32 inches

Strong brown (7.5YR 5/8); many fine distinct yellowish red (5YR 5/6) mottles; very fine sandy clay; moist and firm, moderate medium subangular blocky structure; few fine cracks; few fine roots; abundant large hard and soft laterised sandstone fragments; hard laterised sandstone from 32 inches.

CHEMICAL AND MECHANICAL ANALYSES

Site No. A244
Map Reference Broad Transect Survey, Cut Trace Line R13/Tape 81.5
Soil Family BEKENU
Soil Series Bekenu

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 – 500 µ	Sand 500 – 250 µ	Sand 250 – 100µ	Sand 100 – 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
21677	A0058	1-8	1.0	2.0	17.0	23.0	39	18	4.5	3.7
21678	A0059	8-15	2.7	1.5	18.3	20.5	31	26	5.4	4.1
21679	A0060	15-32	22.8	4.8	10.3	9.1	20	33	5.6	4.3

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Percent: Organic Carbon	C/N Ratio
Nil	0.2	< 0.1	0.1	14.1	0.150	3.48	23.2
Nil	< 0.1	< 0.1	0.1	7.9	0.032	0.56	17.5
Nil	Nil	< 0.1	0.1	10.2			

Nutrients: Milligrams / 100g of Soil — Total: P	Total: K	Total: Mg	Total: Ca	Available: P	Available: K
47	58	70	1	Nil	0.08
28	75	96	Nil	0.1	0.07
65	68	89	Nil	0.2	0.06

Site No.: A259

Map Reference: Broad Transect Survey, Cut Trace Line R12/Tape 14

Topography: Site in very gently undulating terrace, slope 4 degrees west

Parent Material: Older alluvium

Soil Family/Series: MALANG

Vegetation: Mixed, heath-type and poor Dipterocarp primary

Drainage: Moderately well

Description for specified depth

1-0 inch

Leaf litter

0-2 inches

Dark yellowish brown (10YR 3/4); loamy fine sand; moist and very friable; high organic matter content; structureless; abundant fine roots. Abrupt smooth boundary to:

2-18 inches

Light grey (10YR 7/2); many coarse distinct greyish brown (10YR 5/2) mottles; and humus staining; fine sand; moist and loose; low organic matter content; structureless; few fine pores; many fine and medium roots. Clear wavy boundary to:

18-28 inches

Dark brown (10YR 4/3); many coarse prominent mottles - moderately cemented; few medium pores; few fine roots. Diffuse smooth boundary to:

28-39 inches

Dark yellowish brown to dark brown (10YR to 7.5YR 4/4); many coarse prominent dark brown (7.5YR 3/2) mottles; fine sand; moist and slightly hard; high organic matter content; structureless - slightly cemented. Diffuse smooth boundary to:

39-59 inches

Dark brown (10YR 4/3); fine sand; moist and hard; low organic matter content; structureless - moderately cemented.

CHEMICAL AND MECHANICAL ANALYSES

Site No. A259
Map Reference Broad Transect Survey, Cut Trace Line R12/Tape 14
Soil Family MALANG
Soil Series

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 — 500 µ	Sand 500 — 250 µ	Sand 250 — 100µ	Sand 100 — 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
21680	A0061	0-2	1.0	8.3	35.3	35.4	17	3	4.9	3.2
21681	A0062	2-18	0.3	3.3	38.8	26.6	25	6	5.5	4.4
21682	A0063	18-28	0.3	0.5	35.3	27.9	23	13	5.4	4.5
21683	A0064	28-39	0.3	1.0	40.8	24.9	12	21	5.4	4.6
21684	A0065	39-59	0.3	14.3	47.0	10.4	12	16	5.6	4.7

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Organic Carbon	C/N Ratio
0.2	0.7	< 0.1	0.2	17.0	0.158	6.50	41.1
Nil	Nil	< 0.1	Nil	11.5	0.031	0.25	8.1
0.1	Nil	< 0.1	Nil	18.0			
Nil	Nil	< 0.1	Nil	14.5			
Nil	Nil	< 0.1	Nil	9.9			

Nutrients: Milligrams / 100g of Soil — Total: P	K	Mg	Ca	Available: P	K
27	15	20	6	0.6	0.21
8	2	2	Nil	0.1	0.01
107	12	12	Nil	0.6	0.01
55	41	44	Nil	0.2	-
44	40	32	Nil	0.2	0.01

Site No.: A265

Map Reference: Broad Transect Survey, Cut Trace Line R39/Tape 66

Topography: Site in flat, level river valley

Parent Material: River alluvium

Soil Family/Series: BEMANG-PAKAN Family Intergrade

Vegetation: Grasses

Drainage: Imperfect

Description for specified depth

0-6 inches

Dark yellowish brown (10YR 4/4); few fine distinct yellowish red (5YR 5/6) mottles; very fine sandy loam; moist and friable; high organic matter content; strong fine subangular blocky structure; medium faunal activity; many fine cracks; abundant fine and medium pores; abundant medium roots;

6-16 inches

Pale brown (10YR 6/3); many fine distinct yellowish red (5YR 5/6) mottles; very fine sandy clay and loam; moist and friable; structureless; weak medium subangular blocky structure; many medium cracks; many fine pores; many fine and medium roots;

16-23 inches

Light brownish grey (10YR 6/1); many medium distinct yellowish red (5YR 5/6) mottles; very fine sandy clay and loam; wet and sticky;

23-32 inches

Grey (10YR 6/1); few fine distinct yellowish red (5YR 5/6) mottles; fine loamy sand; wet and slightly sticky.

CHEMICAL AND MECHANICAL ANALYSES

Site No. A265

Map Reference Broad Transect Survey, Cut Trace Line R39/Tape 66

Soil Family BEMANG-PAKAN Family Intergrade

Soil Series

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
			Sand				Silt	Clay		
			2000 — 500 μ	500 — 250 μ	250 — 100μ	100 — 50 μ				
21690	A0071	0-6	Nil	0.5	4.8	23.7	45	26	4.9	3.9
21691	A0072	6-16	Nil	0.3	7.3	19.4	37	36	5.3	4.0
21692	A0073	16-23	0.3	0.3	16.8	26.6	33	23	5.4	4.0
21693	A0074	23-32	Nil	0.5	26.5	32.0	25	16	5.6	4.1

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
0.7	0.3	< 0.1	0.2	15.5	0.217	2.04	9.4
0.2	0.1	< 0.1	0.1	11.0	0.087	0.85	9.8
0.1	0.1	< 0.1	0.1	5.8			
0.1	0.1	< 0.1	0.1	3.4			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
59	80	82	17	0.7	0.11
30	112	98	3	0.2	0.03
16	70	64	1	0.2	0.03
14	49	43	Nil	0.3	0.03

Site No.: A280

Map Reference: Broad Transect Survey Cut Trace Line R45/Tape 98

Topography: Site in mid-slope of 13 degrees north-east facing slope

Parent Material: Old alluvium terrace

Soil Family/Series: SILANTEK/Buso

Vegetation: Poor, open primary forest

Drainage: Moderately well drained

Description for specified depth

0-3 inches

Dark reddish brown (5YR 3/2); fine sandy loam; moist and friable; high organic matter content; structureless; abundant medium and large roots. Clear wavy boundary to:

3-16 inches

Light yellowish brown (10YR 6/4); fine sand; moist and very friable; low organic matter content; many fine and medium roots. Diffuse wavy boundary to:

16-32 inches

Dark yellowish brown (10YR 4/4); loose fine shale; moist and hard to moderately cemented (humus); high organic matter content; many coarse prominent roots - humus staining. Diffuse wavy boundary to:

32-48 inches

Dark brown (10YR 4/3); loamy fine sand; moist and hard - slightly cemented (humus); low organic matter content; few medium to few large prominent roots; humus staining. Diffuse wavy boundary to:

48-60 inches

Brown (10YR 5/3); loamy, medium sand; moist and hard; few fine roots.

CHEMICAL AND MECHANICAL ANALYSES

Site No. A280
Map Reference Broad Transect Survey, Cut Trace Line R45/Tape 98
Soil Family SILANTEK
Soil Series Buso

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 – 500 µ	Sand 500 – 250 µ	Sand 250 – 100µ	Sand 100 – 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
21694	A0075	0-3	0.5	7.0	40.5	39.0	10	3	4.9	2.9
21695	A0076	3-16	0.3	5.0	52.8	18.9	17	6	5.2	3.7
21696	A0077	16-32	0.3	3.3	29.8	25.6	23	18	5.0	3.9
21697	A0078	32-48	1.3	4.5	21.5	16.7	37	19	5.3	4.2
21698	A0079	48-60	0.3	14.5	27.0	35.2	9	14	5.2	4.3

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Organic Carbon	C/N Ratio
0.1	0.3	< 0.1	0.3	16.4	0.238	7.60	31.9
Nil	Nil	< 0.1	< 0.1	3.5	0.024	1.08	45.0
Nil	Nil	< 0.1	< 0.1	17.3			
Nil	Nil	< 0.1	0.1	9.0			
Nil	Nil	< 0.1	< 0.1	4.1			

Nutrients: Milligrams / 100g of Soil — Total: P	K	Mg	Ca	Available: P	K
20	10	6	2	0.2	0.22
5	1	1	Nil	0.1	0.02
27	63	48	1	0.3	0.01
14	85	86	Nil	0.1	0.09
12	39	40	1	0.2	0.01

Site No.: B462

Map Reference: Broad Transect Survey Cut Trace Line R19/Tape 11

Topography: Middle of 10 degrees north facing slope

Parent Material: Very fine sandy shale

Soil Family/Series: MERIT/Jakar

Vegetation: Heavily logged primary

Drainage: Moderately well

Description for specified depth

0-5 inches

Brownish yellow (10YR 6/6); loam; slightly moist and friable; low; organic matter content; moderate medium subangular blocky structure; abundant pores; abundant fine and large roots. Smooth clear boundary to:

5-15 inches

Reddish yellow (7.5YR 6/6); fine sandy clay loam to fine sandy clay; slightly moist and very firm; low organic matter content; moderate to strong coarse subangular blocky structure; abundant pores; many to abundant medium and large roots. Smooth abrupt boundary to:

15-21 inches

Reddish yellow (7.5YR 6/6); fine sandy clay; slightly moist and very firm; low organic matter content; weak to moderate medium angular blocky structure; few pores; few medium and large roots; many iron concretions. Smooth abrupt boundary to:

21-54 inches

Very compact grey (2.5Y 6/1); very fine sandy shale with reddish yellow (5YR 6/8); clay containing iron concretions in thin bands.

CHEMICAL AND MECHANICAL ANALYSES

Site No. B462
Map Reference Broad Transect Survey Cut Trace Line R19/Tape 11
Soil Family MERIT
Soil Series Jakar

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
			Sand				Silt	Clay		
			2000 — 500 μ	500 — 250 μ	250 — 100μ	100 — 50 μ				
20082	B0114	0-5	0.5	0.5	1.8	18.2	53	26	4.6	3.6
20083	B0115	5-15	0.8	0.5	1.5	13.2	46	38	4.8	3.7
20084	B0116	15-21	7.3	0.8	3.8	12.1	38	41	5.1	3.8
20085	B0117	21-54	7.8	0.8	4.5	4.9	36	46	5.3	3.9

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
0.2	0.2	< 0.1	0.1	11.1	0.092	1.21	13.2
0.1	0.1	< 0.1	0.1	11.0	0.084	0.54	6.4
0.1	< 0.1	< 0.1	0.1	10.9			
0.1	< 0.1	< 0.1	0.1	11.7			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
20	85	105	4	0.1	0.08
14	110	140	1	Nil	0.05
27	135	154	1	0.1	0.05
23	182	176	2	0.1	0.08

Site No.: B586

Map Reference: Broad Transect Survey, Cut Trace Line R47/Tape 181.5

Topography: Site in upper part of 13 degrees north-east facing slope

Parent Material: Sandstone

Soil Family/Series: BEKENU/Bekenu

Vegetation: Six year secondary

Drainage: Well drained

Description for specified depth

0-4 inches

Black (10YR 2/1); organic fine sandy loam; moist and very friable; very high organic matter content; weak fine crumb structure; abundant fine and large roots. Smooth abrupt boundary to:

4-12 inches

Yellowish brown (10YR 5/6); light fine sandy loam; moist and friable; moderate to low organic matter content; weak medium angular blocky structure; abundant pores; many fine and medium roots. Smooth and clear boundary to:

12-20 inches

Brownish yellow (10YR 6/6); very fine sandy loam; moist and friable; low organic matter content; weak to moderate medium subangular blocky structure; abundant pores; many fine and medium roots. Smooth merging boundary to:

20-32 inches

Brownish yellow (10YR 6/8); light loam; moist and firm; low organic matter content; moderate medium subangular blocky structure; many pores; many fine and medium roots. Smooth abrupt boundary to:

32-43 inches

Brownish yellow (10YR 6/8); fine clay loam; moist and very firm; low organic matter content; structureless; many pores; rare fine roots; abundant iron concretion. Wavy abrupt boundary to:

43-59 inches

Mainly iron concretions; some very fine sandstone fragments and small pockets of clay loam as in above horizon.

CHEMICAL AND MECHANICAL ANALYSES

Site No. B586
Map Reference Broad Transect Survey, Cut Trace Line R47/Tape 181.5
Soil Family BEKENU
Soil Series Bekenu

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 – 500 μ	Sand 500 – 250 μ	Sand 250 – 100μ	Sand 100 – 50 μ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1 : 2.5
21733	B0146	0-4	0.3	0.5	1.5	71.7	18	8	6.1	4.9
21734	B0147	4-12	0.3	0.8	6.8	41.1	35	16	5.5	4.0
21735	B0148	12-20	Nil	0.3	6.5	39.2	36	18	5.5	4.0
21736	B0149	20-32	0.3	0.5	7.0	36.2	30	26	5.6	4.1

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Organic Carbon	C/N Ratio
7.3	2.4	< 0.1	0.5	33.9	0.328	8.14	24.8
0.4	0.2	< 0.1	0.1	10.6	0.096	1.68	17.5
0.1	< 0.1	< 0.1	0.1	7.3			
0.4	0.1	< 0.1	< 0.1	6.7			

Nutrients: Milligrams / 100g of Soil — Total: P	K	Mg	Ca	Available: P	K
53	44	59	376	0.2	0.47
36	37	53	8	0.5	0.08
23	39	59	1	0.2	0.04
17	49	73	7	0.2	0.02

Site No.: D630

Map Reference: Broad Transect Survey, Cut Trace Line R9A/Tape 17

Topography: Site near ridge top with 20 to 40 degrees north west facing slope

Parent Material: Sandstone

Soil Family/Series: NYALAU/Nyalau

Vegetation: Moderate to good primary

Drainage: Well drained

Description for specified depth

0-½ inch

Very dark greyish brown (10YR 3/2); light sand; slightly moist, very friable; high organic matter content; moderate crumb structure; abundant pores; abundant fine and large exposed roots. Smooth abrupt boundary to:

½-2½ inches

Yellowish brown (10YR 5/8); light sandy loam; moist and friable; low organic matter content; moderate coarse angular blocky structure; abundant pores; many fine and medium roots. Smooth gradual boundary to:

2½-10 inches

Brownish yellow (10YR 6/8); light sandy loam; moist and friable; low organic matter content; moderate coarse angular blocky structure; abundant pores; many fine and medium roots. Smooth gradual boundary to:

10-23 inches

Brownish yellow (10YR 6/8); sandy loam to sandy clay loam; moist and friable; low organic matter content; weak to moderate coarse angular blocky structure; abundant pores; many fine and medium roots. Smooth merging boundary to:

23-39 inches

Reddish yellow (7.5YR 6/6); sandy loam; moist and firm to moist and friable; low organic matter content; weak coarse angular blocky structure; many pores; many medium and large roots. Smooth merging boundary to:

39-58 inches

Reddish yellow (7.5YR 6/6); sandy clay loam; moist and firm; low organic matter content; structureless to weak coarse angular blocky structure; many pores; few medium roots.

CHEMICAL AND MECHANICAL ANALYSES

Site No. D630
Map Reference Broad Transect Survey, Cut Trace Line R9A/Tape 17
Soil Family NYALAU
Soil Series Nyalau

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
			Sand				Silt	Clay		
			2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ				
20077	B0109	½-2½	0.5	2.8	44.8	18.9	17	16	4.7	4.0
20078	B0110	2½-10	Nil	1.8	44.3	12.9	18	23	4.8	4.2
20079	B0111	10-23	Nil	1.8	43.5	13.7	15	26	5.1	4.2
20080	B0112	23-39	Nil	2.0	42.5	14.5	15	26	4.7	3.9
20081	B0113	39-58	Nil	2.0	41.8	15.2	15	26	4.8	3.7

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
0.1	0.1	0.1	0.1	10.0	0.143	1.93	13.5
0.1	< 0.1	< 0.1	0.1	7.1	0.066	0.68	10.3
0.1	< 0.1	< 0.1	< 0.1				
0.2	< 0.1	< 0.1	< 0.1	6.6			
0.1	< 0.1	Nil	< 0.1	5.9			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
30	31	48	3	0.3	
17	29	51	4	0.1	
10	37	68	4	0.1	
7	44	75	1	0.1	
7	51	78	1	Nil	

Site No.: D751

Map Reference: Broad Transect Survey, Cut Trace Line R50/Tape 113

Topography: Site on upper part of 6 degrees north-east facing slope

Parent Material: Old alluvium

Soil Family/Series: BEKENU/Tukau

Vegetation: Primary forest, Engkabang, Belian, Keruin etc.

Drainage: Moderately well

Description for specified depth

0-2 inches

Dark yellowish brown (10YR 3/4); fine sandy loam; moist and friable; high organic matter content; weak medium crumb structure; large pores; abundant medium and large roots; medium faunal activity. Clear smooth boundary to:

2-12 inches

Yellowish brown (10YR 5/4); few fine distinct pale yellow (2.5Y 7/4) mottles; fine sandy loam; moist and friable; low organic matter content; weak medium angular blocky structure; medium pores; many medium and large roots; fine faunal activity. Clear wavy boundary to:

12-25 inches

Brownish yellow (10YR 6/6); few fine distinct pale yellow (2.5Y 7/4) mottles; fine sandy loam; moist and friable; low organic matter content; structureless to weak medium angular blocky structure; medium pores; few fine roots. Clear wavy boundary to:

25-44 inches

Pale yellow (2.5Y 7/4); few fine distinct light grey (5YR 7/1) mottles; fine sandy loam; moist and friable; low organic matter content; structureless to weak angular blocky structure; medium pores; few fine roots. Clear wavy boundary to:

44-76 inches

Pale yellow (2.5Y 7/4); few fine distinct light grey (5YR 7/1) mottles; fine sandy loam; moist and friable; low organic matter content; structureless to weak angular blocky structure; medium pores; few fine roots.

CHEMICAL AND MECHANICAL ANALYSES

Site No. D751
Map Reference Broad Transect Survey, Cut Trace Line R50/Tape 113
Soil Family BEKENU
Soil Series Tukau

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
			Sand				Silt	Clay		
			2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ				
21771	D0096	0-2	1.0	6.8	12.8	32.4	28	19	4.5	3.5
21772	D0097	2-12	0.3	0.5	27.0	30.2	31	11	5.4	4.3
21773	D0098	12-25	Nil	0.8	24.8	30.4	31	11	5.1	4.0
21774	D0099	25-44	Nil	0.5	22.0	33.5	30	14	5.5	4.3
21775	D0100	44-76	Nil	0.8	34.8	30.4	25	9	5.5	4.3

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
0.1	0.3	< 0.1	0.2	18.2	0.299	5.26	17.6
Nil	Nil	< 0.1	< 0.1	4.0	0.029	0.40	13.8
Nil	Nil	< 0.1	< 0.1	10.0			
Nil	Nil	< 0.1	< 0.1	3.6			
Nil	Nil	< 0.1	< 0.1	2.2			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
49	39	48	4	1.8	0.13
12	30	43	Nil	0.3	0.01
10	31	43	Nil	0.2	0.01
5	41	48	Nil	-	0.01
3	31	36	Nil	-	0.01

Site No.: F071

Map Reference: Broad Transect Survey Cut Trace Line R6/Tape 14

Topography: At foot of 18 degrees slope facing west

Parent Material: Sandstone

Soil Family/Series: BEKENU/Bekenu

Vegetation: Primary forest

Drainage: Well drained

Description for specified depth

0-2 inches

Brown (10YR 5/3); fine sandy loam; moist and very friable; moderate organic matter content; weak fine crumb structure; many fine roots. Abrupt smooth boundary to:

2-8 inches

Yellowish brown (10YR 5/6); few fine faint reddish yellow (7.5YR 6/6) mottles; fine sandy clay loam; moist and friable; low organic matter content; weak fine crumb structure; few fine cracks; few fine pores; many large roots. Abrupt smooth boundary to:

8-18 inches

Yellowish brown (10YR 5/8); few fine faint reddish yellow and pale yellow (7.5YR 6/6 and 2.5Y 7/4) mottles; fine sandy clay loam; moist and friable; low organic matter content; moderate medium subangular blocky structure; few fine cracks; few fine pores; many large roots. Abrupt smooth boundary to:

18-29 inches

Yellowish brown (10YR 5/8); few fine faint reddish yellow and pale yellow (7.5YR 6/6 and 2.5Y 7/4) mottles; fine sandy clay loam; moist and friable; low organic matter content; moderate medium subangular blocky structure; few medium cracks; few medium roots. Clear smooth boundary to:

29-44 inches

Reddish yellow (7.5YR 6/8); many fine distinct red (2.5YR 5/6) mottles; very fine sandy clay; moist and firm; moderate medium subangular blocky structure; few medium cracks; few fine and medium roots. Abrupt smooth boundary to:

44-66 inches

Reddish yellow (7.5YR 6/8); many fine distinct red and yellow (2.5YR 5/6 and 10YR 7/6) mottles; clay; moist and firm; moderate medium angular blocky structure; few medium cracks; few medium roots; few medium concretions. Abrupt smooth boundary to:

66-72 inches

Reddish yellow (7.5YR 6/8); many fine distinct yellow (10YR 7/6) mottles; clay; moist and firm; moderate medium angular blocky structure; few fine and medium roots; few fine concretions and weathered sandstone fragments.

CHEMICAL AND MECHANICAL ANALYSES

Site No. F071
Map Reference Broad Transect Survey Cut Trace Line R6/Tape 14
Soil Family BEKENU
Soil Series Bekenu

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
			Sand				Silt	Clay		
			2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ				
20109	F0006	0-2	0.3	2.3	11.8	37.6	40	8	4.5	3.5
20110	F0007	2-8	Nil	0.3	1.0	36.7	46	16	4.5	3.7
20111	F0008	8-18	Nil	0.5	9.0	28.5	43	19	4.6	3.8
20112	F0009	18-29	0.3	0.3	7.5	29.9	38	24	4.9	3.9
20113	F0010	29-44	0.3	0.3	6.5	28.9	35	29	5.0	3.9
20114	F0011	44-66	Nil	0.3	6.8	25.9	36	31	5.0	4.0
20115	F0012	66-72	0.5	0.5	4.3	27.7	41	26	5.2	4.0

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
0.3	0.9	< 0.1	0.4	11.0	0.299	4.07	13.6
0.1	0.1	Nil	0.1	9.2	0.071	0.94	13.2
0.2	0.1	Nil	< 0.1	8.5			
0.1	< 0.1	Nil	0.1	8.5			
0.2	< 0.1	Nil	0.1	8.4			
0.1	< 0.1	Nil	0.1	8.3			
0.2	< 0.1	Nil	0.1	8.4			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
38	49	53	10	0.8	0.15
19	44	59	2	0.2	0.05
13	46	59	3	0.1	0.03
14	54	70	1	Nil	0.04
13	75	86	1	Nil	0.04
13	78	84	2	Nil	0.06
14	91	82	2	Nil	0.08

Site No.: B713

Map Reference: Sungai Sawai DP44 north/Tape 21

Topography: Gently sloping low hill less than 10 feet, upper slope 11 degrees

Parent Material: Shale

Soil Family/Series: MERIT/Jakar

Vegetation: Young secondary growth

Drainage: Well drained

Description for specified depth

0-5 inches

Brownish yellow (10YR 6/6); many medium faint grey (5YR 5/1) mottles; fine sandy clay loam; moist and firm; low organic matter content; moderate medium subangular blocky structure; many fine pores; abundant fine and medium roots; much faunal activity. Smooth clear boundary to:

5-13 inches

Reddish yellow (7.5YR 6/6); fine sandy clay loam to fine sandy clay; moist and firm; much faunal activity; moderate coarse subangular blocky structure; coarse fine cracks; many fine pores; many fine roots; few charcoal fragments. Smooth clear boundary to:

13-31 inches

Strong brown (7.5YR 5/8); many coarse faint pale yellow (2.5Y 7/4) mottles; clay; moist and very firm; fine faunal activity; weak coarse prismatic and moderate coarse angular blocky structure; coarse medium cracks; few fine pores; few fine roots. Abrupt wavy boundary to:

31-52 inches

Yellowish red plus strong brown (5YR 5/8 plus 7.5YR 5/8); many medium distinct pale yellow (2.5Y 7/4) mottles; clay; moist and very firm; weak coarse angular blocky structure; coarse fine cracks; few fine pores; few fine roots in top; moderate medium laterised parent material; many concretions.

CHEMICAL AND MECHANICAL ANALYSES

Site No. B713
Map Reference Sungai Sawai DP44 north/Tape 21
Soil Family MERIT
Soil Series Jakar

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
			Sand				Silt	Clay		
			2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ				
22610	B0161	0-5	0.5	0.5	11.8	25.2	37	25	5.0	4.0
22611	B0162	5-13	2.5	0.8	10.8	20.9	32	33	5.2	4.0
22612	B0163	13-31	0.5	0.5	10.5	21.5	32	35	5.3	4.1
22613	B0164	31-52	6.0	1.5	5.8	16.7	27	43	5.5	4.2

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
<0.1	< 0.1	0.1	0.1	15.3	0.090	0.829	9.211
<0.1	< 0.1	0.1	0.1	9.4	0.062	0.452	7.290
0.1	< 0.1	0.1	< 0.1	6.7			
<0.1	< 0.1	0.1	0.1	10.8			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
11	7	7	1	0.2	0.03
5	9	8	1	0.1	0.02
6	8	8	1	Nil	0.02
13	14	12	Nil	Nil	0.03

Site No.: B714

Map Reference: Sungai Sawai Cut Trace Line 33 north/Tape 32

Topography: 14 degrees mid-slope of low hill

Parent Material: Silty shale

Soil Family/Series: MERIT/Jakar

Vegetation: Secondary

Drainage: Moderately well

Description for specified depth

0-4 inches

Light yellowish brown (10YR 6/4) many medium prominent light red (2.5YR 6/6) mottles; fine sandy clay loam; moist and firm; low organic matter content, moderate medium subangular blocky structure; many pores; abundant fine and large roots; medium faunal activity. Smooth clear boundary to:

11-24 inches

Reddish yellow (5YR 6/8); many coarse distinct yellow (2.5Y 7/6) mottles; clay; moist and very firm; low organic matter content; weak coarse prismatic and weak to moderate coarse angular blocky structure coarse medium cracks; few pores; few fine roots; few iron concretions; fine faunal activity, stone line at bottom of horizon. Smooth abrupt boundary to:

24-35 inches

Reddish yellow (7.5YR 6/6); clay; moist and very firm; low organic matter content; weak coarse angular blocky structure; few pores; rare fine roots; many iron concretions; abundant shale fragments. Smooth abrupt boundary to:

35-61+ inches

Compact, light grey silty shale.

CHEMICAL AND MECHANICAL ANALYSES

Site No. B714
Map Reference Sungai Sawai Cut Trace Line 33 north/Tape 32
Soil Family MERIT
Soil Series Jakar

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 — 500 µ	Sand 500 — 250 µ	Sand 250 — 100µ	Sand 100 — 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
22614	B0165	0-4	1.8	2.0	19.5	11.7	35	30	4.8	4.0
22615	B0166	4-11	7.5	2.3	13.8	6.4	27	43	5.2	4.0
22616	B0167	11-24	4.3	1.5	6.0	5.2	28	55	5.4	4.2
22617	B0168	24-35	2.5	1.3	2.8	0.4	38	55	5.5	4.1

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Organic Carbon	C/N Ratio
0.1	0.2	0.1	0.1	9.4	0.132	0.583	4.417
0.1	0.1	0.1	0.1	12.6	0.073	0.564	7.726
0.1	0.1	0.1	0.1	15.6			
0.1	0.1	0.1	0.2	17.2			

Nutrients: Milligrams / 100g of Soil — Total: P	K	Mg	Ca	Available: P	K
18	14	16	1	0.3	0.07
18	16	16	1	0.1	0.05
16	22	23	1	Nil	0.08
11	27	37	1	Nil	0.12

Site No.: B747

Map Reference: Sungai Sawai Cut Trace Line 80/Tape 60

Topography: Mid-slope of 25 degrees north-east facing slope

Parent Material: Sandstone (?)

Soil Family/Series: MERIT/Jakar

Vegetation: Logged primary

Drainage: Moderately well

Description for specified depth

0-3 inches

Yellowish brown (10YR 5/4 to 5/6); loam; moist and friable; moderate organic matter content; moderate, medium and fine subangular blocky structure; abundant pores; abundant fine and medium roots. Smooth clear boundary to:

3-14 inches

Reddish yellow (7.5YR 6/6); heavy clay loam; moist and firm; low organic matter content; moderate medium subangular blocky structure; many pores; many fine and medium roots. Smooth clear boundary to:

14-24 inches

Strong brown (7.5YR 5/8); clay; moist and firm; low organic content; moderate to strong coarse subangular blocky structure; few to many pores; few fine and large roots; few fine sandstone fragments. Smooth clear boundary to:

24-33 inches

Yellowish red (5YR 5/8); heavy clay; moist and very firm; low organic matter content; moderate, coarse angular blocky structure; few to many pores; rare fine roots; many fine sandstone fragments. Smooth clear boundary to:

33+ inches

Fine grained sandstone with pockets of yellowish red (5YR 5/8), clay.

CHEMICAL AND MECHANICAL ANALYSES

Site No. B747
Map Reference Sungai Sawai Cut Trace Line 80/Tape 60
Soil Family MERIT
Soil Series Jakar

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 – 500 µ	Sand 500 – 250 µ	Sand 250 – 100µ	Sand 100 — 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1 : 2.5
22631	B0182	0-3	1.8	1.3	8.8	13.1	37	38	4.3	3.9
22632	B0183	3-14	3.5	1.3	8.5	9.7	34	43	4.6	4.0
22633	B0184	14-24	7.3	1.8	11.3	6.6	25	48	5.0	4.0
22634	B0185	24-33	5.0	1.3	6.3	6.8	25	55	5.2	4.1

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Percent: Organic Carbon	C/N Ratio
0.1	0.1	0.1	0.2	20.0	0.225	1.137	5.053
0.1	< 0.1	0.1	0.1	16.8	0.126	1.039	8.246
<0.1	< 0.1	0.1	0.1	14.4			
<0.1	< 0.1	0.1	0.1	14.4			

Nutrients: Milligrams / 100g of Soil — Total: P	Total: K	Total: Mg	Total: Ca	Available: P	Available: K
25	18	16	2	0.3	0.06
21	17	15	1	0.1	0.09
20	17	13	Nil	0.1	0.06
16	19	13	1	Nil	0.07

Site No.: B890

Map Reference: Sungai Sebubok DP89 north/Tape 68

Topography: Near crest of 26 degrees west facing slope

Parent Material: Shale

Soil Family/Series: MERIT/Merit

Vegetation: Logged primary forest

Drainage: Moderately well

Description for specified depth

0-6 inches

Light yellowish brown (10YR 6/4); clay loam (heavy); moist and firm; low organic matter content; moderate, medium subangular blocky structure; many pores; abundant roots; medium faunal activity; 20 per cent shale fragments. Smooth clear boundary to:

6-20 inches

Brownish yellow (10YR 6/6); clay; moist and very firm; weak to moderate medium subangular blocky structure; fine coarse cracks; few pores; many roots; fine faunal activity; 40 per cent shale fragments. Clear irregular boundary to:

20-50 inches

Light yellowish brown (10YR 6/4); clay, moist and firm; structureless; fine to medium coarse cracks; few pores; few roots; 75 per cent shale fragments. Smooth clear boundary to:

50-61 inches

Mainly grey silty shale; many large coarse stones showing onion-skin weathering.

CHEMICAL AND MECHANICAL ANALYSES

Site No.	B890
Map Reference	Sungai Sebubok DP89 north/Tape 68
Soil Family	MERIT
Soil Series	Merit

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
			Sand				Silt	Clay		
			2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ				
23906	B0244	0-6	4.4	1.4	1.4	9.8	33	50	4.9	4.0
23907	B0245	6-20	3.9	0.8	0.7	8.6	29	57	5.1	4.1
23908	B0246	20-50	2.0	0.3	0.5	11.2	34	52	5.2	4.1

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
0.3	0.6	0.1	0.3	17.5			
<0.1	0.4	0.1	0.2	16.4			
0.1	0.9	0.1	0.2	16.4			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
26	298	364	8		
26	337	445	3		
24	337	569	3		

Site No.: B968

Map Reference: Sungai Sebubok DP82 South/Tape 55

Topography: Lower part of 23 degrees slope

Parent Material: Silty shale

Soil Family/Series: MERIT/Merit

Vegetation: Logged primary

Drainage: Well drained

Description for specified depth

0-6 inches

Yellowish brown (10YR 5/6 to 5/8); fine sandy clay loam to clay loam; moist and firm; low organic matter content; moderate to strong medium subangular blocky structure; many pores; many fine and large roots; much faunal activity; few iron concretions. Smooth clear boundary to:

6-15 inches

Brownish yellow (10YR 6/8); clay; moist and firm; low organic matter content; moderate medium to coarse subangular blocky structure; many pores; many fine and medium roots; few faunal activity; many iron concretions. Smooth clear boundary to:

15-29 inches

Reddish yellow (7.5YR 6/8); many medium distinct reddish yellow plus grey (7.5YR 7/6 plus 10YR 5/1) mottles; clay; moist and firm; low organic matter content; weak, coarse angular blocky structure; medium coarse cracks; few pores; few roots; few faunal activity; many iron concretions. Smooth clear boundary to:

29-39 inches

Brownish yellow (10YR 6/8); abundant medium prominent reddish yellow plus grey (7.5YR 7/6 plus 10YR 5/1) mottles; clay; moist and very firm; low organic matter content; weak coarse angular blocky structure; fine coarse cracks; few pores; few roots; many iron concretions plus shale fragments. Wavy abrupt boundary to:

39-48+ inches

Compact light grey, iron stained, silty shale.

CHEMICAL AND MECHANICAL ANALYSES

Site No. B968
Map Reference Sungai Sebubok DP82 south/Tape 55
Soil Family MERIT
Soil Series Merit

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 – 500 µ	Sand 500 – 250 µ	Sand 250 – 100µ	Sand 100 – 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
24175	B0280	0-6							5.0	4.3
24176	B0281	6-15							5.2	4.4
24177	B0282	15-29							5.2	4.4
24178	B0283	29-39							5.3	4.4

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Organic Carbon	C/N Ratio
0.1	0.6	Nil	0.2				
0.1	0.3	Nil	0.2				
Nil	0.2	Nil	0.1				
Nil	0.1	Nil	0.1				

Nutrients: Milligrams / 100g of Soil: Total P	Total K	Total Mg	Total Ca	Available P	Available K
41	166	134	2		
25	215	141	2		
22	254	191	1		
25	244	181	1		

Site No.: D920

Map Reference: Sungai Galasah DP12/Tap 106

Topography: Upper part of 14 degrees slope west facing

Parent Material: Shale

Soil Family/Series: MERIT/Merit

Vegetation: Logged primary, few big and some medium size trees

Drainage: Moderately well

Description for specified depth

0-2 inches

Dark brown (10YR 4/3); loam; moist and friable; high organic matter content; weak fine crumb structure; few fine pores; abundant medium and large roots; medium faunal activity. Clear smooth boundary to:

2-10 inches

Yellowish brown (10YR 5/8); few fine distinct pale yellow (2.5Y 7/4) mottles; clay loam; moist and firm; low organic matter content; weak medium angular blocky structure; many medium pores; many medium and large roots; few faunal activity. Clear wavy boundary to:

10-21 inches

Reddish yellow (7.5YR 6/8); few fine distinct yellow (2.5Y 7/6) mottles; clay; moist and firm; low organic matter content; weak moderate subangular blocky structure; coarse medium and few fine cracks; medium pores; few fine roots; fine faunal activity. Clear wavy boundary to:

21-37 inches

Yellowish red (5YR 5/8); many medium distinct yellow (2.5Y 7/6) mottles; clay; moist and firm; weak medium subangular blocky structure; coarse medium and few fine cracks; fine pores; few fine roots; abundant loose pieces of shale. Clear wavy boundary to:

37-50 inches

Yellowish red (5YR 5/8); abundant coarse distinct yellow and light grey (2.5Y 7/6 plus 7.5YR 7/0) mottles; clay; moist and firm; structureless; few fine roots; abundant laterised shale fragments. Clear wavy boundary to:

50-59 inches

Soft freshly forming shale fragments, with some yellowish brown (10YR 5/6) clay forming.

CHEMICAL AND MECHANICAL ANALYSES

Site No. D920
Map Reference Sungai Galasah DP12/Tape 106
Soil Family MERIT
Soil Series Merit

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
			Sand				Silt	Clay		
			2000 — 500 μ	500 — 250 μ	250 — 100μ	100 — 50 μ				
23722	D0182	0-2	4.8	3.8	8.8	23.4	40	20	4.6	3.9
23723	D0183	2-10	0.5	0.8	7.3	14.4	39	38	4.5	4.1
23724	D0184	10-21	0.5	0.5	5.0	12.0	29	53	5.1	4.2
23725	D0185	21-37	6.8	1.5	3.8	10.9	24	53	5.2	4.3
23726	D0186	37-50	6.0	2.8	4.0	12.2	25	50	5.3	4.3
23727	D0187	50-59	5.3	2.3	3.5	11.9	29	48	5.4	4.2

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
0.3	0.5	0.1	0.3	20.3			
Nil	0.1	0.1	0.1	14.3			
Nil	< 0.1	0.1	0.1	13.7			
<0.1	< 0.1	0.1	0.1	14.7			
Nil	< 0.1	0.1	0.1	14.5			
Nil	< 0.1	0.1	0.1	14.6			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
24	284	222	2		
54	254	192	9		
22	406	283	2		
26	450	319	1		
28	420	293	2		
22	435	293	1		

Site No.: D1091

Map Reference: Sungai Sebubok Cut Trace Line DP96 north/Tape 9

Topography: Site on lower slope, 12 degrees facing south-east

Parent Material: Shale

Soil Family/Series: KAPIT

Vegetation: Logged primary forest

Drainage: Moderately well

Description for specified depth

0-7 inches

Yellowish brown (10YR 5/4); clay loam; moist and friable; low organic matter content; moderate medium subangular blocky structure; few cracks; many pores; many fine and medium roots; fine faunal activity; many laterised pieces of shale; clear wavy boundary to:

7-16 inches

Yellowish brown (10YR 5/8); few fine distinct yellow (2.5Y 7/6) mottles; clay; moist and firm; low organic matter content; weak medium subangular blocky structure; few cracks; many pores; few fine roots; small faunal activity; abundant laterised pieces of shale. Clear wavy boundary to:

16-38 inches

Yellowish brown (10YR 5/8); clay; moist and firm; weak medium subangular blocky structure; few cracks; few pores; few fine roots; abundant laterised pieces of shale. Clear wavy boundary to:

38-59 inches

Yellowish brown (10YR 5/8); clay with 90 per cent shale.

CHEMICAL AND MECHANICAL ANALYSES

Site No. D1091
Map Reference Sungai Sebubok Cut Trace Line DP96 north/Tape 9
Soil Family KAPIT
Soil Series

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
			Sand				Silt	Clay		
			2000 — 500 μ	500 — 250 μ	250 — 100μ	100 — 50 μ				
24055	D0254	0-7	1.5	0.8	0.8	22.9	64	10	5.3	4.5
24056	D0255	7-16	10.8	3.8	3.9	12.5	46	23	5.3	4.4
24057	D0256	16-38	14.3	3.9	3.3	11.5	37	30	5.2	4.3
24058	D0257	38-59	11.1	2.4	2.3	30.2	34	20	5.6	4.3

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
2.1	1.3	< 0.1	0.5	11.7	0.111	2.392	21.549
0.5	0.5	< 0.1	0.1	12.4	0.049	0.598	12.204
0.1	0.3	< 0.1	0.1	12.9			
0.2	0.5	< 0.1	0.1	11.2			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
41	117	140	41	0.6	0.32
24	225	261	10	0.1	0.08
24	181	273	5	0.1	0.07
25	196	319	4	0.1	0.08

Site No.: E514

Map Reference: Sungai Sawai Cut Trace Line DP42 south/Tape 10

Topography: Site on low hill ridge, 4 degrees sloping north east

Parent Material: Shale

Soil Family/Series: MERIT-KAPIT Family Intergrade

Vegetation: Logged primary forest

Drainage: Well drained

Description for specified depth

0-7 inches

Yellowish brown (10YR 5/8); few fine distinct pale yellow (2.5Y 7/4) mottles; clay loam; moist and friable; low organic matter content; weak crumb structure; medium prominent pores; abundant medium and large roots; termites hole. Clear smooth boundary to:

7-15 inches

Strong brown (7.5YR 5/6); many medium distinct strong brown to light grey (7.5YR 5/6 to 2.5Y 7/2) mottles; clay; moist and firm; low organic matter content; moderate subangular blocky structure; fine coarse cracks; fine prominent pores; few fine roots; many coarse iron stains. Clear wavy boundary to:

15-26 inches

Reddish yellow (5YR 6/8); clay; moist and very firm; low organic matter content; structureless; medium coarse cracks; few fine dead roots, laterised shale and many coarse iron stains. Clear wavy boundary to:

26-45 inches

Shale bed with coarse iron stains.

CHEMICAL AND MECHANICAL ANALYSES

Site No. E514
Map Reference Sungai Sawai Cut Trace Line DP42 south/Tape 10
Soil Family MERIT-KAPIT Family Intergrade
Soil Series

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
			Sand				Silt	Clay		
			2000 — 500 μ	500 — 250 μ	250 — 100μ	100 — 50 μ				
23487	E0082	0-7	2.8	1.5	5.2	17.5	47	26	4.5	4.0
23488	E0083	7-15	3.1	1.0	5.7	14.2	37	39	4.8	4.0
23489	E0084	15-26	5.4	1.9	3.1	9.6	27	53	5.1	4.1
23490	E0085	26-45	3.6	1.0	2.6	17.8	32	43	5.3	4.2

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
0.1	0.2	0.1	0.2	15.2	0.151	2.161	14.312
0.2	0.1	0.1	0.1	12.8	0.083	0.871	10.494
0.1	0.1	0.1	0.1	14.2			
0.1	< 0.1	0.1	0.1	13.0			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
26	152	109	6	0.3	0.10
20	181	131	1	0.2	0.05
30	269	170	1	0.1	0.06
14	230	170	1	0.1	0.10

Site No.: E587

Map Reference: Sungai Sawai Cut Trace Line DP52 north/Tape 0

Topography: Upper part of north-west facing slope

Parent Material: Soft sandstone

Soil Family/Series: BEKENU/Sarikei

Vegetation: Logged primary forest

Drainage: Well drained

Description for specified depth

0-7 inches

Yellowish brown (10YR 5/8); fine sandy loam; moist and friable; low organic matter content; weak crumb structure; medium prominent pores; abundant fine and medium roots; white ant faunal activity. Clear smooth boundary to:

7-17 inches

Reddish yellow (7.5YR 6/6); fine sandy clay loam; moist and friable; weak crumb structure; fine coarse cracks; medium prominent pores; many fine roots; many termite holes. Clear smooth boundary to:

17-30 inches

Reddish yellow (7.5YR 6/6); fine sandy clay loam to clay loam; moist and friable; weak subangular blocky structure; medium coarse cracks; medium prominent pores; few fine roots. Diffuse wavy boundary to:

30-42 inches

Reddish yellow (5YR 6/6); fine sandy clay loam to clay loam; moist and friable; structureless; fine prominent pores; few fine roots. Diffuse wavy boundary to:

42-54 inches

Reddish yellow (5YR 6/6); fine sandy clay loam; moist and friable; weak medium subangular blocky structure; fine prominent pores; many weakly cemented iron concretions.

CHEMICAL AND MECHANICAL ANALYSES

Site No. E587
Map Reference Sungai Sawai, Cut Trace Line DP52 north/Tape O
Soil Family BEKENU
Soil Series Sarikei

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 — 500 µ	Sand 500 — 250 µ	Sand 250 — 100µ	Sand 100 — 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
23534	E0129	0-7	0.5	0.5	22.8	18.2	41	17	4.9	4.0
23535	E0130	7-17	0.3	0.3	22.0	17.4	33	27	4.8	4.1
23536	E0131	17-30	0.5	0.3	20.5	15.7	33	30	5.0	4.1
23537	E0132	30-42	1.3	0.3	20.0	13.4	33	32	5.1	4.3
23538	E0133	42-54	16.5	2.3	14.3	11.9	25	30	5.1	4.3

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Organic Carbon	C/N Ratio
0.1	< 0.1	0.1	0.1	10.8	0.097	1.598	16.474
< 0.1	Nil	0.1	< 0.1	9.6	0.042	0.675	16.071
< 0.1	Nil	0.1	< 0.1	8.4			
0.1	Nil	0.1	< 0.1	6.9			
0.1	< 0.1	0.2	0.1	6.8			

Nutrients: Milligrams / 100g of Soil — Total: P	K	Mg	Ca	Available: P	K
35	18	40	1	0.2	0.01
30	20	50	1	0.1	0.01
25	25	59	1	0.1	0.01
26	28	66	Nil	0.1	0.01
50	66	80	1	0.1	0.01

Site No.: E638

Map Reference: Beluru - Cut Trace Line DP56 East/Tape 38.5

Topography: Site on low hill ridge, sloping 8 to 10 degrees north

Parent Material: Shale

Soil Family/Series: KABULOH/Karabungan

Vegetation: Logged primary forest

Drainage: Well drained

Description for specified depth

0-3 inches

Yellowish brown (10YR 5/4); clay loam; moist and friable; high organic matter content; weak crumb structure; medium prominent pores; abundant medium and large roots; many termites holes. Clear wavy boundary to:

3-12 inches

Yellowish brown (10YR 5/4); few medium distinct strong brown (7.5YR 5/6) mottles; fine sandy clay loam to clay; moist and friable; low organic matter content; moderate medium subangular blocky structure; fine prominent pores; many medium and large roots. Diffuse wavy boundary to:

12-21 inches

Yellowish brown (10YR 5/6); few medium distinct strong brown and pale yellow (7.5YR 5/6 to 2.5Y 7/4) mottles; clay loam to clay; moist and firm; low organic matter content; moderate, medium angular blocky structure; fine prominent pores; few fine roots; many manganese stains. Diffuse wavy boundary to:

21-30 inches

Yellowish brown (10YR 5/6); clay; moist and firm; medium coarse cracks; few fine and medium roots; many manganese; stains. Diffuse wavy boundary to:

30-41 inches

Light olive brown (2.5Y 5/4); clay plus weathered shale; many iron concretions plus manganese stains. Clear wavy boundary to:

41-50 inches

Light grey (10YR 7/1); weathered shale bed.

CHEMICAL AND MECHANICAL ANALYSES

Site No. E638
Map Reference Beluru - Cut Trace Line DP56 East/Tape 38.5
Soil Family KABULOH
Soil Series Karabungan

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
			Sand				Silt	Clay		
			2000 — 500 μ	500 — 250 μ	250 — 100μ	100 — 50 μ				
23565	E0160	0-3	0.8	1.0	3.5	18.7	58	18	4.8	4.2
23566	E0161	3-12	0.3	0.5	3.0	18.2	50	28	4.8	4.0
23567	E0162	12-21	0.3	0.3	2.8	15.6	46	35	5.0	4.0
23568	E0163	21-30	0.3	0.3	2.8	17.6	43	36	5.8	4.3
23569	E0164	30-41	0.5	0.5	3.3	11.7	48	36	6.3	5.1
23570	E0165	41-50	1.3	1.3	2.5	11.9	48	35	6.5	5.3

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
1.6	1.5	0.1	0.5	12.5	0.169	2.802	16.580
0.2	0.5	0.1	0.1	10.5	0.076	1.056	13.895
0.2	0.4	0.1	0.1	11.1			
1.3	0.4	0.1	0.1	12.1			
9.0	1.2	0.1	0.1	12.8			
10.6	3.3	0.1	0.2	16.7			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
22	152	202	39	0.5	0.32
18	215	222	8	0.1	0.07
16	254	263	7	0.1	0.06
21	313	304	173	0.1	0.06
21	283	319	178	0.1	0.06
24	337	445	190	0.1	0.08

Site No.: E710

Map Reference: Sungai Sebubok Cut Trace Line DP97 south/Tape 65

Topography: Site on middle of south facing 38 degrees slope

Parent Material: Soft sandstone

Soil Family/Series: NYALAU/Nyalau

Vegetation: Primary forest

Drainage: Well drained

Description for specified depth

0-5 inches

Brown (10YR 5/3); few fine to medium distinct pale yellow to strong brown (2.5Y 7/4 to 7.5YR 5/6) mottles; medium sandy loam; moist and friable; low organic matter content; crumb structure; medium prominent pores; abundant medium and large roots; few fragments of laterised soft sandstone. Clear wavy boundary to:

5-17 inches

Brownish yellow (10YR 6/6); medium sandy clay loam; moist and friable; weak subangular blocky structure; fine coarse cracks; medium prominent pores; abundant fine and medium roots; termite activity. Clear wavy boundary to:

17-30 inches

Reddish yellow (7.5YR 6/6); medium sandy clay loam; moist and friable; moderate subangular blocky structure; medium coarse cracks; fine prominent pores, few fine roots; many weakly cemented iron concretions. Clear wavy boundary to:

30-50 inches

Reddish yellow (7.5YR 6/6); fine sandy clay loam; moist and firm; many fragments of laterised; soft sandstone and iron concretions. Clear wavy boundary to:

50-58 inches

Grey (10YR 6/1); weakly cemented fine sandstone.

CHEMICAL AND MECHANICAL ANALYSES

Site No.	E710
Map Reference	Sungai Sebubok Cut Trace Line DP97 south/Tape 65
Soil Family	NYALAU
Soil Series	Nyalau

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 — 500 µ	Sand 500 — 250 µ	Sand 250 — 100µ	Sand 100 — 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1 : 2.5
23953	E0190	0-5	1.8	3.5	36.2	19.5	23	16	4.7	4.2
23954	E0191	5-17	0.9	2.5	40.2	14.6	19	23	5.0	4.2
23955	E0192	17-30	1.5	2.0	37.6	9.9	21	28	5.1	4.3
23956	E0193	30-50	2.1	1.9	38.4	10.6	19	28	5.3	4.4

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Percent: Organic Carbon	C/N Ratio
0.2	0.1	0.2	0.1	8.1	0.106	2.112	19.925
Nil	< 0.1	0.1	0.1	5.9	0.037	0.493	13.324
0.1	< 0.1	0.1	< 0.1	7.2			
< 0.1	< 0.1	0.1	0.1	7.1			

Nutrients: Milligrams / 100g of Soil — Total: P	Total: K	Total: Mg	Total: Ca	Available: P	Available: K
46	84	73	6	0.6	0.09
24	98	91	2	0.1	0.03
21	120	114	3	0.1	0.03
20	147	128	3	0.1	0.04

Site No.: E726

Map Reference: Sungai Sebubok, Cut Trace Line DP97 north/Tape 9

Topography: Site on upper hill ridge sloping 4 degrees north-west

Parent Material: Shale

Soil Family/Series: MERIT/Merit

Vegetation: Logged primary forest

Drainage: Well drained

Description for specified depth

0-3 inches

Dark yellowish brown (10YR 4/4); loam; moist and friable; high organic matter content; weak crumb structure; fine coarse cracks; medium prominent pores; abundant medium and large roots; termite activities. Clear smooth boundary to:

3-13 inches

Yellow (10YR 7/6); very fine sandy clay loam; moist and friable; low organic matter content; moderate, medium subangular blocky structure; medium prominent pores; many fine and medium roots; few termite activities. Clear wavy boundary to:

13-30 inches

Reddish yellow (7.5YR 6/6); clay loam to clay; moist and firm; low organic matter content structureless; fine coarse cracks; weathered laterised parent material; sandy shale and iron concretions. Clear wavy boundary to:

30-54+ inches

Hard cemented shale bed.

CHEMICAL AND MECHANICAL ANALYSES

Site No.	E726
Map Reference	Sungai Sebubok Cut Trace Line DP97 north/Tape 9
Soil Family	MERIT
Soil Series	Merit

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 — 500 µ	Sand 500 — 250 µ	Sand 250 — 100µ	Sand 100 — 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
23974	E0211	0-3	1.3	0.6	0.5	20.6	61	16	4.4	3.9
23975	E0212	3-13	1.9	0.3	0.8	10.0	56	31	4.8	4.1
23976	E0213	13-30	4.6	1.1	1.5	7.8	52	33	5.0	4.2
23977	E0214	30-54+	10.4	3.4	2.9	6.3	59	28	5.3	4.2

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Organic Carbon	C/N Ratio
0.2	0.3	0.1	0.2	16.6	0.218	4.152	19.046
0.1	0.1	< 0.1	0.1	10.6	0.055	0.528	9.600
Nil	Nil	< 0.1	0.1	9.6			
< 0.1	< 0.1	< 0.1	0.2	7.5			

Nutrients: Milligrams / 100g of Soil — Total: P	K	Mg	Ca	Available: P	K
68	87	96	7	0.8	0.10
22	107	117	2	0.1	0.03
24	166	144	Nil	0.1	0.03
26	221	148	1	0.1	0.07

Site No.: F336

Map Reference: Sungai Sawai, Cut Trace Line DP39/Tape 31

Topography: Site in flat dry, valley area

Parent Material: Recent alluvium

Soil Family/Series: SEDUAU-BIJAT Family Intergrade

Vegetation: Logged primary forest

Drainage: Subject to flooding

Description for specified depth

0-3 inches

Yellowish brown (10YR 5/4); clay loam; moist and friable; high organic matter content; weak fine crumb structure; many cracks; many pores; many roots. Clear smooth boundary to:

3-10 inches

Brownish yellow (10YR 6/6); few fine faint yellow plus reddish yellow (5Y 8/6 plus 7.5YR 7/6) mottles; clay loam; moist and friable; low organic matter content; weak, medium subangular blocky structure; many cracks; many pores; few roots. Clear wavy boundary to:

10-25 inches

Light yellowish brown (10YR 6/4); many coarse distinct strong brown (7.5YR 5/6) mottles; clay moist and firm; low organic matter content; moderate, medium angular blocky structure; few cracks; few roots. Abrupt wavy boundary to:

25-45 inches

Yellowish red (5YR 5/8); many coarse distinct light grey (5Y 7/1) mottles; clay; moist and firm; moderate medium angular blocky structure; few cracks; few roots.

CHEMICAL AND MECHANICAL ANALYSES

Site No. F336
Map Reference Sungai Sawai Cut Trace Line DP39/Tape 31
Soil Family SEDUAU-BIJAT Family Intergrade
Soil Series

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent: Sand 2000 – 500 µ	Sand 500 – 250 µ	Sand 250 – 100µ	Sand 100 – 50 µ	Silt	Clay	pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
23644	F0104	0-3	0.8	1.0	11.3	13.9	53	20	4.8	4.3
23645	F0105	3-10	0.3	0.5	9.0	12.2	48	30	4.8	4.2
23646	F0106	10-25	0.3	0.3	10.0	9.4	38	42	5.1	4.3
23647	F0107	25-45	0.8	0.8	8.5	9.9	35	45	5.0	4.3

Exchangeable Cations Milliequivalents / 100g of Soil: Ca	Mg	Na	K	C E C	Percent: Total N	Percent: Organic Carbon	C/N Ratio
0.3	0.8	0.1	0.2	11.2	0.146	1.908	13.069
< 0.1	0.6	< 0.1	0.1	9.1	0.080	0.633	7.913
0.1	0.7	0.1	0.1	11.9			
0.1	0.9	< 0.1	0.1	11.4			

Nutrients: Milligrams / 100g of Soil — Total: P	Total: K	Total: Mg	Available: Ca	Available: P	Available: K
14	156	131	2	0.7	0.13
12	230	181	1	0.2	0.07
11	230	192	3	0.1	0.04
10	254	213	4	0.1	0.06

Site No.: F367

Map Reference: Sungai Sawai Cut Trace Line BASE LINE A/ Tape 45.5

Topography: Flat river valley

Parent Material: Recent alluvium

Soil Family/Series: SEDUAU/Seduau

Vegetation: Logged primary forest

Drainage: Imperfect

Description for specific depth

0-2 inches

Dark yellowish brown (10YR 4/4); loam; moist and very friable; high organic matter content; weak fine crumb structure; few cracks; few pores; many roots. Clear smooth boundary to:

2-8 inches

Yellowish brown (10YR 5/4); few fine faint yellow (2.5Y 8/6) mottles; clay loam moist and friable; high organic matter content; weak medium subangular blocky structure; many cracks; many pores; many roots; many manganese stains. Clear wavy boundary to:

8-19 inches

Yellowish brown (10YR 5/4); few fine faint yellow (2.5Y 8/6) mottles; clay loam; moist and friable to firm; low organic matter content; weak, medium subangular blocky structure; many cracks; few pores; few roots; many manganese stains. Clear wavy boundary to:

19-26 inches

Yellowish brown (10YR 5/6); few fine distinct yellow (2.5Y 8/6) mottles; clay loam; moist and firm; low organic matter content; moderate medium subangular blocky structure; few cracks; few pores; few roots; many manganese stains. Clear wavy boundary to:

26-45 inches

Strong brown (7.5YR 5/6); many fine distinct yellow (2.5Y 8/6) mottles; clay; moist and firm; low organic matter content; moderate medium angular blocky structure; few cracks; few roots.

CHEMICAL AND MECHANICAL ANALYSES

Site No. F367
Map Reference Sungai Sawai Cut Trace Line BASE LINE A/Tape 45.5
Soil Family SEDUAU
Soil Series Seduau

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1: 2.5
			Sand				Silt	Clay		
			2000 — 500 µ	500 — 250 µ	250 — 100µ	100 — 50 µ				
23657	F0117	0-2	1.3	1.0	2.8	13.9	61	20	4.3	4.1
23658	F0118	2-8	0.3	0.3	0.8	10.6	58	30	4.9	4.3
23659	F0119	8-19	Nil	0.3	0.8	7.9	56	35	5.0	4.3
23660	F0120	19-26	0.3	0.5	1.3	6.9	51	40	5.3	4.7
23661	F0121	26-45	Nil	Nil	1.5	2.5	48	48	5.3	4.5

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
0.4	1.1	0.1	0.2	15.0	0.231	2.700	11.688
0.1	0.8	0.1	0.1	12.9	0.123	1.038	8.439
0.2	0.6	0.1	0.1	11.0			
< 0.1	0.5	0.1	0.1	10.7			
< 0.1	0.5	0.1	0.1	10.8			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
32	196	181	8	0.6	0.13
20	244	222	3	0.1	0.06
16	230	213	1	0.1	0.03
11	230	202	1	Nil	0.06
11	298	252	1	Nil	0.03

Site No.: F368

Map Reference: Sungai Sawai, Cut Trace Line DP31 south/Tape 13

Topography: Site in flat bottomed river valley

Parent Material: Recent alluvium

Soil Family/Series: BEMANG

Vegetation: Logged primary forest

Drainage: Imperfect

Description for specified depth

0-3 inches

Yellowish brown (10YR 5/4); loam; moist and friable; high organic matter content; weak fine crumb structure; few cracks; few pores; many roots. Clear smooth boundary to:

3-17 inches

Yellowish brown (10YR 5/6); clay loam; moist and friable; high organic matter content; weak crumb structure; many cracks; many pores; many roots. Abrupt smooth boundary to:

17-30 inches

Yellowish brown (10YR 5/6); few fine faint yellow (2.5Y 8/6) mottles; clay loam; moist and friable; low organic matter content; weak medium subangular blocky structure; many cracks; many pores; few roots. Abrupt wavy boundary to:

30-43 inches

Yellowish brown (10YR 5/6); few fine distinct yellow (2.5Y 8/6) mottles; clay loam; moist and firm; low organic matter content; weak medium subangular blocky structure; few cracks; few pores; few roots; weathered manganese fragments. Abrupt wavy boundary to:

43-60 inches

Yellowish brown (10YR 5/6); few fine distinct yellow plus reddish yellow (2.5Y 8/6 plus 5YR 6/6) mottles; clay loam; moist and firm; weak medium subangular blocky structure; few roots; weathered manganese fragments.

CHEMICAL AND MECHANICAL ANALYSES

Site No. F368
Map Reference Sungai Sawai, Cut Trace Line DP31 south/Tape 13
Soil Family BEMANG
Soil Series

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
			Sand				Silt	Clay		
			2000 – 500 µ	500 – 250 µ	250 – 100µ	100 – 50 µ				
23662	F0122	0-3	1.3	3.3	3.8	18.6	50	23	4.5	4.3
23663	F0123	3-17	Nil	0.3	1.8	9.9	58	30	4.9	4.3
23664	F0124	17-30	Nil	Nil	1.3	12.7	53	33	5.2	4.4
23665	F0125	30-43	Nil	Nil	0.8	8.2	53	38	5.2	4.4
23666	F0126	43-60	Nil	Nil	4.5	13.5	47	35	5.4	4.5

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
1.0	1.5	0.1	0.3	16.7	0.116	3.404	29.345
0.1	0.9	< 0.1	0.2	12.1	0.275	1.164	4.233
0.1	0.7	< 0.1	0.1	9.5			
0.1	0.7	< 0.1	0.1	8.0			
0.1	0.6	< 0.1	0.1	8.2			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
41	205	202	19	0.8	0.18
20	298	263	6	0.1	0.10
12	230	263	3	0.1	0.06
8	230	222	2	0.1	0.04
8	244	222	2	0.1	0.03

Site No.: F606

Map Reference: Sungai Sebubok Cut Trace Line DP111/Tape 64

Topography: Site in lower part of 10 degrees west facing slope

Parent Material: Calcareous shale

Soil Family/Series: KABULOH/Kabuloh

Vegetation: Old secondary

Drainage: Moderate

Description for specified depth

0-4 inches

Dark greyish brown (10YR 4/2); clay loam; moist and friable; high organic matter content; fine crumb structure; many pores; many fine roots. Clear smooth boundary to:

4-11 inches

Yellowish brown (10YR 5/4); few fine faint pale yellow (2.5Y 7/4) mottles; clay loam; moist and firm; high organic matter content; weak medium subangular blocky structure; many cracks; few pores; many fine roots. Clear smooth boundary to:

11-25 inches

Light yellowish brown (10YR 6/4); few medium distinct reddish yellow plus pale yellow (7.5YR 7/6 plus 2.5Y 7/4) mottles; clay; moist and firm; low organic matter content; moderate medium subangular blocky structure; few cracks; many fine roots. Clear wavy boundary to:

25-34 inches

Light olive brown (2.5Y 5/4); few fine faint light grey (10YR 7/1) mottles; clay; wet very sticky; low organic matter content; few cracks; few fine roots;

34+ inches

Calcareous shale.

CHEMICAL AND MECHANICAL ANALYSES

Site No. F606
Map Reference Sungai Sebubok, Cut Trace Line DP111/Tape 64
Soil Family KABULOH
Soil Series Kabuloh

Laboratory Number	Sample Number	Depth (Inches)	Partical Size Analyses Percent						pH Soil / Water 1: 2.5	pH Soil / KCl 1:2.5
			Sand				Silt	Clay		
			2000 — 500 μ	500 — 250 μ	250 — 100μ	100 — 50 μ				
24214	F0264	0-4	21.2	4.0	1.2	5.6	39	29	6.2	5.7
24215	F0265	4-11	3.0	0.7	1.0	12.3	33	50	6.0	5.1
24216	F0266	11-25	Nil	0.2	0.2	8.6	29	62	6.0	5.0
24217	F0267	25-34	0.7	0.5	0.7	7.1	31	60	8.0	7.1

Exchangeable Cations Milliequivalents / 100g of Soil					Percent		C/N Ratio
Ca	Mg	Na	K	C E C	Total N	Organic Carbon	
26.6	3.2	0.1	0.4	23.2	0.393	7.032	17.893
10.0	2.1	0.1	0.2	20.8	0.116	1.450	12.500
18.1	1.3	0.1	0.2	20.7			
38.8	0.8	0.1	0.1	25.2			

Nutrients: Milligrams / 100g of Soil					
Total				Available	
P	K	Mg	Ca	P	K
44	176	304	625	0.5	0.13
18	126	304	335	0.1	0.07
13	229	398	345	0.1	0.07
21	221	445	650	1.8	0.03

APPENDIX VII

APPENDIX VII

AREA MEASUREMENTS — TERRAIN, SOILS AND LAND CAPABILITY

VII.1 BROAD TRANSECT SURVEY AREA

TABLE VII.1.1 TERRAIN

Class	Area in acres			Percentage of total land area	
	Sheet 1	Sheet 2	Total	Sub-class	Class
1	231 400	188 500	419 900	27.51	29.38
1 + 2	9 100	7 900	17 000	1.11	
1 + 3	4 300	2 300	6 600	0.43	
1 + 4	3 400	900	4 300	0.30	
1 + 5	-	600	600	0.03	
2	30 800	28 800	59 600	3.90	4.03
2 + 3	900	1 200	2 100	0.13	
3	95 700	62 700	158 400	10.40	10.40
4	92 500	63 300	155 800	10.20	10.23
4 + 5	600	-	600	0.03	
5	90 800	77 900	168 700	11.05	11.14
5 + 6	1 500	-	1 500	0.09	
6	131 000	43 800	174 800	11.45	29.45
6 + 7	36 200	238 200	274 400	18.00	
7	76 300	5 400	81 700	5.35	5.35
Total	804 500	721 500	1 526 000	99.98	99.98

TABLE VII.1.2 SOILS

Symbol	Area in acres			Percentage of total land area	
	Sheet 1	Sheet 2	Total	Sub-class	Class
KY	-	200	200	0.01	
KY.5	-	800	800	0.05	
KY.BM.5	-	2 100	2 100	0.13	
KY-TT.5	-	1 500	1 500	0.10	0.42
KY-TT	1 900	-	1 900	0.12	
KY/SL.4	-	100	100	0.01	
BM.5	-	5 100	5 100	0.33	
BM/BJ.5	300	100	400	0.02	
BM-PK.5	1 200	7 200	8 400	0.55	0.95
BM/KY.5	-	400	400	0.02	
BM/BK.4	-	500	500	0.03	
SD.5	3 800	1 100	4 900	0.32	
SD/MR.4	800	400	1 200	0.08	2.73
SD-BJ.5	20 400	15 400	35 800	2.35	
TT	500	-	500	0.03	
TT.5	4 700	100	4 800	0.31	
TT.5/IG	4 000	-	4 000	0.26	0.76
TT/MK	-	800	800	0.05	
TT.5/MK	-	1 700	1 700	0.11	
BJ.3	-	1 900	1 900	0.12	
BJ.5	19 000	4 300	23 300	1.52	
BJ/MK	6 300	7 900	14 200	0.93	
BJ.5-AN.3	200	-	200	0.01	
BJ/SD.5	6 100	100	6 200	0.40	
BJ/MK.5	500	-	500	0.03	
BJ.5/AN I	2 500	-	2 500	0.16	
BJ/AN	-	1 200	1 200	0.07	4.30
BJ/AN I	800	2 000	2 800	0.18	
BJ/AN II	2 800	1 900	4 700	0.30	
BJ.5/MK	3 000	-	3 000	0.29	
BJ.5/BK.3	1 400	-	1 400	0.09	
BJ.5/MR.3	500	-	500	0.03	
BJ.5/AN	600	-	600	0.04	
BJ.5/MR.4	1 900	-	1 900	0.12	
BJ-SD.5	600	-	600	0.04	
BJ/MR.4	-	600	600	0.04	
BJ-PD.5	500	-	500	0.03	
BL/AN I	300	-	300	0.02	0.03
BL-TT.5	200	-	200	0.01	
RJ	5 900	1 600	7 500	0.49	0.49
MI.3	900	-	900	0.06	
MI.4	200	400	600	0.04	0.12
MI/SL.4	-	400	400	0.02	
SL	200	-	200	0.01	
SL.4	200	500	700	0.04	
SL.5	1 200	1 800	3 000	0.20	
SL.4/5	1 700	-	1 700	0.11	1.78
SL/MI.4	9 600	9 100	18 700	1.22	
SL.5/IG	1 000	-	1 000	0.06	
SL/TK.4	-	2 100	2 100	0.14	
SL/KR.4	-	-	-	-	
TK.4	-	500	500	0.03	0.60
TK/MK	-	400	400	0.03	
SR.4	-	-	-	-	0.13
SR/KR.4	-	2 000	2 000	0.13	
PJ/MN.1	400	-	400	0.02	0.06
PJ.2/MN.1	700	-	700	0.04	
KR/BG.4	-	800	800	0.05	0.05
NY.2	400	-	400	0.03	
NY.3	300	100	400	0.02	
NY.4	1 800	5 600	7 400	0.48	
NY.5	-	3 000	3 000	0.20	
NY.5/MN	-	4 400	4 400	0.28	
NY.3/4	-	900	900	0.06	
NY.4/5	-	500	500	0.03	
NY/BK.2	7 900	400	8 300	0.54	
NY/BK.3	3 900	6 000	9 900	0.65	
NY/BK.4	8 000	22 400	30 400	1.99	
NY/PJ.4	1 400	-	1 400	0.09	8.81
NY.3/NY-KP.1	-	5 700	5 700	0.37	
NY.4/NY-KP.1	-	19 800	19 800	1.29	
NY.2/MN.1	700	-	700	0.04	
NY/BK.2/3	6 000	1 100	7 100	0.46	
NY/SL.4	2 100	-	2 100	0.14	
NY/SL.5	1 500	700	2 200	0.14	
NY.4/MN	-	400	400	0.02	
NY.2/KP.1	6 900	-	6 900	0.45	
NY/BK.3/4	500	-	500	0.03	
NY-KP.1	9 900	-	9 900	0.65	
NY.2/3/NY-KP.1	-	8 400	8 400	0.55	
NY/PJ.5	4 700	-	4 700	0.30	
BK.2	3 700	-	3 700	0.24	
BK.3	6 900	3 000	9 900	0.65	
BK.4	5 100	10 300	15 400	1.01	
BK.5	300	300	600	0.04	
BK.4/5	6 900	76 600	83 500	5.47	
BK/NY.3	15 300	-	15 300	1.00	
BK.4/BK-KP.1	600	34 600	35 200	2.30	
BK/KP	500	-	500	0.03	
BK/MR.4/5	1 300	21 400	22 700	1.49	
BK-KP.1	23 500	500	24 000	1.57	
BK.3/BK-Kp.1	13 600	11 000	24 600	1.61	23.87
BK.2/3/BK-KP.1	31 100	600	31 700	2.07	
BK.2/3	8 800	-	8 800	0.57	
BK.3/4	2 900	27 200	30 100	1.97	
BK/MR.3	800	28 800	29 600	1.94	
BK/MR.4	-	4 800	4 800	0.31	
BK/MR.5	800	500	1 300	0.08	
BK/TT	-	100	100	0.01	
BK/NY.3/4	-	2 100	2 100	0.13	
BK/MR.3/4	-	20 800	20 800	1.36	
BK.2/BK-KP.1	-	400	400	0.02	
MR.2	25 100	-	25 100	1.64	
MR.3	43 600	3 400	47 000	3.08	
MR.4	37 200	22 300	59 500	3.90	
MR.5	2 800	7 900	10 700	0.70	
MR.2/3	36 400	7 200	43 600	2.85	
MR.3/4	64 200	32 600	96 800	6.34	
MR.4/5	6 600	25 200	31 800	2.08	
MR-KP.1	44 300	-	44 300	2.90	
MR/BK.2	10 000	500	10 500	0.69	
MR/BK.3	14 000	2 500	16 500	1.08	
MR/BK.4	3 400	37 300	40 700	2.66	
MR/BK.5	-	800	800	0.05	
MR/BK.2/3	8 000	2 900	10 900	0.71	
MR/BK.3/4	11 600	15 800	27 400	1.79	34.70
MR/BK.4/5	3 600	20 600	24 200	1.59	
MR.4/BJ.5	-	1 000	1 000	0.06	
MR.4/AN I	1 400	-	1 400	0.09	
MR/NY.3	4 100	-	4 100	0.26	
MR/AN III	-	200	200	0.01	
MR.2/KP.1	1 000	-	1 000	0.06	
MR.2/3/KP.1	800	-	800	0.05	
MR.2/3/BJ.5	2 200	-	2 200	0.14	
MR.2/3/AN.1	-	300	300	0.02	
MR.2/3/MR-KP.1	18 100	-	18 100	1.18	
MR.3/SD.5	2 200	-	2 200	0.14	
MR.3/MR-KP.1	-	1 000	1 000	0.06	
MR.5/SD-BJ.5	-	600	600	0.04	
MR.3/4/MR-KP.1	-	4 200	4 200	0.27	
MR.4/SD-BJ.5	-	4 000	4 000	0.26	
KB.2	800	-	800	0.05	
KB.3	400	-	400	0.02	
KB.4	-	-	-	-	0.20
KB.2/3	1 600	-	1 600	0.10	
KB-KP.1	500	-	500	0.03	
PD	400	-	400	0.01	
PD/RJ	900	600	1 500	0.10	0.18
PD-MK	300	-	300	0.02	
PD/NK	800	-	800	0.05	
IG	18 500	3 200	21 700	1.42	1.45
IG/AN	500	-	500	0.03	
AN I	33 800	10 600	44 400	2.91	
AN II	49 200	18 500	67 700	4.43	
AN III	55 600	80 700	136 300	8.93	
AN/MK	-	1 700	1 700	0.11	
AN/TT	600	-	600	0.04	
AN/MR.4	600	-	600	0.04	16.72
AN I/II	-	400	400	0.02	
AN I/MK	400	1 500	1 900	0.12	
AN II/MK	400	-	400	0.02	
AN II/BJ.5	-	400	400	0.02	
AN III/MR.4	-	1 300	1 300	0.08	
KP.1	5 600	-	5 600	0.36	
MK	7 000	12 900	19 900	1.30	1.73
MK.3/4	900	-	900	0.06	
MK.2/KP.1	200	-	200	0.01	
Total	804 500	721 500	1 526 000	100.08	100.08

TABLE VII.1.3 LAND CAPABILITY

Land Class	Area in acres			Percentage of total land area	
	Sheet 1	Sheet 2	Total	Sub-class	Class
I	300	6 400	6 700	0.43	0.46
I + IVe	-	500	500	0.03	
IIw	3 200	-	3 200	0.20	
IIw + Ve	900	-	900	0.05	0.27
IIe + VIe	-	400	400	0.02	
IIIe	100	-	100	0.01	
IIIw	20 900	20 800	41 700	2.73	
IIIe + IVe	200	-	200	0.01	
IIIe + IVw	-	600	600	0.03	2.82
IIIs + Ve	-	300	300	0.01	
IIIs + VIe	-	300	300	0.01	
IIIw + IIIs	-	400	400	0.02	
IVe	30 000	44 600	74 600	4.88	
IVs	7 600	18 800	26 400	1.73	
IVw	34 900	8 800	43 700	2.86	
IVse	2 200	-	2 200	0.14	
IVs/I	400	-	400	0.02	
IVw + Vs	1 700	-	1 700	0.11	
IVw + Ve	1 200	900	2 100	0.13	10.50
IVe + IIIw	100	1 000	1 100	0.07	
IVe + VIs	1 200	-	1 200	0.07	
IVe + s	600	-	600	0.03	
IVe + Vs	500	-	500	0.03	
IVs + IIIw	-	2 700	2 700	0.17	
IVs + IVw	-	1 100	1 100	0.07	
IVe + IVw	2 200	600	2 800	0.18	
IVe + VIsw	-	100	100	0.01	
Ve	75 100	72 300	147 400	9.65	
Vs	40 200	7 300	47 500	3.11	
Vw	9 200	11 600	20 800	1.36	
Vse	16 700	3 000	19 700	1.29	
Vsw	2 000	3 600	5 600	0.36	
Ve + s	26 600	-	26 600	1.74	19.45
Vs + VIe	1 600	-	1 600	0.10	
Ve + IVe	25 000	-	25 000	1.63	
Ve + IVs	1 600	-	1 600	0.10	
Ve/I	1 600	-	1 600	0.10	
Vs/VIIs	-	300	300	0.01	
VIe	39 600	69 300	108 900	7.13	
VIs	47 100	24 500	71 600	4.69	
VIsw	29 000	11 200	40 200	2.63	15.68
VIse	11 700	4 100	15 800	1.03	
VIse/VIsw	3 100	-	3 100	0.20	
VIIe	207 200	288 900	496 100	32.50	
VIIs	130 800	114 600	245 400	16.08	
VIIse	27 800	1 000	28 800	1.88	50.57
VIIs + IVe	400	200	600	0.03	
VIIs + IVs	-	1 300	1 300	0.08	
Total	804 500	721 500	1 526 000	99.75	99.75

VII.2 SEMI DETAILED SOIL SURVEY AREA

TABLE VII.2.1 TERRAIN

Class	Sungai Galasah	Sungai Sawai	Sungai Sebubok	Sub-total	Beluru	Total
	Area in acres					
1	3 622	4 001	3 540	11 163	1 510	12 673
1 + 2	-	-	595	595	-	595
2	891	3 742	5 239	9 872	1 177	11 049
2V	-	-	509	509	-	509
2 + 3	-	-	-	-	1 003	1 003
3	2 695	7 418	4 905	15 018	2 721	17 739
3V	328	-	4 800	5 128	49	5 177
4	3 165	2 611	2 255	8 031	1 714	9 745
4V	19	-	4 806	4 825	93	4 918
4 + 5	-	-	334	334	-	334
5	897	3 958	2 187	7 042	686	7 728
5V	-	-	2 211	2 211	914	3 125
5 + 6	-	-	37	37	-	37
6	1 027	1 172	1 320	3 519	1 486	5 005
6V	-	-	-	-	463	463
6 + 7	2 084	6 590	1 486	10 160	1 022	11 182
7	-	162	25	187	31	218
Total	14 728	29 654	34 249	78 631	12 869	91 500

TABLE VII.2.2 SOILS

Symbol	Sungai Galasah	Sungai Sawai	Sungai Sebubok	Sub-total	Beluru	Total
	Area in acres					
Bm.zl.5	525	-	-	525	99	624
Bm.zcl.5	-	190	124	314	-	314
BM-PK.5	-	81	514	595	-	595
SD.5	93	-	-	93	-	93
SD/BJ.5	-	-	-	-	854	854
SD-BJ.5	111	3 033	321	3 465	-	3 465
SD/BM.5	216	-	-	216	-	216
Sd.c.5	-	-	786	786	155	941
Bj.c.5	568	-	-	568	25	593
BJ.5/MK	204	-	-	204	-	204
Bk.zl.2	-	-	-	-	93	93
Bk.zcl.3	111	221	1 514	1 846	-	1 846
Bk.zl.4	-	-	-	-	68	68
Bk.zcl.4	-	-	155	155	-	155
Bk.zcl.5	-	-	494	494	-	494
Bk.zcl.3/4	-	-	111	111	-	111
BK-KP.1	136	1 049	526	1 711	80	1 791
Bk.zcl.2/BK-KP.1	-	50	-	50	-	50
NY/SL.5	12	-	-	12	-	12
NY/MR.3	37	-	-	37	-	37
NY-KP.1	229	-	-	229	-	229
Mr.c.2	155	-	99	254	1 339	1 593
Mr.c.3	2 785	624	3 757	7 166	142	7 308
Mr.c.4	630	2 446	792	3 868	3 186	7 054
Mr.c.5	656	2 471	3 497	6 624	-	6 624
Mr.c.2/3	1 061	-	-	1 061	1 413	2 474
Mr.c.3/4	-	1 470	334	1 804	-	1 804
Mr.c.4/5	1 308	6 239	14 031	21 578	488	22 066
Mr.c.2/MR-KP.1	736	-	-	736	-	736
Mr.sc.5	25	-	-	25	-	25
Mr/Jk.c.4/5	-	-	-	-	-	-
Mr/Jk.c.2/3	-	-	-	-	124	124
Mr/Jk.c.3	31	573	-	604	-	604
Mr/Jk.c.4	303	716	1 292	2 311	235	2 546
Mr/Jk.c.5	192	624	-	816	-	816
Mr/Jk.c.4/5	-	923	-	923	1 382	2 305
MR/BK.4/5	93	289	-	382	-	382
MR-KP.1	2 291	26	148	2 465	2 370	4 835
Mr.c.2/MR-KP.1	-	-	-	-	816	816
Mr.c.3/MR-KP.1	-	6 367	1 564	7 931	-	7 931
Kb.c.3	-	-	1 341	1 341	-	1 341
Kb.c.4	-	-	1 107	1 107	-	1 107
Kb.c.5	-	-	142	142	-	142
KB-KP.1	-	-	593	593	-	593
Kb/Kg.c.3	-	-	235	235	-	235
Kb.c.3/KB-KP.1	-	-	49	49	-	49
AN I	266	26	-	292	-	292
AN II	-	277	-	277	-	277
AN I/II	940	-	-	940	-	940
AN I/III	-	63	-	63	-	63
AN II/III	507	289	-	796	-	796
MK	278	13	-	291	-	291
MK/AN I	229	-	-	229	-	229
Kg.c.4	-	-	315	315	-	315
Kg.c.3/KB-KP.1	-	-	260	260	-	260
Jk.c.3	-	122	-	122	-	122
Jk.c.5	-	135	148	283	-	283
Jk.c.3/4	-	530	-	530	-	530
Jk.c.4/5	-	444	-	444	-	444
Jk.c.4/MR-KP.1	-	50	-	50	-	50
Sk.zcl.3	-	197	-	197	-	197
Jk.fsc.5	-	116	-	116	-	116
Total	14 728	29 654	34 249	78 631	12 869	91 500

TABLE VII.2.3 LAND CAPABILITY

Class	Sungai Galasah	Sungai Sawai	Sungai Sebubok	Sub-total	Beluru	Total
	Area in acres					
I	-	-	-	-	-	-
IIw	846	6	826	1 678	636	2 314
IIIw	111	3 349	844	4 304	-	4 304
IIIe	130	1 341	288	1 759	-	1 759
IIIs	-	-	906	906	-	906
IVw	958	12	-	970	1 006	1 976
IVe	1 242	7 199	6 794	15 235	3 434	18 669
IVs	111	1 079	3 185	4 375	56	4 431
Vw	-	-	-	-	-	-
Ve	3 627	3 915	7 405	14 947	1 105	16 052
Vs	1 007	-	115	1 122	2 248	3 370
Vse	49	-	-	49	-	49
VIe	741	3 713	6 052	10 506	185	10 691
VIs	1 149	517	2 451	4 117	352	4 469
VIsw	229	-	-	229	-	229
VIIe	3 095	7 869	5 095	16 059	3 798	19 857
VIIs	1 433	654	-	2 087	49	2 136
Ve + VIe	-	-	288	288	-	288
Total	14 728	29 654	34 249	78 631	12 869	91 500

TABLE VII.3.1 TERRAIN

Class and slopes in degrees	Acreage	Percentage of total
1A, 0-2	3 652	18
1R, 0-5	1 017	5
2, 6-10	3 514	18
3, 11-15	4 494	23
4, 15-20	4 190	21
5, 20-25	1 742	9
6, 25-30	835	4
7, over 30	520	2
Total	19 964	100

TABLE VII.3.3 LAND CAPABILITY

Class	Acreage	Percentage of total
I	331	2
IIw	2 062	10
IIIe	483	2
IVe	1 018	5
IVs	2 739	14
IVw	1 012	5
Ve	3 317	17
Vs	332	2
Vw	295	2
VIe	368	2
VIs	6 867	34
VIIe	252	1
VIIs	888	4
Total	19 964	100

TABLE VII.3.2 SOILS

Symbol	Mapping unit	Acreage	Percentage of total
SD.4	Seduau Family	2 594	12.50
BJ.4	Bijat Family	1 056	5.0
BJ/SD.4	Bijat/Seduau Family Complex	144	0.70
BK	Bekenu Family	54	0.30
BK-KP.1	Bekenu-Kapit Family Intergrade	32	0.20
MR.4	Merit Family	28	0.10
MR.3	Merit Family	585	3.00
MR.2	Merit Family	2 172	10.50
MR-KP.1	Merit-Kapit Family Intergrade	3 708	18.48
Kb.c.4	Kabuloh Series	5	0.02
Kb.c.3	Kabuloh Series	482	2.00
Kb.c.2	Kabuloh Series	1 197	6.00
Kg.c.4	Karabungan Series	67	0.30
Kg.c.3	Karabungan Series	525	3.00
Kg.c.2	Karabungan Series	701	4.00
Tg.c.4	Tangap Series	1 061	5.00
Tg.c.3	Tangap Series	82	0.40
Tg.c.2	Tangap Series	176	1.00
Kb/Tg.c.2	Kabuloh/Tangap Series Complex	166	1.00
Kb/Kg.c.2	Kabuloh/Karabungan Series Complex	238	1.00
Kg/Tg.c.3	Karabungan/Tangap Series Complex	928	5.00
Kg/Tg.c.2	Karabungan/Tangap Series Complex	90	0.5
KB-KP.1	Kabuloh-Kapit Family Intergrade	3 121	16.00
KP.1	Kapit Family	344	2.00
KP/MR-KP.1	Kapit Family/Merit-Kapit Family Intergrade Complex	408	2.00
	Total	19 964	100.00

APPENDIX VIII

APPENDIX VIII

AERIAL PHOTO-INTERPRETATION

VIII.1 INTRODUCTION

Stereoscopic examination of air photographs is widely used in soil and land use studies. If used with discretion it will add considerable knowledge concerning the physical characteristics and accessibility of the areas under study. It is also a tool with which the accuracy of soil and terrain mapping units can considerably be improved.

Under dense forest conditions the value of aerial photographs can be considerably reduced by the masking effect of the tree canopy, this is especially the case in areas with gentle topography where slope characteristics are difficult to identify, but other characteristics such as drainage are recognisable.

In this Study aerial photo-interpretation has been used at all stages. The Zonation Plan Map (Hunting Technical Services Limited and Hoff and Overgaard, 1972) was largely based on this technique, but vital and valuable information collected during the schematic reconnaissance soil surveys prior to this Study has been used together with spot checks in the field to verify photo mapping units.

The compilation of the Soils and Terrain maps covering the Broad Transect Survey Area has, to a large extent, been based on this interpretation technique.

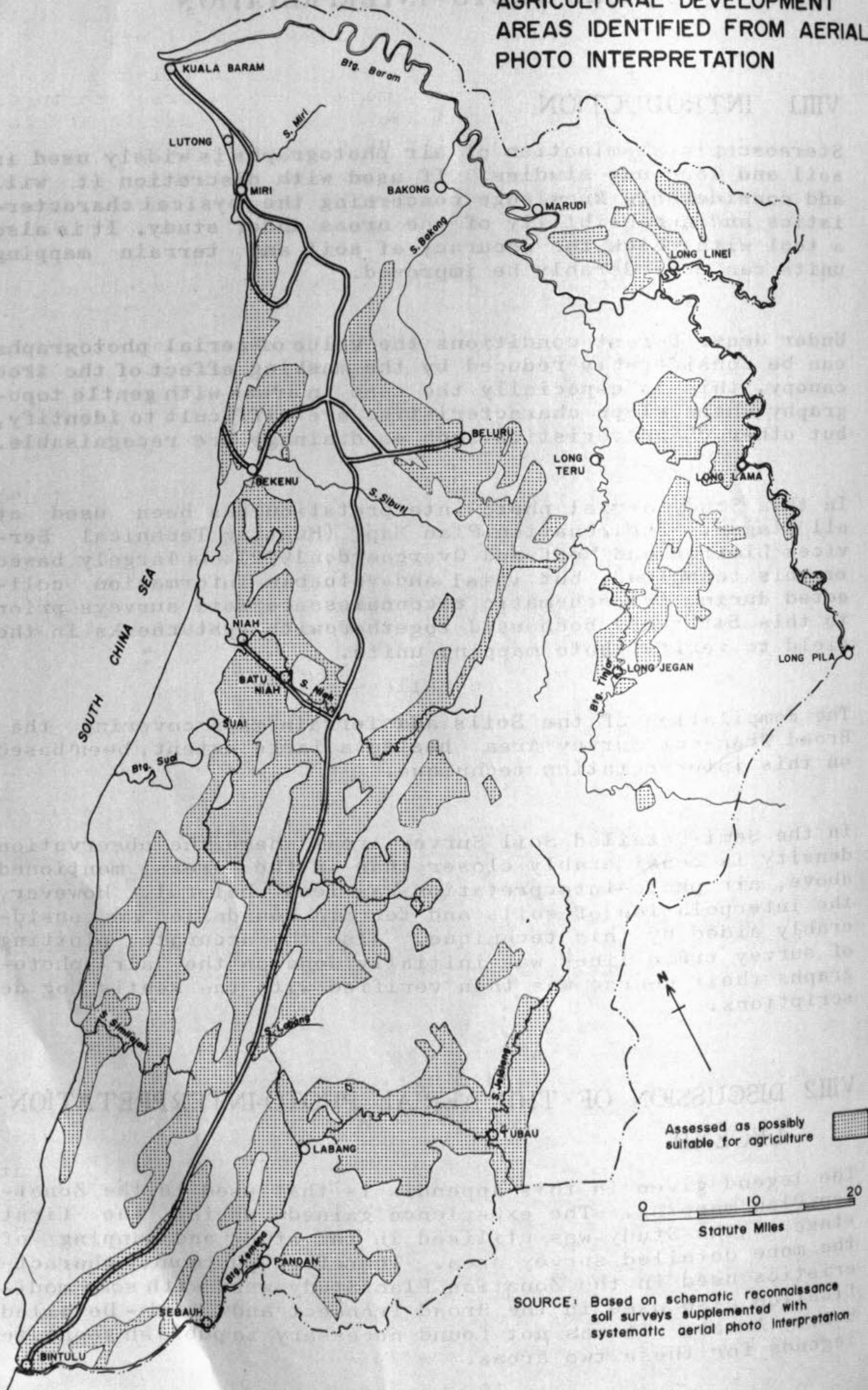
In the Semi-Detailed Soil Survey Areas where the observation density is considerably closer than in the areas mentioned above, air photo-interpretation was less helpful. However, the interpolation of soils and terrain boundaries was considerably aided by this technique. Also the accurate plotting of survey trace lines was initially done on the air photographs their course was then verified with the Rentis Log descriptions.

VIII.2 DISCUSSION OF THE AERIAL PHOTO-INTERPRETATION LEGEND

The legend given in this Appendix is that used in the Zonation Plan mapping. The experience gained during the first stage of the Study was utilised in the study and mapping of the more detailed survey area. Therefore photo unit characteristics used in the Zonation Plan Study were with some modification also used in the Broad Transect and Semi - Detailed Survey Areas. It was not found necessary to publish separate legends for these two areas.

FIGURE VIII.1

AGRICULTURAL DEVELOPMENT AREAS IDENTIFIED FROM AERIAL PHOTO INTERPRETATION



SOURCE: Based on schematic reconnaissance soil surveys supplemented with systematic aerial photo interpretation

(i) Land Type A

Steep, very rugged terrain developed on bedrock. Structurally controlled, elevation generally above 1 000 feet.

A1 - Very steep, rugged terrain with structurally controlled valleys. Dark even tone, moderately coarse texture, white crowns are common above the upper strata of the forest canopy. Generally under primary forest.

A2 - Steep to very steep hills, less rugged than Unit A1, ridges are broad at base, slopes may be concave. Medium textured, dark grey tone. Generally under primary forest.

A3 - Valley in Land Type A, where these are predominantly flat-floored. V-shaped valleys are not differentiated.

A4 - Prominent dip-slopes with heath-like vegetation generally above 500 feet. Fine textured, small trees, dense middle canopy.

(ii) Land Type B

Hills and ridges at low elevation, generally less than 1 000 feet, developed on bedrock.

B1 - Steep hills, moderately to strongly dissected by flat-floored or V-shaped valleys too small to delineate at photo scale. The unit includes isolated areas of cleared and secondary forest. Coarse textures with dark grey tone.

B1v - Steep sided, V-shaped valleys of Unit B1.

B2 - Moderately steep hills, dissected by flat-floored valleys too small to delineate at photo scale. Areas of secondary growth and shifting cultivation are common. Coarse textures with medium dark grey tone.

B2v - Steep sided valleys of Unit B2, flat-floored.

B3 - Undulating terrain, often cultivated. Areas of secondary growth have variable texture and grey tone.

B4 - Broad and flat-floored valleys of Land Type B that are sufficiently wide or clearly defined by topography or by differences in canopy to be delineated.

(iii) Land Type C

Wide alluvial plains, predominantly non-peaty.

C1 - River valleys, identified by position along major rivers, correlating with lighter tones (if cleared), or less uniform canopy (if under primary forest) than in surrounding alluvial areas. The unit is generally bounded by Unit C2 or Land Type D.

Sub-divisions:-

C1r - Levee ridges;

C1p - Pointbars;

C1o - Ox-bows and old river channels;

C1s - Mainly mangrove vegetation identified by position at the lower reaches of major rivers. Smooth canopy, fine textures, dark grey tone.

C2 - Alluvial backswamps, generally non-peaty but in some cases the alluvium may be overlain by shallow peat. Medium coarse and fine textures with medium grey tone, commonly cleared for cultivation or under secondary growth. The uncleared areas in this unit are identified by coarser textures and irregular canopy with dark grey tones. Sometimes the unit is transitional to Unit D1.

C3 - Colluvial fans along the foot of high ridges and hills. Generally cultivated or under secondary growth. The light tones indicate better drainage conditions.

(iv) Land Type D

Wide alluvial plains, predominantly peaty. The land type is identified by distinctive pattern of canopy in primary forest and with less certainty in cultivated or cleared land, by dark tones and by topographic position.

D1 - Peaty backswamps and peat filled valleys, identified by their position.

Sub-divisions:-

D1b - Peaty backswamps. Medium coarse textures and regular canopy of dark grey tone;

D1v - Peat filled valleys. Coarse textured, irregular canopy and dark tones.

D2 - Transitional zone between D1 and D3 Units. Broken irregular canopy which is sloping upwards towards Unit D3. Dark grey tones.

D3 - Domed peat areas. Fine to medium textures and light tones. The unit which is "pock-marked" due to fallen or dead trees has widespread occurrence as discrete areas along the lower and middle reaches of large rivers.

D4 - Flat peat basins. Fine to medium textures and light to medium tones, smooth canopy. Included in this unit are peat basins which have circular lineaments.

D5 - Possibly eroded peat domes within Unit D3. The canopy is lower than the surrounding D3 Unit. Dark grey tones with medium coarse textures. Possibly heath-type vegetation.

D6 - Unit cancelled.

D7 - Coastal peaty plains. Rather featureless terrain, with medium textures and dark grey tone. This unit excludes the Baram-type peat areas.

Sub-divisions:-

D7c - Coastal peaty plains lying directly behind Land Type S. Low canopy with medium even textures;

D7i - Inland section of the coastal peaty plain. Vegetation more mature, canopy shows higher trees, which often grow in clusters. Coarse textures.

(v) Land Type S

Low beach material.

S1 - Spits and bars. Identified by their position on the present beach, often too narrow to delineate at photo scale. Light tones.

S2 - Parallel light toned beach ridges and dark toned swales lying behind the present beach. Mainly scrub vegetation.

S3 - Level, old beach situated between Miri and Lutong lying at same level as Units S1 and S2, but more mature. Dark grey tones with smooth textures. Low vegetation, usually cultivated. Watertable possibly low.

S4 - Parallel dark toned ridges. Identified by their position behind S2 on older beach, its level similar to S1 and S2. This unit lies along rivers running parallel to the present coast line. Vegetation moderately high, generally uncultivated. Watertable is thought to be high.

(vi) Land Type T

Alluvial and marine terraces. Identified by a more or less flat topography at a raised level.

T1 - River terraces above 1 000 feet. Dense, uniform, medium to fine textures and medium grey tones canopy.

T2 - Raised beach and terraces at highest level, 300 to 1 000 feet elevation.

T3 - Raised beach and terraces between 50 to 300 feet elevation. Medium textures, medium to dark grey tones where forested, or smooth light tones where cleared. Eroded surface.

T4 - Raised beach and terraces at lower level than T3. Intermediate between S3 and T3 Units. Generally cultivated.

(vii) Miscellaneous Land Type

U - Built-up urban areas.

APPENDIX IX

APPENDIX IX

EROSION

IX.1 DETAILS OF SAMPLES TESTED FOR LABORATORY ERODIBILITY

Samples collected at four locations in the Study Area have been tested in the laboratories of the Asian Institute of Technology in Bangkok, Thailand. Details of these samples are as follows:-

<u>Sample A</u>
Bekenu family

Location: Bukit Peninjau, near Erosion Trial C on 21 degrees slope. Area planted to oil palm in 1972, ground cover planted, but surface largely uncovered.

Sampling depth: ½ to 6½ inches.

Description: Fine sandy clay loam field texture overlying 8 inches of clay loam over clay; containing moderate contents of sandstone and shale fragments.

Laboratory texture: Silty clay loam.

<u>Sample B</u>
Bekenu family

Location: Bukit Peninjau near Erosion Trial A on 35 degrees slope. Area planted to oil palm in 1972, ground cover planted, but surface largely uncovered.

Sampling depth: 1 to 7 inches.

Description: Field texture loam, 0 to 6 inches overlying 4 inches of fine sandy clay loam over clay, containing high percentage of fine sandstone and shale fragments.

Laboratory texture: Silt loam.

<u>Sample C</u>
Merit family

Location: Low hillock in SOP Estate. One year old oil palm with thick ground cover of legumes and grasses.

Sampling depth: 6 to 12 inches.

Description: Field texture clay loam to clay overlying stone free clay at 15 inches. Overoverlying very stony clay.

Laboratory texture: Silty clay.

<u>Sample D</u>
Nyalau family

Location: Top of steep hill in the Lambir hills, young regrowth.

Sampling depth: 3 to 9 inches.

Description: Field texture sandy clay loam.

Laboratory texture: Sandy loam.

APPENDIX X

APPENDIX X

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