Landform analysis of the Ulu Langat District, Selangor :

A case study in map compilation for planning purposes.

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A thesis presented for the Degree of
Master of Arts in Geography,
Universiti Malaya,
Kuala Lumpur.

October, 1972

CONTENTS

Abstract

Geomorphology, especially applied geomorphology, should be functional in order to contribute to the contemporary plans and needs of man.

It is shown in this study how a geomorphologist, aided by results of studies in related fields, can compile a landform map that is suitable for land planning purposes. Working in the Ulu Langat District as a study area, techniques are introduced, and tested, for the extraction of slope values from topographical maps, and for the classification and compilation of a "user" landform map.

Results show a high association between slope values calculated from the topographical maps and values determined in the field. The coefficients of correlation (r) between these variables are positive and significant, in many cases at 0.1% level. The study illustrates how these slope values can be employed successfully as the main land attribute to classify and compile a "user" landform map. "Land Categories" and "Land Units" (similar to "Land Systems" and "Land Units" of the C.S.I.R.O. Australia) are identified and mapped from the study area on the basis of the slope values (main attribute), and air photograph interpretation, soil, elevation, and drainage attributes. These landform types, which can be recognised in the field, are described and designated for various agricultural uses.

A morphometric analysis of some Land Categories reveals that the landform types are sufficiently different, one from the other, to be valid as separate types. In addition, the results of the analyses of some soil and land attributes in the Land Categories indicate that the top 45 cm of the soil profile in all the land types is highly erodible, and that soil erosion and mass movement are accelerated by poor land management in the study area.

It is suggested that the results of this study could be tested in other parts of West Malaysia, and other humid tropical areas.

Acknowledgements

Many people have helped me throughout the duration of this study, either in the personal, or in the official, capacity. I am very thankful to all, and in particular to : -

a) The Malaysian Federal Ministry of Education (Commonwealth Scholarships) for its financial assistance, without which the study could not have been undertaken;

b) Mr. R. P. C. Morgan and Dr. C. Leigh (my supervisors) for their assistance and constructive criticisms of field and laboratory techniques, and (especially Dr. C. Leigh) for the patience exercised in reading and criticising the various drafts of the manuscript;

c) The Malaysian Ministry of Agriculture for the landuse maps, The District Officer, Kajang, for the Drainage map of the Ulu Langat District and the permission to undertake the study in the District, The Geology Department, Universiti Malaya, for the use of the airphotographs of the District and the stereoscopes, and the Faculty of Engineering, Universiti Malaya, for the use of the shear vane;

d) Professor Ian Douglas for his valuable suggestion regarding a qualitative-quantitative appraisal of soil erosion;

e) Mr. W. L. Low (Assistant Research Officer, MARDI) for his technical advice and help concerning statistical analysis of the data on soil and land attributes, Mr. H.H. Soh (Laboratory Assistant, Jabatan Ilmu Alam, Universiti Malaya) for his advice and help with respect to laboratory procedures, Mr. K. B. Kit (Cartographer, Jabatan Ilmu Alam, Universiti Malaya) for his help in connection with the final drafts of the maps and diagrams, Mrs. Linda Tang (Jabatan Ilmu Alam, Universiti Malaya) for typing the final draft of the thesis, and Mr. D. Williams and Mrs. Adun Olofin for their practical assistance in the field and in reading the proofs of the thesis;

and f) the other members of the Jabatan Ilmu Alam (Geography Department), Universiti Malaya, for assistance rendered throughout the duration of the study.

I take full responsibility for any shortcomings in this work.

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GLOSSARY OF MALAY TERMS USED IN THE STUDY

batu	....	mile (also milestone)
belukar	....	thicket, bushes, underwood
bukit	....	hill
gunong	....	mountain (also Mount...)
kampong (kampung)	....	village
kuala	....	estuary, confluence
lalang (lallang)	....	grass (especially, tall grass)
lapanbelas	....	eighteen
padi	....	swamp rice and its field
nipah	....	marsh palm
sungei (sungai)	....	river, stream
ulu	....	upper course of a river

CHAPTER 1

INTRODUCTION

It would seem that 'a geography of any kind which becomes restricted to the consideration of featureless plains, or their equivalent, is taking a dangerously unrealistic line and one ... which is out of step with contemporary experience and need' (Chorley and Kennedy, 1971; pg. viii). The idea of "contemporary experience and need" is associated with activities which are designed to solve the fundamental problem that faces the world; namely: 'the rapidly increasing pressure of population on physical resources, particularly on the resources of land' (Stamp, 1960 pg. 13). Thus for geomorphology, or any discipline, to be realistic and functional it should be actively involved with the various plans designed to maximise the resources of the earth. One way in which geomorphology can be involved in such development plans might be the compilation of landform maps that are suitable for land planning purposes.

The problem of this study is to compile a land evaluation map of the type mentioned above, as a case study. The study is motivated by recent suggestions by geomorphologists to the effect that there should be a combination of 'work being achieved within the fields of theoretical geomorphology, morphometric analysis and the designation of land systems for development purposes' (Thomas, 1969; pg. 141).

Call for a geographer's geomorphology

The suggestions cited above are a follow-up to an earlier call for a geographer's geomorphology in the nineteen-forties and nineteen-fifties. Before then, it would seem that geomorphology was basically associated with geology.[1] This is especially true in North America (Thornbury, 1954). Since the middle of the nineteen-forties, however, Kesseli (1946, 1950, 1954) has stressed the importance of a geomorphology which recognises an extensive descriptive nomenclature of small and large forms, as well as of type areas. Russel (1949, pg. 4) has noted that a geographer 'wants specific information along the lines of what, where and how much', as against the geological geomorphologist's concern with the question of 'structure, process and time'. Lewis (1959) also suggests that geomorphology should be more geographic in its approach and content, while Hartshorne (1960, pg. 21) believes that geography 'is concerned to provide accurate, orderly and rational description and interpretation of the variable character of the earth"s surface'. It might be argued that geological geomorphology does concern itself with such description and interpretation, but it seems that it does this genetically. Hammond (1962) has suggested that genesis might not be the only device for determining the necessary organising principles in systematic studies; and that function would be equally suitable. Ottmann and Tricart (1964, pg. 2) have also rejected the old

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1. The history of the controversy between geology and geography and/or of the evolution of geomorphology as a discipline is given in Glock (1930), Bryan (1950), Strahler (1953), Baulig, et al. (1956), Ackerman (1958), Shchukin (1960), Mackay (1961), Dixey (1962), Chorley, et al. (1964), Zakrzewska (1967), and Dorall (1968).

methods of geomorphological studies, which are of Davisian origin, and have suggested a method that 'doit fournir une déscription raisonnée de tous les élèments du rélief de la région ...'. More recently, Zakrzewska (1967) has maintained that descriptive landform classification should be the first step in any landform study, and in geography, while Desai (1968, pg. 263) has contended that system terrain evaluation represents 'a major ... advance in the field of physiographical analysis'.

Geomorphological mapping techniques and problems

A period of geomorphological mapping studies followed this call for a functional geomorphology. The initial works were largely concerned with the techniques and problems of geomorphological mapping. Thus, Raisz (1951) illustrates how air photographs can be used in the compilation of a map of the surface configurations of large areas, while Hammon (1954) discusses the desirable points to highlight in the production of small-scale landform maps. Calef and Newcomb (1953) have developed a method for mapping the average slope of the land, and Robinson and Thrower (1957) have introduced the concept of inclined contours to map landsurface forms. Similarly, Miller and Summerson (1960) have developed a method for the compilation of slope-zone maps, while Klimazewski (1961, 1962, 1963) has examined the problems associated with geomorphological mapping techniques. More recent works on techniques have been concentrated on statistical and morphometric analysis of landforms and land-surface maps. (Burton, 1963; Gould, 1969). Such works of statistical and morphometric nature include those by Strahler (1956, 1958), Zvorykin (1963), Chisholm (1964), Chorley and Haggett(1965), Curtis, et al. (1965), Savigear (1965, 1967), Young (1964, 1969a, 1972), Anderson (1969), Eyles (1968a, 1969), Swan (1967, 1970b, 1970c, 1970d), Berlyant (1970), Faniran (1970), Doornkamp and King (1971), and Chorley and Kennedy (1971).

From these works it became apparent that some basic problems must be solved in the compilation of any geomorphological map. Writers, including Mabbutt and Stewart, (1963), Mabbutt (1968), Stewart (1968a), Young (1969b), and Thomas (1969), have assessed these problems. Three main problems have been recognised. They are problems associated with:-

1) the scale of mapping,
2) the basis of land classification, and
3) the method of map compilation.

The scale of a mapping exercise will be determined by the type of the mapping exercise, which, in itself, will depend on the purpose of the exercise. Both the scale and the purpose will combine to determine the basis of land classification and the method of map compilation (Niesława, 1964; Thomas, 1969). These problems are discussed further in Chapter 3.

Other land maps

Independently from the development of geomorphological mapping techniques, there have evolved other land mapping techniques. These include land evaluation maps and reconnaisance resource-survey maps.

Land evaluation maps such as the "Land Systems" series of the Australian Commonwealth Scientific and Industrial Research Organization (C.S.I.R.O.) and the "Land Patterns" maps of the British Military Engineering Experimental Establishment (M.E.X.E.) usually include contributions from geomorphologists (see Christian, 1958; Mabbutt and Stewart, 1963 - C.S.I.R.O.; Beckett and Webster, 1965; Brink, et al., 1966 - M.E.X.E.). More recent maps in these series are based on statistical and morphometric analyses of the land (see Stewart, ed. 1968a; Aitchison and Grant, 1968; Beckett and Webster, 1969; Scott and Austin, 1970). Reconnaissance resource-survey maps based on soil, soil capability, vegetation, and landuse assessments often do not include contributions from geomorphologists. Both the land evaluation and the resource-survey maps are pertinent to "functional", or "user", landform mapping techniques, and are discussed further in Chapter 5.

Present position of geomorphological studies

From the discussion above, it would seem that there exists, in geomorphological studies, a separation of techniques and results, on the one hand, from the utility of the results, on the other. This situation might have resulted from the apparent concentration on establishing procedures for better land classification and land map-compilation, as explained earlier. The concentration on perfecting the methods of making inventories is essential (Ruxton, 1968), since it provides the geomorphologists with a quantitative technique which is 'a most appropriate method of developing theory in geography' (Burton, 1963; pg. 158). There is no doubt that perfected methods, theories and accurate inventories are essential in geomorphological researches. However, if geomorphology must recognise man 'not as an afterthought, but as essential to the unity of nature' (Hartshorne, 1960; pg. 67), there must be a unification of techniques, results, and the utility of results. The planner, or user, should be remembered in geomorphological map-compilation. As it seems, he is more frequently forgotten when writers fail to mention the utility of their maps, or when the explanation of such maps is lost in methematical equations and formulae (Thomas, 1969). Calef and Newcomb (1953), and Thomas (1969) maintain that this separation of results from the utilisation of the results should be discouraged. The efforts of the International Geographical Union (I.G.U.) to co-ordinate its works with those of other bodies, including the United Nations' Food and Agricultural Organization (F.A.O.), the C.S.I.R.O., and the M.E.X.E., are encouraging.

Work done in West Malaysia

Geomorphological studies. The history of geomorphology in West Malaysia has some similarities with the world history of the discipline. Initial works in the geomorphology of West Malaysia were by-products of geological researches and were, consequently, highly genetic in nature. Landform description formed introductory chapters and footnotes to the works of geologists including Scrivenor (1931), Richardson (1947), Roe (1953), and Fitch (1951). Geologists still consider landform description as an introduction to the geological explanation of West Malaysia (Gobbett and Hutchison, ed., in press), although more attention has been paid to landform analysis in the last ten years.

There have been descriptive and analytical works on particular land attributes, which include the morphology of beach ridges and other coastal forms (Nossin, 1961, 1962, 1964; Swan, 1968; Ayob, 1970), mass movement (Eyles and Ho, 1970; Olofin and Morgan, 1971), and lineage and drainage patterns (Tjia, 1971; Barton, 1972). Works on morphometric analysis and landform classification and/or map-compilation include those of Swan (1967, 1970a, 1970b, 1970c, 1970d), Eyles (1968a, 1968b, 1969), and Morgan (1969, 1970, 1971a, 1971b). P. Wong (1968, 1969) has introduced morphometric analysis to landform studies in Singapore, which can be regarded as a geographical extension of West Malaysia. These works are concerned, to a large extent, with the development of basic techniques for landform classification and the establishment of useful procedures for the compilation of land-surface maps. They provide useful background for further landform researches in West Malaysia, although, except for the work of Swan (1970b), they have basically separated techniques and the results, which are obtained, from the utility of such results.

Studies in hydrological and other resource surveys. Other studies, relevant to functional landform classification, which have been undertaken in West Malaysia include studies in hydrological and resource evaluation surveys. Shallow (1956), Renwick (1963), and Tan (1966) have estimated potential water yields, while Charlton (1964), Oh (1965), and Douglas (1969b) have studied floodflows. Studies of rainfall run-off relationships and water-balance in catchment areas have been undertaken (Douglas, 1970; Low, 1971; Low and Goh, 1971; Goh, 1972), and similar water-resource surveys have been executed by the Drainage and Irrigation Department of Malaysia (see Low, 1968). In addition, Dale (1959, 1960), Chia (1968), and Morgan (1971b) have recognised rainfall regions for parts, or the whole, of West Malaysia. Reports of various reconnaissance resource surveys and maps, as well as articles on the evaluation of particular land resources, are available for the country. Wyatt-Smith (1964), and Cheah (1968) have surveyed the vegetation potentialities, while Parbery and Venkatachalam (1964), Panton (1964), Leamy and Panton (1966), I. Wong (1966), Ives (1967), Burnham (1967), Joseph (1964, 1968), Ng (1969), and Joseph and Weaver (1970) have studied and/or mapped the characteristics and capabilities of Malaysian soils. Land capability studies and maps have been undertaken by Alexander (1964), Panton (1969), and the Malaysian Economic Planning Unit (for example, Report for Selangor, 1970), while the Malaysian Landuse Survey Staff (for example, I.Wong, 1969) have surveyed and mapped the contemporary landuse patterns in several States of West Malaysia. "Land Systems" classifications, such as the classifications by the C.S.I.R.O., have not been undertaken for the whole of West Malaysia. Admittedly, the M.E.X.E. (1964) has used West Malaysia as a case study to test a technique of landform classification (see Beckett and Webster, 1969), but the M.E.X.E. study is mainly experimental. Swan (1970b) has observed that the study might not be very suitable for land development in the Malaysian context. More recently, Beaven, et al. (1971)[1] have undertaken a case study of terrain

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1. This thesis had been completed before the investigator became aware of the work; no further reference is made to it in this thesis.

evaluation for an area of 15,500 sq. Kilometres in West Malaysia. The study is concerned with land evaluation for road engineering purposes (see Clayton, ed. 1972).

It can be seen that geomorphological studies undertaken in West Malaysia, like those undertaken in other parts of the world, show a separation of techniques and results from the utility of the results. Recurring suggestions towards a combination of these complementary aspects of geomorphological studies seem to indicate that the call for a "user's" geomorphology might, perhaps, be considered as a major challenge in the discipline today, and that this challenge is still largely neglected. Therefore, geomorphological works of such an applied nature would seem not only to be desirable, but also to be necessary, especially in developing areas which include Malaysia. One of the first, if it is not the very first, geomorphological works of the "user" type in West Malaysia is that of Swan (1970b). Works of this type are needed in this country 'in the face of the F.L.D.A. (Felda) programmes' (Swan, 1970b; pg. 91), and in the face of other land development plans, both on the State and the District levels. It is certain that future land development plans on the scale of, for example, the current Jengka Triangle and the Pahang Tenggara schemes (see Second Malaysia Plan 1971 - 1975, Chapter IX) will benefit from such integrated studies in geomorphology.

Aims of the Thesis

The central aim of this thesis is to illustrate how a geomorphologist can involve himself in the present "experience and need" of man by compiling a land evaluation map that will be suitable for land planning purposes. Such a landform map will need to show the functional significance of landforms, and land elements, to economic utilisation of the land.

To achieve this central aim, it is found necessary to select a suitable land attribute as a dominant element in the compilation of the landform map. In addition, it is considered that some assessment of soil erodibility in classified landform types should be included in the study.

For reasons which will be discussed in Chapter 3, the slope of the land will be employed as the dominant land attribute in the compilation of the "user" landform map, and one of the aims of this thesis, therefore, is to justify the choice of this attribute. Furthermore, the absence of any published slope map for the study area will necessitate the introduction of techniques for obtaining reliable slope values from topographical maps, and for grouping these values into classes suitable for land planning purposes. It is necessary, therefore, to check the reliability of the techniques designed and the validity of the landforms which are mapped.

The check on landform types will include an estimation of soil erodibility in particular landform types. It is believed that an estimation of soil erodibility will indicate the extent to which the soils of the study area can support man and his machines. Such an indication will ensure a reliable designation of the landform types for utilisation.

Attempts will be made to achieve these aims by a combination of morphometric and landform mapping techniques with suggested utility of results to be obtained. The designation of landform types for utilisation will, in part, be based on the results contained in published soil, drainage, and landuse maps. The study will concentrate on the Ulu Langat District for the reasons which will be discussed in Chapter 2.

CHAPTER 2

THE STUDY AREA - THE ULU LANGAT DISTRICT, SELANGOR

A "user" landform map such as the one designed for this study should be based on a study area which will be convenient for planners to manage. Since planners, especially government planners, are familiar with, and frequently plan on the basis of administrative units, the choice of an administrative unit, as a study area, seems to be appropriate and desirable. In a case study such as the present work, it is essential that the administrative unit is selected such that it extends over areas of contrasting land properties. These contrasts are considered necessary to compile a composite and functional landform map, and to facilitate adequate evaluation of the techniques which will be employed.

For these reasons an administrative unit was selected as a study area for the present work. A District was selected because the size of West Malaysian Districts, usually not exceeding 2,000 sq. kilometres, was considered suitable for a single investigator to work. The Ulu Langat District was selected, in particular, because the outline geography, which will be discussed below, was observed to highlight diverse land and soil attributes to a satisfactory degree. The outline geography of other Districts, including the Kuala Selangor, the Seremban, the Ulu Selangor, and the Tampin Districts, was observed to show contrasts in land and soil attributes not to a satisfactory degree.

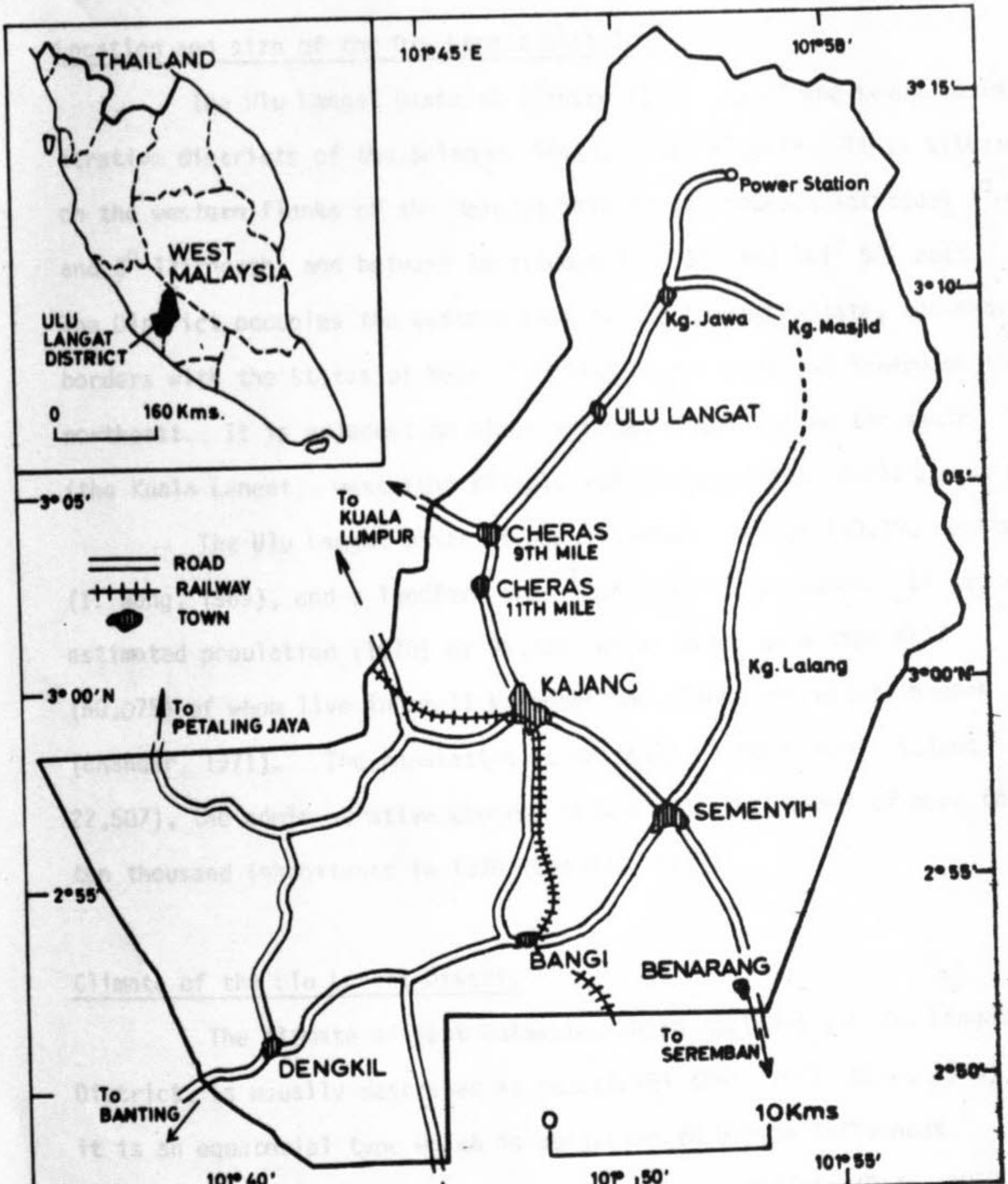

FIGURE 1: Locational map of the Ulu Langat District, Selangor

Location and size of the Ulu Langat District

The Ulu Langat District (Figure 1) is one of the seven administrative districts of the Selangor State, West Malaysia. It is situated on the western flanks of the Malayan Main Range, between latitudes 2^{o} 48' and 3^{o} 17' north, and between longitudes 101^{o} 34' and 101^{o} 58' east. The District occupies the eastern part of the Selangor State, and shares borders with the States of Negri Sembilan on the east and Pahang on the northeast. It is adjacent to other Selangor Districts on the south (the Kuala Langat), west (the Klang), and northwest (the Kuala Lumpur).

The Ulu Langat District has a landuse area of 110,100 hectares (I. Wong, 1969), and a landform area [1] of 110,020 hectares. It has an estimated population (1970) of 96,338 inhabitants, more than half (50,075) of whom live in small kampongs and plantation estate houses (Chander, 1971). The population is basically a rural one. Kajang 22,507), the administrative centre, is the only settlement of more than ten thousand inhabitants in 1970 (Chander, 1971).

Climate of the Ulu Langat District

The climate of West Malaysia, which includes the Ulu Langat District, is usually described as equatorial (Ooi, 1963; Dale, 1963), but it is an equatorial type which is subjected to marine influences, interplay of monsoon winds, and physiographic conditions (Dale, 1959, 1960; Federal Department of Information, 1969; Lockwood, 1970; Morgan, 1971b). These controlling factors affect the climate of the whole of the Selangor State (I.Wong, 1966, 1969; Chia, 1968), including the Ulu Langat District.

1. Landform area is calculated from the Landform map which will be discussed in Chapter 5.

Rainfall. Although there is no dry season, there are two "wet" seasons separated by two "less wet" ones (Dale, 1959, 1960; Chia, 1968; Douglas, 1968, 1969b, 1970; Morgan, 1970, 1971b). The two wet periods are believed to coincide with the two monsoon seasons (North-east Monsoon, and South-west Monsoon) which are caused by the movement of marine air masses over the District, while the less wet periods are believed to coincide with the inter-monsoon seasons (Ooi, 1963). It has been suggested that the inter-monsoon seasons might be the wetter periods, especially in the West Coast of the Malay Peninsula (Dale, 1959; Morgan, 1971b), and that the floods which occur during the monsoon seasons might be due to the higher rainfall intensity during the seasons.

Essentially, the north-east air stream develops over the South China Sea and moves south-westwards over the Main Range where most of its moisture is released. This air mass prevails over the Ulu Langat District from Mid-October to March, and is a considerable source of rainfall in the Ulu Langat, despite the release of moisture over the Main Range (see Table 1). This heavy amount of rainfall is due to the interplay of convectional disturbances, high humidity (80% to 85%, according to Ooi, 1963), and the north-east air stream. Conversely, the south-west air stream develops over the Indian Ocean and moves north-eastwards across the Malay Peninsula from May to August (Wycherley, 1969). Table 1 shows that the period associated with this air stream is the less wet period in the Ulu Langat District.

The interplay of these air streams, the mountain ranges, and tropical temperatures has resulted in three types of rainfall, identified

TABLE 1 : Mean monthly rainfall for selected stations, the Ulu Langat District

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Ulu Langat	3.37	3.88	7.21	9.66	11.72	6.14	5.63	7.25	6.68	16.29	16.75	9.17	97.75
Power Station	93.5	98.5	183.1	245.4	297.7	156.0	146.3	184.1	169.4	413.6	273.6	232.9	2482
Kajang	6.10	6.75	9.97	10.88	8.44	5.34	4.03	5.94	7.01	10.46	10.29	9.02	94.26
District Hospital	154.9	171.0	253.2	276.3	214.4	135.6	103.5	150.9	178.0	265.7	261.4	229.1	2395
Dominion	5.84	5.61	10.58	10.57	8.71	5.51	5.08	6.89	8.01	10.52	10.96	8.26	96.54
Estate	148.4	142.4	268.6	268.4	221.2	140.0	129.0	175.0	203.4	267.2	273.4	200.8	2452
Glengowrie	4.78	4.21	8.25	9.82	10.42	6.81	4.88	7.79	8.24	12.32	10.91	7.27	95.70
Estate	121.4	106.7	209.5	249.4	264.6	173.0	124.0	197.8	209.2	312.9	277.1	184.6	2431
Galloway	7.71	7.19	11.30	12.07	7.52	4.29	4.09	5.25	6.31	10.95	10.99	10.01	96.61
Estate Bangi	195.8	182.6	287.0	309.1	191.0	109.0	101.5	133.4	160.3	255.2	279.1	254.2	2454

Source : Hydrological Data - Rainfall Records 1879 - 1958.
Federal Malayan Drainage and Irrigation Department, 1961.

Note : Values for each station are in inches in the first row, and in millimetres in the second row.

by Dale (1959) as air stream boundary, topographic and convectional rainfall types. All the three types act together over the Ulu Langat District to explain the high rainfall figures in Table 1. The District can be divided into three rainfall belts (Chia, 1968; Wycherley, 1969). The lowland belt, which includes all areas below 150m (500 ft.) above mean sea level (see Dale, 1963), is characterised by an annual mean rainfall of 2286 mm. Kajang (2395 mm) and Glengowrie (2431 mm) are examples from this belt. The foothill belt is characterised by larger rainfall amounts than the lowland belt. The mean annual rainfall in the foothill belt is about 2540 mm (Chia, 1968; I. Wong, 1969; Morgan, 1971b). Ulu Langat Power Station (2483) is an example from the foothill belt. The Main Range belt is usually claimed to be the least wet belt (Dale, 1959, 1960; Chia, 1968), but this contention is open to argument because measuring stations are very few and far in between in this belt. The average rainfall received annually in this belt is estimated at 2034 mm (Chia, 1968). Low (1971) has obtained total areal rainfall of 2109 mm, 2133 mm, and 2163 mm for three sections of the Sungei Lui catchment during the period September 1968/August 1969. This catchment consists of parts of the Main Range and foothill belts in the Ulu Langat District.

As mentioned earlier, there are variations in the amount and in the intensity of the rainfall received in the District. Dale (1959, 1960), and Wycherley (1969) have suggested that the period June/July shows the highest variation in the amount, and that the intensity is highest in the period March/April. It seems, however, that the short-term (daily) variation is more effective as a regulator of surface run-off and water storage than the long-term (seasonal) variation (Douglas, 1970). A great part of the rainfall over the Ulu Langat District is lost to run-off and evapotranspiration. The loss is high in mountain and foothill areas where negative storage changes, which range from -1.52 mm to -35.81 mm, have been obtained from the Sungei Lui catchment area during a one-year period. Low and Goh (1971) have obtained a negative storage change of -4.00 mm for the Sungei Langat catchment area during another one-year period.

Temperature. Topographical conditions and marine influences also affect the temperature characteristics of the District. The tropical marine air streams bring relatively constant warm to hot conditions to the lowland areas of the District. The average air temperature is affected by the elevation of any selected part of the District. Consequently, both the average annual temperature, and the daily and seasonal ranges differ between the lowland and the highland areas.

Two broad temperature regions can be identified (Dale, 1963; Ooi, 1963; Chia, 1968; Wycherley, 1969). 1) The first is a lowland region which has an estimated mean annual temperature of 26.7°C (Dale, 1963; Chia, 1968; Wycherley, 1969). The mean deviation is ± 1.7°C, and the average annual range of temperature is 2.8°C, increasing to 5.5°C, or more, near the foothills. 2) The second is a highland region which is not as hot as the lowland region. This region has a mean annual temperature of about 22°C, but average minima values are generally below 18.3°C (I. Wong, 1969). The annual range of temperature in this highland region is usually over 7.3°C. All over the District, diurnal range of temperature is more than 5.5°C, and it is highest in February when it can be as high as 11.2°C (Dale, 1963; Wycherley, 1969).

It can be inferred, therefore, that the climate of the Ulu Langat District is characterised by high humidity, heavy rainfall, and high temperature. The differences in the climatic conditions from place to place over the District are not very large. Similarly, the daily weather conditions do not vary too markedly in the study area, from one place to the other. For the purposes of classifying "user" landform maps, therefore, the climate and weather of the Ulu Langat District can be considered to be homogeneous.

Geology of the Ulu Langat District[1]

The solid geology of the District consists of sedimentary formations in the lowlying areas, and of intrusive granites in the foothills and mountains (see Figure 2). Both the sedimentary formations and the intrusive granites are believed to have been altered over large areas.

The sedimentary rocks, except for the Quaternary Formations which occupy the coastal plains, are generally considered to be the oldest rocks in the Ulu Langat District. These rocks include 1) the argillaceous-calcareous formations of Ordovician/mid-Silurian age, 2) the argillaceous formations of Early Carboniferous age, 3) the arenaceous-argillaceous formations of Late Carboniferous age, and 4) the argillaceous-arenaceous formations of the Quaternary age. The shales, clays, and sandstones that constitute the original formations have been metamorphosed into indurated shales, phillites, quartz schists,

1. The section on geology is a summary of relevant parts of the following works: Scrivenor (1931), Burton (1964), Paton (1964), Alexander (1965), I.Wong (1966, 1969), Newsletters of Geological Society of Malaysia (1970-1972), and Gobbert and Hutchison (in press). Further reference is not made to these works in this section.

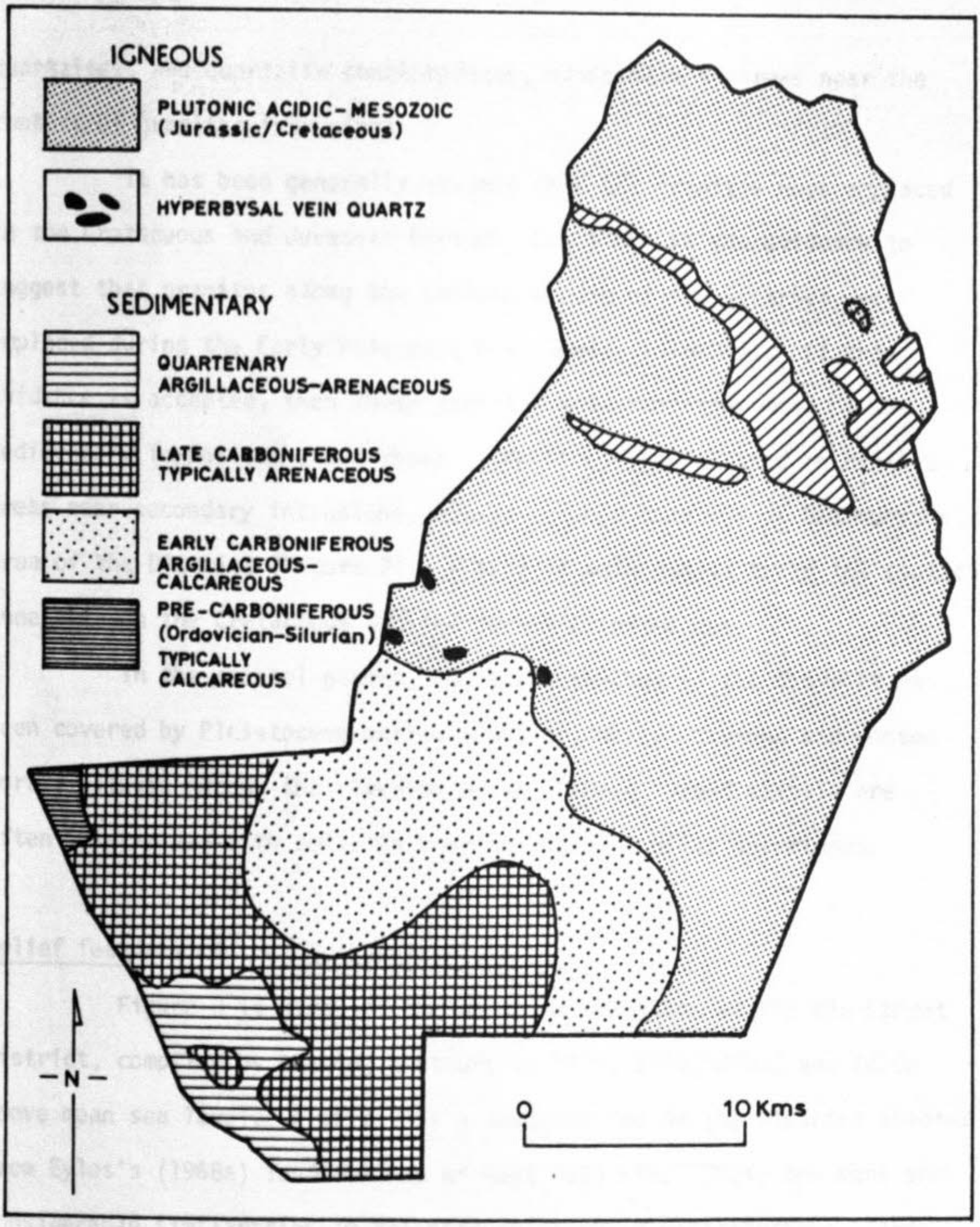

FIGURE 2: Bed-rock geology of the Ulu Langat District
(After Alexander, 1965)

quartzites, and quartzite conglomerates, especially in areas near the contact of granitic intrusions.

It has been generally assumed that the granites were emplaced in the Cretaceous and Jurassic Periods, but there is new evidence to suggest that granites along the eastern border of the District were emplaced during the Early Paleozoic Era (Jones, in press). If this evidence is accepted, then these granites are older than most of the sedimentary formations cited above. Granites, also altered in contact areas near secondary intrusions, occupy more than 50% of the surface area of the District (Figure 2). A band of vein quartz marks the contact zone between the Cretaceous and the Jurassic intrusions.

In the coastal plains, the solid geology of the District has been covered by Pleistocene marine deposits, while Holocene and contemporary alluvia occupy the riverine areas. These inland alluvia are often inter-mixed with colluvia near the base of hills and ridges.

Relief features of the Ulu Langat District[1]

Figure 3 is a map of the absolute elevation of the Ulu Langat District, compiled by tracing contours at 152m, 305m, 610m, and 1220m above mean sea level. Figure 4 is a landform map of the District adapted from Eyles's (1968a) landform map of West Malaysia. These two maps show considerable similarities in the pattern of their distributions. The pattern is also similar to the distribution of the geology map (Figure 2). It would seem, therefore, that the morphology of the land-surface

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1. This is an "on-the-average" type of description of the landforms based largely on the relief maps, and on landform maps of West Malaysia, or the Selangor State, which include the study area. A more detailed description of the landforms is given in Chapter 5 of this thesis.

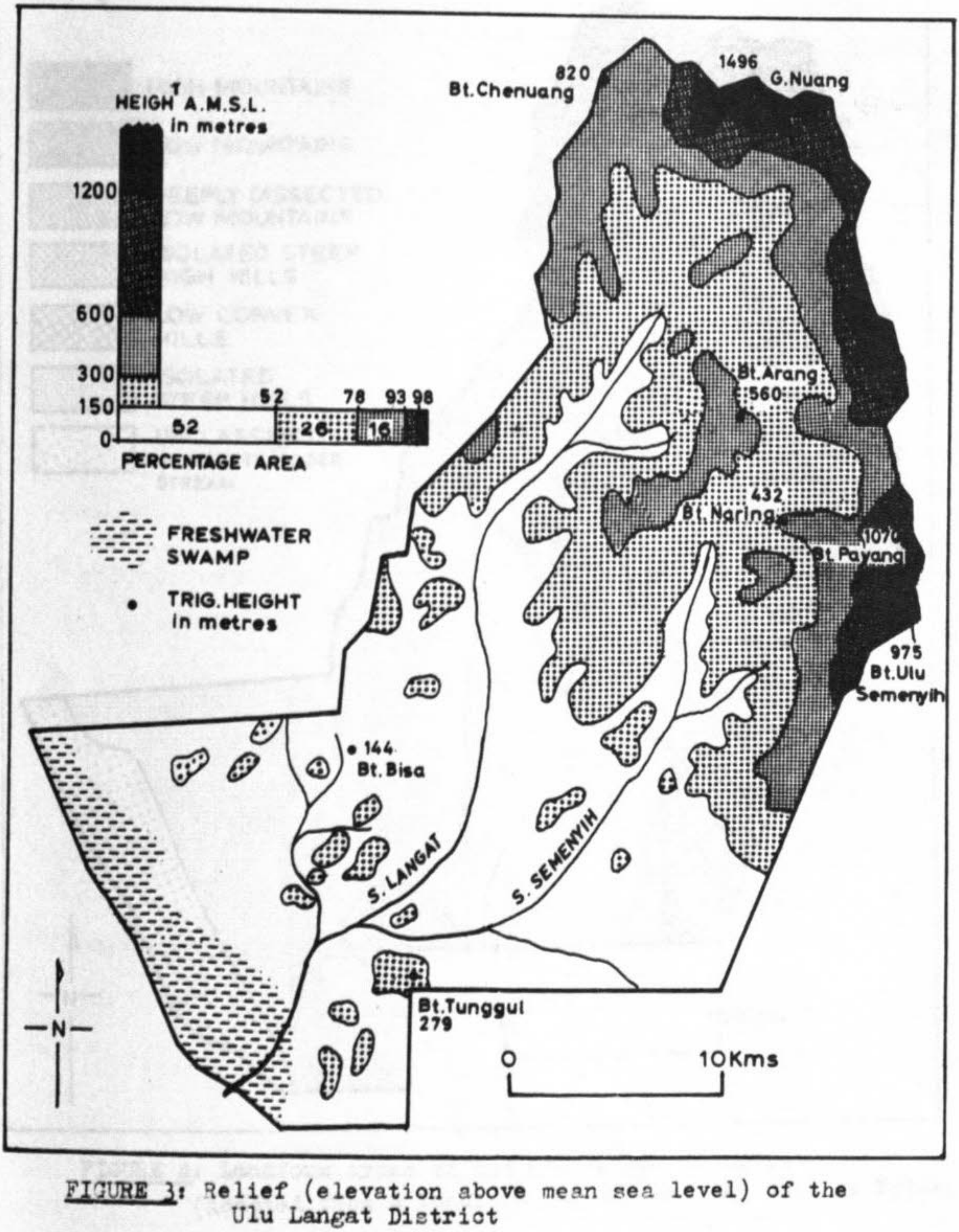


FIGURE 3: Relief (elevation above mean sea level) of the Ulu Langat District

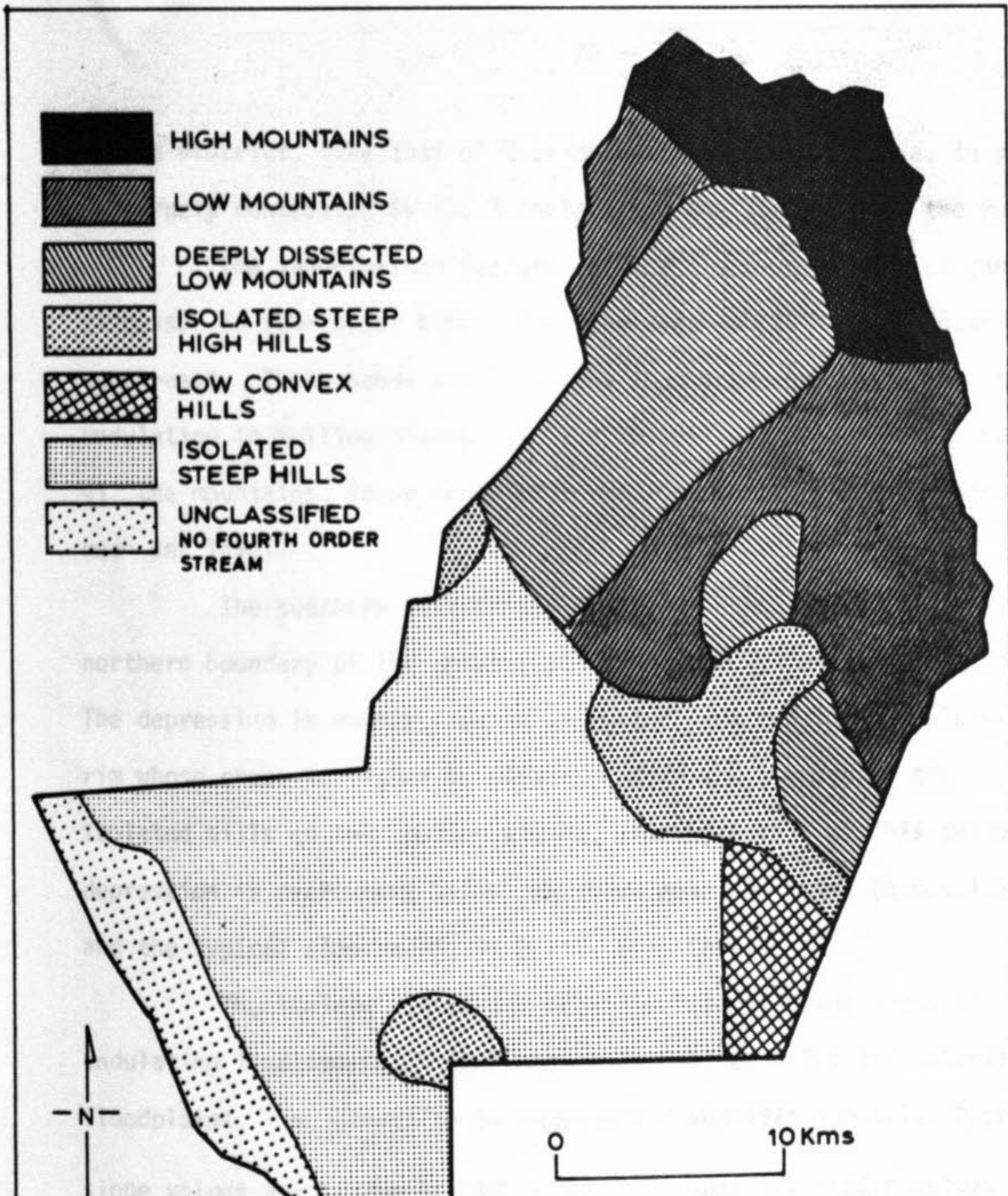


FIGURE 4: Landform types of the Ulu Langat District
(Adapted from a landform map of West Malaysia by Eyles, 1968a)

of the District, like that of West Malaysia as a whole (Tjia, in press), is largely controlled by the lithology and the structure of the rocks.

The land-surface features of the Ulu Langat District can be discussed in four major bands, trending North-north-west to South-south-east. These bands are : 1) the southern depression, 2) the undulating to rolling plains, 3) the foothills and highlands, and 4) the mountains, in an order of increasing total elevation above mean sea level.

The southern depression in the Ulu Langat District forms the northern boundary of the coastal plains of the Kuala Langat District. The depression is swampy, and is separated from the lowland plains by a rim whose crest is higher is elevation than the summits of the isolated hills on the lowland plains. The elevation of this swampy depression is everywhere below 15m above mean sea level (a.m.s.l.), and the typical slope angle is $0 - 1^{0}$ (see Chapter 3).

The lowland plains are characterised by large areas of undulating land separated by "beads" of isolated hills and extensive floodplains. The elevation is between 15m and 152m a.m.s.l. Typical slope values are in the $5 - 10^{0}$ class, although the middle values are the most frequently recurring ones.

The elevation of the foothills and highlands ranges from 152m to 610m a.m.s.l. The areas between 152m and 305m a.m.s.l. are characterised by rolling plains, isolated hills and "amphitheatre-like" incursions of headvalleys into the mountain side. The incursions are characterised by ridge-spurs. The areas between 305m and 610m a.m.s.l. consist of deeply dissected foothills which rise in several places to low mountain peaks. Bukit Ulu Beranang (811m) and bukit Ulu Semenyih (975m) are examples of such low mountain peaks. Typical slope values in the foothills and highlands range from 11^{0} to 19^{0}.

The mountains constitute part of the Malayan Main Range which extends into Pahang and north-western Negri Sembilan. The mountains rise higher than 1220 m a.m.s.l. in the more prominent peaks. Gunong Nuang (1,497m), on the Pahang border, is the highest peak in the Ulu Langat District. The typical slope values in the mountain areas are above 29^{0}.

It can be seen that the relief features of the Ulu Langat District exhibit contrasts in elevation, ruggedness, and form. These contrasting features influence the soil, and the natural surface drainage, of the District.

Soils of the Ulu Langat District

The soils of the Ulu Langat District are influenced by the lithology of the parent materials, the topography, the climate and time (I.Wong, 1966, 1969). Climate has been shown to be relatively uniform over the District. The influence of climate on the soils of the District can be considered to be relatively uniform. Time implies age which has been noted to be of limited importance to the agricultural utilisation of the soils in the District (I. Wong, 1966). The lithology of the parent materials, and the topographical conditions seem to be the two main determinants of soil value in the study area. These have been used in West Malaysia as the bases for soil classification (Joseph, 1964, 1964; Panton, 1964, 1969; Leamy and Panton, 1966; Ng, 1969; Malaysian

Soil Survey Staff, for example, I. Wong, 1966), and for soil capability classification (Malaysian Soil Survey Staff, for example, I. Wong 1966; Panton, 1969).

In general, granites weather, depending on their lithology, into various types of sandy soil with, or without, laterite formation (I.Wong, 1966; Joseph, 1968; Ng, 1969). Arenaceous rocks weather into sandy, or silty, soils, while argillaceous rocks weather into loam, clayey, or silty soils with, or without, laterite. Peat and alluvia are characteristically immature in profile. Peat is basically organic in composition, whereas alluvial soils can either be silty or sandy.

The position of the soils with respect to topography largely determines their thickness, profile structure, and drainage conditions. Soil profiles are thick in summit areas, on valley bottoms, and over areas of gentle slopes. Areas on steep slopes are associated with thin, and disturbed, soil profiles. Flat areas are usually characterised by poor drainage conditions, and by swampy soils in the lowlying parts. Other soil attributes of the District are analysed and discussed in Chapter 6.

Surface drainage of the Ulu Langat District

The natural surface drainage in the Ulu Langat District can be discussed in terms of three morphological units: the highland and mountain areas, the lowland plains, and the southern depression. The present direction of the surface flow is southwards in the highland and mountain areas. These areas are characterised by short, swift headstreams which are mainly rectangular in pattern probably because of the granitic control in the highlands and mountains (see Tjia, in press). Partial trellis patterns are evident in ridge-and-valley areas, while hilly watersheds are characterised by radial drainage patterns. The direction of the surface flow in the lowland plains is principally southwestwards, changing to a westward flow as the streams approach the southern depression. The lowland plains are characterised by meandering streams with extensive floodplains, and by swift headstreams in the isolated hills. The pattern is essentially dendritic, although trellis drainage pattern is associated with ridge-and-valley areas at the edge of the southern depression. The surface drainage becomes diffused as the streams enter the southern depression where their channels are lost in the swampy basins, and where man's drainage activities are evident.

The dominant river in the District is the Sungei Langat which receives about 90% of the surface flow of the District as its tributaries. A small section in the central-western area drains to the Sungei Klang, and another small section in the south-eastern area drains to the Sungei Sepang. It has been postulated that the Sungei Langat could have, at one time, formed part of the Sungei Klang Drainage System, and that the present broad, meandering outlet of the Langat (an apparent misfit) could, in actual fact, have been a former outlet of the Sungei Klang (Barton, 1972). It would seem, therefore, that the present drainage pattern has been evolved largely as a result of a northern migration of the Sungei Klang. As of the present, however, the surface area of the Ulu Langat District belongs approximately to one of Eyles's (1968a) Fourth-Order basins.

The natural surface drainage has been disrupted in certain areas by man's drainage activities. These artificial drainage efforts are most evident on the floodplains. In the southern floodplains, existing river channels have been canalised, and irrigation canals have been constructed. In other areas of the floodplains, mining activities have modified the natural surface flow to a considerable extent. These human activities have far-reaching effects on the processes of soil erosion, debris transportation and sedimentation in the valley areas, as will be illustrated in Chapter 6.

The contrasts in lithology, topography and soils as illustrated above constitute the main reason why the Ulu Langat District has been selected as the study area. It was stated earlier that contrasts in these land and soil attributes are essential to the compilation of the "user" landform map designed for this study, because in a work of this type it is desirable to classify many types of land-surface forms.

Additional reasons why the Ulu Langat District has been selected include: a) the fact that many published maps and articles are available on the Selangor State, which includes the District; b) the fact that approximately 50% of the surface area of the District is classified as undeveloped (I. Wong, 1969; Lee, 1969); and c) the fact that up to 70% of the area is accessible.

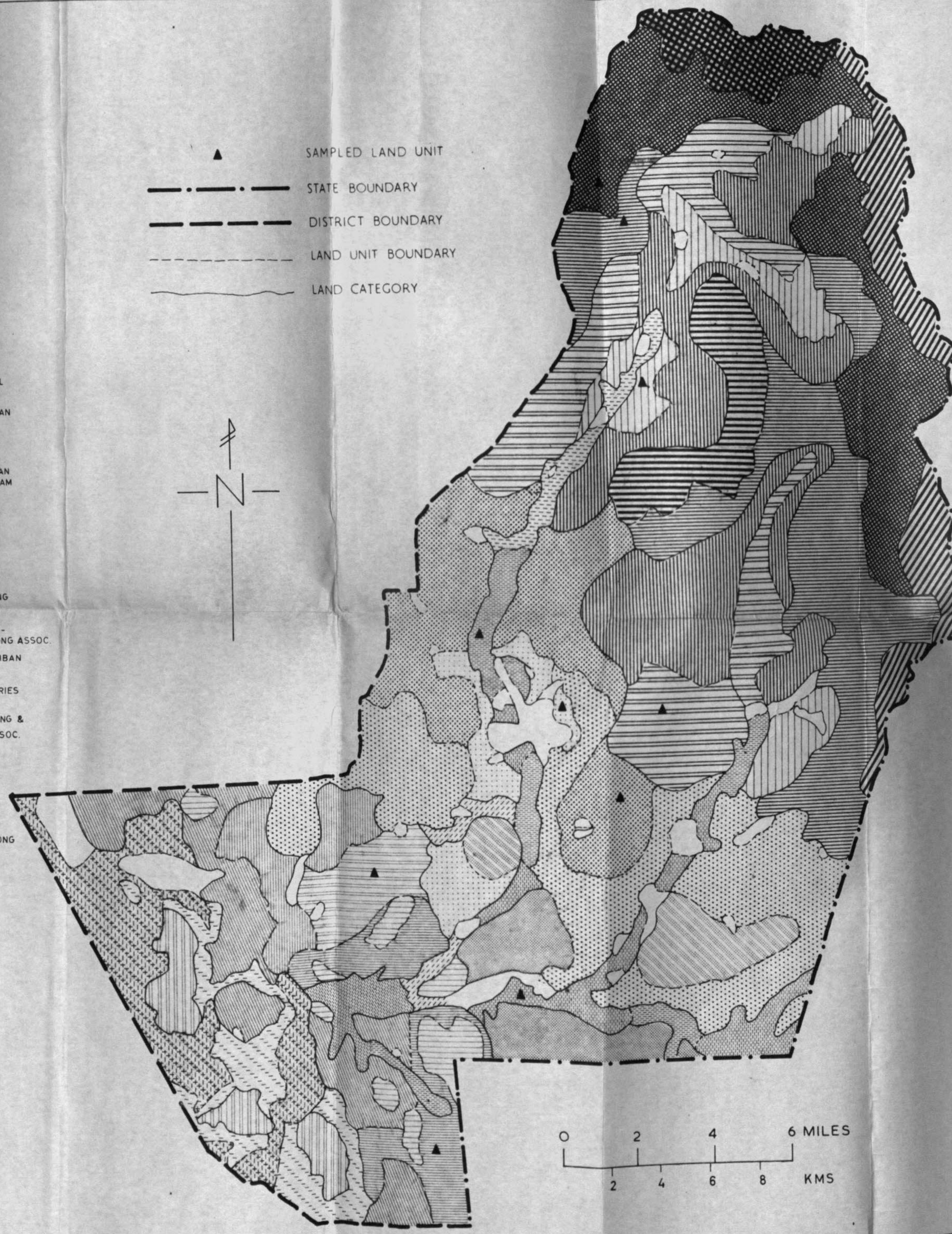
Landuse, soil, drainage, and topographical maps, as well as air photographs, are available for the entire area of the District. Some of these maps are accompanied by discussion-articles (for example, I. Wong, 1966, 1969; Lee, 1969). These published maps and articles contain results that are pertinent to this study.

It is also believed that the evaluation of land attributes, especially in the areas presently classified as undeveloped, will aid effective utilisation of such areas. Timely assessment of the land attributes in these areas will help to eliminate the incidence of inadequate utilisation which characterises certain areas presently classified as developed (see Chapter 5). The inadequate utilisation of these developed areas suggests that a study involved with a functional landform map is relevant in such areas, especially because it is believed that 'as conditions change, objectives also change' (Butler, 1955; pg. 55). Land evaluation would need to be repeated any time there seems to be a significant change in the conditions and objectives.

Accessibility is an important factor to be considered by a single operator with limited time. A high level of accessibility will ensure a better, and speedier coverage of a study area than a low level of accessibility.

The combination of the above factors to a satisfactory extent in the Ulu Langat District, in contrast to conditions in the other Districts examined, makes the Ulu Langat District a suitable area for the investigations designed for this study. The techniques utilised for, and the results obtained from, these investigations are discussed in the remaining Chapters of the thesis.

LAND CATEGORY	LAND UNIT	HECTARE	% AREA	TYPICAL SLOPE CLASS	SOIL (WONG I 1966)
ACTIVE FLOOD PLAINS (0m-90m)	a. LEVEL PLAINS PERMANENTLY WATERLOGGED	1330	1.21	A (0)	INLAND SWAMP ASSOCIATIONS
	b. LEVEL PLAINS SEASONALLY WATERLOGGED	2000	1.81	A(0-1)	LOCAL ALLUVIUM AND COLLUVIUM ASSOC.
	c. LEVEL PLAINS OCCASIONALLY WATERLOGGED	1888	1.71	A(0-1)	INLAND SWAMP ASSOCIATIONS
	d. INCLINED LOWER FLOOD PLAINS	700	0.63	B(2-4)	INLAND SWAMP ASSOCIATIONS
	e. INCLINED HIGHLAND FLOOD PLAINS	900	0.82	B(2-6) C	LOCAL COLLUVIUM ALLUVIUM
	D. DISTURBED LAND	730	0.67	—	DISTURBED LAND
		7540	6.9	A	
SOUTHERN DEPRESSION (0m-10m)	a. PERMANENTLY WATERLOGGED BASINS	5170	4.70	A(0)	INLAND SWAMP ASSOCIATIONS
	b. RAISED LEVEL LAND	3090	2.81	A 0-1	SERDANG MUNCHONG ASSOCIATIONS
	D. DISTURBED LAND	900	0.82	—	DISTURBED LAND
		9160	8.3	A	
LOWLAND PLAINS (0m-150m)	a. LEVEL TO GENTLY INCLINED PLAINS	1820	1.66	B(2-4)	DISTURBED AND LOCAL COLLUVIUM ASSOC.
	b. UNDULATING PLAINS	10530	9.57	C(5-10)	MUNCHONG-SEREMBAN ASSOCIATION
	c. ROLLING TO HILLY PLAINS	2960	2.69	C & D	SERDANG MUNCHONG KEDAH ASSOC.
	d. MAJOR LOWLAND WATERSHEDS	2420	2.20	D (11-19)	MUNCHONG-SEREMBAN ASSOCIATIONS RENGAM SERIES
	e. FOOTHILL PLAINS	7630	6.94	D (11-19)	LOCAL COLLUVIUM & RENGAM SERIES
	D. DISTURBED LAND	920	0.84	—	DISTURBED LAND
		26280	23.9	C & D	
DISSECTED DEPRESSION RIM (30m-200m)	a. UNDULATING WEST-SLOPING LAND	4350	3.96	C(5-10)	SERDANG MUNCHONG ASSOCIATION
	b. RIDGE AND VALLEY SOUTHERN CREST	2690	2.45	D(11-19)	STEEPLAND, KEDAH-SEREMBAN MUNCHONG ASSOC.
	c. NORTHERN DISSECTED LAND	2310	2.10	D(11-19)	MUNCHONG-SEREMBAN ASSOCIATION
	d. ROLLING CENTRAL LAND	1800	1.64	D(11-19)	PRANG BESAR SERIES
	e. WESTERN OUTLIER PLAINS	2020	1.84	B & C	SERDANG-MUNCHONG & INLAND SWAMP ASSOC.
	f. DEEPLY DISSECTED ISOLATED HILLS	1330	1.21	E(20-29)	STEEP LAND
	D. DISTURBED LAND	100	0.09	—	DISTURBED LAND
		14600	13.3	D	
DEEPLY DISSECTED HIGHLANDS (150m-450m)	a. UNDULATING VALLEY TYPE INCURSION	5880	5.35	C(5-10)	SERDANG-MUNCHONG ASSOCIATION
	b. STEEP-SIDED LOW PARALLEL RIDGES	7510	6.83	D & E (11-29)	RENGAM SERIES
	c. STEEP SIDED HIGH RIDGES AND HILLS	10120	9.20	D & E (11-29)	STEEP LAND
	d. DISTURBED LAND	320	0.13	—	DISTURBED LAND
		23 640	21.5	D&E	
HIGH FOOTHILLS AND LOW MOUNTAINS (300m-610m)	a. DEEPLY DISSECTED STEEP FOOTHILLS	9980	9.07	E(20-29)	STEEPLAND AND RENGAM
	b. STEEP LOW MOUNTAINS	8370	7.61	E & F (20->30)	STEEP LAND
	c. MAIN CENTRAL WATERSHED	2930	2.66	E(20-29)	STEEP LAND
		21280	19.3	E	
HIGH MOUNTAINS (>610m)	a. PEAKED EASTERN MOUNTAIN RIDGE	5100	4.55	E&F	STEEPLAND
	b. NORTHERN MOUNTAIN RANGE	2420	2.2	F	STEEPLAND
		7520	6.8	F	
ALL		110,020	100	—	



MAP 2: A LAND CATEGORY MAP OF THE ULU LANGAT DISTRICT, SELANGOR

CHAPTER 3

COMPILATION OF A SLOPE MAP BASED ON TOPOGRAPHICAL MAPS

For reasons discussed below a slope attribute, slope angle, has been employed as a dominant land parameter to classify the landscape of the Ulu Langat District into "user" landform types. In the absence of any existing slope map for the study area, the compilation of a slope map is considered a necessary first step to landform classification in the District. Slope mapping techniques and procedures, and landform classification, are associated with certain problems cited in Chapter 1 as problems of geomorphological mapping which must be solved, or accounted for, in any type of land mapping exercise. These problems are discussed in this Chapter, and the techniques and procedures followed to obtain, classify, and map the slope values are also explained.

Problems of geomorphological mapping

Three basic problems have to be solved in any type of land mapping exercise: 1) a suitable scale must be selected; 2) a decision must be made concerning an appropriate basis of land classification; and 3) a method of mapping must be devised to suit the scale and the basis of classification (Thomas, 1969). The purpose of a study will determine the choice of a suitable scale at which to compile the map, and both the scale and the purpose will determine the basis of classification, and the method of mapping.

Basis of classification. Eyles (1968a) contends that there are two main bases of landform classification: a) the basis of land classification according to the Davisian (1899) erosional cycle theory, and b) the basis of land classification according to Horton's (1945) drainage basin system. With the Davisian basis of classification, it will be possible to identify landform types according to the dominant erosional processes including fluvial, eolian, marine, and so on; and according to the stages of erosional history which includes youth, maturity, and old age. With the Hortonian basis it is possible to identify landform types according to the order-rating of the stream-basin system contained within a given land area. Landform types, therefore, can be identified as first-order basin, second-order basin, ... , and nth-order basin. A third important basis of land classification seems to be the geometric basis. With this basis it is possible to identify landform types according to the characteristics of certain land attribute/s obtained within given geometric working units. The nomenclature employed will depend on the attribute/s investigated, but the classification will be along numerical lines. Smith (1935) and Swan (1967) have used this basis to classify landforms according to their relative relief characteristics. Robinson (1948) and Raisz and Henry (1937) have also used it to classify landforms according to the slope characteristics, while Swan (1967) has done the same with respect to hill frequency characteristics of the land.

Neither the erosional cycle basis, nor the drainage basin-order basis, was found adequate for the purpose of this study for the following reasons. It has been noted that the erosional cycle does not lend itself readily to quantification and morphometric analysis

(Ottmann and Tricart, 1964; Mabbutt, 1968; Thomas, 1969). It also involves considerable genetic interpretations, which Hammond (1954) considers theoretical and of little use to the land planner. Although the drainage basin-order has been recognised as a suitable basis of land classification (Strahler, 1958, 1960; Eyles, 1968a; Doornkamp and King, 1971), it has been suggested that landform systems cannot easily be defined in terms of the drainage basins (Desai, 1968; Thomas, 1969) because the drainage basins of the third and fourth orders transgress lithology and geomorphic boundaries of significance (Thomas, 1969). Eyles (1966) and Faniran (1970) have noted that there is the danger of basin order being in error because of the omission of first-order streams on topographical maps and because of the difficulty of determining, accurately, the pattern of streams from the air photographs of forest areas with even canopies (Eyles, 1966; Oyelese, 1968; Swan, 1970b). The inequality in the size of drainage basins at any given order casts serious doubts on the suitability of drainage basins as sampling units. There is also the possibility of incomplete coverage of a study area with any chosen basin-order. Eyles (1968a) could not analyse his landform type 7 (Coastal Swamps) for West Malaysia because this landform type could not be identified with the fourth-order basin.

The geometric basis of land classification has been adopted in this study because it has been found to be objective, to lend itself to quantification and to be suitable for delimitation of equal-area sampling un Its objectivity lies in the fact that the size of the geometric units selected are generally determined by the scale of base maps and by the characteristics of the land attribute/s to be investigated. These units can be designed such that they are equal in area, and are, therefore, suitable as bases for sampling and statistical analysis. Such units can be designed to cover the whole of any selected study area.

Method of mapping. Three methods of mapping have been recognised (Mabbutt 1968; Thomas, 1969): a) the genetic approach of mapping; b) the landscape approach of mapping; and c) the parametric approach of mapping.

The genetic approach of land mapping concerns itself with genetic groupings of natural phenomena (Mabbutt, 1968), and is only suitable for the compilation of small scale maps where broad generalisations, associated with the genetic approach, cannot be avoided. The landscape approach of land mapping is a synthesis of small regions where 'no one or two characteristics of regions are isolated for study', and where 'a general view of the area in question, and the combined effect of the geographical factors, are taken into account' (Mabbutt, 1968; pg., 16). Interpretation of air photographs is considered as part and parcel of the landscape approach (Christian, 1958; Beckett and Webster, 1965, 1969; Mabbutt, 1968), which is considered to be suitable for reconnaissance surveys (Mabbutt, 1968) and for general-purpose land system maps (Thomas, 1969). It seems, though, that the landscape approach involves some inferences which can be physiographically and morphogenetically biassed (Mabbutt, 1968), and that it is more suited to a qualitative framework than it is to a quantitative one. The parametric approach of land mapping is the division of the land-surface on the basis of selected land attribute/s. This approach is suitable for general-purpose surveys when many attributes are investigated, and for special-purpose maps when very few (one, or two) attributes are investigated (Mabbutt, 1968; Thomas, 1969). The main limitations of this approach (which could be reduced considerably by careful design) are associated with the choice of suitable attribute/s and the grouping of the attribute/s into suitable classes.

The parametric approach was adopted in this study for the compilation of the slope map because it was realised that it would afford precise definition of the slope characteristics of the land; and because neither the landscape, nor the genetic, approach would be practicable for mapping the land-surface on the basis of the characteristics of a single attribute. A combination of the parametric approach and the landscape approach was adopted for the compilation of the landform map (see Chapter 5) because it was noted with Mabbutt (1968) that the combination of the two methods would be of an advantage, in the compilation of a functional landform map, since both methods answer, to a large extent, the requirements of landform classification for the land evaluation user. It was necessary to avoid physiographically and morphogenetically biassed inferences in the classification of the landforms of the study area in order to eliminate the main limitation of the landscape approach cited above. To reduce the main disadvantages of the parametric approach the choice of the main attribute (slope angle) and the complementary attributes (soil, total relief[1], and drainage),

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1. "total relief" is used alternatively with "elevation above mean sea level"

as well as the classification of the main attribute, was designed and executed as will be shown below.

Choice of attributes

It was noted above that the parametric approach would involve the choice of one or more suitable attribute/s. Mabbutt (1968) has stressed the fact that the attribute/s selected must be suitable for the operations involved in the compilation, and must be relevant to the intended use. The operations involved in the compilation of the slope map designed for this study include the determination of the characteristics of land attribute/s within equal-area geometrical units at a scale of 1/63,360. At the scale of operation it has been suggested that the choice of one dominant attribute is the most appropriate choice to be made (Thomas, 1969). The purpose of the landform map designed for this study involves the designation of landform types for land planning uses. This implies that the main attribute selected must be one which is closely associated with land planning techniques, and since the framework for this study is mainly quantitative, such a main attribute must be one that can be measured. A combination of the parametric approach and the landscape approach in the compilation of the functional map designed for the study area necessitates a choice of complementary attributes which are associated with the main attribute and are related to land planning techniques. After a careful consideration of these factors, slope angle was selected as the main attribute, and soil, total relief (elevation above mean sea level), and drainage conditions were selected as complementary attributes.

Main attribute. Slope angle was selected as the main attribute because its importance to landform studies has been expressed by geomorphologists and land planners (Savigear, 1960, 1965, 1967; Young, 1964, 1969a, 1969b, 1972; Curtis et al., 1965; Desai, 1968; Beckett and Webster, 1969). Young (1964, pg. 26) maintains that the technique of slope analysis is of great 'value in assessing the natural resources of areas, and consequently in geographical studies of an applied nature'. He states further (Young, 1969b) that the slope units form the basis of the technique of morphological mapping. Slope angle is often selected as the main attribute in the execution of such morphological maps as the works of Curtis et al. (1965), Savigear (1965, 1967), and Doornkamp and King (1971) would seem to illustrate. Morphological units based on slope angles have been shown to be important in the compilation of landform maps for land planning purposes (Beckett and Webster, 1965, 1969; Young, 1969a; Swan, 1969b). Such morphological units have been observed to be associated with technical-economic practices (Curtis, et al., 1965; Gellert, 1967; Young, 1972), with erodibility of soil (Ruddock, 1967; Jahn, 1967; Eyles, 1968a, 1968b, P. Wong, 1968; Emmett, 1970), and with farm sizes (Faniran and Ajaegbu, 1971). Technical-economic practices, and soil erodibility are factors to be taken into consideration in order to achieve adequate land allocation for different uses (Gellert, 1967, Wycherley, 1969).

It can be stated, therefore, that the angle of the slope of the land is not only important in terms of the landforms, but also (if not more so) in terms of the landuse. Thus the compiler of a "user" landform map could profitably select (as has been done for this study) slope angle as the main attribute for the compilation of such a map.

Complementary attributes. Soil, total relief (elevation above mean sea level), and drainage type are combined with the slope angles to classify and map the landform types of the study area (see Cahpter 5), because these attributes have been observed to be associated with the slope characteristics of the land (James, 1953, Miller and Summerson, 1960; Moss, 1963; Young 1964; Swan 1967). James (1953) maintains that the study of the association of slope, soil, and drainage is essential in land-quality maps. Miller and Summerson (1960) contend that the slope of the land, and the elevation, are two basic concepts of relief, and that relief has a great influence on man's activities. Moss (1963) has observed a close association between soil, slope, and landuse; while Swan (1970b) explains that the combination of slope values with soil characteristics to classify land evaluation maps is necessary, especially in West Malaysia where soil suitability classes are largely defined in terms of the slope of the land (see the reports of the Malaysian Soil Survey Staff, e.g. I. Wong, 1966, Panton, 1969; Ng, 1969). It has also been observed that, generally, areas of high elevation are characterised by high relative relief (Swan, 1967), and by steep slope angles (Wycherley, 1969; Swan, 1970b, 1970d; Khong, 1970). Further, the elevation of the land influences the distribution of crops as can be illustrated by the conventional references to the critical elevations for crops including rubber, cacao, and coffee (Stamp, 1962; Alexander, 1963), and by the usual distinction between

Padi and Upland rice. The drainage type of the land is also essential to the utilisation of landform types. The term "drainage type" is used to include the type of drainage pattern (dendritic, trellis, rectangular, or radial) and the type of drainage condition (well-drained, poorly-drained, waterlogged, and the like). It is believed that both the drainage pattern and the drainage condition indicate the nature of the available land, and the techniques that will be suitable for its utilisation.

It can be concluded that the combination of the soil, elevation, and drainage characteristics of the land with the slope attribute is essential in landform classification, and map compilation, for the purpose of adequate land planning. As stated earlier, the absence of any slope map for the Ulu Langat District has made the compilation of a slope map a necessary part of this study.

Slope mapping exercise

The compilation of a slope map based on topographical maps is associated with other problems, in addition to the general problems of geomorphological mapping discussed above. Strahler (1950) and Swan (1970b) contend that the accuracy of slope maps based on topographical maps is conditioned by the scale and the accuracy of the topographical maps, the size of the contour interval on the base maps, and the nature of the terrain of the area to be mapped. The accuracy of such slope maps will also be conditioned by the techniques employed to obtain and classify the slope values from the base maps.

The accuracy of the base maps employed in the present study has been estimated by Eyles (1966), and the maps have been found by him to be of acceptable standard of accuracy with respect to extrapolation of contours and representation of surface dimensions. While it might be observed with Strahler (1950) that maps on scales smaller than 1/62,500 might not be used as base maps for slope calculation, it can be argued that a scale of 1/63,360 is very close to Strahler's (1950) suggested critical scale; and that Faniran (1970) maintains that slope calculations from topographical maps are not necessarily unsuitable: much will depend on the nature of the project for which the slope values are obtained. Since the contours of the topographical maps and the representation of surface dimensions on them have been found to be of considerable accuracy, these maps have been accepted to be suitable for the purpose of the present investigation. It is realised, though, that the accuracy of the slope map compiled from values obtained from these maps will depend largely on the suitability of the techniques employed to obtain and classify the values. It is one of the objectives of this study to devise techniques that will be suitable for the compilation of a reliable slope map based on the base maps. The remaining part of this Chapter is concerned with discussions on these techniques, and on the compilation of the slope map.

<u>Techniques for extracting slope values from topographical maps</u>

Monkhouse and Wilkinson (1971) have reviewed the existing techniques for extracting slope values from topographical maps. Three methods are recognised.

a) There is the Raisz and Henry (1937) method whereby topographical maps can be divided into small regions within each of which the contours show the same standard spacing. This method involves the recognition of contour-regions, and will lead to inequalities in the sizes of the regions.

b) There is Robinson's (1948) method whereby the topographical maps can be divided into squares, or rectangles, which are equal in area. This is a modification of Smith's (1935) method of relative relief. In this modified form slope angles are calculated for each square, or rectangle, and the values obtained are plotted for each working-area by using a corresponding number of dots to represent the slope values.

c) There is the Miller and Summerson (1960) method whereby base maps are divided into slope zones according to the values of pre-determined guide-samples of four slope types which are classified on the basis of some mathematical functions. This metnod takes into account the inter-contour spacing and agrees 'well with several important aspects of Wood's slope elements' (Monkhouse and Wilkinson, 1971; pg. 142).

Other slope analyses have been concerned with improving, or refining, these three basic techniques. For example, Strahler (1956) introduces the use of isopleths to replace Raisz and Henry's use of the choropleths. Strahler (1958) further introduces the use of the frequency distribution to replace classification along the lines of Wood's four elements of slope. Pitty (1969) has introduced the method of divided histograms to illustrate the slope values over given areas.

It would seem that the method of Raisz and Henry and that of Miller and Summerson are not suitable for the present work. The former is subjective and involves the use of unequal areas as sampling units, while the latter involves some genetic assumptions contained in Wood's (1942) slope elements. In fact, it is believed that four slope zones will be too few for land planning purposes, especially in a humid tropical environment where the smallest difference in slope angle can show distinct differences in soil erosion (Ruddock, 1967; Eyles, 1969; Swan, 1970c). The geometric method of equal-area working squares was adopted in this study because the method is considered to be objective, and to be capable of separating areas of different slope characteristics, when a square size suitable for the scale of the base map is used. Two refinements were made to ~~the~~ Robinson's (1948) method before its application in this study.

First, isopleths were used to map the slope values instead of mapping the values by plotting corresponding numbers of dots as was done by Robinson. This refinement has been suggested by Monkhouse and Wilkinson (1971). It is believed that the slope of the land is more of a linear and/or areal distribution than it is of a point distribution, and, therefore, dots cannot represent the distribution of slope adequately.

Secondly, a concept of "absolute height" within each working square was introduced. "Absolute height" means the sum total of vertical interval within a working square. The consideration of only the differences in elevation between the highest and the lowest points of a working square was regarded to be inadequate, since there is the possibility of relative relief being concelled out in spur and hill working squares. The concept of absolute height is similar in operation to the Raisz and Henry (1937) method of counting the number of contours intersected along a line and multiplying this number by the value of the contour interval on the base map.

To determine the size of the working square that would best suit the scale of the base maps, and the nature of the terrain of the Ulu Langat District, three trials, with each of four different sizes, were conducted to represent gentle, steep, and very steep slope conditions. The four different sizes had side measurements of 3mm, 4mm, 5mm, and 6mm on the base map. These trials showed that squares with sides equal to, or larger than, 6mm (actual, 380m) were too large because field checks revealed that they combined areas of differing slope characteristics. Squares with sides equal to, or less than, 3mm (actual, 190m) were too small since they showed no slope values for some areas where actual slope value could be anything from 1° to 4°. Squares with sides equal to 4mm, or 5mm, were found to be suitable. Preference was given to square-side 5mm because a 1,000-yard-grid square superimposed on the base maps was observed to contain exactly nine 5mm-sided squares. A 5mm-sided square on the base map has an actual surface area of approximately 0.1 square kilometre, and is referred to in this study as a working square, or a sample unit. It should be differentiated from the 1000-yard-grid square which is later referred to as a sample square.

Procedure for the calculation of slope values. For each working square, slope angle was averaged along a linear dimension AB, or AB + BC, as illustrated in Figure 5. A line AB, or AB + BC, was aligned at right-angles to the contours such that the length was not less than 5mm, i.e. the length of the side of a working square. Each line was located

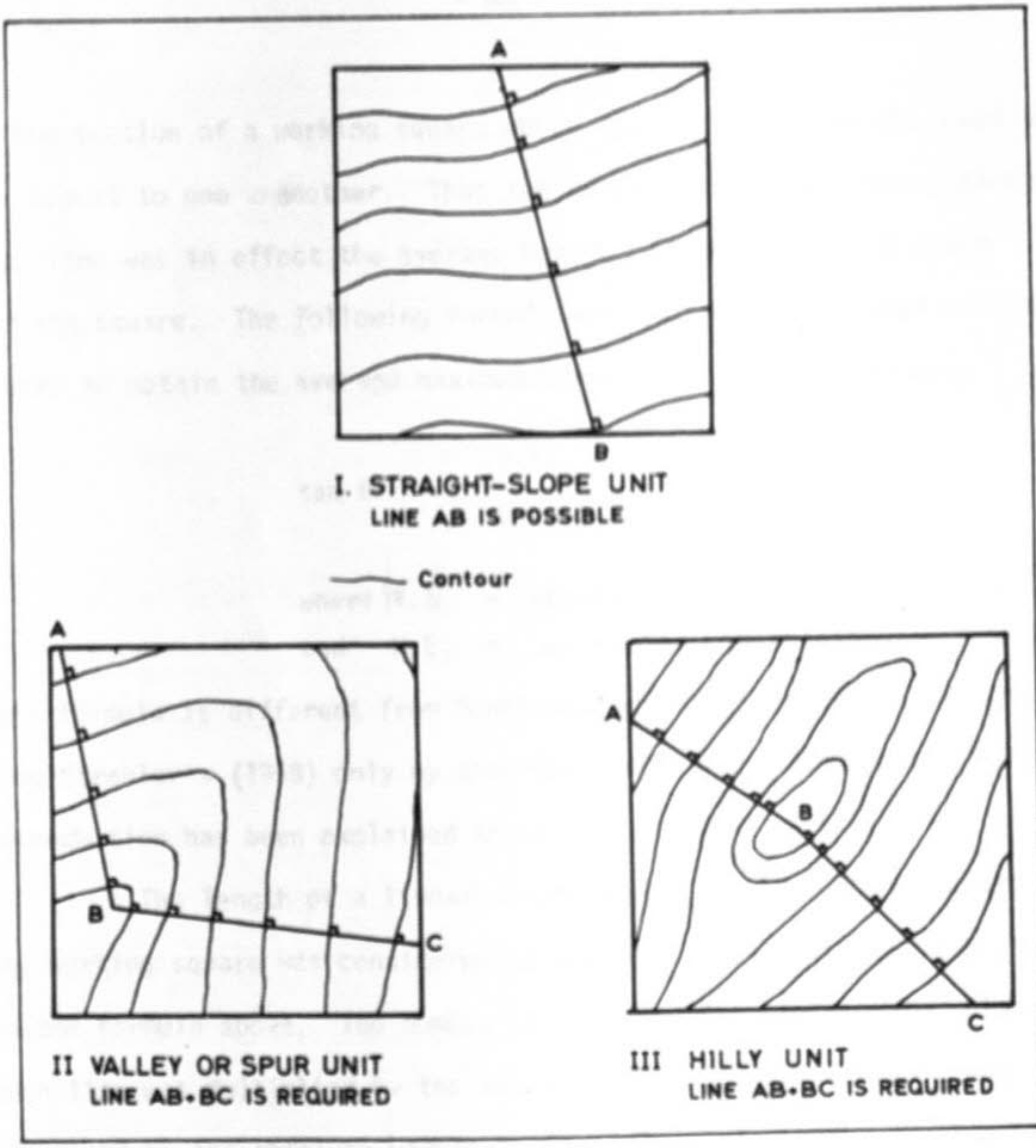

FIGURE 5: A schematic diagram to show the determination of horizontal distances in the working units on the base maps

at the section of a working square where the contours were observed to be closest to one another. Thus the average slope calculated along each line was in effect the average maximum slope value of a given working square. The following formula was applied within each working square to obtain the average maximum slope value for that square.

$$\tan \theta = \frac{|V.I|}{H.E.}$$

where $|V.I|$ = absolute vertical interval,
and H.E. = horizontal equivalent.

This formula is different from Monkhouse and Wilkinson's (1971), and from Strahler's (1958) only by the "absolute" sign. The reason for its introduction has been explained above.

The length of a linear dimension AB, or AB + BC, obtained from any working square was considered as the horizontal equivalent expressed in the formula above. The number of contour lines intersected along each line was multiplied by the value of the contour interval, and expressed as the absolute vertical interval. Inter-contour value was calculated in a place where the boundary of a working square fell in-between two contour lines. Spot heights were estimated for hill summits, spur crests, and valleyfloors. For each working square where any of these extra calculations was undertaken the absolute vertical interval was expressed as the product of the number of contours intersected and the contour interval, plus the extra height calculated as explained above.

Horizontal distances which were measured on the base maps were multiplied by the value of the denominator of the scale of the base map (i.e. 63,360). Since the base maps were on the British measuring system, the inch was used as the unit to obtain the gradient, or tan θ, as expressed in the formula. The corresponding slope value of a gradient obtained was read off natural tangent tables to the nearest whole degree; and 11,073 such values were obtained for the study area. These were eventually grouped into six classes for the purpose of the compilation of a slope map.

Techniques for the classification of slope values

The classification of slope values into groups suitable for land planning involves the consideration of slope boundaries as affected by morphological and technical-economic requirements. These requirements were considered by a critical examination of statistical, morphological-theoretical, and technical-economic techniques of slope classification (see Young, 1972). First, a frequency histogram was constructed (Figure 6) for the 11,073 slope values. Pitty (1969) has used this technique to classify slope values by considering the major breaks in the frequency histogram as probable "natural" slope boundaries. Secondly, theorétical and morphological slope boundaries suggested by workers including Miller and Summerson (1960), Curtis, et al. (1965), Savigear (1965, 1967), Desai (1968), and Bryan (1968) were charted (Figure 7). The suggested boundaries by Savigear and Bryan are based on the theory that slopes gentler than 5° are depositional, and that slopes steeper than 20° are erosional. The boundaries suggested by Miller and Summerson are based on the four hillslope elements of "waxing", "free face", "constant" and "waning", which are introduced by Wood (1942). Desai (1968) claims that the classes he identifies are the classes commonly défined by morphological workers.

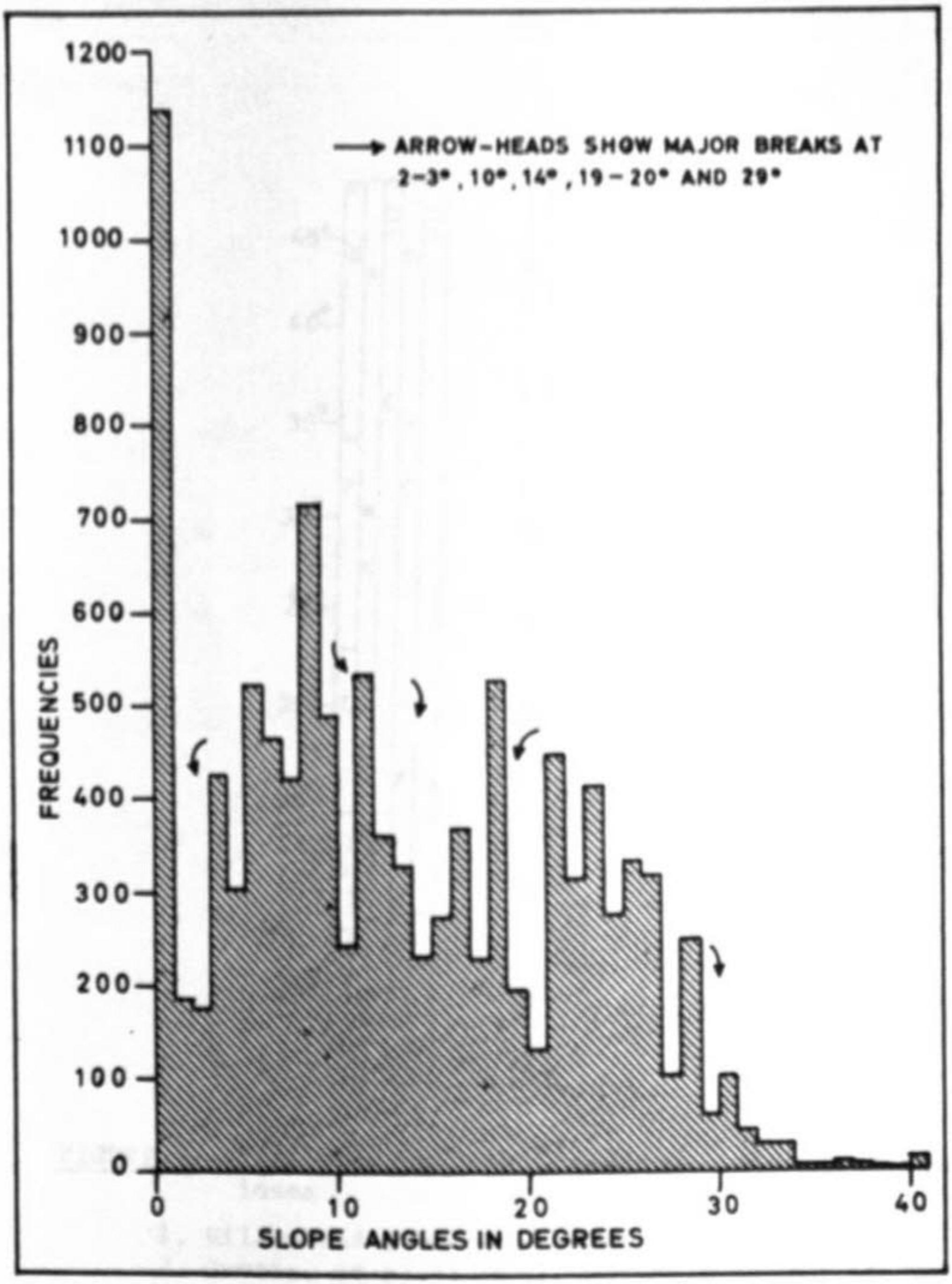

FIGURE 6: A frequency histogram of slope values of the Ulu Langat District

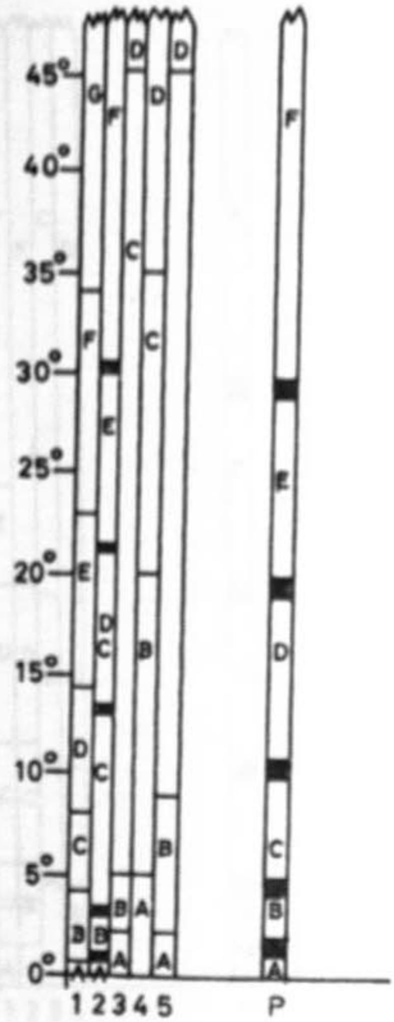

FIGURE 7: Slope classes based on morphological and theoretical ideas

1. Miller and Summerson (1960): Morphological
2. Curtis, et al. (1965): Morphological-technical
3. Savigear (1965,1967): Morphological-theoretical
4. Bryan (1968): Theoretical
5. Desai (1968): 'Common' classes

P. Classes in the present study

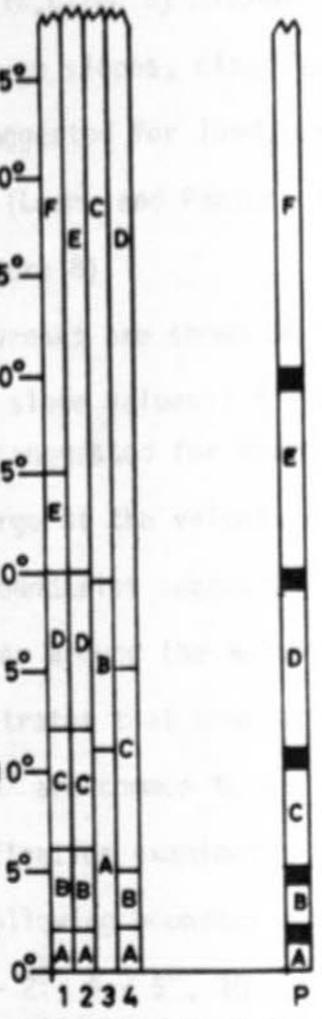

FIGURE 8: Slope classes based on farming and techical-economic requirements

1. Leamy and Panton (1966) and I.Wong (1966): Soil capability, Malaysia
2. Swan (1970b): Terrain types, Johor
3. Land Advisory Committee (Alexander, 1964): Farm practices, Malaysia
4. International Geographical Union (Gellert, ~~1967)~~. Technical-economic requirements

P. Classes in the present study

Thirdly, the boundaries suggested for farming techniques (Land Advisory Committee, Malaysia, cited by Alexander, 1964; International Geographical Union's committee on slopes, cited by Gellert, 1967; Swan, 1970b), and the boundaries suggested for land, or soil, capability classification in West Malaysia (Leamy and Panton, 1966; Panton, 1969; Swan, 1970b) were also charted (Figure 8).

Major breaks are shown on the frequency histogram (Figure 6) at the following slope values: 1 - 2^{0}, 10^{0}, 14^{0}, 19 - 20^{0}, and 29^{0}. Class boundaries suggested for theoretical and morphological reasons (Figure 7) converge at the values: 1 - 2^{0}, 4 - 6^{0}, 13 - 15^{0}, 19 - 23^{0}, 30^{0}, and 45^{0}. Boundaries suggested for technical-economic reasons (Figure 8) cluster around the values: 2^{0}, 5 - 6^{0}, 11 - 15^{0}, and 19 - 20^{0}. This illustrates that boundaries at 1 - 2^{0}, 4 - 5^{0}, 10 - 11^{0}, 15^{0}, and 19 - 20^{0} are common to at least two of the three techniques of slope classification examined.

The following boundary zones were eventually selected for this study: 1 - 2^{0}, 4 - 5^{0}, 10 - 11^{0}, 19 - 20^{0}, and 29 - 30^{0}. This selection is biassed in favour of the "natural" breaks in the frequency histogram and the slope boundaries suggested for West Malaysian conditions (Leamy and Panton, 1966). Slope classes were defined as 0^{0} to less than 2^{0}, 2^{0} to less than 5^{0}, 5^{0} to less than 11^{0}, 11^{0} to less than 20^{0}, 20^{0} to less than 30^{0}, and 30^{0} and over. Since slope values were calculated to the nearest whole degrees, these slope classes are in effect: 0 - 1^{0}, 2 - 4^{0}, 5 - 10^{0}, 11 - 19^{0}, 20 - 29^{0}, and 30^{0} and over. Each of these final class limits is one degree less than each of the class limits suggested by Leamy and Panton (1966), because the "natural" breaks in the distribution of slopes calculated for the Ulu Langat District fall at these lower limits. These lower limits are also expected to provide a wider margin of safety, as regards soil erosion, in the utilisation of the land. It must be remembered that the study area is one of heavy rainfall with high intensity (Chapter 2). The provision of a margin of safety will be desirable in such an environment. Consequently, the six slope classes defined above were later used to compile Map 1 - An average-maximum slope map of the Ulu Langat District, Selangor.

Compilation of a slope map of the Ulu Langat District

A slope map, defined as an average maximum slope map, was compiled for the Ulu Langat District after the slope values, and the slope classes, discussed above had been subjected to field tests (see Chapter 4). These field tests eventually revealed that the calculated map values and the field derived values are significantly correlated, and that the differences among the defined slope classes are significant.

The following procedure, suggested by Monkhouse and Wilkinson (1971), was adopted in the compilation of the slope map. The base maps with the superimposed working squares were pinned together to form a complete map of the study area. A piece of tracing paper was laid over the base maps and the working squares were traced on the paper. The slope value of each square was plotted in the centre of the square. Without removing the tracing paper from the base maps, isopleths were drawn to group together working squares that were contained in the same pre-determined slope classes. Adjustments were made in certain boundary areas where the plotted values did not show any clear alignment. In such areas, the patterns of the contour lines on the underlying base maps were used to separate classes of steeper slopes from those of gentler slopes. Any isolated out-of-class value contained within a large area of one typical class was ignored.

Since final maps are expected to be on smaller scales than the working scales, the slope map (Map 1) was reproduced on half of the original working scale. This agrees with Hodgkiss's (1970) suggestion that original maps for books and theses should be one-and-a-half to two-and-a-half times the scale of the final maps. The area of each slope class is given in hectares (Table 2). the percentage -area of each slope class is illustrated by curve C on Figure 9. It is believed that the areal extent of slopes will best be described in relation to the landform types as will be discussed in Chapter 5. Generally (see Table 2), it is observed that slope classes C (5 - 10^{0})

TABLE 2 : Area of slope classes in the Ulu Langat District

Slope Class	Area (hectares)	% of total area
A (0 - 1^{0})	14,120	12.8
B (2 - 4^{0})	10,230	9.3
C (5 - 10^{0})	27,830	25.3
D (11 - 19^{0})	28,670	26.1
E (20 - 29^{0})	24,090	21.9
F (30^{0} & over)	5,080	4.6
All Classes	110,020	100.0

and D (11 - 19°) cover slightly more than 50% of the surface area of the District. Another 26% of the surface area of the District is covered by slope values higher than 19°. The remaining part of the District is characterised by slope values gentler than 5°. It must be remembered that the area-values quoted above are only approximate figures, though it is believed that a major part of the area contained within a given slope class will be characterised by slope values close to the average for that class. The field investigations and statistical analyses undertaken to test the accuracy of the slope values and the techniques explained in this Chapter are discussed in Chapter 4.

CHAPTER 4

TESTS OF THE ACCURACY OF SLOPE VALUES AND THE VALIDITY OF SLOPE CLASSES

The limitations of direct slope measurement from topographical maps have been discussed in Chapter 3. The influence these limitations (especially the limitations associated with the scale and the nature of the slope map) exert on the accuracy of the slope map, based on the topographical maps, can be correctly estimated only by field checks of the calculated slope values, aided by statistical analyses of the field and the map values. Field checks and statistical analyses are also necessary to test the validity of the techniques employed to calculate and classify the slope angles. In addition, statistical analyses are essential to test the suitability and the statistical viability of the slope classes. A discussion of such field checks and statistical analyses, which were undertaken in this study, is given below.

Sampling method and sample size

A technique of random sampling was used to select one hundred working squares from the topographical maps (see Ezekiel, 1930; Bajpai, 1967; Monkhouse and Wilkinson, 1971). The following procedure was adopted for the selection of the one hundred samples. First, the 1000-yard-grid lines, which are superimposed on the base maps, were re-numbered to form continuous Eastings and Northings for the District. The grid co-ordinate of the extreme southwestern margin of the base maps was regarded as the origin, and was identified as (00,00). From this origin, the Eastings were numbered 01, 02, 03, ..., k eastwards and the Northings were numbered in the same way northwards. The co-ordinates of any grid-intersection on the base maps were taken together as the random number (E,N) for that intersection. Secondly, a Random Number Table (Lindley and Miller, 1953, Table 8) was used to select the first one hundred available co-ordinates (E,N). The grid-square immediately to the northeast of a selected intersection was determined as a sample square. Thirdly, the central working square, one of the nine working squares in a grid-square, was selected as the sample unit by a random technique which involved picking one of nine numbers designed to represent the nine working squares.

The sample had a distribution of at least eight units from each of the slope classes as identified in Chapter 3. Subsequent field work revealed that a pre-determined sample unit was not everywhere accessible in the swampy areas and the forested mountains. When this occurred, the first accessible working square within each sample grid-square was sampled in the field. In none of the cases was a sample square (grid-square) completely abandoned. Despite this fact, the final distribution of sampled units revealed that two slope classes were not adequately covered. These are: the typical slope class in the swampy areas (Class A, 0 - 1^{0}), and the typical slope class in the forested mountains (Class F, 30^{0} and over). The reason for this as noted earlier, is associated with the inaccessibility of the sample units from these areas. Thus when the first accessible working square within a sample square from these areas was sampled in the field, the tendency was for the sampled unit to fall within a class higher than the class of the swampy areas, or within a class lower than the class of the forested mountains. The distribution of the sampled units (map values) for the six slope classes is given in Table 3. The relationship between this distribution and the distribution of the population is illustrated by curves A and B on Figure 9.

TABLE 3 : Distribution of map samples by slope classes

Slope Class	Frequency
Class A ($0 - 1^o$)	4
Class B ($2 - 4^o$)	13
Class C ($5 - 10^o$)	38
Class D ($11 - 19^o$)	34
Class E ($20 - 29^o$)	10
Class F ($\geq 30^o$)	1
All Classes	100

Field procedure and techniques

The first problem to be solved in the field was associated with the identification of the length and width of the sample units as located on the base maps. Land marks, compass directions and measured distances were combined to delimit each sample unit. The most useful land marks were found to include roads and tracks, isolated hills, streams, transmission lines, estate buildings, and road-marks (milestones, benchmarks,

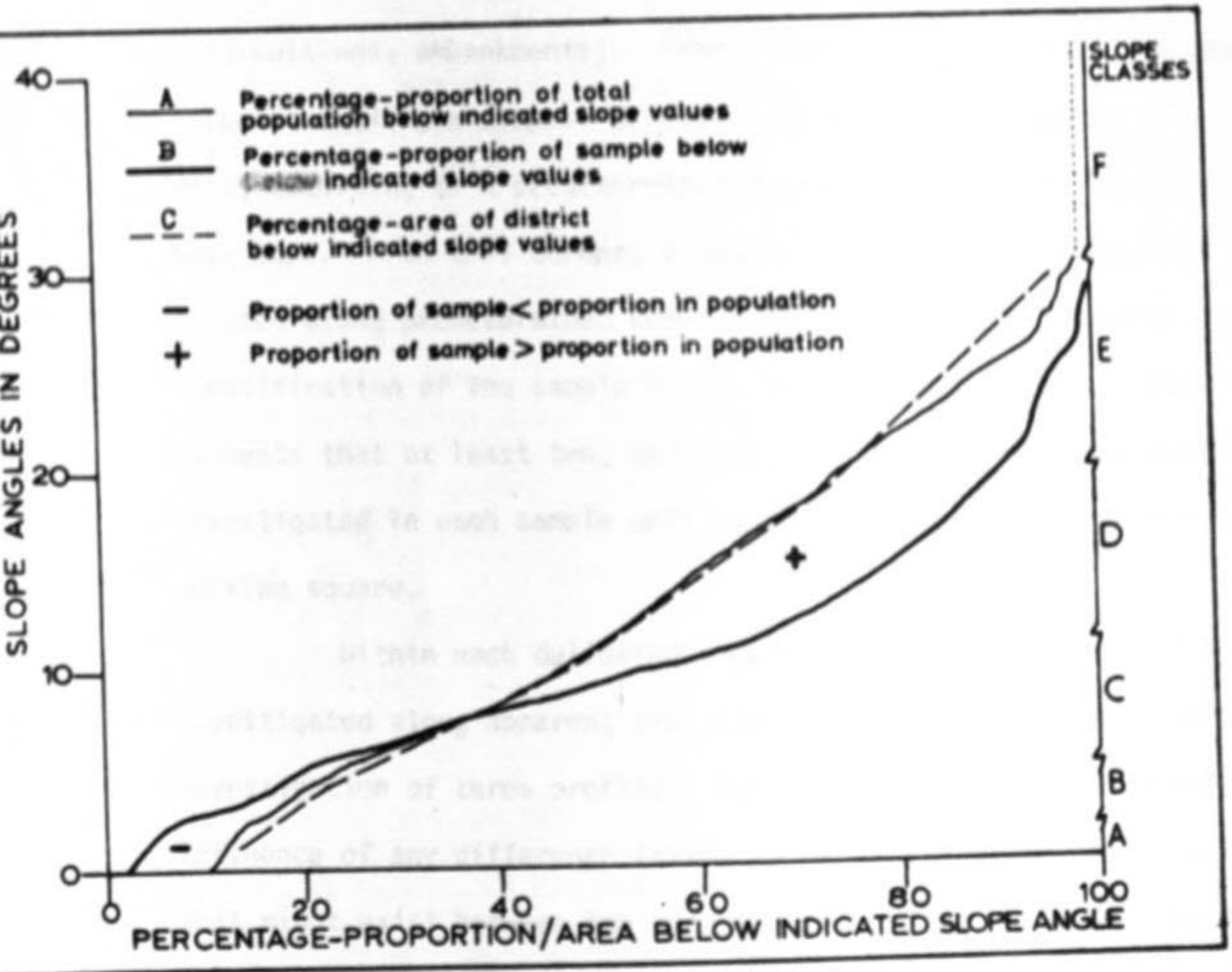

FIGURE 9: Hypsometric curves of percentage-proportion/area below certain slope values

road-cuttings, embankments). From a land mark, a mileage was usually calculated along a compass direction to the nearest corner of a sample unit, according to a predetermined mileage and compass direction on the base maps. From this corner, a square with side 300 metres was delimited along predetermined compass directions. The accuracy of the identification of the sample units was estimated at 90% to 95%. This suggests that at least two, and probably all, of the three profiles investigated in each sample unit would be contained within the map working square.

Within each delimited sample unit, three slope profiles were investigated along apparent true slope zones. It was realised that the investigation of three profiles, instead of one, would eliminate the influence of any difference (cited to be of the order of 5% to 10% above) that might exist between the location of a sample unit and the exact position of its corresponding map working square. It was also realised that an average slope value obtained from three field profiles would probably yield better results than a value obtained from a single field profile, because the average from the three profiles would reflect the areal distribution of slope angles within a sample unit. The three profiles investigated in each sample unit were spaced at about one hundred metres apart, and each profile crossed a sample unit from one edge to the opposite edge. Where a sample unit was a hill, three profiles stretched from one edge of the unit to the other were in effect six profiles radiating from the summit of the hill.

An Abney level was used to measure slope values along each profile. The method of Abney levelling was preferred to other methods in this study because it has been judged to be adequate for works where an accuracy of $\pm$ 0.5^0 is acceptable (Savigear, 1950, 1967; Monkhouse and Wilkinson, 1971; Doornkamp and King, 1971). An accuracy of $\pm$ 0.5^0 is considered acceptable for this study since the calculation of slope values from the base maps was undertaken to the nearest whole degree. The method of Abney levelling also provided quick field checks necessary to investigate the three hundred profiles involved at this stage of the study. To measure slope angles with this method, reading stations were spaced at thirty paces apart on long and straight slopes, but stations were located at apparent changes of slope on irregular slopes (see Doornkamp and King, 1971). At each reading station, the Abney was levelled at a point on a partner (standing at the next reading station) corresponding to the reader's eye-level, or at a pre-marked point on a pole fixed to the ground at the next reading station. Slope angles were read to the nearest whole degree by the investigator, who also did all the pacing.

The technique of pacing was adopted in this study because it has been shown that this technique is adequate for investigations where the emphasis is being placed on the average slope values, and not on slope forms (Doornkamp and King, 1971). The technique of pacing was considered to be a better method to obtain average slope values than a method by which slope readings are added and averagedwithout accounting for the length (i.e., frequency) of individual values. In order that slope frequencies would be meaningful, care was taken to see that the length of the paces employed was uniform. After several measured trials on different terrain conditions, pacing techniques were designed to obtain an average pace-length of one metre on all terrain conditions. This length was employed as the frequency in the analysis of the slope values obtained from the field to determine for each sample unit an arithmetic mean (field average[1]), a modal value (field mode), a seventy-percentile value (field seventy-percentile, or field 70-p), and a median value (field median). These field derived parameters are referred to collectively as field values, or field variables, and are designated as Y_1, Y_2, Y_3 and Y_4 respectively. They should be differentiated from the map values, or map variable (X), which are the one hundred map samples drawn from the "population" (P). Table 4 is a double-page from a field note book which shows the use of the length of paces as slope frequencies to determine the field values. Four field parameters were employed in this study in preference to the use of only the arithmetic mean in order to know which parameter would be the best measure of the accuracy of the map values, and in order to allow for a more specific definition of the slope values than a mere reference to the arithmetic average conditions.

Limitations of sampling and field techniques

The inadequate coverage of slope Classes A ($0 - 1^{o}$) and F (30^{o} and over), and the preference for pacing over tape-measuring are

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1. The term "field average" is used in this study instead of "field arithmetic mean" in order to differentiate the field arithmetic mean (field average) from other arithmetic mean values determined for the field and map variables.

TABLE 4 : A double-page from the field notebook on slope investigation

Area: Sepang Sheet (8266). Map = 7^{0}. Form: low ridge. Remarks: Rubber

Profile 1 paces	Profile 1 angle (degrees)	Profile 2 paces	Profile 2 angle (degrees)	Profile 3 paces	Profile 3 angle (degrees)	Analysis angle(x) (degrees)	Analysis paces(f)	fx	cf
30	6	40	15	30	14	1	36	36	36
30	6	30	8	25	8	2	45	90	81
20	6	30	7	30	8	3	35	105	116
20	6	30	7	30	7	4	25	100	141
30	9	30	7	15	7	5	130	650	271
30	5	20	7	20	5	6	255	1530	526
25	4	20	7	20	5	7	240	1780	766
26	1	15	6	35	7	8	145	1160	911
10	2	15	3	30	5	9	30	270	941
20	3	10	1	20	2	14	30	420	971
30	8	15	2	30	6	15	40	600	1011
30	7	30	6	30	6		1011	6751	
30	8	30	6	20	6				
		30	5						

Results

Average = 6.68 = 7^{0}
Mode = (f=255) = 6^{0}
70-p = (cf = 708) = 7^{0}
Median = (cf = 506) = 6^{0}

c.f. = cumulative frequency

probably the two main limitations of the sampling design and the field techniques. Limitations associated with operator and instrumental errors are believed not to be worse than are usually expected from the type of investigations described above. Concerning the preference for pacing over tape-measuring technique, it was stated above than the pacing technique has been observed to be adequate for the investigations involved in this study. Since care has been exercised to obtain relatively uniform pace length, the slope values determined for each sample unit are, therefore, considered to be of acceptable accuracy for the purpose of the investigations.

The inadequate coverage of slope Classes A ($0 - 1^{\circ}$) and F (30° and over) could not constitute a serious limitation to the over-all test of the accuracy of the map values. The sample size ($k = 100$) employed for this exercise is considered to be sufficiently large to expect viable statistical results. Similarly, the inadequate coverage of the two classes could not be a serious limitation to the test of the accuracy of the slope classes, and of the suitability of these classes for land planning purposes in the study area. It is doubtful if the average slope values for slope Class A, which is associated with swampy areas, would differ from values $0 - 1^{\circ}$, assuming that more sample units of this class had been accessible in the field. Slope Class F is associated with forested mountain areas. Consequently, it will probably make very little, or no difference, to the land planning policies for a humid tropical area whether the slope angles in such mountain areas are 30° and/or over. In fact, the association between curves A and B on Figure 9 suggests that a sample of one percent from slope Class F is more than an adequate representation of this class in the population. In addition, the other slope classes, probably of the greatest importance to land utilisation, are covered to a degree which seems capable of yielding results when methods of small sample analysis are adopted.

Statistical analyses and interpretation of results

It was decided that it would be necessary to ascertain that the map samples adequately represent the population before these samples were compared with the field values as a measure of the accuracy of the population. Two tests were undertaken to measure the degree to which the map samples represent the population. First, curves A and B on Figure 9 were plotted. These curves represent the percentage-proportion of typical slope values in both the population and the map samples respectively. The curves show a very close association between the percentage-proportion values of both variables. This association seems to be perfect for slope Class C (5 - 10°), since the two curves almost merge into one between slope values 6° and 11°. Secondly, statistical tests, including the Null Hypothesis test of the mean (see Appendix III) and the coefficient of variation (CV%), were applied to the arithmetic mean (mean) and the standard deviation (σ) of both the population and the map samples. The differences between the parametric characteristics of the population and those of the map samples were found not to be significant at better than the 5% level of significance, predetermined as adequate for the statistical tests designed for the present investigations. The three parameters (mean, σ, CV%) are shown in Table 5 for all the slope classes combined together, and for each slope class

TABLE 5: Mean, Standard deviation (σ), and Coefficient of variation (CV%) of both the population and the map sample of slope values

PARAMETER	POPULATION	MAP SAMPLE
All slope Classes	N = 11,073	k = 100
Mean (degrees)	12.7 (13)	10.7 (11)
σ	8.9 (9)	6.3 (6)
CV%	69.7	58.6
Slope Class A (0 - 1°)	N = 1,323	k = 4
Mean (degrees)	0.1 (0)	0.5 (0)
σ	0.4 (0)	0.5 (0)
CV%	250.0	100.0
Slope Class B (2 - 4°)	N = 895	k = 13
Mean (degrees)	3.1 (3)	3.3 (3)
σ	0.7 (1)	0.6 (1)
CV%	22.9	18.4
Slope Class C (5 - 10°)	N = 2,845	k = 38
Mean (degrees)	7.3 (7)	7.7 (8)
σ	1.6 (2)	1.5 (2)
CV%	21.6	18.8
Slope Class D (11-19°)	N = 3,055	k = 34
Mean (degrees)	14.7 (15)	13.6 (14)
σ	2.7 (3)	2.6 (3)
CV%	18.4	18.8
Slope Class E (20 - 29°)	N = 2,688	k = 10
Mean (degrees)	23.9 (24)	23.1 (23)
σ	2.4 (2)	2.4 (2)
CV%	10.2	10.1
Slope Class F (30°)	N = 256	k = 1
Mean (degrees)	31.9 (32)	30.0 (30)
σ	2.6 (3)	-
CV%	8.1	-

N = size of population, k = size of sample separtely. The results obtained from both the graphical and the statistical tests illustrate that the map samples represent the population adequately, and that these samples can be used to test the accuracy of the population by comparing the map samples (map variable) with the corresponding field values (field variables).

Since the map samples represent the population adequately, these map samples (map variable) and the corresponding field values (field variables) were analysed and compared. Arithmetic mean (mean), coefficient of variation (CV%), Pearson's product-moment coefficient of correlation (r), coefficient of determination (r^2), and linear regression of Y (field variables) on X (map variable) were analysed and tested for significance. Analyses were executed at two levels. First, the samples were analysed in bulk to test the over-all accuracy of the map values. This is a test of the suitability of the techniques employed to obtain the values from the base maps. Secondly, the slope values were analysed on the basis of individual classes, except for slope Class F where the single sample was ignored since it could stand no statistical analyses. The class-level analyses were undertaken to test the accuracy of the slope values contained within particular slope classes, and to determine the field variable/s that would best explain the map values. Inter-class variations were examined in order to test whether the classes were sufficiently different one from the other to justify the grouping of the classes. This is a test of the suitability of the techniques employed to classify the slope values, and of the viability of the slope classes. In all the cases, methods of small sample analysis were adopted, (see Ezekiel, 1930; Bajpai, 1967; Monkhouse and Wilkinson, 1971). The formulae associated with these methods are given in Appendix III. The raw data, on which the analyses are based, are contained in Appendix I.

Tables 6 to 11 show the numerical results which were obtained for, and between, the map and field variables, and also indicate the level of the correlation between each field variable and the map variable. Figures 10 to 12 show the regression lines of each field (Y) variable on the map (X) variable. The results, illustrated by these Tables and Figures, are discussed on the basis of the two levels of analyses stated above.

Results and interpretation for all slope classes combined.

The contents of Table 6 and Figures 10 and 11 show that there is a high degree of association between each field variable and the map variable. The following results were obtained.

TABLE 6 : Statistical results of map (X) and field (Y) variables for all slope classes combined.

k = 100

PARAMETER	MAP(X)	FIELD AVERAGE (Y_1)	FIELD MODE (Y_2)	FIELD 70-p (Y_3)	FIELD MEDIAN (Y_4)
Mean	10.66(11)	11.03(11)	10.62(11)	11.62(12)	10.18(10)
σ	6.25(6)	6.57(7)	7.62(8)	7.27(7)	6.67(7)
CV%	58.64	59.56	71.83	62.56	65.52
r		0.84*+	0.91*+	0.99*+	0.95*+
r^2		0.71	0.83	0.98	0.90
Y/X		Y =0.88X+ 1.62;	=1.11X-1.21;	=1.15X-0.66;	=1.01X-0.62

* Significant at 0.1% level
\+ Z-ratio demonstrates real association for the r-value

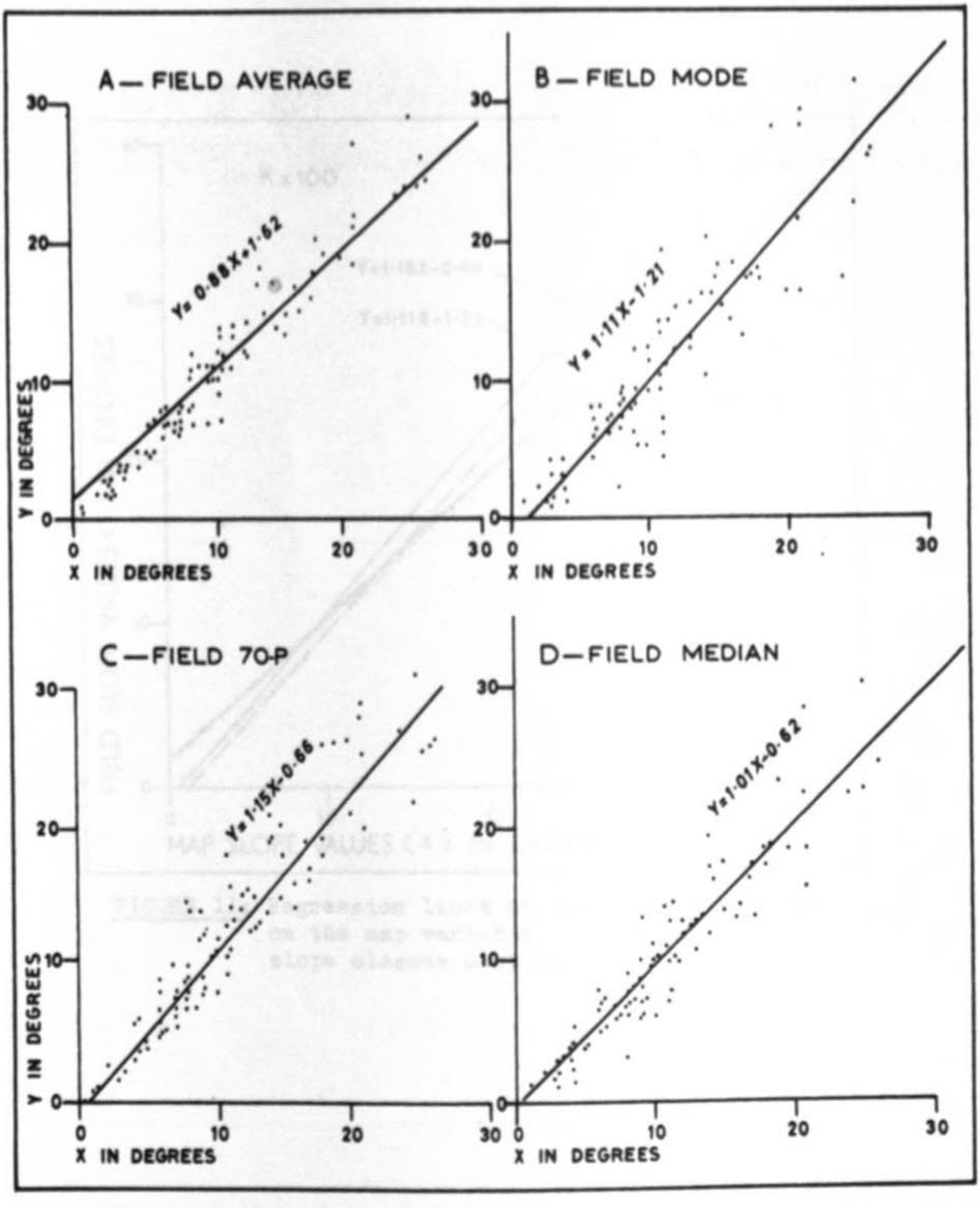

FIGURE 10: Scatter diagrams with superimposed regression lines of the field variables (Y_1, Y_2, Y_3, Y_4) on the map variable (X)

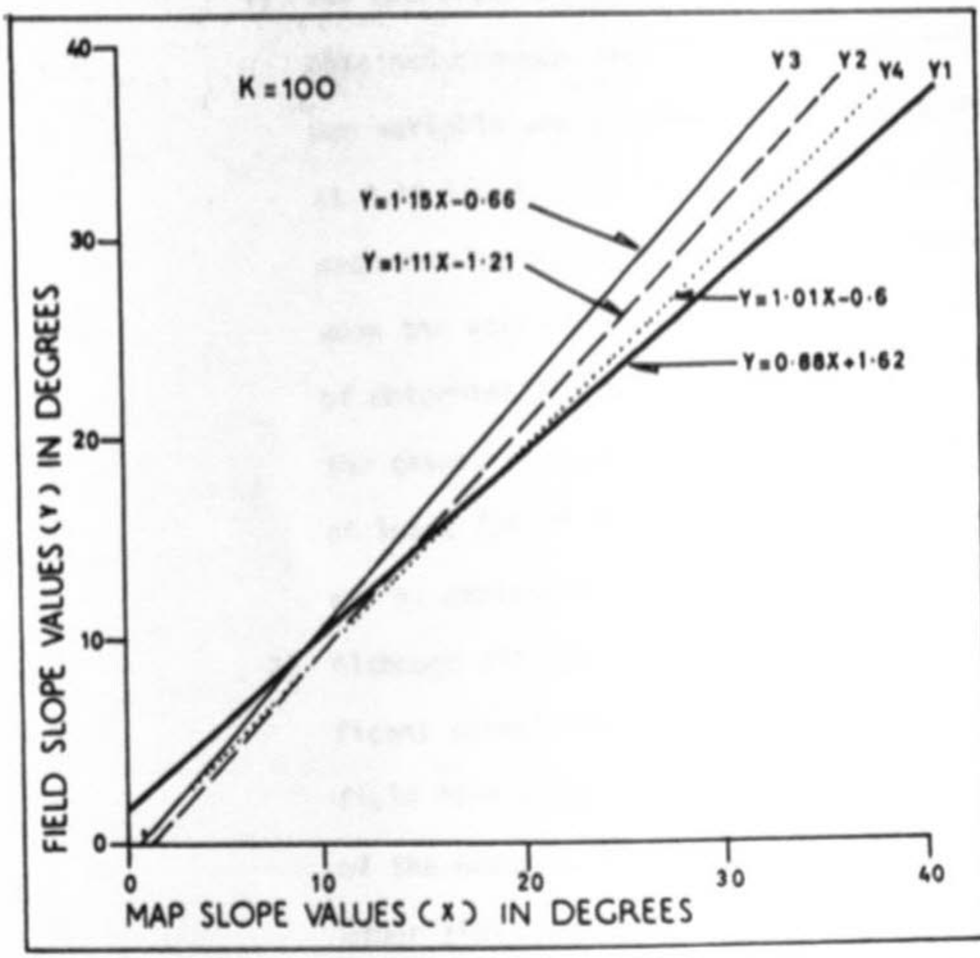

FIGURE 11: Regression lines of the field variables (Y_{1-4}) on the map variable (X) for all the slope classes combined

1) The coefficients of correlation (r) which were obtained between each field variable and the map variable are positive and are significant at 0.1% level. A Z-ratio test revealed that each r-value represents real association between the variables compared. Since the coefficient of determination (r^2) is higher than 0.70 in all the cases, it implies that in all these cases at least 70% of the changes in the field values can be explained by the changes in the map values.

2) Although all the four field variables show significant correlation with the map variable, the field 70-p seems to be a slightly better measure of the accuracy of the map variables than any other field variable. Its arithmetic mean of 11.65° (12) is the closest to the population mean of 12.75° (13) shown in Table 5. The coefficient of determination (r^2) between the field 70-p and the map variable is the highest (0.98), and it suggests that about 98% of the changes in this variable can be explained by the changes in the map variable. Therefore, the field 70-p might, probably, represent more accurately the maximum slope values as calculated from the base maps than other field variables.

3) A Null Hypothesis test of the mean, applied to pairs of map and field variables revealed that the difference between any pair is not significant at better than 5% level. This means that the variables represent the same population.

Results and interpretation for slope Class A ($0 - 1^{o}$). The very small size of this slope class (k = 4) suggests that the results should be interpreted with care, even when methods of small sample analysis are adopted. The results obtained from this class are considered to be considerably representative of the characteristics of this class, in the study area, for one important reason. If it had been possible to investigate a larger sample size in the swampy flats associated with this slope class in the Ulu Langat District, the field values would probably be found not to differ significantly from the map values. Tables 5 and 7 show that all of the arithmetic mean-values obtained for this class, including the mean for the population, approximate to 0^{o}. The following results, illustrated in Table 7 and Figure 12a, were obtained for this slope class.

1) A perfect positive correlation seems to exist between each of the field average and field 70-p and the map variable. Both the r-value and the r^2-value for each of the pairs are given as 1.00. This implies that all of the changes in the field average and the field 70-p can be explained by changes in the map variable.

TABLE 7 : Statistical results of map (x) and field (Y) variables for slope Class A ($0 - 1^{\circ}$)

k = 4

PARAMETER	MAP (X)	FIELD AVERAGE (Y_1)	FIELD MODE (Y_2)	FIELD 70-p (Y_3)	FIELD MEDIAN (Y_4)
Mean ($^{\circ}$)	0.50(0)	0.50(0)	0.25(0)	0.50(0)	0.25(0)
σ	0.50(0)	0.50(0)	0.43(0)	0.50(0)	0.43(0)
CV%	100.00	100.00	172.00	100.00	172.00
r	-	1.0+ *	0.60n.s.+	1.0 + *	0.60 n.s.+
r^2	-	1.0	0.36	1.0	0.36
Y/X		Y = X + 0;	= ½X + 0;	= X + 0;	= ½X + 0

* = Perfect correlation
n.s. = correlation not significant at 5% level.
\+ = Z-ratio shows real association for the r-value.

2) Conversely, the positive correlation ($r = +0.60$), which exists between either of the field mode or the field median and the map variable, is not significant at 5%level, although the r^2 - value (0.36) suggests that approximately 36% of the changes in these field variables can be explained by changes in the map variable. Z-ratio tests of r-values revealed that the association between the field variables and the map variable could be real, even if it might not be significant at 5% level.

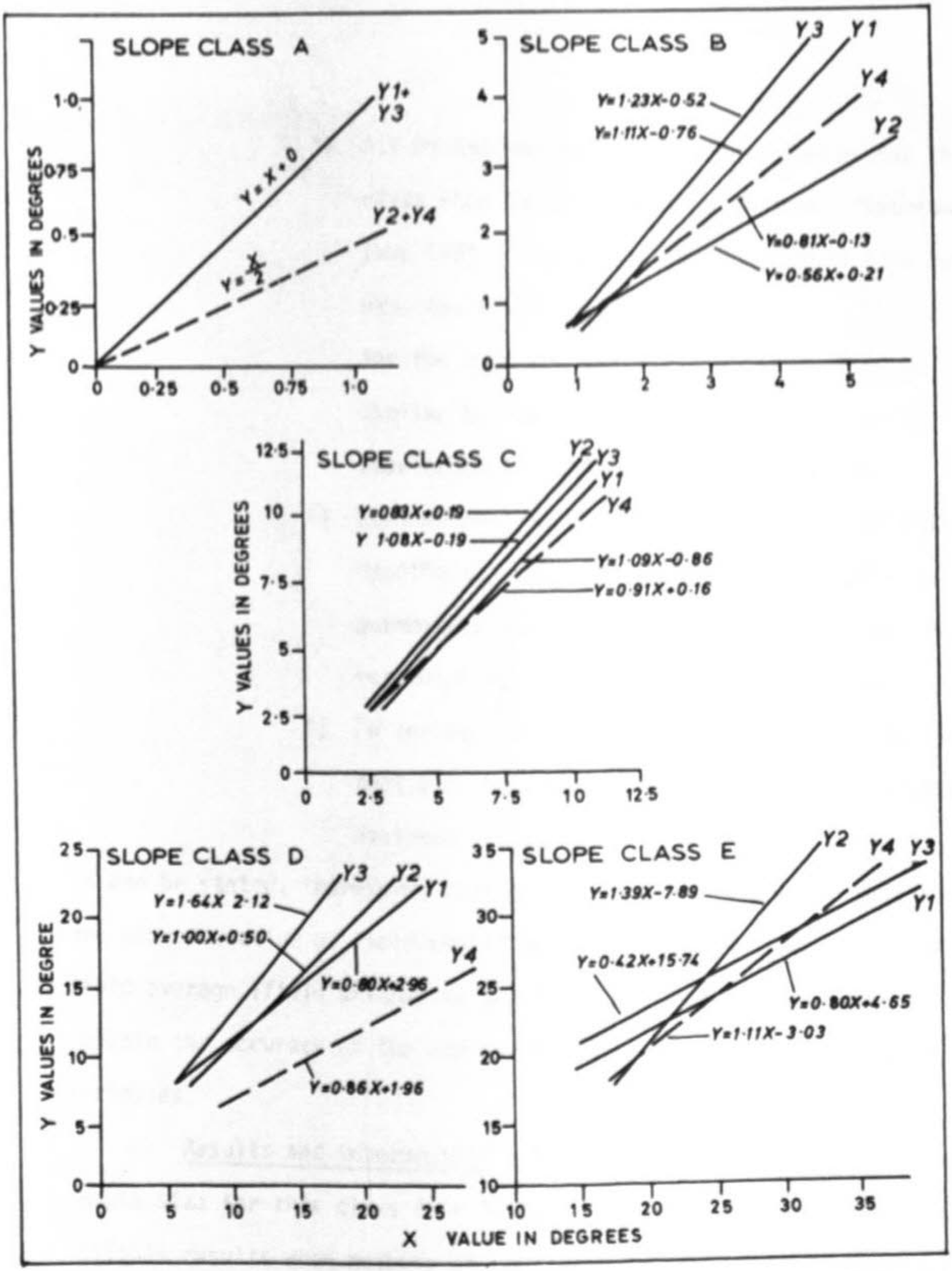

FIGURE 12: Regression lines of the field variables (Y_{1-4}) on the map variable (X) for individual slope classes

3) All of the map and the field variables for this class show large variations in their distribution (see CV%). The variations range from 100% for the map, the field average, and the field 70-p to 172% for the mode and the field median. This is similar to the great variation (250%) in the population for this class (see Table 5).

4) Further analyses of the mean and the CV% (Null Hypothesis) revealed that the differences in parametric values between pairs of map and field variables are not significant at 5% level.

5) An inspection of the raw data (Appendix 1) revealed that all the field values are contained within the assigned class.

It can be stated, therefore, that the calculated values for this class are representative of field conditions, and that the combination of the field average (field arithmetic mean) and the 70-p values seems to explain the accuracy of the map values better than the other field variables.

Results and interpretation for slope Class B (2 - 4^{0}). The sample size for this class (k = 13) might be expected to produce fairly reliable results when methods of small sample analysis are adopted. The following results were obtained for this slope class by the adoption of such methods (see Table 8 and Figure 12b).

1) A positive correlation, significant at 0.1%, exists between the field average and the map variable, and a positive correlation, significant at 5% level, is shown between the field 70-p and the map variable. The r^2-values of these pairs suggest that approximately 66% of the changes in the field average, and 35% of the changes in the field 70-p, can be explained by changes in the map variable.
2) In contrast, the positive correlation which was obtained between the map variable and each of the field mode and field median is not significant at 5% level. Z-ratio tests showed that, while all the other field variables demonstrate real association with the map variable, the field mode does not. This might be explained by the fact that the most recurring value for this class in the field (2^o) is lower than the average maximum slope values calculated from the base maps (see Appendix I).
3) The internal variation of each variable is much lower than the internal variation of the same variable in slope Class A, but the variations within the field variables are larger than the variation within the map variable (see Table 8). The higher variations in the field variables might reflect the combination of steep slopes at head-valleysides and the flat terrains at the summits, interfluves,

TABLE 8 : Statistical results of map (x) and field (Y) variables

For slope Class B (2 - 4°)

PARAMETER	MAP (X)	FIELD AVERAGE (Y_1)	FIELD MODE (Y_2)	FIELD 70-p (Y_3)	FIELD MEDIAN (Y_4)
Mean (°)	3.31 (3)	2.92 (3)	2.08 (2)	3.54 (4)	2.54 (3)
σ	0.61 (1)	0.81 (1)	1.21 (1)	1.22 (1)	1.08 (1)
CV%	18.42	28.42	58.17	34.46	42.51
r	-	0.81 *+	0.30 N.S.	0.59 *+	0.46 n.s. +
r^2	-	0.66	0.09	0.35	0.21
Y/X		Y = 1.11X - 0.76;	= 0.56X + 0.21;	= 1.23X - 0.52;	= 0.81X - 0.13

* = Correlation significant at 5%, or better, level.
n.s. = Correlation not significant at 5% level.
N.S. = Correlation not significant at 5% level, and does not show real association.
\+ = Z-ratio shows real association for r-value.

and valleyfloors, which characterise the land surfaces represented by this slope class.

4) Analyses of the mean and CV% revealed that the difference which exists between each field variable, except for the field mode, and the map variable is not significant at 5% level.

5) An inspection of the basic data showed that 88.5% of the 52 field values involved in the analyses for this class are contained within the assigned class limits.

It seems that the field average is the best estimate of the accuracy of the map values for this class, but that both the field average and the field 70-p can be combined to explain the slope characteristics of the terrain represented by this slope class.

Results and interpretation for slope Class C (5 - 10°). The size of this class (k = 38) is sufficiently large to produce reliable results when methods of small sample analysis are followed. The results which were obtained for this class are illustrated in Table 12c and are tabulated in Table 9. The following are the relationships between the map and field variables.

TABLE 9 : Statistical results of map (X) and field (Y) variables for slope Class C (5 - 10°)

k = 38

PARAMETER	MAP (X)	FIELD AVERAGE (Y_1)	FIELD MODE (Y_2)	FIELD 70-p (Y_3)	FIELD MEDIAN (Y_4)
Mean (°)	7.71 (8)	7.55 (8)	7.34 (7)	8.13 (8)	7.21 (7)
σ	1.45 (1)	1.93 (2)	2.41 (2)	2.32 (2)	2.05 (2)
CV%	18.80	25.56	32.83	28.53	28.43
r	-	0.81 *+	0.58 *+	0.70 *+	0.67 *+
r^2	-	0.66	0.34	0.49	0.45
Y/X		Y = 1.09X - 0.86;	= 0.93X + 0.19;	= 1.08X-0.19;	=0.91X + 0.16

* = Correlation significant at 0.1%
\+ = Z-ratio shows real association for the r-value.

1) A positive correlation, significant at 0.1% is shown between each field variable and the map variable. Z-ratio tests revealed that the r-value for each pair shows real association between the map and the field variables. The values of r^2 suggest that approximately 66% of the changes in the field average, 49% of those in the field 70-p, 45% of the changes in the field median, and 34% of those in the field mode can be explained by the changes in the map variable.

2) The internal variations of the field variables for this class are smaller than the internal variations of the variables in the two lower classes. When it is considered that the size of this class is larger than the size of each of the two lower classes, it would seem that the slope values in the Ulu Langat District vary less in the higher slope classes than they do in the lower slope classes.

3) Null Hypothesis tests of the mean and the CV% showed that the differences in the parametric values between pairs of the field and map variables are not significant at 5% level, which implies that the values represent the same population.

4) An inspection of the basic data (Appendix I) showed that 92.8% of the 152 field values for this class are contained within the class limits, while 1.3%

of these fall below the lower class limit, and
5.9% fall above the upper class limit.

Again, it seems that the field average combined with the field 70-p will explain the accuracy of the map values more than the other field variables.

Results and interpretation for slope Class D (11 - 19^{o}). This class has a sample size of k = 34, and by the adoption of methods of small sample analysis the following results were obtained for the class (see Table 10 and Figure 12d).

TABLE 10 : Statistical results of map (X) and field (Y) variables for slope Class D (11 - 19^{o}).

K = 34

PARAMETER	MAP (X)	FIELD AVERAGE (Y_1)	FIELD MODE (Y_2)	FIELD 70-p (Y_3)	FIELD MEDIAN (Y_4)
Mean (^{o})	13.61 (14)	13.88 (14)	14.18 (14)	15.77 (16)	13.65 (14)
σ	2.56 (3)	2.88 (3)	4.44 (4)	3.88 (4)	3.31 (3)
CV%	18.81	20.74	31.31	24.60	24.25
r	-	0.87 *+	0.72 *+	0.81 *+	0.77 *+
r^2	-	0.78	0.52	0.66	0.59
Y/X		Y = 0.80X + 2.96;	= 1.00X + 0.50;	= 1.64X - 2.12;	= 0.86X = 1.96

* = Correlation significant at 0.1% level
\+ = Z-ratio shows real association for the r-value.

1) A positive correlation, significant at 0.1% level, is shown between each field variable and the map variable. Z-ratio tests revealed that each r-value represents real association between the field and the map variables. The lowest coefficient of determination (r^2) is 0.52, which suggests that at least 52% of the changes in the field variables can be explained by changes in the map variables. The proportion is 78% for the field average and 66% for the field 70-p.

2) The internal variations (CV%) in the field variables are lower than the within-class variations in the field variables of the three lower classes. This would seem to be a further justification of the suggestion that higher slope classes in the Ulu Langat District vary less in individual values than lower slope classes.

3) The application of the Null Hypothesis test to the mean and the CV% values of pairs of field and map variables revealed that the differences in the parametric values are not significant at 5% level. This suggests that all the variables represent the same population.

4) An inspection of the basic data showed that 92.0% of the 136 field values, involved in the analyses for this slope class, are contained within the class limits. Three percent of the values fall below the

lower limit, and five percent of the values fall above the upper limit.

Once again, the combination of the field average and the field 70-p appears to be the best measure of the accuracy of the map values for this slope class.

Results and interpretation for slope Class E ($20 - 29^0$). The size of this class (k = 10) suggests that the results of the statistical analyses for this class should be interpreted with caution, even when such results have been determined by the use of methods of small sample analysis. Table 11 and Figure 12e show the results for this class by the use of such methods.

TABLE 11 : Statistical results of map (X) and field (Y) variables for slope Class E ($20 - 29^0$)

k = 10

PARAMETER	MAP (X)	FIELD AVERAGE (Y_1)	FIELD MODE (Y_2)	FIELD 70-p (Y_3)	FIELD MEDIAN (Y_4)
Mean (^{0})	23.10 (23)	23.30 (23)	24.10 (24)	24.60 (25)	22.7) (23)
σ	2.38 (2)	2.00 (2)	6.38 (6)	2.33 (2)	2.83 (3)
CV%	10.13	8.60	26.47	9.47	12.41
r	-	0.61^{*}+	0.45 n.s.+	0.49 n.s+	0.64^{*}+
r^2	-	0.37	0.23	0.24	0.41
Y/X		$Y = 0.52X + 11.25$;	$= 1.21X - 3.76$;	$= 0.48X + 13.51$;	$= 0.76X + 5.12$

* = Correlation significant at 5% level
n.s. = Correlation not significant at 5% level
\+ = Z-ratio shows real association for the r-value.

1) A positive correlation, significant at 5% level, exists between each of the field average, and field median, and the map variable. The r^2-values show that 37% of the changes in the field average and 41% of the changes in the field median can be explained by changes in the map variable.

2) The positive coefficients of correlation which were obtained between the map variable and both of the field mode and the field 70-p are not significant at 5% level. In fact, the r^2-values for these coefficients suggest that only 23% of the changes in the field mode, and 24% of those in the field 70-p could be explained by changes in the map variable.

3) The internal variations (CV%) within all the field variables are the lowest for all the classes analysed. The field average has a CV% of 8.60% and the others, except for the field mode, have coefficients of variation less than 13%. These low variations suggest that the land surfaces represented by this slope class are characterised by slope angles that differ very little from the mean value for the class.

4) Further tests of the mean and the CV% shows that the differences in the parametric values of pairs of field and map variables are not significant at 5% level.

5) An inspection of the basic data showed that 77.3% of the 40 field values are contained within the class limits. Approximately 15.9% of the values fall above the upper limit, and 6.8% fall below the lower limit. Since the higher values are associated with the field mode and field 70-p (see Appendix 1), it can be suggested that these higher-than-class values constitute the main reason why both the field mode and the field 70-p fail to measure the accuracy of the map values adequately.

For this slope class, it can be seen that the combination of the field average and the field median provides the best measure of the accuracy of the map values. This measure is not as adequate as the measures which were determined in the case of the other classes (compare the regression lines in Figure 12e with the lines in Figures 12 a - d).

<u>Inter-Class variations</u>. The application of the Null Hypothesis of the mean to the mean values and the standard deviation values, of each variable for any pair of classes, showed that the differences in these parameters between any two classes are significant. The lowest level of significance (2% level) is between slope Classes A and B, on the one hand,

and between slope Classes D and E, on the other. All the other combinations of classes show significant differences at 0.1% level. This implies that the slope classes identified for this study are significantly different one from the other in terms of their parametric values.

Discussion and Conclusions

It will be necessary to discuss further three of the points which were raised above. These are:

1) the pattern of the CV% from one class to another;
2) the case of slope Class F (30° and over) which was not analysed; and
3) the selection of the field variable/s that will best estimate the accuracy of the map values and, consequently, the suitability of the techniques which were employed to obtain and classify the values.

Pattern of the CV% from one class to another. It can be noted from the results presented above that the within-class variations in the field variables decrease from the lower slope classes to the higher ones. The highest variation which was obtained is for slope Class A, and it is equal to, or greater than, 100%. The lowest variation is for slope Class E, and it is more than 8%, but not greater than 27%. The decreasing change from the lower to the higher slope classes was never observed to be reversed in any of the field cases. The pattern is the same in the case of the population (see Table 5). It can be contended, therefore, that the slope values in areas associated with the higher slope classes vary less than the values in areas associated with lower slope classes in the Ulu Langat District.

Slope Class F (30^{0} and over). It was stated earlier in this Chapter that it would make very little difference to the land planning policies to be followed in a humid tropical mountain area whether the slope values were actually 30^{0}, or over. The pattern of the CV% as discussed above, and the highly significant results which were obtained for all the classes combined, seem to suggest that the exclusion of slope Class F from the analyses on the individual class level could not have affected, adversely, the test for the accuracy of the map values, and the suitability of the techniques. Consequently, the exclusion of the class from the class-level analyses has not adversely affected the purpose of this study.

Best measure of the accuracy of the map values. In four cases (Classes A, B, C, D) out of the six cases analysed, the field average (field arithmetic mean) combined with the field 70-p was observed to provide the best measure of the accuracy of the map values. The field average was observed to show significant correlation with the map variable in all the six cases, and the field 70-p is significantly correlated with the map variable in five of the six cases. The field median is significantly correlated with the map variable in four cases, while the correlation between the field mode and the map variable is significant at 5%, or better, level in three cases. The results suggest that the field average (field arithmetic mean) and the field 70-p are to be considered as the two best measures of the map values. Consequently, for the purpose of this study, the slope map will best be interpreted in the terms of the class mean value and the class 70-p value.

From all of the above, it can be concluded that the results show that:

1) the map values which were obtained from the topographical maps are highly representative of the slope conditions in the study area;
2) the techniques employed to obtain and classify these values are adequate for the purpose of the study and the scale of the base maps;
3) the classification of the slope values is statistically viable; and
4) the slope classes are considered suitable for land planning purposes in the Ulu Langat District, since the classification was based on morphological and technical-economic requirements (see Chapter 3).

However, the maximum slope values, as calculated from the topographical maps, will best be interpreted in terms of the combination of the field average and the field 70-p values. In practice, individual slope zones on Map 1(An Average-Maximum Slope Map for the Ulu Langat District) should be interpreted as: at least 70% of the surface area represented by the slope zone is inclined at angles equal to, or less, than the mean slope angle for that slope zone.

The slope map is combined with maps of related indices of terrain (cited in Chapter 3) to classify, and map, the land-surface of the Ulu Langat District, as will be shown in Chapter 5.

CHAPTER 5

CLASSIFICATION, COMPILATION, AND DESCRIPTION OF A LAND CATEGORY MAP OF THE ULU LANGAT DISTRICT

The problems of geomorphological mapping which include those of landform mapping have been discussed in Chapter 3, and will not be discussed further in this Chapter. It should be recalled, though, that these problems include those associated with the scale of mapping, the basis of landform classification and the method of mapping. The present Chapter is concerned primarily with 1) the classification of the landforms of the Ulu Langat District, 2) the compilation of the Land Category Map (Map 2) based on the classification, and 3) the description of the classified Land Categories on the basis of their various Land Units. Before these primary objectives are discussed, two other pertinent points will be examined. These are a) the meaning of the term "landform mapping" as employed in this study, and b) existing landform classification in West Malaysia and other parts of "continental" South-East Asia,[1] with particular reference to landform classifications by the Commonwealth Scientific and Industrial Research Organization (C.S.I.R.O.) for New Guinea.

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1. "Continental" South-East Asia is taken to include the Indian sub-continent, and the Peninsulae and islands consisting of what is generally referred to (Ooi, 1963) as the Sunda Shelf, including New Guinea.

Landform Mapping

Thomas (1969), and Swan (1970b) have recognised three main types of land-surface mapping[1] which have emerged from the works of geomorphologists in recent decades. First, there is morphological mapping which recognises the shape and form of the land (Thomas, 1969). With this type of land-surface mapping technique, maps can be compiled on very large scales, and such maps are capable of showing (among other things) breaks and changes of slope, direction of true slope, and micro-reliefs. Savigear is the most frequently quoted authority on morphological mapping. This type is not pursued in this study because it would have required base maps larger in scale than the most comprehensive topographical maps available for the study area, and because a morphological map would involve details that might not be of practical use, without modifications, in agricultural-type land planning. Secondly, there is geomorphological mapping which, according to Thomas (1969), combines the salient aspects of morphological mapping with those of landform mapping, plus additional comments on relative ages, relict features and processes of the evolution of the identified forms. The requirements for this type of land surface mapping are well documented by Klimazewski (1962, 1963). This type of land-surface mapping is not followed in this study because it seeks to explain the present form of the land in terms of genetic interpretations. It has been noted earlier that

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(1) All types of mapping are referred to as "land-surface mapping", or "land mapping" in this study.

genetic interpretations are associated with subjective inferences which would serve no practical purpose in the allocation of the land for various uses. Thirdly, there is landform mapping which recognises shape, surface materials and drainage conditions (Christian, 1958; Mabbutt and Stewart, 1963; Speight, 1968; Beckett and Webster, 1969). In essence this is the identification of landforms for the purposes of qualitative and/or quantitative analyses (Weaver, 1965). The identified and analysed landforms would then be assembled into broader synthesised units (Weaver, 1965; Thomas, 1969; Swan, 1970b). Such synthesised units characterise the C.S.I.R.O. and the Military Engineering Experimental Establishment (M.E.X.E.) Land System maps (see Beckett and Webster, 1969). A "user" landform map, as defined in this study, is a type of landform map whereby the synthesised units are delimited in accordance with the requirements of the users (Benn and Grabau, 1968). The "user" landform type is desirable in an area 'where the accent is to be on land development' (Swan, 1970b; pg. 91).

Existing landform classifications: West Malaysia and parts of "Continental" South-East Asia.

Existing landform classifications in West Malaysia include the experimental classification by M.E.X.E. (1964), the generalised classification by Ho (1964) and by Beaven (1967), and a morphometric classification for the entire country by Eyles (1968a). There has been a morphometric landform classification by Swan (1970b) for Johore State. A summary of these existing landform classifications in West Malaysia is given in Table 12. While the first four landform classi-

TABLE 12 : Existing Landform Classifications in West Malaysia

CLASSIFIER	LANDFORMS
Ho (1964)[1]	Steep mountains, undulating to hilly land, and plains often swampy.
M.E.X.E.(1964)[1]	Dissected upland, rounded hills with moderate relief, undulating lowlands, isolated limestone hills, matured rivers, lowland plains and mangroves, and East Coast sand complex.
Beaven (1967)[1]	(Provisional) mountains, steep hills, low hills, and plains.
Eyles (1968)[2]	High mountains, low mountains, deeply dissected low mountains, isolated steep high hills, isolated steep hills, low convex hills, and (land with no 4th-order stream)
Swan (1970)[2] Johor	(Simplified form) Denudational: Mountains, high hills and ridges, low hills and ridges, high plains, dissected lowlands; (Simplified form) Depositional: Terrace (fluvialite), alluvial plains (sub-divided into 'A, Am, A' according to drainage conditions), "raised" beaches, and tidal swamps.

1. Source: Table 1 in Swan (1970b).
2. Source: Original work cited.

fications in this table are indicative of the terrain conditions in West Malaysia, they are too generalised for practical use in land planning (Swan, 1970b). In fact, the classification by M.E.X.E. (1964) was undertaken to test whether, or not, the landforms of West Malaysia could be classified by Land System mapping techniques designed by the group (Beckett and Webster, 1969). The result was, therefore, very experimental. The last landform classification in Table 12 (Swan, 1970b) is better than the others for land planning purposes, because limitations for agricultural landuse are incorporated in the final map based on the classification.

Examples of landform classifications in other parts of "Continental" South-East Asia include classifications 1) by P.Wong (1968) for Singapore, 2) by Jalal-Ud-Din, et al. (1970) for the Indus Delta, 3) by Mabbutt, et al. (1965) for Port Moresby-Kairuku area in Papua, and 4) by Ruxton, et al. (1969) for Kerema-Vailala area in Papua. P. Wong's classification is similar to Eyles's (1968a) classification for West Malaysia by which landform hierarchy is not clearly indicated. The classification by Jalal-Ud Din, et al. (1970) shows a major landform order based on processes of land evolution, and a secondary order based on drainage conditions. Criteria used in this work are highly qualitative, and there is no indication of the utilisation of the landforms identified. The last two classifications are examples of Land System classifications commonly adopted by the C.S.I.R.O. Such classifications usually show landform orders on the basis of both qualitative and quantitative criteria, specify the extent of individual land types, and suggest the use capability of these types.

The landform classification designed for this study is closer to the Land System classifications by the C.S.I.R.O. than the others cited. In addition, the landform classification adopted in this study incorporates some aspects of the morphometric analysis contained in the landform classification by both Eyles(1968a) and Swan (1970b).

C.S.I.R.O. Land System mapping and this study. The basis of landform classification, the method of compiling landform maps based on the classification, and the scale of preparatory and final maps employed by the C.S.I.R.O. are contained in the Land Research Report Series by the organisation. Such reports include those by Christian and Stewart (1953), Mabbutt, et al. (1965), Speight (1966, 1967), and Ruxton, et al. (1969). They are also discussed in reports of, and discussion-articles on, land evaluation projects. Works in this category include those by Christian (1952, 1958), Mabbutt and Stewart (1963), Stewart, ed. (1968a, 1968b), and Scott and Austin (1971). The objectives of these Land System classifications are discussed by Christian (1952), Haantjens (1965), and Renwick (1968).

Briefly, the Land System classifications are undertaken largely in under-developed areas (Renwick, 1968) in order to compile reconnaissance survey maps which would be suitable as a basis for regional development and for agricultural researches (Haantjens, 1965). The final maps are generally at a scale of 1/250,000 on which Land Systems and Land Units are shown. A Land System is described as 'an area, or group of areas, throughout which there is a recurring pattern of topography, soil and vegetation' (Speight, 1968; pg. 240). A Land System is made up of Land Units grouped morphogenetically in order of increasing slope and altitude (Ruxton, et al., 1969). More recent Land System maps are compiled by extrapolating maps of parametric indices of terrain which include relief, slope, vegetation, soil, and drainage. The maps are supplemented with plans and block-diagrams, and the identified Land Systems are described in tables on the basis of component units, area, slope, vegetation, and capability.

There are three broad areas of similarity between the C.S.I.R.O. Land System mapping concepts and techniques and the concepts and techniques of landform mapping designed for this study.

1) The present study, like the C.S.I.R.O. surveys, is expected to yield information which would be suitable for agricultural land planning. The fact that only 40% of the study area is classified as undeveloped is no deterrent to this objective, because land evaluation is expected to be repeated as often as changes occur in the need of the land, and in the needs of the poeple (Butler, 1955; Stewart, 1968).

2) The criteria for, and the method of, landform classification followed in this study are basically the same with those usually employed by C.S.I.R.O.. Maps of parametric indices of terrain, supplemented by air photograph interpretation, were extrapolated to identify areas of recurring patterns of topographical characteristics. A recurring pattern was classified as a Land Category which is similar to a Land System. A different terminology is adopted because a Land Category is not exactly the same as a Land System for the following reasons.

a) The recurring patterns mapped as Land Categories are based on total relief and the steepness of the land, , and not on tonal patterns of vegetations as usually practised for Land Systems.

b) The scale of mapping and the nature of the investigations followed in this study have made it possible to discuss the Land Categories in greater detail than is generally possible in the case of Land Systems.

c) The term "Land Category" makes it possible to imply these differences and, therefore to prevent any misinterpretation that would have arisen if the term "Land System" had been adopted. Each Land Category was subdivided into Land Units on the basis of soil, slope, and drainage conditions. These Land Units are basically the same as the Land Units of C.S.I.R.O..

3) The techniques adopted to compile and describe the Land Category map (Map 2) follow the techniques employed by C.S.I.R.O.. Compilation involved the superimposition of base maps in order to draw land-type boundaries. A point of difference from the C.S.I.R.O. procedure is that the boundaries of the Land Categories and Land Units identified in the study area were checked in the field for necessary adjustments. A second difference is that panoramic coloured photographs have been preferred

to block diagrams in the description of the landforms. Land Categories and Units are described on the basis of physiography, geology, slope, soil, landuse conditions; as against the practice of describing the Land Units by Tables alone. The latter practice is usually adopted by the C.S.I.R.O..

Classification of Landforms.

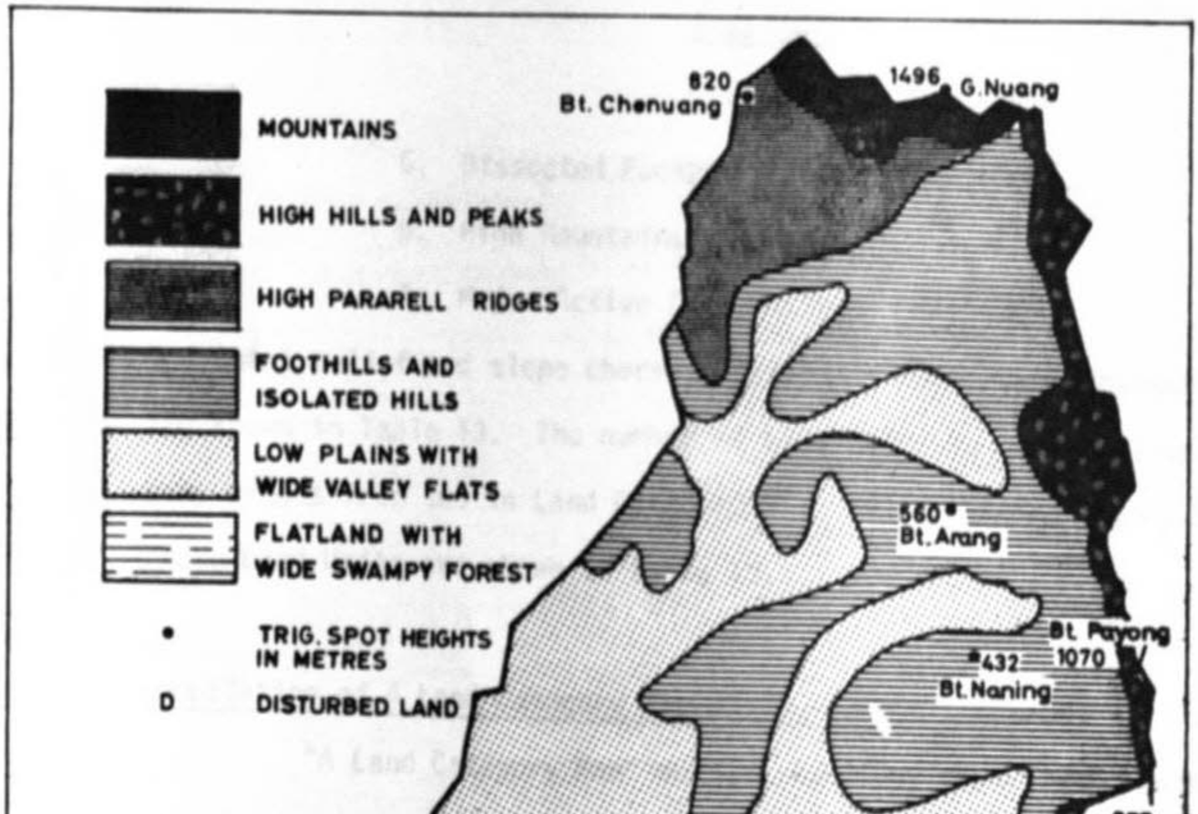
The dominant parameter used to classify the landforms of the Ulu Langat District is the slope angle, for the reasons discussed in Chapters 3 and 4. The complementary land attributes are total relief (elevation above mean sea level), soil characteristics, and drainage types as defined in Chapter 3. These land attributes were supplemented by air photograph interpretation undertaken to identify associations of forms and their orientation, because air photograph interpretation is regarded as an essential part of landform mapping (Christian, 1952; Haantjens, 1965; Speight, 1966; Mabbutt, 1968; Desai, 1968; Beckett and Webster, 1969).

Air photographs covering the study area were interpreted in order to a) obtain a general over-view of the terrain of the study area in terms of the associations of forms and their orientation, b) produce a land-surface map based on recurring patterns of "hilliness" and "steepness". To this end, a Casella Desk Stereoscope was used to read the air photographs which were taken in August 1966, and were produced at an average scale of 1/25,000. Recurring patterns were identified and mapped. Certain photographs on which "form regions" could not easily be identified with the aid of the Desk Stereoscope were scrutinised on a Hilger and Watts (SB 115-1) Sketchmaster to facilitate separation into component form-regions. Form-regions were not identified by the use of tonal patterns of vegetations because the artificial vegetation covering up to 60% of the study area is at different stages of growth. Tonal patterns in such areas might reflect the relative age of the plantations and not necessarily the nature of the terrain.

The "form region" maps sketched from the air photographs were combined into a single land-surface map of the District (Figure 13). This map was combined with Map 1 (A Slope Map of Ulu Langat District) and the map of total elevation (Figure 3) to identify Land Categories. The Land Categories were sub-classified into Land Units by reference to soil and drainage base maps. Slope characteristics were used to readjust the domain of each Land Unit.

Seven Land Categories were identified in the study area. Six were numbered 1, 2, ... 6 in their increasing order of total relief and slope characteristics. The seventh was identified as Major Active Floodplains and was numbered 7. The following are the Land Categories:

1. Southern Depression,
2. Lowland Plains,
3. Depression Rim,
4. Deeply Dissected Highlands,



<u>FIGURE 13</u>: Land-surface map of the Ulu Langat District based on air photograph interpretation

5. Dissected Foothills and Low Mountains,
6. High Mountains,
7. Major Active Floodplains.

The total relief and slope characteristics of these Land Categories are shown in Table 13. The number of Land Units in each Land Category ranges from two in Land Category 1 to six in Land Category 3. These Land Units are shown in Table 13.

Compilation of A Land Category Map of Ulu Langat District

"A Land Category Map" means a landform map showing both the Land Categories and their component Land Units. Such a map was compiled for the study area by a technique of superimposition of base maps. There were two stages in the compilation 1) the delimitation of the Land Categories and 2) the delimitation of the Land Units.

Delimitation of the Land Categories . Three base maps were used in the delimitation of the landforms into Land Categories. These were the slope map (Map 1), the elevation map (Figure 3) and the land-surface map based on air photograph interpretation (Figure 13). All the base maps were at a scale of 1/63,360, and were drawn on tracing sheets. As a first step a fusion of the slope and elevation maps was effected by tracing the elevation boundaries (as shown in Figure 3) on the slope map. The land-surface map was then superimposed on the combined slope-elevation map. A tracing sheet was placed over the superimposition of the base maps. Land Category limits were drawn on this tracing sheet at boundaries common to slope, elevation, and land-surface maps, or at boundaries common to any two of them. Where a boundary common to at least two of these base maps was not obtained, the Land Category limit was drawn to coincide with the slope boundary. The Land Category limits were later checked in the field for necessary adjustments before they were confirmed.

Delimitation of Land Units. The tracing sheet on which the Land Category limits had been drawn was placed on a superimposition of two other base maps in order to delimit Land Units. The two base maps, soil map and drainage map, had been redrawn on tracing sheets on a scale of 1/63,360. The soil map was taken from I. Wong's (1966) report. The drainage map was obtained from the Drainage and Irrigation Department, Ulu Langat District Office, Kajang. Soil boundaries were exclusively employed to draw Land Unit limits in the Southern Depression and in Major Active Floodplains because the drainage types (patterns) in these Land Categories had been observed to be relatively uniform. A combination of both soil and drainage boundaries was generally adopted in the other Land Categories, though some Land Units were delimited exclusively on the basis of the drainage type. Such Land Units include the watersheds. Other Land Units, especially in the Lowland Plains, were delimited mainly on the basis of the soil type. In all the cases, the limits of the Land Units were adjusted on the basis of slope characteristics. These limits were confirmed after subsequent field work and analysis of soil and land attributes had been undertaken.

Mining flats, quarries, and nucleated settlements occupying at least 4 hectares (10 acres) have been mapped as Disturbed Land to differentiate them from Land Units, since such areas require land planning techniques which differ from the techniques of agricultural land planning. The term "Disturbed Land" has the connotation ascribed to it by the Malaysian Soil Survey Staff.

Description of the Land Categories and the Land Units

A Land Category as identified in this study is an area, or group of areas, throughout which there is a recurring pattern of topography, slope and elevation. A Land Unit is a land area over which slope values, soil types, and drainage conditions are approximately the same. A Land Unit is contained within the same total relief zone. Land Categories and Land Units shown in Map 2 are illustrated in Table 13, Figures 15 to 17, and Plates 1 to 15. These illustrations are found with an outline description of the Land Categories and the Land Units in an annexe to this Chapter.

The soil Capability Classification shown in Table 13 is based on I. Wong's (1966) soil report for Selangor. Figure 14 is a summary of the Capability Classification contained in the report. In essence, soil types have capability classes ranging from 1 (soils with little or no limitations to agricultural use) to 5 (soils with at least one very serious limitation). This soil Capability Classification has been combined with the landuse at the time of field investigation, the slope characteristics, and the drainage conditions

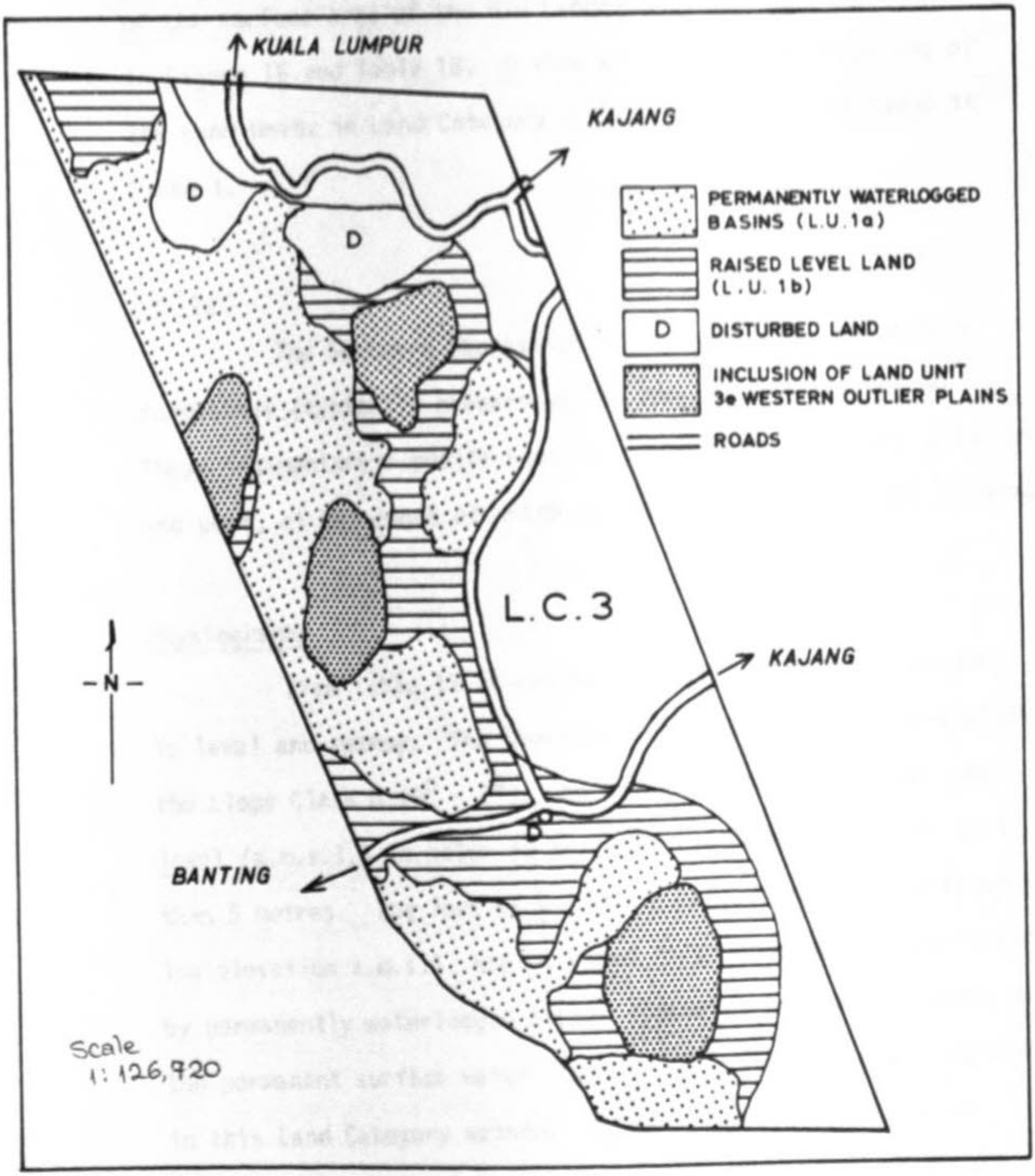


FIGURE 16: A plan of the distribution of Land Category 1 - Southern Depression

of the surface area of the Ulu Langat District as illustrated in Figure 15 and Table 13. A view of the category from one of the Land Units in Land Category 3 (Depression Rim) is shown in Plate 1.

Geology

The Southern Depression is underlain by sedimentary formations (typically arenaceous) of the Quaternary Period. These sedimentary deposits have been covered by Holocene alluvium and peat, at the edges of which current alluvium is still forming.

Physiography

From Table 13 it can be seen that this Land Category is level and swampy. The characteristic slope is contained within the Slope Class A (0^{o} - 1^{o}), and the elevation above mean sea level (a.m.s.l.) is below 10 metres. The local relief is less than 5 metres. The lack of a sloping surface combined with very low elevation a.m.s.l. has resulted in a land-surface characterised by permanently waterlogged basins separated by areas slightly above the permanent surface water-level (Figure 16). The main streams in this Land Category meander in large loops over the areas above the permanent surface water-level. They generally lose their channels in the swampy basins. Poor conditions of drainage would seem to be the most serious physiographic limitations to agricultural use of the Southern Depression.

Land Units

On the basis of drainage and soil conditions two Land Units have been identified from this Land Category. The swampy basins are classified as Land Unit 1a: Permanently Waterlogged Basins. The areas above the surface water-level are classified as Land Unit 1b; "Raised" Level Land. An area of "Disturbed Land" has been recognised within the Land Category. All the areas classified as Disturbed Land in the District are discussed as one at the end of this annexe.

Land Unit 1a: Permanently Waterlogged Basins. This Land Unit occupies 56.6% (5,170 ha.) of the land-surface classified as Land Category 1. Brackish water remains on the ground surface permanently over the Unit beneath a swampy vegetation. Figure 16 shows that these basins which make up this Land Unit are separated one from the other by Land Unit 1b.

Slope Characteristics - Theoretically there is no sloping surface in this Land Unit because the slope angles calculated from the area are zero in value.

Soil and Drainage Conditions - The soil under the swampy water has been mapped as Inland Swamp Association by I. Wong (1966). This Inland Swamp soil Association is made up of 35% to 65% peat, or organic matter, and of 65% to 35% silt + clay material. Where the peat is shallow and drainage is not a very serious problem the soil is rated 3 on the soil Capability Classification scale (see Figure 14). Where the peat layer is deeper than 60 cm and drainage would be a very serious problem, the soil has a rating of 4.

Present Landuse - This Land Unit is largely covered by fresh-water swamp forest, or herbaceous vegetation.

Use Classification - The first Use Classification is B2. This implies that a large part of the area could be developed into an exploitable lowland forest. The second classification is A2, which means that certain parts could be used as croplands. Such A2 areas would include the parts over which the soil has been rated 3. Special techniques would be required before such areas could become productive. Other forms of agricultural landuse (for example, fish-farming) might be more suited to these areas than crop-farming.

Land Unit 1b: "Raised" Level Land. This Land Unit averages about 10 m a.m.s.l., and occupies 34.4% (3,090 ha) of the surface area of Land Category 1. Although this area is not permanently waterlogged, it is seasonally flooded, especially after periods of heavy rainfall.

Slope Characteristics - The average slope angle calculated in this Land Unit is between 0^{o} and 1^{o}, but there are transitional areas near Land Unit 3c, discussed later, where slope angles of 2^{o}, or 3^{o}, have been obtained. The land surface is generally level.

Soil and Drainage Conditions - The inland Swamp soil Association still prevails in the areas characterised by slope angles 0^{o} and 1^{o}. The soils of the areas on higher slope angles belong to the Serdang-Munchong soil Association, which is formed over sandstones and sandy-shale parent materials. The soils in this Association are characterised by 44% to 57% silt + clay fraction. On both soil types drainage is not as serious a problem as it is on the soils of Land Unit 1a. Consequently, the soils of Land Unit 1b have been rated 1.

Present Landuse - Most of the surface area of this Land Unit is covered by "belukar" and "lalang". In such areas shifting cultivation is widely practised. Rubber and pineapples are grown over limited areas.

Use Classification - On account of gentle slopes and relative well-drained soils, this Land Unit is classified as Farmland, parts of which are considered developed (A1). Seasonally flooded areas presently occupied by rubber plantations, and areas over which shifting cultivation is practised could be redeveloped (A3) into more productive farmlands.

LAND CATEGORY 2: LOWLAND PLAINS

The Lowland Plains are "walled-in" by the Depression Rim in the south-west and the Deeply Dissected Highlands in the northeast. They extend into other Districts in the northwest and southeast. These Lowland Plains are separated from the Southern Depression (Land Category 1) by the Depression Rim (Land Category 3). They form the most extensive Land Category mapped in the study area since they make up 23.9% (26,280 ha) of the total surface area of the District. Map 2 shows the extent of these Lowland Plains. It can be seen that this Land Category is the most densely inhabited Land Category in the Ulu Langat District.

Geology

Early Carboniferous sandstones and sandy-shales occupy the west and southwest parts of this Land Category (see Land Units 2c and 2d). These formations border the Late Carboniferous Formations of the Depression Rim which lie to the southwest. The remaining parts of the Lowland Plains are underlain by granites of Jurassic age. Most of the igneous rocks have been altered and the sedimentary rocks have been metamorphosed in several sections into various types of schists which are reflected in the soil types found in the Land Category.

Physiography

These Lowland Plains are lower in elevation than the two surrounding Land Categories, but they are higher than the Southern Depression. The elevation of the plains ranges from 10 m to 150 m a.m.s.l. The land-surface is characterised by broad areas of gentle to hilly plains separated by wide alluvial flats and long distances from the crests (Figure 21a). The local relief is usually below 50 m. Generally this is a well-drained Land Category. The enclosed poorly drained valleyfloors have been mapped as Land Category 7.

Land Units

Five Land Units have been identified from this Land Category on the basis of soil, slope and drainage conditions. These are :- Land Unit 2a: Level to gently-inclined Plains; Land Unit 2b: Undulating Plains; Land Unit 2c: Rolling to Hilly Plains; Land Unit 2d: Major Lowland Watersheds; and Land Unit 2e: Foothill Plains. Some of these Land Units are shown in Plate 2.

Land Unit 2a: Level to Gently-inclined Plains. This Land Unit is developed on sandstones and has a surface area of 1,820 hectares which is approximately 8.0% of the total surface area of Land Category 2. It occurs on both banks of Sungei Langat immediately to the north of Kajang. Its local relief is between 15 m and 20 m.

Slope Characteristics - The typical slope angles of this Land Unit are 2° to 4°. There is usually a single rectilinear slope component which grades gently into a floodplain. This slope component is usually more than 100 m long.

The results of field investigations discussed in Chapter 4 have shown that at least 70% of the surface area of this Land Unit is inclined at angles equal to, or less than, 3^{0}.

Soil and Drainage Conditions - Soils over this Land Unit have been mapped as Disturbed Local Colluvium Association. Field checks by the investigator revealed that this soil Association phases out into Disturbed Alluvium at the edge of the floodplains. The upper part of the slope component is well-drained and has a capability rating of 2. The lower part is suspect to periodic flooding and is rated 2 for padi, and 3 for dryland crops.

Present Landuse - Rubber is grown on the upper part of the slope component, but the lower part of the slope component is disturbed by quarrying, mining and "urban" activities. The middle- and foreground part of Plate 3 shows the slope component and the "urban" buildings on the lower section of it.

Use Classification - The upper part of the slope component in this Land Unit is considered developed (A1). Abandoned quarries and tin mines could be developed into, for example, vegetable gardens (A2). The present farmlands encroached upon by building- and other settlement-activities could be reserved exclusively for urban use (A4).

Land Unit 2b: Undulating Plains. This is the most extensive Land Unit in the Ulu Langat District. Its surface area of 10,530 hectares makes up 9.57% of the surface area of the District and 40.4% of the surface area of Land Category 2. It is composed largely of low, gently sloping ridges and low interfluves.

Slope Characteristics - Slope values of the Slope Class C (5^0 - 10^0) type are common in this Land Unit. Three slope components have been identified. These are the convex crest component, the middle rectilinear component, and the foot-slope rectilinear component. The more common slope angles on the crest and the middle slope components are 6^0 and 7^0. Headvalleys and steepened valleysides are inclined at angles usually steeper than 10^0, whereas the crests of ridges and interfluves, and the lower slope component are inclined at angles of 2^0 to 4^0. The double-page from a field notebook shown in Table 4 (Chapter 4) is an example of slope distribution in this Land Unit.

Soil and Drainage Conditions - The Munchong-Seremban soil Association, developed from schists and indurated shales, is found in this Land Unit. Soils in this Association have silt + clay content of 57% to 62%. The capability rating is 2 for areas sloping at 4^0 to 6^0, and 3 for areas inclined at 6^0 to 12^0. Interfluves and ridge crests which show lateritic horizons in the soil profile are rated 3 inspite of the low angle of inclination.

Present Landuse - Most of the area of this Land Unit is used to grow rubber, although certain areas are being re-planted with oil palm. Some tributary valleyfloors are covered by grass and other herbaceous vegetation.

Use Classification - This Land Unit is Farmland most of which is considered to be adequately developed (A1). Redevelopment (A3) is possible in the valleyfloors on which rubber is grown since these flats are usually inundated after heavy rains. Valleyfloors covered by grass and herbaceous vegetation could be developed (A2), especially for short-term crops.

Land Unit 2c: Rolling to Hilly Plains. This Land Unit (2,960 ha.) occupies about 12% of the surface area of Land Category 2. It extends over areas of low rolling hills and ridges inclined at 6^0 to 8^0, which are separated by isolated steep hills inclined at angles 11^0 to 13^0.

Slope Characteristics - The typical slope over this Land Unit is within the Slope Class C (5^0 - 10^0). Slope angles 6^0, 7^0 and 8^0 are the most frequently recurring. On the steep isolated hills and at the valley sides of headstreams, angles of 11^0, 12^0, and 13^0 are common. The summits, bevels as defined by Morgan (1971a), and the lower slope components are inclined at angles of 2^0 to 4^0. Three slope components are common in this Land Unit. The crest component is convex, the middle slope is rectilinear, while the lower slope component is concave.

Soil and Drainage Conditions - The Serdang-Munchong soil Association develops on the gentle slopes of the low rolling hills and ridges. The soils of this Association are well-drained. This Association is replaced on steeper slopes by the soils of the Serdang-Munchong-Kedah Association. Both soil Associations have silt + clay contents of 40% to 71% and are developed from Early Carboniferous argillaceous-arenaceous formations. The capability rating of the soils of these Associations is 2 for slopes of 6^{o} to 12^{o}, and 3 for steeper slopes. Where they occur on slopes gentler than 6^{o}, they can be rated 1. The rating is 3 for soils with laterite in their profiles.

Present Landuse - This Land Unit is utilised in the same way as Land Unit 2b described earlier.

Use Classification - The use recommended for this Land Unit is the same as the use recommended for Land Unit 2b. Care should be exercised in using the isolated hills on which clear-cutting is to be avoided because the Serdang Soil Series could be easily eroded when its plant cover is removed, and when proper cover is not provided in new fields (I. Wong, 1966).

Land Unit 2d. Major Lowland Watersheds. The Major Lowland Watersheds occupy a total surface area of 2,420 hectares, or about 9.0% of Land Category 2. Lowland Watersheds are identified in two separated areas (see Map 2). One of these is found to the southwest of Kajang. It is developed over schists and indurated shales of Late Carboniferous age. The second watershed is located to the southeast of Semenyih. It is developed on Jurassic granites. Both areas are highly dissected by radiating headstreams. The local relief of about 100 m is much higher than the average local relief for Land Category 2. These watersheds are characterised by steep-sided convex hills with summit laterites.

Slope Characteristics - The typical slope angles found in this Land Unit belong to Slope Class D (11^{0} - 19^{0}). Gentler slopes are obtained only on summits, elongated spurs, bevels and valley-floors. Slope angles in these areas can be as low as 0^{0}, though angles 2^{0} to 4^{0} are typical. Slope angles steeper than 19^{0} are obtained at incised valley-sides and undercut banks. Two slope components are recognised as part of this Unit. A third component has been mapped as part of Land Category 7. The crest component is convex, while the "middle" component is rectilinear. This component contrasts sharply with the third, valleyfloor component. A discontinuity of about 10^{0} usually separates the middle rectilinear component from the valleyfloor component.

Soil and Drainage Conditions - The soils over the western watershed belong to the Munchong-Seremban Association which has a silt + clay content of 57% to 62%, and is rated 3. The watershed to the southeast of Semenyih is occupied by the Rengam Soil Series. The soils of this Series are developed from granites and have silt + clay content of 51% or less. The capability rating is 3. Both soil types are well-drained, but they develop laterite zones in their profiles.

Present Landuse - Rubber is grown in this Land Unit. Some rubber plantations are being replanted with oil palm. A few summit areas are covered by dry forest.

Use Classification - This Land Unit is classified as Farmland (A) because it is presently used as farmland. The nature of terrain suggests that it is a unit that should be left under protective forest, especially in the summit areas. Parts of the present farmland could be forested (A4), while the gentler areas are considered either adequately developed (A1), or redevelopable (A3). Redevelopable areas would include tributary valleyflats on which rubber is presently grown.

Land Unit 2e: Foothill Plains. The Foothill Plains are a southern extension of Land Unit 5c discussed below. They occupy about 34.2% of Land Category 2. Their surface area of 7,630 hectares is developed over granites of Jurassic age, and stands at an elevation of 60 m to 150 m a.m.s.l. The foothill plains constitute an area of rolling plains broken into hilly-blocks with broad summits. Many summit areas higher than 100 m a.m.s.l. develop laterite zones at depths ranging from 25 cm to 50 cm in their soil profiles. These plains end sharply at the foot of the highlands.

Slope Characteristics - The typical slope class for this Land Unit is Slope Class D (11^o - 19^o). The summit areas are inclined at low angles of 1^o to 4^o. There are four slope components identified in this Land Unit. There is a convex crest slope component followed by a middle, or hillslope rectilinear component. This hillslope component becomes a steepened valleyside slope component near the valleyfloor. A fourth component is the footslope (defined as piedmont slope by Swan 1970c) which has merged with the valleyfloor. The valleyside slope component is the steepest, but is the shortest. Typical slope angles for this component range from 18^o to 25^o. Slope angles in the hillslope component range from 11^o to 19^o. The slope values over at least 70% of the Land Unit is expected to be less than, or equal to, 13^o (see Chapter 4).

Soil and Drainage Conditions - Soils over a greater part of this Land Unit belong to the Rengam soil Series. On summits, and at the bases of hills and ridges, local colluvium has either replaced, or covered, the Rengam soils. In either case, the capability rating is 3 because of the occurrence of laterites in the profile, especially on summits. A second reason for the rating is the steepness of the hillslope and valleyside components.

Present Landuse - This Land Unit is exclusively under rubber.

Use Classification - The Foothill Plains are classified as developed farmland (A1) because it has been noted (I. Wong, 1966) that there is hardly any other crop that could replace rubber on steep slopes with Rengam soil Series. Redevelopment is possible on the lower footslope-valleyfloor components and summit areas if it is so desired. Areas around incised headvalleys and on conical summits should not be farmed (A4). Rather, such areas should be left under protective forest. The soil in this Land Unit is suspect to slumping and gullying (I. Wong, 1966; see also Chapter 6); hence clean-clearing and the practice of uncovered new fields should be avoided.

LAND CATEGORY 3 : DISSECTED DEPRESSION RIM

The slope, geology, and relief characteristics of a zone separating the Southern Depression from the Lowland Plains have led to the identification of this zone as a separate Land Category. It is termed "Depression Rim" because it has been dissected into a rougher terrain than the Lowland Plains, and because its position at the edge of the Southern Depression is analogous with the rim of a bowl. This Land Category occupies 14,600 hectares, or 13.3% of the surface area of the Ulu Langat District. The elevation ranges from 30 m - 200 m a.m.s.l. (Table 13).

Geology

The Depression Rim is developed on Late Carboniferous sandstones and schists which are younger than the metamorphosed argillaceous formations that occupy the plains to the west of the Rim. These younger formations appear to be more resistant to subaerial erosion than the argillaceous formations.

Physiography

This Land Category is bounded on the west and southwest by the Southern Depression. Parts are separated from the main Rim by the basins and the raised plains of the depression. The main Rim rises gently eastwards from this depression to a crest of parallel ridges and deeply dissected isolated hills. From this crest it rolls southeastwards and eastwards into the Lowland Plains. The crest is the main axis of the Rim where summits are higher than 100 m a.m.s.l. The largest hill in this area is Bukit Tunggul whose peak, 279 m a.m.s.l., is the highest point.

Land Units

Six Land Units have been mapped from this Land Category as shown in Table 13 and Map 2. The Land Units have been identified on the basis of slope, soil and surface forms. The land Units are: - Land Unit 3a: Undulating West-sloping Land; Land Unit 3b: Ridge-and-Valley Southern Rim Crest; Land Unit 3c: Northern Dissected Hilly Land; Land Unit 3d: Central Rolling

Land; Land Unit 3e: Western Outlier Plains; and Land Unit 3f: Deeply Dissected Isolated Hills.

Land Unit 3a: Undulating West-sloping Land. This Land Unit drains westwards to the Southern Depression. Consequently, the general slope of the land-surface is westwards. The surface area of this Land Unit is 4,350 hectares, or 30% of the total surface area of the Rim. It is the largest Land Unit in Land Category 3. The elevation ranges from a little less than 30 m to about 75 m a.m.s.l. Plates 4 and 5 show the lower and the upper main components of a typical area in the northern section of this Land Unit. The middle ground in Plate 1 shows a typical area in the southern section.

Slope Characteristics - In general, this Land Unit slopes westwards. A typical slope profile shows three slope components which are a) a crest convex component which slopes at angles ranging from 8^{o} - 12^{o}, b) a middle rectilinear component which slopes at angles ranging from 4^{o} to 7^{o}, and c) a footslope component which is inclined at angle 2^{o} or 3^{o} (see Plates 4 and 5). The footslope component merges with the Depression at angles of 0^{o} or 1^{o}. Generally, the slope profiles in the northern section of this Land Unit are gentler and more regular than those in the southern section. (Compare Plates 4 and 5, northern section, with the middle ground in Plate 1, southern section). More than half of the surface area of the Unit is inclined at an angle gentler than 5^{o}.

<u>Soil and Drainage Conditions</u> - The soils on the footslope component belong to the Munchong soil Series which are usually well-drained. These soils are flooded in flat sections of this component during the monsoon seasons, and after any heavy rainfall. On the upper slope components soils of the Serdang-Munchong Association prevail. These soils have a silt + clay content which ranges from 44% (Serdang) to 56% (Munchong). Soils on the footslope component are rated 1, while those on the upper slope components are rated 2.

<u>Present Landuse</u> - Most of the surface area of this Land Unit is devoted to the production of rubber. Short-term crops which include vegetables, topioca, and corn are grown around compounds in the estate villages. Other parts are covered by grass and herbaceous vegetation.

<u>Use Classification</u> - Many parts where rubber is grown are considered to be adequately developed (A1). Areas under grass or herbaceous plants on gentler slopes could be developed (A2). Some seasonally flooded valleyfloors that are presently used to grow rubber could be redeveloped (A3) by introducing more suitable crops such as padi.

Land Unit 3b: Ridge- and-Valley Southern Rim Crest.

This Land Unit consists of three parallel ridges which form the southern crest of Land Category 3. It has a surface area of 2,690 hactares, which constitutes 18.0% of the total surface area of Land Category 3. The three ridges trend NNW-SSE in direction and enclose two major valleys. Plate 6 shows the general alignment of these ridges and valleys. The ridge at the western margin of this unit is the most extensive and the highest of the three ridges. Plates 1 and 6 show this western ridge in their immediate foregrounds. The highest point on this ridge is 192 m a.m.s.l. The middle ridge is the narrowest and the lowest. All the three ridges have been dissected into conical hills and elongated hilly interfluves by short headstreams, and the drainage pattern in the unit is trellis-cum-dendritic.

Slope Characteristics - The typical slope angles over most of this Land Unit are contained in the Slope Class D (11^{0} - 19^{0}). Valleyfloors, bevels, and summit areas are inclined at angles of 1^{0} to 4^{0}, while steepest valleyside and hill slopes measured in the field are up to 26^{0} in angle (Figure 21). Five or more slope components are identifiable on a typical slope profile from this unit. There is a convex crest component which shows an average slope of 10^{0} to 12^{0}, and there is a convex footslope component which shows an average slope steeper than 20^{0}. This footslope component changes sharply into a valleyfloor component at a discontinuity as high as 20^0. The slope components between the footslope component and the crest component alternate between rectilinear and concave forms. The convex footslope component is more prominent on west-facing slopes than on east-facing ones, as the profiles in Figure 21b show.

Soil and Drainage Conditions - Munchong soil series occupy the lower slope components, and Kedah-Seremban soil Association is developed on the steeper, upper components. Soils of these soil types are well-drained, and have a slit + clay content generally over 50% except in summit areas where laterites are developed at a depth of 16 cm to 32 cm in the soil profile. Current alluvia which are not well-drained occupy the valleyfloors.

Present Landuse - This Land Unit is used mainly to produce rubber. Some summit areas are occupied by light forest of secondary type, while the valleyfloors are covered by herbaceous bushes.

Use Classification - Based on the present landuse this Land Unit can be classified first as developed farmland (A1). The light forest on summit areas could be developed into exploitable low-land forest (B2) , while the valleyfloors could be made to produce wetland short-term crops which could include padi, and sugar cane. Clean-clearing should be avoided in the present farmlands, and new fields should be provided with adequate cover crops because the soils in this unit are susceptible to gullying and slumping processes.

Land Unit 3c: Northern Dissected Hilly Land. The Northern Dissected Hilly Land is drained southwards by Sungei Chuau and its tributaries. The northwest limit of this unit coincides with the low water-divide between the south-flowing Sungei Chuau and Sungei Gajah, and the west-flowing Sungei Rasau. Sungei Bisa, a tributary to Sungei Chuau, marks the southern boundary. The unit has a surface area of 2,310 hectares which comprises about 17% of the total surface area of Land Category 3. This is an area of low ridges and isolated low hills with summit areas generally below 100 m a.m.s.l. Hills found within the limits of this Land Unit, but which are higher than 100 m a.m.s.l. have been mapped as Land Unit 3f and are discussed below. It would seem that this Land Unit is divided into two physiographic and landuse sections by the Kajang-Puchong Road. North of this road is an extensive ridge dissected by V-shaped headstream valleys. South of the road are low ridges and hills widely separated by broad valley flats and fringing undulating plains.

Slope Characteristics - The typical slope values obtained from this Land Unit are contained in Slope Class D (11^{o} - 19^{o}). This high average is a reflection of the steep valleysides incised in the ridges and hills. Such valleysides slope at angles steeper than 20^{o}. On the valleyfloors of the southern section of the unit slope angles are between 0° and 2°; and on the fringing plains slope values of 2° to 5° are common. There are three main slope components. The crest component is convex and is followed by a rectilinear middle component. The footslope component is concave and grades smoothly into the valleyfloor.

Soil and Drainage Conditions - The soils of the Munchong-Seremban Association are found in this Land Unit. They are well-drained and have a capability rating of 2 on slopes gentler than 12°, but a capability of 3 on steeper slopes, or summits with laterites. Poorly-drained current alluvia occupy the larger valleyfloors.

Present Landuse - The dissected section north of the Kajang-Puchong Road is covered by light forest. Rubber and oil palm are grown on the section south of the road.

Use Classification - The southern section of this Land Unit is largely developed farmland (A1). Redevelopment (A3) is possible in areas which are flooded seasonally, but which are presently used to grow rubber. The section north of the road is forestland which should be left under protective vegetation cover (B4). The possibility of logging in this forest area is not completely excluded.

Land Unit 3d : Central Rolling Land. The Central Rolling Land is situated south of Sungei Bisa and east of Sungei Chuau. This unit is drained mainly southwards, though about 10% of the surface area drains eastwards to Sungei Langat. The unit consists of three parallel ridges in a northern section and grouped hills in a southern section. Plates 7 and 8 show the southern grouped hills. The surface area of the Land Unit is 1,800 hectares, and takes up about 12.3% of the total area of the Depression Rim. The average elevation is 120 m a.m.s.l. The central ridge which is higher in elevation than 120 m has been mapped as Land Unit 3f.

Slope Characteristics - The average maximum slope angles typical of this Land Unit are contained in Slope Class D (11^0 - 19^0). Hillslopes are usually between 11^0 and 17^0, and steepened head-valley slopes (shown in the foreground of Plate 8) can be as steep as 20^0 to 24^0. The low interfluves, ridge crests, hill summits, and valleyfloors are inclined at gentler slope angles of 2^0, or 3^0. Two slope components are common in the headvalley areas: a convex crest component and a rectilinear component which is a combination of a middle and a footslope component. Three slope components are distinct in other areas. The crest component is convex and is followed by a rectilinear middle slope. The footslope is concave and grades smoothly into the valleyfloor. The smooth grade is interrupted in some areas by undercut channel banks.

Soil and Drainage Conditions - The soils in this Land Unit belong to the Prang Series developed from schists. These soils are well-drained, but are subject to sheet erosion and slumping processes when their vegetation cover is removed. Laterite zones are present in the soil profile, especially on summit areas (see also Eyles 1968a, 1968b). The clay fraction of these soils could be as high as 80%. The soils are rated 2 where the slope angle is less than 12^{0} and where there is no laterite zone in the upper 50 cm of the profile. Where there is a laterite zone, or the slope is steeper than 12^{0}, they are rated 3.

Present Landuse - Almost all the surface area of this Land Unit is used to grow either rubber, or oil palm. Some valleyfloors are covered by herbaceous vegetation.

Use Classification - This Land Unit is regarded as a developed farmland (A1). Redevelopment (A3) could be undertaken in valley-floors presently occupied by rubber because these areas are flooded after heavy rains.

Land Unit 3e : Western Outlier Plains. This Land Unit is a westward extension of Land Unit 3a, but it is separated from Land Unit 3a by the basins and raised plains of the Depression.

Slope Characteristics - The slope components in this Land Unit are exactly the same as the slope components described in the case of Land Unit 3a. Since Land Unit 3e consists of isolated plains their land-surfaces slope to all directions, although south-facing slope forms are the longest. More than half of the area of the unit is inclined at angles less than 5^0.

Soil and Drainage Conditions - The Serdang-Munchong Soil Association occupies the higher lands, while the Inland Swamp Soil Association prevails on areas bordering the Depression. The drainage conditions and the structure of these soils have been discussed earlier.

Present Landuse - Tea and Oil palm are successfully grown on the southern plains. Coffee is produced on experimental plots. The northern plains are used to produce rubber.

Use Classification - This is a developed farmland (A1), although the swampy sections presently used to produce rubber could be re-developed (A3) by the introduction of more suitable crops which might include sugar cane.

Land Unit 3f: Deeply Dissected Isolated Hills. On the crest of the Rim there are several isolated hills and ridges with summits generally higher than 120 m a.m.s.l. These hills and ridges have been mapped as Land Unit 3f which occupies a surface area of 1,330 hectares, or 9.0% of the area of Land Category 3. The main physiographic characteristics of the surface forms of this Unit include: deeply incised, narrow headvalleys; steep hillslopes; and narrow (in the case of ridges), or conical (in the case of hills) summit areas. The summit areas are usually higher than 140 m a.m.s.l. They are the highest parts of Land Category 3.

Slope Characteristics - The typical slope values in this Land Unit belong to Slope Class E (20^{0} - 29^{0}). Under-cutting at valleysides produce slopes steeper than 30^{0}, whereas the middle slope components show slope angles of 11^{0} to 19^{0}.

Soil and Drainage Characteristics - The soils over this Land Unit have been mapped as Steepland Soils. These soils are rated 5 because they are considered unsuitable for agricultural purposes. They are well-drained, but are generally very thin in profile.

Present Landuse - The larger hills and ridges are forested, whereas the middle and footslope components of the smaller ones are used to grow rubber. Patches of bushes and/or light forests perch on the summit areas of these smaller forms.

Use Classification - Since the hills and ridges in this Land Unit are minor watersheds which are characterised by steep slopes, it would be advisable to leave this unit under protective forest (B4). Components on slopes gentler than 25^{0} in angle could be developed into exploitable forest, or nature parks (B2).

LAND CATEGORY 4 : DEEPLY DISSECTED HIGHLANDS

This Land Category is found to the north and northeast of the Lowland Plains. It is enclosed by the Foothills and Low Mountains (Land Category 5). These deeply dissected highlands occupy a surface area of 23,640 hectares. This area is 21.5% of the total area of the Ulu Langat District, and is second in size to the Lowland Plains as illustrated in Figure 15 and Table 13.

Geology

Land Category 4 is developed largely on granites of Jurassic age. Corestones outcrop on the middle and the upper units of this Land Category. These outcrops are shown in Plate 11. According to Alexander (1965), some limited area of this Land Category is underlain by "hyperbysal vein quartz" (see Figure 2).

Physiography

This area is essentially a penetration of the Lowland Plains into the mountain areas along the valleys of the principal streams. The highlands identified in this study are similar to the land-surface Eyles (1968a) has identified as "Deeply Dissected Low Mountain" (see Figure 4). The elevation of the highlands ranges from 75 m to 450 m a.m.s.l. This land-surface encircles the two major rivers (Sungei Langat, Sungei Semenyih) near the foothills and low mountains. It is an area of in-facing slopes which are very steep on the high hills and ridges, steep on the intermediate low hills and ridges, and undulating on the fringing plains of the valley incursions. These zones are illustrated in Plates 9 to 11.

Land Units

Three Land Units have been mapped from this Land Category. These Land Units were identified on the basis of the slope and form characteristics cited above. They are : -
Land Unit 4a: Undulating Valley Incursions; Land Unit 4b: Steep Low Hills and Ridges; and Land Unit 4c: Steep High Hills and Ridges.

Land Unit 4a: Undulating Valley Incursions. The term "valley incursion" is used in this study to define extensive areas of low relief, and undulating fringing plains which occur in highland environments. These incursions are partially enclosed by two-tiered, in-facing high ridge-walls (see Plates 9 and 10), and are similar to the "Highland Plains" identified from Johore State by Swan (1970b). They occupy a surface area of 5,880 hectares which forms about 25.0% of the total surface area of Land Category 4. The elevation ranges from 75 m to 150 m a.m.s.l., and the surface is broken into low interfluves, elongated spurs and bevels.

Slope Characteristics - This unit has a typical slope range of 5^0 to 10^0, though many headstreams have steepened their valleysides to angles as steep as 20^0. Confluence zones and summit areas are generally inclined at about 2^0 to 4^0. There are basically two slope components, a convex crest component, and a concave footslope -valleyfloor component. In the headstream sections the footslope is rectilinear and changes to a valleyfloor with a discontinuity as high as 20^0 to 30^0 (see Figure 21c).

Soil and Drainage Conditions - Local colluvia are found at the bases of the interfluves and on bevels, while current alluvia occupy the valleyfloors. The soils found on other areas belong to the Rengam Series. These soils are well-drained and are rated 2 wherever slope angles are gentler than 12^0, but they are rated 3 on steeper slopes, or where there is laterite in the soil profile.

Present Landuse - Rubber, vegetables, fruit trees, and upland rice are grown in several parts of this unit. Tin mining is practised on a few valley flats. The remaining part, which is more than half, is used for shifting cultivation.

Use Classification - This Land Unit has been classified as farmland because of its gentler slopes and undulating terrain.

Large areas of this farmland are still to be developed (A2). The present croplands are regarded as developed (A1), and the areas on which shifting cultivation is practised could be used more intensively (A3).

Land Unit 4b: Steep Low Hills and Ridges. A zone of low parallel ridges and low hills is situated between the valley incursions and an upper zone of high steep ridges. This zone of low ridges and hills has been mapped as Land Unit 4b. It is the lower part of the two-tiered ridge wall partially enclosing the valley incursions (see Plate 9). In certain areas where the high ridges and hills of Land Unit 4c grade directly into the highland plains, Land Unit 4b is not clearly defined. The total surface area of the unit is 7,510 hectares which constitutes about 33.0% of the total area of Land Category 4. The average elevation ranges from 150 m to 300 m a.m.s.l., and local relief is shown by Figure 21c to be under 100 m. It is often as low as 50 m in several areas.

Slope Characteristics - Slope angles calculated, and determined in the field, from this Land Unit are distributed within Slope Classes D (11° - 19°) and E (20° - 29°). There are three slope "regions" in the Land Unit. The footslope component, valleyfloor, bevels, and summit areas are inclined at angles 2° to 4°. Angles on the hillslope component, and the convex crest slope component are distributed in Slope Class D. Steepened valleysides and rocky outcrops have slope angles of 20^{o} to 30^{o}. Generally, there is a sharp break of slope between the gently sloping and the strongly sloping areas (see Figure 21c). This sharp discontinuity has been observed in the forest areas of West Malaysia by Young (1969a).

Soil and Drainage Conditions - The soils on slopes gentler than 20^{o} have been mapped as Rengam Series. Soils on steeper slopes have been grouped as Steepland soils. Field observations revealed that current alluvia occupy the valleyfloors, while local colluvia are found at the feet of the hills and ridges. The Rengam, local colluvia, and current alluvia have a capability rating of 3, whereas Steepland soils are rated 5.

Present Landuse - Rubber is widely grown on the gentler slopes including the valleyfloors. Other areas are covered by light forest.

Use Classification - Forestlands on this Land Unit could be developed (B2) into exploitable forests, or tree plantation. Headvalleys and high summits should be reserved for protective vegetation (B4). The present rubber plantations might be left as they are, except for those on the seasonally flooded valleyfloors where redevelopment could be undertaken (A3).

Land Unit 4c: Steep High Hills and Ridges. This unit is the upper tier of the ridge-wall which partially encircles the valley incursions. This is the most extensive of the three Land Units of Land Category 4. It occupies 42.8% of the total surface area of the category. It is the second most extensive Land Unit in Ulu Langat, and its area of 10,120 hectares makes up 9.20% of the total surface area of the District. Its long infacing slopes, and its elevation which ranges between 300 m and 460 m a.m.s.l., differentiate this unit from the low mountains. It is made up of short ridges with elongated spurs and isolated steep hills. Plate 11, taken on one of the hills of Land Unit 4b, shows a section of Land Unit 4c. This section slopes generally to the southwest.

Slope Characteristics - Slope Distribution in this Land Unit covers Slope Classes D and E, but the more frequently recurring values are contained within Slope Class E. Hill summit areas are conical, while ridge crests are narrow. Consequently, the gentle slopes, generally inclined at 3° to 6°, found in such areas are very limited in area. A typical slope profile in this Land Unit shows two slope components: a convex crest component, and a rectilinear hillslope component.

Soil and Drainage Conditions - The soils over this unit are Steepland soils which are well-drained, but are rated 5. Plate 11 shows that these soils contain corestones in this Land Unit. Some of the stones measure up to 3 m in diameter.

Present Landuse - A small section of this unit is planted with rubber, or bananas. The larger part is covered by grass (Plate 11) or light bush.

Use Classification - The gentler slopes of this unit could be used for tree-plantations and selective logging (B2). The other parts should be left under protective vegetation (B4). The areas presently used for crop-farming could be converted into tree-plantations (A4).

LAND CATEGORY 5 : DISSECTED FOOTHILLS AND LOW MOUNTAINS

Stretching from the crest of the Steep High Hills and Ridges of Land Category 4 to the zone of High Mountains is a land-surface characterised by steep parallel ridges and steep isolated low mountains. This land-surface has been classified as Dissected Foothills and Low Mountains. This Land Category has an area of 21,280 hectares which constitutes 19.3% of the total surface area of the Ulu Langat District.

Geology

Granites of Jurassic/Cretaceous age underlie most of the area of this Land Category. Sedimentary rocks of Early Carboniferous age have been mapped in certain parts of the unit (see Figure 2). These sedimentary rocks are of argillaceous-calcareous formations. They have been metamorphosed into schists on which the high, extensive ridge of the central part of this Land Category has been developed.

Physiography

Land Category 5 is the main physiographical watershed of the Ulu Langat District. Many of the headstreams of Sungei Langat and Sungei Semenyih rise from the area. The average elevation ranges from 300 m to 610 m a.m.s.l. It is different from the High Mountains mainly because of its lower elevation. It is distinct from Land Unit 4c because headvalleys are not as deeply incised into the hillslopes in this Land Category as they are in Land Unit 4c, and because the general slope of the land in Land Category 5 is not in-facing as it is in Land Unit 4c. The foothills and low mountains identified in this study are similar to the land type classified as "Low Mountain" by Eyles (1968a).

Land Units

There are three Land Units differentiated largely on the basis of land-form assemblages and drainage types. They are :- Land Unit 5a: Dissected Foothills and Ridges; Land Unit 5b: Low Mountains; and Land Unit 5c: Central Main Watershed.

Land Unit 5a: Dissected Foothills and Ridges. This Land Unit is an area of steep hills characterised by elongated spurs. These hills constitute sections of extensive, but broken, ridges which are aligned parallel with the major tributary valleys. The elongated spurs of the hills appear as interlocking spurs when viewed from the summit of one of the hills as shown in Plate 12, but the main streams show U-shaped valley profiles (see Figure 21d). This Land Unit covers an area of 9,980 hectares which constitutes 46.6% of the total area of Land Category 5, or 9.07% of the total area of the District (see Table 13). The elevation averages 300 m to 460 m a.m.s.l. but Figure 21d shows that the local relief ranges from 30 m to 80 m.

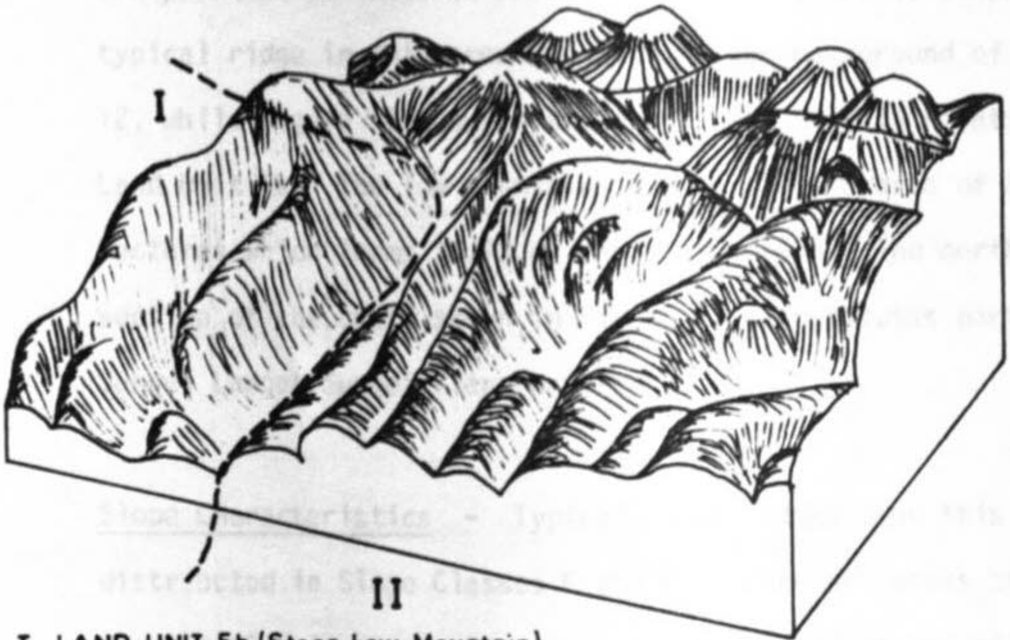
Slope Characteristics - The typical slope values in this Land Unit fall within Slope Class E (20° - 29°). Slope profiles on principal valleysides show three slope components. There is a convex crest component which is characterised by slope angles of 20° to 30°, but by angles 5° to 6° on the summits. There is a middle, or hillslope, component on which slope angles of 5° to 10° are common. This middle component is rectilinear in many areas, but it can be concave wherever the footslope component is not distinctly differentiated from the valleyfloor. There is a footslope component, often merged with the valleyfloor, which is either rectilinear or concave. This component is inclined at angles 2° to 4°; it either changes to, or merges with, a valleyfloor which is inclined at 0^o to 2^o (see Figure 21d).

Soil and Drainage Conditions - The soils over this Land Unit have been classified as Steepland. Soils of the Rengam Series are found on the elongated spurs, while Local-Colluvium-Alluvium Soil Association occupies large parts of the valleyfloors. Corestones are exposed on the valleyfloors of the principal streams. Some of these stones measure up to three metres in diameter.

Present Landuse - Most of the surface area of this Land Unit is covered by rain forest. Lumbering is the main economic activity in the area. One of the hills in this unit has been planted with mountain pines. A recreation park is located within this tree plantation.

Use Classification - The occurrence of the elongated spurs makes the development of exploitable forests, or tree-plantations, possible in several parts of the unit (B2). Areas on steep slopes, summits, and around headvalleys should be reserved for protective vegetation (B4). Some areas in which indiscriminate logging is presently practised should be considered for selective felling practices (B3).

Land Unit 5b: Steep Low Mountains. This unit is an area of steep ridges and hills which have a general elevation of



I LAND UNIT 5b (Steep Low Mountain)
II LAND UNIT 6 b (High Mountain)
SCALE: HORIZONTAL 1:63,360
VERTICAL 1:36,000 VERTICAL EXAGGERATION 1·76

FIGURE 17: A block-diagram to illustrate parts of Land Unit 6b. and Land Unit 5b

460 m to 560 m a.m.s.l. The ridges are largely unbroken and are parallel to enclosed areas of relatively gentle slopes. A typical ridge in this area is shown in the background of Plate 12, while Figure 17 shows a section of the unit in relation to Land Unit 6b. The low mountains have a surface area of 8,370 hectares which forms 39.9% of Land Category 5. The northwestern section of the unit, shown in Figure 17, constitutes part of the Sungei Langat/Sungei Klang watershed.

<u>Slope Characteristics</u> - Typical slope values over this area are distributed in Slope Classes E and F. There are areas of gentler slope angles in the enclosures between the ridges and hills. In these enclosures typical slope angles range from 11^{0} to 19^{0}. Three slope components, which are the same with the components identified from Land Unit 5a, are shown by slope profiles from this unit.

<u>Soil and Drainage Conditions</u> - The Steepland soils found in this Land Unit are well-drained, but they develop lateritic zones in their profile. The capability rating is 5. These soils are susceptible to slumping processes especially when disturbed.

<u>Present Landuse</u> - The area is covered by forests which are exploited in the more accessible parts. Other parts are occupied by protective forests.

Use Classification - This Land Unit would best be reserved for protective cover (B4). The enclosures characterised by relatively gentle slopes could be developed (B2) into hill resorts if desired. Selective felling might be undertaken in areas which are not steeper than 26^{o}.

Land Unit 5c: Central Main Watershed. This unit consists of a very extensive ridge developed over metamorphosed argillaceous-Calcareous formations. The ridge has been dissected into narrow, steep-sided spur-ridges by deeply incised headstreams. As the title implies this is a main watershed in the Ulu Langat District. The average elevation is 300 m to 610 m a.m.s.l., but this unit extends southwards where parts lower than 200 m a.m.s.l. have been classified as Land Unit 2e. The drainage pattern is radial, and the headstreams which start from the unit flow into Sungei Langat situated to the west and into Sungei Semenyih situated to the east.

Slope Characteristics - Typical slope angles in this Land Unit are within the Slope Class E (20^{o} - 29^{o}). Ridge crests slope at angles which range from 5^{o} to 10^{o}. The footslope component has slope angles of 11^{o} to 19^{o}, and changes sharply to a valleyfloor inclined at angles 2^{o} to 4^{o}.

Soil and Drainage Conditions - The soils in this unit have been mapped as Steepland. These soils are well-drained, but are rated 5 on account of steep slopes. Soils of Local Colluvium-Alluvium Association are found on the valleyfloors.

Present Landuse - Rubber occupies the southern lobe of this ridge-unit. Logging is practised in the accessible parts of the forests. The remaining parts are covered by protective forests.

Use Classification - This is a major watershed in the Ulu Langat District. It should be left under protective forest cover (B4).

LAND CATEGORY 6: HIGH MOUNTAINS

This is the highest Land Category in the Ulu Langat District. It is situated on the extreme northern and northeastern section of the District, and it is part of the Main Range of the Malay Peninsula. It has an area of 7,520 hectares which makes it the least extensive Land Category in the study area (see Map 2, and Figure 15).

Geology

The High Mountains are developed over granites of Jurassic/ Cretaceous age. Jones (in press) contends that granites of Early Palaeozoic age are found in parts of the eastern section of this

Land Category. Generally, the younger granites occupy the northern section, while the older granites occupy the southeastern section.

Physiography

The northern section is part of the peninsular water-divide between east-and west-flowing major river systems. The eastern section is the Sungei Langat-Semenyih/Sungei Muar watershed. The general elevation is higher than 610 m a.m.s.l. The peak of Gunong Nuang (1,496 m) is the highest point in this Land Category, and in the District. This peak is situated on the border with Pahang in the northern section. The drainage pattern in this granitic landscape is mainly rectangular.

Land Units

Two Land Units have been classified from this Land Category on the basis of assemblage of forms, and of total relief. These units are : - Land Unit 6a: Eastern "Peaked" Mountain Ridge; and Land Unit 6b: Northern Mountain Range.

Land Unit 6a. Eastern "Peaked" Mountain Ridge. The Eastern "Peaked" Mountain Ridge is classified "peaked" because it is an extension of the Main Range into the Lowland Plains which has been dissected into a chain of peaks. The average elevation of the peaks is about 1,000 m a.m.s.l. These peaks increase in elevation from the south to the north, for example, Bukit Ulu Semenyih (975m), Bukit Payong (1,070 m), and Bukit Ambat (1,149). The surface area is 5,100 hectares, and it occupies 66.7% of the total area of Land Category 6.

Slope Characteristics - The typical slope values in this Land Unit are within Slope Class F (30^{o} and over), though there are areas on the lower parts of the Mountain Ridge where slope angles range from 20^{o} to 29^{o}.

Soil and Drainage Conditions - The soils over this Land Unit belong to the Steepland soils which are well-drained, but are rated 5.

Present Landuse - This Land Unit is a rain forest which is unexploited.

Use Classification - The terrain of this Land Unit precludes it from agricultural utilisation; this includes forest exploitation. It is best left under protective forest cover (B4). Very valuable trees could be selectively felled if they are situated on the less steep lower parts of the Mountain Ridge.

Land Unit 6b: Northern Mountain Range. This Land Unit is part of the crest of the Main Range of the Malay Peninsula. Its area of 2,420 hectares (33.3% of the surface area of Land

Category 6) is everywhere higher than 650 m a.m.s.l. Figure 17 shows that this area rises steeply from Land Unit 5b to a high surface which is higher than 900 m a.m.s.l. This high surface has been dissected into parallel ridges, isolated hills, and major mountain peaks. The highest mountain peak is Gunong Nuang (1,496 m).

<u>Slope Characteristics</u> - A scarp slope which rises from Land Unit 5b, and hillslopes in Land Unit 6b are characterised by slope angles steeper than 30^{o}. Rocky outcrops (identified on air photographs) which are present in the northeastern section of this unit are cliffs. Slope values of 20^{o} to 29^{o} are obtained on the lower components of the hills and ridges.

<u>Soil and Drainage Conditions</u> - The soils in this mountain area have been mapped as Steepland. The soils are thin in profile. These soils are well-drained, but they are rated 5 on account of steep slopes and thin profiles.

<u>Present Landuse</u> - The high mountains are covered by dense tropical rain forest.

<u>Use Classification</u> - This is an area which should be left exclusively under protective forest cover.

LAND CATEGORY 7: MAJOR ACTIVE FLOODPLAINS

Throughout the District of Ulu Langat, active, and semi-active floodplains 100 metres, or more, wide have been mapped as one Land Category. Narrower floodplains have been discussed as parts of the other Land Categories in which they occur. The width of 100 metres has been chosen because areas that are as wide as this are considered large enough for land planning independently from the adjacent valleysides and hills. The valleysides that make the edge of the classified active floodplains are not mapped as part of Land Category 7. A total surface area of 7,540 hectares (6.9% of the area of the District) has been mapped as this Land Category.

Geology

The floodplains are developed on the geologic formations and intrusions discussed earlier in this annexe (see Figure 2).

Physiography

The terrain over this Land Category is essentially riverine. The floodplains are extensive flat lands which usually end abruptly at the bases of hillslopes. Some of these valley flats are as wide as 300 m, especially at confluence areas. These flats might locate wholly on one side of a stream channel, or unevenly on both sides. The river channels, generally less than 30 metres wide, have been cut into the plains at depths which range from a few centimetres to 3, or 4, metres. Plate 13 shows a stream channel which is about one metre deep on the concave section (middle ground) and up to three metres deep on the convex section (foreground, blocked from view).

Land Units

On the basis of soil and drainage conditions, five Land Units have been identified in this Land Category. These are:- Land Unit 7a: Level, Permanently Waterlogged Plains; Land Unit 7b: Level, Seasonally Flooded Plains; Land Unit 7c: Level Occassionally Flooded Plains; Land Unit 7d: Inclined Lowland Floodplains; and Land Unit 7e: Inclined Highland Floodplains.

Land Unit 7a: Level, Permanently Waterlogged Plains. This is a poorly drained riverine extension of the Southern Depression, although small areas of permanently waterlogged plains have been identified in other areas (Map 2). Such floodplains occupy a total surface area of 1,330 hectares which make up 17.5% of Land Category 7.

Slope Characteristics - Theoretically there is no slope in this Land Unit since the average maximum slope angle calculated for the unit is 0^{0}.

Soil and Drainage Conditions - The soils in this Land Unit belong to the Inland Swamp soil Association, and are characterised by poor drainage. The twigs and brackish water which could be seen in the swamp, suggest that the soils might have developed a deep layer of peat, in which case the capability rating would be 4.

Present Landuse - This Land Unit is covered by swampy herbaceous vegetation.

Use Classification - If this land is drained, wetland crops could be grown on it (A2). Drainage might be the most serious factor which would bar the land from agricultural utilisation.

Land Unit 7b: Level, Seasonally Flooded Plains. This is the most extensive unit in this Land Category. It has a surface area of 2,000 hectares which constitutes 26.1% of the total area of the Land Category. It is found along Sungei Langat and along Sungei Semenyih as shown in Map 2. The unit is flooded seasonally during the monsoon periods, but pools of flood water may remain in several areas throughout the "less" wet periods. Plate 14, taken during one of the "less" wet periods, shows some of these pools.

Slope Characteristics - This Land Unit is flat. Slope angles obtained from more than half of the surface area are approximately 0^{o}. An average slope angle of 1^{o} was determined for this Land Unit mainly because slope angles of 2^{o} and 3^{o} occur at the outer edges of the plains.

Soil and Drainage Conditions - Soils in this unit belong to the Local Colluvium-Alluvium soil Association. These soils are not well-drained, and develop peat layers under the stagnant pools. They are generally sandy near the channels and become progressively silty away from it.

Present Landuse - This Land Unit is largely under grass, "nipah" palms and swampy herbaceous plants. Active tin mines, and abandoned mining flats occupy a large area just south of Bangi.

Use Classification - This is a developable farmland (A2), though special techniques would probably be required.

Land Unit 7c: Level, Occasionally Flooded Plains. This unit remains relatively well-drained for the greater part of the year. These plains are not flooded during every monsoon season because the present stream channels and their fringing meander belts are cut into the plain to a depth up to 2 metres in many areas. The Land Unit occupies the area immediately to the north of Land Unit 7b on Sungei Langat and Sungei Semenyih, but it is most extensive along the Sungei Beranang. The total surface area of the unit is 1,880 hectares, and this area makes up 24.7% of the surface area of the Major Active Floodplains.

Slope Characteristics - This Land Unit is level. An average maximum angle of 1^{o} has been obtained for the floodplains. The outer edges of the plains are inclined at angles of 2^{o}, or 3^{o}. The side of the channels cut into the plains can be as steep as 20^{o}, but the proportion of the plains occupied by such steep undercuts is negligible.

Soil and Drainage Conditions - The soils of this unit have been mapped as Inland Swamp Association. Field observation has shown that Alluvium-Colluvium soils have developed on the swampy soil Association, especially in the areas which are cultivated.

Present Landuse - Padi is extensively grown in the section near Kampong Benerang. Other areas are either covered by bushes, or are used to grow rubber. Tin mines occupy a limited area of this Land Unit.

Use Classification - The area around Kampong Benerang is considered developed (A1), though it could be put to more intensive use by double-cropping. Sections on Sungei Langat on which rubber is grown could be redeveloped (A3), while the parts covered by bushes could be developed (A2).

Land Category 7d: Inclined Lowland Floodplains. This Land Unit occurs in two different areas within the Depression Rim. Both of the areas are situated between Land Unit 7a and Land Unit 7b (see Map 2). The floodplains are narrower than 100 metres in the more hilly parts as shown in Plate 15.

Slope Characteristics - The average slope angle in this Land Unit is 2^{o} - 3^{o}. Steeper slope angles occur near the hillslopes where slope angles 4^{o} and 5^{o} are typical (see Plate 15).

Soil and Drainage Conditions - The soils of this Land Unit belong to Inland Swamp soil Association, and are poorly drained. The soils of this Association have been covered in several areas by alluvial deposits and colluvial soils.

Present Landuse - Tin mining is practised on the plains of Sungei Langat shortly before it joins Sungei Semenyih. Rubber and grasses occupy the plains along Sungei Ramal. The other parts of the 700-hectare Land Unit are too narrow for agricultural use, especially along the Kajang-Dengkil Road. Figure 15 shows that this narrow belt is being dredged, presumably to facilitate better drainage conditions in the upper parts of the floodplains.

Use Classification - Some sections covered by grass along Sungei Ramal could be developed (A2). Short-term crops including padi could be grown successfully in such areas. Areas in the Sungei Ramal section on which rubber is grown could be redeveloped (A3). Other parts are too narrow for farm use.

Land Unit 7c: Inclined Highland Floodplains. This Land Unit is found mainly along the Sungei Langat and it extends from just south of Ulu Langat town to Kampong Batu Lapanbelas. Its surface area of 900 hectares occupies 11.7% of the total surface area of Land Category 7. The Land Unit is flooded only during periods of severe flooding such as the one which occurred in January, 1971. The main reason for this is that the stream channel is one to three metres below the general level of the plains (see Plate 13). This channel is actively under-cutting the plains in the process of widening its meandering belt.

Slope Characteristics - The average slope angle on the floor of the channel is 1^0. The typical slope on the floodplains is 2^0, but this rises to 4^0 or 6^0 near the foothills.

Soil and Drainage Conditions - The soils of the highland floodplains have been mapped as Local Colluvium-Alluvium Association. These soils are very sandy on, and near the stream channel, but are silty, or clayey away from the channel. They are generally well-drained when not flooded and are rated 1 and 2.

Present Landuse - Rubber, padi, corn, fruit trees, and vegetables are grown in many areas of the unit. A considerable section of this unit is occupied by homesteads, while certain areas are covered by tall grasses.

Use Classification - Parts of this Land Unit which are covered by grasses could be developed (A2). Areas where rubber occupies floodable flats could be redeveloped (A3). Other areas are considered developed (A1).

DISTURBED LANDS

A total of 2,970 hectares, occupied by settlements, quarries, and tin mines, have been mapped as Disturbed Lands. This total area represents a combination of single units which occupy areas equal to, or larger than, 4 hectares (10 acres). It constitutes 2.7% of the total surface area of the Ulu Langat District. Table 13 shows the distribution of these disturbed lands in the various Land Categories.

Use Classification - Urban planning techniques would improve the general use of the areas occupied by settlements, while better management is evidently required in many mining and quarrying lands. For the purpose of this study lands occupied by settlements, worked tin mines and worked quarries are classified as developed (C1). Abandoned mines and quarries could be redeveloped (C3). The needs of the people, and the technology at their disposal would determine the best alternate use for these wastelands. Wiesława (1964) has shown how wastelands similar to these could be converted into settlement-forest-recreation complexes.

CHAPTER 6

MORPHOMETRIC ANALYSIS OF SOME LAND CATEGORIES IN THE ULU LANGAT DISTRICT

A combination of the parametric and the landscape landform mapping approaches (Mabbutt, 1968) was adopted to compile the Land Category map for the Ulu Langat District. Some standard of quantification was achieved with this combined approach, but further morphometric analysis of some Land Categories was undertaken because such analysis was, and is, considered necessary to agricultural land planning purposes. The morphometric analysis in the sampled Land Categories is concerned mainly with indices of soil erodibility and measures of mass wasting, because it has been observed that the degree to which the West Malaysian soils are resistant to soil erosion and mass wasting is to be considered seriously in the utilisation of the land (Eyles, 1968a; P.Wong, 1968; Wycherley, 1969). Consequently, field work, followed by laboratory and statistical analyses, was designed to estimate soil erodibility and mass wasting, and also to test the validity of the Land Categories on the basis of inter-category differences shown by the soil and land attributes investigated. To satisfy these aims a selection of land and soil attributes was made, bearing in mind the time and the facilities (including equipment) which were available.

Choice of attributes and sites

The following soil and land attributes were measured or determined in each sampled Land Category, because these attributes have been described variously as indices of soil erodibility and land morphology, as will be shown below.

Soil attributes. The soil attributes which were investigated are: 1) aggregate stability, 2) sand/silt + clay ratio (clay ratio), 3) silt + clay fraction (clay content), 4) shear strength (shearing resistance), and 5) shear ratio.

1) Aggregate stability measures the structural stability of the "bounded" soil particles under different ground-water conditions (Terzaghi and Peck, 1967). Aggregate stability has been widely applied as an index of soil erodibility (McCalla, 1944; Woodburn and Kozachyn, 1956; Bryan, 1968). The contention is that aggregate stability indexes the ease with which soil aggregates might be broken into erodible separates (Bryan, 1968; Eyles, 1968a). This implies that the more stable the soil aggregates, the more difficult they are to break into separates. It has been noted that the percentage-weight of Water Stable Aggregates (W.S.A.), greater than three millimetres in diameter, is a reliable index of soil erodibility (Bryan, 1968).

2) Clay ratio is a measure of dispersion based on the theory that only materials in dispersed form can be eroded (Bryan, 1968). This ratio has been employed as an index of soil erodibility by many workers including Bouyoucos (1935), Leopold

et al. (1964), and Eyles (1968a, 1968b). The use of this index as a measure of the erodibility of certain soil types has been criticised by Bryan (1968), because it is known that fine aggregates are moved by low-velocity run-off. Bryan (1968) admits that clay ratio might be an accurate index of the erodibility of soils with high silt + clay content, and that a content of 30% might be a significant threshold value. The soils of the Ulu Langat District have been shown to contain more than 30% silt + clay content (see Chapter 5, and also I. Wong, 1966; and Ng, 1969). It is believed that the combination of the clay ratio with the measure of aggregate stability will provide an adequate indication of the erodibility of the soils in the District.

3) Silt + clay fraction is also a measure of dispersion based on the theory which governs the clay ratio, but the clay content is inversely related to the clay ratio. The clay content (silt + clay fraction) has been used as an index of soil erodibility (Bennett, 1926; Middleton, 1930; Eyles, 1968a). In addition, Jahn (1967) has obtained a direct correlation between slope angles and "silty fraction" (silt + clay content). This index is used in this study mainly as a measure of structural differences among typical soils of different Land Categories.

4) Shear strength is a measure of the cohesion of "bounded" soil (Eyles, 1968a, 1968b). The index has been used to estimate soil erodibility (Chorley, 1959; Eyles, 1968a, 1968b), and its importance as a measure of mass movement has been recognised

(Terzaghi and Peck, 1967; Bryan, 1968; Eyles, 1968a, 1968b). While it might be contended that shearing resistance influences mass movement more than it does soil erodibility (Bryan, 1968), it must be noted that mass movement is a factor of slope development (Jahn, 1967; Savigear, 1967). Any factor of slope development will affect the utilisation of the land on which the slope is developed. Therefore, an index of mass movement is relevant to the present study.

5) Shear ratio is a derivative of shear strength, and it is introduced in this study to measure the degree of the uniformity of the shear strength within the top 45 cm of the soil profile. The ratio is the quotient obtained by dividing the shear strength value of the top 15 cm of the soil profile, at a given site, by the corresponding value determined for a depth of 30 cm to 45 cm of the profile. The ratio was introduced as a result of casual observation in the field, which revealed a) that the top 45 cm of the soils in disturbed areas is characterised by uniform and high shearing resistance, probably, because of the removal of the A horizon in such areas; but b) that the top 45 cm of the soils in areas covered by forests is characterised by stronger shearing resistance with increasing depth, apparently because of the presence of the A horizon. A numerical explanation of this relationship is considered necessary.

Land attributes. Indices of soil erodibility are not necessarily limited to soil attributes. Topographical attributes which are believed to affect soil erodibility include: 1) form of slope (slope profile), 2) angle of slope, 3) local relief, and 4) distance from the crest.

The form of the slope (1) and the angle of slope (2) have been found to affect particle distribution of the soils which are formed, or deposited, on any land area (Jahn, 1967; Terzaghi and Peck, 1967). They are also regarded as indices of valleyside properties (Curtis, et al., 1965; Savigear, 1965, 1967; Swan, 1970b). The investigation of slope form and angles of inclination is relevant to the purposes of the present study, because these land attributes exert limiting effects on the activities of man and his machines (Curtis, et al., 1965).

Local relief (3) and the distance from the crest (4) have been shown to be associated with the length of slope (Swan, 1970b) which is an index of soil erosion (LaMarche, 1968; Emmett, 1970). They are also associated with the slope form and the angle of slope (Swan, 1967; 1970b). An investigation of these attributes is considered necessary because their combination will indicate the proportion of the land-surface that is available for utilisation (see also Sitwell, 1971).

Sample sites. Three sites were selected on each slope profile as sample stations for soil samples, shear strength determination, and slope angle reading. These are: 1) summit area,

2) steepest slope, and 3) valleyfloor.

The summit area (1) is considered the highest point within a given land-surface, and is the place where down-slope surface flow is initiated (Gustafson, 1937). It is also the ultimate source of materials to be transported (Eyles, 1968a). The steepest slope (2) is highly related to soil erosion (Jahn, 1967), soil stability (Eyles, 1968a, 1968b), and run-off rate (Butler, 1955; Emmett, 1970). The valleyfloor (3) is the likely place of sedimentation in the context of a given land-surface, and, consequently, the place where the material removed from the other parts of the profile are deposited, at least temporarily (Ahnert, 1967; Demek, 1967). It is believed that measures of soil attributes at these three sites will indicate the distribution of the attributes over three different, and significant, morphological elements of the valleyside.

Soil samples were drawn from a depth of 30 cm to 45 cm, primarily, to avoid surface disturbances in cultivated areas. The depth of the soil profile which is usually exposed on terraces in such areas ranges, most frequently, from 30 cm to 45 cm. Secondly, the depth of 30 cm to 45 cm is contained within the depth of 15 cm to 120 cm suggested by Mohr and Baren (1954) as the optimum level of regolith stability and tree-crop root penetration. Shear strength was sampled from two levels at each sites: a) the top 15 cm of the soil profile, and b) a depth 30 cm to 45 cm of the soil profile. A depth of 30 - 45 cm was sampled for the same reasons stated in the case of the soil samples. The top 15 cm was investigated because it has been suggested that it is from the top of the soil profile that processes of rill and wash start, and are most active (LaMarche, 1968).

Indicators of soil erosion

In addition to the investigation of the soil and land attributes, indications of soil erosion were observed within a belt, approximately ten metres wide, on either side of a slope profile. An indication of soil erosion is required to facilitate meaningful interpretations of the measures of soil erodibility. Ideally, simulated erosion, and/or measures of debris waste, can provide numerical determination of the rate and quantity of soil erosion, but the nature of this study does not absolutely require such ideal investigations, and, in any case, there was no equipment suitable for simulated erosion, and/or the time for adequate measurement of debris waste. Consequently, a qualitative-quantitative appraisal of soil erosion was followed, based on an idea suggested by Professor Ian Douglas during a personal discussion. The qualitative-quantitative scale of the appraisal of soil erosion, which is illustrated in Table 14, is based on suggestions contained in the works of Gustafson (1937), Ellison (1945), Osborn (1954), Butler (1955), Douglas (1967), Ruxton (1967), and LaMarche (1968), and also on results of field investigations which were discussed in Chapter 4.

TABLE 14 : Qualitative-Quantitative appraisal of some indicators of soil erosion in the Ulu Langat District.

INDICATOR	RATINGS a) Very Serious	b) Serious	c) Slight
1. Tree Roots	i. Roots 8 cm in diameter exposed fully on slopes gentler than 5^0. ii. Roots 8 cm half exposed on slopes steeper than 10^0.	i. Roots 8 cm in diameter half exposed on slopes gentler than 5^0. ii. Slightly exposed roots on slopes gentler than 10^0.	i. Slightly exposed roots on slopes gentler than 5^0.
2. Type of vegetation and nature of canopy	i. Bare ground with patchy upper canopy ii. Single-stand cropping on slopes steeper than 10^0	i. Bare ground with complete upper canopy ii. patchy grass cover iii. Shrubland with patchy bare spaces iv. Single-stand cropping on slopes of 5^0 - 10^0.	i. Single-stand cropping on slopes gentler than 5^0 ii. Grassland with bare spaces.
3. Management	i Cross-contour cropping,or unterraced planting on slopes steeper than 10^0 ii. Cross-contour footpaths on slopes steeper than 10^0 iii. Inadequate diversions of surface drainage on slopes steeper than 10^0.	i. Weak, or crumbling terrace mounds ii. Clean-clearing on slopes of 5^0 - 10^0 iii. Criss-cross tracks on slopes of 5^0 - 10^0 iv. Terraces 3 metres apart v. Inadequate diversions of surface drainage on slopes gentler than 10^0.	i. Clean-clearing on slopes of 2^0 - 4^0. ii. Cross-contour footpaths of slopes of 2^0 - 4^0.
4. Signs of Active erosion	i. Head gullies ii. Gullies deeper than 50 cm iii. Basal sapping iv. Rill 8 cm deep on slopes steeper than 10^0.	i. Rill 8 cm deep on slopes gentler than 10^0 ii. Coarse surface material due to wash iii. Raindrop hollows on slopes steeper than 5^0.	i. Rill 8 cm deep on level ground ii. Raindrop hollows on slopes gentler than 5^0.

Table 14 shows that three ecological indicators of soil erosion have been combined with signs of active erosion to appraise the rate of soil waste in the Ulu Langat District. These are: 1) tree roots, 2) type of vegetation and the nature of its canopy, and 3) soil and land management. Three levels of erosional conditions are also shown in the Table.

Tree roots (1), except for prop roots, which are exposed on any type of slope are considered as indicators of soil erosion on that slope (LaMarche, 1968). The vegetation, especially the nature of its canopy, (2) has been observed to influence the amount and the intensity of the raindrops that reach the ground under the vegetation (Osborn, 1954; Douglas, 1967). Raindrops are capable of breaking down the aggregates of the surface soils (Ellison, 1945; Rose, 1962; Meyer and Monke, 1965; Ruxton, 1967). The separates which are produced in this way can then be easily washed down the slope (Jahn, 1967; Bryan, 1968; Emmett, 1970). Soil and land management (3) is an energy input into the process-response system of the soil, the slope, and the surface run-off. This input energy can induce disequilibrium in the system. The demaging effects of bad management on the soils of disturbed lands are well documented (Sil'vestrov, 1963; Moss, 1963; Jahn, 1967; Panton, 1969; Wycherley, 1969; Emmett, 1970).

The numerical values employed to identify the three levels of soil erosion estimates are: slope angles of 5^{0} and 10^{0}, size of the diameter of roots in centimetres (8 cm), and depths of rills and gullies in centimetres (8 cm, 50 cm).

A slope angle of 5^{0} was selected as a likely lower limit of serious soil waste mainly because this angle has been accepted as the theoretical boundary between depositional gentler slopes, and erosional steeper ones (Savigear, 1965, 1967; Bryan, 1968). Subsequent field work revealed that serious erosion can occur on slopes gentler than 5^{0} in the Ulu Langat District. Where this was observed, necessary adjustments were made in the ratings. Similarly, it was observed that very serious soil erosion can occur on slopes gentler than 10^{0} which was selected as the lower limit of very serious soil erosion. Adjustments were made in the ratings where this was observed. The diameter of 8 cm, and the depths of 8 cm and 50 cm were selected because these measurements represent the upper of the depth-range of optimum tree-crop root penetration, suggested by Mohr and Baren (1954).

Sampling Technique

A stratified random sampling technique was followed because of its advantages over ordinary random sampling technique, especially in geographical investigations of morphometric nature (Monkhouse and Wilkinson, 1971; Doornkamp and King, 1971). Land Categories 1 (Southern Depression), and 6 (High Mountains) were omitted from the analyses because of their inaccessibility (see Chapter 4). From each of the remaining Land Categories, two Land

Units were selected by a random sample technique. The main stream which flows through a selected Land Unit was determined as the focus for field investigations. A stream was selected because it has been explained that streams, especially their valleyside properties, are dominant elements of the landscape (Strahler, 1958, 1960; Eyles, 1968a, 1969; Swan, 1970b, after Horton,1945).

Four valleyfloor-to-crest profiles (at least one from either bank of the stream) were investigated along each selected stream, except in Land Unit 5a (Dissected Steep Foothills) where only three profiles were accessible, and in Land Category 7 (Active Major Floodplains) where the flat nature of the terrain precluded the measurement of slope profiles. In Land Category 7, therefore, only soil samples were obtained for laboratory analyses. In the other investigated Land Units, the profiles were spaced at intervals of one kilometre (approximately half-a-mile). These profiles were aligned at such angles to the stream channel as were considered adequate both to represent the typical characteristics of the valleyside properties, and to obtain base-to-summit transects (after Tivy, 1962). The numerical values of soil and land attributes, which were obtained from field and laboratory techniques for each profile, are contained in Appendix II.

Field Techniques

An Abney level was used to measure slope angles along each slope profile. Slope stations were made to coincide with apparent breaks of slope, but where a slope unit was very long, slope stations were evenly spaced at 20 m apart. This agrees, in principle, with the suggestion of Doornkamp and King (1971) concerning the use of the Abney level for slope measurements. The instrument was levelled at a point on a partner corresponding to the reader's eye-level in order to read the inter-station slope angles. All readings were taken to the nearest whole degree to comform with the method employed earlier in this study.

Along a slope profile, shear strength was measured at the valleyfloor, the steepest slope, and the summit area, for the reasons discussed above. A two-inch shear vane was used to measure shear strength. This vane was mounted on an iron shaft at the end of which was attached a 200-lb torque-wrench handle. Two levels were sampled at each site. First, the fifteen-centimetre-long shear vane was buried into the surface of the soil, at a selected site, to determine the torque value for the top 15 cm level. Secondly, a two-inch soil auger was used to excavate a hole 30 cm deep. The vane was lowered into this hole, and was gently buried into the soil at the base of the hole, such that the soil remained undisturbed. This was undertaken in order to determine the torque value for the 30 - 45 cm level. In all the cases, after a complete burial of the vane had been achieved, the torque handle was wrenched until the soil began to yield. The torque value was then determined as indicated by a scale on the torque-handle. The value was expressed in pound/sq. inch shear force by the use of the formula:

$$T = \frac{M_{max}}{Pi\left(\frac{D^2H}{2} + \frac{D^3}{2}\right)} \quad \text{for one-end shearing}$$

where

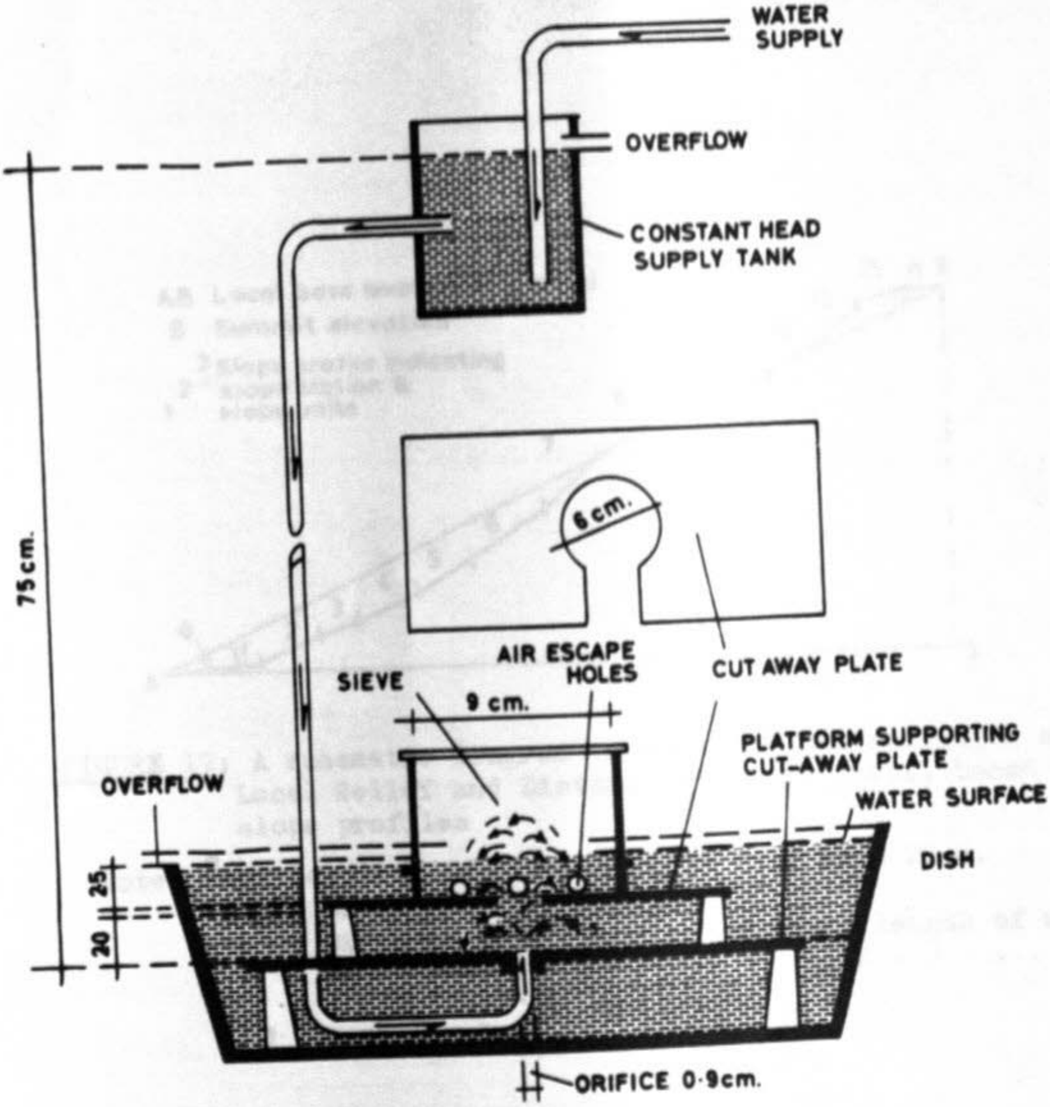
T = shear strength, in pound/sq. inch force,
Mmax = net applied torque,
D = diameter of shear vane,
and H = vertical height of shear vane.

..... See Jumikis (1962, pg.509).

The pound/sq. inch force was then converted to gram/sq. centimetre force. The shear ratio for each site was obtained by dividing the value of the top 15 cm by that of the deeper level.

Soil samples were taken from the depth of 30 - 45 cm with a two-inch soil auger. The samples were later analysed to determine silt + clay fraction, sand/silt + clay ratio (clay ratio), and aggregate stability. The soil samples were drawn from the same soils which were tested for shearing resistance in order to make later comparisons meaningful. Care was exercised to see that the soil aggregates were not disturbed significantly by the shear vane.

Both the local relief and the distance from the crest were determined graphically from the slope profiles as illustrated in Figure 19. The local relief was determined as the height of the summit above the edge of the stream in the valleyfloor. The total length of the slope units that constitute a slope profile was



<u>FIGURE 18</u>: Apparatus for the determination of aggregate stability (Designed by Eyles, 1968a, after Keraites and Ferguson, 1957)

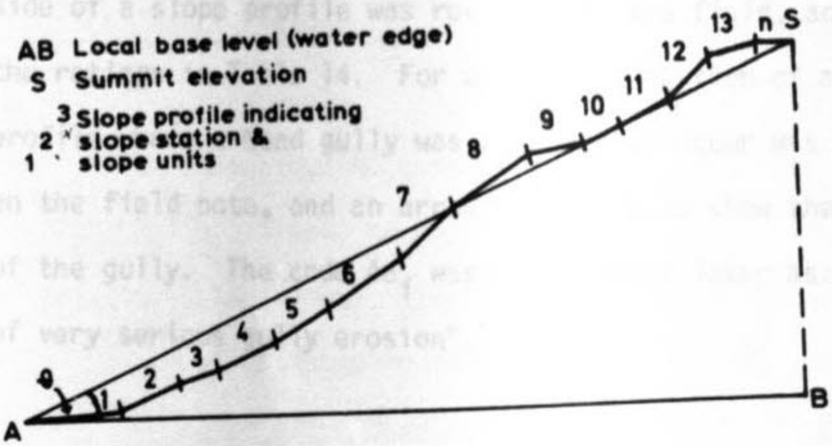


FIGURE 19: A schematic diagram to show the determination of Local Relief and Distance from the crest, based on slope profiles

Note: Profiles were drawn to a scale of 1 cm = 20 m.
Hence, Local Relief = length SB
and Distance from the crest = total length of units (1 + 2 + 3 + ... + m)

θ = average slope

determined as the distance from the crest.

The state of soil erosion within 10 metres on either side of a slope profile was recorded in the field, according to the ratings in Table 14. For example, a section of a slope profile where a head gully was observed to occur was marked $4a_i$ on the field note, and an arrow was drawn to show the length of the gully. The code $4a_i$ was interpreted later as: "an area of very serious gully erosion".

Laboratory Techniques

a) Aggregate stability. The laboratory techniques by which the aggregate stability of a soil sample can be determined have been described by various workers (for example: Rosenak, 1963; Yong and Warkentin, 1966; Terzaghi and Peck, 1967; Bryan, 1968; Eyles, 1968a, 1968b). The technique followed in this study is exactly that of Eyles (1968a, pg. 141) because the apparatus which was available for the laboratory analysis of aggregate stability was the one designed, and used, by him. The apparatus (see Figure 18) is based on the Water Stable Aggregate method of Keraitis and Ferguson (1957).

The procedure of this method is as follows (see also Eyles, 1968a, pg. 142).

1. Sieve a sample of oven-dried soil with British Standard (B.S.) sieves No. 72 (to remove particles smaller than 0.83 mm in diameter) and No. 10 (to

remove aggregates larger than 11.9 mm in diameter).

2. Hand-pick visible vegetable matter from the sample retained on the B.S. sieve No. 72, and mix sample thoroughly.
3. Weigh out 20 grams from the sample retained on the B.S. sieve No. 72.
4. Place a B.S. sieve No. 72 with air escape holes as illustrated in Figure 18. Move the sieve up and down water current to remove trapped air from the mesh.
5. Pour the 20-gram sample onto the mesh, and start to rotate the sieve. Continue to rotate the sieve until water is clear. Then rotate occasionally until fifteen minutes have elapsed since the beginning of the experiment.
6. Remove the sieve with the fraction retained on it, and place in an oven set at 90^{o} Centigrade for one, or two hours (until sample is dry).
7. Remove sample from the oven and allow to cool.
8. Weigh the fraction retained, and determine this as a percentage of the original 20-gram sample.
9. Express the percentage as the aggregate stability of the larger soil sample.

b) <u>Particle-size distribution (clay content, and clay ratio)</u>. Techniques by which the particle-size distribution of a soil sample can be determined are well documented (Herdan, 1960; Capper and Cassie, 1963; Yong and Warkentin, 1966; Terzaghi and Peck, 1967; Eyles, 1968a, 1968b). Since the present study does not require the separation of the clay fraction from the silt content, a technique of wet-sieving was considered adequate to determine the silt + clay content (see, for example, Yong and Warkentin, 1966; Terzaghi and Peck, 1967). The B.S. sieve No. 200 is accepted as the lowest level of practical sieving (Herdan, 1960; Rosenak, 1963). The mesh, approximately 0.076 mm in diameter, is the closest mesh in the B.S. range to the recognised boundary (0.066 mm) between fine sand and silt particles (Herdan, 1960; Capper and Cassie, 1963).

The following is the procedure adopted in this study to determine the silt + clay fraction and the sand/silt + clay ratio.

1. Pick visible organic matter from oven-dried soil sample.
2. Mix sample thoroughly and weigh out 50 grams.
3. Soak the 50-gram sample in a solution of sodium-hexametaphosphate, a chemical dispersing agent, for at least two hours. Stir the 50-gram sample thoroughly in this solution to break the sample into component particles.

4. Pour content onto a B.S. sieve No. 200, for washing. Wash under running tap until sample is clean.
5. Dry the fraction retained on the sieve in an oven set at 90^{o} Centigrade for two hours (or until sample is dry).
6. Remove sample from the oven, allow retained fraction to cool, and weigh the fraction. This is the sand content of the original 50-gram sample.
7. Determine the difference between the sand content and the original 50 grams as the silt + clay content. Express this as a percentage of the 50-gram sample. This is the silt + clay fraction of the larger sample.
8. Divide the sand content by the silt + clay content, and express the quotient as the sand/silt + clay ratio (clay ratio) of the larger sample.

Limitations

Certain limitations are inherent in studies of this nature. These include limitations connected with data, instrumentation, experimentation and observation.

In geomorphological studies, it is often impossible to collect data for the whole of a given area (Doornkamp and King, 1971). Consequently, points were sampled to represent areal dimensions in this study. It is believed that the transect technique, which was followed, improves the coverage of the sampled Land Categories. The eight profiles that formed the basis of the analyses in each Land Category might be regarded as constituting a very small sample size, but there are 24 samples of each attribute determined for a Land Category (except for Land Categories 5 and 7, with 21 and 15 respectively). The size is, therefore, considered to be large enough for small-sample methods of statistical analysis (see Bajpai, 1967; Monkhouse and Wilkinson, 1971). In fact, at least 93 samples of each soil attribute are considered in the combined analysis for the sampled Land Categories.

Instruments used, both in the field and in the Laboratory, are of standards usually recommended for the type of investigations undertaken. Limitations associated with these instruments are believed to be the same as those generally accepted in respect of such instruments. Such limitations are considered to be uniform in all the cases investigated with the same instrument. It is suggested, therefore, that the real association among the attributes is not impaired.

Experimental errors are, most likely, at the minimum and uniform because the same operator performed the experiments, and recognised procedures were followed as discussed above. Second checks, by an independent operator, were used to comfirm the accuracy of the procedures and the numerical results, in the case of the laboratory experiments. It is likely that the silt + clay content determined by the technique of wet-sieving, which was followed in this study, contains some fine particles of organic matter. This, in itself, is an advantage because the organic content of the soil is recognised as a part of the cohesive element of the soil (Bryan, 1968).

Observational errors are believed to be uniform because the same operator was involved throughout the investigations. The errors are probably at the minimum because the observations were based on the actual, and not on the inferred.

Analyses of data, and interpretation of results

The data in Appendix II were analysed in their three site-locations on the basis of individual Land Categories and all the Land Categories combined. Tables 15 to 19, and Figures 20 and 21 show the results of the analyses. Figure 22 shows a combination of these results with the estimates of soil erosion based on the adjusted content of Table 14. The statistical methods and formulae followed are the same as the ones followed in the former analyses, and are given in Appendix III.

The results of the analyses are given on the basis of the statistical parameters of the attributes because the analyses have shown that the attributes combine to influence soil erosion. It appears that a discussion of the results on the basis of individual attributes will not adequately emphasize this combined influence. The basis of statistical parameters brings the attributes together within each Land Category and at each site-location. This makes it easier to determine the inter-relationships of these attributes within the locations.

The statistical parameters are: 1) the arithmetic mean ($\bar{x}$), 2) the coefficient of variation (CV%), 3) Pearson's product-moment coefficient of correlation (r), 4) the coefficient of multiple correlation (R), and 5) the regression equation, and line, of selected Y variable on selected X variable. Selected slope profiles (Figure 21), which adequately represent the typical slope forms in the sampled Land Categories, are discussed.

Arithmetic mean ($\bar{x}$). The mean values (Table 15) were analysed to determine the inter-category differences in the domain of the attributes, and to obtain the pattern of the distribution of the attributes from one site-location to the other. The test of significance of the difference of mean values was used (Appendix III). It was decided that the 5% level of significance must be achieved before a difference was considered adequate. Test values were read on the two-tailed Table of t-Distribution as suggested by Doornkamp and King (1971).

All the attributes, except for the ratios and the local relief, show significant differences in the mean values between one Land Category and the other, and between one site-location and another. The t-values range from 2.09 to over 15.50, and three-quarters of these values are significant at better than 5% level.

TABLE 15 : Mean-values of soil and land attributes investigated in some Land Categories

SITE	L.C.	Local relief (m)	Maximum slope (°) *	Distance from crest (m) *	Shear strength (g/cm²) *	Shear-ratio	Silt + clay fraction *	Sand/silt + clay ratio	Aggregate stability % *
Summit area	2(k=8)	26.00	-	-	279.05	0.71	60.13	0.85	64.18
	3 "	43.62	-	-	294.43	0.64	65.20	0.66	51.06
	4 "	41.62	-	-	296.62	0.57	60.03	0.67	62.67
	5(k= 7)	47.14	-	-	293.75	0.41	46.14	1.33	75.04
	All(k=31)	39.35	-	-	290.87	0.59	58.08	0.86	62.67
Steepest slope	2(k=8)	-	14.13	-	265.86	0.65	55.51	0.88	67.35
	3 "	-	20.00	-	274.65	0.67	62.46	0.61	61.87
	4 "	-	24.00	-	272.45	0.58	60.08	0.70	62.34
	5(k=7)	-	26.71	-	238.55	0.59	51.73	0.94	77.16
	All(k=31)	-	21.03	-	263.66	0.63	57.70	0.78	66.86
Valley-floor	2(k=8)	-	-	240.13	136.23	0.99	45.76	1.90	74.57
	3 "	-	-	265.00	94.48	0.93	55.47	0.86	83.59
	4 "	-	-	223.13	276.82	0.61	61.93	0.79	66.72
	5(k=7)	-	-	192.14	291.29	0.63	41.20	1.70	88.78
	All(k=31)	-	-	231.32	196.76	0.79	53.98	1.30	78.08
PROFILE	(k=93)				250.43	0.67	56.86	0.98	69.27
	(k=31)	39.35	21.03	231.32					
L.C. 7(k = 15)		-	-	-	-	-	69.94	0.53	63.78

* Difference in value between one Land Category and another significant at 5%, or better, level.
k = sample size

Distribution of the silt + clay fraction - The following patterns are noticeable in the distribution of the silt + clay fraction.

1) There is a decrease in value from Land Category 2 (Lowland Plains) to Land Category 5 (Dissected Foothills and Low Mountains).
2) The fraction decreases with increasing slope angle, especially in Land Category 3 (Dissected Depression Rim) and Land Category 4 (Deeply Dissected Highlands). The result is that silt + clay fraction less than 50% is common on slopes steeper than 10^{o}. This result is similar to Eyles (1968a) contention that silt + clay fraction greater than 55% is common on slopes gentler than 13^{o}. However, Land Units developed on argillaceous formations show values which increase with slope angle and local relief.
3) The fraction also differs from the summit to the valleyfloor, probably in response to the lithology of parent materials. Summits on argillaceous formations show the highest values, and the valleyfloors on arenaceous formations the least (see Table 16). In granitic areas, and on summits with laterite formations, silt + clay fraction is generally low. In such areas the highest fraction is found on the steepest slope, and the least on the summits.

Distribution of the sand/silt + clay ratio - The values of the sand/silt + clay ratio have the following distributional patterns.

1) The clay ratio (sand/silt + clay ratio) increases, generally, with increasing slope values, although the highest ratios from Land Category 2 are found at the valleyfloors. This suggests that other factors, apart from the angle of slope, govern the distribution of the clay ratio.

2) The lithology of the parent materials appears to be one of the factors that influence the distribution of the clay ratio. High ratios characterise areas on granites, or sandstones, while the lowest ratios are associated with areas developed on argillaceous formations.

Distribution of the aggregate stability - The values of the aggregate stability are distributed as follows.

1) Generally, the mean values of aggregate stability are highest on the valleyfloors, and also on summits with lateritic cappings (Table 15).

2) The lowest values occur in Land Category 3 at all the site-locations, especially on summits that have no lateritic cappings.

3) It appears that the lithology of the parent materials and the silt + clay content of the soils are related

to the aggregate stability of the soils. Areas on granites and sandstones which have low silt + clay content show high aggregate stability.

Distribution of shear strength and shear ratio - The following patterns of the distribution of the shear strength of the 30 - 45 cm depth, and the shear ratio are shown in Table 15.

1) The shear strength values are lowest at the valleyfloors and highest in areas with lateritic cappings. The highest mean value (296 grams/cm^2) is associated with summit areas of Land Category 4, and the lowest value (94 grams/cm^2) is associated with the valleyfloors of Land Category 3.
2) In general, the shear strength decreases with increasing slope angle.
3) The shear ratio decreases with increasing slope angles and altitude.
4) The type of vegetation, and the nature of the A horizon of the soil profile seem to affect the shear ratio. The influence of these factors on the ratio will be discussed below.

Distribution of the mean values of the Land attributes. The mean values of the three land attributes, which were investigated, are distributed as follows.

1) Local relief and average maximum slope angle

TABLE 16: Mean ($\bar{x}$) values of silt + clay fraction (%) by Land Units

Land Unit	Summit area	Steepest slope	Valley-floor	Profile (k)	Average slope	Geology
2a(k=4)	61.54	57.87	28.31	49.24(12)		typically Arenaceous (sandstones)
2e(k=4)	58.72	53.15	63.20	58.36(12)		Argillaceous (schist, idurated shale)
L.C. 2(k=8)	60.13	55.51	45.76	53.80(24)	6^{o}	
3b(k=4)	54.21	56.41	54.07	54.90(12)		Arenaceous
3d(k=4)	76.20	68.51	56.76	67.16(12)		Argillaceous
L.C. 3(k=8)	65.20	62.46	55.47	61.03(24)	10^{o}	
4a(k=4)	58.50	56.67	55.67	56.89(12)		Older granites
4b(k=4)	61.56	63.65	62.80	60.68(12)		Older granites
L.C. 4(k=8)	60.03	60.08	61.93	60.67(24)	12^{o}	
5a(k=3)	50.57	53.87	30.07	44.83(9)		Younger granites
5b(k=4)	41.07	50.12	49.56	46.92(12)		Younger granites
L.C. 5(k=7)	46.14	51.73	41.20	46.02(21)	15^{o}	
All (k=31)	58.08	57.70	53.98	56.86(93)	11^{o}	

increase from Land Category 2 (Lowland Plains) to Land Category 5 (Dissected Foothills and Low Mountains).

2) Distance-from-the-crest decreases from the lowland plains to the low mountains. The absolute longest distance is associated with the lowland plains (see Appendix II), although the longest average distance is associated with the depression rim. Both the absolute shortest distance and the shortest average distance are associated with low mountains.

Coefficient of variation (CV%). Table 17 shows the CV% values of the soil and land attributes for each Land Category on the basis of the site-locations. This coefficient measures the degree of the internal variations in the domain of these attributes. The following results are contained in Table 17.

1) All the attributes appear to be more variable in Land Category 2 than they are in the other sampled Land Categories. Land Category 2 scores eight of the possible fifteen "most-variable" frequencies.
2) The attributes are least variable in Land Categories 4 and 5, which share equally twelve of the possible fifteen "least-variable" frequencies. The relatively low variation of the attributes

TABLE 17 : The coefficients of variation (CV%) of the soil and land attributes which were investigated in some Land Categories

Land Category	Local relief (m)	Maximum slope (°)	Distance fro.crest (m)	Shear strength (g/cm 2)	Shear-ratio	Sand/silt + clay ratio	Aggregate stability %	SITE
2	50.8+	-	-	18.5-	19.8	28.2	25.0	Summit area
3	40.6	-	-	18.6-	29.7	86.4+	20.8	
4	35.8+	-	-	31.1-	24.6	14.9	18.9	
5	36.7	-	-	16.2-	56.2+	41.3	16.6	
All	45.3	-	-	16.9-	35.6	69.8+	23.9	
2	-	36.7	-	21.5	24.6	47.7+	12.3-	Steepest slope
3	-	31.6	-	18.6	26.9	39.3+	17.1-	
4	-	35.3	-	20.4	17.2	41.4+	14.4-	
5	-	13.5	-	33.2+	28.8	11.6-	14.0	
All	-	37.1	-	23.8	25.8	41.0+	17.5-	
2	-	-	15.1-	57.6	39.4	107.1+	17.3	Valleyfloor
3	-	-	37.4	54.1+	36.6	36.0	9.8-	
4	-	-	14.9-	25.1	22.9	67.1+	19.5	
5	-	-	24.5	23.7	36.5	45.3+	9.2-	
All	-	-	24.1	56.4	43.0	109.9+	17.8-	

- "Least variable" in each Land Category, or all, at the site-location.

+ "Most variable" in each Land Category, or all, at the site-location.

in these Land Categories might be due to the fact that these areas are not as disturbed as Land Categories 2 and 3.

3) Of all the attributes, the sand/silt + clay ratio is the most variable in its values. It shows an extreme variation of 109.9% at the valleyfloors. This high variation reflects the extreme values of silt + clay fraction which characterise the valleyfloors (see Table 16).

4) The aggregate stability varies least. It has average variations of 23.9%, 17.5%, and 17.8% in the valleyfloor, steepest slope, and summit area, respectively.

5) Both the shear strength and the shear ratio are not as variable as the clay ratio. In summit areas and at the steepest slope, the variations in the values of the shear strength are as low as those in the values of the aggregate stability.

<u>Product-moment coefficient of correlation (r), and multiple coefficient of correlation (R)</u>. The product-moment coefficients of correlation (r-values) which were calculated between "independent" (X) variables and "dependent" (Y) variables are given in Table 18. The multiple coefficient of correlation (R) among all

TABLE 18 : Coefficients of correlation (r) between pairs of attributes, and multiple coefficient of correlation (R) among attributes at each site-location

SITE: Summit area

Land Category	Sand/silt + clay ratio (X) and Local relief (Y)	Sand/silt +clay ratio (X) and Shear strength(Y)	Sand/silt + clay ratio (X) and Aggregate stability(Y)	Sand/silt + clay ratio (X) and Shear-ratio (Y)	Aggregate stability (X) and Local relief (Y)	Aggregate stability (X) and Shear-ratio (Y)
2	- 0.26	- 0.15	+ 0.60*	- 0.64*	- 0.40	- 0.13
3	+ 0.11	+ 0.27	+ 0.13	- 0.30	- 0.71*	- 0.51*
4	+ 0.07	+ 0.14	+ 0.25	- 0.70*	- 0.21	+ 0.24
5	+ 0.59*	[illegible]	+ 0.02	- 0.55*	- 0.51*	+ 0.27
All	+ 0.15	+ 0.05	+ 0.43*	- 0.51*	- 0.31*	- 0.25*

$R_{1.2345} = 0.976$; where 1 is sand/silt+clay ratio

SITE: Steepest slope

Land Category	Sand/silt +clay rat. (X) and Aggregate stability(Y)	Sand/silt +clay rat. (X) and Shear-ratio(Y)	Maximum slope (°) (X) and sand/silt+ clay rat.(Y)	Maximum slope (°) (X) and Shear strength(Y)	Maximum slope (°) (X) and Shear-ratio	Maximum slope (°) (X) and Aggregate stability(Y)
2	+ 0.49*	+ 0.61*	- 0.07	+ 0.11	- 0.17	- 0.22
3	+ 0.03	+ 0.10	+ 0.06	+ 0.78*	- 0.96*	- 0.88*
4	+ 0.29	- 0.31	+ 0.50*	- 0.13	- 0.51*	- 0.49*
5	+ 0.40	+ 0.37	- 0.16	- 0.54*	+ 0.32	- 0.46
All	+ 0.35*	+ 0.20	+ 0.11	- 0.02	- 0.36*	- 0.24*

$R_{1.2345} = 0.961$; where 1 is Maximum slope

SITE: Valleyfloor

Land Category	Sand/silt+ clay rat. (X) and Shear strength (Y)	Sand/silt+ clay rat. (X) and Aggregate stability(Y)	Sand/silt+ clay rat. (X) and Shear-ratio(Y)	Distance from crest (X) and sand/silt+ clay rat.(Y)	Distance from crest (X) and Shear-ratio(Y)	Distance from crest (X) and Aggregate stability (Y)
2	- 0.52*	+ 0.59*	+ 0.52*	+ 0.63*	+ 0.05	+ 0.70*
3	- 0.76*	+ 0.61*	+ 0.15	+ 0.75*	+ 0.24	+ 0.05
4	+ 0.53*	+ 0.69*	- 0.19	- 0.14	+ 0.19	+ 0.13
5	+ 0.07	+ 0.89*	- 0.80*	+ 0.48	- 0.50*	+ 0.14
All	+ 0.13	+ 0.51*	- 0.07	+ 0.01	+ 0.16	+ 0.07

$R_{1.2345} = 0.860$; where 1 is sand/silt+clay ratio

* Significant at 10% or better level

the soil and land attributes at each site-location is also given in the Table. The r-values were transformed into Z-ratios (see Appendix III) in order to determine whether there is any real association between the X and Y variables. The r-values which were observed to show real association were tested for significance level. The coefficient of multiple correlation which was obtained among the attributes at each site-location is higher than the individual r-values between pairs of variables at the same site-location. This implies that the correlation among the attributes is a "reinforced" type (Chorley and Kennedy, 1971). For this reason, a 10% level of significance was determined as an adequate measure of the relationship between analysed pairs. Table 18 shows the r-values and indicates the values that are significant at 10%, or better, level. The R-value for each site-location is also given. The following relationships exist among the attributes at each site.

Summit areas:-

1) There is a negative correlation between the sand/silt + clay ratio and the shear ratio which is significant at better than 10% level. The correlation between these attributes is significant at 1% level when the Land Categories are considered together. This negative relationship implies that, in

the summit areas, the higher the sand/silt + clay ratio, the lower the shear ratio.

2) A positive correlation exists between the sand/silt + clay ratio and the aggregate stability in all the Land Categories combined, and it is significant at 2%. These attributes also have a positive correlation which is significant at 10% level in Land Category 2.

3) There is a negative correlation between aggregate stability and local relief which is significant at 2% level in Land Category 3, and at 10% level in Land Category 5 and in all the Land Categories combined.

4) No significant correlation is found between other pairs of attributes in the summit area.

5) The coefficient of multiple correlation (R) which was obtained among the attributes is 0.976, when the sand/silt + clay ratio is held constant. Since this value is higher than any r-value between pairs of attributes in the summit area, the relationship among the attributes is one of reinforcement. The square of R (R^2 = 0.952) shows the proportion of the changes in the sand/silt + clay ratio which can be explained by the combined influence of the

other four attributes. This can be expressed as 95.2% (see Doornkamp and King, 1971).

Steepest slope:-

1) There is a positive correlation between shear strength and maximum slope angle which is significant at 2% in Land Category 3. This implies that, in this Land Category, shear strength increases, or decreases with the slope angle at this site-location.
2) A negative correlation exists between the maximum slope angle and the shear strength in Land Category 5, and it is significant at 10% level.
3) There is a negative correlation between maximum slope angle and aggregate stability which is significant at 5% level in Land Category 3, and at 10% in all the Land Categories combined.
4) The correlation between maximum slope angle and shear ratio is negative. This negative correlation is significant at 0.1% level in Land Category 3, at 10% in Land Category 4, and at 5% in all the Land Categories combined.
5) A positive correlation is shown between the maximum slope angle and the sand/silt + clay ratio in Land Category 4, and it is significant at 10% level.

6) There is a positive correlation between the sand/silt + clay ratio and aggregate stability in Land Category 2. The level of significance is 5%.
7) Other pairs do not show significant correlation at the steepest slope.
8) The R-value is 0.961, when slope angle is held constant. This shows a reinforced association among the attributes, and it seems that 92.3% (R^2 x 100) of the changes in slope angles can be explained by the combined changes in the other four attributes.

Valleyfloor:-

1) There is a positive correlation between sand/silt + clay ratio and aggregate stability in all Land Categories (individually, or combined) which is significant at better than 10% level.
2) The sand/silt + clay ratio has a positive correlation with the distance-from-the-crest in Land Categories 2 and 3. The significance level of the correlation is better than 10% .
3) A negative correlation exists between the sand/silt + clay ratio and the shear strength in Land Category 2 (significant at 10% level), and in Land Category 3 (significant at 2% level).

4) There is a negative correlation between the sand/silt + clay ratio and the shear ratio which is significant at 1% level in Land Category 5, and at 10% in Land Category 2.

5) The distance-from-the-crest has a positive correlation with aggregate stability which is significant at 2% level in Land Category 2.

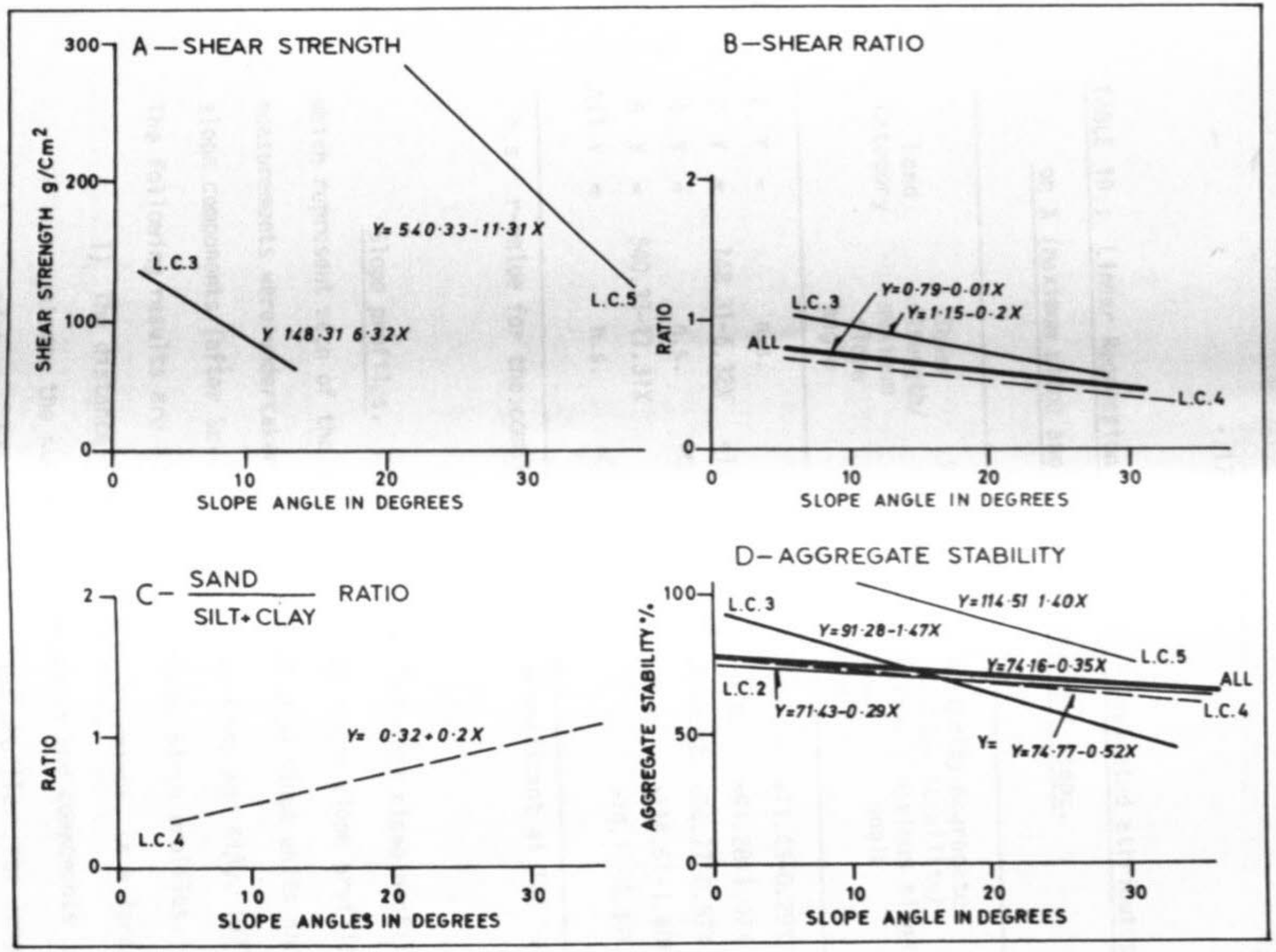
6) A negative correlation exists between the distance -from-the-crest and the shear ratio in Land Category 5, and it is significant at 10% level.

7) Other pairs of attributes show no significant correlation at the valleyfloor.

8) The R-value is 0.860, when the sand/silt + clay ratio is held constant. This suggests a combined influence of the other attributes on the clay ratio. The proportion of the changes in the ratio that might be explained by this combined influence is as high as 73.9%.

Regression equations and lines of Y on X. Table 19 and Figure 20 show the results of the regression analysis of selected (Y) variables on the maximum slope angle (X variable). Regression analysis was undertaken only in the case of the steepest slope because angles of slope have been found to correlate with many indices of erodibility as indicated earlier (see also

Jahn, 1967; Khong, 1970; Doornkamp and King, 1971). Maximum slope angle was selected as the X-variable for the same reason. Only the combinations for which the r-values are significant at 10%, or better, level have been analysed at this stage. The sign of the b constant in the expression $Y = a + bX$ indicates whether the general relationship between two analysed variables is positive, or negative. Although the r-values also show this indication, the indication by the regression coefficient is more readily appreciated because it can be illustrated graphically as shown in Figure 20. It is shown in Table 19 that the relationship between a selected Y attribute and the maximum slope angle is negative, except for the case of the sand/silt + clay ratio which is shown to be positively related to maximum slope angle. Since the silt + clay fraction (clay content) is the inverse of this ratio, it means that the aggregate stability, shear strength, and silt + clay fraction are inversely related to the maximum slope angles in all the Land Categories which are shown in Table 19. Maximum slope angles range from as low as 7^{0} on some profiles in Land Category 2 to over 30^{0} in Land Categories 4 and 5. For this reason, it can be contended that, generally, these selected attributes are inversely related to slope angles in the Land Categories which were investigated.



<u>FIGURE 20</u>: Regression lines of Y (selected attributes) on X (maximum slope angle) at the steepest slope by Land Categories

TABLE 19 : Linear Regression equations of Y (selected attributes) on X (maximum slope angle) at the steepest slope.

Land Category		Shear strength/ maximum slope angle	Shear ratio/ maximum slope angle	Sand/clay ratio/ maximum slope angle	Aggregate Stability/ maximum slope angle
2	Y =	n.s.	n.s.	n.s.	=71.43-0.29X
3	Y =	148.31-6.32X	=1.15-0.02X	n.s.	=91.28-1.47X
4	Y =	n.s.	=0.73-0.01X	=0.32+0.02	=74.77-0.52X
5	Y =	540.33-11.31X	n.s.	n.s.	=114.51-1.40X
All	Y =	n.s.	=0.79-0.01X	n.s.	=74.16-0.35X

n.s. r-value for the combination is not significant at 10% level

Slope profiles. Figure 21 shows selected slope profiles which represent each of the eight Land Units where slope profile measurements were undertaken. The profiles show slope units and slope components (after Savigear, 1967; Doornkamp and King, 1971). The following results are illustrated by these slope profiles.

1) The distance-from-the-crest determines, to a large extent, the number of slope units and components which are obtainable on a slope profile. The longer the distance, the more the number of units and components, and the longer the lengths of these units and components.

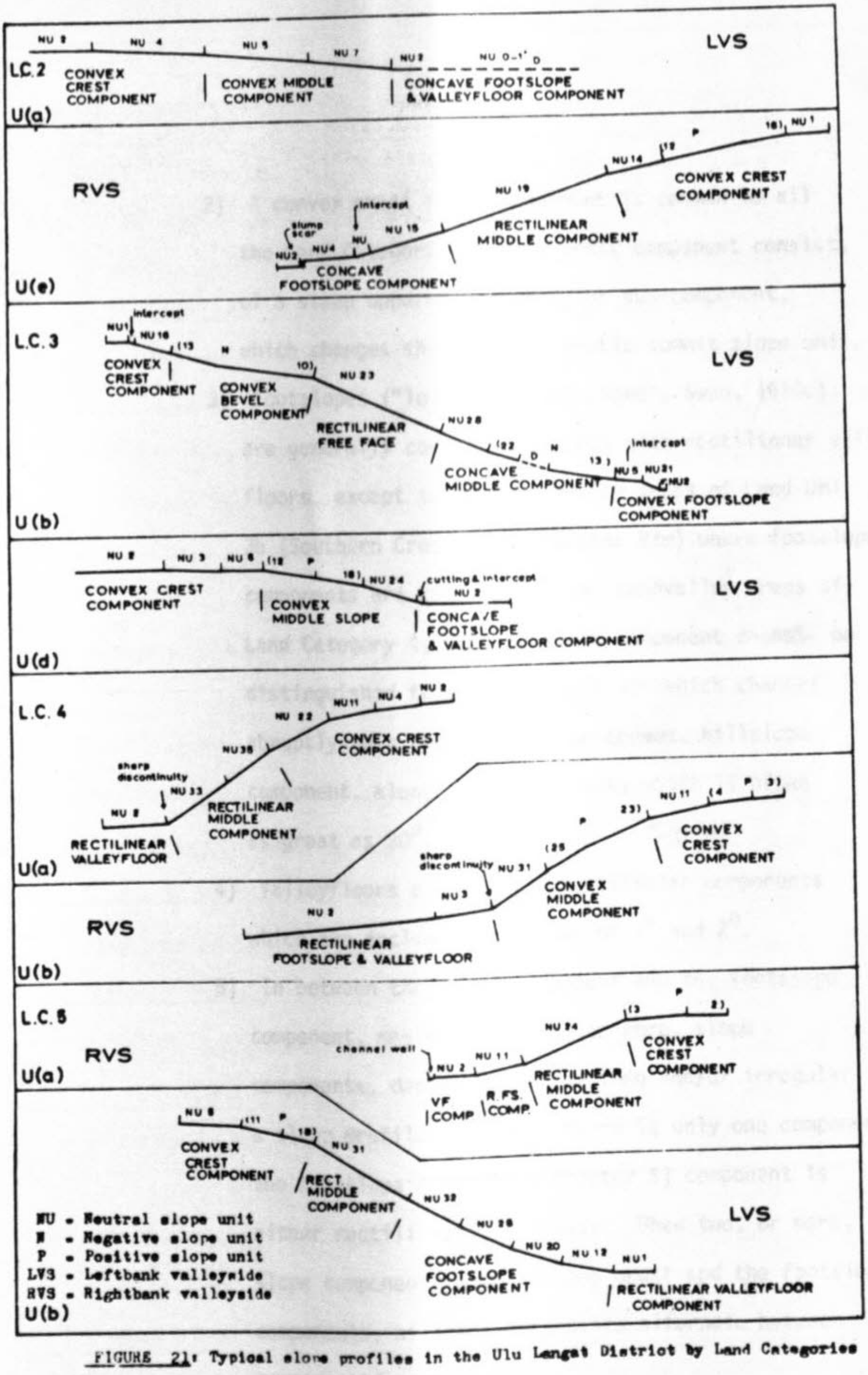


FIGURE 21: Typical slope profiles in the Ulu Langat District by Land Categories

2) A convex crest slope component is common to all the Land Categories. This crest component consists of a steep upper-slope unit, or sub-component, which changes sharply to a gentle summit slope unit.
3) Footslopes ("lower piedmont slope", Swan, 1970c) are generally concave and merge with rectilinear valley-floors, except in the headvalley areas of Land Unit 3b (Southern Crest of Depression Rim) where footslope components are convex. In the headvalley areas of Land Category 4, the footslope component cannot be distinguished from the valleyfloor which changes abruptly to a rectilinear, or convex, hillslope component, along a discontinuity which is often as great as 30°.
4) Valleyfloors are usually rectilinear components which are inclined at angles of 1° and 2°.
5) In between the crest component and the footslope component, may be one, two, or more, slope components, depending on how long and/or irregular a slope profile is. When there is only one component, the hillslope ("middle", Chapter 5) component is either rectilinear, or convex. When two, or more, slope components separate the crest and the footslope components, hillside components alternate between concave and convex forms.

Discussion and Conclusions

The soil and land attributes which were investigated have been found to differ in their mean values from one Land Category to another, and from one site-location to the other. The association among these attributes have been determined to be one of reinforcement. It remains to be seen how the characteristics of the distribution, and the association among, these attributes further justify the classification of the Land Categories, and how these attributes indicate soil erodibility and mass movement in the Land Categories.

Further justification of land classification. The inter-category differences in the mean values of the attributes are significant at better than 5%, and other parameters of these attributes differ from one Land Category to the other, significantly. These significant differences seem to suggest that there are real differences in the landscape properties from one land type to the other. Therefore, the classification contained in the Land Category map (Map 2) is considered to be further justified, and is suitable for this study. It follows that the map can be recommended for future use as a basis for land planning purposes.

Indication of soil erodibility. Four of the attributes discussed above were found to be most related to soil erodibility in the study area. These are: 1) slope angle, 2) sand/silt + clay ratio (which reflects the silt + clay fraction), 3) aggregate stability, and 4) shear ratio. These attributes and the shear strength were found to influence mass movement.

Figure 22 is a schematic diagram which illustrates the inter-relationships among these attributes, on the one hand, and the observed, or induced, land characteristics, on the other. The Figure shows that all the other attributes are inversely related to maximum slope angle. The direct relation between the clay ratio and maximum slope angle reflects the inverse relationship which exists between the silt + clay fraction and the maximum slope angle. Since the observed indicators of soil erosion (Table 14) show that erosion of the soil increases, other factors held constant, with increase in slope angle, it follows that the lower the values of the other attributes the more serious will be soil erosion on steep slopes. Thus a low aggregate stability, combined with a low shear strength and a low silt + clay fraction (high sand/silt + clay ratio) implies a small combined restriction of the influence of slope on soil erosion. Such a combination will result in serious soil loss and mass movement. The various combinations of these attributes and the land characteristics associated with the combinations are shown in Figure 22.

It must be remembered that these attributes do not exert high influence on soil erodibility and mass movement individually (cf: the relationship between the r-values and R-values, as discussed earlier). Consequently, emphasis is placed

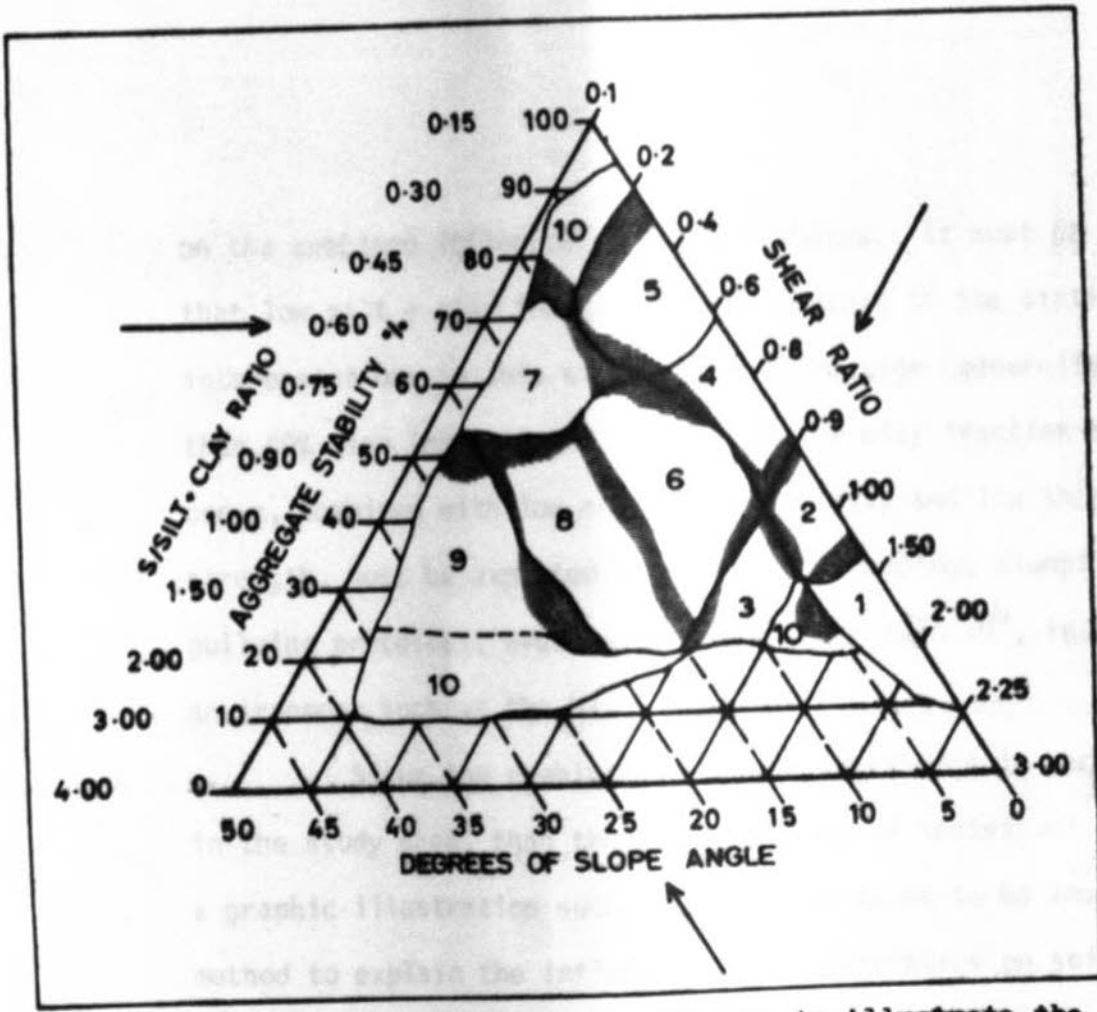


FIGURE 22: A schematic triangle-diagram to illustrate the relationship between combinations of soil attributes and land characteristics

NOTES

1. Silty valleyfloor, usually waterlogged.
2. Silty valleyfloor, or sandy summit area. Well-drained with uniform shearing.
3. Sandy moderate slope, or inclined summit area with the A horizon removed
4. Sandy to silty valleyfloor, more cohesive with depth, or sandy to clayey summit area with A horizon removed. Zone of rill and wash.
5. Summit under vegetation cover. Clayey with possible laterite zone at 30 cm to 45 cm of the soil profile.
6. Moderately sloping land under matured plantation. Sandy to clayey, and subject to rill and wash if bare.
7. Rolling land, or steepland with developed A horizon. Clayey, and subject to gullying and slumping processes if bare.
8. Sandy to clayey steepland, compact under plantation. Gullying and slumping.
9. Clayey, very steep land, compact under plantation. Gullying and slumping.
10. Possible combinations not determined in the Ulu Langat District.

Other combinations are not real in the Ulu Langat District.

Overlapping zone of influence between adjacent land characteristics.

on the combined influence of the attributes. It must be noted that low silt + clay fraction in the context of the statistical interpretations in this study means a fraction generally higher than 40% (see Table 15 and 16). A silt + clay fraction of this order, combined with low aggregate stability and low shear strength, must be expected to result in creeping, slumping, and gullying processes, even on slopes gentler than 10^0, in a humid environment such as the Ulu Langat District.

Since the combination of the attributes is more effective, in the study area, than the consideration of individual attributes, a graphic illustration such as Figure 22 seems to be the best method to explain the influence of the attributes on soil erodibility and mass movement in the Ulu Langat District. The combined effect of these attributes explains, at least partially, the fact that Land Categories 3 and 4, where the effect is most noticeable, are the most actively eroded areas. It might also explain why summits with lateritic cappings, where shear strength and aggregate stability are very high, remain higher than summits with no lateritic cappings. It can be argued, though, that Land Categories 3 and 4 are presently more actively eroded than Land Category 5, mostly because they are more actively cultivated than Land Category 5. They are more actively eroded than Land Category 2, probably, because the land-surface of these Land Categories is steeper than the land-surface of Land Category 2. Slumping

(Plate 16) and gullying processes occur in Land Category 5 near logging-tracks and access-terraces, while isolated hills in Land Category 2, which are characterised by steep slope angles, are actively eroded.

In addition to the above, the shear ratio seems to index the state of the soil profile in relation to soil wash and human disturbances. The ratio is low in areas with well developed humus layer, or leaf litter (A horizon). Such areas are associated with soils under protective natural cover, or fallow. Where the humus layer is thin, or is completely removed, the ratio tends to 1 (unity). Such areas (characterised by high shear ratio and high shear strength) are associated with soils in cultivated, or bare, lands. Exposed tree-roots are common in such areas, even on slopes as gentle as 3^0. When a ratio of 1 occurs in an area which is characterised by high shear strength over 200 grams/ cm^2, it implies that a considerable part of the surface soil has been washed away. A shear ratio of 1 on the valleyfloors might not reflect soil wash, rather, it might show a uniformity in the structure of the sediments within the top 45 cm of the soil profile. Further quantitative analysis of the relationship between the shear ratio and the other soil and land characteristics might provide valuable information on the valleyside properties.

From the discussion above three main conclusions can be drawn.

1) The steeper the slope angle the less cohesive is the soil of the top 45 cm in the Ulu Langat District.

2) The lithology of the parent materials influences soil attributes investigated.

3) The attributes combine to indicate that the top 45 cm of the soil profile in the Ulu Langat District is delicately balanced, and that poor soil and land management tips this balance in favour of serious soil erosion, even on slopes as gentle as 3°.

1) The fact that slope angle correlates negatively with aggregate stability, silt + clay fraction, and shear strength, suggests that the higher the slope angle the less cohesive is the soil. The widespread incidence of slumping processes (Plates 16 and 17) which occur on steep slopes in the District bears this out. Yet this conclusion is in contrast with Eyles's (1968a, pg. 129) findings in another study area that 'slopes on soil of higher shear strength stand at steep angle'. This difference in results might be explained by the fact that Eyles (1968a, 1968b) conducted his investigations on soils under matured

rubber plantations, especially since the difference is most marked in the present Land Categories 4 and 5. Soil samples drawn from these Land Categories were largely from areas under bush, or forest, cover. It might be argued, therefore, that the condition of the shear strength is affected by cultural disturbances.

2) The lithology of the parent materials influences the characteristics of the soil attributes investigated, especially the silt + clay fraction and the aggregate stability. In general, low silt + clay fraction (high clay ratio) is associated with soils developed on arenaceous formations, younger granites, and summit laterite. The highest fractions are associated with soils developed on argillaceous formations. Soils with low silt + clay fraction are associated with high aggregate stability. The coaser the sand content of such soils, the greater is the aggregate stability. Soils on summits with laterites are associated with high aggregate stability and high shear strength. These characteristics of the soil attributes, as conditioned by the lithology of the parent materials, affect soil erosion as explained earlier.

3) The soil and land attributes investigated in the Ulu Langat District indicate that the top 45 cm of the surface soil is so delicately balanced that poor management can tip the balance in favour of soil erosion on slopes as gentle as 3^{o}. Evidence of poor land and soil management is abundant in the Ulu Langat District, in farm- and forest- lands, as well

as in mining areas. Human and machine tracks are located across contours in steep areas. Surface drainage channels are inadequately diverted in farm and mining areas. Plate 18 shows a diversion which is "carved" for surface run-off on a slope steeper than 20^{0}, where other signs of poor land management (for example, bared hillslope) are also evident. Plate 19 shows the diversion of a stream in a mining area. The man-made channel is evidently inadequate to carry the floodwaters of this stream, and the channel is so close to the raod that parts of the road might be flooded during periods of heavy rains. In many areas terraces are cut so deeply, and inter-terrace distances are so short that terrace walls easily slump and crumble, as shown in Plate 20.

There is no doubt that these forms of poor land management accelerate the rate of soil waste in the study area, where the soils are very susceptible to soil erosion and mass movement. Silting in the valleyfloors indexes, among other things, the soil wasted through bad land management. Reports on the amount of silting from various parts of West Malaysia, including the Ulu Langat District, usually cite poor management as the escalator of soil erosion (see Wycherley, 1969; Douglas, 1969a). The importance of the surface soil to land utilisation has been indicated. Good soils 'are a national heritage, and should be preserved from decimation' (Henderson, 1961; pg. 71). It becomes the responsibility of man, therefore, to see that this important national resource is not wasted away, by poor land management, from where it is needed most.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

It was stated in Chapter 1 that the central aim of this study was to show how a geomorphologist, aided by maps of other land indices, could compile a "user" landform map, as a contribution to man's contemporary development needs. It was suggested that the compilation of such a land evaluation map would involve the selection of a suitable land parameter as the dominant attribute, and that the slope of the land could be employed as such to classify and compile such a landform map. It was also suggested that techniques would be designed to obtain and classify slope values from topographical maps, and that the accuracy of these techniques and the validity of the landforms, which were to be based on the slope values, would be tested. In addition, it was specified that soil erodibility and mass movement would be studied within classified land types. These objectives were to be attempted by a combination of morphometric analysis and landform mapping techniques, which would involve the designation of land types for utilisation.

It seems that the techniques employed to obtain, and classify, slope values from the base maps are suitable for these operations at the scale of the base maps. Statistical tests (discussed in Chapter 4) have shown that a high, and positive, correlation exists between map and field-derived slope values. The correlation between each field variable and the map variable has been shown to be significant at better than 0.1% level (r-values range from +0.84 to +0.99). This correlation compares favourably with the correlation obtained between map and field variables by Swan (1970b) who has employed a different method of slope determination. The slope classes, which were determined in this study, have also been found to be sufficiently different, one from the other, for them to be viable as individual classes. It has been demonstrated that at least 70% of the area within a slope class has slope values which might be less than, or equal to, the mean slope value for the class. Since the classification of the slope values was based on existing slope classifications for West Malaysian physiographic conditions (Leamy and Panton, 1966; I.Wong, 1966), combined with slope classifications based on theoretical, morphological, statistical, and technical-economic requirements, it can be concluded that the slope classes can be used as a basis for the compilation of a "user" landform map.

The discussion in Chapters 5 and 6 suggests that the slope of the land, which implies the slope classes, has been employed successfully as a dominant land attribute to classify, and map, the land-surface of the Ulu Langat District. The Land Categories, identified principally on the basis of the slope of the land, have been shown to be real, and to be sufficiently different (in terms of soil and land attributes), one from the other, for them to be valid as separate Land Categories. The use of the slope of the land as the main land attribute for the classification of land types has made it possible to show that different slope components are potentially suitable for different uses. Differentiations of this type are essential to adequate allocation of the land for utilisation.

Morphometric analysis of the valleyside properties in most of the Land Categories (Chapter 6) has stressed the influence of the slope attribute on soil erodibility and, hence, on the utilisation of the land. It was shown that very serious soil erosion and mass movement occur in Land Categories 3 and 4 where steep slopes have been disturbed by human activities, and that serious soil wash occurs on slopes as gentle as 3^{o} in disturbed areas. It seems, therefore, that the hypothesis which states that slopes gentler than 5^{o} are depositional ones is an illusion in the cultivated, or disturbed, areas of the Ulu Langat District. Similarly, it appears that a slope angle of 11^{o} is not an adequate threshold value to indicate the lower boundary of slope values for which a terrace-cropping technique should be recommended. Very serious gullying and slumping processes have been shown to occur on slopes which are as gentle as 5^{o} in the Ulu Langat District (Figure 22). A similar result has been obtained in the Johore State where gullies of 1 - 8 m deep occur on piedmont slopes which average 4.25^{o} (Swan, 1970c). It was also shown that the soil attributes analysed act in combination to limit the influence of slope angles on soil erosion, but that their combined effect is low and inversely related to the angle of slope. Consequently, the top 45 cm of the soil profile in the study area has been found to be delicately balanced and poor land management wastes away this valuable soil layer. It appears, however, that the presence of laterite in the soil profile is a stabilising factor. It might be in the best interest of soil conservation not to disturb laterite zones in the soils of summit areas.

Since the central objective of this study is the compilation of a "user" landform map, precise designation of the classified land types for utilisation has been an integral part of the study. It can be seen (Chapter 5) that the Use Classifications of these land types have been based on the results of morphometric analysis, and on the results discussed in connection with published soil, drainage, and landuse maps. The emphasis on agricultural-type land utilisation is deliberate because the study area is agricultural land, and because the current concern of the Malaysian Government is the diversification of both cash and food crops (for example, the speech of the Sultan of Selangor, The Malay Mail, November 30, 1970, pg. 2; and part of the objectives of the Second Malaysian Plan). Although agricultural landuse has been emphasised, the importance of slope values to a "user" landform classification does not end with farming-type land utilisation.

Slope values are considered an essential land attribute by workers concerned with non-agricultural landuse. For example, Chigarkin (1963), Dowling (1968), and Beckett and Webster (1969) have discussed the importance of the slope of the land in relation to the construction of Highways and rail-roads. It has been shown that the slope of the land is an important consideration in land evaluation for hydrological purposes (Beckett and Webster, 1969; Emmett, 1970), and for military intelligence purposes (Peltier and Pearcy, 1966, Miller, 1967).

It follows, therefore, that geomorphological studies, especially those involved with land-surface maps, can be of practical utility. If it is agreed that geography is 'an inescapable basis to land planning' (Freeman, 1958; pg. 13), then applied, or functional, geomorphology is an essential basis to land evaluation. It has been contended that the nature and the content of applied geography involve 'investigation, interpretation, and integration of the various varied earth features, in so far as they help solve world's problems' (Stamp, 1963; pg. 10). The nature and the content of applied geomorphology also involve these factors.

This applied aspect of geomorphology is an important challenge in the discipline today, especially in developing countries such as Malaysia where emphasis is still placed on land development projects of various types.

It is certain that geomorphological contributions of the applied nature would help land users to understand the resources at their disposal better than might otherwise be possible. This acquired insight would help the planners to 'work with, instead of against, the natural processes' (Wycherley, 1969; pg. 9); for unless the totality of the resources, attributes and limits of land types are recognised, a country faces the prospect of unbalanced development (Renwick, 1968; Pullan 1970). It cannot be agreed more that the system terrain evaluation represents 'a major, even revolutionary, advance in the field of physiographical analysis', and that it 'should be developed at both the national and the international levels' (Desai, 1968; pg. 263). It seems, therefore, that the main contribution of the present work is the concept that binds together the various aspects of the study; namely: the combination of techniques, results, and the utility of the results, plus the assessment of the accuracy of the techniques and the validity of the classified landforms.

Suggestions for further studies

Certain aspects of this study, especially the morphometric aspects, indicate apparent lines for further studies.

1) The technique used to calculate slope values from the topographical maps would need to be converted to a form suitable for computerisation before it can be of general, and quick use. This would involve the recognition of different pattern-systems for different scales, and unit sizes.

2) The slope classification designed for the study area could be tested in other humid tropical environments, in order to determine whether the slope classes will be suitable for land planning purposes in such areas.

3) The land classification and Use Classification designed for the study area could be undertaken on a national level. More precise Use Classifications can be effected by a study of soil/crop-suitability relationships.

4) The influence of cultivation on soil structure and strength could be determined quantitatively by controlled analyses of selected soil attributes in both cultivated and non-cultivated areas. The shear ratio, defined in this study, could be one of the soil attributes to be selected.

5) There is a need to quantify the relationship between types of land management on particular

slope forms and the rate of soil waste on such slopes. Admittedly, this type of investigation lies outside the scope of this study, but field observations revealed that investigations along this line would be valuable to soil preservation and, therefore, to adequate and effective land utilisation.

It is believed that studies in terms of these suggestions would explain the characteristics of land types in greater detail. More detailed explaination of land types would, certainly, make the capability, and the designation, of the land types for various uses more precise.

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APPENDIX I

SLOPE SAMPLES: MAP AND FIELD VALUES

No.	Map(X)°	Field Average(Y_1)°	Field Mode(Y_2)°	F.70-p(Y_3)°	Field Median(Y_4)
1	13	12	12	15	11
2	4	4	2	6	5
3	5	4	4	4	4
4	2	2	2	3	2
5	0	0	0	0	0
6	21	21	21	20	18
7	11	11	10	12	10
8	11	7	7	11	7
9	11	12	9	13	10
10	0	0	0	0	0
11	11	13	14	14	13
12	11	12	14	16	14
13	10	11	9	11	10
14	7	7	6	7	6
15	19	19	28	26	23
16	16	13	14	14	13
17	14	17	16	19	17
18	10	11	10	11	10
19	15	14	15	15	14
20	3	2	1	2	2
21	16	15	18	16	14
22	17	17	17	19	17
23	3	3	1	3	2
24	4	4	4	4	4
25	6	5	6	6	5
26	7	8	7	8	7

APPENDIX I (contd.)

No.	$(X)^o$	$(Y_1)^o$	$(Y_2)^o$	$(Y_3)^o$	$(Y_4)^o$
27	12	14	12	15	13
28	6	7	8	8	7
29	10	11	12	12	11
30	9	12	14	14	13
31	7	6	6	6	6
32	9	8	5	7	6
33	8	7	8	8	8
34	4	4	3	4	3
35	11	12	6	12	11
36	8	8	9	10	9
37	3	2	0	3	1
38	18	16	17	18	17
39	18	18	18	19	18
40	3	3	4	4	3
41	12	13	12	15	12
42	6	7	8	9	8
43	8	7	7	7	7
44	8	7	8	8	7
45	9	10	8	12	9
46	9	8	8	8	7
47	11	14	19	18	14
48	7	8	7	10	7
49	1	1	1	1	1
50	9	7	6	8	7
51	3	3	3	3	3
52	5	4	4	5	4
53	9	11	12	12	10
54	8	8	6	9	8
55	8	7	8	9	7
56	4	4	1	6	1

APPENDIX I (contd.)

No.	$(X)^{\circ}$	$(Y_1)^{\circ}$	$(Y_2)^{\circ}$	$(Y_3)^{\circ}$	$(Y_4)^{\circ}$
57	4	3	3	3	3
58	26	24	26	26	26
59	5	5	4	5	4
60	18	20	18	26	18
61	8	8	8	8	8
62	26	25	26	26	26
63	12	11	15	14	10
64	30	29	31	31	30
65	13	13	15	13	13
66	11	9	4	9	8
67	9	8	9	9	8
68	3	2	1	3	2
69	15	17	17	20	17
70	11	11	11	11	11
71	8	7	8	8	8
72	25	24	22	25	22
73	8	6	7	7	6
74	14	15	16	19	16
75	17	17	13	17	13
76	6	7	6	7	7
77	14	14	20	14	12
78	21	22	16	22	22
79	21	23	28	27	22
80	20	19	17	21	18
81	24	23	18	25	22
82	7	7	7	8	7
83	13	12	13	13	13
84	11	10	13	12	11
85	21	26	29	29	26

APPENDIX I (contd.)

No.	$(X)^o$	$(Y_1)^o$	$(Y_2)^o$	$(Y_3)^o$	$(Y_4)^0$
86	8	8	9	8	7
87	10	7	5	8	6
88	10	10	11	11	10
89	15	15	18	18	15
90	1	1	0	1	0
91	6	5	6	5	5
92	6	7	7	7	7
93	6	5	4	5	5
94	11	12	11	13	11
95	3	2	2	2	2
96	8	8	2	14	3
97	13	14	13	13	13
98	17	15	17	16	16
99	26	25	28	26	24
100	14	18	10	21	19

K = 100.

APPENDIX II

BASIC DATA OF SOIL AND LAND ATTRIBUTES INVESTIGATED

(a) : SUMMIT AREAS

	Silt + clay %	S/S - Clay Ratio (X_1)	Agg. Stability % (X_2)	Shear strength g/cm^2 (Y_1)	Shear Ratio (Y_2)	Elevation (metres) (Y_3)
LAND CATEGORY 2	79.04	0.27	65.95	210.93	0.92	16
	26.54	2.77	95.45	246.09	0.50	14
	59.64	0.68	58.30	351.55	0.75	17
	80.94	0.24	74.40	281.24	0.75	34
	54.72	0.83Gr.	53.95	316.40	0.67	56
	60.22	0.66Gr.	49.75	246.09	0.50	31
	57.75	0.73	57.35	228.51	0.77	18
	62.20	0.61	58.30	351.55	0.85	22
LAND CATEGORY 3	32.87	2.04	60.80	351.55	0.45	36
	57.60	0.74	35.10	316.40	0.67	76
	69.20	0.45	43.70	316.40	0.56	40
	57.16	0.75	41.70	175.78	1.00	69
	76.56	0.30	42.50	333.97	0.63	31
	64.44	0.55	61.85	281.24	0.44	23
	87.00	0.15	62.45	246.09	0.86	30
	76.80	0.31	60.55	333.97	0.47	44
LAND CATEGORY 4	62.86	0.59	67.95	351.55	0.70	33
	55.15	0.81	49.85	316.40	0.22	56
	60.98	0.64	73.65	298.82	0.71	52
	55.03	0.82	76.50	246.09	0.57	16
	64.58	0.55	72.50	281.24	0.56	49
	57.16	0.75	60.70	281.24	0.63	63
	64.86	0.54	39.75	246.09	0.64	36
	59.64	0.68	60.45	351.55	0.50	28
LAND CATEGORY 5	61.70	0.63	58.27	316.40	0.56	58
	47.08	1.13Gr.	85.35	351.55	0.90	30
	42.90	1.33Gr.	94.00	193.35	0.45	48
	42.00	1.38	59.20	316.40	0.22	59
	28.10	2.56	71.05	316.40	0.17	77
	48.40	1.07	74.05	298.82	0.29	28
	45.80	1.18	83.35	263.33	0.27	30

K = 31.

APPENDIX II (contd.)

(b): STEEPEST SLOPE AREAS

	Maximum Slope ° (X_1)	Silt + clay %	S/S - clay Ratio (X_2)	Aggregate Stability % (Y_1)	Shear Strength g/cm² (Y_2)	Shear Ratio (Y_3)
LAND CATEGORY 2	8	64.52	0.55	65.65	351.55	0.75
	8	36.20	1.76	71.20	210.93	0.83
	7	62.80	0.59	71.50	210.93	0.50
	15	67.96	0.47	66.80	246.09	0.64
	19	65.79	0.52	46.60	333.97	0.32
	20	48.92	1.04	73.57	193.35	0.82
	18	45.28	1.21	73.55	263.66	0.67
	18	52.60	0.90	69.95	316.40	0.67
LAND CATEGORY 3	29	66.16	0.51	43.20	316.40	0.45
	28	52.30	0.91	51.10	333.97	0.42
	17	51.24	0.95	72.45	210.93	0.83
	17	55.96	0.79	58.60	246.09	0.86
	23	77.64	0.29	60.75	263.66	0.67
	18	59.87	0.67	72.05	298.82	0.71
	8	67.56	0.45	76.25	193.35	0.91
	20	68.87	0.31	60.55	333.97	0.47
LAND CATEGORY 4	16	64.90	0.54	67.80	351.55	0.65
	29	59.82	0.67	50.30	281.24	0.44
	35	40.54	1.47	67.85	351.55	0.50
	11	60.76	0.65	80.75	281.24	0.63
	31	62.38	0.60	60.77	228.51	0.69
	32	63.60	0.57	57.75	210.93	0.42
	23	66.46	0.50	53.80	281.24	0.69
	15	62.15	0.61	59.67	193.35	0.64
LAND CATEGORY 5	26	57.70	0.73	61.95	351.55	0.60
	21	50.20	0.99	87.07	316.40	0.67
	28	53.70	0.86	91.75	246.09	0.36
	31	49.36	1.03	73.75	228.51	0.62
	32	51.94	0.92	63.30	105.47	0.83
	24	52.10	0.92	76.45	158.20	0.33
	25	47.10	1.12	85.85	263.66	0.73.

K = 31.

APPENDIX II (contd.)

(c) : VALLEYFLOOR AREAS

	Silt + clay %	S/S - Clay Ratio (X_1)	Distance from Crest (m) (X_2)	Shear Strength g/cm^2 (Y_1)	Shear Ratio (Y_2)	Aggregate Stability % (Y_3)
LAND CATEGORY 2	7.02	13.24	260	210.93	0.75	95.85
	29.97	2.34	300	35.16	1.50	87.70
	38.84	1.58	255	87.89	1.40	76.85
	37.44	1.67	230	193.35	0.64	77.28
	64.72	0.54	268	263.66	0.47	66.60
	63.94	0.56	200	105.47	0.67	53.90
	48.96	1.04	228	158.20	1.00	77.90
	75.20	0.33	180	35.16	1.50	60.47
LAND CATEGORY 3	73.38	0.36	153	158.20	0.78	72.25
	46.64	1.14	270	105.47	0.33	90.25
	50.28	0.99	255	35.16	1.00	95.10
	46.00	1.17	497	35.16	1.00	76.00
	59.76	0.67	180	140.62	0.88	78.70
	69.94	0.43	205	158.20	0.89	82.70
	45.52	1.20	300	87.89	1.60	94.75
	51.82	0.93	260	35.16	4.50	79.00
LAND CATEGORY 4	52.82	0.89	228	316.40	0.39	82.90
	69.87	0.43	200	281.24	0.44	62.95
	49.56	1.02	165	316.40	0.56	72.95
	50.42	0.98	277	246.09	0.57	70.50
	93.10	0.07	245	316.40	0.72	37.12
	41.80	1.39	250	333.97	0.63	77.12
	39.36	1.51	195	298.82	0.76	69.40
	98.54	0.01	225	105.47	0.83	60.85
LAND CATEGORY 5	27.64	2.62	240	175.78	0.70	90.75
	41.90	1.39	160	351.55	0.60	94.50
	20.66	3.84	215	351.55	0.25	99.10
	52.56	0.90	230	316.40	0.56	88.30
	49.42	1.02	240	316.40	0.56	82.90
	50.90	0.96	140	193.35	1.09	72.50
	45.38	1.30	120	333.97	0.63	93.40

K = 31

APPENDIX II (contd.)

(d) : ON SOME FLOODPLAINS

	Silt + clay %	Sand/silt + clay Ratio	Aggregate Stability %
LAND UNIT 7b	75.58	0.32	86.75
	85.80	0.17	32.25
	27.00	2.70	87.20
	32.26	2.09	79.10
	69.98	0.43	64.35
	94.42	0.06	42.55
	57.26	0.75	80.70
	72.54	0.38	67.45
LAND UNIT 7d	91.74	0.09	92.25
	33.60	1.98	96.55
	88.58	0.13	81.20
	91.44	0.09	87.25
	53.06	0.88	89.40
	76.74	0.30	67.00
	64.58	0.55	98.00

K = 15

APPENDIX III

Statistical formulae and notations employed in the study.

Arithmetic mean $(\bar{X})$

$$(\bar{X}) = \frac{\sum fX}{f} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

where $\sum$ = sum of all,

X = variable analysed

f = frequency of each domain of X.

Standard Deviation (σ)

$$\sigma = \sqrt{\frac{\sum f(X - \bar{X})^2}{n - 1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

(Bradley, 1968; Monkhouse and Wilkinson, 1971)

where $n = \sum f$

Null Hypothesis : t (of mean)

$$t = \frac{\left| \bar{X}a + \bar{X}b \right|}{\sqrt{\left(\frac{S_a^{\,2}}{n_a - 1} + \frac{S_b^{\,2}}{n_b - 1}\right)}} \quad \ldots\ldots\ldots\ldots 3$$

(Monkhouse and Wilkinson, 1971)

where S = sample standard deviation

a and b = variables X and Y respectively

Coefficient of variation (CV%)

$$CV\% = \frac{\sigma}{\bar{X}} \times 100 \quad \ldots\ldots\ldots\ldots 4$$

(Harper, 1965; Bajpai 1967)

Pearson's Product-moment Coefficient of Correlation (r)

$$r = \frac{\sum XY - n\,\bar{X}\bar{Y}}{n\,\sigma_X\,\sigma_Y} \quad \ldots\ldots\ldots\ldots 5$$

(Harper, 1965)

where X,Y = variables X and Y respectively

and n = number of pairs of variables

Coefficient of determination (r^2) ... (Bajpai, 1967; Doornkamp and King, 1971)

Fisher's Z transformation of r (Z)

$$Z = 1.15129 \log \left(\frac{1 + r}{1 - r} \right) \quad \ldots\ldots\ldots\ldots\ldots 6$$

(Bajpai, 1967)

Standard error of Z (SE_z)

$$SE_z = \frac{1}{n - 3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

(Bajpai, 1967)

where n = number of pairs

Null Hypothesis of r, ie. Z - ratio (Z_r)

$$Z_r = \frac{Z_s - Z_p}{SE_z} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

(Bajpai, 1967)

where Z_s = Z of sample

Z_p = Z of population, assumed to be 0.

Student's Test of Significance .... t of r (t)

$$t = \sqrt{\frac{r^2 (n - 2)}{1 - r^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

with n - 2 degrees of freedom

(Monkhouse and Wilkinson, 1971)

where n = number of pairs

Regression of Y on X .. Y/X

$$Y/X = \left[(Y - \bar{Y}) = r \frac{\sigma_Y}{\sigma_X} (X - \bar{X}) \right] \ldots\ldots 10$$

(Monkhouse and Wilkinson, 1971)

Coefficient of Multiple Correlation (R)

$$R_{1.2345} = \sqrt{1 - \left[(1 - r^2_{12})(1 - r^2_{13.2})(1-r^2_{14.23})(1-r^2_{15.234}) \right]} \ldots 1$$

(adapted from Ezekiel, 1930; Croxton and Cowden, 1955)

where 1 is the dependent variable

and 2,3,4,5 are the independent variables.

R^2 = coefficient of multiple determination.