REPUBLIC OF LIBERIA

MINISTRY OF AGRICULTURE

LAND CAPABILITY SURVEY OF GRAND GEDEH COUNTY

Final Report
Volume 1. Text

W44

SEPTEMBER 1986

ARUP IRELAND INTERNATIONAL INC.
DUBLIN, IRELAND.

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This Study has been carried out by Arup Ireland International Incorporated of Dublin, Ireland, in association with Atkins Land & Water Management of Cambridge, England and with Flynn & Rothwell of Bishops Stortford, England.

LAND CAPABILITY SURVEY OF GRAND GEDEH COUNTY, LIBERIA

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LIST OF ABBREVIATIONS

BCADP	Bong County Agricultural Development Project
CAES	Central Agricultural Experiment Station (now referred to as CARI: see below)
CARI	Central Agricultural Research Institute, Suakoko, Bong County
CCSRP	Coffee, Cocoa and Swamp Rice Project (EDF-funded project based in Zwedru)
CN	Curve Number
FAO	Food and Agriculture Organisation of the United Nations
FDA	Farmer Development Association
IDA	International Development Association
IITA	International Institute of Tropical Agriculture, Ibadan, Nigeria
IRRI	International Rice Research Institute, Philippines
LCCC	Liberia Coffee and Cocoa Corporation
LDU	Land Development Unit
LPMC	Liberia Produce Marketing Corporation
MOA	Ministry of Agriculture
MOP	Muriate of Potash
MSS	Multi-Spectral Scanning
NCRDP	Nimba County Rural Development Project
ORSTOM	Office de la Recherche Scientifique et Technique d'Outremer, France
RDI	Rural Development Institute, Cuttington College, Bong County
SRSP	Smallholder Rice Seed Project, Bong County
TSP	Triple Superphosphate
UK	United Kingdom

UNESCO	United Nations Educational, Scientific and Cultural Organisation
USAID	United States Agency for International Development
USDA	United Stated Department of Agriculture

Currency Note

The local unit of currency is the Liberian Dollar (L$)

L$ 1 = US$ 1.0 (September, 1986)

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Bong County Agricultural Development Project, Suakoko

Central Agricultural Research Institute, Suakoko

Coffee, Cocoa and Swamp Rice Project, Zwedru

Delegation of the Commission of the European Communities, Monrovia

Forestry Development Authority, Monrovia

Consolata Clinic, Tapeta

Liberian-Danish Water Supply Project, Zwedru

Liberian Hydrological Services, Monrovia

Liberian Produce Marketing Corporation, Monrovia and Zwedru

Liberian Telecommunications Corporation, Zwedru

Martha Tubman Hospital, Zwedru

Ministry of Agriculture, Monrovia and Zwedru

Ministry of Commerce, Monrovia

Ministry of Finance, Monrovia

Ministry of Lands, Mines and Energy, Monrovia

Ministry of Planning and Economic Affairs, Monrovia

Nimba County Rural Development Project, Seclapea

Prime Timber Products, Zwedru

Rural Development Institute, Cuttington College, Suakoko

US Peace Corps, Zwedru

USAID, Monrovia

West African Rice Development Association, Monrovia.

Particular gratitude is expressed to the Liberian members of the Survey Team, whose help proved to be invaluable.

Traditional swamp development near Kanweakehn.

Summary

SUMMARY

INTRODUCTION

The study involved general investigations of the land capability, hydrology and agriculture of Grand Gedeh County, aimed at identifying specific village areas suitable for intensifying and improving agricultural production. This was followed by more detailed surveys of five selected sites and preparation of outline development plans for irrigated rice schemes in swamps, and improvements to a range of tree and food crops in surrounding areas. The study was also intended as a Pilot project to develop appropriate methods for extending surveys to other village areas in the Southeast Region.

The study was undertaken in two stages between October 1985 and June 1986, namely a Phase 1 reconnaissance survey followed by a Phase 2 detailed study of five specific areas.

REGIONAL RECONNAISSANCE SURVEYS

During the reconnaissance survey, regional landform and land use maps were prepared at 1:250 000 scale, based on field surveys and interpretation of aerial photographs and satellite imagery. Some 70 per cent of the area was found to be forest-covered, with 29 per cent comprising a mosaic of secondary regrowth and small scale slash-and-burn cultivations. Most of the area comprises a gently undulating peneplain on relatively uniform and strongly weathered parent material. Differences in soils and land capability proved to be more significant, in terms of agricultural potential, at the level of the individual slope sequence than at regional level.

Climatic data for Grand Gedeh County consists of rainfall figures from four stations and six months data from the Coffee, Cocoa and Swamp Rice Project (CCSRP) station at Garley Town. Groundwater resources are insufficient for irrigation and should be conserved for domestic water supplies. Gauging stations were established at the CCSRP swamps to acquire measured flow data and recommendations are made concerning the collection of hydrometeorological data.

Sites for Phase 2 detailed surveys were selected on the basis of suitably large village population and a community interested in swamp development, as well as the existence of a swamp with favourable physical characteristics. Additionally, the aim was to distribute sites throughout the County. Ten possible sites were identified. Following discussions with the Advisory Group, five were selected for more detailed study (Figure S.1) as listed below:-

- Beezohn
- John David Town
- Fishtown
- Tuobo Gbawelekehn
- Tujallah Town

DETAILED SURVEYS OF VILLAGE LANDS AND SWAMPS

Phase 2 land capability studies were undertaken as detailed surveys of the selected swamps and exploratory "semi-detailed" surveys of dryland farming areas around the selected villages.

The semi-detailed surveys extended over the areas affected by cultivation. Maps of vegetation and land use, soils, and land capability were compiled at 1:20,000 scale. Broad patterns of soils were mapped using the 'soil family' concept and the land was classified according to a modified version of the US land capability system. Large proportions of the land were found to be only marginally suitable for cropping, due to shallow soil depth or excessive gravel contents. The maps provide general indications of the features of the village lands and serve as bases for future integrated development of both irrigated rice and dryland crops.

Detailed surveys of the selected swamps and lateral slopes were conducted along trace lines spaced 100m apart. Mapping was at 1:2,000 scale, with separate sheets showing soils and land suitability for rice and for dryland crops. Soil texture proved to be the principal factor determining suitability for rice in the swamp; soil depth and gravel content were the principal determinants of suitability for dryland crops on the lateral slopes. The soils analysis results indicate that the soils have very low fertility. Infiltration rates and hydraulic conductivity are relatively high in coarser-textured swamp soils.

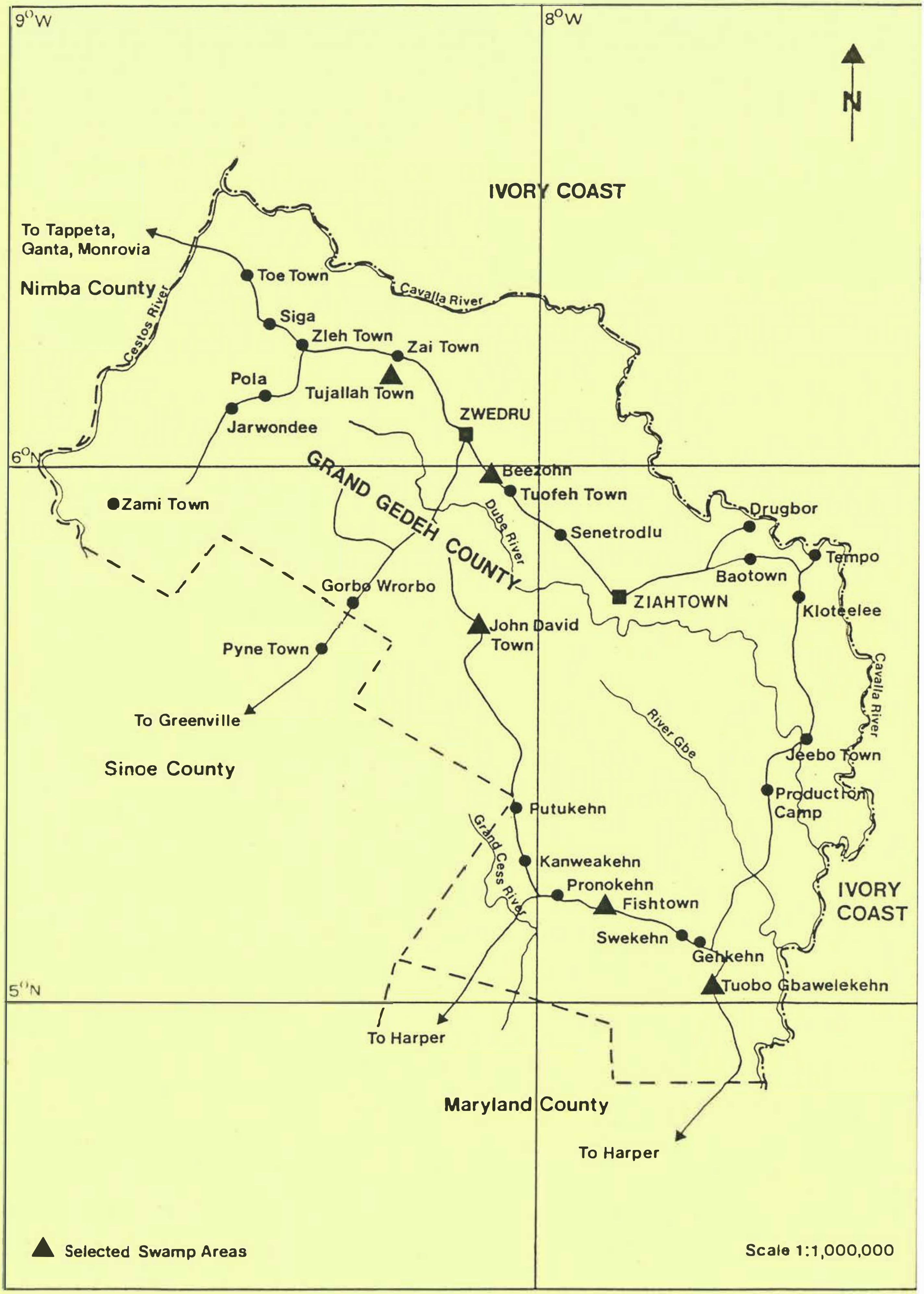
A total of 596 ha were surveyed at detailed level, of which 146 ha were suitable for rice and 228 ha were suited to dryland cropping. Some 222 ha were unsuitable for cropping (see Table 15.1).

A review was made of the farming systems and the agricultural support, marketing services and crop processing facilities within the County. The experiences of the CCSRP were examined in the context of possible implementation procedures for the present study areas.

Two principal farming systems were identified within the village areas, namely an upland farming system and a village farming system. The former is the principal source of the staple subsistence food (rice) and receives priority in terms of labour resources. Any surplus labour is utilised on the village farms, which are orientated towards cash crops, such as tree crops (cocoa, coffee), vegetables and swamp rice.

Location of Selected Swamps

Figure S.1



Labour was found to be scarce. This, combined with a lack of basic marketing systems, support services and physical infrastructure, means there is little incentive for village farmers to increase production. Development of irrigated rice is therefore unlikely to be successful in the long term, without significant financial support, unless the farmers perceive sufficient benefits to warrant transferring their labour resources from the upland rice farms.

Although climatic data are deficient, it was calculated that rainfall should be sufficient for double-cropping irrigated rice. Any deficit should be compensated for by run-off from lateral slopes of the swamps.

Tests on swamp water revealed no pathogens but appropriate control measures and health education programmes are recommended as part of the implementation stage to minimise the risks of Schistosomiasis.

DEVELOPMENT PROPOSALS

Outline proposals are made for agricultural development in the swamps and adjacent upland areas, using the results of the land suitability mapping and hydrological information. Land development units are defined and mapped at 1:2,000 to show the types of cropping systems appropriate. These are separated into irrigated rice and upland crops.

Irrigated rice is recommended for the swamps, either single-cropped or double-cropped, depending on the soil and moisture conditions. From a potential swamp irrigation command area of 152 ha, the total areas suited to these systems are 106 ha (70%) and 29 ha (19%) respectively; 17 ha (11%) are unsuitable for cropping. Maximising double cropping is seen to be essential if returns are to be adequate to cover the swamp development costs (estimated at some L$3,000 - 4,000 ha^{-1}) and to provide a reasonable cash return to the farmer as an incentive. If sufficient incentives exist the farmer can be expected to grow rice, thereby contributing to reducing the present national reliance on imported rice.

Swamp side slopes are classified according to their potential for annual food crops and tree crops. Continuous cropping of annual crops or cocoa is proposed on the best soils, with coffee or single cropping of annuals on more marginal land. Most of the soils surrounding the swamps are marginal or unsuitable for any of these cropping patterns: 50 ha (12%) are suited to the whole range of annual and tree crops, whereas 154 ha (38%) should be restricted to a more limited range of cropping systems. Great care will be needed in selecting areas for cocoa and continuous annual cropping and due attention should be given to soil conservation measures and to the maintenance of soil fertility. Proposals are made for improving husbandry practices of the major crops and for introducing legumes.

Outline irrigation and drainage designs were prepared, based on the practical experience of CCSRP, using channels of a standard size which could be enlarged, if necessary, on the basis of experience. This approach was necessary because of the lack of topographic and climatic data. Topographic surveys are proposed once the swamps are cleared of vegetation, at which stage the layouts can be refined.

RECOMMENDATIONS FOR IMPLEMENTATION

The policy of concentrating food production around the village areas, centred on continuous irrigated rice in swamps, is seen to be appropriate in terms of both the direct social and financial benefits to the rural communities, and the indirect contribution to conservation of the forest ecological resources through the reduction in slash-and-burn upland rice farming.

It is well established that rice can be cultivated in the swamps and that coffee and cocoa can be grown on certain areas of land surrounding the swamps. However, the further development of these crops cannot be considered in isolation from the overall farming system, in which the upland rice farms currently have priority for the limited labour resources, and without first alleviating some of the many other existing constraints to increased agricultural production.

There is an urgent need to provide the farmer with more support to encourage increased crop production. Present constraints include the lack of basic rural infrastructure, markets, inputs and support services. It is therefore recommended that any further swamp development activities or land capability studies of additional swamp areas should be carried out in conjunction with, or as part of, a broad-based rural development programme. A key objective of this programme should be to generate sufficient incentives for the farmers to develop irrigated rice largely through their own efforts as self-help schemes.

Until such a rural development programme is agreed in principle, there is seen to be little point in proceeding with a further major programme of soil and land capability studies of village areas and swamps.

The development programme should cover the following components:-

- Agricultural Inputs
- Agricultural Extension
- Swamp Rice Development
- Storage and Marketing
- Farmer Development Associations
- Social Assessment
- Rural Health
- Rural Water Supply
- Roads and Communications
- Hydro-meteorological Data Collection.

RECOMMENDATIONS FOR FURTHER LAND CAPABLITY SURVEYS

Recommendations are made for further land capability surveys to identify additional village swamp areas for irrigated rice development. These surveys should not proceed until the principle of implementing a positive programme of rural development is adopted for the region.

The main recommendations for the land capability study approach are as follows:-

a) The survey should undertake a rolling programme of selecting and mapping village swamps throughout the region to prepare outline plans for irrigated rice and crop improvement, which would subsequently be implemented as part of the proposed rural development project.

b) A core team should be established comprising soils and land classification specialists and supported by short term expertise in farm economics, marketing, rural sociology and social infrastructure, agriculture, hydrology, irrigation and physical infrastructure engineering. The team should initially be based on expatriate staff but Liberian staff should be included, through employment of RDI graduates and secondment of MOA and Soil Survey Division personnel. The Liberian staff should take increasing technical responsibility for the surveys, and ultimately the expatriate input should be reduced to technical and administrative supervision.

c) Two principal stages are envisaged:-

- A Reconnaissance & Preparation Phase to assemble and review all relevant data and mapping materials and to compile preliminary regional landform and land use maps. Village areas, centred on potentially irrigable swamps, would be identified. The selection procedure should include a brief screening survey in the field to verify the suitability of swamps for more detailed survey. This reconnaissance programme should proceed parallel to the village surveys, so that new sites can be identified as the initial ones are completed.

- Village Area Surveys involving detailed soil and land suitability surveys within the selected swamps. These surveys would not extend further than about 250m beyond the swamp margins. Mapping should be at a scale of 1:2000. At the same time, semi-detailed soil and land capability surveys should be carried out in the areas around the village, including detailed mapping of sample areas. The village lands would be mapped at 1:20,000 scale. The results of the semi- detailed surveys should be used to up-grade the small-scale regional mapping and to compile regional maps of soils and land capability.

d) Analyses should be performed on samples from the principal mapping units to characterise the soils and determine specific fertility constraints. Funds should be included to provide expertise, equipment and materials for the CARI laboratory so that analyses can be carried out in Liberia.

Traditional slash and burn cultivation at Tujallah Town

Section A
Introduction And Approach To Study

1. INTRODUCTION

1.1 LOCATION

Grand Gedeh County occupies some 16 000 km^2 and is located in south-eastern Liberia between 4° 50'N and 6° 30'N and 7° 23'W and 8° 57'W (Figure 1.1). It is bordered on the north and east by the Ivory Coast; to the south and south-west are Maryland and Sinoe counties and the north-western boundary is the Cestos River. Much of the border with the Ivory Coast is formed by the Cavalla River. For administrative purposes, there are five districts in Grand Gedeh County, namely Gbarzon, Tchien, Konobo, Gbeapo and Webbo (Figure 1.2).

1.2 GENERAL DESCRIPTION OF THE STUDY AREA

The area comprises an extensive peneplain formed on metamorphic basement complex rocks, interspersed locally by isolated hills. The peneplain is characterised by a network of shallow swamps in drainage line depressions and undulating "upland" interfluves.

Virtually the whole area is drained by the Cavalla river, with the exception of the south- western and the western and north-western sectors, which lie within the Grand Cess and the Cestos/Sangwin river basins, respectively (Figure 1.3).

The climate is humid tropical. The main rainy season from May to October is governed by the passage of the Inter-Tropical Convergence Zone (ITCZ), which brings moist southerly winds from the Atlantic. The dry season from November to April is characterised by northerly winds bringing the warm dry "harmattan" from the Sahara. The average monthly temperatures are relatively constant at about 25°C with a low diurnal variation. Rainfall ranges from an average of about 2500mm per year in the south-west to 1900mm per year in the drier north-west.

The upland soils are classified mainly as Paleudults; Tropaqualts occur in the drainage lines.

The natural vegetation is tropical rainforest which covers some 70 per cent of the county. Much of this has been disturbed by the extraction of commercial timber and clearing for agriculture. Agriculture is based on family sized units employing a system of rotational bush fallowing which involves the cultivation of annual crops, mainly rice, with coffee and cocoa and rarely rubber as cash crops.

The human population is concentrated in small villages along the main access routes. The population density is around only six inhabitants per km2. The administrative centre of Grand Gedeh County is Zwedru. Other main centres of population are Ziahtown and Kanweakehn. The area is served by the main road from Monrovia and Ganta to Harper which passes through Zwedru and Kanweakehn. A branch road from Zwedru runs through Sinoe County to the port of Greenville. A logging route known as the Glio Road provides an alternative route from Harper and the south of the County through Ziahtown to Zwedru (Figure 1.4).

1.3 SCOPE OF PROJECT

a) Objectives

The objective of the study was to provide the Government of Liberia with technical information to facilitate agricultural development planning. The study comprised soil and land capability surveys, together with associated agronomic and hydrologic studies aimed at providing a general appraisal of the land resources of Grand Gedeh County as well as a more detailed study of the potential for swamp development in selected villages.

It was a pilot study aimed at developing and assessing approaches to gathering soil and land capability data so that terms of reference could be drawn up for similar studies in Grand Gedeh County as well as in other areas of the country. Grand Gedeh County was chosen for this pilot study, since there is a paucity of soil and land resource data and it is currently the focus of various agricultural development projects for which such data are required.

In particular, this study will provide useful data for the EDF-funded Coffee, Cocoa and Swamp Rice Project (CCSRP) based in Zwedru, which is currently implementing a swamp development programme. Although the CCSRP is at present operating mainly in the vicinity of Zwedru, it is expected to be extended to the rest of Grand Gedeh County and the south-eastern region. The soil and land capability data gathered from the present study will therefore provide some basic planning and design information for the next phase of the CCSRP.

b) Phasing

The study was undertaken in two phases:

i) Phase 1:

This was undertaken from October to December 1985 had the following objectives:

- Reconaissance land resources survey of the whole of Grand Gedeh County.

- Selection of villages for study in Phase 2.

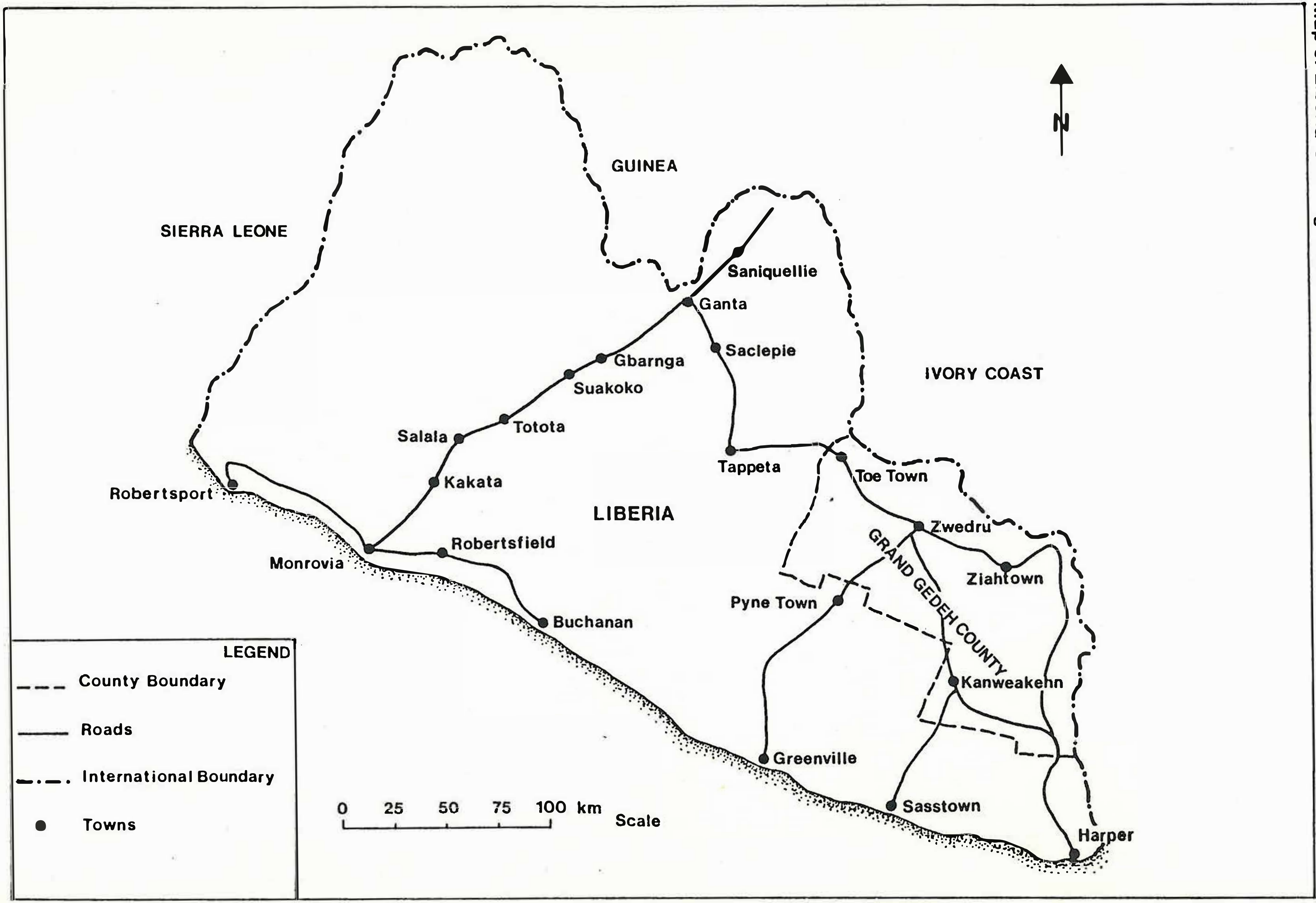
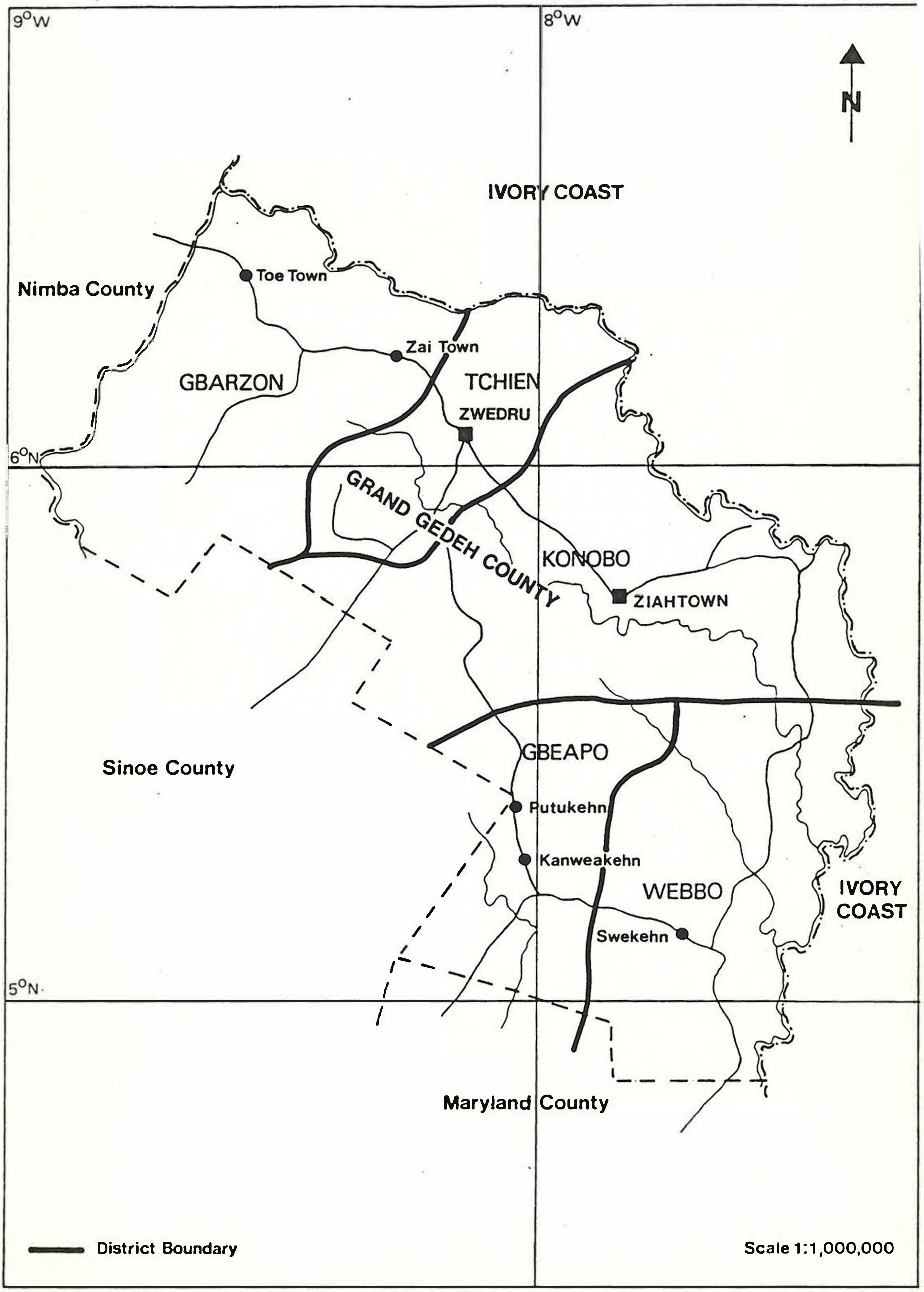
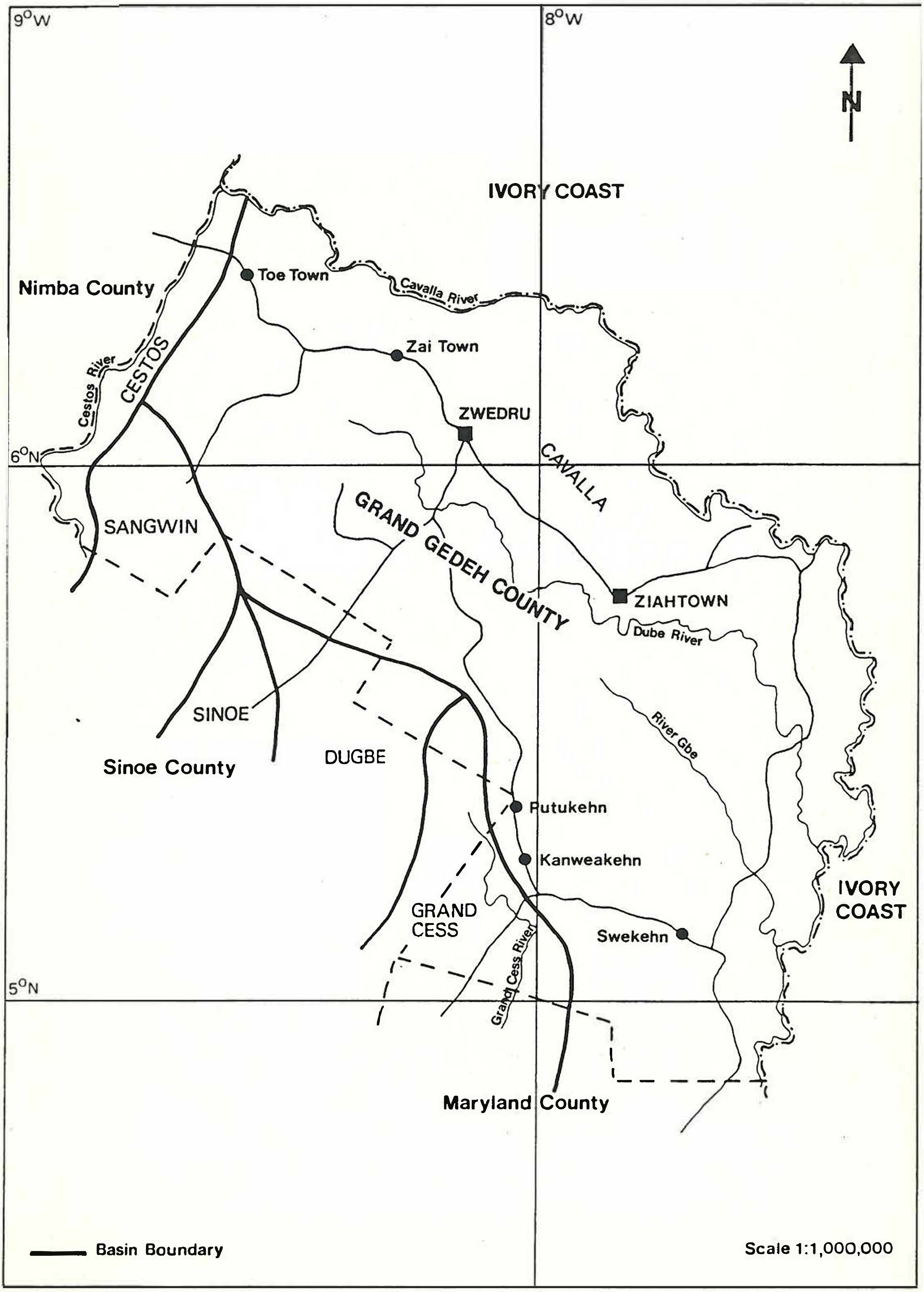


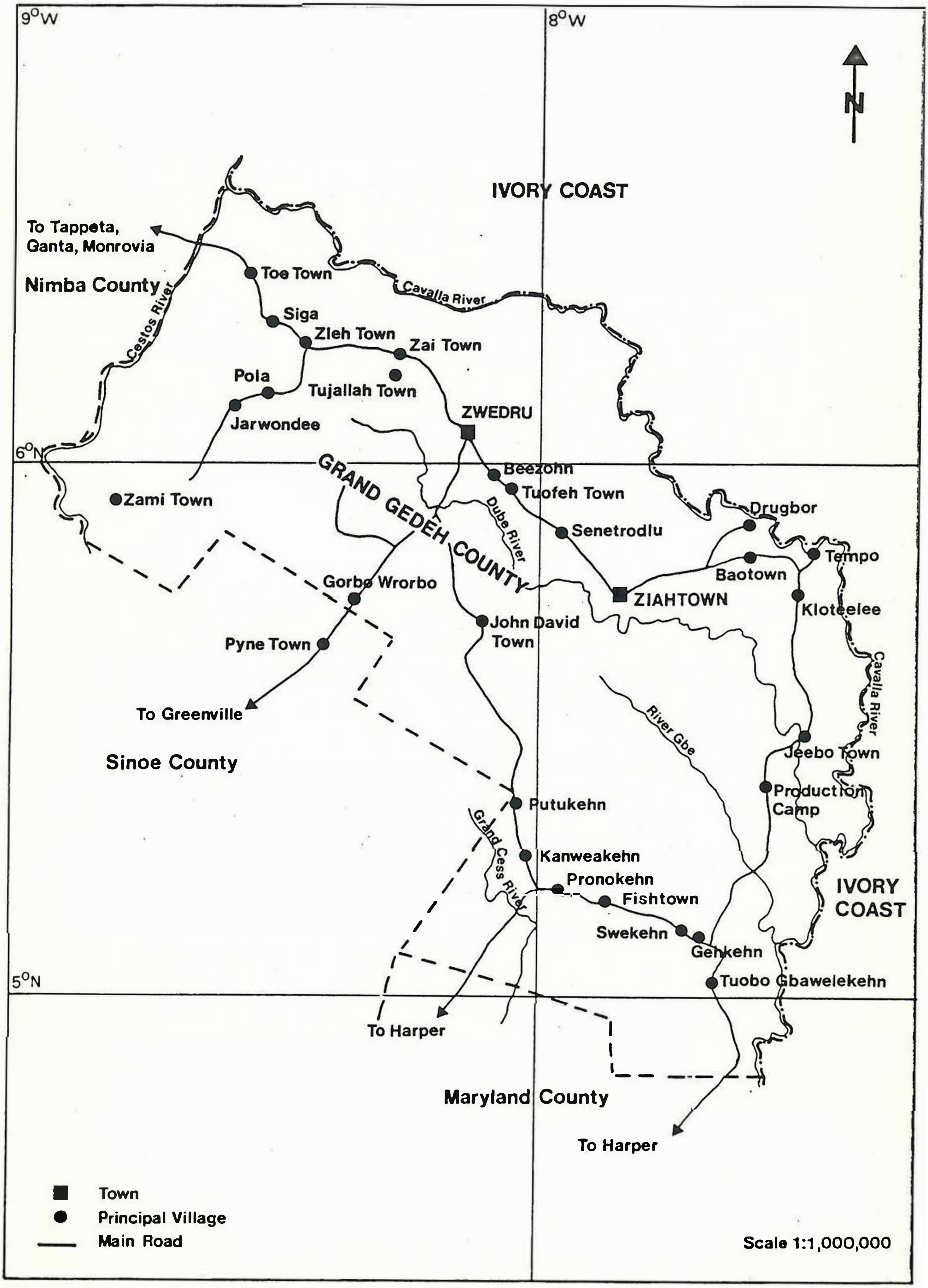
Figure 1.1 Map of Liberia Showing Grand Gedeh County


9°W
8°W
N
IVORY COAST
Nimba County
Toe Town
Zai Town
GBARZON
TCHIEN
ZWEDRU
6°N
GRAND GEDEH COUNTY
KONOBO
ZIAHTOWN
Sinoe County
GBEAPO
Putukehn
Kanweakehn
WEBBO
IVORY COAST
Swekehn
5°N
Maryland County
District Boundary
Scale 1:1,000,000

Drainage Basins

Figure 1.3




9°W
8°W
N
IVORY COAST
To Tappeta, Ganta, Monrovia
Nimba County
Cestos River
Toe Town
Cavalla River
Siga
Zleh Town
Zai Town
Pola
Tujallah Town
Jarwondee
ZWEDRU
6°N
GRAND GEDEH COUNTY
Beezohn
Tuofeh Town
Zami Town
Dube River
Senetrodlu
Drugbor
Tempo
Baotown
Gorbo Wrorbo
ZIAHTOWN
Kloteelee
John David Town
Pyne Town
Cavalla River
To Greenville
River Gbe
Jeebo Town
Sinoe County
Production Camp
Putukehn
Grand Cess River
Kanweakehn
Pronokehn
Fishtown
IVORY COAST
Swekehn
Gehkehn
5°N
Tuobo Gbawelekehn
To Harper
Maryland County
To Harper
Town
Principal Village
Main Road
Scale 1:1,000,000

ii) Phase 2

This extended from January to May 1986, and was concerned with more detailed surveys in selected villages as follows:

- Evaluation of the soils and land capability of the main areas exploited by farmers around each village.

- Detailed survey of a section of swamp and surrounding upland in each village in order to determine its suitability for swamp rice production and associated rainfed crops. The surveys included studies of flood control, drainage and irrigation.

- Agronomic and hydrologic studies.

The soil and land capability studies included a reconnaissance land resource survey of the whole County, which is to be a step towards a nationwide appraisal of land resources.

The village-based studies were centred around a detailed survey of a section of swamp to establish its suitability for swamp rice production. The swamp side slopes often have soils which are deeper and less gravelly than the surrounding upland and they therefore offer opportunities for intensified dryland crop production to complement the development of the swamp; the side slopes up to a distance of about 500m were therefore also included in the detailed swamp survey.

In addition, a semi-detailed survey was made to establish the land capability in the main area exploited by the villagers. This was intended to provide an indication of the potential of the area for improved and/or intensified upland cultivation to complement the proposed production from the swamp.

In order to meet the objectives, and to reflect the different intensities of investigation required, appropriate mapping scales were chosen as follows:

- Reconnaissance survey (Grand Gedeh County):	1:250,000
- Semi-detailed village surveys:	1:20,000
- Detailed swamp surveys:	1:2,000

The agronomic studies were carried out during a six week period in March/April 1986 to determine the present state of agricultural production and to assess potential for integrated cropping systems (based on irrigated, improved swamp rice, with tree and other crops cultivated on the side slopes of the swamp) aimed at stabilising and increasing productivity of rice in the village areas, thereby reducing dependence on rice produced under the wasteful "slash and burn" system.

Studies of the regional hydrology were undertaken during Phase 1, followed by more detailed assessments of the water resources of the selected swamps during Phase 2.

Throughout the study, liaison was maintained with Government officials, and a technical officer from the Ministry of Agriculture was seconded to the team during Phase 2. Progress meetings were held with a technical committee comprising representatives from interested Ministries, the Delegation of the Commission of the European Communities, and the consultants. The dates of the three progress meetings were as follows:

i)	Initial meeting	23rd October 1985
ii)	Meeting at end of Phase 1	16th December 1985
iii)	Round-up Meeting	1st May 1986.

2. REVIEW OF LAND RESOURCE INFORMATION

2.1 LITERATURE REVIEW

2.1.1 Soil Studies in Grand Gedeh County

Previous work on the soils and land capability of Grand Gedeh County is very limited, consisting of a few detailed surveys of particular areas for specific projects such as coffee and cocoa developments.

The earliest survey of the soils was a nationwide exploratory survey by Reed (1951). This was based on flights over the country and observations along accessible motor routes. A small text map at a scale of 1:3,000,000 was produced showing five soil "associations". In this survey, much of the central area of Grand Gedeh County is indicated as having very shallow soils (lithosols), but with latosols around the margins. The descriptions of the soil associations provide some indications of the landform and the report provides some chemical data and indications of appropriate use of the land. Obviously, such a survey cannot be used with any reliability for either national or regional planning but it provides a first account of the range of soils to be found in the country.

In 1974, Subramanian (1975) undertook a survey in the Zleh Town area (north-west Grand Gedeh County) to select areas suitable for tree crops (especially oil palm, coffee and cocoa). He described the area as being a dissected plateau with steep, eroded lands, hillocks and depressional areas. Much of the upland had concretionary soils with the concretions often being tightly packed. These were considered to be unsuitable for development. Deeper and less gravelly soils were found on the lower slopes. Such soils were considered to be suitable for tree crops, though it was thought that cocoa might be sensitive to acidity. The swamps were generally of a sandy nature but were considered to have development potential for rice.

Subramanian pointed out that the soils had been formed under forest and that changing land use and forest clearing is likely to have a number of effects. Amongst these are the following:

- Reduction in topsoil organic matter.

- Risk of hardening of plinthite through increased wetting and drying.

- Increased risks of soil erosion, indicating a need for soil and water conservation.

- Adverse effects on soil structure and infiltration.

The possibility of such adverse effects occurring demand careful attention in any land development scheme.

In 1975/76, SATMACI undertook a soils and land capability survey of eight areas in Liberia to determine their suitability for coffee and cocoa. One of these areas is near Zwedru in Grand Gedeh County; the rest of the sites are scattered throughout the country in Sinoe, Nimba, Bong, Grand Bassa, Lofa and Cape Mount Counties. Their report (SATMACI, 1976) provides background data on the physical conditions in Liberia and a more detailed account of the soils and land capability in the Zwedru site (1772ha). Two maps at a scale of 1:10,000 are presented:

i) Soils;

ii) "Fitness for Farming".

Soils were classified according to the ORSTOM system. Two classes predominated:

Class IX - Ferrallitic Soils on the interfluves

Class X - Hydromorphic Soils in the depressions.

Suitability for coffee and cocoa was judged from soil physical conditions, in particular texture, gravel/stone content (including concretions), wetness/drainage, and soil depth. Almost half the area is classified as moderately suitable, and a similar area is classified as good or very good. Unfortunately neither the map legends, nor the text tables sub-divide the suitability classes according to the limitations which have been defined, but reference to the text suggests that gravel content is the major limitation in these soils. The report also emphasises the very low natural fertility of these soils. A general description of the topogaphy indicates that some steep slopes occur but gradients do not appear to be quantified nor do they seem to have been considered as a factor in determining suitability. Thus the suitability of the land for agricultural development may be somewhat optimistic.

The Ministry of Agriculture (1976) commissioned a report for an oil palm and coconut project (SODEPALM). This study included a soil survey report for one site in Grand Gedeh County (Dube Area). The following maps at a scale of 1:10,000 are presented:-

- Soils;
- Morphology and vegetation;
- Project layout.

The soils, classified according to the ORSTOM system, were predominantly leached ferrallitic soils and were subdivided on the basis of colour, drainage and gravel content. Again, the main limiting factors in these soils were found to be stoniness (gravel and concretions); the presence of indurated horizons; and extremes of texture.

2.1.2 Other Relevant Land Resource Studies

A report for the Mano River Union by van Mourlik (1979) is a reconnaissance appraisal for agricultural purposes of the land resources of western Liberia, along the border with Sierra Leone. The aim was to provide data which will assist planners in identifying projects, and in regional planning.

This is the only major regional reconnaissance land resources survey to have been undertaken in Liberia so far. In this study, the land systems approach was used in which the survey area of some 27,000km^2 was divided into land systems from air photo interpretation. These were used as mapping units and formed the basis for field sampling and land suitability mapping.

The constituent land facets of each land system were described in terms of area, landform, soils, and vegetation and land use. An evaluation was then made of the suitability of each facet for various crops including coffee, cocoa, rubber, oil palm, upland rice and lowland rice. The report contains three maps at a scale of 1:500,000:

i) Vegetation and Land Use;
ii) Land Systems;
iii) Land Suitability.

Soils as such were not mapped, but the report points out some of the difficulties of applying the Soil Taxonomy and FAO/UNESCO classifications (Soil Survey Staff, 1975; FAO/UNESCO, 1974) in the field. In particular, they noted the difficulty of recognising diagnostic horizons, because of the exhaustive laboratory and micromorphological analysis which is often required to correctly identify horizons and because of some anomalies in the application of the definitions under Liberian conditions. Thus an approach on the basis of soil "families" was favoured in which the classification was developed and centred around four concepts:-

- Texture and gravel content of the control section (25-100cm depth).
- Stage of profile development.
- Parent material.
- Colour.

Such features were found to be readily recognised in the field during routine soil surveys and were considered to be directly relevant to assessments of land capability and crop suitability. The families were correlated with Sub-groups of Soil Taxonomy and Units of the FAO/UNESCO Soil Map of the World.

A major land resource study with objectives similar to those of the present study was undertaken in the Blolekin-Zoukougbeu region of the Ivory Coast, adjacent to Grand Gedeh County (Berger, Hunting & SIGES, 1975). This study provides an account of the land resources in a physical environment very similar to that of Grand Gedeh County. The study included a regional reconnaissance followed by semi-detailed surveys of three pilot areas to recommend appropriate land use and management practices and to assess their suitability for the cultivation of various climatically adapted crops.

Soils were classified according to the French ORSTOM system and land was rated according to five land suitability classes with decreasing potential and flexibility. Factors taken into account in rating the land were:

- Depth to limiting layer.
- Texture of fine earth.
- Available water capacity.
- Drainage class.
- Topography and slope class.
- Soil nutrient status.

Much of the land was considered to be of moderate to low potential on account of shallow, gravelly soil and low fertility. Such areas were recommended for semi-perennial crops such as coffee and cocoa and for forestry. Annual cropping was recommended on areas of Classes 1 and 2 land generally associated with flat to gently undulating terrain on the lower colluvial slopes. Such land was estimated to occupy about 33% of the region as a whole.

A paper by Geiger and Nettleton (1979) discusses some of the problems in classifiying Liberian soils. It points out that diagnostic horizons of some soils classified under the USDA system (Soil Taxonomy) as Paleudults have the chemical and mineralogical properties of oxic horizons but the particle size and clay-film distribution of argillic horizons. CEC values were found to be in the range permissible for Oxisols. The authors therefore propose a new sub-group of Aquoxic Paleudults to accomodate these soils.

A document by the Soils Division (1977) of the former Central Agricultural Experiment Station (CAES) provides a catalogue of soil series defined up to that time in Liberia. A description is given of each series together with its classification (Soil Taxonomy) and indications as to its present use. However, the series described were established largely in Bong County and neighbouring areas where most soil surveys had been undertaken. Subsequent surveys in other counties should allow the catalogue to be substantially expanded and updated.

2.2 APPROACHES TO LAND SURVEY AND CLASSIFICATION IN LIBERIA

2.2.1 Soil Survey and Classification

The Soil Survey Division is the national organisation responsible for undertaking soil surveys and land capability assessments in Liberia. The Division falls within the Land and Water Department of the Central Agricultural Research Institute (CARI) based at Suakoko, Bong County. The Soil Survey Division currently has no systematic programme of regional or national survey but its staff undertake ad hoc surveys when requested. These are usually detailed surveys of farms to assess their suitability for a particular crop (eg cash crops such as coffee, cocoa, rubber, oil palm).

An agreed method of soil classification for Liberia is still the subject of discussion. Early surveys (eg Reed, 1951) used the old US system (Baldwin et al, 1938). Fantant (1970) is reported by van Mourlik (1979) to have developed a system based on soil families as described above in Section 2.1.2. Other ad hoc surveys undertaken by consultants have used the French ORSTOM system and the FAO/UNESCO system. Correlation between these systems is quite well established, but the soil classification system currently preferred by technical officers of the Ministry of Agriculture and the Soil Survey Division is Soil Taxonomy.

The advantage of international systems such as Soil Taxonomy or FAO/UNESCO is that they allow comparison of the soils of Liberia with those of neighbouring states and put the soils in a worldwide context. They are therefore particularly appropriate for nationwide or regional soil surveys when soils are being classified at a high level in a hierarchical system (eg. from Orders down to the Sub-group level). In a continuing, long term systematic national or regional survey programme, detailed and exhaustive attention can be paid to pedological criteria such as micromorphology, soil temperature regimes and laboratory analysis which are important in differentiating between classes.

However, for short term or detailed studies where soil mapping units are at a low level in the classification (eg soil series), surveys are usually orientated towards suitability for specific crops or assessment of land capability. Attention is then focussed on soil characteristics of particular relevance to the purpose of the survey and which can be used to assess the relative suitability of the soil for the defined land use. Differentiating criteria may not correspond exactly with those required by international systems. Hence, there is a tendency in individual projects for various approaches to soil classification to be devised which lend themselves to rapid survey techniques, such that soils can be differentiated and mapped in the field, and which meet the requirements of the particular survey.

2.2.2 Land Capability and Crop Suitability Classification

Approaches to land classification and crop suitability assessment are also varied. The Soil Survey Division is generally called upon to perform crop-specific soil survey interpretations and it appears that the Division uses two main approaches. In the first approach, crop suitability is based on recognising soil series in the field during the soil survey, the suitability of each series for a range of crops having been determined in advance from experience, judgement or other means. The approach is therefore relatively easy to apply so long as soil series can be readily identified in the field but the application of this approach depends heavily on a correct assessment of the suitability of the series in the first place; it also creates difficulties when new and previously undefined series are encountered.

The second approach used by the Soil Survey Division is land quality assessment, in which crop suitability is determined by scoring various characteristics of the soil according to the crops' specific requirements and tolerances. The most limiting condition or conditions determines the land suitability class. This approach has the advantage that it can be applied in new areas where no soil mapping has previously been done, as it relies on the recognition of attributes of land which can be measured or estimated. However, it does involve an element of subjectivity, particularly when reliable soil-relatable crop yield data are not available (van Mourlik, 1979).

The land qualities approach was applied in the reconnaissance survey of the land resources of western Liberia for the Mano River Union (van Mourlik, 1979). Each land facet was scored against five land qualities as follows:

- Rooting space
- Soil fertility
- Availability of moisture
- Availability of oxygen
- Resistance to erosion.

The Bong County Agricultural Development Program (BCADP) is currently in the process of undertaking a soil and land resource survey. 1:25,000 scale aerial photographs are being used for stereoscopic examination to recognise and delineate various categories of landform such as:

- Eroded areas
- Dissected plateaux
- Undulating plains
- Gently undulating plains
- Alluvial plains and terraces.

The work is still in an early stage but the aim is to identify priority areas for more detailed soil and land capability investigations.

Land capability assessments can also provide the basis for land use planning; this approach differs in concept from the assessment of the suitability of land for a particular crop. Land is classified according to its potential and the severity of its limitations for crop growth. It is intended to indicate the maximum intensity of use consistent with sustained agricultural production (that is, without incurring risks of environmental degradation such as soil erosion). It provides a guide to appropriate land use practices and soil conservation measures to minimise the risks of erosion.

The most widely used system, upon which many other national systems of land capability assessment have been based is that developed by the Soil Conservation Service of the United States Department of Agriculture (Klingebiel and Montgomery, 1961). The land capability class is determined from an assessment of soil and land data. The system as originally defined had 8 classes, of which the first four are suitable for arable cultivation and the remaining four are unsuitable. Many adaptations of the original system have been made to suit local conditions but the central concepts remain the same. Within any particular capability class, a range of crops may be grown and the class does not reflect suitability for any particular crop.

In defining land capability classes, particular emphasis is placed on factors which affect soil erodibility (eg soil depth, structural stability of the topsoil, inherent fertility, etc) and the landform characteristics (gradients and micro-topography). The presence of rock outcrops and severe climatic constraints such as exposure to cold, wind and rain are also taken into consideration as they influence the range of land use possibilities.

This approach to land classification appears to have received little attention in Liberia compared with the crop specific suitability assessments. Yet, as van Mourlik (1979) has pointed out, suitability for a particular crop can vary rapidly because soil properties change over short distances, even within a land facet. This makes crop suitability assessments and mapping very difficult in small scale regional reconnaissance surveys where soil variation within mapping units is large. At the broad scale, crop suitability can be related to the large scale variation in climatic parameters (particularly rainfall amount and variation, and temperature), while reliable assessments of crop suitability at the local level can only be made after detailed soil surveys have been carried out.

The land capability approach has the advantage that it focusses attention on the risks of soil erosion which is likely to increase as land becomes scarcer, with higher population density and with the introduction of more intensive methods of farming to increase productivity. It would also serve to direct agricultural development towards areas with the lowest erosion hazards.

The approaches to soil and land classification adopted in the present study are discussed in Section 9.2.

2.3 MAPPING MATERIALS

There is currently a lack of topographic or interpretive mapping material covering Grand Gedeh County at medium to large scale. The following materials exist.

2.3.1 Aerial photography

Most of Grand Gedeh County is covered by 1:60,000 aerial photography dating from January/February 1982. This was flown by Hunting Surveys for a mapping project by the Overseas Surveys Department of the UK Ordnance Survey. Infra-red film was used to help combat the effects of cloud, haze and dust. The extreme southern part of Grand Gedeh County is covered by aerial photographs dating from January 1985.

2.3.2 Topographic Maps

The 1:1 000 000 national map of Liberia shows large gaps in topographic information in Grand Gedeh County. A 1:250,000 scale outline map of Grand Gedeh County was produced in 1982 by the Ministry of Planning and Economic Affairs in connection with the preparation of the National Atlas of Liberia. Less than half the map has contours and there is no spot height information for large parts of the County. This sheet was used for preparation of an outline base map for the reconnaissance survey of the present study.

No large scale mapping exists at present although work is in hand by the UK Ordnance Survey (Overseas Survey Department) to produce 1:100,000 scale mosaics of most of Grand Gedeh County during 1987. The more populated southern areas adjacent to Maryland County will be covered by 1:50,000 map sheets.

2.3.3 Geological Maps

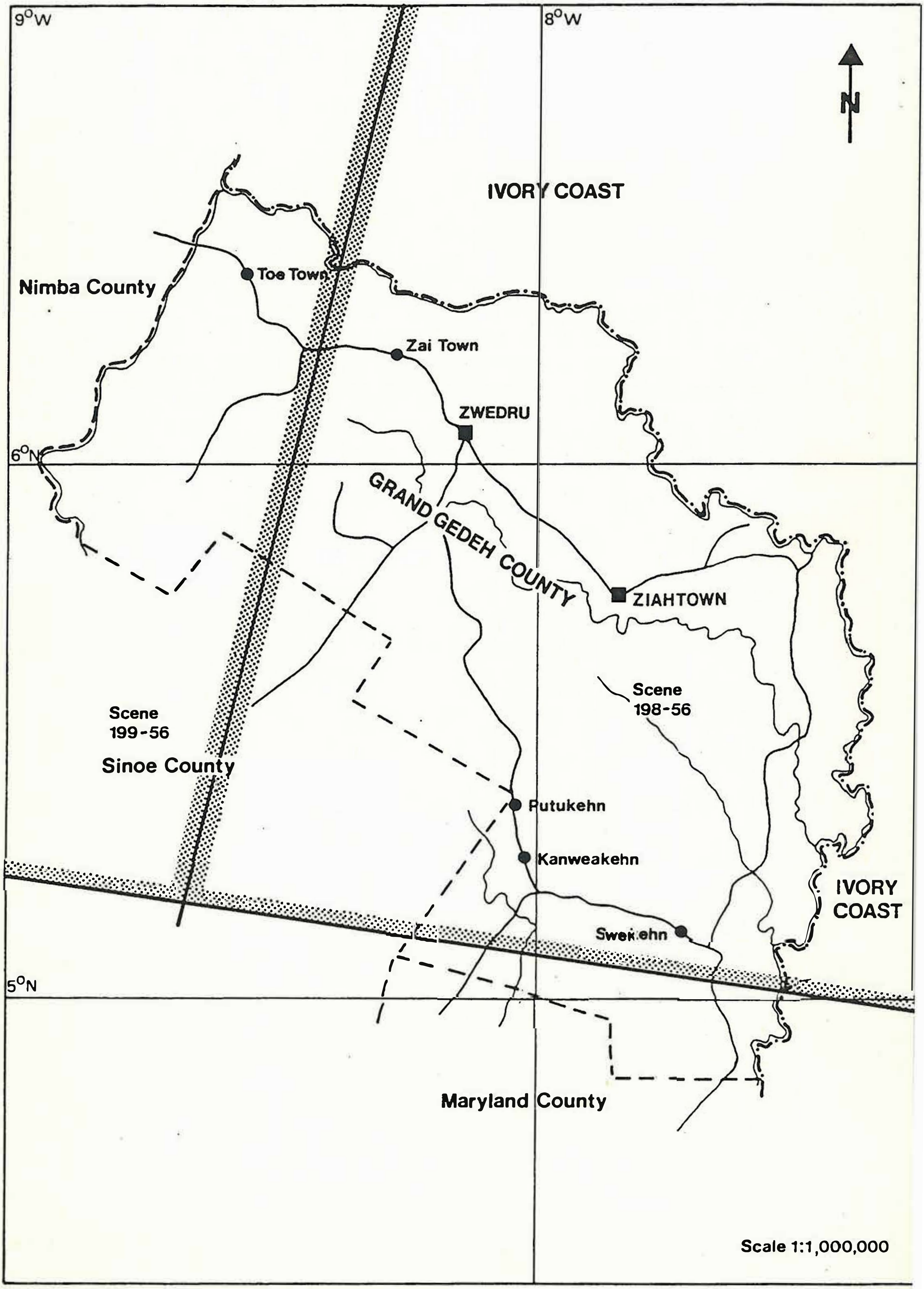
1:250,000 scale geological maps have been prepared by the US Geological Survey. Three sheets cover Grand Gedeh County (Brock, Chichester and Baker, 1977; Force and Beikman, 1977; Tysdal, 1977).

2.3.4 Satellite Imagery

Two scenes of Landsat 5 (198-56 and 199-56) cover all of Grand Gedeh County with the exception of the extreme southern part (Figure 2.1). MSS imagery was obtained as 3-band false colour enlargements at 1:250 000 scale covering each scene. As no single cloud-free image existed for the eastern scene (198-56), two images were obtained for 3rd and 19th December 1984. Both these have 30-50% cloud cover but they are complementary to each other in that the northern part of one image, which is cloud covered, is cloud free on the other and vice versa for the southern part. The two images between them give adequate interpretive cover of the scene. No suitable cloud-free image of scene 199-56 exists.

Incidence of Landsat 5 Scenes

Figure 2.1



3. METHODS OF STUDY AND APPROACH

3.1 LAND CAPABILITY SURVEYS

3.1.1 Regional Reconnaissance Survey

Much of Grand Gedeh County is under forest and is remote and inaccessible. The conditions of the terrain therefore required that the reconnaissance survey of land resources be based primarily on an interpretation of remotely sensed information, with ground checking and field work limited to those areas which are accessible. Mapping of inaccessible areas could then be achieved by extrapolation. The village surveys (Section 3.1.2) subsequently provided more detailed information on the soils in "sample areas" scattered around the county, enabling refinement of the reconnaissance data on the distribution of soils and land capability of different areas.

The survey was undertaken with the aid of satellite imagery and aerial photography (see Section 2.3 for details of Landsat imagery and aerial photography). The aim was to produce two reconnaissance maps of the County, one representing land use and vegetation, the other representing landform/terrain characteristics. The Landsat images were used mainly for the land use and vegetation studies; the landform analysis was undertaken by stereoscopic interpretation of the aerial photographs.

a) Vegetation and Land Use

The major categories of vegetation and land use were relatively easily distinguished on the Landsat images. Six categories were defined:

- High forest
- Mosaic of secondary regrowth and farms (forest occupying more than 50% of the area)
- Mosaic of secondary regrowth and farms (forest occupying less than 50% of the area)
- Large plantations.
- Rice schemes (including those abandoned).
- Urban areas.

These categories allowed an assessment to be made of the extent of high forest remaining in Grand Gedeh County, and the location and extent of areas which have been cleared of forest and which are now within the cultivation cycle. A provisional assessment of the intensity of use under farming was also made.

The boundaries of these units were transferred directly onto the 1:250,000 base maps. In areas not covered by the Landsat images, land use and vegetation were determined from the aerial photographs.

b) Land form

The determination of landform units provides an assessment of the relative hilliness and uniformity of the terrain with particular emphasis on gradients and slope lengths; such an interpretation therefore has a direct bearing on the land capability and the risks of soil erosion which in turn have a bearing on land use potential.

The aerial photographs were examined under a stereoscope to differentiate landform units. The value of air photo interpretation is reduced in areas of dense forest since the vegetation masks nearly all the ground detail and also obscures much of the finer details of the topography which are major criteria in identifying land types. As pointed out in Section 2.3 there are no topographic survey data (spot heights and contours) for much of Grand Gedeh County. Therefore it was not possible to verify the scale accuracy or to determine elevations of features of the interpretive landform mapping.

However, examination of the aerial photographs allowed the recognition of four major landform units corresponding broadly with those used in a similar exercise by Bong County Agricultural Development Project (see Section 2.2 above). The landform boundaries were transferred onto 1:250,000 base maps.

Following the stereoscopic examination of the aerial photographs, field traverses were made along the main motorable routes to allow ground checking of the interpretation and to make auger borings to examine the soil in the different types of terrain. Soil investigations were made by auger at about 100 sites throughout the County and 25 soil samples were submitted to the CARI laboratory for analysis.

3.1.2 Semi-detailed Village Surveys

The objective of these surveys was to assess the physical resources and land capability of the principal areas exploited by villagers around each of five selected villages. 1:20,000 enlargements of aerial photographs covering each selected village were used for field surveys and mapping.

At each village, enquiries were made to determine the boundaries of the area exploited by the villagers in their farming activities. Sometimes this coincided with the boundary of secondary regrowth forest and was apparent on the photographs; occasionally the boundary was marked by a stream or river course; elsewhere it was arbitrarily defined as being approximately midway between two villages.

The method of survey aimed at achieving a reasonable distribution of soil observation points throughout the defined study area, identifying the major landforms which could be recognised on the aerial photographs, and establishing the relationship between soils and landform. Of crucial importance in undertaking a survey of this kind is to be able to locate the positions of the observations on a map, or in this case, on the aerial photographs. This often proved to be very difficult due to the dense bush and forest cover, which masked ground features, and the general lack of distinct, recognisable topographic features on the enlarged photographs.

Two different approaches were used in gaining access to the village areas:

a) In the first village (Beezohn), trace lines were cut on known compass bearings and observations were made at regular intervals along the trace lines. However, trace cutting was time consuming and the observations were not necessarily located to maximum advantage from the point of view of making the best use of the information contained in the aerial photograph.

b) In the rest of the villages, use was made of existing footpaths. In general, these allowed access throughout the survey areas and, by virtue of their nature, passed through the main cultivated areas. Where possible, a local hunter who was familiar with all the footpaths and bush tracks in the area was recruited to assist in these surveys. The footpaths were sometimes apparent on the photographs but, in general, location was determined by the use of a prismatic compass and interpretation of the features shown on the photograph. This method allowed a more flexible approach to surveying the area by giving more freedom to investigate terrain according to the patterns seen on the aerial photographs.

All soil and landform observations were recorded on standard data sheets. Sites were marked on the 1:20,000 scale aerial photographs. The land capability of each observation was determined according to the principles of the USDA land classification system.

Samples for analysis were collected from a representative selection of profiles and were submitted to a laboratory in the UK.

1:20,000 scale maps of vegetation and land use were prepared from the aerial photographs; soil and land capability maps at the same scale were prepared from field observations and air photo interpretation.

During the survey, meetings were held with both village elders and the farmers, in order to assess the level of interest and enthusiasm for swamp rice production and to explain the reasons behind, and possible outcome, of the survey. A village house count was also made in order to ascertain approximate village population.

3.1.3 Detailed Swamp Survey

The method of swamp survey was developed to suit conditions found to exist in each of the five villages investigated.

The largest and/or most suitable swamp was chosen, after consultations with the village elders, on the basis of proximity to the village, accessibility, topography, soils and apparent hydrological conditions.

In the absence of large-scale air photos or maps and virtual absence of footpaths, it was necessary to cut trace lines through the areas. Furthermore, visibility within the swamps was often no more than 10m, and accurate delineation of the swamps on the aerial photos was impossible.

Initially, a suitably aligned base line was cut parallel to the swamp. Traces perpendicular to the base line were then cut across the swamp at intervals of 100m. Trace cutting was continued into the areas surrounding the swamp in order to investigate the potential of the adjacent upland areas. Two main factors influenced where each trace line ended; either the point at which very gravelly upland soils were encountered, or the maximum walking distance from the base line.

Four or five trace-line cutting teams, each comprising one team leader/compass reader and four labourers were used in the swamp surveys: the team leader collected information on slope, extent of swamp, position of streams, and other data relevant to the survey.

Between 300m and 600m of trace line were cut per day per trace-cutting team, the rate depending on the type and density of vegetation, with an average rate of about 500m per day.

The trace line grid was flexible, and in all cases was adapted to the shape and extent of the swamp as the survey progressed and information was gathered. In two villages, a second swamp was investigated due to the insufficient size or location of the initial swamp.

Soils, topography, slope gradient, land use, vegetation and land suitability were investigated along all trace lines. Soil profile observations were made every 50m to a depth of 120cm. Certain selected profiles were examined to 220 cm and special note was taken of both soils and gradient on the side-slopes of the swamps.

All field data were recorded on standard data sheets, or diagrammatically on a cross-sectional drawing of each trace line. On completion of the trace cutting and subsequent line survey, soil profile pits were dug and hydraulic conductivity measurements and infiltration tests were carried out at selected sites. Samples for analysis were collected from representative sites of the main soil types, in both the swamp and surrounding upland, and submitted for analysis at a UK laboratory.

Each swamp survey area was mapped at 1:2,000 scale, with separate sheets showing soils, land capability and land use/vegetation. Land suitability was assessed according to a system based on the FAO "Framework for Land Evaluation" (FAO, 1976) for both irrigated rice production and upland rainfed production.

3.2 AGRICULTURE

Agronomic studies were undertaken in each of the five selected villages. Discussions were held with Town Chiefs and farmers to determine husbandry practices and identify constraints to improved crop production. Each of the potential swamps for development was visited and particular features were discussed with the soil survey team.

The availability in Zwedru of necessary agricultural support services and inputs was assessed, including extension services, supply of materials, markets, crop storage and processing facilities. Special attention was given to the Work and See Cooperative near Zwedru, in which 100 ha of swamp are cultivated for irrigated rice.

Discussions were held with senior personnel of agricultural projects in neighbouring counties, national research organisations concerned with development of irrigated rice production and interested Ministries in Monrovia. Appendix C gives further background information arising out of these discussions.

3.3 WATER RESOURCES AND ENGINEERING ASPECTS

Data for the region were collected and reviewed. This consisted of rainfall data, mainly from stations that are now closed, and a limited amount of data from a newly established station at Garley Town, a few kilometres from Zwedru. Climatic data were processed to give monthly values of reference crop evapotranspiration.

Mapping was examined for coverage of Grand Gedeh County. South of Fishtown this was at a scale of 1:250 000 with contours at 50m intervals. North of Fishtown there were no maps which contained contours.

Because of the lack of suitable mapping, it was not possible to estimate catchment area and run-off characteristics. The alternative source of information was aerial photography but these provided inadequate topographic definition due to the haze caused by cloud cover and the masking effect of dense forest canopy.

In spite of the lack of suitable mapping, it was possible to carry out desk studies to give an estimate of the amount of water that will be available for irrigating crops.

Gauges were established in selected swamps being developed by the CCSRP. It was felt that these gauges would be more closely supervised than if established in the swamps that were being investigated under the present Study. Furthermore, many of the streams had little or no flow during the second phase of the Study and would have yielded no useful data. It is intended that the installed gauges will now give several years of data as well as having stage-discharge curves relating gauge level to discharge of the stream.

Fluctuations in groundwater levels were ascertained from observations made during the soil survey, fluctuations in wells and consideration of the geology of the area.

Water samples were collected from the swamps that were being studied in detail and examined for incidence of Schistosomiasis. Public health records were inspected to obtain the number of cases of Schistosomiasis and Onchocerciasis.

Preliminary engineering designs were prepared for the five swamps giving outline measures for flood control and irrigation.

Soil augering at Tujallah Town

Section B
Regional Reconnaissance

4. POPULATION AND INFRASTRUCTURE

4.1 POPULATION

The latest available population statistics are those of the 1974 national census (Ministry of Planning, 1977). Data from the 1984 census are not yet available. In order to give an indication of present (1986) population, the 1974 figures have been increased by 27% (2% per annum). Table 4.1 gives the estimated population by district.

TABLE 4.1: ESTIMATED POPULATION (1986) GRAND GEDEH COUNTY

District	1974 Population	Estimated 1986 Population*	Percentage of Total
Gbeapo	14090	17900	20
Gbarzon	15895	20200	22
Konobo	10983	13900	15
Tchien	14393	18300	20
Webbo	16462	20900	23
TOTAL	71823	91200	100

* Based on 1974 census data, assuming 2% per annum population growth, rounded to nearest 100.

The total area of the County is approximately 16,000 km^2. The average population density of just under 6 persons km^{-2} is extremely low.

The principal tribes are Grebo and Krahn, representing about 43 per cent of the total population.

Zwedru is the largest town in the County and forms the administrative centre. The present population is estimated at 7,700, based on upgrading the 1974 figures. However, it is possible that Zwedru has experienced a faster growth rate than the rest of the county due to immigration from rural areas, in which case the present population could be larger. According to the 1974 census, a majority of settlements in the County had less than 200 persons and 90 per cent of the settlements had less than 500 persons (Table 4.2).

TABLE 4.2: NUMBER OF LOCALITIES BY SIZE, 1974

Population Range	Number	Per Cent
5,000 - 9,999	1	0.3
2,000 - 4,999	-	-
1,000 - 1,999	5	1.7
500 - 999	19	6.5
200 - 499	88	29.9
100 - 199	95	32.2
Under 100	86	29.3
	294	100.0

Source: 1974 Population Census

4.2 ROADS AND COMMUNICATIONS

The Ganta to Harper highway, comprising one of the major routes in Liberia, passes through Grand Gedeh County. This route crosses the Cestos River near Toe Town and extends, via Zwedru, down the western side of the County through Kanweakehn to Maryland County. A branch from Zwedru links Grand Gedeh County to Sinoe County and the port of Greenville (Figure 1.4).

Road communications within Grand Gedeh County are poor and few of the roads are passable throughout the year. Other than in Zwedru there are no paved surfaces and the roads have been formed from the natural soil with varied degrees of grading. Many of these roads deteriorate rapidly during the main rainy season, preventing access for long periods. The major roads are provided with permanent concrete bridges across the rivers. Highway maintenance is minimal. Most of the grading is carried out by the logging companies which have concessions in the area, although the Public Works Department carries out some maintenance.

There are no railways in Grand Gedeh County.

Zwedru has an airstrip for small aircraft, and there are several other minor airstrips in the County.

Telephone communication centres exist in Zwedru, Harper and Greenville, but no other settlements are on the telecommunications network. Communications between towns and villages is by messenger or letter. Logging companies and other private and Government operations use radio links.

5 CLIMATE AND WATER RESOURCES

5.1 INTRODUCTION

Climatic data have been abstracted from several sources and assembled to give an assessment of rainfall and reference crop evapotranspiration within Grand Gedeh County. Four rainfall stations with records of monthly precipitation were utilised in Grand Gedeh, Sinoe and Maryland Counties. Data for the Liberian Meteorological Services Station at Bawo, with three years of daily records of precipitation, were also used.

The only comprehensive daily climatic data are for the CCSRP Station at Garley Town, near Zwedru, covering the period from November 1985 to March 1986. These include data on temperature, relative humidity, incoming shortwave radiation, wind speed at 2m above ground level, and sunshine duration. Mean monthly temperatures for the years 1963-72 were available for a climatic station about 13 km west of Zwedru; the source of these data are unknown.

Using the climatic data it has been possible to calculate tentative values of reference crop evapotranspiration. These should be improved and updated as more data become available, but it is thought that changes in the monthly values presented here will not be very great because the climatic changes throughout the year are not very pronounced.

Surface and groundwater resources have been reviewed. Although the amount of data is very limited in extent and quality, as compared with the climatic data, it was possible to establish general criteria for the potential use of surface and groundwater.

The incidence of Schistosomiasis and Onchocerciasis associated with swamp development have been examined.

Recommendations have been made concerning future data collection.

5.2 RAINFALL DATA

Rainfall data were collected for the stations given in Table 5.1; the locations are shown in Figure 5.1. Data from the CCSRP station at Garley Town have not been used because these will be for a short period. However, the station does have an autographic rainfall recorder and this will be of great value when sufficient data is available to determine rainfall intensities. Data for other stations are available, but are not worth recording because they are either of short duration or have many missing values.

TABLE 5.1: DETAILS OF RAINFALL DATA

Location	Latitude	Longitude	Duration of Records	Frequency of Reporting
Firestone Cavalla	4° 34'N	7° 38'W	1928-81	Monthly
Pyne Town	5° 42'N	8° 24'W	1952-73	Monthly
Ziahtown	5° 45'N	7° 51'W	1952-61	Monthly
Zwedru	6° 04'N	8° 08'W	1952-73	Monthly
Zwedru (Dube River)	5° 58'N	8° 11'W	1982 to present	Daily

The Firestone Cavalla data have been used because it should have an application to southern Grand Gedeh County and because the long period of records (54 years) should improve the reliability of the frequency analysis.

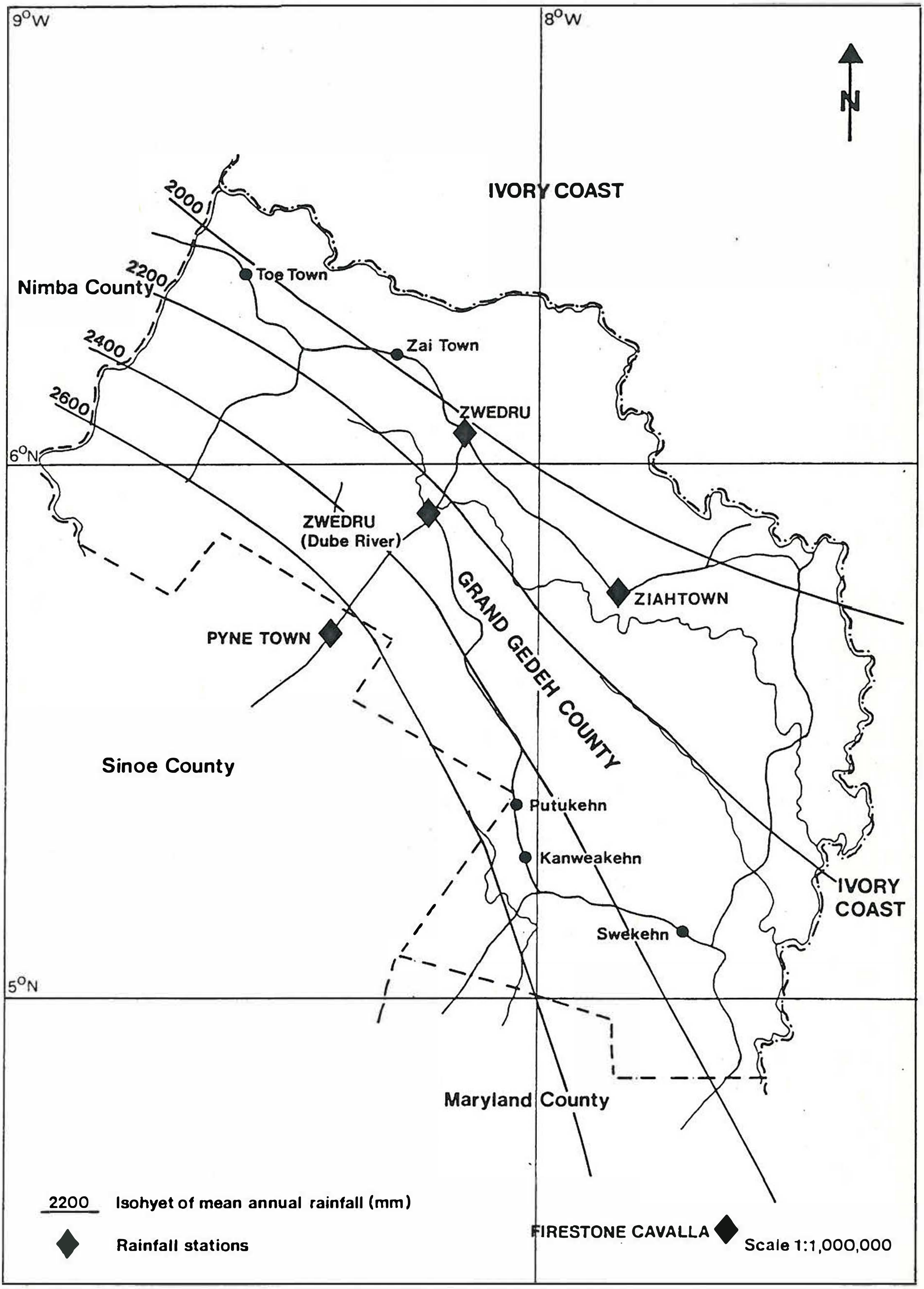
All the data listed in Table 5.1 can be found in Appendix B.1. The monthly data for each station have been ranked in order of decreasing magnitude and the mean, median, 20% exceedance and 80% exceedance monthly values are given in Table 5.2. The mean annual isohyets are shown in Figure 5.1.

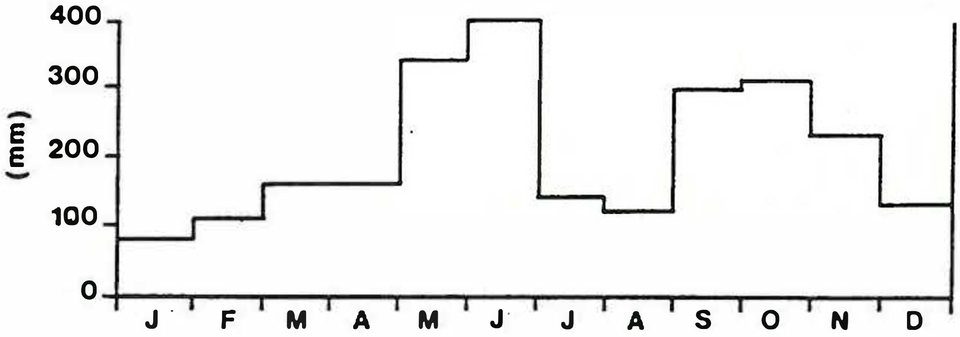
Figure 5.2 shows the monthly distribution of rainfall throughout the year. This demonstrates the bimodal variation with a distinct period of lower rainfall during July and August compared with the months before and after this period. This is particularly pronounced for the Firestone Cavalla station which has a higher annual total rainfall than for stations further north, such as Zwedru. However Pyne Town, with the highest annual rainfall of the four stations does not have such a distinct dry period during July and August when compared with the other stations.

Figure 5.3 shows the monthly rainfall as a percentage of the annual rainfall and demonstrates the more pronounced dry season in the middle of the year at the Firestone Cavalla and Ziahtown stations. This dry period is of importance because if two crops of rice are grown, then one should be cultivated from, say, May to August and the other crop planted during September or October. In most years there should be sufficient rainfall to sustain such a system of rice production without the need for supplementary irrigation, with the drier period between the two crops giving good conditions for harvesting and drying the rice.

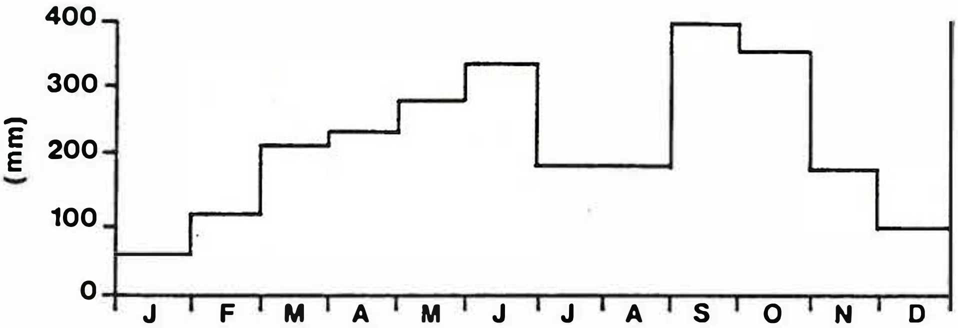
Location of Rainfall Stations and Isohyets

Figure 5.1

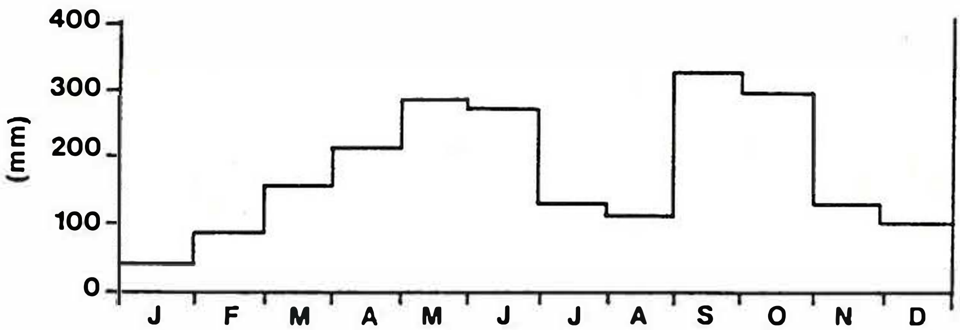




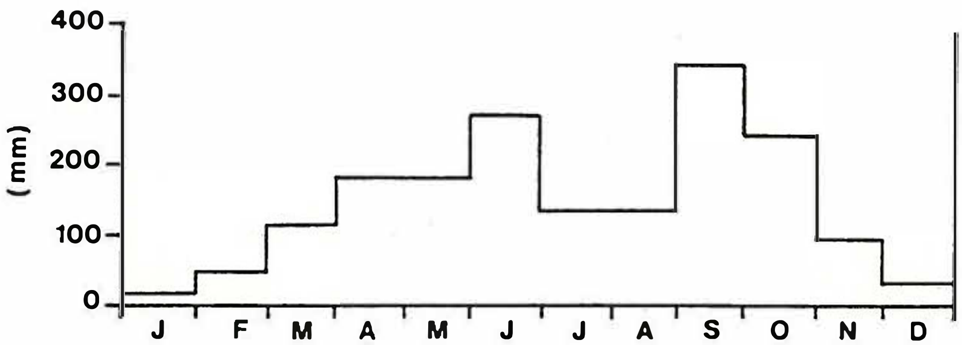
Firestone Cavalla



Pyne Town

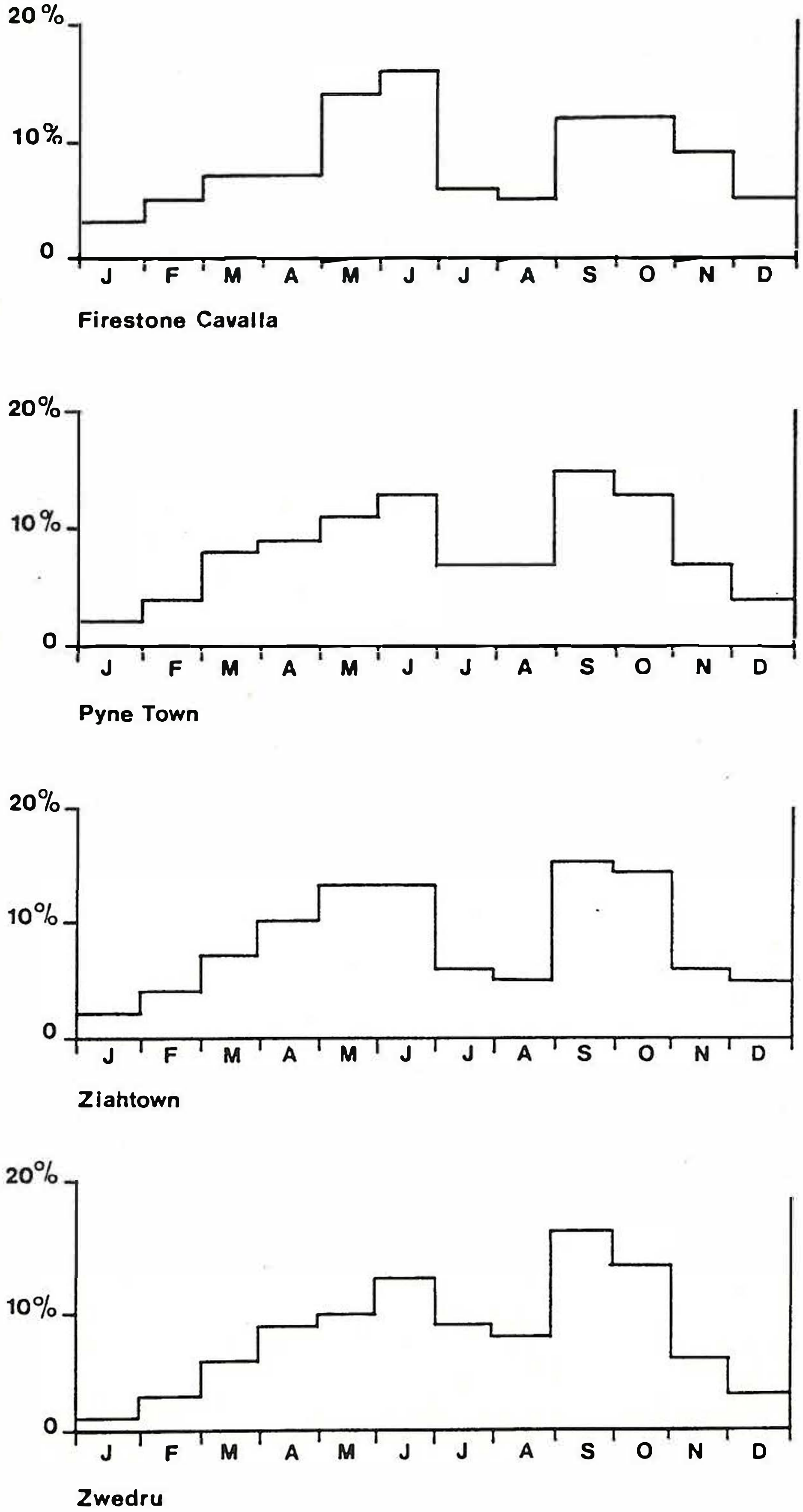


Ziahtown



Zwedru

Figure 5.3


20 %
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Firestone Cavalla
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Pyne Town
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Ziahtown
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Zwedru

TABLE 5.2: RAINFALL STATISTICS

MONTH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Values													
Firestone Cavalla	78	113	162	162	341	401	137	119	297	310	229	131	2480
Pyne Town	60	118	217	240	285	342	192	194	406	359	184	100	2697
Ziahtown	41	86	154	210	280	265	126	111	321	288	125	100	2107
Zwedru	21	63	118	189	204	271	186	160	349	282	126	60	2029
Median Values													
Firestone Cavalla	64	110	144	150	315	360	90	100	280	295	210	125	
Pyne Town	48	100	210	230	275	325	135	165	380	335	160	85	
Ziahtown*	30	70	145	210	280	265	135	80	310	290	120	100	
Zwedru	20	50	115	185	185	280	140	140	350	250	100	35	
20% Exceedance Values (occurring 1 year in 5)													
Firestone Cavalla	120	160	240	215	430	530	195	175	420	410	330	170	
Pyne Town	100	175	275	320	385	460	305	280	510	465	250	160	
Ziahtown*	90	135	200	310	370	350	215	160	405	365	180	135	
Zwedru	35	105	155	250	270	340	260	250	445	360	175	90	
80% Exceedance Values (occurring 4 years in 5)													
Firestone Cavalla	30	65	100	95	205	250	40	40	150	180	140	85	
Pyne Town	20	50	170	155	185	210	50	70	295	220	100	40	
Ziahtown*	5	30	90	110	190	180	55	45	230	200	80	65	
Zwedru	5	20	75	120	125	210	70	70	255	170	65	10	

*These values should be treated as approximate because of the limited amount of data available.

5.2.1 Daily Rainfall Distribution

Although it is not possible to be specific concerning the distribution of rainfall throughout the month, some general observations can be made concerning the three years records of daily rainfall for Zwedru given in Appendix B.1. These show a considerable number of dry days within the month. This is of importance when considering such activities as rice drying which should be able to proceed without undue disruption from rainfall. Also, when carrying out studies for the adequacy of rainfall in sustaining rice cultivation, monthly rainfall values can be used with a reasonable degree of confidence. The rainfall is distributed throughout the month rather than falling continuously over a few days, which would result in a major portion being lost to drainage and causing temporary water stress in the crop prior to the next period of rainfall.

5.2.2 Areal Distribution of Rainfall

From observations of road conditions after rainfall in an area, it is evident that rainfall is not uniform. Precipitation appears to range from high intensity storms at some points to no rainfall within a short distance.

Obviously, it would be preferable to support these observations with a number of autographic rainfall recorders which would have to be spaced at relatively short distances. However, at present there is no justification for installing such gauges because of the initial cost and logistical problems in operating and maintaining the instruments. On the other hand, the CCSRP team are installing daily rainfall recorders on the swamps that they are developing, and in the future there may be a sufficient number of gauges to investigate areal rainfall distribution, at least in the Zwedru area.

5.2.3 Rainfall Intensity

From the limited observations it can be shown that rainfall occurs in short duration high intensity storms, but it is impossible to be more precise than this without adequate autographic rainfall records. At present there is one recorder operated by CCSRP at Garley Town. When some years of records are available it should be possible to derive a rainfall intensity relationship.

Watkins and Fiddes (1984) discuss rainfall intensities in the tropics. The nearest country to Liberia for which examples are given is Ghana. The following expression relates intensity to duration:-

$$I = a/(b + T)^n$$

where I = rainfall intensity (mm/hr)
T = duration (hr)
and a, b and n are constants.

From this formula, it is possible to predict the distribution of rainfall in a 24 hour period if values of b and n are known. For Ghana, values of b=0.6 and n=0.86 to 1.03 have been derived; this is equivalent to over 50% of the daily rainfall falling during the first two hours of a storm.

5.2.4 Recommendations for Future Data Collection

It is regrettable that most of the rainfall stations in and around Grand Gedeh County have been closed. There is no short term solution to this because dedicated personnel are required to operate these stations with a minimum of supervision. It is recommended that continuity of recording is maintained for the Liberian Hydrological Service Station at Zwedru and the various rain gauges operated by the CCSRP. It is recommended that these two organisations should continue to manage the existing stations and any future recording stations that may be installed. If sufficient funds can be obtained, then consideration should be given to re-establishing rainfall stations that have been closed.

5.3 OTHER CLIMATIC DATA

Climatic data other than rainfall are extremely limited. Only six months of continuous records are available from the CCSRP Station at Garley Town for the period October 1985 to March 1986. These data consist of daily records of temperature, relative humidity, incoming shortwave radiation, sunshine duration and wind speed. The only other data available are long term temperature records for a station near Zwedru.

The availability of climate data for the Ivory Coast was also investigated. Some data for Man and Gagnoa exist but these were not pursued because of the remoteness of both these stations from Grand Gedeh County and the fact that, unlike Liberia, the isohyets in western Ivory Coast are not parallel to the coast, suggesting a different weather pattern.

A correlation between sunshine duration and incoming radiation has been carried out using the daily data from the Garley Town station (Appendix B.2). This gave the relationship:-

$$Rs/Ra = 0.34 + 0.35n/N$$

where n actual hours of sunshine in one day
N maximum possible hours of sunshine in one day
Ra extra-terrestrial incoming radiation
Rs actual shortwave incoming radiation

5.3.1 Reference Crop Evapotranspiration

Penman's method was used to calculate reference crop evapotranspiration using both the limited amount of data from Garley Town station and estimated values of some parameters, together with the adjusted long-term temperature records for Zwedru.

Table 5.3 gives the Garley Town data and calculated values of reference crop evapotranspiration which have been corrected to allow for the variation in wind run between day and night. It has been estimated that night time wind speeds are in the order of 3 times those which occur during the day. A correction for this situation is not given by FAO (1977) and, therefore, the wind speeds have been reduced to 25% of the recorded values and the calculations repeated.

Because the records from Garley Town covered only six months it is preferable to utilise longer term records if these are available. Unfortunately, the only long-term records available for Zwedru were for mean temperature and these were consistently higher than the values obtained from Garley Town. Approximately 1°C of this difference could be accounted for by the different approach to calculating mean temperatures with the long-term records using the average of the maximum and minimum temperatures whereas the Garley Town station values were based on the integrated values of the temperature; the latter method is the more correct but does rely on having a continuous recording of temperature.

The Garley Town station mean temperatures for October 1985 to March 1986 were averaged and compared with the average of the long-term mean temperatures for October to March: the difference was 3.75°. Therefore, the long-term means were reduced by 3.75° and reference crop evapotranspiration was calculated using measured and assumed values (Table 5.4).

Although some of the data used in Table 5.4 is only estimated, the values of reference crop evapotranspiration should not change appreciably because the difference between the assumed climatic parameters and accurately derived values cannot be large. For instance, temperature has been defined, and relative humidity during the wet season will approach 100 per cent. Radiation values have been calculated from estimated sunshine duration and increasing this will increase incoming shortwave radiation as well as increasing, but not by the same amount, outgoing longwave radiation. Wind speed has little effect on evapotranspiration because of the high humidity. Therefore, the corrected values of reference crop evapotranspiration given in Table 5.4 should be sufficiently reliable for irrigation water requirement calculations in this study.

5.3.2 Recommendations for Future Data Collection

What has already been said concerning the collection of rainfall data is even more pertinent to the collection of other climatic data, because more diligence and skill is required. If another climate station is to be set up this should be at either Harper in Maryland or Greenville in Sinoe County. Greenville and Harper both have airports and some climatic records are already available.

TABLE 5.3: REFERENCE CROP EVAPOTRANSPIRATION (using Garley Town data from October 1985 to March 1986)

Month	Mean Temp	Relative Humidity	Radiation	Wind Speed	n/N	Evapotranspiration				
						Radiation	Aero-Dynamic	Total		Corrected*
	(^{o}C)	(%)	($cal/cm^2/d$)	(km/d)				(mm/d)	(mm/mth)	(mm/mth)
October	24.5	87.1	446	35.6	0.52	3.52	0.38	3.90	121	119
November	24.5	88.1	423	30.8	0.50	3.33	0.34	3.67	110	108
December	22.7	83.0	411	30.7	0.49	3.06	0.46	3.52	109	107
January	22.2	77.7	460	38.2	0.58	3.31	0.63	3.94	122	118
February	24.3	81.4	464	55.4	0.60	3.52	0.62	4.15	116	111
March	23.7	82.5	475	51.3	0.46	3.76	0.56	4.33	134	130

*Wind speed reduced by factor of 4.

n/N = proportion of actual house of sunshine to maximum possible hours of sunshine in one day.

TABLE 5.4: REFERENCE CROP EVAPOTRANSPIRATION (using long term temperature records)

Month	Mean Temp (^{o}C)	Relative Humidity (%)	Radiation ($cal/cm^2/d$)	Wind Speed (km/d)	n/N	Evapotranspiration Radiation	Evapotranspiration Aero-Dynamic	Evapotranspiration Total (mm/d)	Evapotranspiration Total (mm/mth)	Corrected* (mm/mth)
January	23.2	78	444	40	0.58	3.24	0.65	3.89	121	116
February	24.0	81	478	55	0.60	3.63	0.63	4.26	119	114
March	24.6	82	454	50	0.46	3.63	0.58	4.22	131	126
April	24.2	84	452	50	0.45	3.61	0.51	4.12	124	120
May	24.6	85	433	55	0.42	3.50	0.50	4.01	124	120
June	23.0	85	416	60	0.40	3.25	0.50	3.75	113	108
July	21.8	86	422	60	0.40	3.23	0.45	3.68	114	107
August	21.2	86	446	50	0.45	3.35	0.42	3.76	117	113
September	23.0	86	432	40	0.40	3.41	0.41	3.82	114	112
October	23.2	87	461	35	0.52	3.56	0.37	3.92	122	119
November	23.8	88	430	30	0.50	3.34	0.33	3.67	110	108
December	23.2	83	412	30	0.49	3.10	0.46	3.56	111	108
TOTAL										1371

NOTES: 1 Values for Garley Town Station used for October to March. Summer values estimated taking into account climatic conditions.

2 Calculated using Rs/Ra = 0.34 + 0.35 n/N.

n/N = proportion of actual house of sunshine to maximum possible hours of sunshine in one day.

*Windspeed reduced by factor of 4.

5.4 SURFACE WATER RESOURCES

The three largest rivers in the area are the Cavalla, Cestos and Dube. During the dry season there is very little water in the Cestos and Dube and this would indicate low groundwater storage and subsequent recharge. If necessary, further work could be carried out to quantify the magnitude of this storage using recession analysis (Johnson, 1972). This would require development of stage discharge curves based on the sites of the existing automatic water level recorders; in the case of the Dube near Zwedru, such a relationship is said not to exist at present.

Although the large rivers are indicative of the nature of base flow during the dry season, they are of no use as a water resource for supplying swamp developments with supplementary water because they lie at the downstream end of the system and cannot command areas further upstream. Moreover, land slopes are such that even during the periods of high river levels, it is unlikely that there is any significant backing-up of flows upstream into the swamps.

Many of the smaller rivers and streams have negligible flow during the dry season and should not be relied on for supplementary irrigation. However, their response to rainfall is almost immediate, indicating rapid runoff and low infiltration in their catchments. The stream entering the Beezohn swamp near Zwedru clearly demonstrates this: on Friday 11th April Zwedru had 19mm rainfall during the night and on Sunday 13th April the stream was flowing. By Wednesday 16th April flow had ceased. It is claimed that before land was cleared upstream, flow was perennial; this would indicate that the base flow is derived from retained surface water storage rather than any groundwater storage.

Because of the lack of topographic data for Grand Gedeh County it was impossible to define catchment areas or longitudinal profiles for the rivers. This, and the lack of rainfall data, made it impossible to simulate river flows using a technique such as the Unit Hydrograph. Hence, for any particular swamp, it was not possible to give estimates of the water available for irrigation or to predict flood flows which should be allowed for in any swamp development. The latter criterion is not very critical because the size of the channel can be enlarged if it is found to be of insufficient capacity to carry the flood flows. Although stream flows cannot be estimated, it is possible to examine the amount of water running off the slope adjacent to swamps and estimate the quantity available to give supplementary irrigation within the swamp.

5.4.1 Surface Runoff

Two factors affect the value of water available for supplementary irrigation, namely when is the water available after rainfall occurs and how much water is available? The question of when the water is available can be answered by considering the time of concentration for which Kirpich (1940) gave the following relationship:-

$$Tc = 0.00025\ (L/\ S)^{0.80}$$

where Tc is time of concentration in hours

L is length of catchment in metres

S is overall catchment slope.

This formula was derived for a river channel rather than for overland flow. Hence, if used for catchment side slopes it will tend to underestimate time of concentration because of the smaller velocities that will occur with the small overland flows, compared with the more concentrated flow in a major channel. Even with this constraint the values derived using Kirpich's expression can be considered: these are given in Table 5.5 for a range of length and slopes.

TABLE 5.5: TIME OF CONCENTRATION (hours)

Catchment Length (m)	Catchment Slope (%)					
	1	2	4	6	8	10
100	0.06	0.05	0.04	0.03	0.03	0.02
1000	0.40	0.30	0.22	0.19	0.17	0.16
10000	2.50	1.90	1.40	1.20	1.10	1.00

Even increasing the values in Table 5.5 by a factor of 5 (to allow for the overland flow) still gives times of concentration of less than one day and shows that any surplus water would be available for supplementary irrigation.

In determining the quantity of water available, reference was made to the United States Bureau of Reclamation (USBR, 1973) Design of Small Dams, which deals with rainfall-runoff relationships. The amount of runoff will depend on the crop cover, soil type and antecedent moisture condition.

The soil type on the slopes will be one with high runoff potential and slow infiltration, and crop cover corresponding to secondary forest will be scrub (native brush). The corresponding Curve Numbers (CN) are 66 and 82 relating to normal soil conditions and near saturated soil conditions respectively. Table 5.6 gives runoff values for a given precipitation and CN values of 66 and 82.

TABLE 5.6: STORM RUNOFF (mm)

Rainfall (mm)	CN = 66 Runoff	CN = 66 Percentage of rainfall	CN = 82 Runoff	CN = 82 Percentage of rainfall
25	0	0	3	13
51	4	8	17	34
76	14	19	36	47
102	28	28	57	56
127	45	36	80	63
152	64	42	103	67
178	83	47	126	71
203	104	51	150	74

Because many of the side slopes to the swamps have very low permeability, the CN value of 82 is probably most relevant. Also, during the rainy season the soil will tend to remain saturated. Runoff will be high and tending to a fixed amount, probably about 50mm less than the rainfall in the case of high precipitation. Because the area of the side slopes is usually large compared with the area of the swamp, the volume of water generated by runoff will be appreciable and should be more than adequate for any supplementary irrigation required in the swamp.

5.4.2 Surface Water Quality

The water quality of surface streams should be good because of the abundant rainfall and lack of groundwater recharging the streams. Electrical conductivity measurements made at Beezohn gave values of 55 to 60 mS cm^{-1} for the surface water. This is equivalent to a total dissolved solids of about 40 ppm and confirms that the water is of good quality for agricultural use.

5.4.3 Stream Gauging

At the time of the hydrological study, most of the swamps selected for survey were dry. Installing gauge boards would therefore have yielded little data and, moreover, results would have covered only a very brief period. It was felt that a more positive contribution could be made by installing gauge boards in swamps being developed by the CCSRP. These provided an opportunity for recording at regular intervals by supervised gauge readers, to give more reliable data over an entire year. The swamps in which gauge boards were installed were:

- Gwehn Town (on Zwedru to Tapeta road)
- Pola (20 km from Zleh Town on Zwedru to Tapeta road)
- Babo Town (on Zwedru to Putu road at the Sinoe turning)
- Putukehn (70 km from Zwedru on Zwedru to Harper road).

The gauges were made from 50mm x 75mm (2in x 3in) timber and had grooves cut in one face every 100mm (4in). The position of the grooves was defined at 200mm centres by numbers fixed to the face of the gauge.

5.4.4 Recommendations for Future Data Collection

Although it may be desirable to have records of water availability before a swamp is developed, this will take several years to determine and could be affected by upstream development, making the data collected useless. The CCSRP has a policy of establishing gauge boards in the stream flowing through a swamp that is being developed. Not only should they be able to obtain reliable records of water level, but they also have facilities for establishing stage-discharge curves for each gauge; this requires observations over much of the year. While this may not answer the question of quantifying water availability before the swamp is developed, it will indicate the nature of the water regime after development and it may be possible to extrapolate the finding for use on undeveloped swamps. It is recommended that the present arrangements are continued.

If manpower is available, then the automatic water level recorder on the River Dube, on the Zwedru to Putu road, should be brought back into operation. Furthermore, stage-discharge curves should be produced for this recorder and that situated on the River Cestos near the Zwedru to Tapeta road. There is little point in having a continuous record of water level unless they can be related to river discharge.

5.5 GROUNDWATER

5.5.1 Introduction

The stratigraphic sequence in the area is one of gneiss and granite overlaid by weathered gneiss, schist and lateritic clay with the occasional bands of sand. The overburden has an average thickness of about 20m but can vary from 5m to 65m. The valley bottoms which contain the swamps comprise sands and gravels as well as silts and clays.

Groundwater levels outside the swamps are between 5 and 15 metres below the surface in March, and between March and July there is very little change in level. Also there is little difference between groundwater levels in the overburden and the underlying fractured rock. Wells in Zwedru, which are hand-dug in yellow and white clay and are used as a domestic water supply, have an annual water level fluctuation of about two metres (6.0 feet).

Water quality in the underlying rock is good. A sample taken from the Prime Timber Products supply at Zwedru, had an electrical conductivity of 220 mS cm^{-1}, equivalent to a total dissolved solids of about 150 ppm.

5.5.2 Groundwater Flow in the Swamps

Groundwater conditions differ in the swamps, where alluvial soils (1.0-2.0m deep) overlie weathered bedrock. The water table is close to the surface. Measurements made during the present study (March 1986) showed that whereas there was some variation, the groundwater level was on average about 0.50m below ground level. The reasons for the high water table are a combination of groundwater seepage into the area from the surrounding side slopes, and residual flows in the streams before these become dry. Drainage down the swamp is slow and may be non-existent if the slope is small or if the transmissivity of the alluvium is low. The major cause of any fall in water table in the swamp, under these circumstances, will be evapotranspiration from the vegetation.

During the wet season the water table will be at the surface. The only way that groundwater can be lost will be as flow through the alluvium along the direction of fall of the swamp; this is usually referred to as down-valley flow. Any down-valley flow will be compensated for by seepage from the surface. This can be calculated as follows:-

$$Q = KDi$$

Where
- D depth of alluvium in the swamp
- i slope along the axis of the swamp
- K hydraulic conductivity of the alluvium
- Q horizontal flow in the alluvium

The depth of alluvium in the swamp is 1.0 to 2.0m and the hydraulic conductivity varies from 1.0m d^{-1} to 10.0m d^{-1}. Slopes can vary: for example Beezohn has a slope of 0.25% whereas Putukehn swamp is at least 1% at the downstream end. Hence, values of Q can vary from $0.0025 m^3\ m^{-1}\ d^{-1}$ to $0.2 m^3\ m^{-1}\ d^{-1}$. A simplistic way of converting this to seepage would be to divide Q by x, the distance from the top of the swamp. However, the water table will be at the surface at the head of the swamp and will remain so throughout the swamp. Therefore, all the seepage will be contributed at the top of the swamp, say over the first 100m. This gives seepage losses of 0.25 mm d^{-1} to 2.0 mm d^{-1}. The lower value is quite acceptable but the higher value could cause water shortage in a rice crop during a long period with no rainfall.

A seepage rate of 2.0 mm d^{-1} may be unreasonably high because it is unlikely that a deep, highly permeable soil with a large ground slope will occur in the same swamp. Also swamps tend to be narrow at the upstream end, widening out in the centre and then becoming narrow at the downstream end. This restricts the seepage in the upstream part of the swamp (as the swamp widens, the value of Q will increase) and constricts outflow at the downstream end of the swamp. This latter condition may cause negative seepage or upflow in the lower part of the swamp. Obviously, a particular swamp could be modelled to predict seepage at any point, provided the depth of alluvium, hydraulic conductivity and ground levels are known.

It is concluded that seepage losses under a crop of rice during the wet season will probably not exceed 2.0 mm d^{-1} and, in many cases, losses will be zero because of any small downward flow being more than offset by upward flows caused by the side slopes to the swamp giving a positive phreatic surface above the swamp.

During the dry season the water table drops below the surface. Adequate supplies of supplementary surface water would therefore be required to retain water levels at the surface for rice production.

5.5.3 Groundwater Development

In view of the high costs of drilling, operating and maintaining wells and the low yields, there appears to be negligible scope for groundwater in agricultural development. The only opportunity is for open wells to provide water for high value crops such as vegetables or nursery seedlings.

5.5.4 Recommendations for Future Data Collection

Groundwater potential is limited and should be reserved for domestic supplies. The only locations where groundwater levels are of interest to agriculture are in the swamps that will be developed. In these cases the depth to water table can be measured during the soil survey of the swamp. Further observations should be made during February or March when the water table will be at its lowest level. With this information, it should be possible to estimate the quantity of water required to saturate the soil profile before rice can be planted.

5.6 WATER-BORNE DISEASES

An examination was made of the possible effects of swamp development on the incidence of the principal water-borne diseases which currently occur in the region, namely Schistosomiasis and Onchocerciasis. The nature of these diseases is described in Appendix B.3.

In spite of many visits to Zwedru hospital, it was not possible to obtain the County records for incidence of Schistosomiasis and Onchocerciasis. However, a limited amount of data was obtained from the Medex USAID Project which is investigating diseases in Grand Gedeh County (Table 5.7).

It was thought that the cases of Schistosomiasis recorded in Table 5.7 in fact include some urinary infections wrongly diagnosed. One doctor in Zwedru hospital stated that he had seen approximately 10 patients in 3 years and all these had Schistosoma haematobium. In spite of the apparently larger number of cases of Onchocerciasis compared with Schistosomiasis, the disease does not occur to any great extent within the swamp areas of Grand Gedeh County. It is possible that the number of cases recorded are inflated by people from Ivory Coast seeking treatment at clinics in Liberia.

The Consolata Clinic at Tapeta provided records of the number of cases of Schistosomiasis and Onchocerciasis in 1985 and 1986 (Table 5.8). This clinic treats people from a large area, some of whom travel from as far as Zleh Town in Grand Gedeh County. However, not too much importance should be placed on the figures because the diseases are known to occur in Nimba County and, therefore, it would be inconclusive to say how many, if any, cases came from Grand Gedeh County. More cases of Schistosomiasis mansoni are diagnosed than Schistosomiasis haematobium but tests are carried out on patients only when there is evidence of the disease.

Samples of water were taken from the five swamps investigated as part of the present study. The samples were examined under a microscope in Zwedru hospital within 24 hours of sampling. None were found to contain evidence of Schistosomiasis and remarkably few pathogens were evident in the samples. The only sample that contained anything of interest was from Tujallah Town, but this was thought to be algae.

TABLE 5.7: INCIDENCE OF SCHISTOSOMIASIS AND ONCHOCERCIASIS, GRAND GEDEH COUNTY, 1984

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Schistosomiasis	0	1	0	2	7	0	2	3	21	2	2	-	40
Onchocerciasis	6	8	6	13	11	32	38	41	40	13	6	-	214

Source: Medex USAID Project, Zwedru

TABLE 5.8: INCIDENCE OF SCHISTOSOMIASIS AND ONCHOCERCIASIS, RECORDED BY CONSOLATA CLINIC, TAPETA

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
Schistosomiasis													
1985	8	20	9	11	12	7	5	8	6	10	5	7	108
1986	8	5	7										
Onchocerciasis													
1985	12	15	15	16	26	23	15	19	10	22	15	5	193
1986	11	12	11										

6. LAND CAPABILITY SURVEY

6.1 GEOLOGY AND GEOMORPHOLOGY

The geology of the County has been mapped by the US Geological Survey at a scale of 1:250,000 (Section 2.3.3).

The geological substratum consists of Pre-Cambrian metamorphic rocks, comprising gneisses with inclusions of schist, diorite, amphibolite, granite and iron formations. There is also a dyke swarm of diabase running in a north-west to south-east direction, concentrated in the southern part of the county (Figure 6.1). Deposits of recent alluvium are limited in extent and confined to the channels of the main rivers and streams.

The gneiss rocks occur extensively throughout the County and form the dominant source of soil parent materials. The gneisses represent a complex series of rocks which vary according to the degree of metamorphism to which they have been subjected. The gneisses vary in mineral composition: those rich in biotite give rise to weathering products which have a red colour, are rich in iron oxides and have greater clay contents than those formed on the normal gneiss. The landform on the gneiss rocks is an undulating peneplain in which is developed a dendritic drainage pattern. Outcrops of gneiss rocks are rare.

The schists occur in the south-east corner and along the northern boundary, with minor inclusions elsewhere. The schists are rich in muscovite, biotite, sericite and chlorite. The quartz grains are less coarse than in the gneisses and the rocks produce finer textured soils. The relief is mostly undulating but locally it is very steep where the schists are interbedded with quartzites and form chains of hills. The rock is usually weathered to a considerable depth and outcrops of schist rock were observed only on the steeper slopes of the hills. Most of the area is covered by a fine textured colluvium rich in ferruginised gravel-sized fragments of weathered parent rock.

The main area of diorite occurs along the Cestos River forming low, gently undulating terrain. A few outcrops of amphibolite occur and are associated with small chains of hills due to the resistance of the rock to erosion. The rock contains about equal parts of hornblende and plagioclase.

The iron-formation underlies the Putu Range, the most notable topographic feature in the County. The rock is composed of magnetite, quartz and minor iron silicate minerals.

Diabase occurs locally as a swarm of dykes forming linear ridges that are commonly 10 to 30m high.

In general, therefore, the area has fairly uniform geological and geomorphological characteristics. The region has been subjected to long periods of intense weathering, which have resulted in a fairly uniform soil parent material and a subdued relief except where erosion resistant rocks outcrop. The upper layers have usually been subject to subsequent colluvial redistribution. The mantle of weathering is relatively deep, especially on the peneplain. This superficial weathered material commonly comprises mottled clay which is enriched with iron and aluminium oxides, derived from weathering in the surface layers, and is termed "plinthite".

6.2 VEGETATION AND LAND USE

6.2.1 Introduction

The vegetation and land use have been mapped from Landsat imagery and aerial photography and the results are presented in Map 1 (Volume 2). Five vegetation/land use categories are shown on this map.

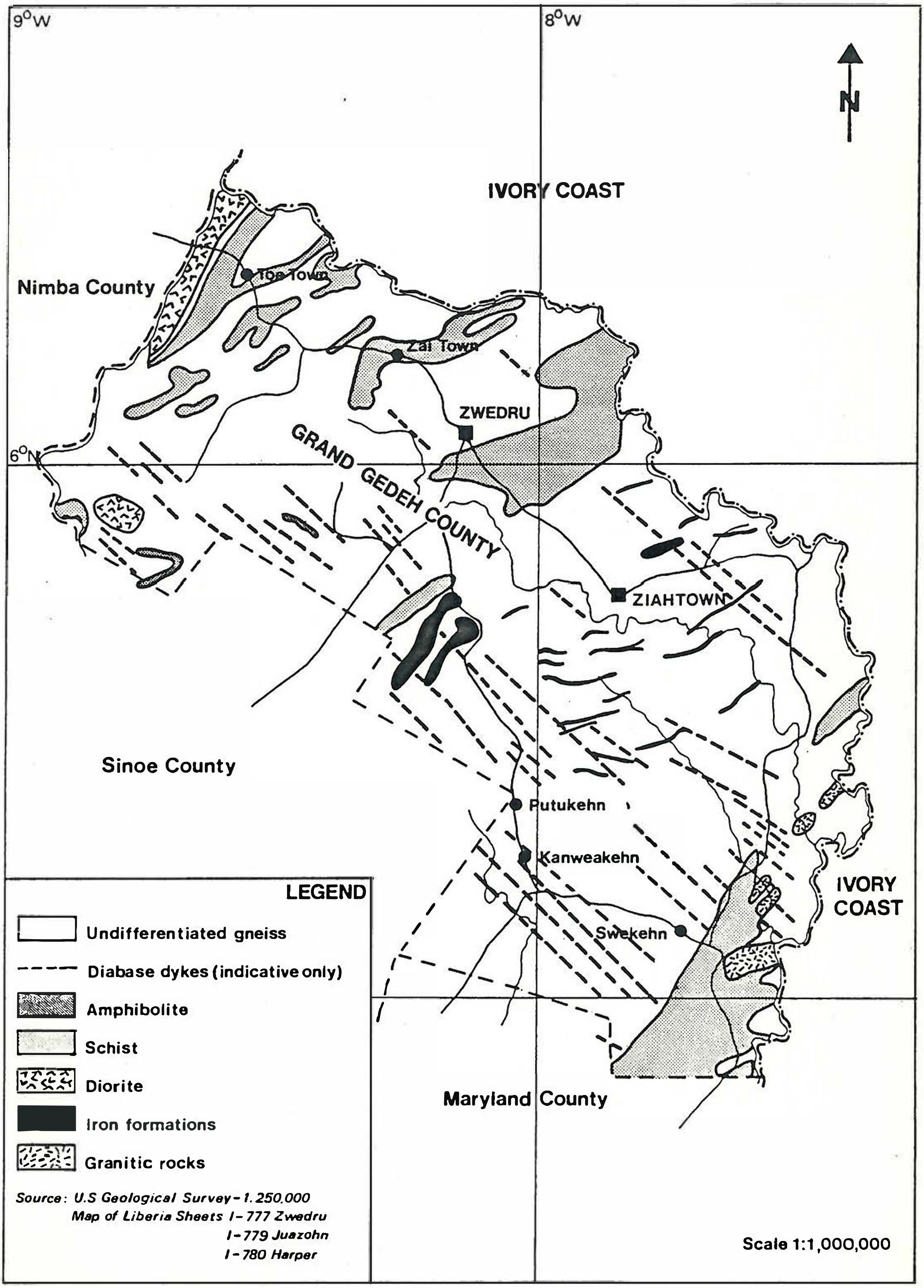
6.2.2 Vegetation

The natural vegetation of the county is a climax of dense tropical rain forest. Such forests contain an extremely wide range of species, but two major upland forest types can be recognised (Ministry of Planning and Economic Affairs, 1982). Over most of the County the natural forest is a deciduous moist type; towards the north-east in a strip along the Cavalla River, where the annual rainfall is lower and the dry season is longer and more severe, the climax vegetation is a mixed deciduous and semi-deciduous forest.

The swamps and other lowland areas which are periodically inundated carry a distinctive range of tree species adapted to the fluctuating water table conditions and temporary flooding.

In the main areas of human population, the natural forest ecology has been largely destroyed by felling and burning. Cultivated land which is abandoned and left to fallow quickly attains a dense secondary bush regrowth vegetation which comprises many scrubby and grass species. This bush regrowth is supplemented by invading tree species after a few years which in turn would normally develop into a secondary forest but this final stage in the sequence of regeneration is usually interrupted by re-clearing and renewed cultivation. All stages of this regeneration can be seen in the County.

Figure 6.1


9°W
8°W
N
IVORY COAST
Nimba County
Toe Town
Zai Town
ZWEDRU
6°N
GRAND GEDEH COUNTY
ZIAHTOWN
Sinoe County
Putukehn
Kanweakehn
Swekehn
IVORY COAST
Maryland County
LEGEND
Undifferentiated gneiss
Diabase dykes (indicative only)
Amphibolite
Schist
Diorite
Iron formations
Granitic rocks
Source: U.S Geological Survey - 1.250,000
Map of Liberia Sheets I-777 Zwedru
I-779 Juazohn
I-780 Harper
Scale 1:1,000,000

6.2.3 Present Land Use.

The two main forms of land use in the study area are commercial exploitation of forest timber and small scale peasant agriculture.

a) Forestry

Some 70 per cent of the county is classified as high forest, and all this area is demarcated as forest concessions to logging companies. The forests are usually exploited by selective felling of valuable species rather than clear felling. Logging companies build extensive road networks throughout the exploited areas for machinery access but these are not maintained after the logging activities have ceased.

Parts of Grand Gedeh County are reserved as national forest (Figure 6.2), within which agriculture is not supposed to be practised. These areas amount to some 5000 km^2.

b) Agriculture

Land affected by agriculture is concentrated along the main access routes and occupies some 29 per cent of the area. This figure comprises all land currently or recently within the cultivation cycle of rotational bush fallow and usually includes more than 50% fallow land. Under this system the natural vegetation is cleared and the land cultivated with food crops. Cultivation continues for one or, occasionally, two years until the soil fertility is exhausted or when weed growth becomes excessive. The land is then abandoned and allowed to regenerate bush and secondary forest for up to 10 or more years.

Two categories of land affected by agriculture are shown on Map 1. One category is a mosaic of upland farms with bush fallow and forest where the forest component occupies less than 50% of the area. The other category is a similar mosaic of farms, bush and forest but the forest has been less extensively felled and accounts for more than 50% of the area, but mainly in small patches. In both these categories cultivation occurs as small units within the secondary forest or fallow regrowth. The zone of cultivation remains limited to the walking distance from main roads and village centres. The farms include upland plots devoted to food crops to meet the family's subsistence requirements (growing rice, maize, cassava, etc) and plots for cash crops (mainly coffee, cocoa, smallholder rubber, pineapples and vegetables, etc).

Further details of cropping and agricultural practice are given in Chapter 7.

c) Other Land Uses

Some large commercial plantations of tree crops are found in the County. These are shown on Map 1 and include oil palm plantations near Zlehtown and Senetrodlu and teak plantations at Production Camp and to the north-west of Zwedru. Extensive rubber plantations, as found in adjacent counties (especially Nimba), do not occur in Grand Gedeh County.

Small scale swamp rice production is poorly developed though a few swamps are exploited in an informal manner without flood control and drainage, mainly by Mandingo people. Large scale rice schemes include a co-operative venture in Zwedru and an abandoned scheme on the Cestos River near Toetown. Such schemes are too small in size to delineate at the 1:250 000 scale of mapping.

6.3 LANDFORM, SOILS AND LAND CAPABILITY

6.3.1 Introduction

Landform has been mapped by stereoscopic interpretation of aerial photographs and the results are presented in Map 2 (Volume 2). Seven major landform categories are shown in this map.

Landform provides the key to physical terrain analysis since soil patterns are related to topography. At the broad level, development potential is also related to landform since terrain, topography and gradient are the dominant factors in determining land capability.

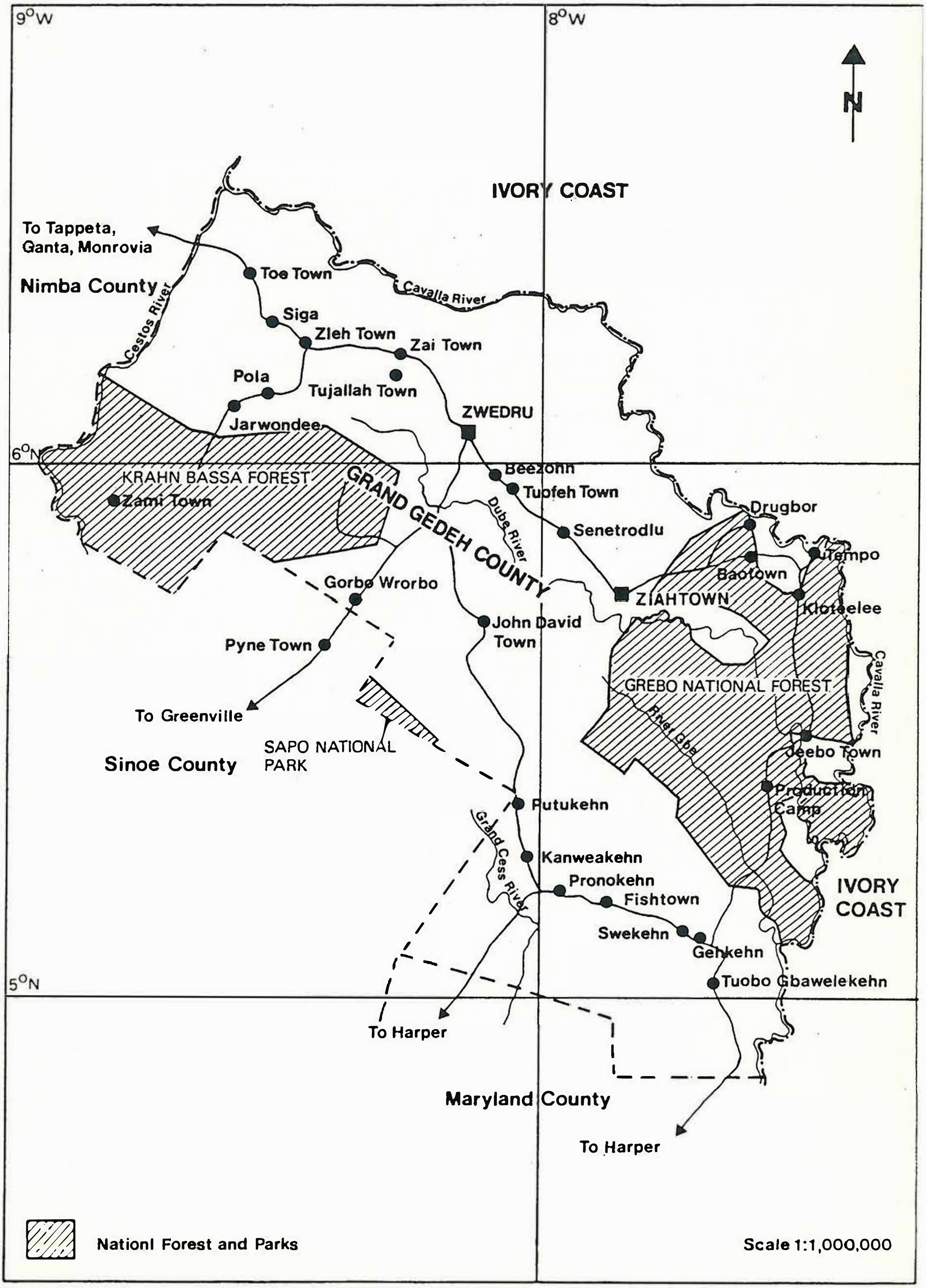
6.3.2 Pedogenesis

The climate is probably the most important factor affecting pedogenesis in the region. The high rainfall, in conjunction with the constant high soil temperatures, produces optimum conditions for rapid chemical weathering. In all the soils there is a net downward movement of water during most months of the year. Consequently, the primary minerals in the soil, with the exception of quartz, are decomposed and the products are leached downwards either to be removed from the profile or to form secondary minerals such as kaolinite and hydroxides of iron and aluminium in the lower horizons. These secondary minerals, which dominate the soil clay fraction, have very low cation exchange capacities and retain only small quantities of plant nutrients against the downward leaching process. The soils are therefore acid and deficient in nutrients.

The effects of climate are fairly uniform over the region although the soils in the north-east may be slightly less leached as a result of the drier climatic regime in that area. Soils were observed to be paler and often contain fewer concretions in the extreme south of the county and this may be due to the wetter rainfall regime and short dry season with the soil staying moist almost continuously throughout the year.

Forest Reserves

Figure 6.2



The effects of weathering and leaching are modified by topography and are less pronounced in the residual soils in areas of steep relief, where accelerated erosion of the soil surface results in a continuous rejuvenation of the soil profile. These soils are thus shallower and less nutrient deficient than those on the more stable topography of the peneplain. Although the topography of the peneplain is fairly uniform on a regional scale, the topography is probably the most important factor affecting the distribution of soil profile types at the scale of individual interfluves.

The parent material is an important factor in the formation of a soil, affecting the mineral content, infiltration rate, permeability and drainage of the profile. The study area has been subject to a long period of relatively stable geomorphological conditions. Thus the original products of weathering of the underlying rocks have been considerably modified by subsequent weathering and local colluvial action and consequently often bear little relationship to the parent rock. The parent materials are therefore recognised according to their mode of formation as well as their geological origin. They are divisible into sedentary, colluvial and alluvial parent materials.

Soils derived from sedentary parent materials occur only on steep hills, where erosion has proceeded as fast as weathering. The rate of weathering of sedentary parent materials determines factors such as soil depth and the presence or absence of stones and rock outcrops.

The colluvial group of parent materials occurs near the base of slopes; the colluvium is derived from downslope movement of material and there has therefore been considerable local redistribution of the surficial materials by erosion influenced by topography. This has resulted in the downslope accumulation of moderately deep layers of relatively gravel free colluvium and the exposure of gravelly subsoil materials on the interfluve crests. The variations in colluvial parent material often given rise to a complex soil pattern.

Alluvial parent materials are confined to the narrow floodplains and terraces of major streams and rivers which dissect the terrain. The material comprises mainly coarse materials but finer textures can be found locally.

Vegetation plays a largely passive but important role in pedogenesis. Under the natural forest vegetation the majority of plant roots are concentrated at or near the surface. Few roots extend below 50cm depth. Despite the intense weathering and leaching processes the surface soil under forest remains moderately fertile and the dense vegetative cover insulates the soil surface from the full effects of the climate, in particular, rainfall impact, and therefore minimises erosion. Under forest, plant debris is rapidly decomposed to release nutrients for re-assimilation by the vegetation. Thus there is a delicately balanced nutrient cycle based on the shallow fertile surface horizon. Micro-organisms, such as termites, play an important part in the circulation of nutrients within the soil profile and also provide increased soil porosity.

The removal of the forest vegetation by man has profound effects on the soil. Exposure to the effects of intense radiation causes dessication of the soil and increases the rate of oxidation of organic matter, which combined with the cessation of leaf-fall, results in a rapid depletion of organic matter in the soil. This depletion is accelerated by burning during clearance and by the increased rate of erosion from the bare soil surface. Thus the main source of soil fertility can be rapidly destroyed and subsequent cultivation can be successful only if adequate artificial fertilisers are applied and the wastage of fertility reduced.

The process of the mobilisation and redistribution of iron is a feature of the pedogenesis of the soils of the humid tropics which is particularly significant in the study area. This redistribution can result in local concentrations of iron compounds in the soil known as plinthite, which is a red, mottled, iron-rich clay. Plinthite occurs widely in the soils of the area and under certain conditions it can harden irreversibly to form concretions or continuous indurated iron pan.

The clearance of forest, without subsequent replacement of vegetation cover, can have serious effects on soils containing a plinthite horizon. Accelerated erosion reduces the protective surface layers of the soil and exposes the sub-surface plinthite horizon to alternating wetting and drying, accelerating the process of hardening and ultimately in its exposure as an indurated cuirasse sheet at the soil surface.

6.3.3 Landform, Soils and Land Capability

Extensive areas in the central and eastern parts of the County have undulating terrain (Map Unit 'u') characterised by broad interfluves between a dendritic drainage pattern; the relief is regular and slopes are gentle to moderate. In certain areas, rocky outcrops and inselbergs arise out of the undulating plain, and these are designated as Unit 'u(h)' on the map. The soils of the higher parts of the interfluve have red colours and deep sub-surface gravelly horizons. Lower down the slope the gravelly layers are thinner and the colours are less red. At the transition with the swamp moderately deep yellow, non-gravelly soils are to be found. In the depressed topography of the swamp the soils are poorly drained and often subject to seasonally high watertables. Although leaching is reduced in these depressional sites the soils have inherited the nutrient deficient characteristics of the source material.

The most promising areas for intensified agricultural production in this type of terrain are the lower colluvial slopes. These are however often narrow and discontinuous. The upper and mid slopes are frequently gravelly giving rise to further reduction in soil fertility, and in water holding capacity (low resistance to short periods of drought in the growing season). They are also difficult to cultivate.

Gradients in these undulating areas are low to moderate (up to 15%) but locally they are steeper. Such slopes can be cultivated provided adequate attention is given to soil conservation including physical support measures for intensified or continuous crop production where appropriate.

In some areas, the relief is very subdued and this is described as gently undulating (Map unit 'g'). Slopes are very gentle and broad, almost level, colluvial areas occur with deep, generally gravel free soils. These areas are favourable for cropping with low erosion hazards, but will require fertilisation and cropping rotations for intensified production.

In the south and north-west of the County in particular, but also elsewhere, the terrain is more hilly and dissected. The terrain is uneven with greater amplitude of relief and steeper, longer slopes of varying gradient. Three categories of hilly terrain are mapped. Map unit 'h' is reserved for major hill chains and ranges (eg. Putu Range) and other very dissected land. Such areas are steep and uneven and are not suitable for agriculture; they should be reserved for forest.

Map unit 'm' denotes hilly terrain which is moderately dissected. Such areas are also predominantly steep and are not generally suitable for agriculture, though limited areas associated mainly with stream courses and the lower slopes may have some potential for agricultural development.

Slightly hilly terrain, denoted on the map by symbol 's', has less amplitude of relief than the 'm' category, but the terrain is still uneven. Intensified agricultural production may be possible in carefully selected areas within these zones, but the erosion risk is high on the steeper slopes and intensified agricultural production can only be recommended with the introduction of a programme of soil conservation.

Limited areas in valley bottoms along the main rivers and streams are occupied by floodplains, terraces and swamps (Map unit 'v'). Such areas frequently have deep gravel-free soils of coarse to medium texture and gently sloping and even relief; together with the adjacent colluvial side slopes they often offer very good prospects for intensified agricultural production, provided that areas with risks of flooding are avoided.

The major rivers often have well defined, even side slopes (Map unit 'l'). In many cases these are relatively steep and are often rocky. They therefore have low potential for agricultural development.

6.4 ENVIRONMENTAL DEGRADATION

Environmental degradation occurs when physical and biological resources in the environment are inappropriately used or over exploited. It results in a deterioration in the quality of the environment and shows itself in effects such as soil erosion, siltation of lakes, rivers and estuaries, flash flooding and reduced diversification of animal and plant populations. It leaves the environment exposed and vulnerable and with less ability to withstand further change.

The tropical rain forest environment is exceptionally rich, having a diverse array of plant and animal species. It provides a home for a vast range of insects and other animals. It contains many valuable hardwood trees which are exploited for timber. Some plant species may prove to have products useful to man (e.g. medicines). The forest protects the soil from erosion and regulates the dispersal of surface and groundwater from catchments. Through evapotranspiration the forest also returns moisture to the atmosphere, and in this way may contribute substantially to the stability of the global climate.

Environmental resources are able to withstand a certain pressure or rate of exploitation by man, whether by hunting of animals, selective logging or clearing of forest for agriculture. But once this rate is exceeded, the exploitation is no longer sustainable and environmental degradation results.

A substantial proportion of Grand Gedeh County is still covered by rain forest although much of it has been selectively logged. Environmental degradation is occurring here since the logged trees which are frequently slow growing species are not replaced. An indirect effect of the activities of logging companies is to open up the forest through the network of roads, giving access to cultivators and hunters and so further expanding the zone of exploitation.

In areas exploited by farmers, one of the major environmental degradation concerns is soil erosion. Slopes which are much too steep are being cultivated without any attention to soil conservation measures and physical support structures. Under the present pattern of cultivation for one year and up to 15 subsequent years under fallow soil erosion may appear to be slight since the soil has a certain resistance to erosion in the first year through its structure and being held together by roots. But as population density increases and pressure grows to exploit the land more frequently, so erosion will become increasingly evident. In this respect, every effort should be made now to introduce some of the basic concepts of soil conservation and water control to the farming population through a programme of extension and training. A key factor in such a programme is the assessment of land capability by qualified technical personnel as discussed in Sections 2.2 and 9.2 of this report. Such an assessment provides a basis for land use planning, recommendations on appropriate types of agriculture, and of the need for soil conservation.

The continued destruction of the forest for agriculture is likely to cause the flow of streams and rivers to become less even, with greater peak flows and reduced low flows. More importantly for this study, the swamps will also be subject to an altered hydrological regime and will therefore require more sophisticated flood control structures as well as facing the risk of drying out. Local people have already commented on such changes in swamps. Such effects can be reduced by policies to protect the most sensitive parts of the catchments particularly the vulnerable upper parts.

Uncontrolled exploitation of animal populations is also occurring through hunting. This has already decimated populations of larger mammals in areas around the main centres of human population and uncontrolled fishing has led to some rivers becoming almost devoid of those fish preferred for eating.

The reversal of environmental degradation can only be achieved by the correct identification of the forms of over-exploitation of resources, by an assessment of appropriate, sustainable intensities of exploitation, and by the development of policies to protect the environment. This requires a commitment by the authorities to implement the policies, to persuade the local population of the need for controls and to gain their co-operation. While curbing to some extent the freedom of individuals to exploit resources as they would wish, such controls will nevertheless result in the long term stability and productivity of the natural environment upon which individual prosperity ultimately depends.

7. AGRICULTURE

7.1 FARMING SYSTEMS

7.1.1 Introduction

The farming systems practised within the village communities are broadly divisible into two principal types:-

- Upland Rice Farming System: this system caters for the subsistence needs of the community and therefore receives priority in terms of labour. The principal crop is upland rice, grown under the slash-and-burn bush fallow system. This farming system is practised in areas relatively remote from the main village, where "high bush" forest is available, and usually includes an encampment for temporary accommodation of the farmers.

- Village Farming System: this system is orientated towards cash-cropping of tree crops, vegetables and swamp rice. The actual mix of crops varies between communities. This farming system is usually concentrated around the village but can be included within the Upland Rice Farming System in more remote areas.

Grand Gedeh County has a comparatively low population density. The demand for agricultural land is therefore correspondingly low, and there remain considerable areas of high bush forest, often within only one hour's walk of the village. The slash-and-burn fallow system is therefore used widely on the Upland Rice Farms. Moreover, once a farmer has cleared land of high bush, he traditionally retains the right to cultivate that land. His prior permission is required before any other farmer may crop this land.

Generally the upland rice farm is cultivated for one to two years and left to fallow for 10-15 years. Farmers will tend to clear high bush each year while they are young, so that when they become older it is only necessary to clear secondary bush to prepare the farm. Occasionally, an upland farm will be planted to cocoa in the second year and shade for the young trees is provided by planting cassava, plantain and banana.

The village farms include coffee, cocoa, swamp rice and small vegetable areas. Old or non-productive cocoa, coffee or rubber farms are left to return to bush rather than be rehabilitated. Swamp rice farms are generally cultivated for a season and then left fallow for several years. However, around Zwedru, there are areas of improved swamp where irrigated rice cultivation is practised on an annual basis. Sometimes, close to a village, a small plot of plantain, banana or vegetables is found, and rotation practices will depend on labour availability.

7.1.2 Upland Rice Farms

The subsistence needs of the farmer and his family are provided by this farm. The clearing and burning of the high bush or secondary bush for land preparation is therefore most important and vital to his survival. An area of land about 0.75 - 1.5 ha (1.8 - 3.7 acres) will be selected within 30 - 60 minutes walk of the village. In most villages the farmers walk to their farm every day as required. However, in Tujallah Town the farms are 1-2 hours walking distance and farmers live on their farm during busy periods.

Land clearing is undertaken by the farmer and his unmarried sons during January to April and women assist later with burning the bush. Power saws and operators are sometimes hired at a rate of L$35 - 45 per day, plus food for the operator and fuel.

Rice and maize are planted together in April/June by women. Other crops planted during the early growth stages of the rice or after harvest, are cassava, bitterball, pepper, tobacco, cocoyam, eggplant, pumpkin and sweet potato. These crops are often planted in the spaces between the rice or next to unburnt tree trunks. Cassava may be planted either in a freshly burnt area or after harvesting the rice.

Harvesting of the crops commences with maize in June/July, followed by rice in July/September and then the other crops according to maturity.

7.1.3 Village Farms

The amount of village farm activity is dependent on the availability of labour, after meeting the requirements of the upland rice farm. Clearing of swamps for rice is carried out by men but all other activities, such as broadcasting the seed and harvesting, are the responsibility of women. No land levelling is done. Swamp rice production is considered to be mainly a women's task and the crop is often sold to provide cash for household purchases. Some swamp rice is inter-cropped with maize and cassava planted on higher ground.

Coffee and cocoa are the two principal cash crops. The produce is sold for cash to traders or cooperatives. The trees are underbrushed once or twice a year.

Other crops such as plantain, banana, kola, citrus, sugar cane, pineapple and vegetables are cultivated according to individual preferences, but are not considered as important cash crops due to low demand. No rubber and very little oil palm are cultivated in the areas studied.

7.1.4 Labour

Grand Gedeh has the sixth largest county population in Liberia, estimated at 72,000 in 1974 (Ministry of Planning, 1977), with 83% of the working population occupied in agriculture. The working population is considered to be 30% of the total population.

Since 1980 there has been a steady emigration of working people and their dependants to Monrovia to take up positions within the armed forces and the Government. As a result, there is a shortage of labour both within families and for hire. In addition, the local demand for food produce has declined. Labour rates are about L$2-2.50 per day which is higher than most farmers can afford. Some farmers hire labour for underbrushing of cocoa and payment is by piece work.

A farmer has an average of about 1.75-2.0 family labour units available, with the number of wives representing his principal labour asset. Although a farmer may have a large family, the children can assist only during the long school holidays. As the children grow up, they either seek jobs in Monrovia or get married and thus are not available to assist with the family farm. Children are used mainly for bird scaring on the rice farms and harvesting. Generally, a farmer can provide labour for a 0.75-1.5 ha (1.8-3.7 acre) upland farm and for a small village cocoa farm. Estimates of actual man days labour required per crop are given in Table 7.1.

TABLE 7.1: ESTIMATE OF ACTUAL MAN DAYS LABOUR BY CROP

	Man days ha^{-1}	Principal Activities
Upland Rice	150-200	Land Clearing, Harvest
Swamp Rice (traditional)	80-100	Land Clearing, Harvest
Irrigated Rice 1st Year (swamp development)	150-200	Land Clearing, Harvest
Irrigated Rice 5th Year	100-150	Land Preparation, Harvest
Coffee	10- 20	Underbrushing, Harvest
Cocoa	5- 15	Underbrushing, Harvest

There is no established system of communal labour (kuu) as practised in Bong and Nimba counties, whereby farmers assist each other in return for similar services. Often, however, villagers will cultivate a plot of land with rice using communal labour but the proceeds are used for village festivities or to buy materials for construction of a village hall or storage shed.

7.2 UPLAND RICE

7.2.1 Husbandry

The upland farm is prepared by family labour in January to April. A good burn of the felled trees and bush is essential to ensure adequate weed control, wood ash for supply of nutrients and easy access for planting and harvesting. Weed control is most effective when the burning period is close to the start of the wet season and planting. A metal tipped dibble stick is used to plant rice, often mixed with maize, during April to June.

Local rice varieties are used. These tend to be medium to long strawed and reach maturity in 4-5 months. No farmers indicated knowledge of the availability of improved rice varieties (such as LAC 23) which are widely used in Nimba and Bong Counties. There is a strong preference for the use of local varieties because of taste, when compared to imported rice. For planting, farmers use their own seed, which is stored in the rice kitchen along with the rice for consumption. Often, due to the demand of seed rice for planting, farmers run short of rice for eating and may plant a small area of the upland farm with a short maturing local variety.

Weeding of the rice crop is seldom practised. Where sowing is delayed after clearing and burning, weeding will be carried out by family labour if necessary. Occasionally, a fence is constructed around the upland rice to prevent damage from the ground hog but more often, an additional area of land is cropped to compensate for the loss. Bird scaring is carried out during the heading period of rice, but often bird damage is just accepted.

Harvesting takes place in July to October depending on the time of planting, and is carried out by all available family labour. A small serrated edge knife is used for harvesting the heads of rice, which are then dried in the fields or carried to the rice kitchens in the village for drying and storing in the thatched storage area above the cooking area. The heat from the charcoal fires dries the seed and the smoke helps reduce pest damage. As harvesting by hand is time consuming, losses occur due to shattering as the grains dry out and as the panicles are carried to the rice kitchens.

Yields are variable and influenced by the amount of inter-cropping and the accessibility of field areas, which affects the standard of clearing and burning. Rice yields are generally about 1,100 kg ha^{-1} (1,000 lbs per acre) excluding the yield of the inter-crops.

Threshing and dehusking is carried out by pestle and mortar. Outside of Zwedru, there are no mechanised (pedal) thresher or rice mills. Farmers in the Work and See Cooperative in Zwedru have access to a pedal thresher and within Zwedru there are three diesel operated rice mills. The panicles of rice are generally threshed and milled as required. Parboiling of rice is practised by some women as it is recognised as improving the milling quality and is considered to satisfy the appetite more.

7.2.2 Pests and Diseases

Major pests are groundhogs and birds. Groundhog damage is reported to be reduced by fencing the rice farm or by the presence of a dog. Generally, an extra area is planted to compensate for damage. Bird damage occurs more in the earliest maturing rice farms and those closer to the villages. Several farmers expressed interest in purchasing nets to catch the birds but control is presently effected by the use of sling-shots or tin rattles.

The most important plant disease is Blast (Pyricularia oryzae), with lower incidences of Brown Spot (Helminthosporium oryzae), Leaf Scald (Rhynchosporium oryzae) and glume discolouration (various fungi).

Grain losses occur during storage in the rice kitchens due to rats and insects. Some control of rats could be achieved by placing metal strips around the supporting poles of the rice kitchen to prevent rats climbing up. Storage losses are estimated at 10-15 per cent.

7.2.3 Improvement Potential

Yields of rice could be improved by the use of CARI recommended upland rice variety, LAC 23. A good burn of the felled trees during land preparation and weeding of rice during the early growth stages, also assist in increasing the yield.

Yields at CARI during trials in 1983/84 were 2,720 kg ha^{-1} for LAC 23, while some of the new lines yielded up to 3,800 kg ha^{-1}. Yields of 1,500 kg ha^{-1} of LAC 23 are being achieved by outgrowers of the Smallholder Rice Seed Project in Bong County, but these include use of a recommended package of fertilizers and chemicals and provision of credit. Details are given in Appendix C.

The groundhog is reported to cause more damage to rice intercropped with cassava and therefore the benefits of growing these crops separately should be investigated. Other methods for control of the groundhog, through knowledge of its habitats or breeding cycle, should be explored.

7.3 CASSAVA

7.3.1 Husbandry

Cassava is either inter-cropped with upland rice or cultivated in pure stands on specially prepared and fenced fields.

Cassava grows well in low fertility soils and can be kept stored in the ground for up to one year. When cassava is inter-cropped, it is planted 4-6 weeks after the rice, generally in the spaces where rice plants have failed or near unburnt tree trunks and branches. Pure stands of cassava are about 0.4-0.6 ha (1-1.5 acres) and often closely fenced with branches, bamboo or wood stakes to keep out pests like groundhog and porcupine.

Cuttings of cassava are planted in shallow trenches at a density of two to three cuttings per metre. A short duration cassava crop will be weeded once, whereas an eight month crop may be weeded twice. Only local varieties are used as the farmers are unaware of the CARI improved varieties.

Harvesting takes place from April onwards depending on the farmers' needs for food or cash. Cassava is sold either as fresh tubers or as sun dried pieces. Yields are reported to be about 4,500 kg ha^{-1}, but are very dependant on the amount of intercropping and pest damage. Cassava leaves are picked and eaten as a green vegetable.

7.3.2 Pests and Diseases

Groundhogs and porcupines are the principal pests. Cassava mosaic is the main plant disease: yields are substantially reduced by its occurrence.

7.3.3 Improvement Potential

The cassava varieties, CARICASS 1, 2 and 3, which have been developed at CARI, should be introduced to the farmers in Grand Gedeh. These varieties are resistant to cassava mosaic and cassava bacterial blight and yielded, under trials, some 20,000 kg ha^{-1} without fertilizer. A few years ago an attempt was made to grow CARICASS 1, 2 and 3 in Zlehtown for local distribution, but was not followed up by either CARI or the Ministry of Agriculture.

CARICASS 1, 2 and 3 have been distributed in Bassa, Nimba and Bong Counties and are being multiplied up by various projects for further distribution to farmers. Although farmers quite like the quality of the improved varieties, they apparently do not keep the stems to make cuttings for replanting. This is hindering the further distribution, as new cuttings have to be supplied each year. One possible explanation is the lapse of time between harvest in April/May and planting in August to October after the rice crop. Cassava cuttings do not germinate well if kept for longer than 45 days. Work is being carried out at CARI to identify varieties with good inherent keeping characteristics so that a farmer can obtain good germination after a lengthy period of storage in the field.

7.4 IRRIGATED RICE

7.4.1 Introduction

Rice that is grown in roughly cleared, unlevelled, swamps is referred to as "swamp rice". It is not widely cultivated in Grand Gedeh County and is therefore not discussed further. Irrigated rice, which is referred to locally as "improved swamp rice", is cultivated in plots where the land has been levelled and where some degree of water control exists. The plots, which measure approximately 30m by 40m, are separated by bunds and have a water channel nearby to serve for irrigation and/or drainage.

Irrigated rice is grown on 100 ha (250 acres) of levelled swamp on the south side of Zwedru. Water control is effected through a series of channels and ditches. There is no water storage, but the rainfall run-off from the surrounding areas is sufficient to successfully grow rice from April to November on the puddled soils.

At Zlehtown, irrigated rice is being grown on 2 ha (5 acre) using a dammed stream to raise the height of water for command and storage during the dry season. Irrigated rice has been grown at Saye Dube Research Sub-station and at a cleared swamp south of Zlehtown, which was established through external technical assistance.

The development history of the Zwedru swamp is interesting as it is now successfully cultivated after an initial poor beginning. It also demonstrates that any swamp rice development programme should be of 7-10 years duration and include an ongoing participation to maintain its impetus. It is briefly summarised as follows:

1973 - Land cleared and levelled mechanically through externally funded project.

- Formation of "Work and See Cooperative".

1977-80 - Gradual decline in number of farmers cultivating rice.

1980-82 - Additional external technical assistance.

- Provision of power tiller and pedal thresher.

- Additional land cleared by farmers themselves.

- Loan from Agricultural Cooperative Development Bank to Work and See Cooperative misused.

1986 - Most land (100 ha) used for irrigated rice production from April to November.

- One farmer growing two crops rice per year.

- Work and See Cooperative membership rises to 250, with joining fee at L$21 (1973 - L$6.25).

- Cooperative provide Field Manager to ensure members maintain and clean their water channels.

7.4.2 Husbandry

The rice plots are weeded and prepared by hand in March and April. Weed growth is considerable and weeding or turning in the soil before flooding is a major task. Some farmers in Zwedru hire a tractor and disc plough at L$50 ha^{-1} plus fuel and subsistence for the driver.

Rice is generally transplanted or broadcast from April onwards, which is the beginning of the rainy season. One farmer at Zwedru had transplanted rice in February and was expecting to grow two crops in 1986. Transplanted rice is not planted in rows as it is considered too time consuming and to be of little benefit when weeding by hand. Often rice is transplanted too late when it is over 25 days old: this increases the period for adjustment and reduces the amount of tillers, with consequent reduction in yield.

Improved varieties of rice released by CARI are not used and are not readily available to farmers, although one farmer claimed to use IR5. Often the same upland rice variety is used for irrigated rice. Fertilizers and chemicals are not generally used, although one farmer claimed to have used one bag in 1973 and another farmer purchased two bags in 1984.

Weeding is either carried out once or twice, depending on whether there has been sufficient rainfall run-off to maintain adequate water depth in the plot for weed control. All weeding is by hand and carried out by the women and older children.

Rice is harvested by use of a hand held serrated knife. In Zwedru the rice is either threshed by the Cooperative pedal thresher and stored in sacks at the house, or stored on the panicle in the rice kitchen. Yields of unimproved varieties of rice with no fertilizer are estimated at 1,500 kg ha^{-1}. Improved varieties of rice, such as IR5, Suakoko 8 and BG90-2, are reported to yield 2,000-2,500 kg ha^{-1} with no fertilizer, but within the first three years of clearing the land. Where improved varieties of rice are grown each year in the absence of any fertilizer, yields are estimated at 1,500-2,000 kg ha^{-1}.

The rice plots should be drained 10-20 days before harvest to ensure even grain maturing and to facilitate access for harvesting. The panicles or grains are dried on concrete slabs or in the rice kitchen. A moisture content of 13-14 per cent is desirable for storage and milling.

7.4.3 Pests and Diseases

Principal pests are rats and birds. Bird scaring is carried out by women and children using tin rattles or slingshots. Some farmers have expressed an interest in using bird nets which has proved reasonably successful in Nimba and Bong County. Bird nets cost L$15-30 depending on length. Stem borers (*Tryporiza, Chilo, Sesamia* spp.) cause damage to stems and result in white heads.

Plant diseases are basically confined to Blast (Pyriculana oryzae), Leaf Scald (Rhynchosporium oryzae) and Brown Spot (Helminthosporium oryzae). The various rice varieties exhibit different degrees of tolerance to these diseases. Researchers at CARI are evaluating the disease tolerance of promising new rice varieties.

7.4.4 Improvement Potential

The concept of developing swamps for high yield rice production is sound. However, many factors will need to change and new methods will need to be introduced together with improved support from the Government. These changes should ultimately result in a new method of cultivation which could make Liberia self-sufficient in rice.

For high yields of rice, the following factors are required:

- use of high yielding, disease resistant varieties
- adequate water supply and control
- adequate supply of fertilizer and chemicals
- adequate planting density
- high solar radiation.

Factors that prevent yield increases are diverse, but can be summarised as:

- insects and plant diseases
- damage by rodents
- weeds
- shortage of water or lack of control
- adverse soils and temperatures
- shortage of labour
- shortage of inputs
- lack of farmer motivation.

These factors are considered in detail in relation to improving rice productivity:-

a) Rice Varieties and Yields

CARI has selected and developed several different rice varieties resulting from a breeding programme between 1973 to 1979. The characteristics of the varieties Suakoko 8, Suakoko 10, Suakoko 12 and IR5 are given in Appendix C. These varieties all exhibit some disease resistance and tolerance to iron toxicity. Suakoko 8 and 10 perform well on soils with marginal fertility, whereas Suakoko 12 performs better under well managed conditions. All varieties respond well to fertilizer.

BG90-2 is a variety with increasing demand in Bong County and is grown on the Chinese Farm at Katapwee. It is proposed to multiply up seed for this variety through the Smallholder Rice Seed Project. It is moderately tolerant to iron toxicity, highly tolerant to zinc deficiency, but moderately susceptible to Blast disease. It performs well under good management and responds to fertilizer.

Immediate yield increases could be obtained if the most suitable of these varieties were distributed to farmers in Grand Gedeh County. Iron toxicity is a potential problem and it is likely that most of the local varieties used are not as tolerant as those recommended by CARI. IR5, although high yielding, is susceptible to iron toxicity and is not readily acceptable to the people due to it stickiness after cooking.

Current irrigated rice yields are estimated at about 2,000 kg ha^{-1}. Ranges in yield potential, according to location, variety and input are given in Table 7.2.

The two most important factors affecting rice yield are water and fertilizer. It is reported (Yoshida & Oka, 1982) that, assuming all other factors are equal, the yield of rice is proportional to the amount of nitrogen absorbed by the crop. Absorption rates vary according to soil type, timing, amount applied and management practices, but is between 30-50 per cent N applied. Long term experiments indicate that 50 kg N ha^{-1} per crop needs to be applied to achieve a consistent yield of 2.5t ha. Table 7.2 indicates the yield of rice under varying conditions and it is evident that to achieve yields in excess of 2t ha^{-1}, fertilizer should be applied.

Yoshida and Oka (1982) also cite solar radiation as an important yield factor: 300 cal cm^{-2} day^{-1} is considered to be required during the wet season for a potential yield of 9.5t ha^{-1}. During the dry season a solar radiation of 500 cal cm^{-2} day^{-1} is required for a potential yield of 16t ha^{-1}. Solar radiation in Grand Gedeh County is between 400 to 500 cal cm^{-2} day^{-1} over the course of a year, and therefore is probably not a constraint.

b) Husbandry

Poor water control will cause flooding and damage to the crop. A good drainage system will assist greatly in reducing localised flooding. However, as the surrounding forest cover is removed through slash and burn techniques, rainfall run-off will probably increase and, consequently, the likelihood of flooding.

TABLE 7.2: RICE YIELDS

Location	Variety	Inputs/Management	Yield ('000 kg ha^{-1})
Liberia	Suakoko 8	No fertilizer, chemicals	3*
Liberia	Suakoko 8	Fertilizer, good management	4-5*
Liberia	Suakoko 12, BG90-2	Fertilizer, good management	6*
Lofa County	IR5,Suakoko 8	Fertilizer, good management	4
Lofa County	IR5,Suakoko 8	No fertilizer	2
Bong County	IR5	200 MOP, 200 NPK, Urea, TSP	4
Bong County	Suakoko 8	200 MOP, 200 NPK, Urea, TSP	2-3
Bong County	BG90-2	No fertilizer	2
Nimba County	Suakoko 8	No fertilizer	2
Nimba County	IR5	First year crop	5
Grand Gedeh	IR5	Occasional fertilizer	3
The Gambia	IR34-450-1, BG90-2	Fertilizer, chemicals 1st year	7
Ivory Coast	SE349D, IR5	Fertilizer, chemicals	5-6
Ivory Coast	Bouake 189	150 NPK (10:18:18) 75 Urea, Chemicals	4-5
CARI Liberia	New Varietal Trials	Good management	6-8
India	Max. experi-mental yield	Good management	17.8

*Indicative potential yield.

MOP - Muriate of Potash
NPK - Nitrogen: Phosphorus: Potassium
TSP - Triple Superphosphate

Rice seedlings for transplanting should be grown in a nursery measuring 1/20 or 1/25 of the area to be planted. A seed rate of about 40 kg ha^{-1} is required. The seedlings should be transplanted at around 21 days, with 2 seedlings per hill at 10cm spacing giving an adequate plant density. Weed growth is reduced by flooding to allow the transplanted seedlings to outgrow the weeds. It is especially important to weed rice during the early growth stages to obtain high yields.

Chemicals are required to control weeds and insects. The rice varieties used should be resistant or tolerant to the major diseases. The Smallholder Rice Seed Project supplies the following chemicals to its outgrowers: Furadon, Malathion, Dieldrin, Ficam, MCPA, Grammaxone, Round-up and Propanil. In the Ivory Coast, it is recommended that farmers apply two applications of Propanil and 2.4D at 6 litres and 1 litre ha^{-1}, respectively, and 14 kg/ha Furadon at 21 and 45 days after planting (BETPA 1980).

The Brown Plant Hopper (Nilaparvata lugens) has caused significant rice losses in all the Far East countries, India and Sri Lanka. The insect also transmits two viruses (grassy stunt and ragged stunt virus) which reduce yield. Although the Brown Plant Hopper is presently unknown in Liberia, it represents a great potential danger to any rice development programme. IR5 is susceptible to both the insect and the viruses.

Late harvesting can cause grain losses due to shattering and additional pest losses. In work carried out by CARI, it was found that a five to ten day delay in harvesting could result in 5-10 per cent losses. Harvesting should therefore be carried out promptly and quickly when the crop is ready.

Losses during storage will depend on grain moisture, length of storage and method, but are estimated at about 10 per cent. The practice of par-boiling rice should be encouraged as it reduces breakage from milling, increases insect resistance and improves nutrient value and taste. Parboiled rice should be dried to 14 per cent and milled soon after drying. Rice stored in metal bins or in rice kitchens supported on wooden stakes with strips of metal around them, will suffer less from rodent damage.

Double cropping of rice during the wet season is considered feasible if short maturing varieties are used and adequate fertilizers and chemicals, together with extension advice, are provided. Varieties such as BG90-2 and PR103 mature in 110 days which would mean 20 days in the nursery and 90 days in the field. For double cropping, a timely programme of management is required and advantage would be taken of the relatively low rainfall in August for harvesting the first crop and planting the second. The sequence of events recommended for double cropping would be as shown in Table 7.3.

TABLE 7.3: RECOMMENDED SEQUENCE FOR DOUBLE-CROPPED RICE

Month	1st Crop Activity	2nd Crop Activity
April (mid)	Sow rice nursery Fertilize	
May (early-end)	Transplant Apply Insecticide/ Herbicide Weed	
June	Apply Insecticide/ Herbicide Fertilizer	
July (mid)	Drain land	
August (early, mid, late)	Harvest Dry, store grain	Sow rice nursery Prepare land Fertilize
September (early-end)		Transplant Apply Insecticide/ Herbicide Weed
October		Apply Insecticide/ Herbicide/ Fertilizer
November (mid)		Drain land
December (early, mid end)		Harvest Dry, store grain Plant, short term vegetables & legumes

Single cropping of irrigated rice should produce enough rice for subsistence needs and double cropping will produce a surplus for sale. Considerably less land will be required for the upland rice farm, as only cassava and certain other crops will be cultivated. Therefore, labour will be released for irrigated rice production. The change-over will be a gradual process but will result in better labour utilisation.

Draught animals for ploughing and land levelling are widely used in the Far East and India and recently trials have been conducted at CARI using N'Dama cattle. Although these animals are relatively small in stature, a pair of oxen could plough 0.3-0.4 ha (0.7-1.0 acre) of cleared, irrigated land per day. Ploughing was to a depth of 15-20cm (6-8 in) and a day was 4.5 hours. The oxen can also be used for harrowing, puddling and land levelling. The initial results are encouraging and further work should be carried out at farmer level to determine the acceptability of this cultivation method. The alternative method to reduce labour for cultivation is to use small, two wheel tractors. Where these have been introduced in the past, they have quickly broken down due to poor operational standards, lack of maintenance and poor availability of spare parts.

c) Labour and Motivation

There is currently a shortage of family labour and a lack of cash to pay for hired labour. Rice is considered a subsistence crop and irrigated rice production is a new and unknown system to most farmers.

Various labour saving techniques could be introduced, as follows:

- use of chain saws for tree felling
- use of draught oxen for ploughing, harrowing and levelling
- use of 4-wheel drive tractors through a Government hire scheme
- use of pedal threshers and winnowing machines
- introduction of rice milling facilities in areas distant from Zwedru
- improved roads and communications to facilitate transportation and marketing of produce.

To encourage irrigated rice production through swamp development, the farmer needs to be given adequate incentive and support from the Extension department of the Ministry of Agriculture. Current yields and prices of paddy rice provide little incentive to produce quantities in excess of subsistence requirements. To provide motivation to the farmer, a development programme involving farmer participation is required. Items in such a programme should include:

- involvement and financial commitment in time or money by farmers during swamp clearing and development

- provision of adequate technical assistance and extension advice to farmer

- provision of improved rice seed, fertilizer and chemicals at subsidised prices

- a higher guaranteed purchase price and improved marketing system for paddy rice

- encouragement and technical advice on double-cropping of rice, which should provide additional cash incentive to farmers.

7.5 COCOA

7.5.1 Husbandry

Farmers plant either local (Amazonas) varieties or seedlings or varieties imported from Ivory Coast and supplied by Liberian Cocoa and Coffee Corporation (LCCC) or Liberian Produce Marketing Corporation (LPMC). It is reported that the Amazonas cocoa is more tolerant to drought, poor soils and disease such as black pod and capsid damage than the Ivory Coast cocoa. The yield of local cocoa varieties is about 250-300kg ha^{-1}, whereas Ivory Coast varieties under reasonable management, yield 800kg ha^{-1}. These facts were supported by discussions with farmers and by field observation.

Cocoa plantings range in age from 5 to 30 years but the majority had been established for 15 to 20 years. Spacing between the trees varies considerably, even within a farm, but was on average 2.0 by 2.5m. The shade trees left to protect the young cocoa seedlings are usually allowed to continue growing in the fear that felling trees will damage the cocoa bushes. Most mature plantings are therefore heavily over-shaded.

Underbrushing takes place when surplus labour is available which is generally after completion of work on the upland rice farm (March to May). Most cocoa farms are poorly maintained and there was little evidence of underbrushing.

Harvesting takes place in October to December. The lower pods are picked by hand, the higher ones being knocked down by a stick: knives are not used. The number of pods harvested per tree is very variable, ranging from 5 to 20, although some farmers claimed to harvest 50 to 80 pods. After harvest the pods are left to dry for two to six days and then broken open. The beans are put into heaps, completely covered by banana leaves and left to ferment for three to six days. Occasionally they are turned after a few days. The fermented beans are then dried in the sun for three to seven days and stored until sold either to a Mandingo trader or through the local cooperative. Reported prices paid to farmers were L$0.44-0.66 kg^{-1} (L$0.20-0.30 per lb) from traders who visit the villages and L$0.88 kg^{-1} (L$0.40 per lb) from village cooperatives who sell to the LPMC in Monrovia. Transport costs are refunded by the LPMC.

7.5.2 Pest and Diseases

The main disease of cocoa is Black Pod caused by Phytophthora palmivora L. Losses are severe and between 50-70 per cent of the crop is presently being lost. The farmer is generally unaware of any preventive measures. Black Pod disease starts to spread at the beginning of the wet season when temperatures are low and humidity is high. A dry period in August will temporarily halt the spread of the disease but such a period seldom occurs in Grand Gedeh County. Some control can be effected by use of copper-based fungicides but recent research indicates that root infections play an important part in the annual cycle of the fungus. Certain husbandry practices can be introduced to reduce the incidence of Black Pod, such as:-

- Removal of infected pods from all trees and either burning or burying pods in the ground away from the cocoa trees.
- Improved spacing between trees (3m by 3m) to allow movement of air.
- Reduction or removal of shade trees in mature cocoa farms to permit more sunlight to penetrate the cocoa canopy.
- More frequent underbrushing of undergrowth.
- Establishment of a 5m (16ft) wide area, cleared of all trees and undergrowth around the perimeter of the cocoa plantation.
- Removal of kola and rubber trees from within the cocoa plantation. The kola tree is possibly an alternative host for the Black Pod fungus. Black Stripe and Leaf Blight of rubber trees are also caused by Phytophthera palmivora L.

Other important pests of cocoa are the capsids or mirids (Salbergella singularis L. and Distantiella theobramae L). They attack the young shoots, which delays development or kills the young plants. In mature trees there is loss of leaf and exposure of the soil to sunlight which causes rapid weed growth and subsequent weakening of the tree. Control can be achieved through use of Lindane (gamma HCH).

Other pests are those that damage the trees and pod such as deer, squirrel, racoon and ants. Several trees were observed with large growths of a red-flowered parasitic plant towards the end of the branches. These should be removed.

The use of chemicals such as Dieldrin, Dithane and Pyrenox would be most beneficial. However, there are problems with supply, availability of cash and misuse of such chemicals.

7.5.3 Improvement Potential

The principal opportunities for improvement of cocoa can be summarized as follows:

- Selection of more suitable soils for cocoa which have at least one metre of non-gravelly soil.
- Spacing of seedlings 3.0m x 3.0m.
- Reduction of shade trees as cocoa bushes mature.
- Use of plantain or banana as shade for seedlings.
- Improved husbandry practices to remove dead wood and parasitic growths from the trees, reduce weed undergrowth, and use of a knife to remove pods at harvest.
- Improved husbandry practices for better control of Black Pod disease (Section 7.5.2).
- Improved fermentation practices to produce better quality beans.
- Introduction of differential price structure for beans so that a premium can be paid for quality beans.
- Improved storage conditions at village level and bulk selling of beans through the village cooperative or farmer development association direct to the LPMC.

7.6 COFFEE

7.6.1 Husbandry

Little coffee is grown in the areas covered by the study. Robusta is the principal type grown but some Liberica coffee was observed. Coffee is generally planted on the poorer soils that are not considered deep enough for cocoa.

Coffee seedlings for planting have been, in the past, obtained either as seed from the Ivory Coast or local farms, or as seedlings from the LCCC or LPMC. The seedlings are generally spaced about 2m apart so that a good canopy is formed to reduce weed growth. No pruning is carried out nor is the main stem bent over to encourage lateral growth and more main branches to pick from. The absence of these practices, coupled with severe over-shading result in tall, spindly coffee bushes.

Underbrushing is recognised to be necessary two or three times per year but in practice, one underbrushing is done. It is not clear whether this reflects the low returns on coffee or a real shortage of labour.

Harvesting generally takes place in November to December. The cherries are harvested in one or two pickings with red and green cherries being picked together. As there is no payment for quality there is no incentive for the farmer to produce quality beans. The cherries are dried in the sun for about seven days and then stored until sold to a Mandingo trader. Reported prices paid to farmers were L$0.33-0.44 kg^{-1} (L$0.15-0.20 per lb). None of the coffee is sold as beans by the farmer.

7.6.2 Pests and Diseases

Farmers mentioned few disease or pest problems with coffee. Red ants were reported to make harvesting difficult and termites were observed to be attacking dead and live wood on trees where maintenance was poor. Damage to new shoots was observed, which is probably caused by the Coffee Stem Borer (*Bixadus sierricola*).

7.6.3 Improvement Potential

Husbandry practices should be improved, particlarly those relating to pruning and underbrushing. The amount of shading should be drastically reduced and farmers should be encouraged to plant coffee using plantain and banana to provide initial shade.

A differential payment for quality cherries should be introduced to encourage farmers to harvest a greater percentage of ripe cherries.

7.7 OTHER CROPS

7.7.1 Annual Crops

Many other crops are grown in small amounts and used to supplement the principal crops discussed in previous sections.

Small, scattered plantings of pineapples occur near the villages and along tracks to the upland rice farms. Sugar cane is grown only around Fishtown, where it is used to make cane alcohol which sells at L$7 per gallon. Tobacco was found on one farm near Fishtown, and used by the farmer for his own consumption.

Beans were observed growing by the village of Jaybo on the road to John David Town but were not seen elsewhere. Okra, eggplant, bitterball and chilli pepper are grown widely and found near villages or scattered amongst the crops of the upland rice farm.

Cocoyam and sweet potato are extensively grown but generally in small plots close to the villages.

7.7.2 Tree Crops

A wide variety of tree crops are grown but usually as individual trees scattered around the village or mixed with the cocoa plantings.

Kola trees are often found growing mixed with cocoa bushes. Surplus kola nuts are occasionally sold. Citrus are grown close to village houses and most of the fruit is consumed by the families. Some oranges are sold but this is during the harvest period when there is a surplus.

Banana and plantain are grown by villagers as food crops and used as shade for cocoa seedlings. Plantains are preferred to banana due to their longer keeping qualities.

Mango trees are plentiful and scattered papaya and avocado trees are found throughout the village lands.

7.7.3 Improvement Potential

A need is seen for greater diversification of crops to improve nutritional standards and to reduce risks due to failure of individual crops.

Greater emphasis should be given to cultivating legumes (such as beans) due to their nutritional qualities, usefulness as a break crop and nitrogen fixing abilities. Unfortunately, beans do not form part of the staple diet and demand is low. Lima, soya beans and black eye peas have given promising results on trials using them as a cover crop with young rubber trees.

The cultivation of groundnuts should be encouraged as there is a reasonable local demand, but none were seen growing.

Citrus crops offer good potential but grafted citrus seedlings should be used so that fruit is produced earlier. The full development potential for citrus is dependant on the establishment of small juice and canning industries at town level.

The potential for new crops remains to be assessed: available resources will be best utilized by improving cultivation of existing crops. However, one crop that should be considered is the spice, black pepper(Piper nigrum L). It is widely grown in Malaysia, Indonesia, India and to a lesser extent in Brazil, Ivory Coast and the Malagasy Republic. The most serious disease of pepper is Foot Rot, Phytophthora palmivora L. which also causes Black Pod disease in cocoa and Black Stripe disease in rubber. Careful consideration should be given to this crop but root rot resistant stocks should be used. In addition to the crop husbandry practices, the marketing aspects and the demand within Liberia and for export should be assessed to determine the economic feasibility of production.

7.8 CROP WATER REQUIREMENTS

7.8.1 Rice

Rice yields are higher under flooded conditions due to control of non-aquatic weeds, improved availability of nutrients, lack of water stress and disease control. For optimum yield a water depth of 10cm is required although good yields should be obtainable with water depth varying between 5-15cm.

Water stress, which can be broadly defined as 50 per cent depletion of available water in the soil, causes reduction in yield. The most critical period is during the reproductive phase when panicle initiation and development occurs. Another, but less critical period for water stress is the vegetative phase when tillering occurs.

When the swamps are developed for irrigated rice production there will be a certain amount of water control provided through the irrigation and drainage ditches. Although there will be little or no water storage at the head of the swamps, rainfall runoff from the surrounding areas is anticipated to be adequate to supplement any shortfalls in water availability for maintaining a flooded rice field.

Water requirements have been calculated in two stages, to demonstrate that rainfall alone is adequate to grow rice without causing water stress and that only a limited amount of supplementary irrigation will be required to maintain a flood depth of 5-10cm.

The crop cultivation calender for two crops of rice in the wet season (Section 7.4.4) is as follows:

1st Crop	Seed bed	mid-April
	Transplant	early May
	Harvest	early August
2nd Crop	Seed bed	mid-August
	Transplant	early September
	Harvest	early/mid-December

Mean monthly rainfall values for Zwedru have been used. It is assumed that only 80 per cent of the rainfall is effective, as some will be lost to evaporation and some will overtop the 10cm field bunds.

Reference crop evapotranspiration values (ETo) have been taken from Table 5.4 for April to December and appropriate crop coefficients (kc) used (FAO, 1977). Evapotranspiration values for rice and overall water requirements, including deep percolation losses are given in Table 7.4.

TABLE 7.4: WATER REQUIREMENTS FOR RICE(mm)

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo mm/mth	120	120	108	107	113	112	119	108	108
Crop Coeff.kc	-	1.1	1.07	1.0	0.95*	1.1	1.07	1.0	0.95*
Crop Requirement	0	132	116	107	54	123	128	108	51
Pre-Plant Water	100								
Effective Rainfall	151	163	217	149	128	279	226	100	48*
Difference (mm)	+51	+31	+101	+42	+74	+156	+98	- 8	-27
Pre-Plant Flood		50				100			
Percolation	60	60	60	60	0	60	60	60	0
Water Deficit (mm)	9	79	(41)	18	(74)	4	(38)	54	27

* Reduce by 0.50 to give water requirement/rainfall for half month
() Indicates surplus water to monthly requirement.

Table 7.4 shows that there is more than sufficient rainfall to grow rice without water stress if pre-plant flooding requirements and deep percolation losses are not taken into account. There is a small deficit shown for November and December, but this is the period when the field will be drained and the rice will be using up the available soil moisture.

A pre-plant flood requirement of 50mm and 100mm has been provided for during the months of May and September when the rice is transplanted. Deep percolation losses will vary according to swamp and the amount and effectiveness of soil puddling. A percolation rate of 2mm day^{-1} has been assumed for all months except those when the field is drained for harvest. A bund height of 10cm has been assumed which will therefore allow a flood depth of up to 10cm which will in practice fluctuate according to rainfall distribution within the month.

The shortage of water in May should cause only a fluctuation in the flood depth level and should be compensated for by diversion of rainfall runoff from the surrounding areas into the irrigation channels. The other deficits in April, July and September are very small and will be made up by fluctuations in rainfall distribution and/or by use of rainfall runoff from surrounding areas. The small water shortage in July occurs when the field is likely to start being drained-down for harvest in early August.

Similar calculations have been carried out using rainfall data from Firestone Cavalla: the overall potential water deficits are slightly smaller as the rainfall is greater.

7.8.2 Coffee and Cocoa

Coffee and cocoa both have similar water requirements and similar crop factors (kc) can be used (FAO, 1977). A crop factor of 1.1 has been used, assuming use of shade trees, but allowing for significant weed growth under the bushes. If shade is removed and the crop is clean cultivated (no weed growth) the crop factor can be reduced to 0.9. Water reqirements for coffee and cocoa are given in Table 7.5.

Potential deficits occur in five consecutive months from November through to March with the largest deficits being in December, January and February. Generally, the readily available soil moisture will be sufficient for the crops to avoid severe water stress during November and December. From February to March the crops are likely to suffer from water stress but as both crops are harvested in October to December, this is unlikely to have a major effect on future yield.

The importance of selecting deep, non-gravelly soils for coffee and cocoa is emphasised by these observations so as to ensure adequate soil moisture is available to the crop during the dry periods. Soils with less than 100cm and 50cm of gravel-free topsoil are considered unsuitable for cocoa and coffee, respectively. The necessity of maintaining minimal undergrowth and minimal or no shade, is again emphasised as a means of reducing water loss. As mentioned earlier, absence of shade and clean cultivation reduces water requirements by some 18 per cent.

TABLE 7.5: WATER REQUIREMENTS FOR COFFEE AND COCOA(mm)

	Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo	116	114	126	120	120	108	107	113	112	119	108	108
kc	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Crop Requirement	128	125	139	132	132	119	118	124	123	131	119	119
Effective Rainfall	15	44	83	132	143	190	130	112	244	197	88	42
Water Deficit (Surplus)	113	81	56	0	(11)	(71)	(12)	12	(121)	(66)	31	77

Mean rainfall data for Zwedru have been used and it was assumed that 70 percent was effective.

7.9 MARKETING AND PROCESSING

7.9.1 Rice

All the rice produced in Grand Gedeh County is consumed by the local population. Some local rice is sold in the market to raise cash for household necessities, but generally farmers grow only enough for subsistence needs. Most of the rice seen for sale in the market was imported rice from either the USA or Indonesia.

The official price for paddy rice is L\$0.33 kg^{-1} (L\$0.15 per lb) but a farmer selling to a trader will receive only L\$0.17-0.22 kg^{-1} (L\$0.08-10 per lb). The trader allows a margin of 11-16 cents kg^{-1} for transport and profit. The low price paid to the farmer provides little incentive to grow rice in excess of his own requirements.

Three rice mills are operating in Zwedru. These are thought to be the only mills within the whole County. A fixed charge of L\$3.0 is payable to produce 45 kg (100 lbs) of milled rice. The mills are Lewis Grant M1-8B type, belt driven by a 13-15 hp diesel engine. A milling percentage of 60 per cent is generally accepted, however, the percentage obtained by the Zwedru mills was probably between 50-55 percent. The milled rice contains considerable broken grains and women sieve the rice husks to extract these. The high percentage of broken grains is probably due to the mill plate being worn and set too close, in addition to the rice possibly being of incorrect moisture content and of a type difficult to mill. A moisture content of between 13-14 percent is required for milling. The discarded rice husks do not appear to be used, although they may have value as chicken feed.

Transporting rice to Zwedru for milling can be an expensive and time-consuming task for farmers, often involving many hours of walking or the hire of local taxi services. Encouragement and financial assistance should be given for the establishment of milling facilities in Fishtown or Tuobo Gbawelekehn, so as to reduce travelling times.

Clean rice is sold in the Zwedru market for L0.25t^{-1}$, which represents a price of L$0.65 kg^{-1} (L$0.295 per lb). The same price applies for local or imported rice and although there were reported rice shortages during the study period, the price remained constant.

Imported rice is bought for L$22.50 per 100 lb bag in Monrovia and sold for L$27 in Zwedru. Transport costs amount to L$2-2.50 per bag.

These figures indicate that a market trader will make a profit of L$0.055 kg^{-1} on imported rice, assuming it is purchased from one of the five rice buyers in Zwedru. Little or no profit is made on local rice unless it is grown by the seller.

7.9.2 Cocoa

Cocoa is grown as a cash crop for export. However, the local market is poorly developed and does not favour the local farmer. The farmer in small villages has no storage facilities for cocoa beans and sells to the first Mandingo trader who visits the village. Prices paid range from L$0.44-0.66 kg^{-1} (L$0.20-0.30 per lb) and no premium is paid for quality beans. Generally the trader pays for the beans according to the number of filled bowls, so that the farmer has little idea of the weight sold or price paid per kilogram.

The producers in the bigger villages who are members of a Cooperative (e.g. Zwedru, Tuobo Gbawelekehn, Tujallah Town) obtain a more favourable price for their cocoa beans. The cooperative often has access to storage facilities and is therefore able to store the beans until a truck load is ready for transport to the LPMC in Monrovia. The cooperative receives the official price of L$0.88-0.99 kg^{-1} (L$0.40-0.45 per lb) according to the grade, and also receives a subsequent payment to cover transport costs. The cooperative takes a commission of about L$0.12 kg^{-1} (L$0.5 per lb) to offset transport and other costs. The payment from the LPMC for transport is often delayed for six to nine months and has to be collected in Monrovia.

It is interesting to note that the London market price for cocoa for May and June 1986 was almost US$2.0 kg^{-1}, which is about four times that paid to farmers.

Cocoa marketing would be considerably improved by the establishment of a LPMC buying station in Zwedru, together with the introduction of a grading programme for licenced buyers. Through such a programme the buyers would be able to introduce a premium payment for good quality beans. This in turn would encourage the farmer to ferment the cocoa beans properly so as to obtain a good quality product.

An extension programme should be introduced to farmers to teach them proper cocoa fermentation techniques and to grade their own beans.

7.9.3 Coffee

Little coffee is grown in the areas visited but the marketing problems are similar to those for cocoa.

Coffee is sold as the cherry to traders for L$0.33-0.44 kg^{-1} (L$0.15-0.20 per lb). There is no premium payment for quality cherries so the farmers usually pick a mixture of unripe and ripe cherries. No hulling or grading is carried out at farm or village level.

The official LPMC prices which are payable to licenced buyers and cooperatives are:

Clean coffee FAQ	L$1.32 kg^{-1}	(L$0.60 per lb)
Sub-grades (prices from)	L$1.10 kg^{-1}	(L$0.50 per lb)
Broken, black beans	L$0.99 kg^{-1}	(L$0.45 per lb)
Cherry coffee	L$0.66 kg^{-1}	(L$0.30 per lb)

The world market price for coffee beans for May and June 1986 was US$3.3 kg^{-1} (US$1.5 per lb).

Coffee marketing could be substantially improved by introducing a grading and quality production programme for licenced buyers and farmers. This would encourage an extra payment for quality produce and enable the farmer to grade his own coffee. The LPMC is intending to start such a programme for coffee buyers, but it is unlikely to affect Grand Gedeh County due to its remoteness from the LPMC coffee and cocoa buying stations. As with cocoa, an LPMC buying station should be established in Zwedru.

Simple hulling machines should be introduced and used by cooperatives or large village groups. This would enable farmers to sell coffee beans and obtain a better price.

7.10 AGRICULTURAL EXTENSION

7.10.1 Staffing

The Ministry of Agriculture has a county office in Zwedru with some twenty staff attached. There is a Regional Agricultural Officer who is responsible for Grand Gedeh, Sinoe and Maryland Counties, which in turn each have their own County Agricultural Officer. Within Grand Gedeh there are five districts (Gbarzon, Tchien, Konobo, Gbeapo and Webbo), each with a District Officer who is assisted by two to three extension workers. Some of the extension workers have had limited training but the majority are untrained.

7.10.2 Extension Activities

The extension activities of officers are severely limited by the total lack of transport facilities. At present, the officers have to obtain lifts to an area and then stay at a village for 7-10 days. They walk to various farms but during the course of a village visit only a few farmers are counselled.

No improved seeds, tubers or rootstocks are available through the MOA. Improved rice and cassava varieties are available in Nimba and Bong Counties and these should be made available to farmers in Grand Gedeh. Grafted citrus rootstocks are available only through CARI (at L$0.35 each), but the distance and problems of transportation deter interested farmers from purchasing them.

Various farmers expressed interest in purchasing fertilizer. However, none is currently available through the MOA office in Zwedru, as stocks have ceased to be held due to lack of demand.

Chemicals for pest, disease and weed control are not generally recommended as they are not available locally and are even difficult to obtain in Monrovia. When chemicals are obtained, they are often misused for killing fish.

7.11 COOPERATIVES AND FARMER DEVELOPMENT ASSOCIATIONS

Cooperatives are known to exist in Zwedru, Kelipo, Toetown, Tuobo Gbawelekehn and Tujallah Town. The record of cooperatives is poor and funds have often been misused, resulting in general disenchantment with such organisations. The cooperatives in Tuobo Gbawelekehn and Tujallah Town have been recently formed solely for marketing of cocoa, and members are presently enthusiastic due to the higher cocoa prices received.

A different approach was adopted in the Nimba County Rural Development Project (NCRDP), where Farmer Development Associations (FDA) have been formed. An FDA consists of several groups of farmers who benefit from working together on a farm. The concept of farmers joining together was started in 1980, primarily for swamp rice development. It has developed rapidly: farmers now work together to clear swamps and build all the water control structures and canals at their own cost. The project provides technical advice, surveyor services and use of chain saws. Some 400 ha of swamp has been developed for rice production since 1980.

The principal function of the FDA is to bulk produce crops (such as rice, coffee and cocoa) to obtain the benefits of improved marketing. This approach has been successful and several FDAs are able to lend money at reasonable interest rates, purchase equipment and improve village facilities.

The NCRDP support to the working groups and to the formation of the FDAs has been vital. A similar approach is recommended for the development of irrigated rice and up-grading coffee and cocoa production in Grand Gedeh.

8. SELECTION OF VILLAGES AND SWAMPS

A primary aim during the first phase of the study was to select swamps and villages for more detailed study in Phase 2. A list of swamps in Grand Gedeh County was provided by the South-east Regional Office of the Ministry of Agriculture and this provided a starting point in locating swamps. The list is reproduced in Appendix D.

An initial examination of the Landsat imagery and aerial photographs was made to determine the main centres of population and areas of cultivation. A number of such nuclei of agricultural activity was identified. These identified areas were visited and the main villages within these areas with a population large enough to support a swamp development project were located. Discussions were held with village representatives to explain the nature of the study and to make a preliminary assessment of the interest of the people in a swamp development project.

Some of the principal criteria for selecting swamps were explained to the villagers. These included the following priority requirements:-

- Reasonable size;
- Good access and close to the village;
- Persistence of wet conditions throughout the year;
- Existence of fine textured soils;
- Level microtopography;
- Side slopes with shallow gradients and cultivable soils.

The village representatives were then requested to show the team any swamps which might meet these criteria. In this way, up to three swamps around each village were visited. Existing footpaths were used to gain access to and within the swamp and the soil was examined by hand auger.

Potentially suitable swamps were identified at 13 villages. Three of these were subsequently rejected due to unfavourable soil conditions or for other reasons. The remaining ten swamps (Figure 8.1) formed the long-list for selection of the five swamps scheduled for more detailed survey under Phase 2 of the study.

An important criterion for the final selection was to achieve a reasonably even distribution around the County, taking account of the swamps already being developed by the CCSRP, which are located mainly in the north and northwest of the County (within a radius of 80 km from Zwedru).

Moreover, as the swamps surveyed in this study were intended as pilot schemes, it was clearly important to select areas served by a relatively large population, or at least be easily accessible, so as to provide a visible and effective demonstration over a wide area. As far as possible, an attempt was also made to include one swamp in each of the administrative districts of the County.

Taking account of these various considerations, a final list of swamps at five locations was selected. The selection process and the final choice of village swamps was discussed and agreed with the Advisory Group in Monrovia on December 16th 1985.

The priority swamps selected for Phase 2 study were at the following villages:-

- Beezohn;
- John David Town;
- Fishtown;
- Tuobo Gbawelekehn;
- Tujallah Town.

Other potentially suitable swamps identified, but which were not studied under this project, are as follows:-

- Drugbor/Paye;
- Gehkehn;
- Zai Town;
- Sehniwein;
- Toe Town.

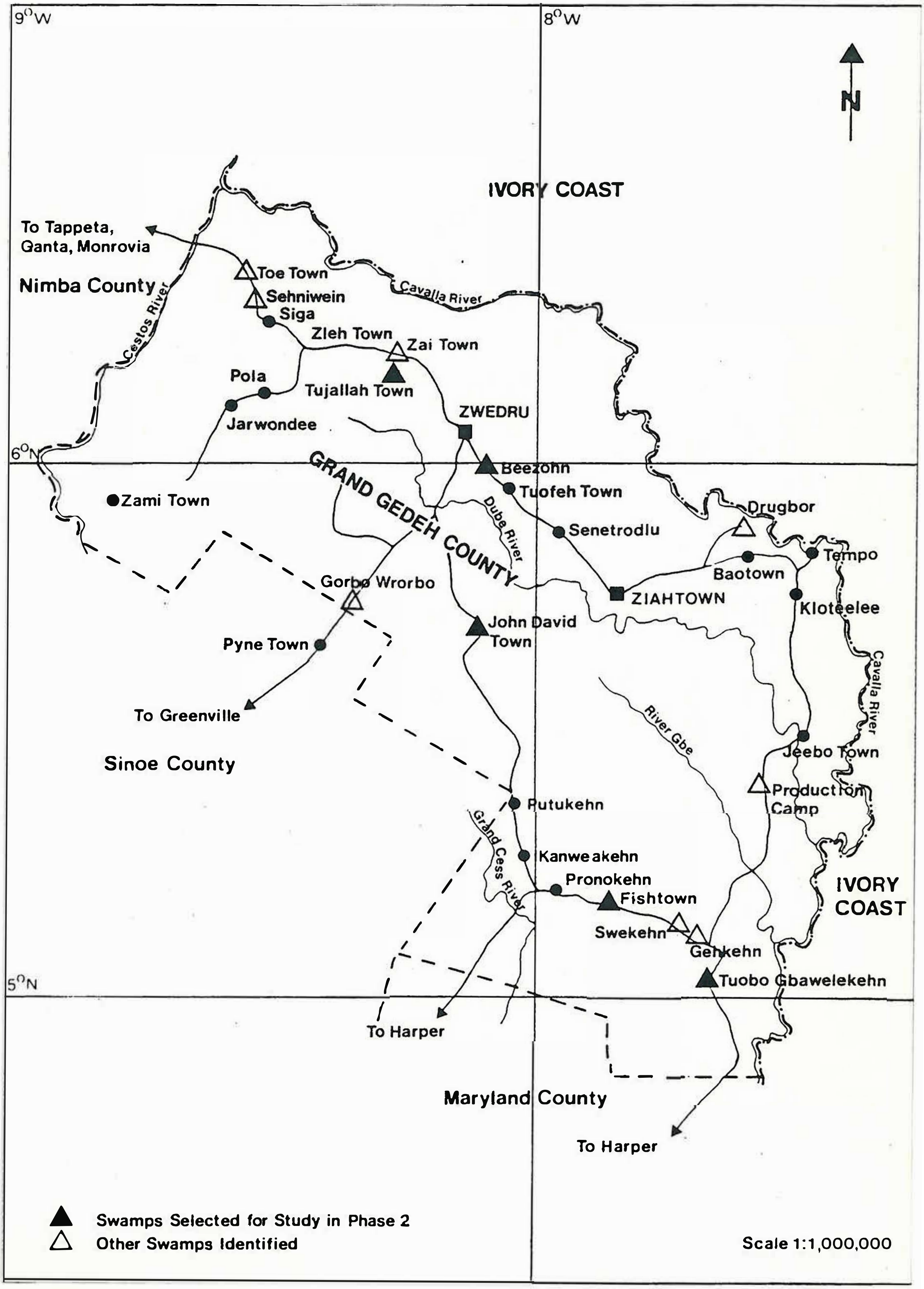
The above five swamps would appear to be worth future study.

The following three swamps were also identified but on initial examination were considered to have unfavourable characteristics:-

- Swehkehn (coarse sandy soil);
- Gorbo-Wrorbo (coarse sandy soil);
- Production Camp (within teak plantation; restricted land use on the side slopes; small size).

Location of Identified Swamps

Figure 8.1



Conducting infiltration test at John David Town

Section C

Detailed Studies Of Villages And Swamps

9. SURVEY APPROACH FOR VILLAGE AND SWAMP AREAS

9.1 INTRODUCTION

A general summary of the methods of study adopted for the detailed surveys of village lands and swamps in the five areas selected for study during Phase 2 are given in Chapter 3. This chapter provides detailed technical descriptions of the approaches used for soil and land classification as well as the principles used in irrigation and drainage design for swamp development planning. These have been applied to the surveys and mapping of each of the village areas, which are described separately in Chapters 10 to 14.

9.2 SOIL AND LAND CLASSIFICATION

9.2.1 Soil Classification

The aims of a soil classification system are to group together soils with similar characteristics, so as to show the relationships between different soils and to provide a basis for soil mapping.

The approach adopted for soil classification in this study was to devise a system which was appropriate to rapid survey techniques in which soils could be readily classified from observations of field characteristics, and which had relevance to the specific objectives of the study. It was evident that many of the soils occurring had not been previously recognised and could not be identified as existing soil series in the Soils Division Catalogue (Soils Division, 1977). Thus, an approach similar to the 'soil families' concept of Fantant (1970) was devised in which soils were grouped according to similarity of morphological characteristics. The factors differentiating between soil units were chosen so as to provide ready correlation with their suitability for upland or swamp crop production.

In the first place, three major divisions were made according to the landscape position of the soil: (Swamp, Lowland and Upland). In general, the boundary between the swamp and the dryland areas was readily determined in the field, and all soils occurring within the swamp were classified as swamp soils (denoted as 'W'). In the dryland areas, a distinction was made between the lowland soils (L), formed primarily in colluvium and colluvio-alluvium, on generally gently sloping land at the margin of the swamp, and upland soils (D) on the undulating land upslope of the lowland fringe.

The distinction between upland and lowland is necessarily somewhat arbitrary as the areas often merge into each other but, in practice, it was generally a simple matter to decide in which major division to classify the soil. In general, the lowland soils were deeper, paler coloured, less well drained and less gravelly than the upland soils.

In making further sub-divisions of the swamp soils, emphasis was placed on the soil texture since this was the major variable between swamp soils, and the texture is a major determinant in assessing the suitability of the swamp for rice, both in terms of the agronomic preference of the rice crop itself, and in terms of water control. Other parameters of the soil often varied in association with the texture. Four sub-divisions of swamp were defined, based on the predominant soil textural class in the 30-100cm depth. A description of the four swamp soil units, including their texture and associated characteristics, is given in Table 9.1.

In sub-dividing the lowland soils, emphasis was again placed on textural differences but certain other characteristics were also given prominence in grouping the soils such as soil depth, drainage and gravel content. Four lowland soil sub-divisions were recognised. (Table 9.1).

The upland soils were initially grouped according to gravel content (stones and concretions) and particularly the depth at which gravelliness occurs, as high gravel contents create a barrier to rooting. Gravel was found to be a dominant feature of many of the soils in all the areas surveyed. In less gravelly profiles, soils were separated on the basis of other characteristics, such as soil colour, texture and presence or absence of plinthite within 1m depth. Eight sub-divisions were recognised in the Upland soils.

Full details of the soil mapping units are provided in Table 9.1. A tentative correlation between the soil mapping units and other classification systems is given in Table 9.2.

9.2.2 Land Suitability and Capability Classification

Different approaches to land classification have been adopted for the semi-detailed village survey and the detailed swamp survey, in keeping with the different objectives of the two studies.

In the case of the swamp survey, the aim was to produce an assessment of the physical suitability of the swamp for a single crop (viz rice), and of the adjacent side slopes for dryland crop production to complement rice production in the swamp.

In the case of the village land survey, a classification was required to reflect the general agricultural potential or capability of the area from which decisions on appropriate land use, cropping systems and erosion control measures could be made.

TABLE 9.1: DOMINANT SOIL CHARACTERISTICS (Page 1 of 3)

Soil Group and Map Symbol	Topographic Location	Colour	Texture	Depth to limiting layer (ii) (cm)	Structure	Mottles	Drainage	Flooding Hazard	Geology
D1	Upland-gentle slopes and plateau locations	Dark greyish brown over yellowish brown over strong brown to yellowish-red	LS (or SL) over SCL over SC/C	100+	Granular and crumb over moderate SAB	Occasionally few orange.	Good	None	Gneiss and Granite
D2	Upland - Slope Sites	Dark yellowish brown over yellowish brown to strong brown.	LS/SL over gravel-ly(iii) SCL or SC	50 to 100	Granular and crumb over weak to moderate SAB	Occasionally few orange.	Good	None	Gneiss and Granite
D3	Upland - Slope Sites	Ditto	LS/SL over gravel-ly(iii) SCL or SC	25 to 50	Granular over weak SAB	Rarely, few to common, fine, faint to distinct orange mottles	Good	None	Gneiss and Granite
D4	Upland - often steeper slope sites	Ditto	Gravelly LS or SL over gravelly SCL	Less than 25	Granular over loose gravel	None	Good	None	Gneiss and Granite
D5	Upland - gentle slopes and plateaux	Dark greyish brown over brown to pale brown and yellowish brown	LS over SL (sometimes slightly gravelly below 60 cm)	100+	Granular and crumb over weak SAB	Occasionally few greyish or yellowish below 60 cm	Good	None	Gneiss and Granite
D6	Upland - slopes of undulating terrain	Dark brown over yellowish brown	LS over slightly to moderately gravelly SL or SCL (often weathering bedrock within 1 m)	100+	Granular and crumnb over weak SAB	Usually common red mottles below 60 cm	Good	None	Gneiss and Granite

TABLE 9.1: DOMINANT SOIL CHARACTERISTICS (Page 2 of 3)

Soil Group And Map Symbol	Topographic Location	Colour	Texture	Depth to limiting layer (ll) (cm)	Structure	Mottles	Drainage	Flooding Hazard	Geology
D7	Upland - slopes of undulating terrain	Dark brown over yellowish brown to strong brown	LS over slightly to moderately gravelly SCL or SC (often weathering bedrock within 1 m)	100+	Granular and crumb over weak SAB	Usually common red mottles below 60 cm	Good	None	Gneiss and Granite
D8	Upland - slopes of undulating terrain	Dark brown over yellowish brown to strong brown	LS over SL or SCL (sometimes slightly gravelly below 60 cm with weathering bedrock)	100+	Granular and crumb over weak SAB	Usually common red mottles below 60 cm	Good	None	Gneiss and Granite
L1	Lowland - gentle slope sites	Dark greyish brown over yellowish brown to strong brown	LS/SL over SCL or SC	100+	Granular and crumb over moderate SAB	Few to many, fine and medium, faint to distinct orange below 80cm	Moderately well or well drained	Low risk of short term flooding during wet season	Colluvium
L2	Lowland - level sites	Dark yellowish brown over light yellowish brown to yellow	Fine S to SL throughout	100+	Single grain or granular throughout	None	Well to excessively well drained	Very low risk of flooding	Coarse alluvium
L3	Lowland	Dark brown over pale or olive brown over grey/greenish grey	LS/SL over SCL/ZCL or finer	100+	Granular or crumb over weak to moderate SAB	Common to many, distinct, medium, pale brown and grey	Moderate to poor	Liable to flood in wet season	Colluvium
L4	Swamp fringe sites - flat to gently sloping	Dark greyish brown over grey	LS over S to coarse SL	100+	Weak granular and single grain	Few, faint, and distinct, fine yellow	Moderate to poor	Liable to flood in wet season	Colluvio-Alluvium

TABLE 9.1: DOMINANT SOIL CHARACTERISTICS (Page 3 of 3)

Soil Group And Map Symbol	Topographic Location	Colour	Texture	Depth to limiting layer (ii) (cm)	Structure	Mottles	Drainage	Flooding Hazard	Geology
W1	Swamp	Dark brown over grey, light grey or greenish grey	Fine - dominantly C, CL, ZC, and fine SC in top metre	100+	Crumb over SAB	Few to many, faint to prominent, medium and coarse, yellow brown to orange	Poor to very poor	Regularly or permanently flooded in wet season	Colluvio-alluvium
W2	Samp	Dark (greyish) brown over grey or greenish grey	Fine to medium - dominantly ZCL, CL/SC, fine SCL in top metre	100+	Crumb over SAB	Few to common distinct, medium, yellow brown, yellow and orange	Poor to very poor	Regularly or permanently flooded in wet season	Colluvio - alluvium
W3	Swamp	Dark brown over grey to light grey or greenish grey	Medium to Coarse: dominantly coarse SC, SCL and SL in top metre	100+	Crumb over SAB	Few to common, faint to distinct, medium orange and yellows	Poor to very poor	Regularly or permanently flooded in wet season	Colluvio - alluvium
W4	Swamp	Dark brown over grey to light grey, dark grey (when organic staining occurs) or white	Coarse: dominantly LS and S with associated coarse quartzitic stones in top metre	100+	Granular over single grain	Occasionally, few, distinct, fine to medium grey or light brown at depth	Poor to very poor	Regularly or permanently flooded in wet season	Colluvio-alluvium

NOTES:
(i) For further details see profile descriptions in Appendix A.
(ii) Limiting layer constitutes 50 % Fe concretions, other gravel or stones (moderately hard to hard), ironstone or rock.
(iii) Soil horizon is described as 'gravelly' when over 15% of the soil mineral material constitutes coarse material (0.2 - 7.5 cm diameter.)

SAB = Sub-angular blocky
SL = Sandy loam
SC = Sandy clay
CL = Clay loam
ZC = Silty clay

LS = Loamy sand
SCL = Sandy clay loam
S = Sand
ZCL = Silty clay loam
C = Clay

TABLE 9.2: TENTATIVE CORRELATION BETWEEN SOIL CLASSIFICATION SYSTEMS

Soil Unit (1)	Liberian Soil Series (Soils Division,1977)	Soil Taxonomy (Soil Survey Staff, 1975)	FAO (FAO/UNESCO,1974)
D1	Kollieta	Typic Paleudult Plinthic Paleudult	Orthic Acrisol Plinthic Acrisol
D2	Gbaokele	Plinthic Paleudult Typic Paleudult	Plinthic Acrisol Orthic Acrisol
D3	-	Plinthic Paleudult Typic Paleudult	Plinthic Acrisol Orthic Acrisol
D4	Sinyea	Plinthic Paleudult	Plinthic Acrisol
D5	-	Typic Paleudult	Orthic Acrisol
D6	-	Plinthic Paleudult	Plinthic Acrisol
D7	-	Plinthic Paleudult	Plinthic Acrisol
D8	Suakoko	Plinthic Paleudult	Plinthic Acrisol
L1	Kpatawee	Typic Paleudult	Dystric Nitosol
L2	Samukata	Typic Dystropept	Dystric Cambisol
L3	Kitomo	Plinthaquic Paleudult	Plinthic Acrisol
L4	-	Typic Tropaquult	Gleyic Acrisol
W1	?Gbelle	Typic Tropaquult	Gleyic Acrisol
W2	Grayzohn	Typic Tropaquult	Gleyic Acrisol
W3	Ballam	Acric Tropaquult	Gleyic Acrisol
W4	Cuttington	Typic Tropaquult	Dystric Gleysol

Note (1) See Table 9.1 for summary of soil units mapped

a) Swamp Survey

In classifying the swamp and side slopes, the principles of the FAO "Framework for Land Evaluation" (FAO, 1976) have been followed, modified as appropriate to meet the circumstances of this particular survey.

The swamp itself was classified separately from the surrounding dryland areas and classified as major division 'R'. Four suitability classes, were used in the swamps, of which the first three have decreasing suitability for irrigated rice production (Classes RS_1 to RS_3), whereas the fourth is not suitable (Class RN). The surrounding dryland areas were classified as major division 'U' with five suitability classes, of which the first four have decreasing suitability for dryland crops (Classes US_1 to US_4) and the fifth is not suitable (Class UN).

Suitability sub-classes were mapped showing the nature of the physical limitations. Four limiting factors were considered, denoted by lower case letters. The same four limiting characteristics were used in classifying both the swamp and the surrounding dryland areas, but the range of characteristics of each limiting factor allowed in any class differed in the classification of the swamps and surrounding upland respectively (for example, poor drainage and impermeable heavy textured soils are favourable for irrigated rice, but unfavourable for dryland farming).

The four limiting factors considered were as follows:-

- s = soil texture
- g = depth to excessively gravelly (or other limiting) layer
- t = gradient (slope class)
- d = drainage.

In the dryland classification, indications are given of the suitability of each class for specific crops, according to the nature of the limitation (see Map legends and Table 9.3).

b) Village Land Survey

In classifying land in the semi-detailed village survey, the aim was to determine the potential of the land for sustained agricultural production and to reflect the inherent erosion hazards. A somewhat more intensive system of agriculture than the traditional practice is envisaged, since it is assumed that the capability studies should reflect the potential of the land to support more intensive and/or improved farming techniques to increase the productivity of the dry land village and upland rice farms and thereby reduce pressure on the forest resources. The current low intensity/low input farming systems are often carried out in areas of shallow and gravelly soil and on steep slopes which are entirely inappropriate for improved agricultural practice.

TABLE 9.3 : LAND SUITABILITY CATEGORIES FOR SWAMP SURVEY

Map Symbol	Applicability	Definition	Major limiting factor and suffix used where dominant: g Depth to Limiting Layer(cm)	t Topography and Maximum Slope (%)	d Drainage Characteristics	s Dominant Texture	e Potential Erosion Hazard	Crop Recommendation	Conservation Measure (+)
RS1	FOR FLOOD IRRIGATED RICE	Highly suitable for swamp rice production	30	0 - 0.5	Poorly	Fine	-	Rice	-
RS2	CULTIVATION IN	Moderately suitable for swamp rice production	30	0.5 - 1	to	Fine to Medium	-	Rice	-
RS3	WETLAND DEPRESSIONS AND	Marginally suitable for swamp rice production	30	1 - 2	Very Poorly	Medium to coarse	-	Rice	-
RN	SWAMPS ONLY	Unsuitable for swamp rice production	30 *	>2	Drained	Coarse	Slight to moderate	Unsuitable for rice cropping	-
US1	FOR RAINFED	Highly suitable for dryland cropping	100	Flat to gently undulating 0 - 3	Well drained	Medium to fine	Slight	Selected vegetables, arable and tree crops (e.g. coffee and cocoa)	None
US2	AGRICULTURE	Very suitable for dryland cropping	100	Undulating 4 - 8	Well to Mod. well drained	"	Slight to moderate	"	Contour cultivations and channel terraces where required
US3	IN UPLAND	Moderately suitable for dryland cropping	50 - 100	Undulating to rocky 9 - 15	Moderately well drained	Medium	Moderate	Selected tree crops - not cocoa (susceptible to moderately shallow soils	Channel or Bench Terraces
US4	AND LOWLAND	Marginally suitable for for dryland cropping	25 - 50	Rolling to moderately steep 16 - 25	Imperfectly drained	Medium to Medium Coarse	Moderate to Severe	Selected tree crops only, not susceptible to shallow soils, (not coffee or cocoa)	Groundcover with Bench Terraces
UN	LOCATIONS	Unsuitable for dryland cropping	<25	Mod. steep to steep >25	Imperfectly to Poorly drained	Coarse	Severe	Forest only	-

- = not applicable
* from 'Swamp Development Manual for EIADP', Appendix I, B. Brewer, 1984
\+ from FAO Bulletin No. 33, 'Soil Conservation and Management in Developing Countries'

Thus, it was considered appropriate to use the principles of the US Land Capability Classification (Klingebiel and Montgomery, 1961). The system, as originally defined, has 8 classes of which the first four are suitable for cultivation; Class 5 is a special category for wetland areas; Classes 6 to 8 are not suitable for cultivation but have potential for pasture, forestry and wildlife/recreation respectively.

A modified version of the US system was adopted in the present survey. Upland areas were classified separately from the swamps. The first four classes correspond with those of the original US system. The original US Class 5 for wetland has been dispensed with and replaced by "Class R" for swamps. Land not suitable for cultivation is here denoted by Class 5. Table 9.4 indicates the criteria used in classification and Table 9.5 gives a summary of the interpretation of the land capability classes.

Sub-classes were defined to show the nature of the limiting factor. The following were recognised:

- g = gravel (stones/concretions)
- t = topography/gradient (slope class)
- d = soil drainage/flooding
- r = soil depth.

Land in Class 1 is very flexible in its use; it has a wide range of cropping possibilities and, being restricted to almost level areas, the risks of soil erosion are low. Only minimum soil conservation techniques are required.

Land in lower classes has an increasingly restricted range of land use and crop options, and requires progressively more elaborate physical and agronomic techniques to ensure soil conservation. Land in Classes 3 and 4, in particular, is likely to require physical structures such as bunds or terracing to control run-off, to reduce gradients and lengths of the slope. Cover crops are recommended under tree cropping.

Class 5 land is unsuitable for cultivation and should remain under forest. Class R (swamp land) has not been further sub-divided since these should be the subject of additional detailed surveys to establish their suitability for swamp rice production.

TABLE 9.4 : CAPABILITY CLASSIFICATION FOR VILLAGE LAND SURVEY

Class	Gradient (t) %	Gravel (in top 1m, most gravelly horizon more than 10cm thick) (g)	Soil Texture (predominant textures in top 1m) (s)	Drainage/flooding (d)	Soil Depth (r)
1	0- 3	None to sightly gravelly.	Medium	Well drained, no flooding risk	More than 100cm
2	4- 8	Slightly gravelly	Fine to medium	Mod. well drained; no flooding risk	More than 100cm
3	9-15	Slightly to moderately gravelly	Coarse to fine	As above	50-100cm
4	15-25	Moderately gravelly	Very coarse to very fine	Poorly drained, no flooding risk	25- 50cm
5	More than 25	Excessively gravelly	-	Seasonal flooding risk	Less than 25cm

TABLE 9.5 : LAND CAPABILITY CLASSES FOR VILLAGE LAND SURVEY

CLASS	DESCRIPTION	SOILS AND LAND CHARACTERISTICS	CONSERVATION PRACTICES
1	No or very slight permanent physical limitations.	Usually deep, easily worked on level sites.	Fertilizers; crop rotations.
2	Slight physical limitations for use as cropland.	Have one or more of the following limitations:- slight slopes; slightly restricted depth; require drainage; slightly stony.	Crop rotations; water control; special tillage.
3	Moderate physical limitations for use as cropland.	May be on moderately steep slopes; moderately shallow or gravelly soils; inherent low soil fertility.	Restricted choice of crops; timing of planting and tillage; maintain crop cover at critical times; comprehensive physical conservation structures.
4	Severe physical limitations for use as cropland.	Steep slopes subject to erosion; shallow or gravelly; uneven terrain.	Very restricted cropping; maintain cover; comprehensive physical conservation structures.
5	Unsuitable for cultivation.	Steep slopes; rocky terrain; exposure to wind/rain.	Reserve for forest; wildlife.
R	Wetlands	Seasonally or permanently water-logged.	

9.3 IRRIGATION AND DRAINAGE DESIGN

9.3.1 Introduction

This section describes the principles used in preparing outline irrigation and drainage designs for the selected swamps. It also provides general guidelines for developing typical swamps. However, during implementation, these will need to be modified to suit the needs of individual swamp areas (Sections 10 to 14).

9.3.2 Available Mapping

The land classification mapping indicates the limits of the swamp at a scale of 1:2,000. In practice, a scale of 1:5,000 would suffice for the design.

The maps contain no precise topographic information except the divide between the swamp and the side slopes, and approximate alignments of streams and footpaths. Depth to water table is inferred and can, to some extent, be used to indicate land levels, although water table depths may be depressed around streams.

It will not be possible to obtain exact topographic information until the site is cleared.

9.3.3 Layout

Layouts have been prepared on the basis that disposal of excess water to the drain is of equal importance to supplying irrigation water, and many of the channels and structures therefore fulfill a dual role.

Every layout has a main drain running through the lowest part of the area and a peripheral channel round the outside of the area, except where this coincides with the drain. The object of the peripheral channel is to collect surface runoff from the side slopes and either run this into the irrigated area, if the water is required to supplement rainfall, or discharge it into the drain in the case of there being too much water.

The main drain should be designed with a small central channel with a bed width and depth of approximately 0.5m. This should have a berm on each side at ground level, approximately 1.5m wide. The berm should have a flood bank between it and the cultivated area. The drain is designed to carry small flows in the central channel whereas the berms and flood banks are intended to accommodate flood flows.

The main drain should be made no deeper than is necessary to convey the surface water, because an excessively deep drain will lower the water table depth, especially in the dry season. This would increase losses from the rice fields and could reduce the sub-irrigation potential if dryland crops were being grown.

If the main drain is constructed through areas with non-cohesive soils, care will be required to avoid channel erosion. This can be accomplished by either reducing slope and, hence, water velocity, or by protecting the side slopes with grass. Grassing can be relatively expensive, with turfing costing more than seeding, although the former method is more immediately effective.

Channels should also be constructed from the peripheral channel to the drain to carry excess water from outside the area, either to the drain or for irrigation in the area.

Field layout and plot size depend on farming practices, soils in the area and land levelling requirements. If the soils in the area are shallow clays overlying sand, then the amount of land levelling must be controlled in order that the sand is not exposed at the surface. This may necessitate contour levelling rather than rectangular plots. The only objection to the former layout is that it can give long narrow fields which may not be the most efficient use of the land. A further objection is that narrow plots are not so suitable for mechanised cultivation but this is not important at present because hand cultivation is practised. In the case of rectangular plots the maximum size will depend on land levelling, land tenure and irrigation management. A typical rectangular plot size of 0.1 ha has been used in the outline designs.

The layouts proposed for swamps in each selected village (Sections 10 to 14) are considered to be adequate for outline planning and costing of swamp development. Once the forest cover is cleared, and it is possible to verify the topography, these preliminary designs may need to be modified before implementation can proceed.

9.3.4 Structures

The structures proposed are simple and involve use of readily available materials (earth and rough cut timber). Concrete should not be used because of the cost and the fact that the farmers do not have the expertise to repair it. Typical structures recommended are:-

a) Head bunds across the upstream end of the area. These will be constructed from earth with a timber weir where the stream flows through the structure. Some form of stilling basin will be required downstream of the weir. The function of the head bund is to give command of the peripheral channel by the steam and provide a limited amount of storage upstream of the area.

b) Control structures to raise the water level in the main drain. These may be required during the dry season if rice is being grown and water losses are excessive. They can be built from timber. They may be washed out by a flood and therefore need periodic replacement.

c) For supplying water from the peripheral canal to the fields, bamboo pipes can be used.

d) Stilling basins will be required downstream of head bunds, at main drain junctions and where peripheral channels and cross-channels discharge into the main drain. The stilling basin will be required for energy dissipation and, therefore, erosion control will be essential. This can best be fulfilled by a combination of making the basin larger than the main drain and by grassing the side slopes to aid stability. In unstable soils, it may be necessary to strengthen the banks by means of walls constructed from timber cut from the area being cleared.

9.4 LAND DEVELOPMENT SUITABILITY

The development potential of the swamps and surrounding areas have been assessed through the land suitability categories given in Section 9.2. These categories have been grouped into three Land Development Units (LDU) representing suitable, marginal and unsuitable land for swamp and upland development. Appropriate crop proposals are made for sustainable cropping according to the LDU. These, together with specified inputs, are shown in Table 9.6.

In the swamp areas LDU RS1/2 represents a fine to medium textural soil which is suitable for single or double cropping of rice. Appropriate fertilizer applications will be required according to the cropping intensity. LDU RS3 denotes the most marginal land, with moderately coarse textured soils. These lands are expected to retain few nutrients and to require a good supply of water and fertilizer for single cropping of rice. Double cropping is not recommended under these conditions, as considerable applications of fertilizer will be required and a dam will be necessary for water storage. Unsuitable lands are designated LDU RN and are mainly coarse textured soils associated with gravel.

The LDUs for the upland areas are based on similar criteria, with topography and drainage also being considered. The most suitable lands are LDU US1/2 which denote areas with at least 1m of non-gravelly topsoil, good to moderate drainage and a slope of 0 to 8%. These lands are considered suitable for all annual crops and tree crops. Double cropping of annual crops is feasible if fertilizer is applied and if there is sufficient available soil moisture.

The marginal lands are denoted by LDU US3/4 and consist of areas with gravel horizons at 25 to 100cm depth, slopes 9 to 25% and poor to imperfect drainage. These areas are suitable for certain tree crops and annual crops. Cocoa is not suitable for these areas but coffee can be cultivated on the US3 suitability category lands as gravel horizons are found at 50-100cm depth. Double cropping of annual crops is not recommended due to the low nutrient status of the soil and the low water holding capacity. Fertilizer applications and appropriate crop rotations involving legumes or a fallow break for annual crops will be required.

Unsuitable land, due to gravel horizons within 25cm of surface, slope over 25% or imperfect drainage, are designated LDU UN.

TABLE 9.6: LAND DEVELOPMENT UNITS (LDU)

Location	Land Suitability (LDU)		Crop Proposed	Inputs for Continuous Cropping	
				Single Crop	Double Crop
Swamp	RS1/2	Suitable	Irrigated rice	+	++
	RS3	Marginal	Irrigated rice	++	Not recommended
	RN		Not suitable		
Upland	US1/2	Suitable	All annual and tree crops	*	**
	US3/4	Marginal	Selected tree crops (excl. cocoa) and food crops. US4 not suitable for coffee.	*	Not recommended
	UN		Not suitable		

+ Denotes small fertilizer application required after 2nd or 3rd year.

++ Denotes moderate fertilizer application required after 1st crop, good water management and husbandry practices.

* Denotes appropriate crop rotation with legume or fallow required for annual crops.

** Denotes small fertilizer application required for double cropping and appropriate rotation for annual crops.

Fertilizer applications have not been specified as they depend on many inter-related factors and trials should be carried out to determine economic application rates for a sustainable system of cropping.

The LDUs and outline engineering designs are shown, for each selected village area, on the Outline Development Plan maps (Volume 2). These maps are summarised in the text in Sections 10 to 14 for each village. Minor areas which appear to be out of command of the irrigation/drainage channels are excluded and denoted as "OC" on the maps.

10. BEEZOHN

10.1 LOCATION AND SIZE

Beezohn is situated in Tchien District on the main road from Zwedru to Ziahtown some 8km south southeast of Zwedru (Figure 10.1). Two small neighbouring villages (Mennyetown and Nyonkolebo) were also included in the study. Tuofeh Town, the headquarters of the area is situated about 3km south of Beezohn on the same creek.

The size of each village is shown in Table 10.1.

TABLE 10.1: NUMBER OF HOUSES AND DISTANCE FROM SWAMP

Village	Number of Houses Houses	Distance from swamp (walking time in minutes)
Mennyetown	9	15
Beezohn	24	5
Nyonkolebo	10	10
TOTAL	43	

The total number of houses in the three villages is 43. This suggests a total population of around 200 persons.

The number of farmers who have expressed an interest in participating in a swamp development project is shown in Table 10.2.

TABLE 10.2: FARMERS INTERESTED IN SWAMP DEVELOPMENT

Village	Number of Interested Farmers	Number of Helpers
Mennyetown	18	18
Beezohn	24	28
Nyonkolebo	14	20
TOTAL	56	66

The surveyed swamp is located along a creek which flows from north to south immediately to the west of Beezohn.

10.2 VILLAGE LAND SURVEY

10.2.1 General Description

The Beezohn area is undulating with several major interfluves between a series of streams or small rivers flowing in a north-west to south-east direction into the Dube River. Slopes up to about 15% generally occur on the undulating upland though steeper slopes also exist. Stretches of flatter alluvial land (terraces and floodplains) occur along the drainage courses.

The larger rivers maintain a base flow during the dry season but the small creek on which the swamp is situated dries out.

10.2.2 Vegetation and Land Use (Map3)

Much of the area surrounding Beezohn is within the cultivation cycle. To the north in a zone of influence around Zwedru, virtually all the natural high forest has been felled. However to the west and south-east of Beezohn, patches of forest remain, though large blocks of forest are at some distance (4km) from the village. The land use of most of the area around Beezohn is a mosaic of farms and secondary regrowth, with extensive areas especially to the north of Beezohn carrying older regrowth.

10.2.3 Soils and Land Capability (Maps 4 and 5)

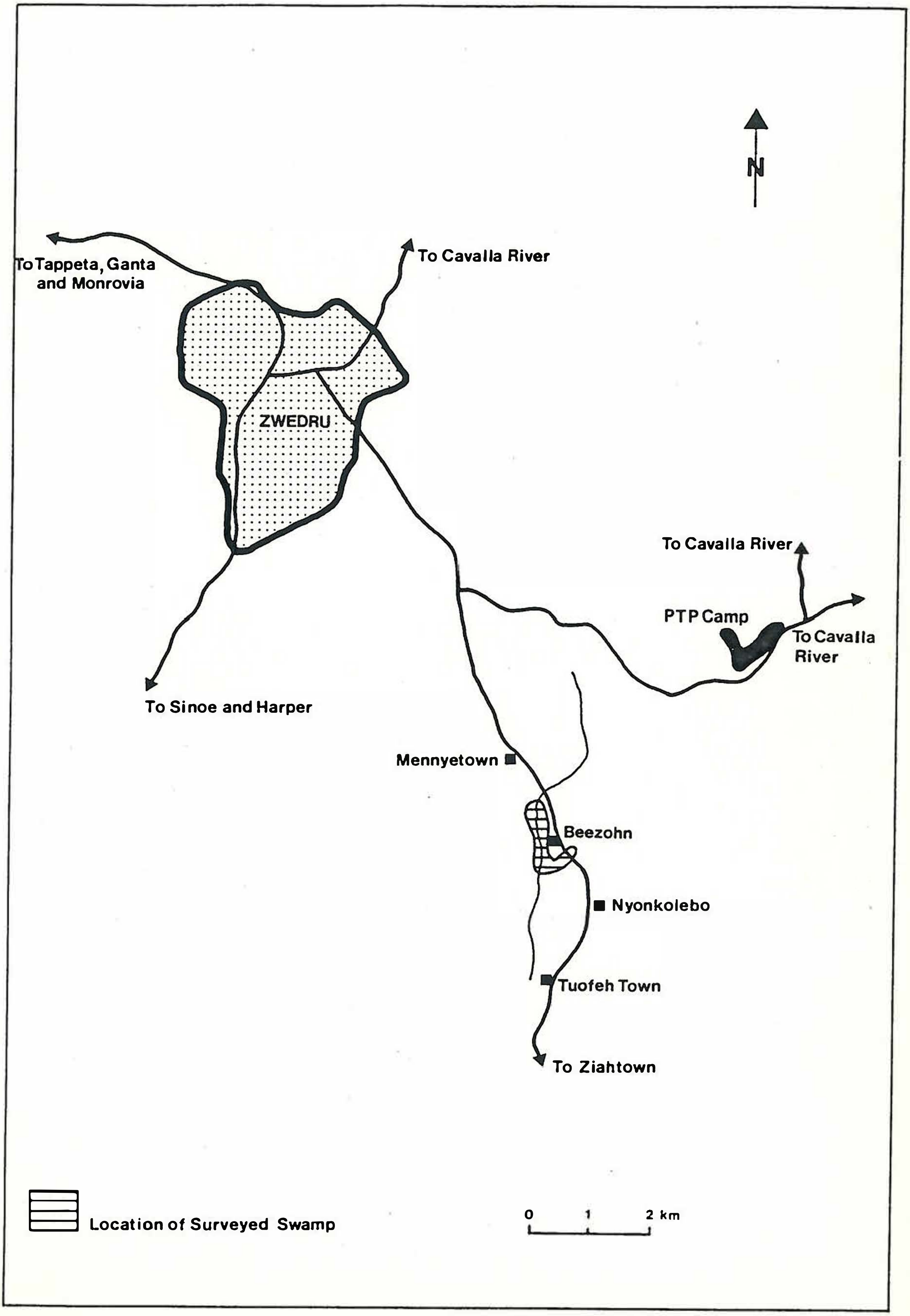
An area of some 2765 ha was surveyed.

The soils of the undulating uplands are predominantly gravelly with rooting depth restricted by iron concretions or iron pan within 25cm of the surface. Concretions are often seen on the soil surface in cultivated areas indicating loss of topsoil by erosion. The restriction on rooting depth imposed by the gravelliness, together with low fertility and water holding capacity are the main limiting factors to the use of these soils and they cannot be recommended for improved or intensified agricultural production. The land capability of these areas is therefore Class 5.

The alluvial areas along the stream courses however, provide deeper, generally non-gravelly soils of medium to fine texture. Such alluvial land has narrow width, confined by the upland, but appears to be fairly continuous along the major stream courses. Included within the alluvial areas are sections of swamp which could not be separately identified. The main risk for rainfed, dryland cropping in these areas is from flooding on land in the immediate vicinity of the

General Plan of Beezohn Area

Figure 10.1



streams due to overtopping of the water course during the rainy season. This should be less of a risk on slightly higher terraces or raised areas flanking the uplands. The land capability of such land (apart from areas with a flooding hazard) is therefore Class 1. Such land should be capable of growing a wide range of crops with low erosion hazard and requiring only minimal soil conservation techniques.

The soils on the lower slopes of the undulating upland leading down to the main streams are formed from colluvium and are extremely variable in texture, depth and stoniness. They are sometimes concretionary but often not so gravelly as typical upland soils and the depth to a limiting gravel layer is frequently deeper. Such areas are shown on the soil map as a complex of two soil units (D3 and D7). These appear to be the commonest soils occurring in such locations, but the soil pattern is complex and the whole range of upland soils may occur. Included within these colluvial areas however, there are likely to be patches of land with at least moderate potential. Better areas have a land capability of Class 2, although most of the land is excluded from Class 2 on account of the gradients. Most of the remainder of these areas is Class 3 or 4, with the main limiting factors being gravelliness and/or soil depth.

Class 2 land is likely to be suitable for a wide range of crops. Class 3 and 4 land is more gravelly and/or shallower and is less suited to upland rice and sensitive tree crops such as cocoa. However, for all cropping on these colluvial slopes, attention will need to be paid to the hazards of soil erosion and appropriate techniques for soil and water conservation will need to be applied.

10.3 SWAMP SURVEY

145.7 ha around the village of Beezohn were surveyed in January and February 1986 in order to identify suitable areas of both swampland for irrigated rice cultivation and upland for rainfed tree and arable cropping (Table 10.3).

The main swamp at its nearest point was within 5 minutes walk of the village centre. A smaller area of swamp covering 3.1 ha, was also identified to the west of the main swamp, 15 minutes walking distance from the village centre.

Soil observations were made at 223 sites by soil auger and at 10 sites by profile pit. Depth to ground water table was measured wherever encountered. Hydraulic conductivity measurements were made at two locations, and infiltration rate tests at three sites.

Soil samples from six pits were sent for chemical analysis, the results of which are recorded and discussed in Appendix A.

TABLE 10.3: SWAMP SURVEY SUMMARY TABLE : BEEZOHN

DESCRIPTION	AREA ha	%
AREA SURVEYED (inc. village area, 1.3 ha)	145.7	-
Area of Swamp*	32.4	100
Highly suitable for rice	0	0
Moderately suitable	1.5	5
Marginally suitable	28.9	89
Unsuitable	2.0	6
Area of Upland*	112.0	100
More or less suitable for one or other form of cropping	48.1	43
Unsuitable for cropping	63.9	57
Area under+ - rice, 1986 growing season	9.2	6
- other fruit or vegetable crops	5.3	3
- tree crops	1.7	1
- regrowth	80.3	55
- dryland forest	24.0	17
- wetland forest	23.9	17
- village	1.3	1

*See Tables 9.3 and 10.5 for further information on land suitability.

+See Map 6 for further details.

10.3.1 Soils (Map 7)

The soils investigated during the Grand Gedeh survey are described in Table 9.1, and the crop suitability classification criteria are given in Table 9.3. Full profile descriptions of the major soil units are given in Appendix A. Distribution of soil units at Beezohn are shown in Table 10.4 below.

TABLE 10.4 : SOILS DISTRIBUTION IN BEEZOHN

Soil Unit	Location	Area ha	%
D1		2.6	2
D2	Upland	12.8	9
D3		26.1	18
D4		62.1	43
L1	Lowland and	1.1	1
L2	Swamp Fringe	0	0
L3		5.1	3
L4		2.2	1
W1		0	0
W2	Swamp	1.5	1
W3		28.9	20
W4		2.0	1
	TOTAL	144.4	

Note: Total area excludes 1.3ha for the village of Beezohn.

a) The Swamp

The majority of swamp soils at Beezohn are only marginally suitable for rice cultivation except in a small area (1.5 ha) in the north, which are well suited. 2.0 ha around the swamp fringe are unsuited to irrigated rice because of coarse textures.

The swamp soils are of colluvio-alluvial origin and are generally deep, but texturally variable; finer textured soils are more common in the north of the swamp than in the south. Commonly, deep sandy loams lie over sandy clay loams and sandy clays in the south (W3): less deep sandy loam surface horizons in the north lie over occasional silty clays and clays (W2). Coarse textured horizons (medium sand) in the top metre act as shallow aquifers in the wet season; these horizons occur especially at swamp fringe locations where sand has accumulated due to colluvial wash. Where these horizons dominate the surface metre, the soils are considered unsuitable (W4). Consistence is generally friable over firm, or soft over sticky in moister profiles.

At depths greater than 150cm, predominant textures are fine sandy clay and silty clay or clay over fine textured weathering micaceous parent material.

Soil colours are generally greyish browns over greys and light greys, or whites (where textures are coarse): the weathering parent material is greenish or bluish grey. Yellow-brown, yellow and orange mottling is common within many profiles.

b) The Upland and Swamp Fringe

The soils range from well drained, concretionary-free, moderately fine textured profiles to imperfectly drained, very gravelly, or coarse textured profiles.

A haphazardly distributed area of low lying land occurs around the main swamp, all of which to the east of the swamp is coarse textured (essentially loamy sand/sandy loam or coarser to 120 cm), imperfectly well-drained and of colluvial origin (L4).

To the west of the swamp, there is a large area of imperfectly drained land, with moderately coarse to moderately fine textured soils of colluvial/alluvial origin (L3). A small area of moderately well-drained, moderately fine textured soil occurs to the north west of the swamp (L1).

Surrounding the lowland and often abutting directly against the swamp, are large areas of upland soils (D4) which are very shallow due to the presence of concretions (more than 50% of the soil matrix in the surface 25cm). Other more or less gravelly soils occur in much of the remainder of the area. Gravel-free, deep, well drained, moderately fine to fine textured soils (D1) occur to only a very limited extent.

10.3.2 Topography

a) The Swamp

The swamp is generally flat though within it, areas of slightly higher land are located: these 'islands' do not constitute large areas, and slopes are only rarely greater than 2%. Until the land is fully cleared of vegetation, it will not be possible to delineate these areas, which may be out of command in terms of irrigability.

b) The Upland amd Swamp Fringe

The great majority of gradients recorded on the colluvial footslopes surrounding the swamp are gentle (less than 8%) and landform is undulating.

Within the Upland, slopes are also generally less than 8%: however, in the west and northwest on lines A (A13 to 17), B (B13 to 17), D (D16) and E (E14 to 17), gradients of between 12 and 35% are recorded, characteristic of rolling terrain with the occasional steep slope. Similarly in the east, on lines B, C and D (B-5, C-6, and D-3 to D-8), the terrain is rolling and moderately dissected.

10.3.3 Land Suitability (Map 8).

a) The Swamp

Three suitability classes for irrigated rice production are mapped (Table 10.5), the great majority being only marginally suitable for rice (RS3).

The major limiting factor is soil texture: rice production on the moderately coarse topsoils and in soils with inclusions of coarse sand lenses can be only marginally successful. Where the depth of coarse textured horizons is over 50 cm within the surface metre, the site is seen as unsuitable for swamp rice cultivation for reasons of poor nutrient availability and retention, and low moisture holding capacity during drier periods. Two small areas fall into this unsuitable category (RN).

The soils of one small area in the north of the swamp are fine to moderately fine textured and are moderately well suited to irrigated rice production (RS2).

The location and size of the small islands of higher lying ground within the swamp also require further investigation, preferably in the wet season when their suitability will be more perceptible.

TABLE 10.5: LAND SUITABILITY AT BEEZOHN

Applicability	Suitability Category	Major Limiting Feature	Area ha	Area %
	Highly suitable			
	US 1	No limiting feature	1.2	1
Upland	Well suited	Dominant slopes between		
	$US2_t$	4 and 8%	1.7	1
for	Moderately suitable			
	$US3_t$	Dominant slopes between 9 and 15%	1.1	1
rainfed	$US3_g$	Very gravelly horizons between 50 and 100cm	14.0	10
cropping	Marginally suitable			
	$US4_t$	Dominant slopes between 16 and 25%	0.3	-
	$US4_g$	Very gravelly horizons between 25 and 50cm	24.3	17
	$US4_s$	Moderately coarse textured soils	0.8	(1)
	$US4_d$	Imperfect drainage with seasonally high water tables	4.7	3
	Unsuitable except for forestry			
	UN_t	Dominant slopes over 25%	0.8	(1)
	UN_g	Very gravelly horizons within surface 25cm	60.9	42
	UN_s	Coarse textured soils to 1m depth	2.2	2
	Moderately suitable			
Swamps for	$RS2_s$	Medium textured soils	1.5	1
flood	Marginally suitable	Moderately coarse textured		
	$RS3_s$	soils	28.9	20
irrigated				
	Unsuitable	Coarse textured soil to		
rice	RN_s	1m depth	2.0	1
	Village area	Not available	1.3	1
		GRAND TOTAL:	145.7	100

b) The Upland and Swamp Fringe

The major limiting factor in the upland fringe area is the occurrence of gravel concretions within the surface metre of soil. Only small areas are limited by topography, drainage characteristics or soil texture.

About 64 ha are unsuitable (Table 10.5) for all considered land use types because of very gravelly topsoils, fertility and water holding capacity, all of which are important factors during the dry season in the north of Grand Gedeh County.

Only small areas are well suited to agriculture: in these locations, there is no gravel within the top metre, soils are moderately well to well-drained and moderately fine textured, and topography is gentle to undulating with gradients not exceeding 8%.

10.3.4 Vegetation and Land Use (Map 6).

a) The Swamp

The swamp is largely under wetland forest; in the south especially, this comprises thick bamboo forest. Palm and bamboo species are common throughout. The regrowth areas within the swamp are characteristically thick and tangled especially when less than three years old. There is no evidence that the swamp has been used for flood irrigated rice in the past and it is clear that local farmers much prefer the upland areas for their cropping activities.

b) The Upland and Swamp Fringe

The vegetation is dominated by regrowth, though there are significant areas of high forest remaining in the east and west peripheries of the survey area.

The newly cleared farms for 1986 rice production are mostly to the west of the village, some of which are over 3 kilometres from the village and outside the swamp survey area. Certain cleared areas are within moderately dissected rolling terrain, which has led to severe erosion in places: for example at E14 (Map 6), the cleared area is on a slope of over 20% with the result that the surface is strewn with concretions, even after the infrequent, relatively gentle pre-season rains.

Several areas of banana, plantain, bitterball, pepper and cassava occur within young regrowth areas. These crops are not tended well and following the rice harvest in the first year after land clearance these secondary vegetables and fruits are largely left to survive as best they can.

Only three areas of cocoa plantation were seen, two smaller areas near the village and a larger area to the west of the village which occupies a swamp and lowland area. All the cocoa seen was overgrown, poorly managed and diseased: that in the swamp, however, appeared to be moderately healthy, though stunted, presumably due to shallow rooting depth as a result of seasonally high water tables.

There are no vegetable gardens within the village, though some tree crops were observed, (eg. breadfruit, kola nut and "walnut").

The choice of land cleared by farmers for the annual rice crop appeared to depend on how easily it could be cleared rather than on the quality of the terrain and soils. Some of the worst land, in terms of steep slopes, and gravelly soils, is used for rainfed rice production.

10.3.5 Water Resources

None of the streams or drainage lines feeding the swamp were flowing at the time of survey (March 1986) and standing water was observed at only a very few sites.

Water tables were deeper than 1m in most areas of the main swamp, as the area was surveyed before the onset of the 1986 rains. Soil colours indicate that the ground water table rises significantly during the wet season. In the smaller western swamp, water tables were higher, between 20 and 70 cm below ground level, in spite of being located at a slightly higher elevation than the main swamp.

Information from villagers, the nature of the vegetation and soils indicates that water tables are high within the main swamp for at least six months of the year, and that certain areas were naturally flooded for longer periods. With sensible water management, flood irrigation should be possible.

With the arrival of the first heavy rain, the water table rose very rapidly and there was some flow in the stream: this soon dropped, however to become dry again, once surface runoff had ceased.

Further information on the extent of flooding and wet season groundwater table levels is required before development begins.

10.4 SWAMP DEVELOPMENT PROPOSALS (Map 9)

The proposed cropping patterns for Beezohn swamp and the surrounding area are given in Table 10.6. The location of the land types and outline engineering designs, are shown in Figure 10.2 and Map 9.

TABLE 10.6: PROPOSED CROPPING PATTERN FOR BEEZOHN SWAMP AREA

Location	Land Suitability (LDU)		Area Ha	Area %	Crop Proposed	Inputs for Sustainable Cropping: Single Crop	Inputs for Sustainable Cropping: Double Crop
Swamp	RS1/2	Suitable	1.5	6	Irrigated rice	+	++
	RS3	Marginal	23.0 (1)	87	Irrigated rice	++	Not recommended
	RN	Not suitable	2.0	7	None		
			26.0	100			
Upland	US1/2	Suitable	3.1	3	Annual crops and tree crops	*	**
	US3/4	Marginal	45.2	40	Selected tree crops (excl. cocoa) and food crops. US4 not suitable for coffee	**	Not recommended
	UN	Not suitable	63.7	57	None		
			112.2	100			

NOTES (1) Some swamp area out of command

\+ Denotes small fertilizer application required after 2nd or 3rd year.

++ Denotes moderate fertilizer application required after 1st crop, good water management and husbandry practices.

* Denotes appropriate crop rotation for annual crops with legume or fallow break. Small fertilizer application required after 2nd or 3rd year.

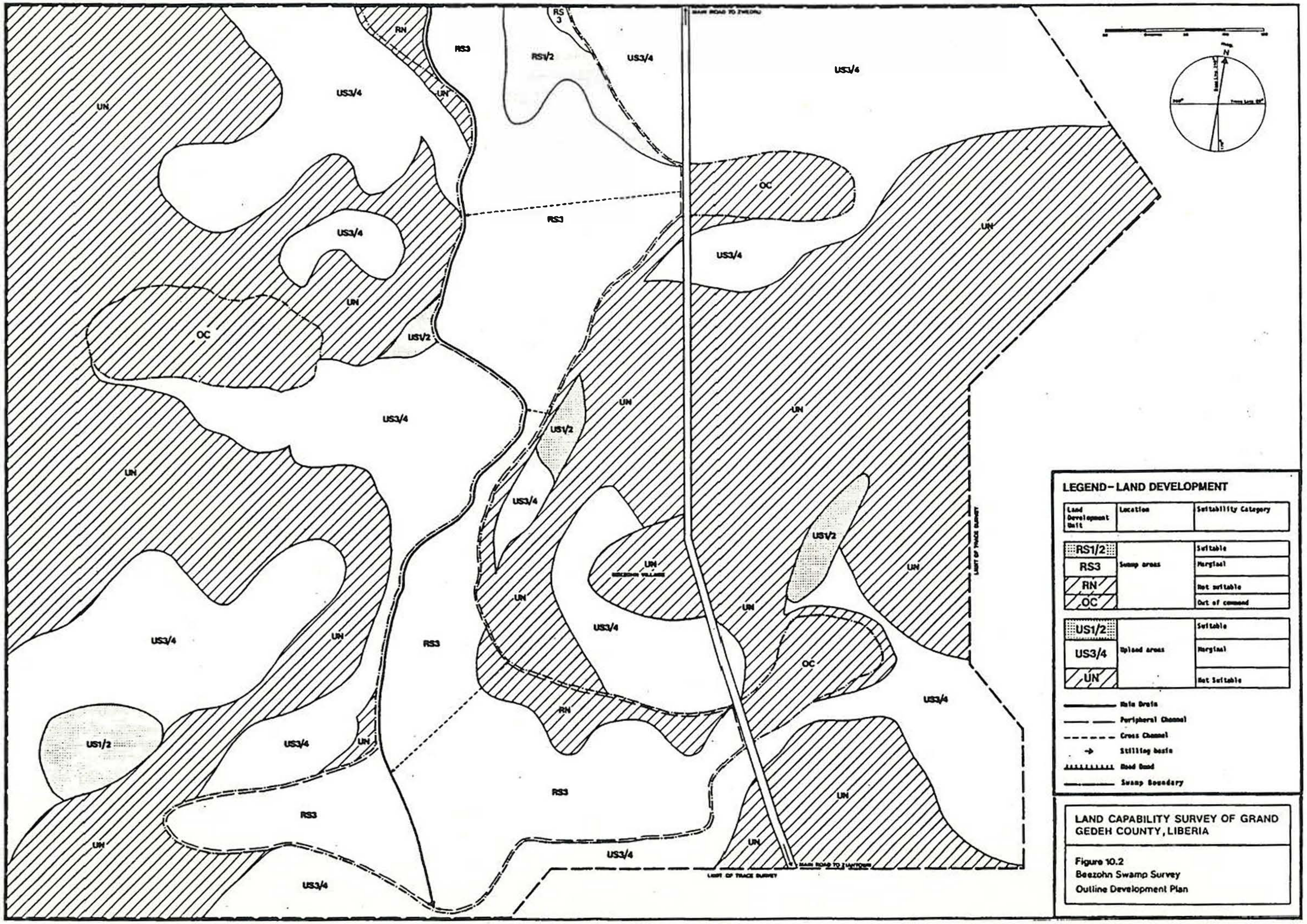
** Denotes small fertilizer application and appropriate rotation for annual crops.

The area of swamp surveyed was 32.4 ha, of which none was classed as highly suitable (RS_1) and only 1.5 ha (5%) was classed as RS_2 (suitable for continuous irrigated rice cultivation with appropriate inputs). The majority of the lands (89%) were classed as RS3, which are moderately coarse textured soils indicating fairly rapid drainage and poor nutrient retention. For continuous rice cultivation on these lands, there should be adequate applications of fertilizer and a good supply of water. It was noted that Beezohn swamp was one of the drier swamp areas and it was reported to be dry from December to March.

Unsuitable land comprises 6.0% of the swamp, located at the top and lower end of the swamp.

The area of swamp side slope surveyed was 112 ha. The soils exhibit a poorer trend, with only 2.9 ha (2-5%) classed as US1 and US2 which are suitable for all annual and tree crops. The remainder of the lands are a scattered mixture of marginal areas of US3 and US4 (40%) which are suitable for selected tree and food crops, and unsuitable UN Class (57%). There are large areas of unsuitable soils around the swamp and due caution should be exercised when areas are identified for selected crops, especially cocoa and coffee.

Outline engineering designs are shown in Figure 10.2 (and Map 8). A peripheral channel follows the eastern limit of the swamp but excludes the area east of the main road to Zwedru. The main channel is located along the natural drainage course to the west of the swamp and is connected by cross drains to the eastern peripheral channel. A small peripheral channel is also located around the lower south-west point. The northern section of the swamp is some 250m wide and therefore the provision of a head bund is not feasible.



LAND CAPABILITY SURVEY OF GRAND GEDEH COUNTY, LIBERIA

Figure 10.2
Beezohn Swamp Survey
Outline Development Plan

11. JOHN DAVID TOWN

11.1 LOCATION AND SIZE

John David Town is situated in Konobo District on the main road from Zwedru to Harper some 50km from Zwedru and near the foot of the Putu mountain range (Figure 11.1). There are three sections of John David Town, all situated along the main road but separated from each other by a kilometre or two. Two small villages to the north of John David Town 1 (Baa's Town and Mean Town) are also part of the community. Tiematown, the headquarters is situated 12km to the south west along the main road.

The number of houses in each section of John David Town is given in Table 11.1.

TABLE 11.1: NUMBER OF HOUSES AND DISTANCE FROM SWAMPS

Village	No of houses	Distance from Swamp 1* (walking time in minutes)
John David Town 1	20	30
John David Town 2	18	15
John David Town 3	10	10
Baa's Town	6	35
Mean Town	9	45
TOTAL	63	

*NB Distances to Swamp 2 are about 5 minutes shorter.

The total number of houses in the villages is 63, suggesting a total population of 250-300 persons.

35 farmers expressed an interest in participating in a swamp development programme. These farmers have some 59 helpers between them.

Two swamps were surveyed in John David Town. Swamp 1 is located to the south of John David Town 3 on the south side of the Gebe River. Swamp 2 crosses the main road just to the south of John David Town 3.

11.2 VILLAGE LAND SURVEY

11.2.1 General Description

John David Town is situated in a hilly area with the Putu Range to the west. The River Gebe which flows from southwest to northeast, almost parallel to the main road, forms a flat broad valley infilled with colluvial-alluvial material. A tributary flowing from the northwest joins the Gebe River near John David Town 1 and has a similar broad valley. These valleys are surrounded by steep sided forested slopes with gradients up to and over 25%.

The Gebe River and its main tributary flow throughout the dry season.

11.2.2 Vegetation and Land Use (Map 10)

Cultivation is practised mainly in the valleys of the rivers and tributaries and on the lower side slopes of the surrounding upland. These areas have a mosaic of secondary bush regrowth and farms. The steep land is occupied by high forest although cultivation is encroaching up the hillsides. The forest has been selectively logged in the past, as evidenced by several abandoned logging roads. This activity appears to have ceased.

11.2.3 Soils and Land Capability (Maps 11 and 12)

An area of some 1500 ha was surveyed.

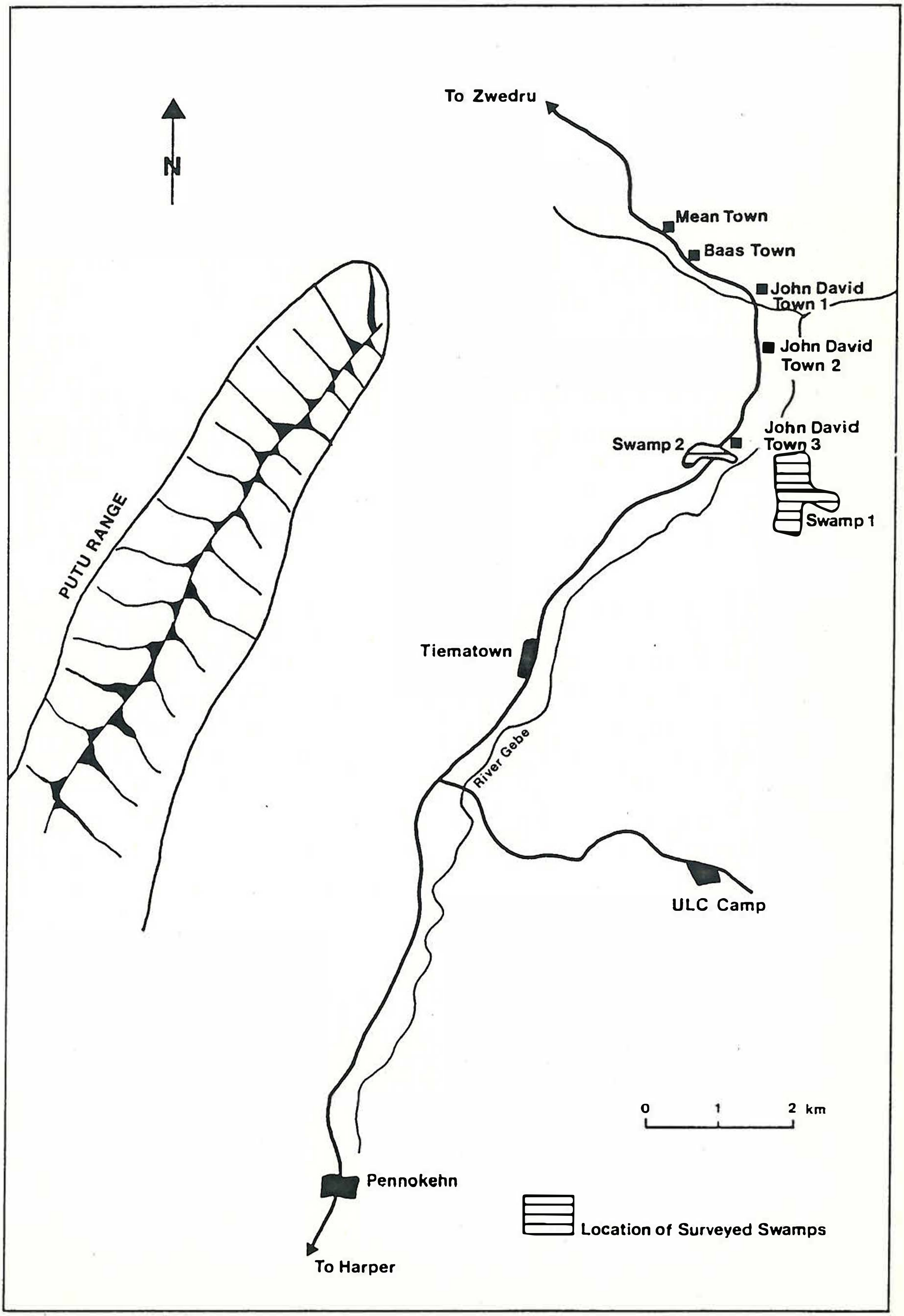
The forested side slopes are occupied by very concretionary and shallow soils (soil unit D4) on steep slopes, sometimes with gradients exceeding 35%. Such land cannot be recommended for use under improved or intensified dryland crop production on account of the poor soils and steep slopes, with their attendant erosion hazards. The capability of this land is therefore Class 5. The most appropriate use for such land is for it to remain under forest.

The soils in the river valleys formed from colluvio-alluvial material are generally deep and of fine to medium texture (soil unit L1). These soils occupy extensive and almost continuous stretches along the course of the valleys. Apart from the lowest areas adjacent to the water courses, which are liable to flooding, these areas have high potential for sustained agricultural production and their land capability is Class 1. Some of the minor tributaries flowing into the Gebe are occupied by swamps which are generally of small size and with coarse soil texture.

Located between the forested side slopes and the colluvio-alluvial areas of the river valleys are various colluvial soils on the lower slopes. The boundary between the forest and the secondary regrowth also often marks the boundary between the shallow gravelly soils and the soils of the lower colluvial slopes. The soils

General Plan of John David Town Area

Figure 11.1



of these areas are variable in texture, depth and stoniness and they form a complex pattern. However, they are generally deeper and less gravelly than the soils on the forested uplands. The land capability of such areas with gentle slopes (up to about 8%) is generally Class 2 provided that soil depth and stoniness are not limiting.

Areas to the east of John David Town 1, across the Gebe River and to the south of John David Town 3, have been mapped as Class 2. Such land should be capable of growing a wide range of row and tree crops with due attention to requirements for soil conservation. Much of the rest of the lower colluvial slopes are considered to be Classes 3 or 4 according to the predominant gradients and the amount of gravel occurring in the profile. Such areas have moderate to low potential for cultivation, requiring careful choice of crops according to the soil physical conditions and due attention to soil conservation.

11.3 SWAMP SURVEY

A total of 133 ha were surveyed during February 1986. Two swamps were investigated as the area initially surveyed was felt to be too small and lacking sufficient colluvial arable and tree crop land. As there were several areas of wetland in the near vicinity of John David Town, it seemed sensible to extend the survey. In fact, there proved to be little gently sloping colluvial land associated with either swamp (Tables 11.2 and 11.3).

The main swamp (1) was, at its nearest point, 10 minutes walk southeast of John David Town 3. Swamp 2 at the closest point, was 5 minutes walk southwest of the village.

Both swamps were characterized by narrow finger-like forms, associated with stream courses, running north in Swamp 1 and northeast in Swamp 2.

Soil observations were made at 188 sites by soil auger, and at 11 sites by profile pit. Depth of groundwater tables was measured wherever observed. Hydraulic conductivity measurements were made at eight locations, and infiltration rate tests at four sites.

Soil samples from four pits were sent for chemical analysis, the results of which are recorded and discussed in Appendix A.

11.3.1 Soils (Maps 14 and 18)

The soils are described in Table 9.1 and the crop suitability classification criteria are given in Table 9.3. Full profile descriptions of the major soil units are given in Appendix A.

TABLE 11.2: SWAMP SURVEY SUMMARY : JOHN DAVID TOWN SWAMP 1

DESCRIPTION	AREA ha	%
AREA SURVEYED	110.0	
Area of Swamp*	28.4	100
Highly suitable for rice	1.5	5
Moderately suitable	4.5	16
Marginally suitable	21.5	76
Unsuitable	0.9	3
Area of Upland*	81.6	100
More or less suitable for one or other form of cropping	35.8	44
Unsuitable for cropping	45.8	56
Area under+ - rice, 1986 growing season	5.6	5
- other fruit or vegetable crops	0	0
- tree crops	0	0
- regrowth	40.0	37
- dryland forest	50.8	46
- wetland forest	13.6	12

*See Tables 9.3 and 11.6 for further information on land suitability.

+See Map 13 for further details.

TABLE 11.3: SWAMP SURVEY SUMMARY : JOHN DAVID TOWN SWAMP 2

DESCRIPTION	AREA ha	%
AREA SURVEYED	23.0	-
Area of Swamp*	6.0	100
Highly suitable for rice	0	0
Moderately suitable	0.6	10
Marginally suitable	5.4	90
Unsuitable	0	0
Area of Upland*	17.0	100
More or less suitable for one or other form of cropping	10.2	60
Unsuitable for cropping	6.8	40
Area under+ - rice, 1986 growing season	1.2	5
- other fruit or vegetable crops	0	0
- tree crops	0	0
- regrowth	15.9	69
- dryland forest	2.7	12
- wetland forest	3.2	14

*See Tables 9.3 and 11.7 for further information on land suitability.

+See Map 17 for further details.

a) The Swamps

In Swamp 1 the soils are variable but largely suitable for swamp rice production (Tables 11.2 and 11.4).

The main relevant features of the soils of Swamp 1 are discussed below.

A very small area of coarse soil (loamy sand over sand, W4) occurs on line I. Moderately coarse textured soil (W3), dominantly sandy clay loam interlayered with more or less coarse horizons in the top metre, are the most common soil type, and occur extensively throughout the swamp.

Smaller areas of moderately fine textured soils, characteristically clay loam and sandy clay to one metre, occur in places, and a moderately large area of fine textured soils (silty clays and clays) lies in the north of the swamp.

All soil units, whether dominantly moderately coarse or fine textured, often contain a variably shallow horizon of coarse material commonly medium sand; this horizon was observed at depths between 30 and 110cm.

Consistence varies widely from loose in the shallow, coarse textured horizons to very sticky in the clays and silty clays of the W1 soil group.

Water table levels vary according to the day on which measurement was made, microtopography and proximity to stream and swamp limit.

Soil colours are generally greyish browns over greys or light greys and greenish/ bluish greys in the more fine textured horizons; mottling was more common in the fine textured profiles.

The soils and land suitability of Swamp 2 are summarised in Tables 11.3 and 11.5. The soils were either moderately coarse or moderately fine textured: the majority were moderately coarse, some 50% of which were characterised by histic topsoils (W3h). Water tables tended to be higher, especially nearer the culvert under the main road. A common feature of the W3 soils in this swamp was a coarse textured horizon at depths greater than 70 cm.

b) The Upland and Swamp Fringe

Upland soils in the areas surrounding both swamps were usually concretionary. The main features are discussed below:-

Around both swamps occur haphazardly distributed areas of lowland in which soils ranged from coarse to moderately fine textured, and well-drained to imperfectly well-drained (L1, L3 and L4).

TABLE 11.4 : SOIL DISTRIBUTION IN JOHN DAVID TOWN, SWAMP 1

Soil Unit	Location	Area ha	%
D1		9.5	9
D2	Upland	3.4	3
D3		18.4	17
D4		40.9	37
L1		4.6	4
L2	Lowland and Swamp Fringe	0	0
L3		3.7	3
L4		1.1	1
W1		4.6	4
W2	Swamp	4.7	4
W3		18.2	17
W4		0.9	1
	TOTAL	110.0	

TABLE 11.5 : SOILS DISTRIBUTION IN JOHN DAVID TOWN, SWAMP 2

Soil Unit	Location	Area ha	%
D1		3.9	17
D2	Upland	3.0	13
D3		1.6	7
D4		4.4	19
L1	Lowland and	1.4	6
L2	Swamp Fringe	1.3	6
L3		1.1	5
L4		0.3	1
W1		-	0
W2	Swamp	1.5	6
W3		4.5	20
W4		-	0
	TOTAL	23.0	

Highly concretionary shallow soils (D4), often abutting directly against the swamps, occupy much of the survey area, especially around Swamp 1. Only small areas of non-concretionary deep, well-drained and moderately fine to fine textured soils (D1), occur within the area surveyed.

11.3.2 Topography

a) The Swamps

Certain areas within Swamp 1 are characterised by uneven microtopography and small isolated higher- lying islands. Further investigation is required in this respect, as land levelling may be required to ensure certain areas are irrigable by gravity flow. The swamp is generally flatter in the south, where two streams occur at either side of the swamp: between those two streams (eg. lines A, B and C), microtopographic variation may need particular attention.

In Swamp 2, the microtopography is not limiting, except in a small area to the east of the road; again, this area is occupied by the more suitable moderately fine textured soils.

b) The Upland and Swamp Fringe

A feature of the John David Town area is the steep slopes surrounding certain areas of the swamps. Around Swamp 1, slopes of over 25% quite frequently occur (unit UNt, see Map 15), and there are significant areas where topography is a minor constraint. Away from the swamp side, the terrain is undulating to gently rolling: slopes are not limiting except in certain land use types.

A small area to the northwest of Swamp 2 is characterised by steep slopes, but generally this location is less affected by limiting gradients and topography.

11.3.3 Land Suitability (Maps 15 and 19)

a) The Swamps

Suitability of Swamp 1 for flood irrigated rice ranges from highly suitable to unsuitable (Table 11.6), mainly on account of soil texture. However, variable microtopography and the presence of slightly higher lying islands within the swamp are also limiting in the north and east, where land levelling may be required.

As a result only one small area is classified as highly suitable (RS1); where the swamp is flat, the soils are fine textured and the water tables high. Another small area in the central part

TABLE 11.6: LAND SUITABILITY AT JOHN DAVID TOWN, SWAMP 1

Applicability	Suitability Category	Major Limiting Feature	Area ha	Area %
Upland for rainfed cropping	Well suited $US2_t$	Dominant slopes between 4 and 8%	10.1	9.2
	Moderately suitable $US3_t$	Dominant slopes between 9 and 15%	3.8	3.5
	$US3_g$	Very gravelly horizons between 50 and 100cm	2.6	2.3
	Marginally suitable $US4_t$	Dominant slopes between 16 and 25%	1.7	1.6
	$US4_g$	Very gravelly horizons between 25 and 50cm	16.6	15.1
	$US4_d$	Imperfect to poor drainage with seasonally high water table	1.0	0.9
	Unsuitable except for forestry UN_t	Dominant slopes over 25%	4.2	3.8
	UN_g	Very gravelly horizons within surface 25cm	40.5	36.7
	UN_s	Coarse textured soils to 1m depth	1.1	1.0
Swamps for for flood irrigated rice	Highly suitable RS1	No limiting features	1.5	1.4
	Moderately suitable $RS2_s$	Medium textured soils	4.5	4.1
	Marginally suitable $RS3_t$	Presence of slopes within range 1 to 2%	5.4	4.9
	$RS3_s$	Moderately coarse textured soils	16.1	14.6
	Unsuitable RN_s	Coarse textured soil to 1m depth	0.9	0.8
		GRAND TOTAL:	110.0	100.0

of the swamp is moderately suitable (RS2) on account of finer textured soils. The great majority of the rest of the swamp is only marginally suitable (RS3) on account of both variable and uneven microtopography and moderately coarse textured soils.

In Swamp 2 only one small area is moderately suitable due to soil texture, and the remainder is only marginally suitable because of moderately coarse textured soils and/or uneven microtopography (Table 11.7).

b) The Upland and Swamp Fringe

Suitability of land use types in the upland (Tables 11.6 and 11.7) is governed by both concretionary soils and topography (steep gradients). Very large areas are deemed unsuitable for all considered land use types (except forestry), especially around Swamp 1, due to shallow concretionary soils and, to a much lesser extent, gradients of over 25%. In addition, considerable areas are usable only for selected crops which are not susceptible to highly gravelly horizons between 25 and 50cm soil depth.

Imperfect and poor drainage also limit land suitability in small areas around both swamps. In addition coarse soil textures deem certain small areas to be only marginally suitable or unsuitable for dryland cropping.

The levee soils which are found adjacent to the river Gebe near Swamp 2 are deep and well drained but coarse textured, which make them unsuitable for rainfed cropping.

The most suitable land (US2), covers only 13.5 ha. It is poorly distributed, but generally located along the periphery of Swamp 1 and within 50m of Swamp 2.

In conclusion, there are only small areas of upland suitable for coffee, cocoa and the more demanding arable and vegetable crops.

11.3.4 Vegetation and Land Use (Maps 13 and 17)

a) The Swamp

Almost all of Swamp 1 is under wetland forest or young regrowth: the small rice farm area (A) in the south was being planted at the time of survey. It is clear from the presence of the young regrowth, that this swamp is quite frequently used for rainfed rice production. No irrigation or drainage structures were seen.

Swamp 2 is wholly under wetland forest and regrowth, certain areas having been used as farmland in the past three years. In both swamps, the wetland forest is characterised by a generally

TABLE 11.7: LAND SUITABILITY AT JOHN DAVID TOWN, SWAMP 2

Applicability	Suitability Category	Major Limiting Feature	Area ha	Area %
	Well suited $US2_t$	Dominant slopes between 4 and 8%	3.4	15
Upland for rainfed cropping	Moderately suitable $US3_t$	Dominant slopes between 9 and 15%	0.8	3
	$US3_g$	Very gravelly horizons between 50 and 100cm	3.0	13
	Marginally suitable $US4_g$	Very gravelly horizons between 25 and 50cm	1.4	6
	$US4_s$	Moderately coarse textured soil	1.6	7
	Unsuitable except for forestry UN_t	Dominant slopes over 25%	0.7	3
	UN_g	Very gravelly horizons within surface 25cm	3.9	17
	UN_s	Coarse textured soils to 1m depth	1.6	7
	UN_d	Imperfectly to poorly drained	0.6	3
Swamps for flood irrigated rice	Moderately suitable $RS2_s$	Medium textured soils	0.6	3
	Marginally suitable $RS3_t$	Presence of slopes within range 1 and 2%	0.9	4
	$RS3_s$	Moderately coarse textured soils	4.5	19
		GRAND TOTAL:	23.0	100

full canopy of bamboo and palm species. Regrowth in the swamps comprises adapted wetland bush and invasion species together with ferns, reeds and other fleshy species : young regrowth in wetland can be particularly thick, tangled and difficult to penetrate.

b) The Upland and Swamp Fringe

High forest occupies nearly 50% of the upland around Swamp 1, especially on the higher-lying land. The remainder is under regrowth or 1986 upland rice. No areas of vegetable or fruit crops were seen within the survey limits, though some do occur between the river Gebe and the village of John David Town to the northwest of the swamp.

Around Swamp 2, all the land has been used in the past twelve years except for a small strip of dryland forest lying along the levee of the river Gebe. New farmland is providing the 1986 upland rice crop on line R: this land had been cleared at the time of survey but planting was being delayed until the onset of the heavier, more regular rains.

No tree crop areas were seen within the swamp survey limits: the farmers grow only very small amounts of cocoa and coffee - a finding supported by both the village land and agronomy surveys.

11.3.5 Water Resources

Swamp 1 is fed by two main streams, the larger from the south was flowing in February, 1986, but the smaller one from the southwest was dry. At the limit of the trace survey, both streams were associated with only narrow areas of riverine swamp. At the time of survey, the main north-south stream was flowing gently in the upstream section of the swamp (parallel to line KX) but only intermittently in the north of the swamp.

Swamp 2 was fed by a more substantial stream, two metres wide and over 50cm deep, flowing moderately fast. Swamp 2 was wetter than Swamp 1, due to the larger size of the catchment and the stream, and to the effect of the main road and culvert, which appeared to cause some back-up of water.

Both swamps were naturally wetter than the surveyed area at Beezohn and as the rains were beginning at the time of the John David Town survey, water tables were significantly higher. Levels of groundwater ranged widely between near the surface and 1.5 metres below ground level: one heavy overnight rain could significantly saturate a profile and raise the water table by 50cm. Thus measured levels very much depended on when observations were made. However, considering that the rains had only just begun, there appears to be no lack of water resources for flood irrigated rice in these two swamps.

11.4 SWAMP DEVELOPMENT PROPOSALS (Maps 16 and 20)

a) John David Town Swamp 1

The proposed cropping patterns for John David Town Swamp I and surrounding area are given in Table 11.8. The location of the land development units (LDU), together with outline engineering designs are summarised in Figure 11.2.

The area of swamp surveyed was 28.4 ha. Some 6.0 ha (21%) are classed as LDU RS1/2 which is suitable for double cropping of irrigated rice. Land classed as LDU RS3 totals 21.4 ha (76%) and is suitable for single cropping of rice. A small area of 0.9 ha on the eastern side of the swamp is classed as unsuitable (RN).

The upland area comprises 81.6 ha, of which 10.1 ha(12%) is classed as LDU US1/2 as being suitable for all annual and tree crops. Almost a third of the area (some 25.7 ha) is classed as LDU US3/4 which is suitable for selected tree crops and food crops. Over half the upland area (45.8 ha) is LDU UN and is located in reasonably large blocks of land all around the swamp.

The engineering outline design in Figure 11.2 proposes a main drain following the natural drainage along the west side, with a peripheral channel along the other side. Branch drains connect the two eastern extensions of the swamp to the main drain. A head bund is located at the southern end of the swamp.

b) John David Town Swamp 2

Table 11.9 gives the recommended cropping pattern for this small swamp and surrounding area, while Figure 11.3 shows the location of the area, together with outline engineering designs.

The swamp has an area of 6.0 ha, of which 90% (5.4 ha) is LDU RS3. There is 0.6 ha (10%) of LDU RS 1/2 suitable for double cropping of irrigated rice.

The upland area comprises 17 ha, of which 3.4 ha is LDU US1/2 and suitable for all crops. The remainder of the area is equally divided between LDU US3/4 (6.8 ha - 40%) and LSU UN (6.8 ha - 40%).

The engineering outline design indicates a main drain running along the east of the area, passing through an existing culvert and then through the centre of the swamp. At the time of construction the level of the culvert should be checked to determine whether it is low enough. If possible, this should not be moved because of the high cost.

Peripheral channels are provided where the main drain is not running along the side of the swamp. These can be fed from a head bund. No provision has been made for passing the peripherals under the road because of the high cost, although this could result in inadequate water supplies for the areas downstream of the culvert. However, the peripheral channels in the area may be able to gather sufficient water from the surrounding slopes.

TABLE 11.8: PROPOSED CROPPING PATTERN FOR JOHN DAVID TOWN SWAMP 1

Location	Land Suitability (LDU)		Area Ha	Area %	Crop Proposed	Inputs for Sustainable Cropping: Single Crop	Inputs for Sustainable Cropping: Double Crop
Swamp	RS1/2	Suitable	6.0	21	Irrigated rice	+	++
	RS3	Marginal	21.4(1)	76	Irrigated rice	++	Not recommended
	RN	Not suitable	0.9	3	None		
			28.3	100			
Upland	US1/2	Suitable	10.1	12	Annual crops and tree crops	*	**
	US3/4	Marginal	25.7	32	Selected tree crops (excl. cocoa) and food crops. US4 not suitable for coffee	**	Not recommended
	UN	Not suitable	45.8	56	None		
			81.6	100			

NOTES (1) Some swamp area out of command

+ Denotes small fertilizer application required after 2nd or 3rd year.
++ Denotes moderate fertilizer application required after 1st crop, good water management and husbandry practices.

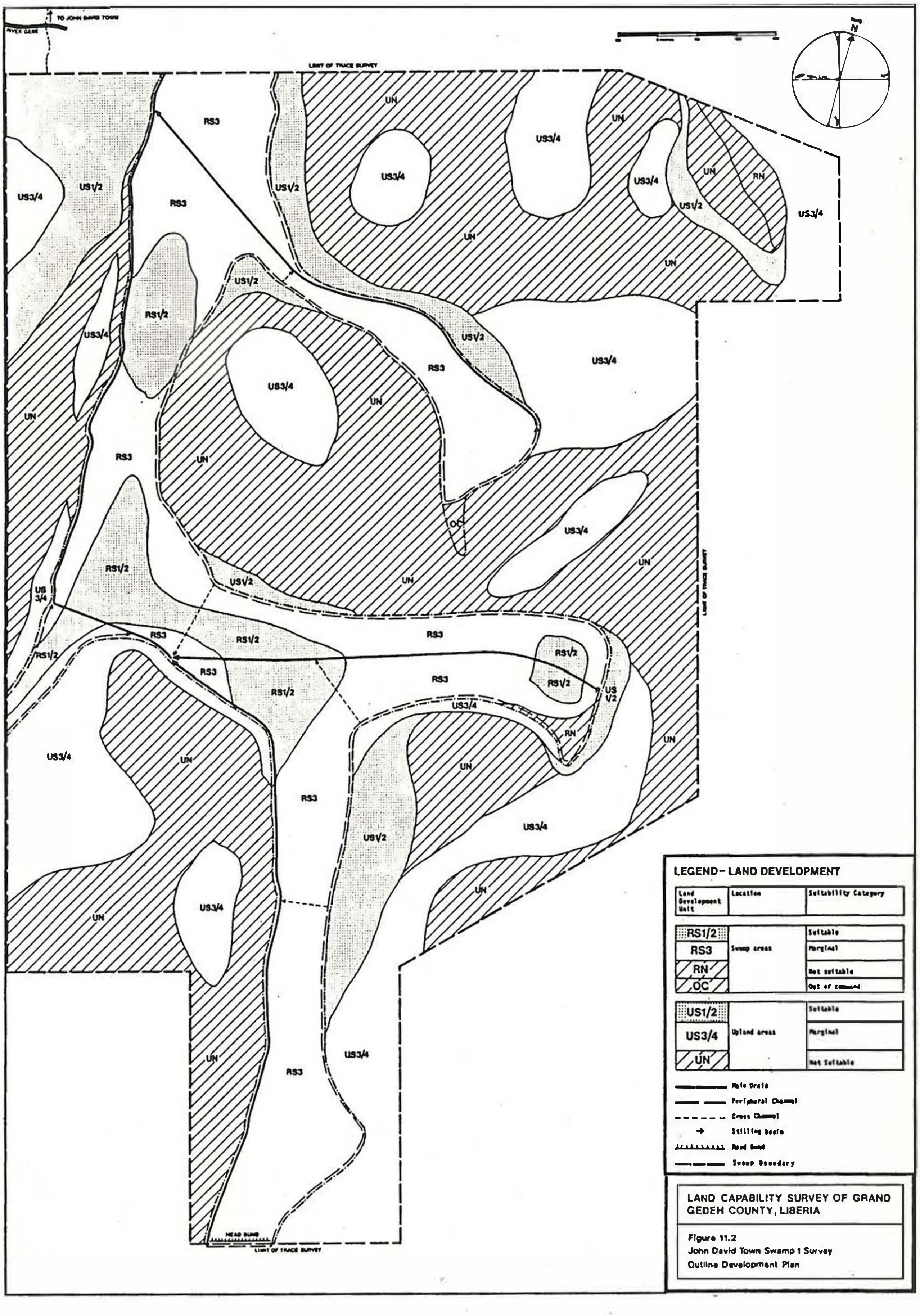
* Denotes appropriate crop rotation for annual crops with legume or fallow break. Small fertilizer application required after 2nd or 3rd year.
** Denotes small fertilizer application and appropriate rotation for annual crops.

TABLE 11.9: PROPOSED CROPPING PATTERN FOR JOHN DAVID TOWN SWAMP 2

Location	Land Suitability (LDU)		Area Ha	Area %	Crop Proposed	Inputs for Sustainable Cropping: Single Crop	Inputs for Sustainable Cropping: Double Crop
Swamp	RS1/2	Suitable	0.6	10	Irrigated rice	+	++
	RS3	Marginal	5.4	90	Irrigated rice	++	Not recommended
	RN	Not suitable	0	0	None		
			6.0	100			
Upland	US1/2	Suitable	3.4	20	Annual crops and tree crops	*	**
	US3/4	Marginal	6.8	40	Selected tree crops (excl. cocoa) and food crops. US4 not suitable for coffee	**	Not recommended
	UN	Not suitable	6.8	40	None		
			17	100			

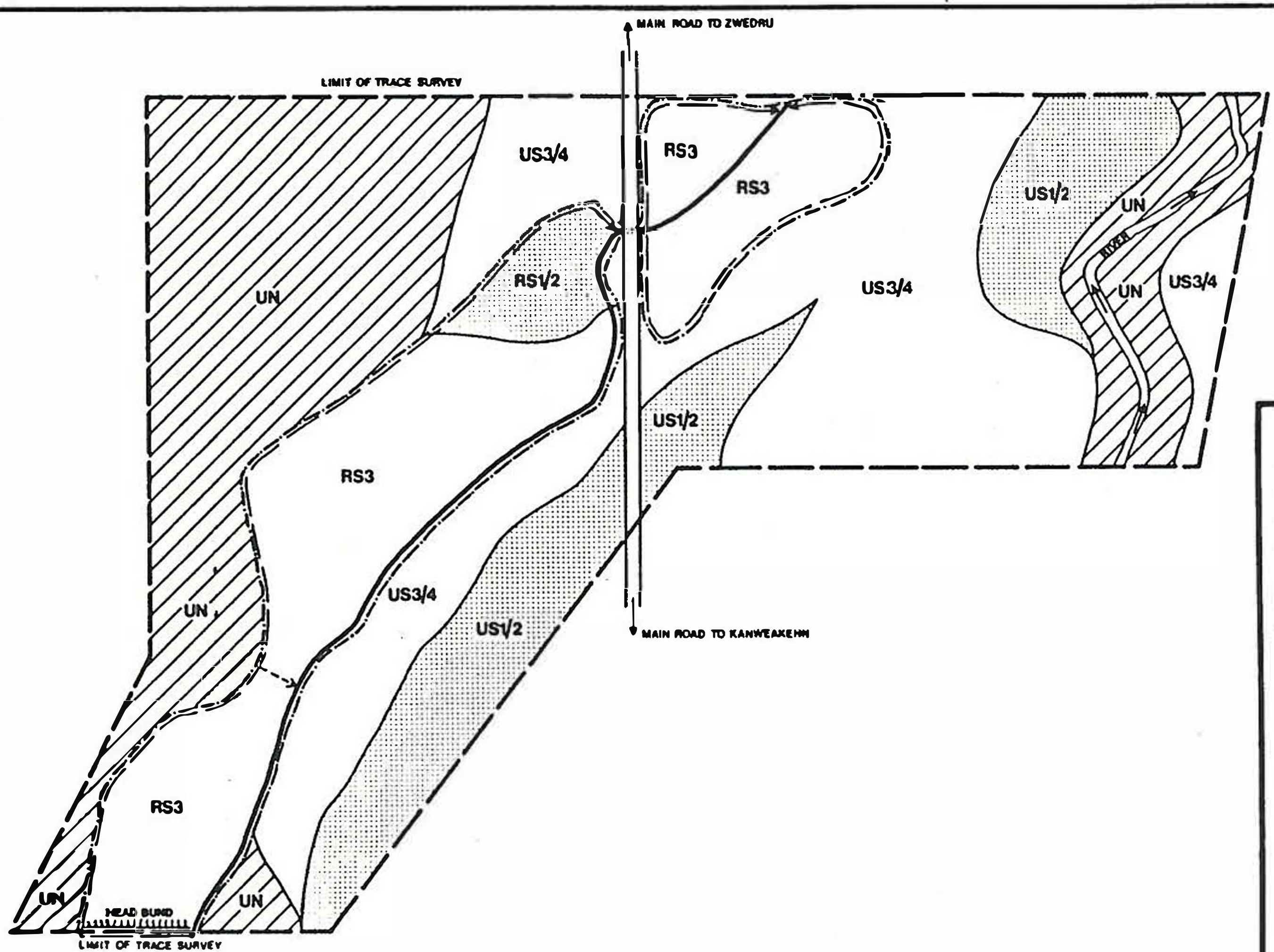
NOTES: + Denotes small fertilizer application required after 2nd or 3rd year.
++ Denotes moderate fertilizer application required after 1st crop, good water management and husbandry practices.

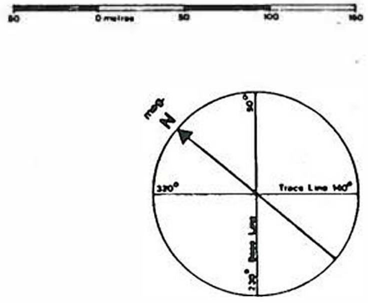
* Denotes appropriate crop rotation for annual crops with legume or fallow break. Small fertilizer application required after 2nd or 3rd year.
** Denotes small fertilizer application and appropriate rotation for annual crops.



LAND CAPABILITY SURVEY OF GRAND GEDEH COUNTY, LIBERIA

Figure 11.2
John David Town Swamp 1 Survey
Outline Development Plan





LEGEND – LAND DEVELOPMENT

Land Development Unit	Location	Suitability Category
RS1/2	Swamp areas	Suitable
RS3		Marginal
RN		Not suitable
OC		Out of command
US1/2	Upland areas	Suitable
US3/4		Marginal
UN		Not Suitable

Main Drain
Peripheral Channel
Cross Channel
Stilling basin
Head Bund
Swamp Boundary

LAND CAPABILITY SURVEY OF GRAND GEDEH COUNTY, LIBERIA

Figure 11.3
John David Town Swamp 2 Survey
Outline Development Plan

12. FISHTOWN

12.1 LOCATION AND SIZE

Fishtown is situated in Webbo District on the main road from Zwedru to Harper, some 25km to the east of Kanweakehn (Figure 12.1). The town lies at an intersection with a road leading to the villages of Tealokehn and Jabolokehn to the north. There are some 40 houses in Fishtown which suggests a population of 200-250 persons. The surveyed swamp is immediately to the north and west of the town and walking time from the village to the edge of the swamp is no more than 5 minutes.

Forty-seven farmers expressed interest in participating in a swamp development programme. These farmers have between them some 112 helpers.

12.2 VILLAGE LAND SURVEY

12.2.1 General Description

The Fishtown area is undulating to hilly. Gradients are generally steeper to the north and east of Fishtown than to the south and west. The Nismeh River flows from northwest to southeast, crossing the main road some 3km northwest of Fishtown and flowing just to the south of the village. Small tributaries flow into the Nismeh from both north and south and a major tributary flows from the west to meet the Nismeh to the west of Fishtown. The Nismeh River maintains flow throughout the dry season.

12.2.2 Vegetation and Land Use (Map 21)

Cultivation is practised mainly in the valley of the Nismeh and its tributaries and also on the uplands particularly along the routes of the motor roads which provide easy access to the adjacent land. Farmers from Fishtown cultivate land as far as the boundary between Webbo and Gbeapo districts (about 5 km to the west) and as far north as the River Gbe. They also cultivate along the road and the Nismeh river to the east for about 6 km, but to the south cultivation is restricted by hills.

Land in the cultivation cycle carries a mosaic of secondary bush regrowth and farms; high forest occupies most of the hilly terrain outside the cultivated areas.

12.2.3 Soils and Land Capability (Maps 22 and 23)

An area of some 2750 ha was surveyed.

The forested land bordering the Nismeh River is occupied by shallow concretionary soils (soil unit D4) on shallow to steep slopes. Although not always limited by gradient, such gravelly and shallow soils cannot be recommended for improved or intensified agriculture even where they occur on gentle slopes and such land has a land capability classification of Class 5. Such land should be reserved for forest.

Hilly terrain to the north of Fishtown along the roads to Tealokehn and Jabolokehn often has deeper, less concretionary soils with plinthite within 1m depth. Such soils are classified as D7 and D8 and the capability of this land is limited by the steepness of the terrain. Generally, the terrain is no better than capability Class 4 where slopes are less than 25%; steeper slopes are Class 5.

The soils in the valley of the Nismeh River and its major tributaries are formed from colluvio-alluvial material. They are generally deep and of coarse to medium texture (soil unit L3) and sometimes of finer texture (soil unit L1). These soils occupy fairly extensive stretches of land in the valleys and on the fringes of the surrounding upland. Apart from the lowest areas adjacent to water courses which are liable to flooding, these areas have high potential for sustained agricultural production and their land capability is Class 1. Swamps occupy some of the minor tributaries of the Nismeh River but they are generally of small size and with coarse soil texture.

12.3 SWAMP SURVEY

An area of 98.5 ha was surveyed during March 1986 (Table 12.1). The area consisted of one large swamp and surrounding area and the most distant parts of the swamp were within 20 minutes walking from the village.

Soil observations were made at 162 sites by auger and at ten sites by profile pit. Depth of groundwater tables was measured wherever they were seen at the observation sites. Hydraulic conductivity measurements were made at nine locations and infiltration rate tests at four.

Soil samples from four pits were sent for chemical analysis, the results of which are recorded and discussed in Appendix A.

General Plan of Fishtown Area

Figure 12.1

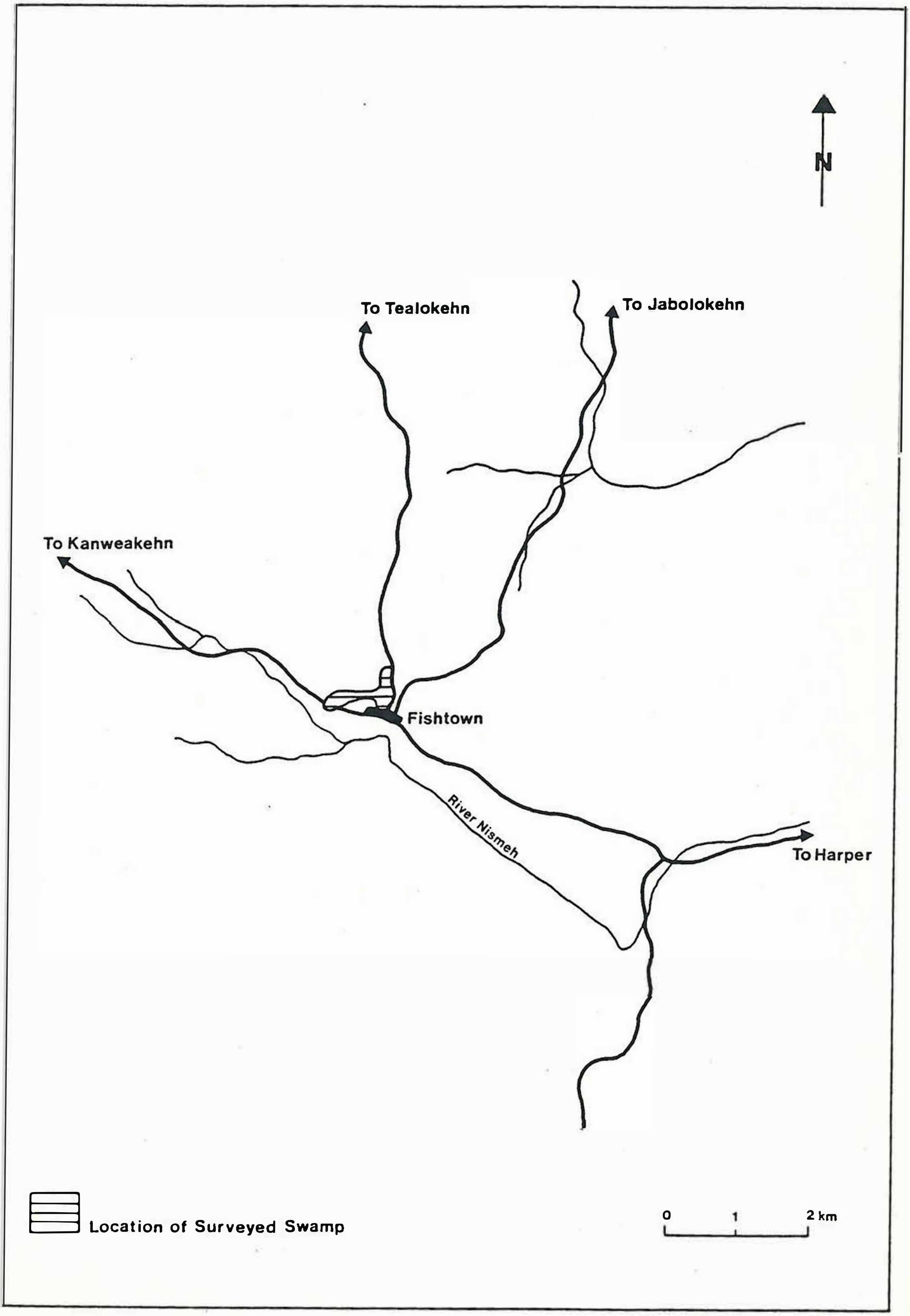


TABLE 12.1: SWAMP SURVEY SUMMARY : FISHTOWN

DESCRIPTION	AREA ha	AREA %
AREA SURVEYED (inc. village area, 3.9 ha)	98.5	-
Area of Swamp*	38.2	100
Highly suitable for rice	0	0
Moderately suitable	0	0
Marginally suitable	28.6	75
Unsuitable	9.6	25
Area of Upland*	60.3	100
More or less suitable for one or other form of cropping	26.7	44
Unsuitable for cropping	33.6	56
Area under+ - rice, 1986 growing season	1.8	2
- other fruit or vegetable crops	1.3	1
- tree crops	0.7	1
- regrowth	59.9	61
- dryland forest	8.2	8
- wetland forest	22.7	23
- village	3.9	4

*See Tables 9.3 and 12.3 for further information on land suitability.

+See Map 24 for further details.

12.3.1 Soils (Map 25)

The soils are described in Table 9.1, and the crop suitability classifications criteria are given in Table 9.3. Full profile descriptions of the major soil units are given in Appendix A. Distribution of soil types is shown in Table 12.2.

TABLE 12.2: SOILS DISTRIBUTION IN FISHTOWN

Soil Unit	Location	Area ha	Area %
D1	Upland	7.0	7
D2		6.1	6
D3		6.1	6
D4		29.0	30
L1	Lowland and Swamp	3.3	3
L2	Fringe	0	0
L3		4.5	5
L4		4.3	4
W1	Swamp	0	0
W2		0	0
W3		28.6	29
W4		9.6	10
	TOTAL	98.5	

a) <u>The Swamp</u>

The main feature of the soils of the Fishtown swamp is that all profiles observed were either coarse or moderately coarse textured, although the soils in the south of the swamp are generally slightly finer textured than those in the north and west.

In the moderately coarse profiles (W3), which occupy some 75% of the swamp, textures are sandy clay loams and sandy loams. Within the top metre, in which there are often narrow horizons of medium to coarse sand, few profiles contain materials which are finer than sandy clay loam.

Textures at depths of greater than 1.2m are silty clay with weathering parent material influence, or sandy clay in which the sand fraction is often coarse.

In the coarse soils (W4), the top metre generally contains up to 80 cm of medium to coarse sand, often associated with up to 10 per cent angular quartzitic gravel, 2 - 3 cm in diameter, derived from granitic parent material. At a few sites, 10 cm diameter quartzitic gravels were seen at depths greater than 1m; none of these gravels constituted a limitation to agricultural potential. Significant areas are characterised by these coarse soils, especially in the west, which tend to occur adjacent to the swamp fringe.

Soil colours are commonly dark browns and greyish browns over greys and light greys: the medium and coarse sand horizons range from a bleached white to an organically stained dark greyish brown, even at depths of 50 to 60 cm. The silty weathered parent material below 1.5 m is mostly white, with brown and grey blemishes.

Histic topsoils of over 25 cm depth were seen in two areas and are mapped as $W3_h$. Profiles were moist to wet and consistency is generally soft to slightly sticky; in the coarser textured horizons (sands and loamy sands), consistency is loose and non-sticky. Few, faint to distinct mottles occur only in the sandy clay loam and finer sandy loam horizons nearer the surface, although brown to white blemishes do occur in the coarser horizons.

There was no limitation to rooting depth within the top metre except at three haphazardly distributed locations where granitic parent material occurs at between 50 and 100cm.

b) The Upland and Swamp Fringe

Much of the area is characterized by gravelly soils. The main features are discussed below:-

Soils are generally much finer textured (sandy clay loams and sandy clays) than the swamp soils especially in locations away from the swamp periphery. The most widespread category is D4 soils, with highly gravelly horizons within the surface 25 cm; these soils generally occur upslope away from the swamp in the northwest, southwest and southeast. Only a very few fine roots penetrate the gravel horizons which were often impenetrable by auger where gravel constituted over 60 per cent of the soil material.

Deep gravel-free, well drained upland soils (D1) occur only as a narrow band in the northeast.

Much of the available swamp-fringe lowland is coarse textured (L4), though there are more finely textured soils in the north and west (L1 and L3). A small lowland area in the middle of the swamp (line G) needs further investigation in respect of its extent, as the soils are moderately fine textured though imperfectly to well drained.

12.3.2 Topography

a) The Swamp

The Fishtown swamp is generally very flat; however, three locations require further topographic survey to assist in the definition of areas in command.

The tongue of lowlying land in the north which crosses lines A, B and C has been moderately well defined by the survey: however, much of the peripheral region of this area is low lying and imperfectly to poorly drained and further topographic survey is required at the time of land clearing to clearly delineate usable swamp land from higher lying lowland, which is probably out of command.

The area on line A (A15 to A20) tends to be on slopes of around 1 to 2 per cent, and may require some levelling to ensure even irrigation.

Finally, the lowland area on line G may encompass an 'island' surrounding sites H3 and H4 to the south: the extent of this island should be investigated at the time of land clearance.

b) The Upland and Swamp Fringe

Gentle to undulating topography characterises the area around the Fishtown swamp. However, moderately steep slopes were seen behind the village on lines I and K; on the latter line, a very short sharp fall between K2 and K3 indicates the boundary between upland and swamp. The farm at K1 is on a moderately steep slope, with the result that severe erosion has occurred, the soil surface being strewn with gravel.

Abrupt slopes were also seen in the northwest on lines A, B, C, D and E, where highly gravelly soils abut directly against the swamp.

The upland in the northeast and southwest is undulating, slopes only very rarely exceeding 8 per cent.

12.3.3 Land Suitability (Map 26)

a) The Swamp

Because of the coarse to moderately coarse textured nature of the profiles, the swamp is either only marginally suitable or unsuitable, (see Table 12.3).

About 25 per cent of the swamp is classified here as unsuitable for irrigated rice (RN_S) because of highly infertile coarse soils, with very little capacity for holding applied nutrients. Rice trials should be carried out on these soils once the better soils have been developed successfully, to determine if they have any potential for development.

TABLE 12.3: LAND SUITABILITY AT FISHTOWN

Applicability	Suitability Category	Major Limiting Feature	Area ha	Area %
	Highly suitable US1	No limiting feature	2.7	3
Upland	Well suited $US2_t$	Dominant slopes between 4 and 8%	2.4	2
for	$US2_d$	Moderately well drained	5.5	6
rainfed cropping	Moderately suitable $US3_g$	Very gravelly horizons between 50 and 100cm	5.8	6
	Marginally suitable $US4_t$	Dominant slopes between 16 and 25%	0.4	(1)
	$US4_g$	Very gravelly horizons between 25 and 50cm	6.1	6
	$US4_s$	Moderately coarse textured soils	0.4	(1)
	$US4_d$	Imperfectly drained soils	3.4	4
	Unsuitable except for forestry UN_t	Dominant slopes over 25%	2.0	2
	UN_g	Very gravelly horizons within surface 25cm	27.3	28
	UN_s	Coarse textured soils to 1m depth	4.3	4
Swamps for flood	Marginally suitable $RS3_s$	Moderately coarse textured soils	28.6	29
irrigated rice	Unsuitable RN_s	Coarse textured soils, often in association with quartzitic gravel	9.6	10
		GRAND TOTAL:	98.5	100

The remainder is only marginally suitable because of texture, though the presence of sandy loam and sandy clay loam horizons at least affords some nutrient and water retention capacity.

Fortunately, the swamp is well fed with streams that flow throughout the wet season and the lower horizons are fine textured and relatively impermeable. Thus the low water holding capacity of these soils does not present a major limitation.

Uneven microtopography may present a problem in terms of irrigability and hence create the need for land levelling in certain locations; this should be investigated at the time of land clearing.

b) The Upland and Swamp Fringe

The presence of gravel affects much of the upland and large areas are unusable because of surface gravel horizons, or usable for only a limited range of selected crops because of gravel within the top metre (Table 12.3).

Swamp fringe lowland areas are affected by imperfect drainage, and/or coarse textures, making considerable areas unsuitable.

Nearly all of the upland is affected by limitations, but the most usable areas occur in the northeast. Around the village itself, most of the land is either unsuitable for cropping or only moderately suitable due to gravelly soils.

12.3.4 Vegetation and Land Use (Map 24)

a) The Swamp

Almost all the swamp is under wetland forest or regrowth. The small rice farm area in the west of the swamp was being planted to rice at the time of survey. From the blocks of regrowth scattered throughout the swamp, it is clear that the local farmers frequently use this area of wetland. No irrigation or drainage structures were seen.

The wetland forest is dominated by bamboo with full canopy, together with palm species and other trees adapted to survival in areas prone to flooding. Adaptations of the trees include aerial roots, nemataphores and shallow roots. Climbing vines, parasitic and saprophytic plants are also common.

b) The Upland and Swamp Fringe

The main feature of the upland vegetation is that it is almost entirely regrowth, which is due to the fact that the area surveyed surrounds the village of Fishtown.

A small area of high forest occurs in the northwest, but the rest of the area has been cleared at some stage. Two small farm areas were seen where land was being cleared for upland rice; in addition, a small area of bananas in young regrowth occurs in the northeast.

Also in the northeast, there is an overgrown cocoa plantation, representing the only tree crop seen in the survey area. Around the village a few areas of vegetables, pineapples and fruit trees occur, but generally the farmers at Fishtown showed little apparent interest in growing coffee and cocoa.

12.3.5 Water Resources

The swamp follows the course of two small meandering streams flowing from the north. The maximum width of the streams was 1.5m, and depth at the time of survey did not exceed 50cm. The stream beds tend to be shallow and ill-defined in the north of the swamp, becoming deeper and better defined in the south by Fishtown village, where the landform channels the stream into a narrower swamp prior to discharging through a culvert under the main road.

Water tables are generally within the surface metre throughout the swamp, though significantly wetter areas do exist: standing water occurred on lines A, B and C near the streams, as well as on line F, whereas the area between sites F8 and F12 was flooded at times during the survey, groundwater tables being at or near the surface.

Most water tables during March were perched in the coarse or moderately coarse surface horizons, lying on top of the relatively impermeable subsoil or weathering parent material. Wherever this impermeable layer was punctured by the extension auger, water table levels usually dropped to below 1m and occasionally 2m.

Profiles are probably waterlogged throughout the wet season, and much of the delineated swamp area will be flooded. It is likely that the surface horizons will be saturated first at the onset of the rains, the deeper horizons being affected at a later data by the gradual rise of the regional water table as the wet season progresses.

Water resources, therefore, appear to be adequate for flood irrigated rice during the wet season, given good water management and the construction of the required water control structures.

12.4 SWAMP DEVELOPMENT PROPOSALS (Map 27)

The proposed cropping patterns for the Fishtown swamp and surrounding area are given in Table 12.4 and the location of the land development units (LDU), together with outline engineering designs, are shown in Figure 12.2.

TABLE 12.4: PROPOSED CROPPING PATTERN FOR FISHTOWN SWAMP AREA

Location	Land Suitability (LDU)		Area Ha	Area %	Crop Proposed	Inputs for Sustainable Cropping: Single Crop	Inputs for Sustainable Cropping: Double Crop
Swamp	RS1/2	Suitable	0	0	Irrigated rice	+	++
	RS3	Marginal	26.6[1]	80	Irrigated rice	++	Not recommended
	RN	Not suitable	6.6[1]	20	None		
			33.2	100			
Upland	US1/2	Suitable	10.6	17	Annual crops and tree crops	*	**
	US3/4	Marginal	16.1	27	Selected tree crops (excl. cocoa) and food crops. US4 not suitable for coffee	**	Not recommended
	UN	Not suitable	33.6	56	None		
			60.3	100			

NOTES (1) Some swamp area out of command

\+ Denotes small fertilizer application required after 2nd or 3rd year.

++ Denotes moderate fertilizer application required after 1st crop, good water management and husbandry practices.

* Denotes appropriate crop rotation for annual crops with legume or fallow break. Small fertilizer application required after 2nd or 3rd year.

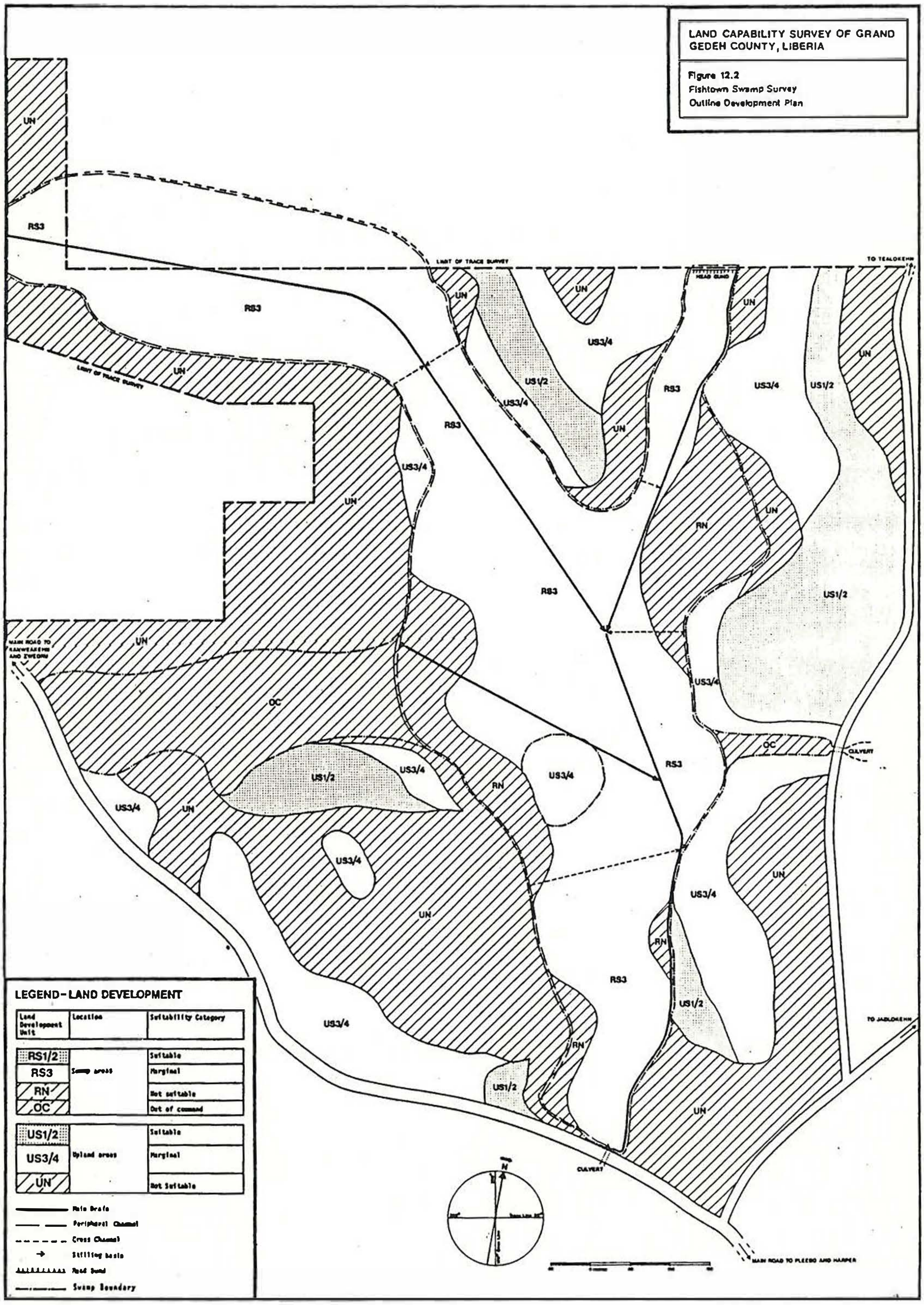
** Denotes small fertilizer application and appropriate rotation for annual crops.

The swamp is notable for the total absence of any LDU RS1/2. There are 26.6 ha (80%) of marginal land (RS3) suitable for single cropping and 6.6 ha of unsuitable land (RN) located on each side of the swamp.

The upland area has 10.6 ha (17%) of LDU US1/2 suitable for all annual and tree crops located mainly on the northeastern side of the swamp. More marginal lands (US3/4) totalling 16.1 ha are found scattered throughout the area. The unsuitable land areas (UN), amounting to 33.6 ha (56%), are located in fairly large blocks on all sides of the swamp.

This is a large swamp but parts of the western fringe are excluded from the development proposals because of unsuitable soils. Other parts are out of command. The main drain is in the centre of the area and follows natural drainage lines. A peripheral channel should be built where the main drain does not run along the side of the swamp.

A head bund should be constructed at the northern end and the culvert at the southern end should be checked to ensure that it is deep enough to accommodate the drain. If possible, drain levels should be changed rather than the culvert having to be deepened.



LAND CAPABILITY SURVEY OF GRAND GEDEH COUNTY, LIBERIA
Figure 12.2
Fishtown Swamp Survey
Outline Development Plan
LIMIT OF TRACE SURVEY
TO TEALOKEHN
HEAD BUND
CULVERT
MAIN ROAD TO PLEEBO AND HARPER
RS3
UN
US3/4
US1/2
RN
OC
LEGEND-LAND DEVELOPMENT
Land Development Unit
Location
Suitability Category
RS1/2
RS3
RN
OC
Swamp areas
Suitable
Marginal
Not suitable
Out of command
US1/2
US3/4
UN
Upland areas
Suitable
Marginal
Not Suitable
Main Drain
Peripheral Channel
Cross Channel
Stilling basin
Road Bund
Swamp Boundary

13. TUOBO GBAWELEKEHN

13.1 LOCATION AND SIZE

Tuobo Gbawelekehn is situated in Webbo District on the main road from Zwedru to Harper, some 37km south of Fishtown (Figure 13.1). Two small neighbouring villages (Jalatokehn and Wartekehn) were also included in the study. Weah Town is situated about 5km to the north. Unmaintained motor roads lead to the northeast from Gbawelekehn to Diebo and to the southwest towards the River Gee.

The size of each village is shown in Table 13.1.

TABLE 13.1 NUMBER OF HOUSES

Village	Number of houses
Gbawelekehn	83
Wartekehn	28
Jalatokehn	10
TOTAL	121

The total number of houses in all three villages is 121, suggesting a total population of the order of 600 persons.

The number of farmers who have expressed an interest in participating in a swamp development project is shown in Table 13.2.

TABLE 13.2: FARMERS INTERESTED IN SWAMP DEVELOPMENT

Village	No. of Interested Farmers	Number of Helpers
Gbawelekehn	45	134
Wartekehn	18	39

Two swamps were surveyed in the Tuobo area. One is situated immediately to the north of Gbawelekehn and consists of two branches which join together downstream. This swamp is within 5 minutes walking distance of the town. Jalatokehn is about 20 minutes walk from the swamp. The second swamp is north of Wartekehn and about 15 minutes walking distance from that village.

13.2 VILLAGE LAND SURVEY

13.2.1 General Description

The Tuobo Gbawelekehn area is gently undulating to moderately hilly, but with isolated hills standing some 100-150 feet (35-50m) above the general level of the plains. Slopes on the undulating plains are gentle; steeper slopes occur on hilly terrain particularly to the north and west and on the isolated hills. Drainage is provided by a number of small rivers flowing towards the east and southeast to outfall in the Cavalla River; these rivers have generally only narrow floodplains and terraces. The rivers have perennial flow.

13.2.2 Vegetation and Land Use (Map 28)

A large area around Tuobo Gbawelekehn consists of a mosaic of secondary regrowth bush and farms. High forest is largely confined to distant areas to the south and to hilly areas to the southwest, southeast and northwest. Cultivation extends well inside the area, away from the motor roads along a network of footpaths.

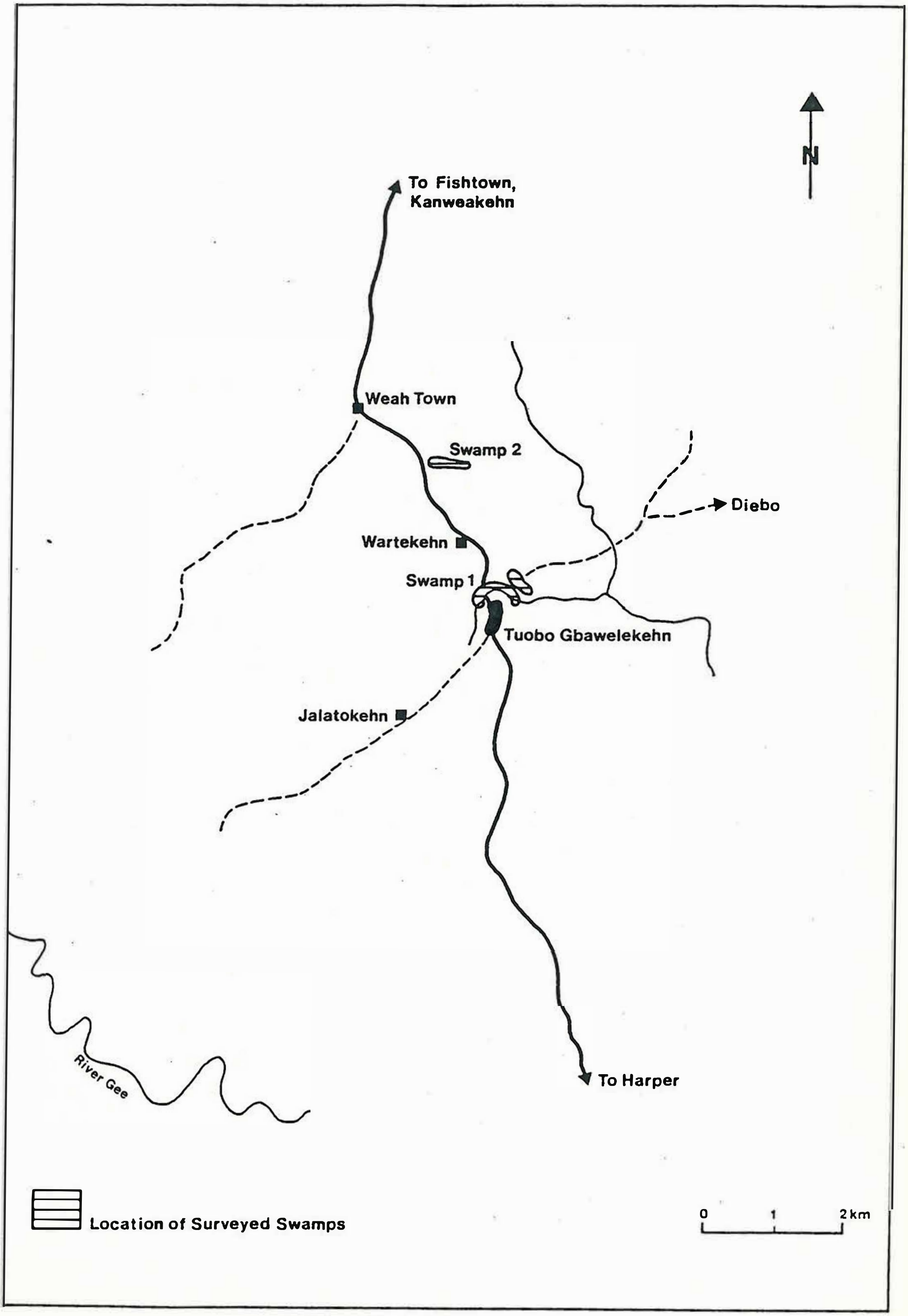
13.2.3 Soils and Land Capability (Maps 29 and 30)

An area of some 2400 ha was surveyed.

Much of the gently undulating upland is characterised by deep well drained soils of coarse to medium texture; the soils are either free of concretions or are only slightly gravelly (soil units D1 and D8). Many of the soils are noticeably pale in colour and are of predominantly sandy loam texture (soil unit D5). Such land with gentle slopes is considered to have a capability of Classes 1 or 2 and has the potential to grow a wide range of row and tree crops with appropriate attention to the soil conservation requirements. Undulating areas with similar deep and relatively gravel-free soils have a capability of Class 3 and will require more comprehensive soil conservation measures on steeper sloping land.

Areas mapped as soil units D6 and D7 are more gravelly, containing concretions and small stones; they also tend to occur on more undulating terrain with steeper slopes and may have restricted root depth. Such areas are less suitable for cropping and cultivation than the more gently undulating areas described above, and they have a land capability of Class 3 or 4.

River valleys are generally narrow and the alluvium is restricted to narrow bands in the immediate vicinity of the river. The alluvium is generally of medium to coarse texture and the main hazard in using these areas for upland production is the risk of flooding. Swamps tend to occur in the upper reaches of the river courses. Most of the swamps in the Tuobo Gbawelekehn area are coarse textured (sand) and are therefore not very suitable for swamp rice development.


N
To Fishtown,
Kanweakehn
Weah Town
Swamp 2
Diebo
Wartekehn
Swamp 1
Tuobo Gbawelekehn
Jalatokehn
River Gee
To Harper
Location of Surveyed Swamps
0
1
2 km

Hilly terrain with shallow, gravelly soils (soil unit D4) are largely restricted to the margins of the surveyed area. These areas, together with the isolated rocky hill outcrops (unit H) are unsuitable for improved and intensified agricultural production.

13.3 SWAMP SURVEY

Two locations, covering a total area of 87.7 ha were surveyed during April 1986. The major swamp (Swamp 1) lies close to the north and east of the village, 2 to 15 minutes walking distance. The area surveyed was 60.6 ha out of which the swamp itself occupies 14.3 ha (Table 13.3).

27.1 ha were surveyed at swamp 2 which is about one hour's walking distance from Tuobo Gbawelekehn, but was chosen with the farmers of Wartekehn in mind. There were no substantial areas of wetland available in the near vicinity of Wartekehn and after a rapid reconnaissance of the surrounding land, Swamp 2 was seen as having the most potential, despite its moderately distant location. However, the detailed survey showed that it is very small, and only marginally suitable due to moderately coarse soils (Table 13.4). Development is therefore not recommended and the swamp is not discussed further in this section. Vegetation and land use, soils and land suitability for Swamp 2 are shown on Maps 35, 36 and 37.

Swamp 1 consists of two parts, A and B. Part A is very near the village and follows the course of the stream which flows eastwards.

Part B of the swamp lies to the northeast and east of the village and follows the course of another stream, also flowing east and parallel to the stream in Part A.

Soil observations were made at 150 sites by auger and at 10 sites by profile pit (Swamps 1 and 2). Depth of groundwater tables was measured wherever observed. In Swamp 1, hydraulic conductivity measurements were made at 10 locations and infiltration rate tests at three sites.

Soil samples from four pits were sent for chemical analysis, the results of which are recorded and discussed in Appendix A.

13.3.1 Soils (Map 32)

The soils are described in Table 9.1, and crop suitability criteria are given in Table 9.3. Full profile descriptions of the major soil units are given in Appendix A. The distribution of soil units is given in Table 13.5.

TABLE 13.3: SWAMP SURVEY SUMMARY : TUOBO GBAWELEKEHN SWAMP 1

DESCRIPTION	AREA ha	AREA %
AREA SURVEYED (inc. village, 0.8 ha)	60.6	-
Area of Swamp*	14.3	100
Highly suitable for rice	0.8	6
Moderately suitable	11.5	80
Marginally suitable	1.5	10
Unsuitable	0.5	4
Area of Upland*	45.5	100
More or less suitable for one or other form of cropping	41.3	91
Unsuitable for cropping	4.2	9
Area under+ - rice, 1986 growing season	4.7	8
- other fruit or vegetable crops	0.1	(1)
- tree crops	14.9	25
- regrowth	37.7	65
- dryland forest	0	0
- wetland forest	0	0
- residential areas	1.2	2

*See Tables 9.3 and 13.6 for further information on land suitability.

+See Map 31 for further details.

TABLE 13.4: SWAMP SURVEY SUMMARY : TUOBO GBAWELEKEHN SWAMP 2

DESCRIPTION	AREA ha	AREA %
AREA SURVEYED	27.1	-
Area of Swamp*	1.3	100
Highly suitable for rice	0	0
Moderately suitable	0	0
Marginally suitable	1.0	77
Unsuitable	0.3	23
Area of Upland*	25.8	100
More or less suitable for one or other form of cropping	24.8	96
Unsuitable for cropping	1.0	4
Area under+ - rice, 1986 growing season	0	0
- other fruit or vegetable crops	0	0
- tree crops	0	0
- regrowth	19.6	72
- dryland forest	6.6	25
- wetland forest	0.9	3
- residential areas	0	0

*See Table 9.3 for further information on land suitability.

+See Map 35 for further details.

TABLE 13.5: SOILS DISTRIBUTION IN TUOBO GBAWELEKEHN SWAMP 1

Soil Unit	Location	Area ha	Area %
D1		16.1	26
D2	Upland	5.8	9
D3		6.3	10
D4		0.4	1
L1		8.9	15
L2	Lowland and Swamp Fringe	0	0
L3		14.2	23
L4		0	0
W1		1.0	2
W2	Swamp	5.5	9
W3		1.6	3
W4		0	0
	TOTAL	59.8	

N.B. Total area excludes 0.8 ha, representing the village

a) The Swamp

Part A of the swamp is largely characterised by moderately fine textured soils; an east-west aligned strip of moderately coarse textured soils lies only along part of the northern fringe. Main relevant features are described below:

The moderately fine textured soils (W2) are commonly sandy clay loams over fine sandy clays, clay loams or silty clays; topsoils are dark brown to dark yellowish brown, overlying grey to light grey, often highly and distinctly mottled subsoils.

The moderately coarse textured soils are predominantly sandy loams and sandy clay loams, and usually contain up to 50 per cent angular quartzitic gravel in narrow bands at depths below 50 cm; these soils are also commonly mottled throughout the profile, and are similarly coloured. The coarser textures are due to both the presence of quartzitic gravel and colluvial wash material.

Water tables were high at the time of survey (within 50 cm of ground level), especially in the section to the west of the road (e.g. line X).

Part B of the swamp is characterised by soils of moderately fine to fine texture. However, as water tables rise and fall very rapidly in the north and northeastern section of the swamp during the wet season, and fall well below 1 m during the dry season, the soils have been classified under the Lowland/swamp fringe category, L3. During the rains the majority of this land is suitable for flood irrigated rice providing simple dam structures can be built at suitable locations to maintain high water levels.

In this area, textures are moderately fine to fine sandy clay loams and clay loams over fine sandy clays; coarser horizons occur locally at depths greater than 1 metre - these horizons probably account for the rapid rise and fall in water table.

Profiles are dark greyish brown over grey and light grey; no weathering material was seen within the upper 1.75 m. All profiles are moderately to highly mottled, reflecting the fluctuating water table.

The W2 soils, located further downstream, are waterlogged for longer periods than the L3 soils. They are gleyed to within 20 cm of the surface, moderately fine to fine textured and highly mottled.

Water tables throughout this swamp were within 80 cm of the surface at the time of survey: levels were measured on lines E and F on the morning following a night of particularly heavy rain, hence the high water tables recorded. Information from local farmers suggested that levels would fall significantly to between 50 cm and 1 metre during the following 48 hours.

b) The Upland and Swamp Fringe

A complex pattern of upland and lowland soils occurs. In comparison with the other four villages surveyed in this study, there is a proportionately larger area of lowland soils.

Only one profile with a highly concretionary topsoil (D4) was seen in the east, and areas of the deeper concretionary soils

(D2 and 3) are small and haphazardly distributed. There is, however, a considerable area of deep, well drained concretionary-free upland soil (D1) throughout the area.

Lowland soils lie not only within the swamp boundary and along most of the swamp fringe, but also in the northwest, from where the stream feeding Part B of the swamp meanders through a low-lying colluvio-alluvial area. All lowland soils are mapped as either L1 or L3, all profiles being moderately fine textured but of variable drainage due to proximity of the swamp or position on the slope.

There are no coarse textured profiles in the land surrounding the swamps or drainage lines, but water table levels in the L3 soils lie within 50 cm of the surface after periods of heavy rainfall during the wet season.

13.3.2 Topography

a) The Swamp

In both parts of this swamp the terrain is flat: uneven microtopography is unlikely to present problems. However, as the elevation of the wetlands falls as the streams progress eastwards, minor engineering works will be required to ensure manageable and easily irrigable areas. As mentioned previously, the swamp fringe area in Part B of the swamp may require more major earthworks to ensure that water levels can be maintained throughout the growing season. Further investigation, however, may conclude that this is not possible or outside the scope of the project.

Within the delineated swamp, however, no islands of lowland were found.

b) The Upland and Swamp Fringe

There are several areas of very gentle lowland (average slopes less than 3 %), associated with streams or adjacent to the swamp.

The major topographic feature of the upland, however, is the occurrence of very steep slopes where the streams have incised at the swamp periphery. Slopes of up to 70% occur on lines D, E, F and G where the upland abuts abruptly against the lowland or swamp (Part B). This boundary is approximately delineated by the easterly flowing stream. Shorter, but similarly steep slopes occur on lines A and B (sites A1 and B1) where the upland again abuts abruptly against the swamp (Part A). Slopes to the north of both parts of the swamp are much gentler, only very rarely exceeding 10%.

Two small hillocks occur in the north of the swamp, at sites A6 and C5, on the south side of the stream leading to Part B of the swamp.

The remainder of the upland area is undulating to rolling with slopes ranging from 2 to 12%.

13.3.3 Land Suitability (Map 33)

a) <u>The Swamp</u>

Suitability of the swamp for rice cultivation ranges from highly suitable to marginally suitable; no areas however, are considered unsuitable (Table 13.6).

A small area to the west of the road is highly suitable on account of level topography, high water tables and fine textured soils: efficient drainage systems will be required here as it is liable to deep flooding, a problem probably exacerbated by the presence of the road which acts as a partial dam, despite the culvert.

The suitability of the remainder of the swamp is limited by soil texture; as the great majority of the soils are moderately fine textured, suitability for flood irrigated rice is considered moderate. Of the five villages surveyed, the soils of the swamp at Tuobo Gbawelekehn were the most suitable for flood irrigated rice.

The area of swamp-fringe lowland, characterised by fluctuating water tables (Swamp 1 Part B), may pose problems for irrigation but these have been considered surmountable for the purposes of suitability classification.

A small area of only marginally suitable rice land occurs on the northern fringe of Part A of the swamp; the limiting factor here is moderately coarse textured soils.

b) <u>The Upland and Swamp Fringe</u>

The suitability is complex, being affected by the presence of gravelly soils, steep slopes and areas of poor drainage (Table 13.5). Significantly, the presence of coarse textured soils does not limit land use in the survey area.

Steep slopes (Section 13.3.2) are unsuitable for all considered land use types except forestry, but the area covered by this category is not large. In other locations, deemed to be only moderately suitable, however, the degree of slope does affect the suitability and hence the choice of crop.

TABLE 13.6: LAND SUITABILITY AT TUOBO GBAWELEKEHN, SWAMP 1

Applicability	Suitability Category	Major Limiting Feature	Area ha	Area %
	Highly suitable US1	No limiting feature	7.7	13
	Well suited $US2_t$	Dominant slopes between 4 and 8%	6.4	10
Upland	$US2_d$	Well to moderately well drained	2.8	5
for	Moderately suitable $US3_t$	Dominant slopes between 9 and 15%	5.2	9
rainfed	$US3_g$	Very gravelly horizons between 50 and 100cm	5.0	8
cropping	$US3_d$	Moderately well drained	1.0	2
	Marginally suitable $US4_t$	Dominant slopes between 16 and 25%	1.9	3
	US4gt	Very gravelly horizons between 25 and 50cm	3.0	5
	$US4_d$	Imperfectly well drained	7.9	13
	Unsuitable except for forestry UN_t	Dominant slopes over 25%	4.2	7
	UN_g	Very gravelly horizons within surface 25cm	0.4	1
Swamps for	Highly suitable RS1	No limiting features	0.8	1
flood irrigated	Moderately suitable $RS2_s$	Medium textured soils	12.0	20
rice	Marginally suitable $RS3_s$	Moderately coarse textured soils	1.5	2
	Village area	Not available	0.8	1
		GRAND TOTAL:	60.6	100

Gravelly soils limit the suitability in certain higher lying areas but only one very small pocket of land in the east is ruled unusable because of this feature.

Imperfect to poor drainage is a seasonal feature of much of the lowland. The area in the northwest, at present under rubber, is flat with moderately fine textured soils, but suffers from high water tables in the wet season. Considering the rubber is approximately 30 years old and has remained untapped for many years, this area might now be best used for rainfed rice.

Scattered haphazardly throughout the survey area are generally small blocks of highly suitable land, in which there are no major limitations to land use.

13.3.4 Vegetation and Land Use (Map 31)

a) The Swamp

The entire swamp is under regrowth, except for a significant area under cocoa and two small rice farms.

The cocoa is planted in Part B of the swamp. Much of it is overgrown and suffers from both black pod and parasitic growth. However, the trees looked surprisingly healthy, considering that for much of the wet season the water tables are within 50 cm of the surface. The area is not recommended for cocoa.

The small area of farmland (one in Part A, one in Part B) was in the process of being cleared prior to rice planting.

Much of the young swamp regrowth throughout the swamp is thick and tangled, comprising ferns, reeds, small bushes and trees.

The entire swamp area has been used in the past for cropping: certain locations in the recent past have been used for rice, but no irrigation or drainage structures were seen.

b) The Upland and Swamp Fringe

Two features of significance were noted: first, there are no remaining areas of high forest around the swamp and second there are much larger areas under tree crops than in the other villages surveyed.

The major tree crop is cocoa which covers considerable areas in both upland, lowland, and swamp fringe locations. Certain areas are well managed (e.g. towards the northern end of lines A and B), whereas other areas are poorly managed and diseased.

Two extensive areas of rubber occur in the north; these plantations are well laid-out, but are around 30 years old and have remained untapped for many years. The western area occupies seasonally poorly drained lowland around a meandering stream. The eastern area is partially on steep slopes and partially on undulating low-lying land.

Part of a moderately extensive and well managed oil palm plantation occurs in the extreme east of the survey area, some of which lies on extremely gravelly soils.

Five farm areas were seen in the survey area, all of them clear-felled and burnt, two of them recently planted to upland rice. Two farms were located on particularly steep slopes where the risk of erosion was extremely severe.

The remainder of the area is under regrowth of age varying from 2 to 12 years.

Some of the householders on the periphery of the village tend small plots of vegetable and fruit crops. One individual farm to the north of the main village (at site A5) included a large area of cocoa and vegetable crops.

Generally, the agricultural activities of Tuobo Gbawelekehn were better managed and much more widespread than at the other villages surveyed. Interest and enthusiasm in farming was also markedly keener and more developed.

13.3.5 Water Resources

Tuobo Gbawelekehn was surveyed after the rains had begun with the result that both major streams in the area were in flood after periods of overnight rain. The maximum depth of the stream feeding Part A of the swamp was between 1 and 1.5 m in April, and the width was in places up to 4 m, especially upstream to the east and west of the main road. The major stream feeding Part B of the swamp was up to 1.5 m deep and 2 m wide. Both streams overtopped the banks on a number of occasions during the survey.

A feature of both streams is that they drain the swamps efficiently; the rise and fall in stream depth was rapid and measurable over 24 hours.

The confluence of the two streams occurs 500 m to the east of the village at site G-3.

There is no doubt that sufficient water is fed into the swamp during the rains for flood irrigated rice production. However, maintaining high water tables at certain drier periods during the wet season in Part B may be a problem due to the moderately rapid drainage by the streams.

13.4 SWAMP DEVELOPMENT PROPOSALS (Map 34)

The proposed cropping patterns for the swamp and surrounding area are given in Table 13.7. The location of the land development units (LDU) and outline engineering designs are shown in Figure 13.2.

TABLE 13.7: PROPOSED CROPPING PATTERN FOR TUOBO GBAWELEKEHN SWAMP 1

Location	Land Suitability (LDU)		Area Ha	Area %	Crop Proposed	Inputs for Sustainable Cropping: Single Crop	Inputs for Sustainable Cropping: Double Crop
Swamp	RS1/2	Suitable	11.8 [1]	91	Irrigated rice	+	++
	RS3	Marginal	1.5	8	Irrigated rice	++	Not recommended
	RN	Not suitable	0	0	None		
			13.3	100			
Upland	US1/2	Suitable	16.9	37	Annual crops and tree crops	*	**
	US3/4	Marginal	24.0	53	Selected tree crops (excl. cocoa) and food crops. US4 not suitable for coffee	**	Not recommended
	UN	Not suitable	4.6	10	None		
			45.5	100			

NOTES (1) Some swamp area out of command

\+ Denotes small fertilizer application required after 2nd or 3rd year.

++ Denotes moderate fertilizer application required after 1st crop, good water management and husbandry practices.

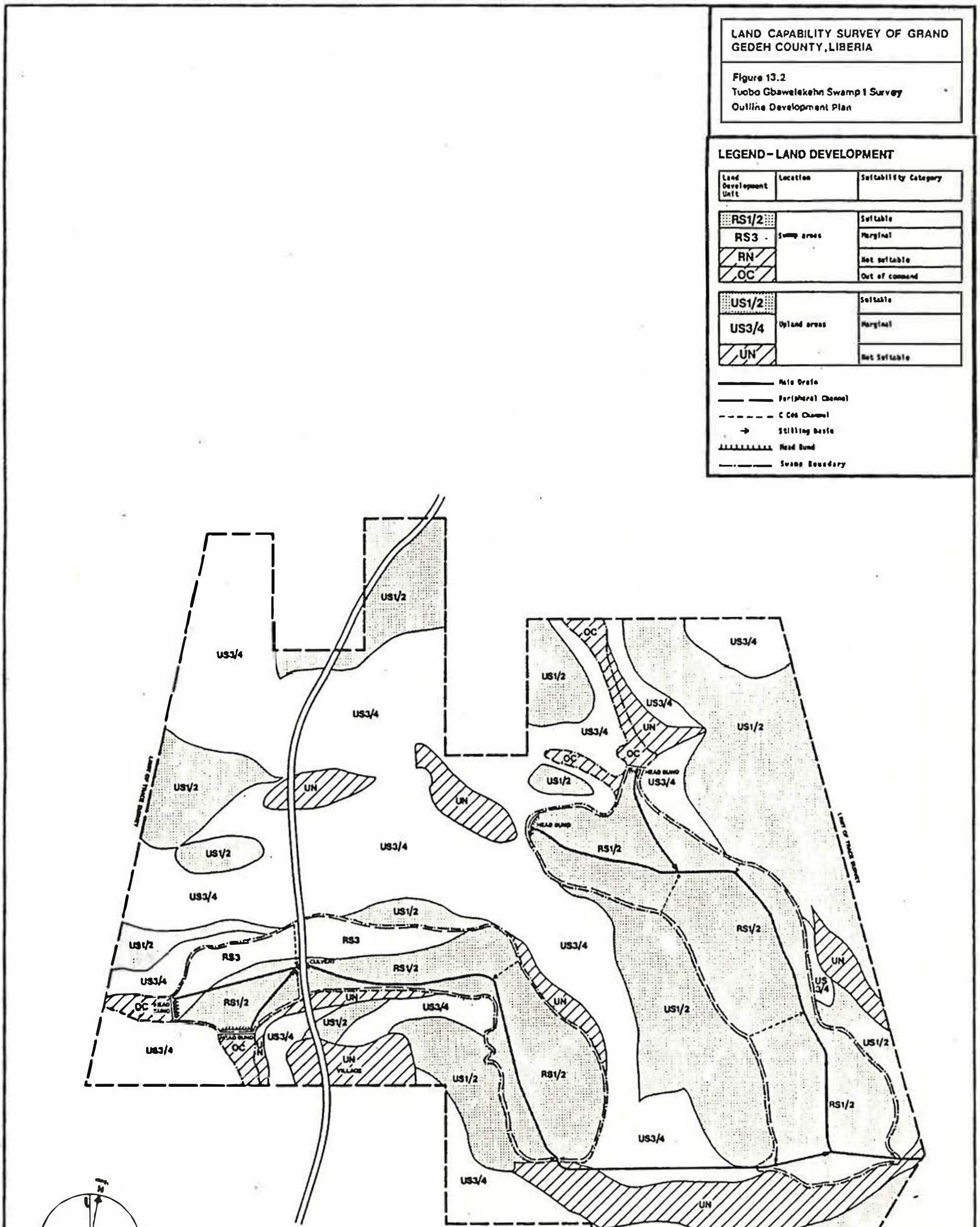
* Denotes appropriate crop rotation for annual crops with legume or fallow break. Small fertilizer application required after 2nd or 3rd year.

** Denotes small fertilizer application and appropriate rotation for annual crops.

The two parts of the swamp have a high proportion (91%) of LDU RS1/2 lands which are considered most suitable for continuous irrigated rice production with appropriate inputs. There is a small amount of LDU RS3 land towards the western end of Part A of the swamp. No unsuitable soil types were identified in the swamp area and therefore all the land can be cropped with rice.

The upland area surrounding the swamp has a mixture of soil types, with much of the suitable lands (US1/2) being in close proximity to the swamps. These areas are considered suitable for all annual and tree crops. The more marginal lands (US3/4 - 53%) are randomly scattered throughout the area and are best suited to selected tree and food crops. There are small amounts (10%) of unsuitable areas, mainly due to steep topography, close to the swamps and these should remain in natural vegetation.

The outline engineering design in Figure 13.2 shows the location of the main drain and of the peripheral channels and cross drains. Each swamp has a head bund at the top with peripheral channels running each side of the swamp. The natural drainage pattern of the western swamp is towards the east and through the south of the eastern swamp. The proposed drains follow this route. Both swamps are long and narrow and only a few cross drains are seen to be needed.


LAND CAPABILITY SURVEY OF GRAND GEDEH COUNTY, LIBERIA
Figure 13.2
Tuobo Gbawelekehn Swamp 1 Survey
Outline Development Plan
LEGEND - LAND DEVELOPMENT
Land Development Unit
Location
Suitability Category
RS1/2
RS3
RN
OC
Swamp areas
Suitable
Marginal
Not suitable
Out of command
US1/2
US3/4
UN
Upland areas
Suitable
Marginal
Not Suitable
Main Drain
Peripheral Channel
Stilling basin
Head Bund
Swamp Boundary
US3/4
US1/2
RS1/2
RS3
UN
OC
CULVERT
HEAD BUND
VILLAGE
LIMIT OF TRACE SURVEY

14. TUJALLAH TOWN

14.1 LOCATION AND SIZE

Tujallah Town is located in Gbarzon District, some 17km south of Zai Town which is on the Ganta to Zwedru highway (Figure 14.1). Gbagbolo Town lies to the north, between Tujallah Town and Zai Town. The road to Tujallah Town from the junction with the Zai Town - Gbagbolo Town road crosses a river bridge which is in a poor state of repair and requires urgent attention before any development project can be considered. There are about 65 houses in Tujallah Town with a population of around 400 persons.

The surveyed swamp lies to the north of the village, within about 5 minutes walking distance. Some 60 farmers expressed an interest in participating in a swamp development scheme.

14.2 VILLAGE LAND SURVEY

14.2.1 General Description

The area is gently undulating with several small rivers providing drainage to the Dube River situated some 5km to the south. Gradients are generally gentle, and hilly terrain is largely confined to the southwest of the town at the margins of the surveyed area.

14.2.2 Vegetation and Land Use (Map 38)

A substantial area around Tujallah Town has been cleared of forest and brought into the cultivation cycle. Much of the area between the town and the Dube River to the south is a mosaic of secondary bush regrowth and farms. High forest still remains in some of the drainage courses adjacent to the rivers and also on hilly terrain to the south-west. The forest to the south of the Dube River is very extensive. Evidence of extensive forestry activity in the past is provided by a large number of abandoned tracks.

The river (about 1.5km to the north of the town) effectively forms the boundary between the areas cultivated by farmers from Tujallah Town and those cultivated by farmers from Gbagbolo Town. Most of the farming activity occurs over a wide area but mostly to the south of the town. Because of the distances involved, there are a number of small satellite villages in which farmers and their families stay during the cropping season. The villages are sometimes abandoned after a few years when the surrounding land area is allowed to return to fallow.

14.2.3 Soils and Land Capability (Maps 39 & 40)

An area of some 2350 ha was surveyed.

Extensive gently undulating uplands towards the south of the surveyed area are occupied by shallow concretionary soils (soil unit D4). Although gradients are gentle (5-10%), the gravelly nature of the soils, and the restrictions to rooting depth mean that they cannot be recommended for improved or intensified agricultural production; they are placed in Class 5. Similarly, hilly terrain towards the western boundary of the surveyed area is also Class 5.

The area to the east of Tujallah town has soils with very variable gravel content and depth. Shallow gravelly soils (soil unit D4) appear to predominate but some areas have deeper soils (soil unit D7). This area is therefore mapped as a complex. Areas with deeper soils are land capability Classes 3 or 4 depending on the amount of gravel and the depth to the limiting layer. Areas with D4 type soils are mapped as Class 5.

A belt of land near the centre of the surveyed area has somewhat deeper and less gravelly soils (soil units D2, D7, and D8). Again the pattern of soils is complex, with the soil varying rapidly over short distances. However, these areas have generally more agricultural potential and are considered to be land capability Classes 2 and 3. The limiting factor is usually the amount of gravel (concretions) and such soils should not be used for crops which require great rooting depth or which are sensitive to stoniness. The erosion hazards are however, less serious in this gently undulating terrain.

Narrow bands of deep colluvio-alluvial soils occur along the drainage courses. These are generally of medium to coarse texture but have high agricultural potential provided they are protected from flooding. Extensive areas of deep silty alluvial soils flank the Dube River and these also have a high potential for sustained agricultural production, subject to satisfactory drainage and flood protection. A number of small swamps occur in the upper catchments of the minor tributaries but these are generally of coarse sand texture and are therefore relatively unsuitable for swamp rice development.

14.3 SWAMP SURVEY

The swamp chosen for survey was the most extensive, suitably located and endowed with the best physical attributes of the relatively large number of wetland areas in the region surrounding the village. It was also the largest swamp surveyed during the project.

The swamp lies, at its closest point, only 2 minutes walking distance from the village, but extends over 40 minutes walking distance to the northeast.

General Plan of Tujallah Town Area

Figure 14.1

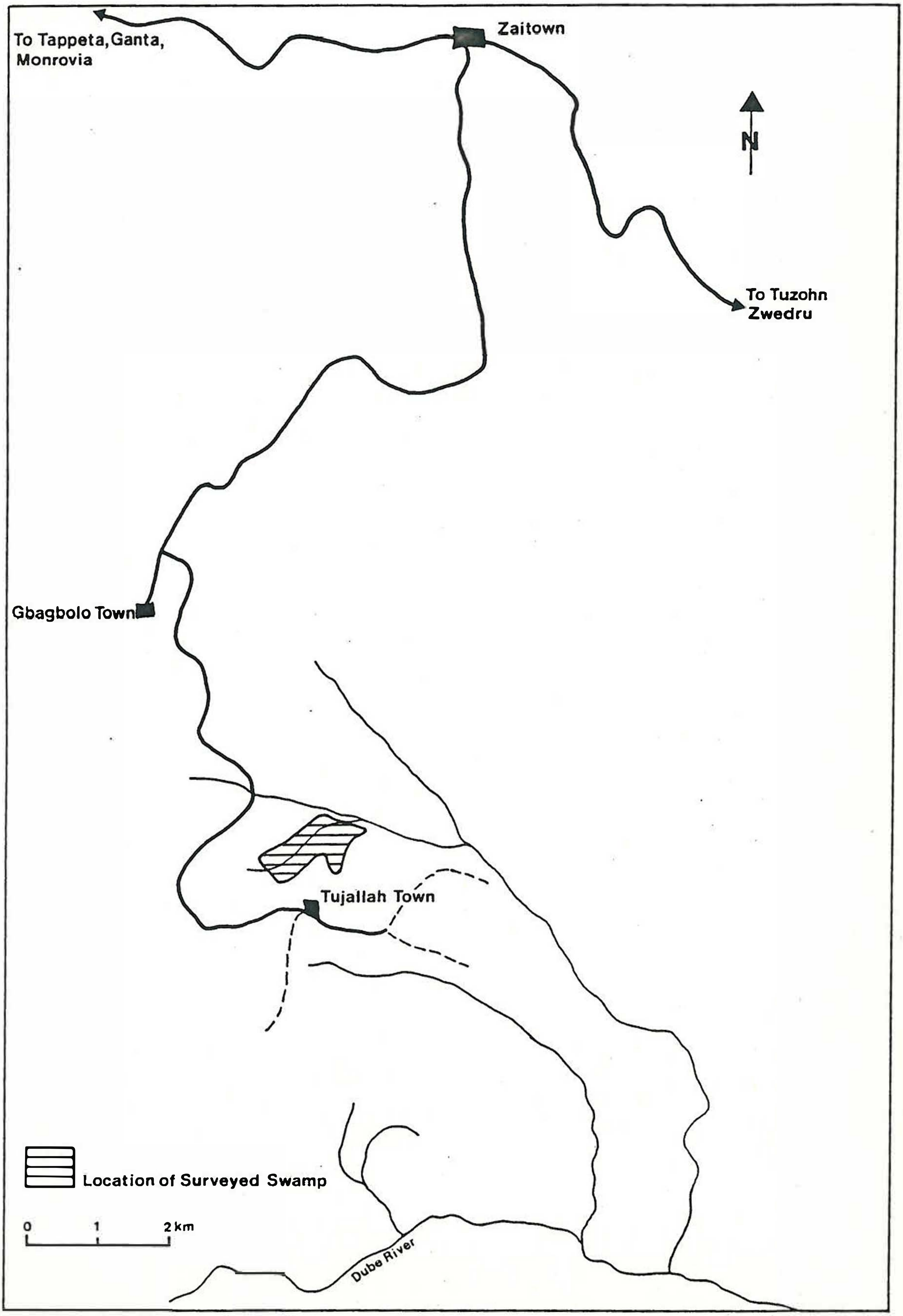


TABLE 14.1: SWAMP SURVEY SUMMARY: TUJALLAH TOWN

DESCRIPTION	AREA	
	ha	%
AREA SURVEYED	133.3	-
Area of Swamp*	46.0	100
Highly suitable for rice	0	0
Moderately suitable	8.7	19
Marginally suitable	29.1	63
Unsuitable	8.2	18
Area of Upland*	87.3	100
More or less suitable for one or other form of cropping	41.5	48
Unsuitable for cropping	45.8	52
Area under+ - rice, 1986 growing season	8.7	7
- other fruit or vegetable crops	1.2	1
- tree crops	3.1	3
- regrowth	71.7	53
- dryland forest	11.2	8
- wetland forest	37.2	28
- satellite villages	0.2	(1)

* See Tables 9.3 and 14.3 for further information on land suitability.

\+ See Map 41 for further details.

The survey area was conducted in April 1986 and covered 133.3 ha, of which 46 ha were swamp (Table 14.1).

Soil observations were made at 210 sites by auger and at 10 sites by profile pit. Depth to groundwater table was measured wherever observed, which was at all but six sites in the area delineated as swamp.

Hydraulic conductivity measurements were made at 10 locations, and infiltration rate tests at four sites. Soil samples from four pits were sent for chemical analysis, the results of which are recorded and discussed in Appendix A.

14.3.1 Soils (Map 42)

The soils are described in Table 9.1 and the crop suitability criteria are given in Table 9.2. Full profile descriptions of the major units are given in Appendix A. Distribution of soil units is recorded in Table 14.2

TABLE 14.2: SOIL DISTRIBUTION IN TUJALLAH TOWN

Soil Unit	Location	Area ha	%
D1	Upland	1.6	1
D2		2.5	2
D3		12.5	9
D4		34.3	26
L1	Lowland and Swamp Fringe	13.9	11
L2		3.1	2
L3		12.6	10
L4		6.8	5
W1	Swamp	0.4	(1)
W2		8.3	6
W3		29.1	22
W4		8.2	6
	TOTAL	133.3	

a) The Swamp

The soils of the swamp are characterized by the presence of all four groups of swamp soil units.

In the upstream course of both streams, to the southwest of each limb of the swamp, small areas of coarse soil occur (W4). These profiles are composed almost entirely of medium to coarse sand to depths exceeding 1 metre; soil colours were very dark greyish brown and dark brown over grey to light grey.

Moderately coarse textured profiles predominate. Often there are fine textured horizons (silty clays, clay loams and fine sandy clays) within these soils - so too, however, are there loamy sand and sandy loam horizons. A feature of these coarser horizons is that they often appear as if coarse sand and clay have been intimately mixed producing a gritty but sticky feel: in certain locations, the 'mixing' has not been so thorough, and pockets of clay occur within a sandy matrix. Occasionally, 40 cm of sandy clay loam or clay loam lie over sandy loam or loamy sand: at 80 to 100 cm sandy clays are recorded. Generally however, the coarser material lies over the finer. Soil colours are as for the W4 soils, but mottling is common to abundant and generally distinct, especially in the more finely textured horizons.

Moderately fine textured soils are found more frequently in the lower course of the streams in the north and northeast of the swamp: a small area of fine textured soils occurs in the extreme northeast.

Water tables were often recorded within the top metre. However, at sites where auger extensions were used it appears that the auger punctures an impermeable layer on which the water tables are perched, with the result that water levels often fall to well below 1 metre. The same feature was observed at Fishtown. Regional water tables will rise as the wet season progresses so that the perched water table occurs only in the early stages of the seasonal rains.

In all profiles, colours are generally dark brown or dark greyish brown over grey. These overlie bluish and greenish greys of the micaceous, moderately fine textured weathering parent material at about 1.5m. Towards the edge of the swamp the weathering parent material may occur at shallower depths, where there is less depositional material and infill.

All profiles were deep. No physical limitation to rooting depth was seen.

b) The Upland and Swamp Fringe

Significant areas of imperfectly drained gently sloping land occur around the swamp fringe. Soils are occasionally coarse textured (L4, loamy sand and medium sand throughout the top metre), but more generally medium to moderately coarse textured (L3); these soils are often gleyed at depths below 50 cm.

Narrow bands of moderately well drained, medium textured soils also occur at swamp fringe sites and in the north on the flood plain of the major easterly-flowing stream. A small lowland area occurs in the middle of the swamp in the southwest; this island is characterised by seasonally high water tables and the soils are coarse or moderately coarse.

Further from the swamp are the upland concretionary soils, which in several areas abut directly against the swamp; in these locations there are often short sharp slopes. The majority of the soils are highly concretionary within the surface 50 cm.

Less concretionary soils are not common, and occur only as small areas, generally in the southwest of the survey area.

14.3.2 Topography

a) <u>The Swamp</u>

Besides the delineated area of lowland in the southwest, the swamp is generally flat. However, the microtopography around sites HO, IO and JO is slightly variable and warrants further investigation during land clearance operations. Within this locality there are two meandering stream courses, which cause the varied micro-relief.

b) <u>The Upland and Swamp Fringe</u>

Slopes are gentle in the upland and are critical only in a few swamp fringe locations (for example, lines I and J where the upland abuts directly against the swamp and abrupt slopes occur where the stream has incised, and on lines D and E similar slopes occur at the edge of the swamp).

Moderately steep slopes (up to 20%) occur to the north of the swamps (Line F and G), around the extreme south of the swamp and at swamp fringe sites (site BL-1).

Generally, the terrain within the upland is undulating to rolling and only slightly dissected, with gradients rarely exceeding 12 to 15%. Within the flat to undulating swamp fringe lowland, slopes rarely exceed 6%.

14.3.3 Land Suitability (Map 43)

a) <u>The Swamp</u>

The suitability of the swamp is largely determined by soil texture (Table 14.3). Most of the land is graded as marginally suitable (RS3) because of moderately coarse textured soils, which are haphazardly variable in that the depth at which coarser textured horizons occur cannot be predicted.

TABLE 14.3: LAND SUITABILITY AT TUJALLAH TOWN

Applicability	Suitability Category	Major Limiting Feature	Area ha	Area %
	Highly suitable			
	US1	No limiting feature	1.2	1
Upland	Well suited US2$_t$	Dominant slopes between 4 and 8%	4.6	3
for	Moderately suitable			
	US3$_t$	Dominant slopes between 9 and 15%	1.3	1
rainfed	US3$_g$	Very gravelly horizons between 50 and 100cm	1.7	1
	US3$_d$	Moderately well drained	8.5	6
cropping	Marginally suitable			
	US4$_t$	Dominant slopes between 16 and 25%	0.3	(1)
	US4$_g$	Very gravelly horizons between 25 and 50cm	12.5	11
	US4$_d$	Imperfectly drained soils	11.4	9
	Unsuitable			
	UN$_t$	Dominant slopes over 25%	1.3	1
	UN$_g$	Very gravelly horizons within surface 25cm	34.3	26
	UN$_s$	Coarse textured soils to 1m depth	9.9	7
	UN$_d$	Poorly drained soils	0.3	(1)
	Moderately suitable			
Swamps	RS2$_t$	Presence of slopes around 1%	0.4	(1)
for	RS2$_s$	Medium textured soils	8.3	6
flood	Marginally suitable RS3$_s$	Moderately coarse textured soils	29.1	22
irrigated				
rice	Unsuitable			
	RN$_s$	Coarse textured soil	8.2	6
		GRAND TOTAL:	133.3	100

Soils more suitable for irrigated rice occur in the northeast; two smaller pockets of similarly medium textured soils lie around the water courses further upstream.

No areas are considered highly suitable for irrigated rice, and certain areas of coarse textured soils in the south of each limb of the swamp are deemed unsuitable.

b) The Upland

Highly gravelly, coarse textured soils and imperfect to poor profile drainage limit suitability in the upland area (Table 14.3).

Soil with over 50% concretionary material in the surface 50 cm is the most common factor affecting suitability. Such upland soils are considered marginally suitable or unsuitable for the land use types considered, except forestry. Furthermore, coarse textured soils occur in certain areas around the swamp and these too are considered unsuitable for agriculture.

Imperfect drainage in the lowland fringe soils makes significant areas only moderately or marginally suitable for agriculture. Topography is rarely a limiting factor in these areas.

Usable land is generally found only near the swamp, except in the extreme northeast, where highly gravelly soils occur within 10 to 75m of the swamp boundary.

14.3.4 Vegetation and Land Use (Map 41)

a) The Swamp

Almost the entire swamp is under mature wetland forest, composed of palm and bamboo species, reeds and phreatophyllous tree species. The vegetation is thick and often tangled, and produces a full canopy.

A few areas have been cleared and used recently; one area was being planted to rice during the survey. No attempt has been made to control flooding.

b) The Upland

Most of the area has been used for upland rice cultivation within the last 12 years. However, areas for cultivation appear to have been selected regardless of soil quality, drainage or slope. High forest now occupies only small areas.

Several 1986 upland rice farms occur. The northern area is relatively intensively farmed, centred around two small houselot areas. All the farms were in the process of being planted to rice at the time of the survey. Plantings of peppers, cassava, bananas and maize were observed in moderately extensive plots.

Nearer the village of Tujallah Town, coffee, cocoa, and palm trees are grown. The swamp itself remains largely unused except for palm wine tapping, harvesting of wild palm kernel nuts and bitter root, and hunting wild game.

14.3.5 Water Resources

The main part of the swamp follows a north to northeasterly meandering stream; the smaller part of the swamp follows a minor stream, also flowing northeast. These two streams meet to the northeast of the survey area.

Both streams were flowing during the survey, and flooded after heavy rains. The course of the major stream ranged from 1 to 3m wide, and 0.5 to 1m deep. In certain locations it had incised into the abutting upland, creating steep slopes, especially in the north of the swamp.

Water resources do not constitute a limitation for flood irrigated rice, given good water management and a properly conceived system of irrigation and drainage channels.

14.4 SWAMP DEVELOPMENT PROPOSALS (Map 44)

The proposed cropping patterns for the Tujallah Town swamp and surrounding area are given in Table 14.4. The location of the land development units (LDU), together with outline engineering designs are shown in Figure 14.2.

The swamp comprises 44.8 ha and is the largest covered under this survey. There are 8.7 ha of LDU RS1/2 suitable for double cropping of irrigated rice, located in the northeast sector of the swamp. There is no RS1 land suitability class, but the large block of RS2 located in that area indicates that further soil survey work beyond the limits of the present survey may be worthwhile. Some 28.5 ha (64%) of LDU RS3 occur in the swamp with the southern end containing an area of unsuitable high ground. RS3 land is suitable for single cropping of irrigated rice. There are 7.6 ha (17%) of LDU RN which is unsuitable for rice because of the coarse soil texture.

The upland area has a small area (5.8 ha) of LDU US1/2 which is suitable for all annual and tree crops. There are 35.7 ha (41%) of LDU US3/4 scattered throughout the survey area, which is suited to selected tree and food crops. Over fifty per cent of upland area (45.8 ha) is LDU UN and should remain under natural vegetation cover.

TABLE 14.4: PROPOSED CROPPING PATTERN FOR TUJALLAH TOWN SWAMP AREA

Location	Land Suitability (LDU)		Area Ha	Area %	Crop Proposed	Inputs for Sustainable Cropping: Single Crop	Inputs for Sustainable Cropping: Double Crop
Swamp	RS1/2	Suitable	8.7	19	Irrigated rice	+	++
	RS3	Marginal	28.5(1)	64	Irrigated rice	++	Not recommended
	RN	Not suitable	7.6(1)	17	None		
			44.8	100			
Upland	US1/2	Suitable	5.8	7	Annual crops and tree crops	*	**
	US3/4	Marginal	35.7	41	Selected tree crops (excl. cocoa) and food crops. B4 not suitable for coffee	**	Not recommended
	UN	Not suitable	45.8	52	None		
			87.3	100			

NOTES (1) Some swamp area out of command

\+ Denotes small fertilizer application required after 2nd or 3rd year.

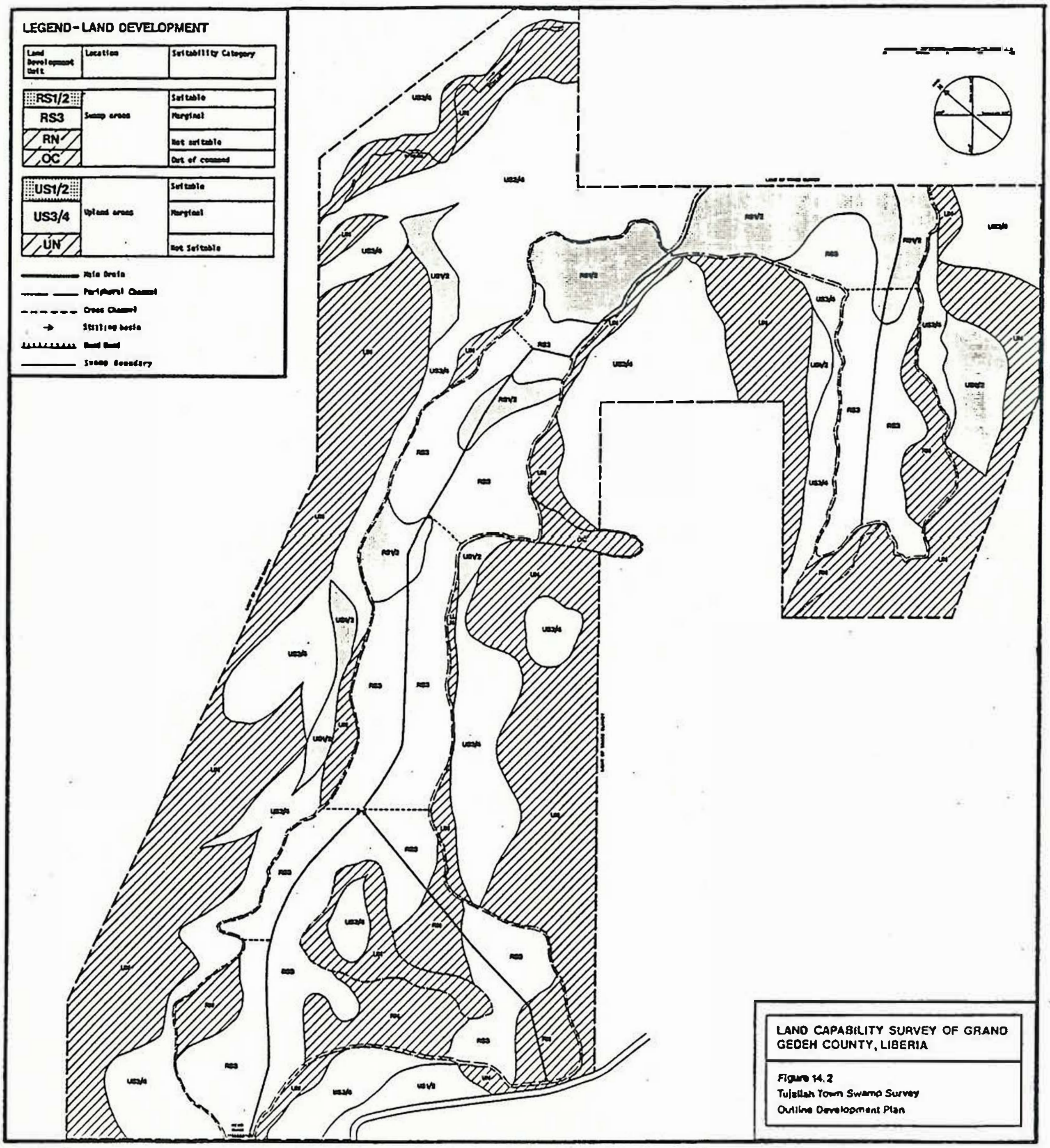
++ Denotes moderate fertilizer application required after 1st crop, good water management and husbandry practices.

* Denotes appropriate crop rotation for annual crops with legume or fallow break. Small fertilizer application required after 2nd or 3rd year.

** Denotes small fertilizer application and appropriate rotation for annual crops.

The outline engineering designs encompass nearly all of the long narrow swamp with the exception of two small areas towards the eastern side which have unsuitable soils, or are out of command. Peripheral channels are located along both sides and the main drain follows the centre of the swamp. There is an area of high land at the southern end but run-off from this should not be sufficiently large to inundate the adjacent areas. The northern boundary of the swamp has been defined, at present, by the limit of the trace survey and the two drains could probably continue northward and join at a suitable point.

A head bund should be built at the southern end, probably in the vicinity of the road culvert.



LAND CAPABILITY SURVEY OF GRAND GEDEH COUNTY, LIBERIA

Figure 14.2
Tujellah Town Swamp Survey
Outline Development Plan

A developed rice swamp near Saglapea illustrating main drain and field bunds.

Section D
Conclusions And Recommendations

15. CONCLUSIONS AND RECOMMENDATIONS

15.1 INTRODUCTION

The study has covered technical investigations of the land capability, hydrology and agriculture of Grand Gedeh County, aimed at identifying specific sites suitable for intensifying and improving village agricultural production. Emphasis in the study was placed on the ultimate objective of preparing outline development plans for irrigated rice schemes in swamps and improvements to a range of tree and food crops in surrounding areas.

As envisaged in the Terms of Reference, the study was undertaken in two stages:-

- Phase 1: An initial reconnaissance was made of the whole county to assess regional land resource, hydrological and land use characteristics, and to select specific village areas suitable for further study.

- Phase 2: This involved more detailed studies of five specific village areas and swamps, including detailed surveys and outline development planning for selected swamps.

In this Section the general conclusions to be drawn from the results of the study are discussed in relation to the principal technical disciplines. In particular, the study identified a severe lack of basic mapping, hydrological statistics, physical infrastructure and agricultural support services within the County. The possible methods for implementing swamp rice and agricultural development programmes at village level are discussed in the light of these deficiencies.

Furthermore, the present survey was also intended as a pilot study, through which to develop appropriate methods for extending the survey programme, especially the land capability aspects, to include additional village lands and swamps within Grand Gedeh County, the Southeast Region and elsewhere in Liberia. In the final part of this Section, therefore, recommendations are made for possible future studies, taking account of the results of the present study.

15.2 LAND CAPABILITY

The reconnaissance survey confirmed that small scale mapping (1:250 000) has a value in identifying broad regional differences in landform and land use in this region. Interpretations of satellite imagery showed that 70 per cent of the area is forest- covered, with 29 per cent as a mosaic of secondary regrowth and small scale slash-and-burn cultivations.

Most of the area comprises a gently undulating peneplain on relatively uniform and strongly weathered parent material. Differences in soils and land capability proved to be more significant, in terms of agricultural potential, at the level of the individual slope sequence than at regional level. Meaningful mapping of soil and land capability at small scale would therefore necessitate surveys of a large number of sample areas, distributed throughout each of the main landform units, to establish the local patterns.

Such surveys were not feasible in the time available for the present study and would not have directly contributed to the primary objective of selecting village areas for irrigated rice development. In a region of minimal road access and dense forest cover, such surveys constitute a major logistical exercise. Moreover, until topographic map cover is produced for Grand Gedeh County, mapping has to be based on uncorrected aerial photographs and satellite images, with consequent deficiencies in scale accuracy. A more efficient approach is seen to be to proceed with the village survey programme, as started during the present study, and use the results as sample area information from which subsequently to prepare small scale regional soils and land capability maps.

As part of the reconnaissance stage, a series of villages were identified which possessed swamps with potential for irrigated rice development. The selection criteria developed during Phase 1 appeared to be appropriate. However, it proved to be impossible to identify the swamp or accurately locate the boundaries on the available 1 : 60 000 scale aerial photographs or the 1:20 000 enlargements. Moreover, it was often extremely difficult to gain access into the swamps to confirm their extent, topography and soil conditions. As a result of subsequent detailed surveys, some of the swamps proved to be less suitable or less extensive than had originally been anticipated. For future studies it is suggested that more time should be allowed for an initial field screening stage, during which a low density of traces could be cut through potentially suitable swamps in order to confirm their extent and general soil characteristics before detailed studies commence.

The Phase 2 land capability studies concentrated on detailed surveys of the selected swamps and exploratory "semi-detailed" surveys of the dryland farming areas around the selected villages. Separate teams were responsible for each of the different survey types, but working from a single base at each village. This proved to be an efficient method of operation. Most of the manpower effort was directed at the swamp surveys, which involved cutting trace lines and a closer density of soil observations.

The semi-detailed surveys extended over the areas affected by cultivation around the selected villages. Initial attempts to cut wide-spaced trace lines proved to be inefficient and unnecessary, as footpaths give adequate access. However, in the absence of topographic maps, and with the relatively small scale of the aerial photography and the ephemeral pattern of slash-and-burn farming, accurate location was difficult. Broad patterns of soils and land capability were mapped at 1:20 000 to indicate the extent of land suited to annual and tree crops and to delineate additional swamp areas. The mapping provided a general indication of the village features and a useful base for future integrated development of both irrigated rice and dryland crops.

In future studies it is suggested that the semi-detailed surveys should include investigation of specific sample areas to establish the catenary sequence of the soils, as a prelude to subsequent up-grading of the regional mapping.

The detailed surveys of the selected swamps were conducted on 100m-spaced trace lines, which were extended 500m up the side slopes, except where topography or soils were obviously unsuitable. Soil investigations were made at 50m intervals along the traces. Mapping was at 1:2,000 scale, with separate sheets showing soils, and land suitability for rice and for dryland crops. Soil texture proved to be the principal factor determining suitability for rice in the swamp; soil depth and gravel content were the principal determinants of suitability for dryland crops on the side slopes.

A total of 596 ha were surveyed at detailed level, of which 146 ha were suitable for rice and 228 ha were suited to dryland cropping (Table 15.1).

The approach adopted for the swamp surveys proved to be effective but, as discussed earlier, it is considered that a screening survey prior to final selection of swamp areas for detailed studies would have improved the success rate of finding suitable sites for irrigated rice development. Such surveys could follow the initial selection process, involving cutting of a base line and two or three lateral traces at 500m intervals along which a rapid check of soils, slopes and watertable conditions could be made. Furthermore, it was concluded that the additional work and time involved in extensively surveying the lateral slopes of the swamps is not always justified. Sufficient information should be obtainable if lateral surveys are limited to areas where soils conditions are favourable within about 250m of the swamp. Additional information should also be provided by the semi-detailed mapping. This change of approach would reduce the survey effort, without detracting from the primary objective of determining suitability for rice cultivation.

TABLE 15.1: LAND SUITABILITY CLASSIFICATION OF DETAILED SURVEY AREAS (ha)

Village Area	Swamp Lands Rice RS1/2/3	RN	Uplands Dryland Crops US1/2/3/4	UN	Total
Beezohn	30.4	2.0	48.1	63.9	144.4
John David Town Swamp 1	27.5	0.9	35.8	45.8	110.0
John David Town Swamp 2	6.0	0.0	10.2	6.8	23.0
Fishtown	28.6	9.6	26.7	33.6	98.5
Tuobo-Gbawelekehn Swamp 1	14.3	0.0	40.9	4.6	59.8
Tuobo-Gbawelekehn Swamp 2	1.0	0.3	24.8	1.0	27.1
Tujallah Town	37.8	8.2	41.5	45.8	133.3
TOTALS	145.6	21.0	228.0	201.5	596.1

NOTES: RS1/2/3 refers to classes suitable for rice, RN: unsuitable.

US1/2/3/4 refers to classes suitable for dryland crops, UN: unsuitable.

15.3 HYDROLOGY AND IRRIGATION ENGINEERING

The study revealed a paucity of climatic data for Grand Gedeh County. Rainfall data exist for only four stations, some of which are no longer operating. Full climatological data exist for six months (1985-86) at the CCSRP station at Garley Town. These data were analysed to determine effective monthly rainfall and to estimate evapotranspiration. This indicated that rainfall should be sufficient for double cropping of irrigated rice, although some supplementary water will be required during periods of deficit, which occur even during the rainy season. This should be available as surface run-off from lateral slopes around the swamps. Groundwater resources are insufficient for irrigation and would become extremely expensive to develop for extensive use, and are recommended to be conserved for village domestic water supplies.

In the absence of contoured topographic maps and due to the poor access within and around the swamps, it proved to be impracticable to define catchment areas, measure stream flows or estimate flood flows. In fact, many streams were dry or mostly dry during Phase 2 of the study. Although such information would have been useful in defining sizes of drainage channels, it is not considered to be a serious limitation for outline designs of irrigation and drainage systems. It is recommended that standard channels be built and enlarged, if necessary, on the basis of experience. Similarly, the soil survey results provided adequate information on levels for outline designs: topographic surveys are proposed once the swamps are cleared of vegetation, at which stage the layouts can be refined.

Recommendations were made for improvements in recording of climatic and hydrological data. Gauging stations were established at the CCSRP swamps as a first step in acquiring measured flow data for swamps.

Tests on swamp water revealed no pathogens, but appropriate control measures and health education programmes are recommended as part of the implementation stage to minimise the risks of Schistosomiasis, which at present has a low incidence within Grand Gedeh County. It is a well known fact that swamp development causes an increased occurrence of the disease.

Outline designs (1:2,000 scale) were prepared for irrigation and drainage systems within each surveyed swamp, taking account of the land suitability and drawing on the experience of the CCSRP swamp developments.

15.4 AGRICULTURE

A review was made of the farming systems within the selected areas to determine the types of crops grown and the relative importance of different systems and practices within the rural communities. Studies were also made of the agricultural support and marketing services and processing facilities for the principal crops in Grand Gedeh County. Visits were made to national research stations and to agricultural development projects in other counties. The experiences of the CCSRP were examined in the context of possible implementation procedures for the present study areas.

Two principal farming systems were identified, namely an upland rice farming system and a village farming system. The former is the principal source of the staple subsistence food (rice), and receives priority in terms of labour resources. Any surplus labour is utilised on the village farms, which are orientated towards cash crops, such as tree crops (cocoa, coffee), vegetables and swamp rice. Proposals are included for improving husbandry of the major crops and for introducing legumes to improve nutritional standards.

Labour was found to be scarce. This, combined with a lack of basic marketing systems, support services and physical infrastructure, means there is little incentive for village farmers to increase production. Development of irrigated rice is therefore unlikely to be successful in the long term, without significant financial support, unless the farmers perceive sufficient benefits to warrant transferring their labour resources from the upland rice farms.

It is therefore concluded that in future studies it would be essential to include additional expertise in the survey team to cover farm economics and marketing, as well as to investigate social attitudes towards swamp rice development.

Outline agricultural development proposals were prepared for the swamps and adjacent upland areas, using the results of the land suitability mapping and hydrological information. Land development units are defined to show the types of cropping systems appropriate (Table 15.2).

a) Irrigated Rice

Development is recommended as either single- cropped or double-cropped rice, depending on the soil and moisture conditions. Table 15.2 shows that totals of 106 ha (70%) and 28 ha (19%) are available for these systems, respectively. About 17 ha was considered unsuitable for rice cultivation and a further 11 ha were out of command of the irrigation and drainage system.

Maximising double cropping is seen to be essential if returns are to be adequate to cover the swamp development costs (estimated at some L$ 3,000 - 4,000 per ha) and to provide a reasonable cash return to the farmer as an incentive. If sufficient incentives exist, the farmer can be expected to grow rice surplus to his family's food requirements. This surplus will be sold on the market, thereby contributing to reducing the present national reliance on imported rice and ultimately offering the possibility of Liberia becoming self-sufficient in rice.

b) Dryland Crops

The upland areas surrounding the swamps were grouped according to their potential for annual food crops and tree crops. Continuous cropping of annual crops or cocoa is proposed on the best soils, with coffee or single cropping of annuals on the more marginal land. Table 15.2 shows that most of the soils surrounding the swamps are marginal or unsuitable for any of these cropping patterns: 50 ha (12%) are suited to the whole range of annual and tree crops, whereas 153 ha (38%) should be restricted to a more limited range of crops. Great care will therefore need to be taken in selecting areas for cocoa and continuous annual cropping and due attention should be given to soil conservation measures. Moreover, there appears to be no regular pattern as to the location of good upland soils in relation to the swamps. The suitability of land, in terms of topography or soil depth and gravel content, should therefore be verified before planting.

TABLE 15.2: SUMMARY OF LAND SUITABILITY AND CROPPING PATTERN PROPOSALS

Location	Land Suitability (LDU)		Area ha	Area %	Crop Proposal	Inputs for Sustainable Cropping: Single Crop	Inputs for Sustainable Cropping: Double Crop
Swamp	RS1/2	Suitable	28.6	19	Irrigated Rice	+	++
	RS3	Marginal	106.4	70	Irrigated Rice	++	Not recommended
	RN	Not suitable	17.1	11	None		
			152.1	100			
Upland	US1/2	Suitable	49.9	12	Annual crops and tree crops	*	**
	US3/4	Marginal	153.5	38	Selected tree crops (excl. cocoa) & food crops. US4 not suitable for coffee		
	UN	Unsuitable	200.3	50	None	**	Not recommended
TOTAL			403.7	100			

NOTES: Total area refers to area within command of irrigation/drainage system.

+ Denotes small fertilizer application required after 2nd or 3rd year.

++ Denotes moderate fertilizer application required after 1st crop, good water management and husbandry practices.

* Denotes appropriate crop rotation for annual crops (legume/fallow break); small fertilizer application required after 2nd or 3rd years.

** Denotes small fertilizer application and appropriate rotation for annual crops.

c) Indicative Development Priorities

The actual order of swamp development will depend on the location of the next phase of the project and on the willingness of farmers and the community to participate in the development. However, an indicative ranking of the swamp and village areas is possible through the consideration of the areas with the greatest amount of most suitable land.

The swamp and surrounding area at Tuobo Gbawelekehn has the highest proportion of suitable land (LDU RS1/2 accounts for 89 per cent of the area of the swamp; LDU US1/2 accounts for 37 per cent of the swamp fringe and side slopes) and is recommended for development first. John David Town and Tujallah Town are ranked next in order for development, with some 20% suitable RS1/2 swamp land and about 10% suitable US1/2 upland. John David Town Swamp I should be developed first as it is the largest, and the second swamp of the town should be left for subsequent development.

Beezohn and Fishtown each have a small amount of suitable land (RS1/2; US1/2) and a large amount of marginal and unsuitable land. These areas should therefore be developed with caution and draw on the experience gained through development of the other swamp areas. In particular, the management of coarse textured soils for rice production should be carefully considered.

15.5 INTEGRATED APPROACH FOR IMPLEMENTATION

The policy of intensifying agricultural production through development of irrigated rice in swamps, combined with improvement of dryland food and tree crop production in the vicinity of the villages, should result in financial and social benefits for the rural population and is seen to be appropriate for Grand Gedeh County.

Moreover, the policy should also be justified in wider ecological terms, by relieving pressure on the forest resources. Southeastern Liberia possesses some of the last remaining areas of primary tropical rainforest in West Africa: these represent an ecological asset of immense international importance. However, the forests are under severe threat from insidious encroachment by uncontrolled timber extraction and slash-and-burn agriculture. If the present policy is successful in concentrating food production in the vicinity of the villages, especially through introducing continuous cropping rice in the swamps, it should therefore reduce the need for the present wasteful practice of extensive slash-and-burn upland rice farming and thereby contribute to the conservation of the forests.

It is well established that rice can be cultivated in the swamps and that coffee and cocoa can be grown on certain areas of land surrounding the swamps. However, the further development of these crops cannot be considered either in isolation from the overall farming system, in which the upland rice farms have priority for the limited labour resources, or without first alleviating some of the many other existing constraints to increased agricultural production.

Reviews of previous reports and discussions with the village people have highlighted the need to provide the farmer with more incentives and better infrastructural support to encourage increased crop production. Many of the constraints have been discussed in this report: these mainly involve the lack of basic rural infrastructure, markets and support services. It is therefore recommended that any further swamp development activities or land capability studies of additional swamp areas should be carried out in conjunction with, or as part of, a broad-based rural development programme. A key objective of this programme would be to generate sufficient incentives for the farmers to develop irrigated rice largely through their own efforts as self-help schemes.

Until such a rural development programme is agreed in principle, there would appear to be little point in proceeding with a further major programme of soil and land capablity studies of village areas. Recommendations are given in Section 15.6 for the approach to be used.

a) Rural Development Programme

The rural development programme should be phased according to the specific requirements of the region, but should include the following components:-

- Agricultural Inputs	Provision of improved varieties of seeds and tree seedlings, fertilizers and agro-chemicals to farmers at subsidised prices, as well as appropriate tools and equipment to reduce labour requirements.
- Agricultural Extension	Improved support services for the farmer through more trained extension officers and provision of transport for the officers.
- Swamp Development	Technical assistance provided to participating farmers or working groups on soils, water resources, irrigation/drainage layout, land levelling and husbandry practices for irrigated rice. Swamps should be cleared through a farmer self-help scheme and include subsidised chain saw use and provision of credit for farm establishment (see Para (b) below).
- Storage and Marketing	A full review of the present marketing system and implementation of measures to provide more financial incentive to the farmer. Introduction of improved storage methods and provision of decentralised collection and storage points.
- Farmer Development Associations	Establishment of FDAs for rice, cocoa and coffee farmers, with technical support from the overall rural development programme.
- Social Assessment	Investigation of the interactions of the farming systems in relation to village life and the social attitudes to introduction of a swamp rice development programme.

- Rural Health	Investigation of the implications of swamp development for human diseases, especially Schistosomiasis, and implementation of appropriate health education and disease control programme. This should also include other health aspects.
- Rural Water Supply	Implementation of a programme to provide clean domestic water supplies in the villages, in liaison with existing programmes.
- Roads and Communications	Implementation of a general programme to improve communications and, through improved maintenance, ensure that roads are serviceable throughout the year for the passage of agricultural produce and supplies; bridges also require regular maintenance.
- Hydrometeorological Data	Initiation of a programme for up-grading hydrological and meteorological recording stations in the region and establishing new stations as appropriate.

b) Swamp Development

It is important that the approach adopted for swamp development is acceptable to the farmers and involves their participation. In the past, several swamps have been cleared using heavy equipment and hired labour; all of these schemes have experienced initial success followed by failure. It is evident that until the farmer becomes committed through his own self-help involvement, irrigated rice farming cannot be sustained on a permanent basis in these swamps.

Farmers expressed wariness and caution over projects that did not involve any self-help or financial committment from them. In particular, they were concerned over the long-term right to use the land and the proportion of the harvest that would be retained by them.

The CCSRP is developing a number of swamps which should demonstrate to the farmers that the land can be successfully cleared and cropped with rice. Information on swamp clearance costs should soon be available. These costs should be related to the rice production potential of the swamp and also compared with the costs of self-help swamp clearance schemes as practised in Bong and Nimba Counties.

Although no financial assessment has been made on swamp development, a farmer self-help development programme together with technical assistance and provision of certain inputs, is recommended.

A swamp development programme should be incorporated into a wide-based rural development programme with technical assistance through consultants, volunteer organisations, RDI graduates and Ministry of Agriculture personnel. Farmers will need assistance to:-

- Determine the limits and area of the selected swamp
- Assess soil suitability
- Clear the land
- Determine layout of main drains and peripheral channels
- Construct the drains
- Level the land
- Undertake the cultivation of irrigated rice and to adopt the appropriate husbandry practices.

In addition, chain saws with operators should be provided through the project for felling large trees. Credit packages, repayable over three to four years, should be made available to help with initial labour expenses.

Agricultural inputs, such as seeds, fertilizers and extension advice, should be available through the proposed strengthening of the Ministry of Agriculture.

15.6 PROPOSALS FOR FURTHER LAND CAPABILITY SURVEYS

On the assumption that the principle of implementing a positive programme of rural development is adopted for the region, it is recommended that land capability surveys be carried out in order to select further village swamp areas for irrigated rice development. Such surveys could extend to further villages in Grand Gedeh County and to sites elsewhere in the Southeast Region.

On the basis of experience gained in the present studies, the following general approach is recommended:

a) Survey Rationale

The survey should undertake a rolling programme of selecting and mapping village swamps throughout the region to prepare outline plans for irrigated rice and crop improvement, which would subsequently be implemented as part of the proposed rural development project. The two programmes would be separate but would need to liaise regularly. The duration of the study would depend upon the extent of the area to be covered, about two years would probably be needed to establish an on-going programme to cover the Southeast Region (Grand Gedeh, Sinoe and Maryland Counties).

b) Team Composition

A core team should be established comprising soils and land classification specialists, led by a land capability expert and supported by short term expertise in farm economics, marketing, rural sociology and social infrastructure, agriculture, hydrology, irrigation and physical infrastructure engineering. In the initial stages the team would be based on expatriate staff but it is recommended that Liberian staff should be included, through employment of RDI graduates and secondment of MOA and Soil Survey Division personnel. Through technology transfer, the Liberian staff would take increasing technical responsibility for the surveys and ultimately the expatriate input could be reduced to technical and administrative supervision.

c) Components of the Surveys

Two principal stages are envisaged, including a reconnaissance and preparation stage and a village survey stage:-

- Reconnaissance & Preparation: In this initial stage, all relevant data and mapping materials would be accumulated and reviewed. Preliminary regional maps of landforms and land use would be compiled at 1:250 000 scale. The selection procedure for swamps would commence in order to identify the initial batch for more detailed survey. Provisionally selected swamps would be subjected to a standard field screening procedure to verify the potential of the swamp, as proposed in Section 15.2.

  This reconnaissance programme should proceed parallel to the village surveys, so that new sites can be identified as the initial ones are completed.

- Village Area and Swamp Surveys: Detailed soil and land suitability surveys should be undertaken within the selected swamps. These surveys would not extend further than about 250m beyond the swamp margins. Mapping should be at a scale of 1:2,000. At the same time semi-detailed soil and land capability surveys would be carried out in the areas around the village which are affected by farming, preferably including the upland rice farms. The village lands would be mapped at 1:20 000 scale. These surveys should include detailed mapping of sample areas to establish the slope relationships between soil units for subsequent use to up-grade the small-scale regional mapping and to compile regional maps of soils and land capability.

- Manuals should be prepared during the initial village surveys to provide guidelines for planning and undertaking the village area surveys, covering the swamps and village lands. These should be up-dated as the surveys proceed and ultimately form the basis for enabling the Liberian staff to carry out the work themselves, under the overall supervision of the expatriate core team.

- Soil Analyses: These should be undertaken on principal soil units to characterise the soils and determine specific fertility constraints, such as aluminium toxicity and micro-nutrient deficiencies.

  Funds should be provided for equipment and materials for the CARI Laboratory so that analyses can be undertaken within Liberia.

- Associated Studies: There will be no value in undertaking land capability studies unless the areas surveyed have a chance of being successfully developed. The studies should therefore be accompanied by inputs from specialists in other disciplines, as listed above. Short-term inputs are proposed for the initial Reconnaissance Stage to investigate marketing, farm economics, social attitudes and rural infrastructure. Specialists in these disciplines would then make further inputs during the Village Survey Stage. Longer term inputs are envisaged for an agriculturalist and irrigation engineer/hydrologist throughout the study period. These various specialists should liaise closely with members of the proposed Rural Development Programme team, so that experiences gained during implementation of swamps and village areas can be fed-back to the land capability study team.

Conducting hydraulic conductivity test at John David Town.

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Trace line surveying at Tujallah Town

Appendices

APPENDICES

CONTENTS

APPENDIX A

SOILS AND LAND CAPABILITY

A.1 REPRESENTATIVE SOIL PROFILE DESCRIPTIONS

Typed transcripts of the field soil descriptions are given for selected pits and auger borings. Specific locations can be checked by reference to the soils map for each swamp (Volume 2).

Soil chemical analysis data are reported in Appendix A2 for all profiles marked with an asterisk (e.g. Profile No: C4*).

Profile No:	C4*	Village: Beezohn
Date:	24.2.86	
Soil Class:	W3	
Suitability Class:	$RS3_s$	
Location:	150m from C0 on line C	
Landform:	Swamp	
Gradient:	Less than 1%	
Aspect:	-	
Microtopography:	Uneven	
Surface Features:	Thin leaf litter and twig debris; many rotting logs.	
Vegetation/Land Use:	Swamp forest, dominant species bamboo, undergrowth mainly reed species.	
Moisture Conditions:	Slightly moist to moist	
Profile Drainage:	Poorly drained	
Groundwater Table:	245cm	

Horizon	Depth (cm)	Profile Description
1	0- 7	Very dark greyish brown (10YR 3/2), slightly moist; organic loam; slightly sticky; medium crumb structure; common vesicular pores; abundant roots.
2	7- 33	Dark brown (10YR 3/3), slightly moist; sandy loam, slightly sticky; medium subangular blocky structure; few tubular pores; common roots.
3	33- 60	Grey (10YR 6/1), moist; medium sandy clay, sticky; few faint fine orange mottles; weak subangular blocky structure; few tubular pores; very few roots.
4	60- 90	Dark grey (N4/), moist; medium sandy clay loam, sticky; very few distinct medium white mottles; weak subangular blocky structure; few, fine tubular pores; very few fine roots; 5% angular riverine pebbles; organic staining along root channels.

Horizon	Depth (cm)	Profile Description
5	90-118	Bluish grey (5G 6/1), moist; medium to coarse sandy clay loam, sticky; common, distinct, medium to coarse grey mottles, associated with pockets of sand within clayey matrix; weak subangular blocky structure; few fine tubular pores; very few fine roots.
6	118-200	Greenish grey (5GY 6/1), moist; common, faint, fine and medium pale grey mottles; clay loam, sticky; weak subangular to massive structure; few, fine tubular pores; very few fine roots.
7	200-280	Greenish grey to light greenish grey (5GY 6/1, to 5GY 7/1), very moist to wet; very few, faint, fine, grey and yellow mottles.

Profile No:	D4*	Village: Beezohn
Date:	21.2.86	
Soil Class:	W3	
Suitability Class:	$RS3_s$	
Location:	200m west of site DO on line D (see Map 4)	
Landform:	Swamp	
Gradient:	Less than 1%	
Aspect:	-	
Microtopography:	Moderately uneven	
Surface Features:	Leaf litter, twig debris, few fallen trees.	
Vegetation/Land Use:	Swamp forest, dominantly palm species; few ferns.	
Moisture Conditions:	Slightly moist to wet	
Profile Drainage:	Poorly drained	
Groundwater Table:	Not seen	

Horizon	Depth (cm)	Profile Description
1	0- 10	Dark brown (10YR 3/3), slightly moist; organic loam, friable; crumb structure; common fine and medium vesicular pores; abundant roots.
2	10- 23	Dark brown (10YR 4/3), slightly moist; very few faint, fine brown mottles; sandy loam, friable; weak subangular blocky to crumb structure; common, fine and medium vesicular pores; many roots, fibrous and woody.
3	23- 40	Light brownish grey (2.5Y 6/2), slightly moist; common, faint, fine orange mottles; loamy sand, friable; weak subangular blocky structure; common fine and medium tubular pores; fine, medium, fibrous roots.
4	40- 80	Light grey (10YR 6/1), moist; common, distinct, fine and medium orange mottles; loamy sand, soft, slightly sticky; common fine and medium tubular roots; few medium fibrous roots; small pockets of pure yellow sand occur within matrix.

Horizon	Depth (cm)	Profile Description
5	80-135	Light grey (10YR 6/1), very moist; variation in matrix colour to bluey grey and grey brown; sandy loam, soft, slightly sticky; weak, sub-angular blocky structure; common, fine and medium tubular pores; very few, medium fibrous roots.
6	135-185	Grey (N5/), very moist; variation in matrix colour to bluey grey and grey brown; gravelly loamy sand, soft, slightly sticky; many fine and medium tubular pores; few medium fibrous roots; 60% angular riverine pebbles.
7	185-195	Pale green (5G 6/2), very moist to wet; loamy sand, flaky weathering micaceous rock; soft, non-sticky; platy structure; common fine and medium interstital pores; very few fibrous roots; 5% angular riverine pebbles.
8	195-210	Light olive brown (2.5Y 5/6), wet weathering 'loamy sand' parent material.

NOTES: (i) Water table not seen.
(ii) Roots seen down to 2m.

Profile No:	E2*	Village: Beezohn
Date:	21.2.86	
Soil Class:	W3	
Suitability Class:	$RS3_s$	
Location:	50m from main road, north of Beezohn village.	
Landform:	Swamp	
Gradient:	Almost level	
Aspect:	-	
Microtopography:	Very uneven surface, caused by seasonal flooding.	
Surface Features:	Leaf litter and twig debris.	
Vegetation/Land Use:	Swamp forest, dominant species bamboo and palm together with adapted species with aerial roots.	
Moisture Conditions:	Slightly moist to very moist	
Profile Drainage:	Poorly drained	
Groundwater Table:	Not seen.	

Horizon	Depth (cm)	Profile Description
1	0- 5	Dark yellowish brown (10YR 4/4), slightly moist; organic sandy loam, very friable to loose; weak crumb and single grain structure; many fine vesicular pores; abundant fine, few medium fibrous roots.
2	5- 18	Olive brown (2.5Y 4/4), slightly moist; few, faint fine orange and greyish mottles; medium sandy loam, friable; subangular blocky structure; common fine and medium tubular pores; common fine, few medium roots.
3	18- 42	Light olive brown (2.5Y 5/4), slightly moist; many distinct, fine and medium orange and greyish mottles; medium sandy loam, friable; weak, fine subangular blocky; common fine and medium tubular pores; few, fine and medium fibrous and woody roots.

Horizon	Depth (cm)	Profile Description
4	42- 70	Light yellowish brown (2.5Y 6/4), slightly moist; many distinct, fine and medium orange and light grey mottles; loamy sand with coarse sand fraction, very friable; weak fine and medium subangular blocky structure; common fine tubular pores; very few fine and medium fibrous and woody roots.
5	70- 95	Grey (5Y 6/1), moist; many distinct, fine and medium orange mottles; sandy loam with coarse sand fraction, friable to slightly firm; weak, fine and medium subangular blocky; few, fine medium and coarse tubular pores; very few fine and medium roots.
6	95-122	Light grey (5Y 6/1), moist; common, distinct fine orange mottles; sandy loam with medium sand fraction, slightly firm; moderate, medium, subangular blocky structure; very few fine and medium tubular pores; only one coarse woody root seen.
7	122-162	Light grey (N6/), moist; common, distinct, fine and medium orange mottles; gravelly sandy clay, very firm; moderate medium subangular blocky structure; very few fine tubular pores; only one coarse root seen; 15% angular quartzitic stones, fine and medium.
8	162-190	Light grey (N6/), moist; common, distinct, fine and medium orange mottles; gravelly sandy clay, very firm; moderate medium subangular blocky structure; very few fine tubular pores; only one coarse root seen; 15% angular quartzitic stones, fine and medium.
9	190-270	Bluish and greenish grey (5B 6/1 and 5BG 5/1), moist to very moist; few, distinct fine white mottles; silty clay, extremely firm; massive structure; no pores or roots seen; pockets of micaceous material occur at depths greater than 250cm; highly weathered parent material.

NOTES (i) No water table seen.
(ii) Horizon 9 is largely impervious.

Profile No:	F5*	Village: Beezohn
Date:	22.2.86	
Soil Class:	W2	
Suitability Class:	$RS2_s$	
Location:	200m from road, north of Beezohn village.	
Landform:	Swamp	
Gradient:	Less than 1%	
Aspect:	-	
Microtopography:	Moderately uneven.	
Surface Features:	Leaf litter and twig debris.	
Vegetation/Land Use:	Wetland forest, many palm trees in near vicinity.	
Moisture Conditions:	Slightly moist to moist	
Profile Drainage:	Poorly drained	
Groundwater Table:	Not seen.	

Horizon	Depth (cm)	Profile Description
1	0- 6	Dark yellowish brown (10YR 3/4), slightly moist; organic loam, very friable; weak crumb structure; abundant fine and medium vesicular pores; abundant fine and few medium fibrous and woody roots.
2	6- 15	Olive brown (2.5Y 4/4), slightly moist; few, faint fine orange and greyish mottles; silty clay loam, friable; moderate, fine, subangular blocky structure; common fine and medium tubular pores; common fine and few medium fibrous roots.
3	15- 42	Olive grey (5Y 5/2), slightly moist; common, distinct, fine and medium orange and grey mottles; clay, very firm; weak, medium subangular blocky structure; few, fine tubular pores; few fine, common medium fibrous and woody roots.
4	42- 80	Grey (5Y 6/1), slightly moist; many prominent medium orange mottles; clay loam, very firm; weak, medium subangular blocky structure; few, fine tubular pores; few fine and medium fibrous roots.

Horizon	Depth (cm)	Profile Description
5	80-110	Grey (5Y 6/1), slightly moist; many distinct, medium orange mottles; slightly gravelly clay loam, very firm; weak, medium subangular blocky structure; few fine tubular pores; very few, fine and medium, fibrous and woody roots; 5% quartzitic gravel.
6	110-140	Light grey (N6/), slightly moist; few distinct fine mottles; clay, very firm; moderate, medium subangular blocky structure; few fine tubular pores; very few, fine fibrous roots; cutans on structural faces.
7	140-180	Greyish brown (10YR 5/2), moist; abundant faint medium and coarse brown and grey mottles; medium to coarse sand, very friable to loose; structureless; abundant, fine, vesicular pores; no roots seen.
8	180-230	Greyish green and dark bluish grey (5G 5/2), 5B 5/1), moist; common blue and grey mottles; highly micaceous silty clay, firm; flaky, platy structure; no roots or pores seen; weathering parent material.

Profile No:	J2*	Village: Beezohn
Date:	27.2.86	
Soil Class:	W3/W4	
Suitability Class:	$RS3_s$	
Location:	100m from Jo, located on baseline extension, 200m south of Beezohn village.	
Landform:	Swamp/swamp lowland	
Gradient:	1 - 2%	
Aspect:	180°	
Microtopography:	Moderately even.	
Surface Features:	Leaf litter and twig debris; thick and tangled undergrowth.	
Vegetation/Land Use:	Regrowth, haphazardly cleared, close to the village.	
Moisture Conditions:	Slightly moist to moist	
Profile Drainage:	Poorly drained	
Groundwater Table:	Not seen.	

Horizon	Depth (cm)	Profile Description
1	0- 6	Greyish brown (10YR 5/2), slightly moist; loamy sand, loose to very friable; very weak crumb; abundant fine vesicular pores; many fine and medium fibrous roots.
2	6- 20	Greyish brown (2.5Y 5/2), slightly moist; fine to medium loamy sand, very friable; very weak subangular blocky; many fine vesicular pores; few fine and medium fibrous roots.
3	20- 48	Light olive brown (2.5Y 5/4), slightly moist; few faint fine orange and grey mottles; loamy sand, friable; weak subangular blocky structure; many fine tubular pores; few fine and medium fibrous roots.
4	48- 80	Light browish grey (2.5Y 6/2), slightly moist; common, distinct, fine and medium orange mottles, together with very pale pockets of sand; loamy sand, friable; weak subangular blocky structure; few, fine tubular pores; very few fine fibrous roots.

Horizon	Depth (cm)	Profile Description
5	80-110	Light grey (5Y 7/1), slightly moist; few fine, faint yellow to orange mottles; loamy sand, very friable; weak subangular blocky structure; few fine and medium tubular pores; very few fine fibrous roots.
6	110-130	Light grey (5Y 7/1), slightly moist to moist; few, distinct fine orange mottles; coarse sandy loam, friable; weak subangular blocky structure; few coarse and medium tubular pores; very few fine tubular roots.
7	130-150	Light grey (5Y 7/1), slightly moist to moist; common, distinct, fine and medium orange mottles; gravelly, sandy clay loam, friable; very weak subangular blocky structure; few medium and coarse tubular pores; no roots seen; 80% coarse quartzitic gravel, 0.5 to 4cm diameter, embedded within matrix.
8	150-180	Light grey (N7/), moist; abundant, distinct, medium orange and red mottles; fine sandy clay, very firm; massive; no pores or roots seen.
9	180-230	Highly variagated colours; highly weathered fine textured micaceous weathering parent material; contains pockets of coarse quartzitic gravel within matrix.

Profile No:	K2*	Village: Beezohn
Date:	27.2.86	
Soil Class:	W3	
Suitability Class:	$RS3_s$	
Location:	300m south of the village of Beezohn	
Landform:	Swamp	
Gradient:	Less than 1%	
Aspect:	-	
Microtopography:	Moderately uneven, but natural "ridge and furrow" features in places.	
Surface Features:	Leaf litter and twig debris.	
Vegetation/Land Use:	Wetland swamp forest; bamboo species dominant; very thick tangled undergrowth.	
Moisture Conditions:	Slightly moist to moist	
Profile Drainage:	Poorly drained	
Groundwater Table:	195cm	

Horizon	Depth (cm)	Profile Description
1	0- 5	Dark brown (10YR 3/3), slightly moist; organic loam, friable; moderate crumb structure; many medium and fine vesicular pores; many fine and medium roots.
2	5- 12	Light brownish grey (10YR 6/2), slightly moist; few faint, fine orange mottles; fine sandy loam, friable; weak, moderate subangular blocky structure; common fine and medium tubular pores; few fine and medium roots.
3	12- 42	Grey (10YR 6/1), slightly moist; many distinct, fine and medium orange and grey mottles; sandy clay loam, friable to firm; weak subangular structure; common fine and medium tubular pores; few fine and medium roots.
4	42- 62	Grey (5Y 6/1), slightly moist; common, distinct, fine and medium, orange and white mottles; sandy clay loam, friable; weak subangular blocky structure; common fine and medium tubular pores; very few fine and medium roots; matrix speckled with small white sand pockets.

Horizon	Depth (cm)	Profile Description
5	62- 81	Grey (5Y 6/1), slightly moist; common, distinct, fine and medium orange mottles; sandy loam, friable; weak subangular blocky; common fine and medium tubular pores; very few fine and medium roots; very few small white sand pockets.
6	81-110	Grey (10YR 6/1), slightly moist to moist; common distinct fine and medium orange mottles mainly along root channels and pores; medium sandy loam, soft, slightly sticky; weak subangular blocky; few fine and medium tubular pores; very few fine and medium roots.
7	110-140	Light grey (5Y 6/1), moist; few distinct fine orange mottles; sandy clay, slightly sticky; structure not seen; few fine tubular pores; very few fine roots; few pale brown pockets of sand haphazardly distributed within matrix.
8	140-180	Light grey (N6/), very moist; fine sandy clay, very plastic and sticky; massive structure, pores and roots not seen.
9	180-280	Highly variegated micaceous weathering parent material; dominant texture is medium-fine (e.g. clay loam) but with coarser patches in places; platy structure; wet.

NOTE: i) All roots seen in this profile were fibrous.

Profile No:	B3*	Village: John David Town

Date:	16.3.86
Soil Class:	W1
Suitability Class:	$RS3_t$
Location:	150m from site B0 on base line, south of the village of John David Town 3
Landform:	Swamp
Gradient:	1 - 2%
Aspect:	-
Microtopography:	Slightly uneven.
Surface Features:	Thin leaf litter and twig debris.
Vegetation/Land Use:	Swamp regrowth.
Moisture Conditions:	Moist to wet
Profile Drainage:	Poorly drained
Groundwater Table:	58cm.

Horizon	Depth (cm)	Profile Description
1	0- 3/5 (merging)	Brown (10YR 5/3), moist; few fine indistinct grey mottles; organic silty clay, friable; well developed medium prisms breaking to medium subangular blocky; no visible pores, with few fine vertical cracks; root mat to 2cm, then few medium fibrous roots.
2	3/5- 26	Light grey (10YR 7/1), moist; common yellowish brown mottles along structured faces; silty clay, firm; well developed coarse prismatic breaking to medium prismatic; few medium and common fine tubular pores; few fine and medium roots.
3	26- 41	Light grey (10YR 7/1), moist; common prominent fine brownish yellow mottles; silty clay, firm to friable; moderate, medium prismatic structure; no visible pores but common fine vertical cracks; few fine roots.

Horizon	Depth (cm)	Profile Description
4	41- 55	Light grey (N7) wet; common, prominent fine, strong brown mottles; silty clay, plastic and sticky; no visible pores, but common fine vertical cracks; few fine roots.
5	55-130	Light grey (N7), wet; few prominent fine strong brown mottles, especially along cracks; silty clay, plastic and sticky; indeterminate structure; no visible pores but common fine vertical cracks; few medium roots.
6	130-165	Greenish and light greenish grey (5G 6/1, 5BG 7/1), wet; very few fine brown mottles; overall sandy clay loam, probably mixed pockets of sand within sandy clay matrix, firm to friable; indeterminate structure; no pores, cracks or roots seen.
7	165-195	Light grey (N6/), wet; few indistinct medium pale brown; medium sand, soft, non-sticky; other features not seen.

Profile No:	C4	Village: John David Town
Date:	16.3.86	
Soil Class:	W3	
Suitability Class:	$RS3_s$	
Location:	200m from Co (base line) on line C, south of the village of John David Town 3	
Landform:	Swamp	
Gradient:	Less than 1%	
Aspect:	-	
Microtopography:	Slightly uneven.	
Surface Features:	Loose grey sand and thin leaf litter.	
Vegetation/Land Use:	Swamp regrowth.	
Moisture Conditions:	Moist to wet	
Profile Drainage:	Poorly drained	
Groundwater Table:	79cm (probably perched during dry season)	

Horizon	Depth (cm)	Profile Description
1	0- 2	Very dark greyish brown (10 YR 3/2), moist; loamy sand, loose; undetermined structure; pores and cracks not seen; fine and medium root mat.
2	2- 25	Very dark greyish brown (10YR 3/2) moist; common indistinct weak crumb to massive structure; few medium tubular pores; few fine and medium roots.
3	25- 45	Dark grey (10YR 4/1), moist; few prominent brown mottles in root channels; loamy sand (medium), soft; massive structure; no pores seen; very few fine and medium roots.
4	45- 73	Grey (10YR 5/1), moist; few prominent brown mottles in root channels; medium sand, soft; massive structure; few coarse tubular pores; few fine and medium roots.
5	73-101	Grey (10YR 6/1), wet; common prominent, medium brownish yellow mottles; loamy sand (medium), soft; massive structure; few coarse tubular pores; no roots seen.

Horizon	Depth (cm)	Profile Description
6	101-150	Light olive brown (2.5Y 5/4), wet; common, distinct fine grey mottles; overall sandy clay loam, comprising more or less sandy pockets within clayey matrix; slightly sticky and plastic; indeterminate structure; no pores or roots seen.
7	150-160	Light grey (N7/), wet; common, distinct, coarse brown mottles; coarse sandy clay loam, firm; indeterminate structure; pores and roots not seen; few fine quartzitic gravels.
8	160-195	Light blue grey to pale green (5B 7/1, 5G 7/2), moist; very few distinct medium brown mottles; silty clay loam, firm; indeterminate structure; pores and roots not seen; few flakes of mica.
9	195-220	Variegated greys, wet; silty loam, soft; many mica flakes in this weathering parent material.

Profile No:	D3*	Village: John David Town
Date:	16.3.86	
Soil Class:	W1/W2	
Suitability Class:	RS1	
Location:	150m from D0 (base line) on line D, south of the village of John David Town 3	
Landform:	Swamp	
Gradient:	Less than 1%	
Aspect:	-	
Microtopography:	Moderately uneven.	
Surface Features:	Dark organic surface with channels and raised clumps of roots.	
Vegetation/Land Use:	Swamp regrowth.	
Moisture Conditions:	Moist, wet below 40cm	
Profile Drainage:	Poorly drained	
Groundwater Table:	44cm.	

Horizon	Depth (cm)	Profile Description
1	0- 3	Dark brown (7.5YR 3/2), moist; organic loam, soft and friable; medium crumb structure; few fine pores and abundant horizontal cracks; abundant fine and medium fibrous roots; roots also occur in clumps above ground level.
2	3- 11	Grey (10YR 5/1), moist; few fine brown mottles; silty clay, friable; moderate fine to medium prismatic; common, medium tubular pores; common fine, medium and coarse roots.
3	11- 31	Grey (10YR 6/1), moist; common, fine and medium strong brown mottles in root channels; silty clay loam, friable to firm; fine to medium moderate prismatic structure, few medium and large tubular pores and common medium vertical cracks; few very fine roots.

Horizon	Depth (cm)	Profile Description
4	32- 51/55 (wavy)	Light grey (10YR 7/1), very moist; few fine strong brown mottles; sandy clay loam, friable to firm; weak fine prismatic structure; very few medium tubular pores and few vertical cracks; few very fine and few medium roots.
5	51/55- 85	Light grey (10YR 7/1), wet; very few, fine strong brown mottles; sandy clay loam, slightly sticky; structure, pores and cracks not seen; no roots.
6	85- 95	Grey (10YR 5/1), wet; very few dark brown mottles; silty clay loam, sticky and plastic; structure, pores, roots not seen.
7	95-130	Light grey (5Y 6/1), wet; silty clay, plastic and sticky; structure, pores, roots not seen.
8	130-170	Light grey (N6/), wet: silty clay (loam), plastic and sticky; structure, pores, roots not seen.

Profile No:	H1*	Village: John David Town

Date:	16.3.86
Soil Class:	L3
Suitability Class:	$US4_d$
Location:	50m from C0 (base line), south of the village of John David Town 3.
Landform:	Colluvial footslope, swamp fringe
Gradient:	3%
Aspect:	190^o
Microtopography:	Moderately uneven
Surface Features:	100% leaf litter cover, and twig debris in moderately thick undergrowth.
Vegetation/Land Use:	At fringe of bamboo forest, mostly adapted dryland species.
Moisture Conditions:	Slightly moist to wet
Profile Drainage:	Poorly drained
Groundwater Table:	148cm

Horizon	Depth (cm)	Profile Description
1	0- 2	Dark brown (10YR 3/3), slightly moist; organic sandy loam, friable; weak, medium crumb structure; many fine, few medium roots; many fine, common medium vesicular pores.
2	2- 11	Dark greyish brown (10YR 4/2), slightly moist; many faint fine and medium orange mottles; sandy clay loam (medium sand fraction), friable; weak subangular blocky structure; many fine, few medium tubular pores; common fine and few medium roots.
3	11- 24	Grey (10YR 5/1), slightly moist; common, distinct fine and medium orange mottles; sandy clay (fine sand), firm; moderate subangular blocky; many fine, few medioum tubular pores; few fine and medium roots.
4	24- 54	Grey (10YR 5/1), moist; common distinct, fine and medium mottles of variable brown to yellow; coarse sand, very friable to loose; structureless; many fine and medium tubular pores; few fine, medium and coarse roots.

Horizon	Depth (cm)	Profile Description
5	54- 92	Light grey (10YR 6/1), very moist; common, faint, fine brown and yellow mottles; coarse sand, soft and non- sticky; structureless; many fine and medium tubular pores; few fine roots.
6	92-113	Grey (5Y 5/1 and 6/1), very moist; common distinct, fine and medium, orange and reddish brown mottles; gravelly sandy clay, firmish and sticky; massive structure; few, fine and medium pores; very few fine roots; over 30% quartzitic gravel, of diameter between 0.5 and 3cm.
7	113-165	Light greenish to bluish grey (5GY 7/1 to 5B 5/1), very moist to wet; few distinct, medium yellow mottles along root channels; silty clay loam, firm and slightly sticky; massive structure; roots and pores not seen.
8	165-200	Variable grey colours - increasingly less weathered parent material with silty texture and massive structure.

Profile No:	H5*	Village: Fishtown

Date:	29.3.86
Soil Class:	W4
Suitability Class:	RN_s
Location:	270m from H0 (base line), north of Fishtown village.
Landform:	Swamp - fringe site; near boundary between swamp and lowland.
Gradient:	Less than 1%
Aspect:	-
Microtopography:	Moderately uneven
Surface Features:	Moss and lichen on organic surface, with thin leaf litter and twig debris within tangled undergrowth.
Vegetation/Land Use:	Bamboo, palm trees, reeds and ferns within secondary regrowth. Some climbing grasses.
Moisture Conditions:	Very moist to wet
Profile Drainage:	Very poorly drained
Groundwater Table:	60cm

Horizon	Depth (cm)	Profile Description
1	0- 6	Dark reddish brown (5YR 2.5/2), very moist; organic fine sandy loam, soft and slightly sticky; crumb structure; many fine and medium vesicular pores; abundant fine, many medium and few coarse roots.
2	6- 22	Dark brown (10YR 3/3), very moist; few coarse pale brown patches of sand; organic loamy sand (medium and fine sand fraction), soft, non-sticky; crumb structure; many fine and medium vesicular pores; abundant fine and medium, common coarse roots.
3	22- 62	Very dark greyish brown (10YR 3/2) wet; common, coarse, light brown patches of sand; organically stained, fine and medium sand, soft, non-sticky; structureless; many fine and medium vesicular roots; many fine, common medium and few coarse roots; sharp boundary with horizon 4.

Horizon	Depth (cm)	Profile Description
4	62- 82	Light brownish grey (10YR 6/2), saturated; few lighter and darket patches; medium and coarse sand, loose, non-sticky; structureless; many fine and medium vesicular roots; few fine, medium and coarse roots; 20% hard angular quartz stones less than 1.5cm in diameter.
5	82-180	Bluey-white (bluer than 5Y 8/1), saturated; patches of whiter and bluer material; coarse sandy clay (coarse sand within clayey matrix), firmish and sticky; massive structure; few fine, medium and coarse pores; no roots seen; 5% hard, angular quartz stones, less than 1.5cm in diameter; highly weathered parent material.
6	180-230	As for 5, but more variable bluer and greener colours, more micaceous material, and siltier texture.

NOTE: On south face of pit, there is a massive granite outcrop from 70cm.

Profile No:	F5*	Village: Fishtown

Date: 28.3.86

Soil Class: W3

Suitability Class: $RS3_s$

Location: 250m from F0 (base line) on line F north of Fishtown village.

Landform: Swamp

Gradient: 1%

Aspect: -

Microtopography: Moderately even

Surface Features: Thin leaf litter within thick undergrowth and ferns, reeds and grasses.

Vegetation/Land Use: On fringe of wetland forest and secondary regrowth over 5 years old; bamboo and young palms predominate.

Moisture Conditions: Moist to wet

Profile Drainage: Very poorly drained

Groundwater Table: 42cm

Horizon	Depth (cm)	Profile Description
1	0- 6	Dark brown (10YR 3/3), very moist; organic sandy loam (fine sand fraction); soft, slightly sticky; crumb structure; many fine and medium vesicular pores; abundant fine common medium and few coarse roots.
2	6- 18	Dark yellowish brown (10YR 3/4), very moist; very few faint, fine grey mottles; organic sandy loam (fine sand fraction), soft and slightly sticky; weak subangular blocky structure; common fine and medium tubular roots; common fine and few medium and coarse roots.
3	18- 29	Dark greyish brown (10YR 4/2), moist; common distinct fine and medium greyish brown mottles; medium sandy clay loam, friable, subangular blocky structure; common fine and medium tubular pores; common fine and few medium roots.

Horizon	Depth (cm)	Profile Description
4	29- 74	Grey (10YR 6/1), very moist to wet; common distinct medium orange mottles; medium sandy clay loam, firm and slightly sticky; subangular blocky structure; common fine and medium, few coarse pores; common coarse, few fine and medium roots; less than 5% hard angular quartz stones, diameter of less than 1cm.
5	74-102	Light grey (10YR 7/1), saturated; many distinct medium yellow brown, grey and brown mottles around pores and root channels; pockets of coarse sand in clayey matrix; loose non-sticky; massive structure; common fine and medium tubular pores; few fine and medium stones, mostly less than 2cm in diameter, some much coarser, up to 20cm.
6	102-142	Light grey (10YR 6/1), saturated; few distinct medium rust mottles around pores and old root channels; coarse sandy clay, firm and sticky; massive structure; common, fine and medium tubular pores; few fine and medium roots; 15% hard angular quartzitic stones of less than 3cm in diameter.
7	142-210	Light greenish grey (5GY 7/1), saturated; sandy clay (with distinct silty fraction), very firm and sticky; massive structure; pores and roots not seen; 15% hard, angular, fine quartzitic stones of less than 1.5cm in diameter; highly weathered micaceous parent material.

NOTE: Water reflooding the pit from horizons 5 and 6.

Profile No:	B11*	Village: Fishtown

Date:	28.3.86
Soil Class:	W3
Suitability Class:	$RS3_s$
Location:	At 530m along line B, north of the village of Fishtown.
Landform:	Swamp
Gradient:	Almost level
Aspect:	-
Microtopography:	Very uneven
Surface Features:	Wet, 80% leaf litter cover and twig debris over organic surface.
Vegetation/Land Use:	Wetland swamp forest, dominant species include bamboo, reeds and some adapted dryland species.
Moisture Conditions:	Wet throughout, after heavy overnight rain on 27.3.86
Profile Drainage:	Very poorly drained
Groundwater Table:	25cm

Horizon	Depth (cm)	Profile Description
1	0- 9	Dark brown (7.5YR 3/2), wet; organic loam, soft and non-sticky; crumb structure; common vesicular pores; abundant fine, many medium and few coarse roots.
2	9- 18	Greyish brown (10YR 5/2), very moist; few faint fine yellow brown mottles; fine sandy clay loam, friable; moderate subangular blocky structure; common fine, few medium and coarse roots; few tubular pores.
3	18- 42	Greyish brown (10YR 5/2), wet; common, distinct fine and medium yellow brown mottles; fine sandy clay loam, firmish and slightly sticky; moderate to weak subangular structure; common fine, few medium, very few coarse roots: pores not seen.

Horizon	Depth (cm)	Profile Description
4	42- 60	Greyish brown (10YR 5/2), wet; common, distinct fine and medium yellow brown mottles; medium sandy clay loam, soft and slightly sticky; structure and pores of indeterminate nature; few fine and medium roots; 5% hard, angular quartzitic gravel, diameter less than 3cm.
5	60±120	Light brownish grey (10YR 6/2), saturated; medium sand, loose and non-sticky; structureless; pores of indeterminate nature; few fine roots; 5% quartzitic gravel, diameter up to 15cm in diameter.
6	120+	White (10YR 8/1), wet; coarse sand pockets within silty loam matrix, firmish and slightly sticky; massive structure; pores of indeterminate nature; no roots seen; 5% hard, angular quartzitic gravel, of diameter less than 3cm.

NOTE: Water reflooding the pit (after emptying) from horizon 5 which acts as aquifer.

Profile No:	C9*	Village: Fishtown
Date:	28.3.86	
Soil Class:	L3/W3	
Suitability Class:	$RS3_s$	
Location:	450m from C0 (base line) along line C, north of Fishtown village	
Landform:	Swamp/lowland fringe area	
Gradient:	2%	
Aspect:	260°	
Microtopography:	Moderately even	
Surface Features:	90% leaf litter cover and twig debris.	
Vegetation/Land Use:	Secondary regrowth, approximately 5 years old; few palms within near vicinity and moderately open undergrowth.	
Moisture Conditions:	Moist to very moist	
Profile Drainage:	Imperfectly well drained	
Groundwater Table:	Not seen	

Horizon	Depth (cm)	Profile Description
1	0- 4	Very dark greyish brown (10YR 3/2), moist; organic loamy sand, very friable; granular structure; abundant fine and medium vesicular pores; abundant fine and common medium roots.
2	4- 17	Dark greyish brown (10YR 4/2), moist; loamy sand, soft, non-sticky; granular and weak subangular blocky structure; many fine and medium vesicular pores; few fine and medium roots.
3	17- 40	Greyish brown (10YR 5/2), moist; medium sandy loam, friable, non-sticky; weak subangular blocky structure; many fine and medium tubular pores; few fine and medium roots.
4	40- 60	Brown (10YR 5/3), moist; common, faint, fine and medium yellow brown mottles; medium sandy clay loam, friable and slightly sticky; moderate subangular blocky structure; common fine and medium tubular pores; few fine and medium roots.

Horizon	Depth (cm)	Profile Description
5	60-114	Pale brown (10YR 6/3), moist; many faint and distinct fine and medium orange mottles; medium to coarse sandy clay loam, friable and slightly sticky; moderate subangular structure; common fine and medium tubular pores; few fine, medium and coarse roots.
6	114-140	Light grey (10YR 7/2), moist; many faint and distinct fine and medium orange mottles; medium to coarse sandy clay loam; friable and slightly sticky; moderate subangular blocky structure; common, fine and medium tubular pores; few fine and very few medium roots; less than 5% hard angular quartzitic gravel, less than 1cm in diameter.
7	140-165	Light grey (10YR 7/1), moist; many distinct medium bright orange mottles; gravelly clay loam, friable and sticky; weak subangular blocky structure; common fine and medium tubular pores; few fine roots; 40% hard angular quartzitic gravel of diameter less than 3cm.
8	165-210	White (10YR 8/1), very moist; many distinct medium bright orange mottles; coarse sandy clay, soft and slightly sticky; weak subangular blocky structure; few fine and medium tubular pores; roots not seen; 5% quartzitic gravel of diameter less than 1cm.

Profile No:	E-1*	Village: Tuobo Gbawelekehn

Date: 6.4.86

Soil Class: D1

Suitability Class: US1

Location: 50m from Eo (on base line), east of the village of Tuobo Gbawelekehn (see Map 4)

Landform: Mid-slope site on gentle fall within lowland area

Gradient: Less than 3%

Aspect: 120°

Microtopography: Moderately even

Surface Features: 100% leaf litter cover with some twig debris; clumps of broad leaf weeds.

Vegetation/Land Use: Secondary regrowth, 5-7 years old; comprising dryland species in moderately open undergrowth.

Moisture Conditions: Moist

Profile Drainage: Well to moderately well drained

Groundwater Table: Not seen

Horizon	Depth (cm)	Profile Description
1	0- 7	Very dark greyish brown (10YR 3/2), moist; loamy sand, very friable; weak crumb to granular structure; common fine and medium vesicular pores; many fine and medium, few coarse roots.
2	7- 16	Dark greyish brown (10YR 4/2), moist; sandy loam, friable; weak fine subangular blocky; common fine and medium tubular pores; common fine, few medium, very few coarse roots.
3	16- 29	Dark yellowish brown (2.5Y 4/4), moist; sandy loam, friable; weak fine subangular blocky; common fine and medium tubular pores; common fine, few medium and very few coarse roots.

Horizon	Depth (cm)	Profile Description
4	29- 59	Yellowish brown (2.5Y 5/4), moist to very moist; sandy clay loam, friable; weak fine subangular blocky; common fine and medium tubular pores; few fine and medium, very few coarse roots.
5	59- 92	Yellowish brown (2.5Y 5/4), moist to very moist; common, faint fine yellowish mottles; sandy clay loam, friable; weak fine subangular blocky structure; common fine and medium, very few coarse tubular pores; few fine and very few medium roots.
6	92-120	Light olive brown (2.5Y 5/6), moist; few distinct fine rusty mottles; fine sandy clay, friable; weak medium subangular blocky structure; few fine and medium tubular pores; few fine and very few medium and coarse roots.
7	120-145	Olive yellow (2.5Y 6/6), moist; common, distinct fine orange mottles; fine sandy clay, firm; weak medium sandy clay; few fine and very few medium tubular pores; very few fine roots.
8	145-168	Light yellowish brown (2.5Y 6/4), slightly moist; many distinct, fine and medium orange mottles; fine sandy clay, firm; weak medium subangular blocky; few fine and very few medium tubular pores; very few fine roots.
9	168-210	Pale yellow (2.5Y 7/4), slightly moist; many distinct, medium and coarse orange and red mottles, associated with a few soft to medium hard Fe concretions; fine sandy clay, very firm; weak medium subangular blocky massive structure; few fine and very few medium tubular pores; roots not seen; few isolated quartzitic angular stones less than 2cm in diameter.

NOTES:

i) Horizons 6-9 increasingly compact with depth.

ii) On other face of pit, hard plinthitic horizon encroaches on profile face at 200cm.

Profile No:	BL11*	Village: Tuobo Gbawelekehn

Date: 9.4.86

Soil Class: L3

Suitability Class: $RS2_S$

Location: 550m from L0 (base line zero), east of the village of Tuobo Gbawelekehn

Landform: Swamp lowland

Gradient: Less than 1%

Aspect: -

Microtopography: Moderately uneven

Surface Features: Thick mat of roots and stems; 2cm deep organic debris.

Vegetation/Land Use: Completely overgrown cocoa plantation; many trees are dead, stunted and nearest trees are all infected by parasite. Black Pod (fungal disease) is also common.

Moisture Conditions: Very moist to wet

Profile Drainage: Very poorly drained

Groundwater Table: 60cm

Horizon	Depth (cm)	Profile Description
1	0- 6	Dark yellowish brown (10YR 3/4), very moist: common distinct fine and medium root mottles; silty clay loam, friable; moderate, fine to medium subangular blocky structure; common, fine and medium, few coarse vesicular pores; abundant fine, common medium, few coarse roots.
2	6- 18	Olive brown (2.5Y 4/4), very moist; common, distinct fine and medium rust mottles; silty clay, friable to firm; moderate medium subangular blocky structure; common fine and medium and few coarse tubular pores; common fine and medium roots.

Horizon	Depth (cm)	Profile Description
3	18- 36	Yellowish brown (10YR 5/4), very moist; common, distinct, fine and medium yellow, olive and grey mottles; silty clay, friable to firm; moderate, medium subangular blocky structure; common fine and medium, and few coarse pores; few fine and medium, and very few coarse roots; thin cutans observed on structural faces.
4	36- 58	Yellowish brown (10YR 5/6), wet; many distinct, fine and medium olive, yellow and grey mottles; silty clay, firm and sticky; moderate medium subangular blocky structure; common fine and medium tubular pores; few fine and medium roots.
5	58- 75	Pale olive (5Y 6/4), wet; many distinct, fine and medium yellow and grey mottles; very fine sandy clay, firm and sticky; moderate medium subangular blocky structure; common fine and medium, and very few coarse tubular pores; few fine and medium roots.
6	75- 92	Pale olive (5Y 6/3), wet; abundant distinct orange and grey mottles; very fine sandy clay, firm and sticky; moderate, medium subangular blocky; common fine and medium and few coarse tubular pores; few fine roots.
7	92-130	Light grey (5Y 6/1), wet; abundant, distinct orange and grey; medium sandy clay in slurry form and very sticky; structure not seen, pores not seen; few fine roots.

NOTES:

i) Much more sand in horizon 7, which acts as aquifer.

ii) Water reflooding the pit from horizon 7, especially around 1m depth.

Profile No:	A2*	Village: Tuobo Gbawelekehn Swamp I

Date:	9.4.86
Soil Class:	W3
Suitability Class:	$RS3_s$
Location:	100m from site A0 (base line), north of the village of Tuobo Gbawelekehn
Landform:	Swamp, near gradient leading upslope to lowland
Gradient:	1-2%
Aspect:	170°
Microtopography:	Moderately uneven
Surface Features:	Thinnish leaf litter and twig debris, over thickish root mat within tangled undergrowth.
Vegetation/Land Use:	Swamp regrowth, less than 5 years old, comprising ferns, reeds and a few trees and bushes.
Moisture Conditions:	Moist to wet
Profile Drainage:	Very poorly drained
Groundwater Table:	42 cm

Horizon	Depth (cm)	Profile Description
1	0- 6	Dark greyish brown (2.5Y 4/2), very moist; sandy loam, soft and non-sticky; weak, medium granular structure; common fine and medium vesicular pores; many fine, common medium and few coarse roots.
2	6- 12	Dark yellowish brown (10YR 4/4), very moist; sandy loam, soft and non-sticky; weak moderate subangular structure; common fine and medium tubular pores; common fine and medium roots.
3	12- 26	Dark greyish brown (2.5Y 4/2), very moist; common, distinct, fine and medium rust mottles; sandy clay loam, soft and non-sticky; structure not seen; common fine, few medium and coarse tubular pores; few fine and medium, very few coarse roots.

Horizon	Depth (cm)	Profile Description
4	26- 46	Light olive brown (2.5Y 5/6), wet; sandy clay loam, softish, slightly sticky though moderately coarse sand fraction; weak, moderate subangular structure; common fine, few medium and coarse tubular pores; few fine and medium, very few coarse roots.
5 (irregular occurrence)	46-66	Light yellowish brown (10YR 6/4), wet; gravelly sandy clay loam, loose; structure not see, not seen, structureless; common fine and medium, very few coarse vesicular pores; very few fine and medium roots; 80% hard, angular quartzitic stones, diameter usually less than 5cm.
6	66- 84	Brownish yellow (10YR 6/6), wet; many distinct fine and medium orange mottles; gravelly sandy clay loam, soft, slightly sticky; structure not seen; common, fine and medium, very few coarse vesicular and tubular pores; very few fine and medium roots; 15% hard, angular, quartzitic stones of diameter less than 2cm.
7	84-130	Pale yellow (2.5Y 7/4), wet; abundant, distinct fine medium and coarse orange, yellow and grey mottles; gravelly sandy clay loam, soft and sticky; structure not seen; roots and pores not seen; 60% hard angular quartzitic gravel, mostly of diameter less than 3cm.
8	130-160	Grey, gravelly and coarse sandy clay matrix, containing 80% quartzitic stones, up to 25cm in diameter; impenetrable at 160cm; this horizon acts as main aquifer, water reflooding the pits from about 150cm.

Profile No: A2*	Village: Tuobo Gbawelekehn Swamp II
Date:	8.4.86
Soil Class:	W3
Suitability Class:	$RS3_s$
Location:	80m from site Ao (on base line), in Swamp II, north or Wartekehn.
Landform:	Swamp fringe site
Gradient:	3%, upslope to lowland
Aspect:	170°
Microtopography:	Moderately uneven
Surface Features:	Regrowth, less than 1 year old, from 1985 farm; small bushes, few ferns and grasses.
Vegetation/Land Use:	Very thin, scattered leaf litter and twig debris within dense low undergrowth.
Moisture Conditions:	Moist to wet
Profile Drainage:	Poorly drained
Groundwater Table:	65cm

Horizon	Depth (cm)	Profile Description
1	0- 5	Dark yellowish brown (10YR 3/4), moist; few faint fine rust mottles in root channels; loamy sand, friable; weak crumb structure; common fine and medium vesicular pores; many fine and common medium roots.
2	5- 19	Grey (10YR 5/1), very moist; common distinct fine orange mottles; loamy sand, soft, non-sticky; weak fine subangular blocky; common fine and medium vesicular pores; common fine, few medium and coarse roots.
3	19- 30	Light grey (10YR 7/1), very moist; common, distinct, fine and medium yellow to orange mottles; sandy loam, firmish, slightly sticky; weak, fine subangular blocky structure; common fine and medium tubular pores; few fine and medium roots.

Horizon	Depth (cm)	Profile Description
4	30- 44	Light grey (10YR 7/1), very moist to wet; common, distinct fine and medium yellow to orange mottles; gravelly sandy clay loam, firm and slightly sticky; of indeterminate structure; common fine and medium tubular pores; few fine and medium roots; 30% hard angular quartzitic stones, less than 5cm in diameter.
5	44- 73	Light grey (5Y 7/2), wet; many distinct fine and medium orange mottles; fine silty clay loam, firmish and sticky; massive structure; few fine and very few medium tubular pores; few fine and very few medium roots.
6	73-108	Greenish grey (5GY 6/1), wet; common distinct, fine, medium and coarse, orange and olive mottles; silty clay, including micaceous material, softish and sticky; massive structure; few fine and very few medium tubular pores; few fine and very few medum roots.
7	108-160	Greenish grey (5G 5/1), wet; few, faint fine and medium rusty mottles; silty clay (predominantly silt), firmish and sticky with much micaceous material; flaky structure; pores and roots not seen; weathering parent material.

Profile No:	G0*	Village: Tujallah Town

Date: 25.4.86

Soil Class: L4

Suitability Class: UN_S

Location: Situated on the base line 600m from A0, north-east of the village of Tujallah Town.

Landform: Lowland, swamp fringe area

Gradient: 2%

Aspect: 150°

Microtopography: Moderately even

Surface Features: Thin 100% leaf litter cover, twig, branch and log debris from 1985 bush clearance operation.

Vegetation/Land Use: Secondary regrowth, one year old, on 1985 rice farm, predominantly reeds and small 'dryland' bushes.

Moisture Conditions: Moist to wet

Profile Drainage: Poorly drained

Groundwater Table: 120cm

Horizon	Depth (cm)	Profile Description
1	0- 4	Dark brown (10YR 3/3), moist; organic loamy sand, very friable and non-sticky; granular structure; abundant fine, common medium and few coarse vesicular pores; abundant fine, common medium and few coarse roots.
2	4- 18	Dark greyish brown (10YR 4/2), very moist; few, distinct, fine orange and white mottles; medium loamy sand, very friable and non-sticky; very weak subangular blocky structure; abundant fine, common medium, and few coarse tubular pores; common medium and fine and few coarse roots.
3	18- 42	Greyish brown (10YR 5/2), very moist; few distinct and faint fine rust and pale brown mottles; medium sand, loose and non-sticky; structureless; common fine and medium, few coarse pores; common fine, few medium and very few coarse roots.

Horizon	Depth (cm)	Profile Description
4	42- 73	Light grey (10YR 7/1), very moist; few distinct, fine yellow and white mottles; medium to coarse sand, loose, non-sticky; structureless; common fine and many medium pores; few fine and medium roots.
5	73-104	Light grey (10YR 7/1), very moist; common faint, fine and medium, yellow, pale brown and white mottles; coarse sand, very friable; structureless; common fine, many medium and few coarse pores; very few fine and medium roots.
6	104-170	Light grey (2.5Y 7/1), wet; few faint fine yellow mottles; medium sandy clay, friable to firm and slightly sticky; weak subangular blocky structure; common fine and medium tubular pores; roots not seen; uneven distribution of sand within matrix containing much more clay than horizons 1 to 5.

Profile No:	F2*	Village: Tujallah Town
Date:	25.4.86	
Soil Class:	L1	
Suitability Class:	$US2_t$	
Location:	100m from F0 (on base line) north of the village of Tujallah Town.	
Landform:	Mid-slope site within lowland area	
Gradient:	3%	
Aspect:	320°	
Microtopography:	Moderately even	
Surface Features:	Thinnish 100% leaf litter cover with some twig debris.	
Vegetation/Land Use:	Secondary regrowth, 7-8 years old, includes a few palm trees.	
Moisture Conditions:	Moist	
Profile Drainage:	Well drained	
Groundwater Table:	Not seen	

Horizon	Depth (cm)	Profile Description
1	0- 5	Dark brown (10YR 3/3), moist; loamy sand, very friable; weak crumb structure; many fine and medium vesicular pores; abundant fine, many medium, few coarse roots.
2	5- 15	Dark greyish brown (10YR 4/2), moist; medium sandy loam, friable; weak subangular blocky; many fine, common medium and few coarse tubular pores; common fine, and few medium and coarse roots.
3	15- 30	Yellowish brown (10YR 5/4), moist; medium sandy clay loam, friable; weak subangular blocky; common medium and fine tubular pores; few fine, very few medium and coarse roots.
4	30- 73	Yellowish brown (10YR 5/6), moist; medium sandy clay loam, friable; moderate subangular blocky; common, medium and fine, few coarse tubular pores; very few, fine, medium and coarse roots; clay accumulation in this horizon, cutans observed.

Horizon	Depth (cm)	Profile Description
5	73-109	Brownish yellow (10YR 6/6), moist; few faint fine and medium, very pale orange mottles; sandy clay, friable; moderate subangular blocky structure; few fine and medium tubular pores; very few fine and medium roots; clay accumulation also in this horizon, cutans observed.
6	109-133	Brownish yellow (10YR 6/6), moist; common faint and distinct, fine and medium orange mottles; fine sandy clay, friable to firm; moderate subangular blocky structure; few fine and medium tubular pores; few fine and medium roots.
7	133-160	Brownish yellow (10YR 6/8), moist; common, faint and distinct, fine and medium orange mottles; fine sandy clay, firm; moderate subangular blocky structure; few fine and medium tubular pores; roots not seen; less than 5% hard round iron concretions.
8	160-200	White (10YR 8/2), moist; abundant, distinct medium and coarse red plinthitic mottles; gravelly clay loam, friable; pores, roots and structure not seen; 20% hard round iron concretions; increasingly white coloured with depth, but Fe concretions never exceed approximately 20%; silt fraction also increases with depth.

Profile No:	D4*	Village: Tujallah Town

Date: 25.4.86

Soil Class: W3

Suitability Class: $RS3_s$

Location: 200m from site D0 (on base line), north of the village of Tujallah Town

Landform: Swamp

Gradient: Indeterminate

Aspect: -

Microtopography: Moderately uneven

Surface Features: 60% leaf litter cover with twig debris over soft dark organic mat, with common surface roots.

Vegetation/Land Use: Wetland swamp forest, dominant species bamboo, reeds with a few palms and many climbing and creeping species.

Moisture Conditions: Moist to wet

Profile Drainage: Poorly drained

Groundwater Table: 135cm

Horizon	Depth (cm)	Profile Description
1	0- 4	Very dark greyish brown (10YR 3/2), moist; organic sandy loam, soft, slightly sticky; weak crumb structure; common fine and medium vesicular pores; many fine, few medium and coarse roots.
2	4- 12	Greyish brown (10YR 5/2), very moist; common, distinct medium yellow mottles; fine sandy loam, soft to friable, slightly sticky; weak subangular blocky structure; common fine and medium tubular pores; common fine and medium roots.
3	12- 34	Greyish brown (10YR 5/2), wet; common, distinct, fine rust mottles; fine to medium sand, soft and non-sticky; indeterminate structure; many fine and medium, few coarse vesicular pores; few fine, very few medium roots.

Horizon	Depth (cm)	Profile Description
4	34- 69	Grey (10YR 6/1), very moist; many distinct, medium yellow and rust mottles; medium sandy clay loam, firm; weak subangular blocky; common fine and medium, few coarse tubular pores; few fine and medium roots.
5	69- 91	Grey (10YR 6/1), very moist; few distinct, fine yellow mottles; medium sand, friable; weak subangular blocky structure; few fine, medium and coarse vesicular pores; very few fine and medium roots.
6	91-130	Bluish grey (5B 5/1), wet; variable blue and grey mottles; medium sandy clay, firm and sticky; massive structure; few fine, medium and coarse tubular pores; very few fine and medium roots.
7	130-160	Greenish grey (5BG 6/1), wet; few smears of variable grey colours; medium to coarse loamy sand, soft, non-sticky; structureless; common fine, medium and coarse tubular pores; roots not seen.
8	160-186	Bluish grey (5B 6/1), wet; few smears of variable grey colours; coarse sand, loose and non-sticky; structureless; pores and roots not seen.

Profile No:	Y4*	Village: Tujallah Town
Date:	25.4.86	
Soil Class:	W4	
Suitability Class:	RN_s	
Location:	200m from site Y0 (on base line minus), south of the village of Tujallah Town	
Landform:	Swamp	
Gradient:	Less than 1%	
Aspect:	-	
Microtopography:	Moderately uneven, low hummocks and hollows.	
Surface Features:	Dark organic topsoil, scattered bleached sand grains, and thin leaf litter.	
Vegetation/Land Use:	Old oil palm plantation now within wetland swamp forest, few bamboos and adapted dryland species; scattered ferns with little other ground vegetation.	
Moisture Conditions:	Moist to wet	
Profile Drainage:	Poorly drained	
Groundwater Table:	152cm	

Horizon	Depth (cm)	Profile Description
1	0- 3	Very dark grey (10YR 3/1), moist; abundant bleached sand grains; organic medium sand, soft; single grain structure; indeterminate pores; manyfine and medium roots.
2	3- 16	Dark brown (10YR 3/3), Moist; common bleached sand grains; medium sand, soft; single grain structure; indeterminate pores; common fine and medium roots.
3	16- 31	Light brownish grey (10YR 6/2), moist; medium sand, soft; single grain structure; indeterminate pores; few fine roots.
4	31- 45	Greyish brown (10YR 5/2), moist; few, faint, fine yellow brown mottles; medium sand, soft; single grain structure; indeterminate pores; very few fine roots.

Horizon	Depth (cm)	Profile Description
5	45- 66	Light brownish grey (10YR 6/2), moist; common indistinct, fine yellow brown mottles; medium sand, soft; single grain structure; indetermiated pores and no root seen.
6	66- 90	Grey (10YR 6/1), moist; common distinct, fine and medium strong brown mottles; loamy sand to medium sand, friable; very weak, fine subangular blocky structure; few fine tubular pores; very few fine roots.
7	90-106	Light grey (2.5Y, 5Y 7/2), moist; common, distinct, fine strong brown mottles in old root channels; sandy loam, friable; weak, fine angular blocky structure; few fine tubular pores; very few fine roots.
8	106-144	Light grey (10YR, 5Y 7/2), moist; many distinct medium dark grey mottles; silty loam, slightly firm; weak fine and medium subangular structure; common old 'root channel' pores; very few fine roots; few fine mica flakes.
9	144-235	Greenish grey and greyish green, variable (e.g. 5G 6/2, 5BG 6/1); very moist to wet; variable faint mottling; silty loam, slightly firm; weak, moderate prismatic structure; few fine tubular pores and many old root channels; very few fine roots; common mica flakes.
10	235-260	Greyish green and greenish greys (5G 5/1, 5G 4/2, 5G 5/2); moist; rare fine rusty mottles; silt, slightly firm; massive structure; indeterminate pores; few fine dead roots; common mica flakes.

NOTES: i) soil below GWT appears moist only; perched water table;

ii) siltiness due to mica flakes;

iii) roots only common in horizons 1 and 2.

Profile No:	V92	Village: Tuobo Gbawelekehn

Date: 10.4.86

Soil Class: D2

Suitability Class: 3_g

Location: 600m south east Tuobo Gbawelekehn

Landform: Plateau: edge of slope down to stream

Gradient: 3%

Aspect: 140°

Micro topography: Even

Surface Features: Thin litter, sandy

Vegetation/Land Use: Thin woody regrowth (approx. 5 years); scattered patches of ground vegetation (grass and ferns etc.)

Moisture Conditions: Moist

Profile Drainage: Well drained

Groundwater Table: Not seen

Type of Observation: Auger boring

Horizon	Depth (cm)	Profile Description
1	0- 2	Brown (10YR 4/3) friable sandy loam; few fine roots; no stones.
2	2- 10	Dark yellowish brown (10YR 4/4) friable sandy loam; no stones.
3	10- 30	Yellowish brown (10YR 5/6) firm sandy clay; no stones.
4	30- 55	Yellowish brown (10YR 5/6); few small prominent red mottles; firm/loose; gravelly sandy clay; common small concretions.
5	55-	Impenetrable to auger - concretions and gravel.

Profile No:	V67	Village: Tuobo Gbawelekehn
Date:	8.4.86	
Soil Class:	D3	
Suitability Class:	4_{gr}	
Location:	c. 4 km north north-east of Tuobo Gbawelekehn	
Landform:	Gently undulating	
Gradient:	3%	
Aspect:	240°	
Microtopography:	Slightly uneven	
Surface Features:	Thin litter and twigs	
Vegetation/Land Use	Forest regrowth; open canopy; low shrub vegetation; sparse ground cover.	
Moisture Conditions:	Moist	
Profile Drainage:	Well drained	
Groundwater Table:	Not seen	
Type of Observation:	Auger boring	

Horizon	Depth (cm)	Profile Description
1	0- 5	Dark yellowish brown (10YR 4/4) soft loamy sand; abundant fine and medium roots; no stones.
2	5- 15	Yellowish brown (10YR 5/6); rare fine red streaks; friable sandy loam; few small gravel.
3	15- 40	Yellowish brown (10YR 5/6) friable sandy loam; few small and medium gravel.
4	40-	Impenetrable to auger - rocks and gravel.

Profile No:	V83	Village: Tujallah Town
Date:	24.4.86	
Soil Class:	D4	
Suitability Class:	5_{gr}	
Location:	c. 2.9 km south south-east of Tujallah Town	
Landform:	Sloping to swamp; undulating	
Gradient:	10%	
Aspect:	310°	
Microtopography:	Slightly uneven	
Surface Features:	Burnt twigs and leaves; scattered gravel	
Vegetation/Land Use	New farm being prepared; recently burnt	
Moisture Conditions:	Moist	
Profile Drainage:	Well drained	
Groundwater Table:	Not seen	
Type of Observation:	Auger boring	

Horizon	Depth (cm)	Profile Description
1	0- 3	Dark brown (10YR 4/3) soft loamy sand; common fine roots; common small concretions and gravel.
2	3- 10	Yellowish brown (10YR 5/4) friable gravelly sandy loam; common small concretions.
3	10- 35	Yellowish brown (10YR 5/6) firm gravelly sandy clay loam; abundant small concretions.
4	35-	Impenetrable to auger - probably rock and/or concretions.

Profile No:	V7	Village: Tuobo Gbawelekehn
Date:	31.3.86	
Soil Class:	D5	
Suitability Class:	1	
Location:	c. 4 km south south-west of Tuobo Gbawelekehn	
Landform:	Very gently undulating	
Gradient:	Less than 2%	
Aspect:	Indeterminate	
Microtopography:	Slightly uneven	
Surface Features:	Thin leaf litter; sandy	
Vegetation/Land Use	Thin bushy regrowth; (7-10 years)	
Moisture Conditions:	Moist	
Profile Drainage:	Well drained	
Groundwater Table:	Not seen	
Type of Observation:	Auger boring	

Horizon	Depth (cm)	Profile Description
1	0- 5	Dark brown (10YR 4/3) soft loamy sand; few fine roots; no stones.
2	5- 10	Brown (10YR 5/3) soft loamy sand; no stones.
3	10- 45	Yellowish brown (10YR 5/5) friable sandy loam; no stones.
4	45-100	Yellowish brown (10YR 5/6) friable sandy loam to sandy clay loam; no stones.

Profile No:	V52	Village: Tuobo Gbawelekehn
Date:	4.4.86	
Soil Class:	D6	
Suitability Class:	3_g	
Location:	c. 300m north west of Wartekehn, close to main road.	
Landform:	Gently undulating	
Gradient:	3 - 5%	
Aspect:	225°	
Microtopography:	Slightly uneven	
Surface Features:	Decomposing leaf litter	
Vegetation/Land Use	Small rubber plantation; herbaceous ground vegetation	
Moisture Conditions:	Moist	
Profile Drainage:	Well drained	
Groundwater Table:	Not seen	
Type of Observation:	Auger boring	

Horizon	Depth (cm)	Profile Description
1	0- 5	Dark brown (10YR 4/3) soft loamy sand; frequent fine roots; no stones.
2	5- 25	Yellowish brown (10YR 5/4) friable sandy loam; no stones.
3	25- 55	Yellowish brown (10YR 5/6); few fine reddish mottles; friable sandy clay loam; few small gravel.
4	55- 90+	Yellowish brown (10YR 5/6); few fine and medium red mottles; gravelly sandy clay loam; common small gravel.

Profile No:	V1	Village: Fishtown
Date:	20.3.86	
Soil Class:	D7	
Suitability Class:	3_g	
Location:	Near bamboo bridge across Nismeh R, c. 500m south east of Fishtown	
Landform:	Gently undulating; sloping to Nismeh R.	
Gradient:	3%	
Aspect:	80°	
Microtopography:	Slightly uneven	
Surface Features:	Thin litter; sandy	
Vegetation/Land Use	High Forest	
Moisture Conditions:	Moist	
Profile Drainage:	Well drained	
Groundwater Table:	Not seen	
Type of Observation:	Auger boring	

Horizon	Depth (cm)	Profile Description
1	0- 10	Brown (10YR 4/3) friable/loose gravelly sandy clay loam; common small concretions.
2	10- 25	Dark brown (7.5YR 4/4) friable/loose gravelly sandy clay loam; common small concretions.
3	25- 45	Strong brown (7.5YR 4/6) friable/loose; gritty and gravelly sandy clay loam; common small concretions.
4	48- 80	Strong brown (7.5YR 5/8) friable gritty and gravelly sandy clay loam; common small concretions.
5	80- 90+	Yellowish red (5YR 5/8) with indistinct redder patches and variegation; firm silty clay loam; no concretions; micaeous.

Profile No: V53	Village: Fishtown
Date:	26.3.86
Soil Class:	D8
Suitability Class:	1
Location:	c. 400m along track from road junction, which is about 4 km east south-east of Fishtown
Landform:	Gently undulating; crest location
Gradient:	2%
Aspect:	135°
Microtopography:	Slightly uneven
Surface Features:	Litter and twigs
Vegetation/Land Use	Secondary regrowth forest
Moisture Conditions:	Moist
Profile Drainage:	Well drained
Groundwater Table:	Not seen
Type of Observation:	Auger boring

Horizon	Depth (cm)	Profile Description
1	0- 10	Very dark greyish brown (10YR 3/2) soft loamy sand; common fine roots; no stones.
2	10- 20	Yellowish brown (10YR 5/4) friable sandy loam; no stones.
3	20- 50	Yellowish brown (10YR 5/6) friable sandy loam; no stones.
4	50- 80	Yellowish brown (10YR 5/6 to 10YR 5/8) friable sandy clay loam; no stones.
5	80-100+	Brownish yellow (10YR 6/8) with few to common soft red variegations and nodules; friable sandy clay loam; few small concretions.

A.2 LABORATORY ANALYSIS DATA

A.2.1 INTRODUCTION

The laboratory soil analysis results are presented and discussed in this chapter. Phase 1 samples (reconnaissance survey) were submitted to CARI for laboratory analysis. Samples from Phase 2 (semi-detailed and detailed surveys) were submitted to a laboratory in Europe. Appropriate internationally accepted methods were used.

The following analyses are reported for the Phase 1 samples:

- pH in water
- cation exchange capacity
- exchange acidity
- available P
- organic carbon
- total nitrogen.

In Phase 2, the following analyses were undertaken on all samples:

- pH in water
- exchangeable cations
- exchange acidity
- available P.

Additionally for the Phase 2 samples, organic matter and total nitrogen were undertaken on selected topsoil samples. Electrical conductivity was determined on selected swamp samples. pH in potassium chloride was determined in the majority of samples.

A.2.2 METHODS

Soil pH (H_2O). The soil pH was measured in a suspension of distilled water. For the Phase 1 samples, a soil:water ratio of 1:1 was used. For the Phase 2 samples, 20g of soil were shaken with 50ml of water (soil:water ratio 1:2.5).

Soil pH (KCl). 20g of soil were shaken with 50ml of 1N potassium chloride (Dewis and Freitas, 1970).

Exchangeable Cations. Determined by leaching with 1N ammonium acetate buffered at pH 7.0 (Dewis and Freitas, 1970).

Exchange Acidity. Determined by leaching with 1M potassium chloride. A suitable aliquot was then titrated with NaOH to pH 8.3 to determine total acidity. Exchangeable aluminium was estimated by reaction of the titrated extract with excess NaF to produce an equivalent amount of OH^- which was back titrated with standard acid. Exchangeable hydrogen determined by difference between total acidity and that derived from aluminium. (Dewis and Freitas, 1970).

Cation Exchange Capacity. Determined by leaching with 1N ammonium acetate buffered at pH 7.0 for Phase 1 samples. Determined as the sum of the exchangeable bases and exchange acidity for Phase 2 samples.

Electrical Conductivity. Determined on 1:5 soil- water suspension. A relationship between the electrical conductivity of the saturation extract (EC_e) and of the 1:5 suspension ($EC_{1:5}$) is reported by Landon (1984) as:

$$EC_e = 6.4 \times EC_{1:5}$$

The results of the determination are reported as "saturation extract equivalent" using the above transformation.

Available Phosphorus was determined on the Phase 1 samples by the "Bray 1" method using a 0.03N ammonium fluoride solution. For the Phase 2 samples the Olsen method was used (0.5M sodium bicarbonate at pH 8.5, as extractant). Both methods are described by Dewis and Freitas, 1970.

Organic Carbon. "Readily oxidisable carbon" was determined by cold digestion with potassium dichromate in concentrated sulphuric acid (Walkeley and Black method).

Total Nitrogen was determined by digestion using the Kjeldahl method.

A.2.3 RESULTS AND DISCUSSION

A.2.3.1 Phase 1 (Reconnaissance Survey)

All profiles sampled are moderately acid and cation exchange capacity (c.e.c) is low, reflecting the highly weathered and leached nature of these soils. Available phosphorus is highly variable, ranging from low to very high. Organic carbon decreases generally down the profile. Carbon : nitrogen ratios in the range 10:1 to 12:1 are common.

The fertility status of these soils is dominated by the inherently low fertility imparted by their low c.e.c. and pH.

A.2.3.2 Phase 2 (Semi-detailed and Detailed Surveys of Villages and Swanps)

The laboratory analysis data show that the soils are predominantly moderately acid. 73% of the Phase 2 samples have a pH in water in the range 4.5 - 5.5. 13% of the samples are strongly acid (pH less than 4.5), and 9% are weakly acid to neutral (pH 5.6 - 6.95). A few samples (4%) are slightly alkaline; these are all in the Beezohn swamp but do not seem to be related to any obvious field observed characteristics. There is also no evidence that the swamp soils are either more acid or less acid than the upland soils.

As is normally the case pH, as measured in IN potassium chloride shows lower values than measured in water. In half the samples the depression of pH is more that 0.80 units; in the other half, the depression is less than 0.80. The relative degree of depression is usually taken as an indication of the "reserve of acidity" or buffering capacity of the soil to resist changes in pH.

In almost all cases, cation exchange capacity (c.e.c) is very low. In more than 90% of the samples it is less than 5 meq/100g. This reflects the excessive leaching of the soils under the high rainfall regime and implies low inherent soil fertility. C.e.c. is usually relatively higher in the top sample of the profile, presumably a reflection of the organic matter content of these samples. Some samples from depth in the swamps also show considerably higher c.e.c; in some cases this is related to the more clayey textured subsoils often found at depth below coarser sandy layers.

In all cases, calcium and magnesium dominate the exchange complex; exchangeable sodium rarely occurs in detectable amounts. Base saturation is generally high, but in a few cases it is very low (exchange acidity dominates the exchange complex). These instances do not appear to be mecessarily related to low pH nor to particularly great depression of pH measured in potassium chloride, and the explanation of this is therefore difficult.

The electrical conductivity of the swamp soils is invariably very low (soils are salt free) apart from one sample from the Fishtown swamp which has a slightly higher value. Even this sample does not, however, reach the slightly saline class which is usually defined as ECe values of 4 - 8 mS cm^{-1}. Thus no problems of salinity are envisaged, although this aspect should be regularly monitored and EC values should preferably be considered in conjunction with data on the electrical conductivity and sodium content of the irrigation water.

Amounts of available phosphorus are generally very low and, in most cases, crops are likely to respond to applications of phosphate fertilizer. In most profiles, available phosphorus is higher in the top one or two depths sampled, but even here the amounts are generally low.

As might be expected, the organic matter content of the topsoil horizon is generally greater in the swamps than in the uplands. The average organic carbon content of the swamp soil samples is 2.52% (11 samples) while the average for samples from the semi-detailed village survey is 1.26% (12 samples). Individual values of organic carbon greater than 5% were recorded in some swamp samples; the highest recorded from the upland soils in the village survey is 1.77%.

Emerging from these results is a not unexpected picture of generally acid soils with inherently low fertility. Thus, crops are likely to respond well to applications of plant nutrients but, at the same time, the soil's ability to retain nutrients is limited by the low cation exchange capacity. Successful intensification of cropping will therefore depend on a careful management of the soil to slowly build up fertility with balanced application of fertilizers as necessary, but taking care to ensure that fertilizer application does not lead to further acidification of the soil.

Differences in the apparent chemistry of the swamp soils and upland soils are not obvious, apart from the organic matter content of the topsoils. All soils suffer from the same limitations.

It should be emphasised that the results reported here are those obtained by standard methods of analysis by rewetting dried soil samples in the laboratory. However, they may not accurately reflect the actual growing conditions in the field, especially in the swamps, when inundated for rice production. It is a well documented fact that the pH of a submerged acid soil generally increases (e.g. de Datta, 1981); the chemistry of waterlogged soils is a complex subject and the changing redox conditions as the soil is alternately drained and flooded have considerable impact on the solubility of compounds and hence on the availability of nutrients. In this respect, correspondence between the soil laboratory at CARI with colleagues at the International Rice Research Institute (IRRI) in the Philippines on appropriate methods of analysis of swamp soils might prove valuable.

LABORATORY ANALYSIS DATA

Profile No: R27
Soil Class: D7

Reconnaissance Survey

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g) Ca	Mg	K	Na	Exchangeable Acidity (meq/100g) H	Al
0-10	4.0						0.60	0.15
25-45	4.5						0.65	0.5
45-75	4.5						0.75	0.5
75-100	4.5						0.75	0.95

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity (mS cm^{-1})	Available P (ppm)	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0-10	6.1	88		18	1.35	1.2
25-45	3.7	69		13	0.39	0.3
45-75	3.7	66		10	0.94	0.2
75-100	2.7	37		150	0.32	0.3

Profile No: R36
Soil Class: D5

Reconnaissance Survey

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g) Ca	Mg	K	Na	Exchangeable Acidity (meq/100g) H	Al
0-10	4.3						0.55	0.3
10-35	4.5						0.55	0.05
50.75	4.7						0.3	0.15

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity (mS cm^{-1})	Available P (ppm)	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0-10	3.8	78		288	0.6	0.5
10-35	6.1	90		9	0.39	0.3
50-75	2.4	81		13	0.3	0.2

LABORATORY ANALYSIS DATA

Profile No: R10
Soil Class: D5/D6

Reconnaissance Survey

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 15	4.7						0.95	0.75
35 - 60	4.2						0.60	0.15
60 - 95	4.9						0.70	0.20
95 - 110	5.0						0.30	0.15

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity (mS cm^{-1})	Available P (ppm)	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0-15	2.9	41		18.4	0.88	0.8
35-60	2.9	74		2.3	0.52	0.9
60-95	3.6	75		2.3	0.24	0.2
95-110	3.8	88		12.8	0.32	0.3

Profile No: R17
Soil Class: D2

Reconnaissance Survey

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0-15	4.2						0.50	0.15
35-65	4.5						0.50	0.95
65-90	4.5						0.40	0.25

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity (mS cm^{-1})	Available P (ppm)	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0-15	3.2	80		231	0.96	0.8
35-65	2.3	37		150	0.48	0.4
65-90	2.6	75		13[illegible]	0.56	0.5

LABORATORY ANALYSIS DATA

Profile No: R45
Soil Class: D1

Reconnaissance Survey

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0-10	4.4						1.25	0.15
10-45	4.5						0.4	0.1
45-80	4.4						0.5	0.2
80-100	4.5						0.6	0.25

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity (mS cm^{-1})	Available P (ppm)	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0-10	3.5	60		22	0.48	0.4
10-45	2.7	81		42	0.24	0.2
45-80	2.7	74		2	0.28	0.2
80-100	3.4	75		13	0.24	0.2

Profile No: R55
Soil Class: D7

Reconnaissance Survey

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0-10	5.4						0.3	0.10
10-55	4.5						0.75	0.4
55-75	4.2						0.65	0.2
75-100	4.0						0.5	0.3

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity (mS cm^{-1})	Available P (ppm)	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0-10	8.0	95		32	1.6	1.4
10-55	3.7	69		10	0.48	0.4
55-75	5.6	85		14	0.36	0.3
75-100	2.1	62		15	0.28	0.9

LABORATORY ANALYSIS DATA

Profile No: R71
Soil Class: D1

Reconnaissance Survey

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0-15	4.0						0.8	0.45
5-30	4.5						0.5	0.2
50-75	4.7						0.75	0.25

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity (mS cm^{-1})	Available P (ppm)	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0-15	3.9	68		20	0.76	0.7
5-30	3.1	77		14	0.39	0.3
50-75	3.1	68		10	0.16	0.1

LABORATORY ANALYSIS DATA

Beezohn Village Survey

Profile No: E-42
Soil Class: D1

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 15	4.40	3.65	0.39	0.25	0.08	<0.1	0.67	1.08
15 - 40	4.60	3.90	0.13	0.09	0.04	<0.1	0.82	1.18
40 - 60	4.50	3.90	0.12	0.09	0.03	<0.1	0.70	1.05
60 - 80	4.85	3.95	0.12	0.06	0.03	<0.1	1.05	1.48

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 15	2.47	29.1		4		
15 - 40	2.26	11.5		<1		
40 - 60	1.99	12.1		<1		
60 - 80	2.74	7.7		<1		

Beezohn Village Survey

Profile No: M1
Soil Class: D4

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 10	5.05	4.60	5.37	0.93	0.19	<0.1	0.05	0.10
10 - 20	5.00	4.40	3.64	0.64	0.13	<0.1	0.15	0.15
20 - 35	5.15	4.30	2.05	0.44	0.04	<0.1	0.10	0.18

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 10	6.64	97.7		2	1.77	2.19
10 - 20	4.71	93.6		2		
20 - 35	2.81	90.0		<1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Profile No: M6(a)
Soil Class: L2

Beezohn Village Survey

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 10	5.05	4.60	1.46	0.24	0.08	<0.1	0.05	0.10
10 - 50	5.00	4.40	0.57	0.15	0.10	<0.1	0.15	0.15
50 - 90	5.15	4.30	0.42	0.15	0.03	<0.1	0.10	0.18

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 10	6.64	97.7		2	1.77	2.19
10 - 20	4.71	93.6		2		
20 - 35	2.81	90.0		<1		

Beezohn Swamp Survey

Profile No: C4
Soil Class: W3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
7 - 33	4.45	3.60	2.03	0.48	0.09	<0.1	0.20	0.55
33 - 60	4.95	3.65	2.05	0.90	0.04	<0.1	0.05	0.18
60 - 90	5.70	4.30	2.09	0.95	0.02	0.1	neg	neg
90 - 118	5.95	4.30	2.45	1.06	0.02	0.1	neg	neg
118 - 200	6.65	5.05	4.46	1.87	0.20	0.1	neg	neg

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
7 - 33	3.35	77.6		7	2.36	1.91
33 - 60	3.22	92.6		<1		
60 - 90	3.16	100		<1		
90 - 118	3.63	100		<1		
118 - 200	6.63	100		1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Beezohn Swamp Survey

Profile No: E2
Soil Class: W3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
5 - 18	4.80	3.90	0.60	0.31	0.05	.0.1	0.08	0.23
18 - 42	5.00	3.70	0.35	0.21	0.02	<0.1	0.08	0.30
42 - 70	5.40	4.10	0.57	0.37	0.02	<0.1	neg	neg
70 - 95	6.30	4.90	2.20	1.37	0.02	<0.1	neg	neg
122 - 162	6.70	4.85	4.53	2.66	0.05	<0.1	neg	neg
190 - 270	7.40	5.95	6.19	2.95	0.13	<0.1	neg	neg

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
5 - 18	1.27	75.6		2		
18 - 42	0.96	60.4		<1		
42 - 70	0.96	100		<1		
70 - 95	3.59	100		<1		
122 - 162	7.24	100		<1		
190 - 270	9.27	100		<1		

Beezohn Swamp Survey

Profile No: F5
Soil Class: W2

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
6 - 15	5.10	3.85	2.19	0.88	0.17	<0.1	0.10	0.15
15 - 42	4.95	4.15	0.66	0.47	0.03	<0.1	0.20	0.48
42 - 80	5.00	4.10	0.50	0.39	0.02	<0.1	0.21	0.63
80 - 110	5.15	4.20	0.51	0.46	0.17	<0.1	0.17	0.63
110 - 140	5.30	4.05	2.30	2.08	0.02	<0.1	0.19	0.48
140 - 180	6.00	5.10	0.95	0.72	0.01	<0.1	neg	neg

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
6 - 15	3.49	92.8		4	2.02	2.28
15 - 42	1.84	63.0		3		
42 - 80	1.75	52.0		<1		
80 - 110	1.94	58.8		<1		
110 - 140	5.07	86.8		<1		
140 - 180	1.67	100		<1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Beezohn Swamp Survey

Profile No: D4
Soil Class: W3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
10 - 23	6.00		4.77	1.28	0.14	0.15	neg	neg
23 - 40	7.35		2.40	1.09	0.03	0.1	neg	neg
40 - 80	7.80		3.09	1.59	0.03	0.1	neg	neg
80 - 135	7.65	6.25	3.33	1.65	0.07	0.1	neg	neg
135 - 185	8.00	6.80	2.28	1.14	0.08	<0.1	neg	neg

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
10 - 23	6.34	100	0.66	3		
23 - 40	3.62	100	0.15	<1		
40 - 80	4.81	100	0.14	<1		
80 - 135	5.15	100		1		
135 - 185	3.50	100		1		

Beezohn Swamp Survey

Profile No: K2
Soil Class: W3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
5 - 12	4.55		0.47	0.23	0.06	< 0.1	0.42	0.48
12 - 42	5.00		0.76	0.46	0.09	< 0.1	0.28	0.32
42 - 62	6.75		2.31	1.79	0.02	< 0.1	neg	neg
62 - 81	7.20	5.25	3.32	2.55	0.01	0.1	neg	neg
81 - 110	7.45	5.90	3.93	2.67	0.21	0.2	neg	neg
140 - 180	7.95	6.55	5.97	3.57	0.12	0.1	neg	neg

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
5 - 12	1.66	45.8	0.29	1		
12 - 42	1.91	68.6	0.13	<1		
42 - 62	4.12	100.0	0.08	<1		
62 - 81	5.97	100.0		<1		
81 - 110	7.01	100.0		<1		
140 - 80	9.76	100.0		<1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Beezohn Swamp Survey

Profile No: J2
Soil Class: W3/4

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
6 - 20	4.60	4.05	< 0.1	< 0.05	0.02	< 0.1	0.20	0.65
20 - 48	4.95	4.10	< 0.1	< 0.05	0.01	< 0.1	0.05	0.93
48 - 80	4.95	4.10	< 0.1	< 0.05	0.02	< 0.1	0.47	0.83
80 - 110	5.20	4.05	< 0.1	< 0.05	0.03	< 0.1	0.47	0.98
150 - 180	5.25	4.00	0.3	0.21	0.03	< 0.1	0.90	1.68

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
6 - 20	0.87	2.3		1		
20 - 48	0.98	**		<1		
48 - 80	1.32	1.5		<1		
80 - 110	1.48	2.0		<1		
150 - 180	3.12	17.3		<1		

John David Town Village Survey

Profile No: V27
Soil Class: D1

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 10	4.75	4.05	0.81	0.35	0.10	< 0.1	0.06	0.53
10 - 20	4.60	3.95	0.64	0.27	0.05	< 0.1	0.02	0.68
35 - 50	4.65	3.95	0.37	0.15	0.06	< 0.1	0.20	0.81
50 - 75	4.60	3.95	0.22	0.11	0.05	< 0.1	0.23	0.51

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 10	1.85	69.6		<1	0.83	0.98
10 - 20	1.66	52.2		<1		
35 - 50	1.59	35.8		<1		
50 - 75	1.12	36.2		<1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

John David Town Village Survey

Profile No: V59
Soil Class: D1

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 5	5.50	4.85	3.58	0.88	0.14	<0.1	neg	neg
5 - 15	5.00	4.30	1.85	0.58	0.07	<0.1	0.04	0.14
15 - 40	4.50	4.05	1.06	0.33	0.04	<0.1	0.14	0.60
40 - 90	4.65	4.05	0.47	0.12	0.03	<0.1	neg	1.42

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 5	4.60	100		1		
5 - 15	2.68	94.7		<1		
15 - 40	2.17	70.4		<1		
40 - 90	2.04	30.4		<1		

John David Town Swamp 1 Survey

Profile No: B3
Soil Class: W1

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 3/5	4.45		1.75	0.53	0.12	<0.1	0.33	0.83
3/5 - 26	4.95		0.54	0.21	0.04	<0.1	0.12	0.45
26 - 41	4.90		0.36	0.37	0.02	<0.1	0.07	0.42
41 - 55	4.85	3.85	1.10	0.84	0.04	<0.1	0.06	0.27
55 - 130	5.20	4.10	1.15	1.19	< 0.01	<0.1	0.03	0.14
130 - 165	5.55	4.05	2.29	2.42	0.01	<0.1	neg	neg

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 3/5	3.56	67.4	0.48	12	2.04	2.63
3/5 - 26	1.36	58.0	0.05	<1		
26 - 41	1.24	60.5	0.05	<1		
41 - 55	2.31	85.7		2		
55 - 130	2.51	93.2		<1		
130 - 165	4.72	100.0		<1		

<u>Notes</u>

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of <u>soil</u>

LABORATORY ANALYSIS DATA

Fishtown Village Survey

Profile No: V63
Soil Class: L1

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 10	4.50	3.85	0.42	0.18	0.11	<0.1	0.34	1.14
10 - 40	4.40	3.85	0.16	0.09	0.07	<0.1	0.38	1.43
40 - 60	4.50	3.85	0.10	0.07	0.05	<0.1	0.41	1.66
60 - 90	4.15	3.90	0.10	0.08	0.03	<0.1	0.19	0.63

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 10	2.19	32.4		1	0.85	0.78
10 - 40	2.13	15.0		<1		
40 - 60	2.29	9.6		<1		
60 - 90	0.93	11.8		<1		

Fishtown Village Survey

Profile No: V65
Soil Class: D3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 10	4.10	3.60	0.11	0.16	0.10	<0.1	0.33	1.15
10 - 25	4.40	3.90	0.10	0.09	0.05	<0.1	0.33	1.80
25 - 40	4.65	4.00	0.10	0.15	0.03	<0.1	0.09	0.40

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 10	1.85	20.0		2		
10 - 25	2.37	6.2		<1		
25 - 40	0.77	26.9		<1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Fishtown Swamp Survey

Profile No: B11
Soil Class: W3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 9	4.60		3.71	1.89	0.39	<0.1	0.43	0.39
9 - 18	4.65		0.10	0.13	0.04	<0.1	0.60	0.75
18 - 42	4.30		0.29	0.23	0.07	<0.1	0.28	1.19
42 - 60	4.85	4.00	0.13	0.14	0.03	<0.1	0.47	0.55
120+	5.05	3.95	1.96	1.44	0.11	0.1	0.04	0.07

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 9	6.81	88.0	0.76	13	5.16	4.28
9 - 18	1.52	11.2	0.33	7		
18 - 42	2.06	28.6	0.33	2		
42 - 60	1.32	22.7		1		
120 +	3.72	97.0		4		

Fishtown Swamp Survey

Profile No: C9
Soil Class: L3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
17 - 40	4.55	4.15	< 0.10	<0.05	< 0.01	<0.1	0.11	0.45
40 - 60	4.70	4.15	< 0.10	<0.05	< 0.01	<0.1	0.13	0.54
60 - 114	4.90	4.10	< 0.10	<0.05	0.03	<0.1	0.11	0.44
114 - 140	3.80	3.80	< 0.10	<0.05	0.03	<0.1	0.12	0.98
140 - 165	5.15	4.00	0.19	0.14	0.02	<0.1	0.09	0.40

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
17 - 40	0.56	* *		<1		
40 - 60	0.67	* *		<1		
60 - 114	0.55	* *		<1		
114 - 140	1.10	* *		<1		
140 - 165	0.84	41.7		<1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Fishtown Swamp Survey

Profile No: F5
Soil Class: W3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
6 - 18	4.65	3,75	0.38	0.13	0.05	<0.1	0.20	0.82
18 - 29	4.60	3.90	0.12	0.08	0.06	<0.1	0.12	0.62
29 - 74	5.15	3.90	0.12	0.09	0.10	<0.1	0.11	0.32
74 - 102	4.90	3.90	0.12	0.11	0.03	<0.1	0.06	0.36
102 - 142	4.90	3.85	1.18	0.80	0.03	<0.1	0.03	0.18
142 - 210	4.70	3.80	3.05	2.06	0.08	0.15	0.12	0.32

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
6 - 18	1.58	35.4		4		
18 - 29	1.00	26.0		3		
29 - 74	0.74	41.9		<1		
74 - 102	0.68	38.2		<1		
102 - 142	2.22	90.5		<1		
142 - 210	5.78	92.4		<1		

Fishtown Swamp Survey

Profile No: H5
Soil Class: W4

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 6	4.55		5.13	0.47	0.25	0.1	0.19	0.09
6 - 22	4.75		0.22	0.07	0.06	< 0.1	0.19	0.48
32 - 62	3.25		< 0.10	0.05	0.03	< 0.1	0.36	1.80
62 - 82	4.80	3.95	0.27	0.23	0.01	< 0.1	0.07	0.22
82 - 180	5.50	4.15	0.62	0.49	0.08	< 0.1	0.06	0.22

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 6	6.23	95.5	0.84	15	5.39	3.58
6 - 22	1.02	34.3	0.25	2		
32 - 62	2.24	* *	2.78	<1		
62 - 82	0.80	63.8		<1		
82 - 180	1.47	81.0		3		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Tuobo Gbawelekehn Village Survey

Profile No: V10
Soil Class: D5

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 10	4.60	4.05	0.71	0.39	0.12	< 0.1	0.10	0.50
10 - 50	4.50	4.25	0.15	0.11	0.05	< 0.1	0.15	0.83
50 - 90	4.70	4.25	0.12	0-06	0.04	< 0.1	0.08	0.60

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 10	7.22	67.0		3	1.49	1.28
10 - 50	1.29	24.0		1		
50 - 90	0.90	24.4		1		

Tuobo Gbawelekehn Village Survey

Profile No: V53
Soil Class: D1

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 10	4.60	3.80	0.27	0.28	0.11	< 0.1	0.24	0.80
10 - 20	4.55	4.05	0.55	0.10	0.04	< 0.1	0.22	1.02
20 - 55	4.50	4.10	<0.10	0.06	0.02	< 0.1	0.07	0.55
55 - 90	5.05	4.10	0.13	0.05	0.14	< 0.1	0.02	0.38

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 10	1.70	38.8		3		
10 - 20	1.93	35.8		1		
20 - 55	0.70	* *		<1		
55 - 90	0.72	44.4		1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Tuobo Gbawelekehn Village Survey

Profile No: V55
Soil Class: L3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 10	4.55	4.00	0.52	0.48	0.15	< 0.1	0.37	0.91
10 - 20	4.30	3.95	0.20	0.19	0.06	< 0.1	0.23	0.86
20 - 55	4.50	4.00	0.16	0.13	0.03	< 0.1	0.25	0.88
55 - 80	4.75	4.05	0.21	0.18	0.03	< 0.1	0.03	0.36

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 10	2.43	47.3		6	1.48	2.09
10 - 20	1.54	29.2		2		
20 - 55	1.45	22.1		1		
55 - 80	0.81	45.1		2		

Tuobo Gbawelekehn Village Survey

Profile No: V74
Soil Class: D1

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 5	4.60	3.90	0.12	0.11	0.06	< 0.1	0.43	0.81
5 - 20	4.55	4.05	<0.10	0.07	0.02	< 0.1	0.03	0.62
20 - 50	4.65	4.10	0.14	0.07	0.02	< 0.1	0.09	0.39
50-110	4.90	4.20	0.24	0.07	0.02	< 0.1	0.03	0.20

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 5	1.53	19.0		3	0.96	1.14
5 - 20	0.74	**		2		
20 - 50	0.71	32.4		2		
50 - 110	0.56	58.9		2		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Tuobo Gbawelekehn Swamp 1 Survey

Profile No: A2
Soil Class: W3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 6	4.75		0.34	0.14	0.13	< 0.1	0.35	0.77
6 - 12	4.95		0.12	0.08	0.04	< 0.1	0.26	0.70
12 - 26	4.60		0.11	< 0.05	0.02	< 0.1	0.07	0.55
26 - 46	4.70	4.25	0.14	0.06	0.01	< 0.1	0.16	0.63
46 - 66	4.85	4.25	0.15	0.07	0.02	< 0.1	0.17	0.58
66 - 84	4.65	4.25	0.17	0.08	0.02	< 0.1	0.21	0.71

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 6	1.73	35.3	0.34	3	1.52	1.67
6 - 12	1.20	20.0	0.17	<1		
12 - 26	0.75	17.3	0.09	<1		
26 - 46	1.00	21.0		<1		
46 - 66	0.99	24.2		<1		
66 - 84	1.19	22.7		<1		

Tuobo Gbawelekehn Swamp 2 Survey

Profile No: A(75m)
Soil Class: W3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 5	5.65	4.75	1.67	0.92	0.28	< 0.1	neg	neg
5 - 19	4.90	4.10	<0.10	0.42	0.02	< 0.1	0.10	0.24
19 - 30	5.00	4.10	0.22	0.57	0.03	< 0.1	0.08	0.21
44 - 73	4.65	3.60	1.26	2.25	0.08	< 0.1	0.23	0.68
73 - 108	4.30	3.20	1.14	1.85	0.13	0.1	0.14	0.34

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 5	2.87	100		4	1.35	1.43
5 - 19	0.78	56.4		<1		
19 - 30	1.11	73.9		<1		
44 - 73	4.50	79.8		<1		
73 - 108	3.70	87.0		<1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Tuobo Gbawelekehn Swamp 1 Survey

Profile No: BL11
Soil Class: L3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 6	4.95		4.16	1.74	0.33	< 0.1	0.08	0.12
6 - 18	4.80		2.09	0.95	0.10	< 0.1	0.24	0.61
18 - 36	5.15		1.91	1.01	0.08	< 0.1	0.12	0.41
36 - 58	5.35	4.45	2.03	1.11	0.07	< 0.1	neg	neg
58 - 75	5.50	4.80	1.85	1.01	0.07	< 0.1	neg	neg
75 - 92	5.30	4.60	1.39	0.72	0.07	< 0.1	neg	neg
92 -130	5.20	4.25	1.21	0.57	0.07	< 0.1	neg	neg

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 6	6.43	96.9	0.65	4	2.55	3.52
6 - 18	3.99	78.7	0.24	1		
18 - 36	3.53	85.0	0.09	3		
36 - 58	3.21	100		1		
58 - 75	2.93	100		1		
75 - 92	2.18	100		1		
92 - 130	1.85	100		3		

Tuobo Gbawelekehn Swamp 1 Survey

Profile No: E-1
Soil Class: D1

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 7	4.95	4.00	0.67	0.46	0.16	< 0.1	0.24	0.58
7 - 16	4.70	4.00	<0.10	0.12	0.06	< 0.1	0.24	1.51
16 - 29	4.60	4.05	<0.10	0.05	0.03	< 0.1	0.29	1.14
29 - 59	4.80	4.10	<0.10	< 0.05	0.03	< 0.1	0.11	0.78
59 - 92	4.65	4.10	0.12	0.05	0.05	< 0.1	0.09	0.58
92 -120	4.60	4.10	<0.10	< 0.05	0.02	< 0.1	0.08	0.52
120 -145	4.25	4.10	<0.10	0.07	0.04	< 0.1	0.14	0.77

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 7	2.11	61.1		4		
7 - 16	1.93	9.3		3		
16 - 29	1.51	**		3		
29 - 59	0.92	**		1		
59 - 92	0.89	24.7		1		
92 - 120	0.62	**		<1		
120 - 145	1.02	**		1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Tujallah Town Village Survey

Profile No: V8
Soil Class: L1

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 10	4.80	3.95	1.03	0.43	0.10	<<0.1	0.16	0.29
10 - 30	5.80	4.95	1.80	0.69	0.05	<0.1	neg	neg
30 - 70	5.50	4.85	1.63	0.75	0.06	<0.1	neg	neg
70 - 90	5.25	4.60	1.01	0.49	0.06	<0.1	neg	neg

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 10	2.01	77.6		4	1.65	1.75
10 - 30	2.54	100		1		
30 - 70	2.44	100		1		
70 - 90	1.56	100		1		

Tujallah Town Village Survey

Profile No:V48
Soil Class: D7

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 5	6.50	5.70	4.08	0.80	0.16	< 0.1	neg	neg
5 - 15	4.30	4.10	0.30	0.25	0.06	< 0.1	0.07	0.23
15 - 40	4.40	4.10	0.17	0.21	0.04	< 0.1	0.10	0.30
40 - 70	4.50	4.15	0.14	0.15	0.03	< 0.1	0.13	0.34

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 5	5.04	100		3	1.21	1.34
5 - 15	0.91	67.0		2		
15 - 40	0.82	51.2		<1		
40 - 70	0.79	40.5		<1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Tujallah Town Village Survey

Profile No:V55
Soil Class:L4

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 10	6.20	5.50	2.71	0.43	0.05	< 0.1	neg	neg
10 - 25	4.65	4.10	< 0.10	0.06	0.04	< 0.1	0.10	0.27
25 - 65	4.55	4.05	< 0.10	< 0.05	0.02	< 0.1	0.08	0.28
65 - 90	4.75	4.10	< 0.10	0.05	0.02	< 0.1	0.08	0.23

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 10	3.19	100		2	1.04	0.58
10 - 25	0.47	**		1		
25 - 65	0.38	**		<1		
65 - 90	0.38	**		<1		

Tujallah Town Swamp Survey

Profile No: D4
Soil Class: W3

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 4	5.25		5.16	2.34	0.40	< 0.1	neg	0.10
4 - 12	4.85		1.42	0.59	0.06	< 0.1	0.04	0.19
12 - 34	4.90		0.54	0.29	0.03	< 0.1	neg	0.13
34 - 69	5.05	3.75	2.03	1.31	0.02	0.1	neg	0.10
69 - 91	5.75	4.35	1.37	0.85	0.02	< 0.1	neg	neg
91 - 130	6.95	5.40	4.71	2.88	0.06	0.1	neg	neg

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 4	8.00	98.8	0.36	12	4.82	4.00
4 - 12	2.30	91.6	0.14	10		
12 - 34	0.99	86.9	0.13	4		
34 - 69	3.46	97.2		1		
69 - 91	2.24	100		1		
91 - 130	7.75	100		2		

<u>Notes</u>

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of <u>soil</u>

LABORATORY ANALYSIS DATA

Tujallah Town Swamp Survey

Profile No: F2
Soil Class: L1

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 5	5.60	4.80	3.29	0.80	0.15	≤0.1	neg	neg
5 - 15	4.45	3.90	0.48	0.21	0.06	<0.1	0.17	0.27
15 - 30	4.40	3.95	0.10	0.07	0.04	<0.1	0.22	0.52
30 - 73	4.60	4.00	0.10	<0.05	0.01	<0.1	0.21	0.51
73 -109	4.35	4.05	0.10	<0.05	0.05	<0.1	0.15	0.29

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 5	4.24	100		6	1.78	1.49
5 - 15	1.19	63.0		3		
15 - 30	0.85	12.9		2		
30 - 73	0.73	**		1		
73 - 109	0.49	**		2		

Tujallah Town Swamp Survey

Profile No: G0
Soil Class: L4

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 4	4.25	3.45	1.46	1.15	0.19	< 0.15	0.42	0.48
4 - 18	4.40	4.00	<0.10	0.08	0.03	< 0.1	0.20	0.53
18 - 42	4.65	4.20	<0.10	< 0.05	<0.01	< 0.1	0.12	0.33
42 - 73	5.05	4.10	0.12	0.07	<0.01	< 0.1	0.13	0.22
73 -104	5.20	4.05	0.41	0.25	<0.01	< 0.1	0.03	0.17

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 4	3.70	76.6		11		
4 - 18	0.84	**		3		
18 - 42	0.45	**		2		
42 - 73	0.54	35.2		1		
73 - 104	0.86	76.7		1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

LABORATORY ANALYSIS DATA

Tujallah Town Swamp Survey

Profile No: Y4
Soil Class: W4

Depth (cm)	pH (H_2O)	pH (KCl)	Exchangeable Cations (meq/100g)				Exchangeable Acidity (meq/100g)	
			Ca	Mg	K	Na	H	Al
0 - 16	5.20		1.20	0.21	0.05	< 0.1	neg	0.10
16 - 31	5.35		0.16	< 0.05	< 0.01	< 0.1	neg	neg
31 - 45	5.05		0.24	< 0.05	< 0.01	< 0.1	0.03	0.15
45 - 66	4.90	4.40	0.11	< 0.05	< 0.01	< 0.1	0.03	0.17
66 - 90	4.65	3.95	0.26	0.15	< 0.01	< 0.1	0.23	0.65
90 -106	4.75	3.85	0.58	0.36	< 0.01	< 0.1	0.42	1.79

Depth (cm)	Cation Exchange Capacity (meq/100g)	Base Saturation (%)	Electrical Conductivity(1) (mS cm^{-1})	Available P(2) mg l^{-1}	Organic Carbon (%)	Total Nitrogen mg g^{-1}
0 - 16	1.56	93.6	0.17	4	1.00	0.27
16 - 31	0.16	100	0.04	1		
31 - 45	0.42	57.1	0.05	2		
45 - 66	0.31	* *		<1		
66 - 90	1.26	31.8		<1		
90 - 106	3.15	29.8		<1		

Notes

neg = Negligible (amounts are below limit of detection)

** = Base cations very low

(1) = Electrical conductivity (saturation extract equivalent, based on determination of 1:5 suspension)

(2) = Units are mg per litre of soil

A.3 HYDRAULIC CONDUCTIVITY AND INFILTRATION

A.3.1 INTRODUCTION

Hydraulic conductivity and infiltration determinations were carried out in each of the swamps investigated. The methods are described and the results presented and discussed in the following paragraphs.

A.3.2 METHODS

A.3.2.1 Hydraulic Conductivity

A number of representative sites were selected at each swamp for the determination of hydraulic conductivity. Sites with a shallow water table were chosen so that the test could be carried out by the auger hole method (van Beers, 1958). An auger hole of 8cm diameter was used and the rate of rise of the groundwater was determined over the first quarter of the recovery distance.

The results of the tests were plotted as log(y/2H-y) against t

where y = distance of water level below rest water level
H = depth of hole below ground water level
t = time

The straight line portion of the graph was used to determine the initial and final values of the expression log(y/2H-y) at times t_1 and t_2 for substitution in one of the following equations.

Equation 1 (For S 0.5H):-

$$K_A = \frac{4600a^2}{H+20a} \frac{(\log(y_1/2H-y_1)-\log(y_2/2H-y_2))}{t_2 - t_1}$$

Equation 2 (For S=0):-

$$K_A = \frac{4140a^2}{H+10a} \frac{(\log(y_1/2H-y_1)-\log(y_2/2H-y_2))}{t_2 - t_1}$$

where K_A = hydraulic conductivity
a = auger hole radius

Equation 1 is used when the impermeable layer is at a depth greater than half the wetted auger hole depth below the bottom of the auger hole ($S \geqslant 0.5H$). Equation 2 is used when the impermeable layer is at the bottom of the hole ($S=0$).

A.3.2.2 Infiltration Tests

Representative sites, which were generally at the locations of pits were selected at each swamp. Infiltration tests were carried out with double ring infiltrometers (inside ring diameter approximately 30cm; outside ring diameter approximately 50cm). An initial water depth level of approximately 10cm was established in both the inner and outer rings and the time for a 2cm drop in the water level in the inner ring was recorded. The rings were then topped up again to the mark and the process was repeated until a steady rate was achieved. In some cases, the initial rates were extremely rapid and it was not possible to carry water to the site of the test fast enough to maintain the test continuously. To allow for this in the interpretation of the results, the start and finish times of the test were recorded and a special computer programme was prepared to distribute the individual readings over the total length of the test period so that cumulative times could be estimated. The immediate infiltration rates were then plotted against cumulative time.

At Tujallah Town, a second test of infiltration rate was undertaken on a puddled soil to compare with the results of the standard test on an undisturbed soil surface. It was felt that this might more accurately reflect the infiltration rates likely to occur on cultivated rice swamp soils. After completing the test in the standard way, the rings were removed and the soil surface was puddled by adding more water, turning it with a shovel and treading it in. The infiltration test was then repeated in the normal way.

A.3.3 RESULTS

A.3.3.1 Hydraulic Conductivity

The results of the determination of hydraulic conductivity are presented in Table A.3.1

TABLE A.3.1 HYDRAULIC CONDUCTIVITY

Village	Site	Hydraulic Conductivity (m day^{-1})
Beezohn	C4	0.006
	E2	0.006
John David Town	B3	0.08
	C6	1.08
	D3	0.03
	E2	1.99
	E10	0.40
	H9	0.53
	I6	10.3
	N1	4.01
Fishtown	A12	8.10
	C10	12.3
	E9	3.64
	F6	1.63
	G3	0.26
	I4	0.77
	J2	1.25
	K4	1.39
Tuobo-Gbawelekehn	A2	0.73
	C1	2.77
	D-2	0.35
	D4	1.72
	D5	too rapid
	E4	8.62
	F1	8.55
	G1	1.8
	X8	5.95
	BL11	too rapid
Tujallah Town	A4	2.08
	A7	2.43
	B4	2.5
	B5	0.02
	C3	1.31
	D3	6.50
	F5	0.36
	G1	2.56
	G3	18.7
	X9	7.84

These results indicate a wide variation in permeability ranging from slow in clayey subsoils at Beezohn to some profiles in which the rate of water rise in the auger hole was too rapid to measure. Within an individual swamp, there is much variation in permeability related largely to the variation in texture of the soil profiles. Sandy profiles have generally rapid rates. A large proportion of the water moving through the swamp will pass through these soils with higher hydraulic conductivity. This has implications for leaching of nutrients and those soils with high hydraulic conductivity are likely to be prone to rapid loss of soluble nutrients to drainage.

A.3.3.2 Infiltration Tests

The results of the infiltration tests are given in Table A3.2. This table shows, for each ring set, the initial infiltration rate, an apparent final rate determined by inspection of the graph of infiltration rate against cumulative time and the total length of the test.

It is evident from these results that infiltration into an undisturbed soil is extremely rapid with apparent final rates of the order of 60mm/hr upwards. However, it is also evident from the results at Tujallah Town that puddling the soil in an effort to more closely reflect soil conditions under swamp rice reduces the infiltration rates dramatically.

Despite the apparent rapid rates in the undisturbed condition, the swamps are flooded with standing water during the rainy season when the effective infiltration rate is virtually zero, since the rate of loss of water from the swamp is less than or equal to the rate at which water enters the swamp. Under the flooded conditions required for swamp rice, the soil profile is virtually saturated with water. In this situation, the requirements of water management are then for flood and drainage control. The aim is to apply water to top up the profile or to allow a certain amount of water to drain off according to the needs of the rice crop in relation to its stage of growth.

In these circumstances, deep percolation losses and the hydraulic conductivity are more important measurements in relation to total water requirements for rice production than infiltration rate.

TABLE A.3.2 INFILTRATION RATES

Village	Site No. No.	Initial Rate (mm/hr)	Apparent Final Rate (mm/hr)	Length of Test (mins)
Beezohn	K2 Ring 2	750	720	180
	H8 Ring 1	742	330	300
	H8 Ring 2	471	217	240
John David Town	D3 Ring 1	2322	225	325
	D3 Ring 2	2769	91	385
	E2 Ring 1	480	58	305
	E2 Ring 2	121	<60	250
	I6 Ring 1	338	81	350
	I6 Ring 2	400	<103	324
Fishtown	A12 Ring 1	325	135	285
	A12 Ring 2	250	95	285
	C10 Ring 1	1142	190	325
	C10 Ring 2	389	62	325
	F6 Ring 1	76	65	165
	F6 Ring 2	197	57	350
	H5 Ring 1	1440	120	345
	H5 Ring 2	5143	<67	345
Tuobo-Gbawelekehn	A2 Ring 1 (Day 1)	193	119	324
	A2 Ring 1 (Day 2)	143	91	422
	A2 Ring 2 (Day 1)	576	324	324
	A2 Ring 2	385	129	410
Tujallah Town	A7 Ring 1 (Unpuddled)	1469	380	304
	A7 Ring 1 (Puddled)	30	30	391
	I1 Ring 1 (Unpuddled)	129	88	289
	I1 Ring 1 (Puddled)	0	0	360
	F5 Ring 1 (Unpuddled)	75	>116	335
	F5 Ring 1 (Puddled)	0	0	327

APPENDIX B

CLIMATE AND WATER RESOURCES

B.1 RAINFALL DATA

This Section contains rainfall data for stations in or near Grand Gedeh County. The locations of the stations and frequency of the records is given in Table B.1. The data are given in Tables B.2 to B.8.

TABLE B.1: DETAILS OF RAINFALL DATA

Location	Latitude	Longitude	Duration of Records	Frequency of reporting
Firestone Cavalla	4°34'N	7°38'W	1928-81	Monthly
Pyne Town	5°42'N	8°24'W	1952-73	Monthly
Ziahtown	5°45'N	7°51'W	1952-61	Monthly
Zwedru	6°04'N	8°08'W	1952-73	Monthly
Zwedru (Dube River)	5°58'N	8°11'W	1982-to present	Daily

The data were checked for arithmetical errors and corrected where necessary. In the case of the Firestone Cavalla records a copy was obtained from Firestone at Harbel because the original contained exactly the same monthly values for April and May 1948 and for July 1959 and 1960; it was thought that this could have been an error caused when transcribing the original data. The data obtained from Firestone was in inches and this was checked against the other set of data which was in millimetres. With the exception of February 1942 all the values agreed and it is impossible to comment further on the discrepancies.

The monthly rainfall values have been ranked in order of decreasing magnitude and the results of this analysis have been given in Chapter 5. Because of the limited amount of data the results for Ziahtown should be treated as approximate.

TABLE B.2

FIRESTONE CAVALLA, MONTHLY RAINFALL (mm) 1928-81

4°34'N 7°8'W

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1928	190	19	174	183	343	519	414	204	455	312	231	87	3131
1929	18	99	277	256	366	404	103	72	87	261	168	116	2227
1930	93	160	88	88	430	411	126	46	191	160	245	96	2134
1931	98	54	113	118	313	190	37	156	266	425	138	113	2021
1932	9	153	157	60	432	490	179	29	190	319	282	125	2425
1933	79	78	287	216	440	552	178	189	332	195	318	167	3031
1934	4	75	254	62	183	234	427	201	370	541	145	115	2611
1935	95	39	81	194	317	336	129	85	328	485	219	126	2434
1936	84	198	168	200	419	357	109	29	204	287	347	264	2666
1937	10	133	141	161	318	473	71	107	274	459	185	72	2404
1938	62	94	107	208	595	305	66	22	409	178	356	79	2481
1939	96	197	280	111	381	405	92	123	76	68	137	166	2132
1940	54	53	102	265	833	266	98	244	262	282	382	151	2992
1941	54	36	153	226	649	365	196	207	396	366	244	180	3072
1942	182	85	74	119	302	448	100	34	215	275	115	135	2084
1943	49	158	306	317	345	222	52	135	327	366	326	183	2786
1944	36	82	244	53	116	902	100	171	493	391	156	130	2874
1945	110	178	120	108	228	258	92	97	479	346	216	164	2396
1946	21	9	140	172	347	238	30	31	294	648	270	83	2283
1947	14	134	165	264	169	552	202	446	408	358	232	82	3026
1948	73	126	122	201	201	254	105	115	353	228	140	105	2023
1949	128	69	118	78	225	777	102	121	515	362	186	72	2753
1950	89	127	163	229	191	763	20	19	134	396	175	132	2438
1951	130	115	112	52	388	416	74	110	705	1026	340	134	3602
1952	39	136	306	133	330	621	145	37	429	305	370	221	3072
1953	108	92	235	117	540	360	294	27	172	335	182	155	2617
1954	201	181	243	233	316	342	22	97	457	509	317	177	3095
1955	105	158	308	165	456	668	33	98	488	454	294	159	3386
1956	167	119	115	179	381	104	53	44	336	421	372	214	2505
1957	89	158	221	190	204	686	67	166	129	370	383	119	2782
1958	135	90	165	348	672	98	12	56	118	144	418	150	2406
1959	52	140	163	114	463	291	141	176	672	449	331	92	3084
1960	137	140	269	135	206	705	141	75	458	337	230	179	3012

TABLE B.2 (Cont'd)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1961	27	183	144	212	228	241	5	6	292	273	166	133	1910
1962	102	157	103	158	369	549	230	53	132	268	340	160	2621
1963	55	73	119	169	167	528	837	66	350	453	122	91	3030
1964	96	65	59	185	391	389	72	56	107	85	89	414	2008
1965	121	56	107	116	357	255	48	180	138	122	183	62	1745
1966	31	82	160	157	183	504	319	88	226	266	135	42	2193
1967	56	65	112	86	270	402	20	87	153	224	154	222	1851
1968	116	197	82	144	268	539	375	450	354	296	202	94	3117
1969	43	42	200	278	337	420	154	119	149	396	398	139	2675
1970	101	201	90	145	286	419	86	202	620	380	227	82	2839
1971	135	100	71	105	238	362	55	142	279	38	121	121	1767
1972	167	116	107	165	434	335	271	20	70	231	217	144	2277
1973	14	58	214	62	156	215	74	215	223	260	151	111	1753
1974	41	68	85	88	128	442	150	78	282	170	101	170	1803
1975	17	137	202	127	174	340	4	26	146	186	269	134	1762
1976	51	138	174	147	655	345	52	140	59	133	206	34	2134
1977	41	90	149	94	308	342	153	140	397	181	180	95	2170
1978	40	160	262	336	574	355	67	37	127	183	269	41	2451
1979	38	179	117	186	196	332	81	295	346	241	183	89	2283
1980	44	117	107	116	322	137	203	133	254	111	111	44	1699
1981	42	123	139	91	262	202	158	128	300	185	117	131	1878
Av.	78	113	162	162	341	401	137	119	297	310	229	131	2480

TABLE B.3

PYNE TOWN, MONTHLY RAINFALL (mm) 1952-73

5°42'N 8°24'W

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1952	-	-	-	-	271	235	23	759	402	415	228	85	(2418)
1953	75	16	84	111	438	380	186	24	253	164	48	76	1855
1954	120	101	176	165	247	208	55	148	485	423	-	26	(2154)
1955	45	89	199	170	296	341	255	181	336	427	110	41	2490
1956	17	211	166	201	211	198	60	84	416	350	165	185	2264
1957	20	29	174	150	165	209	142	-	-	361	127	180	(1557)
1958	109	-	-	342	122	112	27	46	364	266	253	108	(1749)
1959	-	128	160	230	291	450	190	58	364	619	-	122	(2612)
1960	37	115	309	336	380	447	94	164	465	465	70	118	3000
1961	18	82	216	298	174	293	220	6	471	274	221	-	(2273)
1962	25	110	310	165	156	588	65	108	309	46	274	48	2204
1963	102	244	193	283	226	238	693	-	594	375	220	-	(3168)
1964	38	37	195	105	323	194	190	162	375	342	128	242	2331
1965	149	77	-	405	429	214	-	312	367	284	101	14	(2352)
1966	139	164	223	215	286	672	470	206	193	697	123	-	(3388)
1967	-	-	-	318	374	379	96	127	436	-	125	71	(1926)
1968	69	225	268	184	326	440	440	286	495	350	210	208	3501
1969	43	38	219	267	189	427	179	209	300	560	319	109	2859
1970	6	108	195	293	397	453	58	217	670	290	150	65	2902
1971	72	312	296	240	448	415	101	230	580	328	159	-	(3181)
1972	38	81	266	224	264	299	296	198	333	450	199	70	2718
1973	10	80	255	339	249	337	193	360	316	57	442	29	2667
Av.	60	118	217	240	285	342	192	194	406	359	184	100	2697

TABLE B.4

ZIAHTOWN, MONTHLY RAINFALL (mm) 1952-61

5°45'N 7°51'W

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1952	-	-	-	-	-	300	93	36	365	241	113	74	(1222)
1953	2	48	201	101	399	383	258	53	187	230	79	121	2062
1954	27	23	70	230	295	240	-	142	309	335	99	-	(1770)
1955	71	23	85	197	330	406	166	90	490	309	123	138	2428
1956	32	154	195	339	144	146	53	106	232	403	74	132	2010
1957	10	98	231	248	294	240	129	335	326	373	168	80	2532
1958	141	97	150	275	309	329	22	74	289	150	220	53	2109
1959	38	152	195	38	373	179	222	53	296	263	-	95	1904
1960	5	94	130	106	190	278	66	111	396	288	125	108	1897
1961	-	-	132	353	190	145	-	-	-	-	-	-	(820)
Av.	41	86	154	210	280	265	126	111	321	288	125	100	2107

TABLE B.5

ZWEDRU, MONTHLY RAINFALL (mm) 1952-73

$6^{o}04'N$ $8^{o}08'W$

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1952	-	-	-	-	362	285	142	46	510	-	124	41	(1510)
1953	0	107	131	80	278	272	389	43	222	207	37	0	1766
1954	41	152	149	297	221	180	61	119	371	297	140	8	2036
1955	47	19	154	196	305	327	142	148	402	359	118	53	2270
1956	7	146	89	229	120	184	121	80	359	272	80	152	1839
1957	4	21	110	164	210	312	237	187	353	533	123	132	2386
1958	62	32	66	225	154	79	47	104	230	290	281	58	1628
1959	23	60	125	128	306	242	284	112	461	240	-	94	(2075)
1960	15	51	158	132	230	302	66	204	317	296	96	83	1950
1961	24	21	67	342	131	-	138	9	379	255	86	20	(1472)
1962	0	95	-	145	112	398	100	172	227	149	238	55	(1691)
1963	32	75	-	-	146	339	752	296	426	404	165	48	(2683)
1964	27	20	-	-	311	267	191	304	522	215	315	-	(2172)
1965	-	41	99	-	-	327	128	125	-	158	92	-	(970)
1966	-	28	201	-	106	-	325	316	162	320	65	60	(1583)
1967	-	88	65	238	117	300	57	112	424	281	-	14	(1696)
1968	8	143	80	195	196	208	280	274	428	360	188	287	2647
1969	29	36	119	235	152	357	206	111	295	532	80	48	2200
1970	34	50	113	166	170	236	20	85	359	85	48	0	1366
1971	21	77	146	160	169	347	123	172	329	200	71	45	1860
1972	2	14	87	195	304	254	107	71	292	294	72	8	1700
1973	5	40	168	79	174	207	181	434	260	170	91	0	1809
Av.	21	63	118	189	204	271	186	160	349	282	126	60	2029

TABLE B.6

ZWEDRU DAILY RAINFALL (mm)

5°58'N 8°11'W

Year 1982

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.8	0	0	0	0	23.2	0	9.4	0	0	6.3	0
2	0	0	0.2	0	0	8.2	3.7	19.7	0	2.3	0	0
3	0	0	0	0	10.3	22.5	0	4.2	0	0	6.4	2.0
4	0.4	0	0	0	0	0	16.0	9.8	4.7	13.9	5.1	
5	0	0	0	0	0	1.8	17.4	1.6	0	0	9.2	
6	0	0	0	0	50.5	5.9	0	0	12.4	17.2	0	
7	0	0	0	0	0	125.1	0	0	0	17.0	0	
8	0	0	0	8.0	0	17.3	0	0	8.7	97.6	6.0	
9	0	20.0	0	0	49.0	24.4	0	0	57.3	12.8	0	
10	0	0	0	0	0	7.4	0	0	5.1	35.8	1.4	
11	0	0	0	0	3.8	0	0	0	0	2.1	0	
12	0	0	0	0	0	0.3	0	10.8	0	3.4	0	
13	0	0	0	0	0	18.4	0	61.8	0	1.6	0	
14	0	0	0	9.0	0	0	26.0	10.7	0	0	0	
15	0	0	0	0	0	0	1.4	11.8	0	7.7	37.6	
16	0	0	0.9	0	0	1.7	12.3	11.0	77.1	4.9	21.3	
17	0	0	0	0	0	0	0	0	0	4.7	0	
18	0	0	0.6	6.0	0	0	2.1	6.8	0	0	0	
19	0	0	0	4.0	0	0	0	0	1.0	0	7.2	
20	0	30.0	0	0	0	4.6	0	0	0	1.4	0	
21	0	0	0	10.0	0	0	16.0	0	0	15.0	0	
22	0	0	0	0	26.8	0	112.1	0	0	0	0	
23	0	0	0	0	3.3	0	12.3	8.4	1.3	1.3	0	
24	0	0	0	1.0	0	0	2.4	0	0	24.6	0	
25	0	46.6	0	18.2	9.5	22.4	0	1.2	19.6	39.2	0	
26	0	0	0	7.3	4.4	1.6	2.4	3.0	0	62.6	0	
27	0	0	0.7	0	5.3	2.1	9.6	6.1	0	8.0	0	
28	0	0	0	0	4.3	1.1	0	0	0	0	0	
29	0		0.9	0	8.5	0	0	34.5	18.6	0	0	
30	0		0	3.8	7.2	0	5.9	1.2	0	0	0	
31	0		1.0		9.6		0	0		38.5		
TOTAL	1.2	96.6	4.3	67.3	192.5	288.0	239.6	212.0	205.8	411.6	100.5	2.0

Annual Total : 1821.4

TABLE B.7

ZWEDRU DAILY RAINFALL (mm)

5°58'N 8°11'W

Year 1983

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	4.2	3.2	8.0	21.8	0	0	0	0	10.7	38.4
2	0	0	0	2.1	1.9	15.3	0	0	0	14.8	0	20.8
3	0	0	0	21.4	0	54.4	0	5.7	0	7.3	0	0
4	0	0	0	0	36.9	1.0	0	0	0	0.7	4.1	0
5	0	0	0	0	5.7	0	0	0	13.0	0	0	0
6	0	0	0	0	14.6	8.6	4.6	4.3	64.6	0	11.8	0
7	0	0	0	0	1.3	0.2	0	20.2	3.0	0	1.6	4.1
8	0	0.6	0	0	0.9	0	0	0	0	7.2	0	0
9	0	0	0	23.5	0	0	6.2	0	0	0	0	0
10	0	0	0	0	0	0	0	0	37.6	0	0	0
11	0	4.6	0	0	0	3.3	0	0	5.0	0	0	0
12	0	0	0	2.1	0	0	0	32.3	36.2	0	0	35.2
13	0	0	0	0	3.2	0	0	0	1.5	7.3	4.5	0
14	0	0	0	0	13.0	4.1	0	0	14.2	19.2	0	0
15	0	4.2	0	0	0	0	0	3.3	0	23.4	0	0
16	0	0	0	0	0	3.2	0	0	29.2	43.1	0	0
17	0	0	0	0	14.9	0	37.2	10.0	5.1	0	0	9.2
18	0	0	0	9.1	4.3	14.4	0	0	0	1.0	0	0
19	0	5.4	0	0.3	4.7	26.5	0	13.4	90.7	0	0	48.2
20	0	0	0	0	0	14.1	0	0	37.9	0	0	0
21	0	0	0	0	1.4	2.4	0	0	14.2	0	0	0
22	0	0	0	0	2.2	1.0	0	0	14.1	0	0	0
23	0	0	19.1	0	19.3	2.0	0	0	4.4	0	0	0
24	0	0	0	0	0	0	0	0	3.2	0	0.8	0
25	0	0	19.6	0	22.6	0	0	0	0.9	0	2.0	0
26	0	0	0	0	1.6	0	0	0	25.0	19.3	0	0
27	0	0	17.5	0	7.1	0	0	39.2	0	0	0	17.3
28	0	0	0	0	2.1	1.4	0	0	0	0	8.7	0
29	0		0	0	13.1	0	0	0	14.3	0	0	0
30	0		0	0	23.2	1.2	0	1.3	0	0.7	0	0
31	0		0		0		0	0		0		0
TOTAL	0	14.8	60.4	61.7	202.0	174.9	48.0	129.7	414.1	144.0	44.2	173.2

Annual Total : 1467.0

TABLE B.8

ZWEDRU DAILY RAINFALL (mm)

5°58'N 8°11'W

Year 1984

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	1.0	0.9	0	0	0	28.8	0	0	0	0
2	0	0	0	1.8	0	0	3.5	1.4	0	0.5	0	0
3	0	0	26.5	1.5	0	17.1	0	14.6	0	2.5	27.4	0
4	0	0	0	20.2	8.6	0	0	3.1	0.8	1.1	0	0.7
5	0	0	0	0	0	1.0	12.6	105.1	2.5	0	0	0
6	0	0	0	0	67.4	5.9	27.3	15.3	42.5	0	0	0
7	0	0	0	11.5	0	0	16.6	0	43.6	6.3	16.5	0
8	0	0	0.6	0	0.6	25.7	19.3	1.8	3.7	0	0	0
9	0	0	0	11.8	6.8	2.6	0	35.9	0	4.4	0.9	0
10	0	0	0	16.2	7.3	0	77.2	4.6	0	0	0	0
11	0	0	16.6	0	0	101.4	0	0	4.3	0.3	3.1	0
12	0	0	4.0	0	8.5	0	0	5.9	23.2	19.2	0	0
13	0	0	0	0	0	16.9	0	8.5	104.2	0	0	0
14	0	0	0	0	2.1	0	0	12.6	13.4	5.8	0	0
15	0	0	0	0	1.2	14.8	2.3	0	0	0	0	0
16	0	0	34.3	1.4	0	4.4	53.3	3.8	17.3	17.5	0	11.5
17	0	0	0	0	27.0	20.4	0	7.6	0.9	24.1	0	0
18	0	0	13.6	3.4	0	0	21.5	3.4	0	0	0	0
19	0	0	14.2	12.4	0	41.9	0	0	3.4	0	0	0
20	0	0	0	0	0	9.4	3.6	7.2	7.7	0	1.1	0
21	0	0	20.8	0	6.5	0	0	9.6	8.5	0	19.2	0
22	0	0	9.2	0.5	25.2	0	1.5	0	0	0	0	0
23	0	0	0	0	0	33.5	17.5	6.7	0	0	0	0
24	0	6.0	0	11.4	0	0	1.6	13.4	1.8	0	0	0
25	0	0	0	3.6	16.1	52.4	0	16.3	0	0	0	0
26	0	0	0	0	2.4	1.2	34.0	0	0	13.7	23.3	0
27	0	17.7	0	8.9	40.9	8.3	21.3	6.9	27.7	8.1	7.2	6.6
28	0	5.9	0	0	0	24.9	0	0.4	0	0	0	0
29	0		10.2	44.3	0	14.2	0	0	0	0	0	0
30	0		0	0	20.0	0	2.3	13.8	0	0	0	0
31	0		18.4		3.0		0	18.1		0		0
TOTAL	0	29.6	169.4	149.8	243.6	396.0	315.4	344.8	305.5	103.5	98.7	18.8

Annual Total 2175.1

Source: Liberian Hydrological Service
Department of Mineral Exploration and Research
Ministry of Lands and Mines.

B.2 ANALYSIS OF SUNSHINE HOURS AND INCOMING SHORTWAVE RADIATION

B.2.1 INTRODUCTION

The only available data for calculating reference crop evapotranspiration has been recorded by the Zwedru Coffee, Cocoa and Swamp Rice Project Station at Garley Town, near Zwedru. As well as the temperature, humidity and wind speed measurements, the station also has a Campbell-Stokes sunshine duration recorder and a Gunn-Bellani incoming shortwave radiation recorder.

It is the intention to compare and correlate the corresponding values of sunshine duration and incoming solar radiation. While this cannot be used to confirm the calibration of the Gunn-Bellani instrument, it can be used to check changes in calibration. Also, the relationship between sunshine and incoming solar radiation can be compared with published values to see if this is sensible.

B.2.2 NOTATION

- n Actual hours of sunshine in one day.
- N Maximum possible hours of sunshine in one day.
- T_A Extra-terrestrial incoming radiation.
- R_S Actual shortwave incoming radiation.

B.2.3 SUNSHINE DURATION

Data of actual hours of sunshine for October 1985 to March 1986 are given in Table B.9. It is necessary to compare these values with maximum possible values to give a ratio of actual to maximum possible on a daily basis.

Values of maximum possible hours of sunshine are given by FAO (1977). Values applicable to 6^{o} 10' 5"N are given in Table B.10, and shown in Figure B.1.

TABLE B.9 SUNSHINE DURATION AND INCOMING SHORTWAVE RADIATION

1985

Date	OCTOBER n (hours)	OCTOBER Ra (Cal $cm^{-2}d^{-1}$)	OCTOBER n/N	OCTOBER Rs/Ra	NOVEMBER n (hours)	NOVEMBER Ra (Cal $cm^{-2}d^{-1}$)	NOVEMBER n/N	NOVEMBER Rs/Ra	DECEMBER n (hours)	DECEMBER Ra (Cal $cm^{-2}d^{-1}$)	DECEMBER n/N	DECEMBER Rs/Ra
1	5.95	441	0.49	0.49	8.75	496	0.74	0.58	5.75	360	0.49	0.44
2	7.60	517	0.63	0.58	5.80	382	0.49	0.45	9.50	544	0.81	0.67
3	7.05	463	0.59	0.52	8.05	477	0.68	0.56	3.50	290	0.30	0.36
4	8.05	487	0.67	0.54	7.60	522	0.64	0.61	6.70	428	0.57	0.53
5	5.10	450	0.42	0.50	6.30	496	0.53	0.58	5.80	382	0.49	0.47
6	4.00	363	0.33	0.41	3.40	347	0.29	0.41	0	363	0	0.45
7	7.55	501	0.63	0.56	4.70	385	0.40	0.45	4.20	393	0.36	0.49
8	8.80	541	0.73	0.61	3.80	355	0.32	0.42	5.25	398	0.45	0.49
9	8.35	525	0.70	0.59	8.30	512	0.70	0.61	6.80	431	0.58	0.53
10	7.95	536	0.66	0.60	5.65	436	0.40	0.52	4.90	396	0.42	0.49
11	7.10	463	0.59	0.52	6.35	439	0.54	0.52	5.10	398	0.43	0.49
12	2.00	223	0.17	0.25	0	282	0	0.34	7.90	468	0.67	0.58
13	7.20	482	0.60	0.54	7.15	439	0.61	0.52	8.40	496	0.72	0.62
14	5.00	442	0.42	0.50	7.65	474	0.65	0.57	8.70	496	0.74	0.62
15	6.30	468	0.53	0.53	5.20	414	0.44	0.50	7.00	566	0.60	0.70
16	4.45	393	0.37	0.45	4.90	431	0.42	0.52	8.90	463	0.76	0.58
17	7.00	460	0.59	0.52	4.30	390	0.36	0.47	3.40	339	0.29	0.42
18	5.60	364	0.47	0.41	0	263	0	0.32	0.50	280	0.04	0.35
19	6.80	424	0.57	0.48	6.40	463	0.54	0.56	5.80	385	0.49	0.48
20	6.95	504	0.58	0.58	6.90	417	0.59	0.50	8.70	493	0.74	0.61
21	5.65	404	0.47	0.46	5.60	388	0.47	0.47	7.00	428	0.60	0.53
22	7.35	482	0.62	0.55	8.10	512	0.69	0.62	5.15	442	0.44	0.55
23	7.05	466	0.59	0.53	7.70	442	0.65	0.54	4.45	406	0.38	0.51
24	6.50	509	0.55	0.58	7.35	447	0.62	0.54	8.10	468	0.69	0.58
25	6.60	436	0.55	0.50	7.00	431	0.59	0.53	4.90	347	0.42	0.43
26	5.90	423	0.50	0.49	6.50	425	0.55	0.52	3.35	298	0.29	0.37
27	5.20	409	0.44	0.47	8.75	501	0.74	0.61	4.00	304	0.34	0.38
28	7.70	479	0.65	0.55	5.85	374	0.50	0.46	4.15	358	0.35	0.45
29	3.55	290	0.30	0.34	5.65	390	0.48	0.48	7.85	474	0.67	0.59
30	8.70	466	0.73	0.54	5.15	360	0.44	0.44	7.60	458	0.65	0.57
31	2.55	420	0.21	0.49					4.65	398	0.40	0.49

TABLE B.9 (concluded)

1986

	JANUARY				FEBRUARY				MARCH			
Date	n (hours)	Ra (Cal $cm^{-2}d^{-1}$)	n/N	Rs/Ra	n (hours)	Ra (Cal $cm^{-2}d^{-1}$)	n/N	Rs/Ra	n (hours)	Ra (Cal $cm^{-2}d^{-1}$)	n/N	Rs/Ra
1	3.85	412	0.33	0.51	7.90	541	0.67	0.64	8.75	571	0.73	0.64
2	6.15	444	0.52	0.55	5.00	412	0.42	0.49	9.50	576	0.80	0.64
3	5.85	482	0.50	0.60	6.85	490	0.58	0.58	7.80	544	0.65	0.61
4	7.05	458	0.60	0.57	6.55	477	0.55	0.56	4.65	414	0.39	0.46
5	6.75	439	0.57	0.54	7.10	490	0.60	0.57	5.15	442	0.43	0.49
6	6.75	414	0.57	0.51	7.00	447	0.59	0.52	6.85	509	0.57	0.57
7	6.00	455	0.51	0.56	5.55	439	0.47	0.51	5.95	474	0.50	0.53
8	6.45	420	0.55	0.52	2.55	231	0.22	0.27	5.20	501	0.43	0.56
9	7.55	433	0.64	0.53	8.80	533	0.74	0.62	3.20	404	0.27	0.45
10	5.15	390	0.44	0.48	9.35	512	0.79	0.59	6.50	447	0.54	0.49
11	6.00	404	0.51	0.50	7.60	425	0.64	0.49	5.90	452	0.49	0.50
12	8.80	496	0.75	0.61	6.30	447	0.53	0.52	4.25	450	0.35	0.50
13	8.80	525	0.75	0.64	7.20	442	0.61	0.51	6.80	487	0.57	0.54
14	9.10	520	0.77	0.64	4.05	406	0.34	0.47	7.35	509	0.61	0.56
15	7.90	496	0.67	0.61	8.55	493	0.72	0.57	5.80	498	0.48	0.55
16	7.90	450	0.67	0.55	9.60	541	0.81	0.62	2.45	401	0.20	0.44
17	8.10	501	0.69	0.61	6.65	471	0.56	0.54	6.55	514	0.54	0.57
18	7.90	460	0.67	0.56	8.20	509	0.69	0.58	4.95	455	0.41	0.50
19	9.30	544	0.79	0.66	5.25	404	0.44	0.46	5.30	471	0.44	0.52
20	9.00	493	0.76	0.58	8.55	482	0.72	0.55	5.30	522	0.44	0.57
21	8.20	477	0.70	0.58	7.25	436	0.61	0.49	5.65	485	0.47	0.53
22	7.50	463	0.64	0.56	7.95	479	0.67	0.54	0.20	406	0.02	0.45
23	6.10	420	0.52	0.51	8.95	528	0.75	0.60	3.90	450	0.32	0.49
24	6.40	474	0.54	0.57	8.55	485	0.72	0.55	4.85	442	0.40	0.49
25	6.10	444	0.52	0.53	8.20	436	0.69	0.49	3.35	388	0.28	0.43
26	4.45	412	0.38	0.49	9.00	506	0.76	0.57	5.35	482	0.44	0.53
27	4.10	433	0.35	0.52	5.55	463	0.47	0.52	4.90	468	0.41	0.51
28	6.45	490	0.55	0.58	5.20	466	0.52	0.52	4.30	468	0.36	0.51
29	2.65	393	0.22	0.47					8.55	536	0.71	0.59
30	7.80	504	0.66	0.60					6.50	509	0.54	0.56
31	6.95	506	0.59	0.60					6.50	436	0.54	0.48

TABLE B.10: ACTUAL AND CALCULATED VALUES OF MAXIMUM POSSIBLE HOURS OF SUNSHINE AND EXTRA-TERRESTRIAL RADIATION

MONTH	MAXIMUM POSSIBLE HOURS SUNSHINE		EXTRA-TERRESTRIAL RADIATION (Cal $cm^{-2}d^{-1}$)	
	Actual	Calculated	Actual	Calculated
January	11.75	11.76	817	817
February	11.88	11.86	870	870
March	12.00	12.02	907	907
April	12.22	12.21	908	908
May	12.37	12.38	890	890
June	12.47	12.45	867	867
July	12.37	12.41	879	879
August	12.32	12.28	896	896
September	12.10	12.12	901	901
October	11.95	11.95	883	883
November	11.83	11.81	835	835
December	11.73	11.74	805	805

To compare daily values of actual and maximum hours of sunshine, it is preferable to express the maximum hours of sunshine as a Fourier series from which daily values can be calculated. Using mid-February as zero degrees, the series is given by:-

$$N = 12.082 + 0.279 \sin \phi - 0.007 \sin 2\phi - 0.003 \sin 3\phi - 0.216 \cos \phi - 0.012 \cos 2\phi + 0.005 \cos 3\phi$$

As a check, mid-monthly values were calculated and compared with actual values (Table B.10) producing a good agreement.

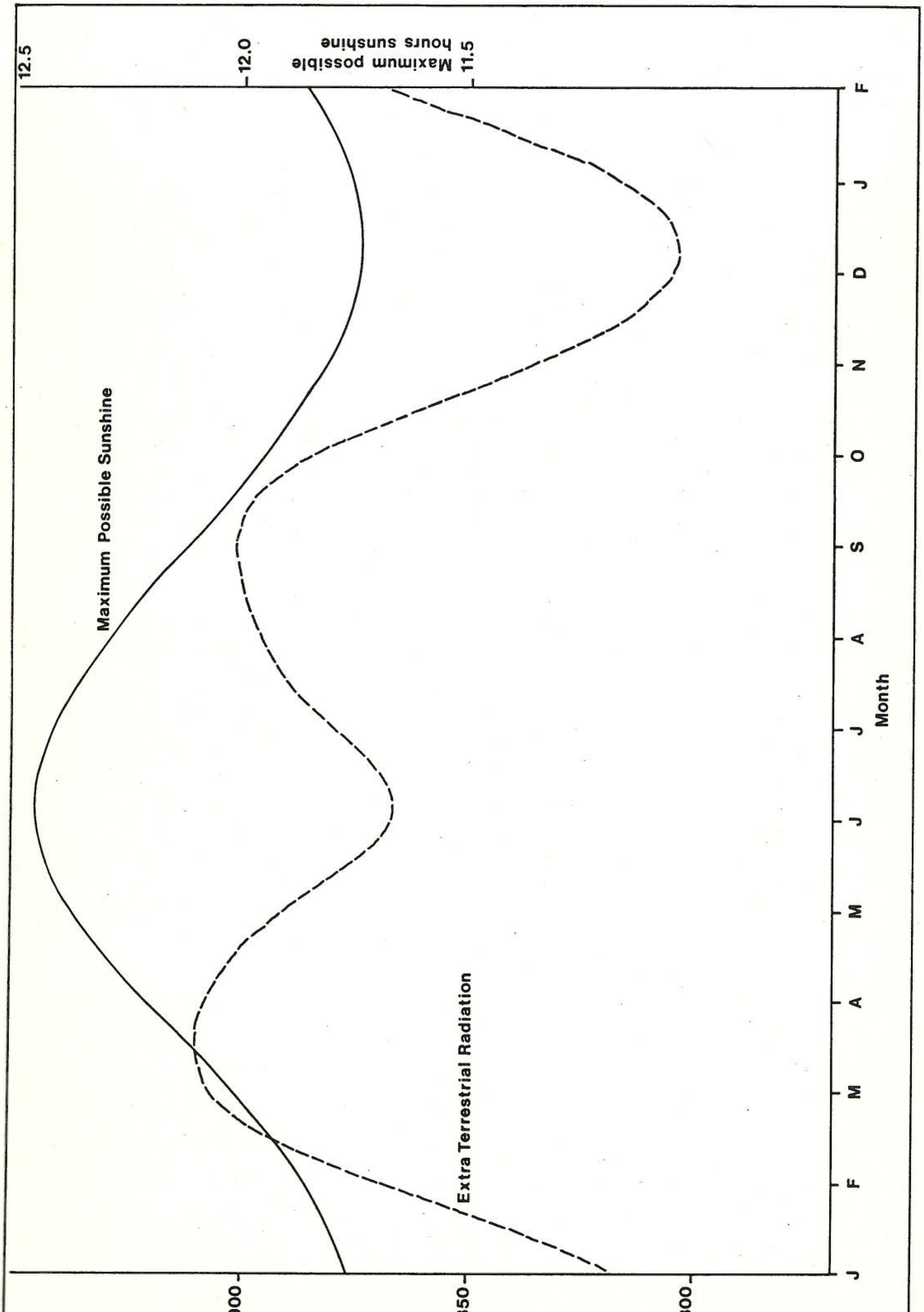
The ratio of actual to maximum possible sunshine hours was calculated by using a value of $\phi = 226^{\circ}$ corresponding to 1st October and advancing by $360/365^{\circ}$ for each day. The actual value was divided by the maximum possible value and these are given in Table B.9.

B.2.4 EXTRA-TERRESTRIAL SOLAR RADIATION

As for sunshine duration, measured incoming shortwave radiation data from October 1985 to march 1986 are given in Table B.9. Values of extra-terrestrial radiation derived from FAO (1977) are given in Table B.10 and shown in Figure B.1. These were derived as a Fourier series:-

$$R_A = 871.5 + 27.4 \sin \phi + 33.3 \sin 2\phi + 2.2 \sin 3\phi - \sin 4\phi + 2.3 \sin 5\phi - 15.5 \cos \phi + 10.2 \cos 2\phi + 1.8 \cos 3\phi + 1.2 \cos 4\phi + 0.7 \cos 5\phi$$

Extra Terrestrial Radiation and Maximum Possible Sunshine (Lat. 6°10' 5"N) **Figure B.1**



(Source : FAO 1977)

A comparison of actual and calculated values is given in Table B.10 and agreement is extremely good.

The ratio of incoming shortwave radiation and extra-terrestrial radiation was calculated in exactly the same way as the sunshine hours, using a value of $\phi = 226^{\circ}$ corresponding to 1st October. Table B.9 gives the calculated daily ratios.

B.2.5 CORRELATION OF HOURS OF SUNSHINE AND INCOMING SHORTWAVE RADIATION

A general expression for hours of sunshine and incoming shortwave radiation is given by:-

$$R_S/R_A = a + b.n/N$$

By plotting R_S/R_A against n/N it should be possible to determine values of a and b. Figure B.2 shows the values of R_S/R_A plotted against corresponding values of n/N. Because some points on the graph are covered by more than one observation regression analysis was used to determine monthly values of a and b. a and b were also determined using all the data up to the end of a particular month. These values are given in Table B.11

TABLE B.11 VALUES OF a AND b

Month	Monthly Value		Value to End of Month	
	a	b	a	b
1985				
October	0.27	0.45	0.27	0.45
November	0.32	0.38	0.30	0.40
December	0.33	0.37	0.31	0.39
1986				
January	0.40	0.28	0.32	0.38
February	0.30	0.38	0.32	0.38
March	0.39	0.29	0.34	0.35

The equation derived from the observations is given as:-

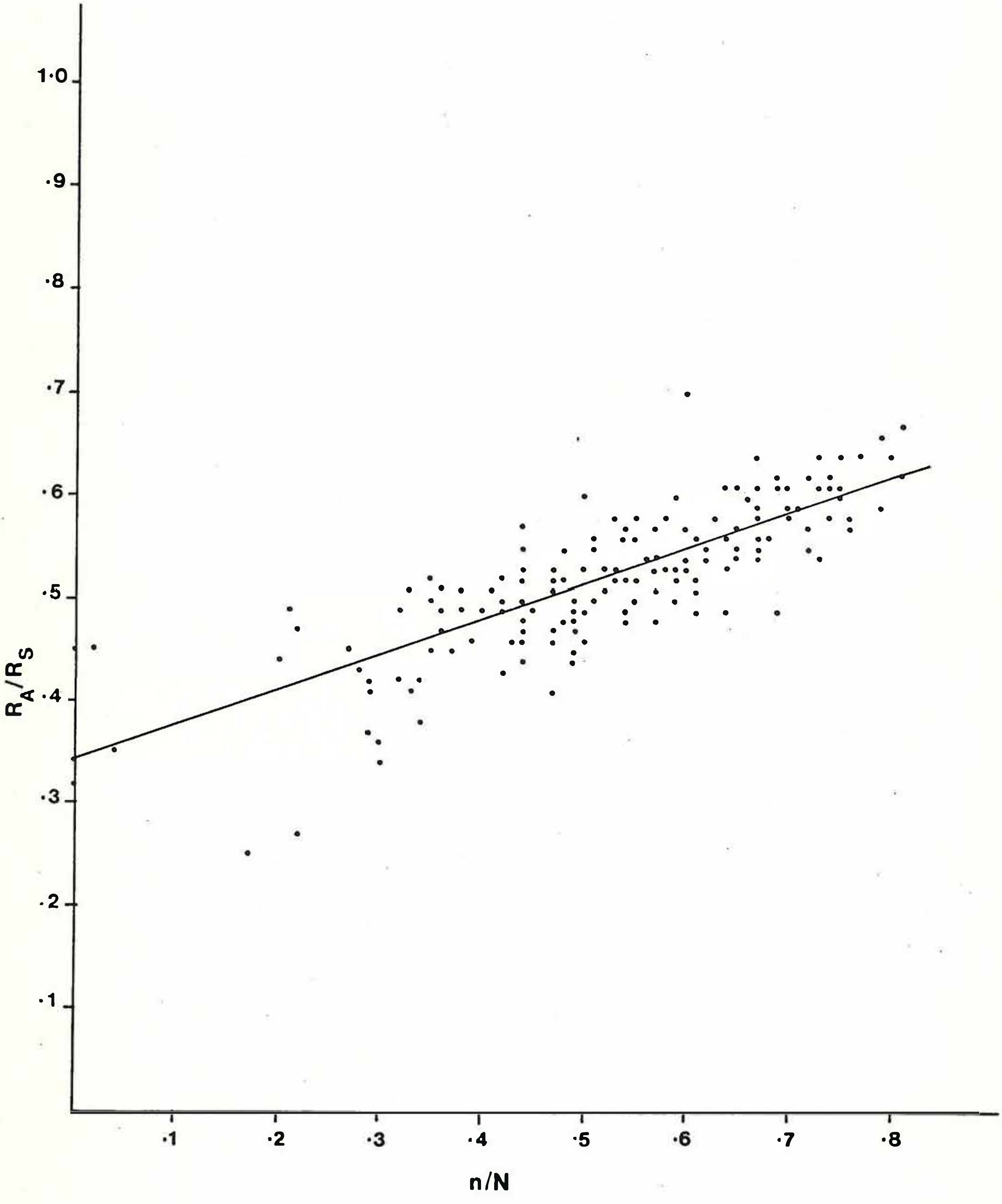
$$R_S/R_A = 0.34 + 0.35\ n/N$$

FAO (1977) gives values of a and b from numerous sources. Of most relevance are values of a and b of 0.30 and 0.37 given by Davies for

Ghana. Also Glover and McCulloch gave a general expression for a and b as 0.29 cos ϕ and 0.52 respectively. If $\phi = 6^{o}$ then the corresponding values are 0.29 and 0.52, with b somewhat higher than that obtained from the Zwedru observation. Stanhill quotes values of 0.26 and 0.38 for Benin City, Nigeria and Davies quoted 0.28 and 0.33 for the same location. Therefore it can be concluded that the values of a and b derived from Zwedru data are acceptable.

Relation Between Incoming Shortwave Radiation and Sunshine Duration (R_S/R_A and n/N)

Figure B.2



Source:

Based on data collected by Zwedru Coffee, Cocoa and Swamp Rice Project October 1985 – March 1986

B.3 WATER BORNE DISEASES

B.3.1 SCHISTOSOMIASIS

Schistosomiasis is a disease transmitted by snails living in stagnant or slow flowing water. It is therefore a hazard where irrigation is practised. There are three main types of Schistosoma (Feachem et al, 1977):-

a) Schistosoma haematobium occurring in Africa and the Middle East;

b) Schistosoma mansoni occurring in Africa, south and central America, including the Caribbean;

c) Schistosoma japonicum occurring in East Asia and the Philippines.

Schistosoma haematobium and Schistosoma mansoni both occur in Liberia.

The disease results in small adult worms which live up to 25 years, but usually 3-8 years, in the human excretary system. These worms can lay hundreds or even thousands of eggs which cause tissue damage and blood loss when they are excreted from the body. Eggs also migrate within the human body and may be lodged in various organs causing general lassitude and debility.

Eggs which are excreted by the human host can live only a short time out of water, after which they hatch to release ciliated larvae. These die unless they reach and penetrate an appropriate species of freshwater snail within a few hours. The eggs and larvae die if snails are not penetrated within 24 hours of initial egg release and the cycle of infection is therefore broken.

Development of the parasite within the snail takes about a month, after which numerous free-swimming larvae are shed daily throughout the remainder of the snails' fairly short life. During this time the parasite has the ability to reproduce asexually within the snail (MacDonald, 1965) and this must increase the number of larvae.

The larvae live up to two days and usually less, in water. They can penetrate the unbroken human skin. Maturation within the human, accompanied by migration within the body takes two to three months.

Control of Schistosomiasis can be by:-

- Reducing the snail population;
- Limiting human contact with infected water;
- Killing the adult worm in infected humans.

Killing the worm, whilst necessary, does not eliminate the cause of the problem, which is human contact with infected water. Eliminating such contact may be impossible but at least it could be limited by proper education and the use of protective foot-wear.

Reducing the snail population should be the aim of any swamp development project, bearing in mind that the rice fields should be drained before the harvest in order to promote ripening and prevent anaerobic decomposition and subsequent toxicity in the soil. This draining of the field may kill the snails and it would also be beneficial if the drains also became dry, although this may not occur because of groundwater seepage. It is beyond the scope of this study to examine the migratory habits of the snails to determine if they will re-infest the fields during the subsequent rice crop, but this matter should be considered in the future.

Snails and their eggs can be destroyed using molluscicides such as Niclosamide and N-trityl- morpholine. These will kill the snails but not the eggs. Molluscicides are not recommended at present because it will be impossible to control their use at numerous dispersed sites.

Although it does not cover Grand Gedeh County, 'A Bulletin of Tecnical Activities 1982/83' does give statistical data for Lofa County, Bong County Agricultural Development Project, and Nimba County.

The two types of Schistosomiasis that occur are Schistosoma haematobium and Schistosoma mansoni. The intermediate hosts being Bulinus globosus and Biophalaria pfeofferi. In Lofa County there is a higher prevalence of S. haematobium than S. mansoni, with a corresponding wider distribution of Bulinus globosus than Biomphalaria pfeiffeni. Between July 1976 and September 1982 there was a varying positive response to tests on samples of the snail population but the average values were 12% for S. haematobium and 0.5% for S. mansoni. In many cases both intermediate hosts (Bulinus globosus and Biomphalaria pfeifferi) were found to be negative. Two further snail types were found, Ferrisia chudeaui and Gyraulus constalatus. Ferrisia is the intermediate host for S. haematobium in certain parts of India and Gyraulus constalatus can be mistaken for Biomphalaria. There was a high prevalence of S. haematobium in school children.

In Bong County Agricultural Development Project the incidence of S. haematobium and S. mansoni were almost equal, with positive results of 11% and 13% respectively. Although a limited amount of work has been carried out in Nimba County there is ample evidence that schistosomiasis does occur.

B.3.2 ONCHOCERCIASIS

Onchocerciasis, or "river blindness", is transmitted by Simulium flies (buffalo-gnats). These breed in rapidly flowing water. The larvae attach themselves to rocks in torrents and rapids and develop rapidly to the adult stage in as little as 5 days. The adult flies can have a flight range of many miles in tree cover.

Because most water in the study areas is slow moving, it does not provide a suitable habitat for the Simulium flies. Therefore, Onchocerciasis should not be a problem. However, Hanson (1983) states that the disease is endemic on the Firestone Plantation with Simulium yahense making up 98.5% of the vector population. It is suggested that the interstitial network of creeks, streams, tributaries and rivers throughout the plantation provide breeding habitats throughout the year. However, because of the large flight range of the vector, it is quite possible that they are able to migrate to the plantation from a large, fast flowing river.

APPENDIX C

AGRICULTURE

C.1 UPLAND RICE YIELD ANALYSIS

Table C.1 provides an analysis of yields of rice obtained on the Smallholder Rice Seed Project, Bong County.

TABLE C.1: UPLAND RICE YIELDS, SRSP, 1985

	OUTGROWERS BY VARIETY			
ITEMS	Mixed Varieties at Kpain Farm	LAC-23	IR-5	SUA-8
No. of farmers/ outgrowers	1	78	21	19
Average yield (kg/ha)	1119	1650	4237	-
Area (ha)	*25.7	433	11.5	26.9
Average farm size (ha)	-	5.5	0.5	1.4
Seed rate (kg/ha)	-	50	40	40
Fertilizer (kg/ha)				
MOP	46.7	100	200	200
NPK	145.5	100	200	200
Urea	67.4	100	200	200
TSP	91.5	100	200	200

*This includes the following: SUA-8 1.2 ha
IR-5 0.2 ha
LAC-23 24.3 ha

Source: Smallholder Rice Seed Project, 1985.

C.2 CHARACTERISTICS OF RICE VARIETIES

Extracts from the Terminal Report of IITA/IDA - Liberia Rice Project; S.S. Virmani International Institute of Tropical Agriculture, June 1979:-

VARIETAL IMPROVEMENT PROGRAMME

The accomplishment of the varietal improvement programme are discussed as follows:

1. Selection and Release of Improved Rice Varieties for Lowland Conditions

   Until 1973, Gissi 27, a local selection and IR-5, an IRRI variety, were selected and recommended for cultivation under lowland conditions in Liberia.

   Gissi 27 was selected for its good adaptability to inland valley swamp and moderately good yield potential (2,000-4,000 kg ha^{-1}). Later it was also found to be tolerant to iron toxicity. It is a tall (140-170cm) variety with good tillering potential, prolific root system, thick culm, long heavy panicles, and possesses resistance to blast, sheath rot, sheath blight and glume discolouration diseases. Its cooking and keeping quality and palatability are good. The major drawback of Gissi 27 is, however, its late maturity. It take about 195 days (if planted in May) to 147 days (if planted in September-October). The later planted crop has been found to give lower yield, however. Farmers generally cultivate Gissi 27 in the wet season under traditional management in undeveloped or incompletely developed swamps where iron toxicity is expected and water and fertility management is poor. If planted in dry season (January), Gissi 27 does not flower. Also, it is susceptible to brown spot disease.

   IR-5, introduced from International Rice Research Institute, Philippines in the later sixties was recommended in 1971-72 for improved swamps and irrigated paddies where yields of 2,500 kg to 7,000 kg ha^{-1} have been obtained, depending upon the basic fertility status of the soil and the level of water and fertilizer management. It has fairly good adaptability to lowland conditions in Liberia. It is weakly photoperiod-sensitive and can be cultivated in both wet and dry seasons without much difference in growth duration (140-150 days). It has intermediate height (100-110cm), moderately good tillering, moderately good root system, medium-long panicles and medium bold grains. It is resistant to glume discolouration and moderately susceptible to sheath blight, and sheath rot diseases. The drawbacks of IR-5 are: its susceptiblity to blast disease and iron toxicity and poor cooking and keeping quality, in comparison to Gissi 27.

During the tenure of this project, three additional improved rice varieties (viz. Suakoko 8, Suakoko 10 and Suakoko 12) have been selected and recommended for cultivation under lowland conditions. These varieties are described below:

Suakoko 8

This variety was released in 1977 for general cultivation in iron toxic inland swamps where it was found to outyield IR-5 by about 20 per cent, although under non-toxic conditions Suakoko 8 yields similarly to, or slightly less than, IR 5.

Also, its grain quality, cooking quality and palatablity are adjudged to be superior to IR 5. In fact, if processed properly, Suakoko 8 rice can be compared well with imported rice. Farmers in different parts of the country have accepted Suakoko 8 for its adaptability to iron toxic conditions, high yield potential and good grain quality. In 1978, 32 tons of seed of Suakoko 8 were distributed to the farmers by the Ministry of Agriculture. Additional quantities were also distributed through autonomous rice development projects. In Lofa County Agricultural Development Project area and Bong Mines Agricultural Project, it has been decided to replace IR-5 with Suakoko 8. In the Bong County Agricultural Development Project area, both IR-5 and Suakoko 8 are being multiplied for distribution to the farmers.

Suakoko 8 was introduced into Liberia from Malaysia in 1973 as an experimental strain 2526, which was derived from the cross Siam 25/Malinja[3]. Further selection was made at Suakoko for adaptability and uniformity. Because of its photoperiod-sensitivity, Suakoko 8 is also superior to Gissi 27. Its plant type is well suited to Liberian peasant farm conditions which include imperfect water control, moderate fertilization and manual harvesting.

The major weakness of Suakoko 8 is its susceptibility to lodging (under heavy fertilization, i.e. more than 60-80 kg/ha of nitrogen). It is also moderately susceptible to blast disease.

Suakoko 10

This variety has been proposed for release in 1979 for cultivation in newly developed swamps during wet season. Results have indicated that Suakoko 10 can out-yield IR-5 and Suakoko 8 during the wet season. It has been found to be better adapted than IR-5 and Suakoko 8 to low fertility swamp conditions and also its response to fertilizer application was higher than that of IR-5 and Suakoko 8. Besides, it is tolerant to iron toxicity.

Suakoko 10 was introduced in 1975 from Malaysia under the name Improved Mahsuri. It is derived from variety Mahsuri which was developed from the cross: Mayang Ebos 80 X Taichung 65. Suakoko 10 is also lodging susceptible under high fertility conditions, and its grains are small.

Suakoko 12

This variety has been recommended for release in 1979 for cultivation under good water and fertilizer management conditions. It was selected primarily for its resistance to blast disease, but it has also higher yield potential than IR-5 and Suakoko 8 in both wet and dry seasons (Table C.2). It is moderately tolerant to iron toxicity.

Suakoko 12 was introduced from IRRI in 1974 as experimental strain IR 1416-131-5 which was developed from the cross: $Peta^4TNI$//Tetep.

Its blast resistance has been also confirmed in Nigeria, Sierra Leone and Ivory Coast. The major weakness of Suakoko 12 is its susceptiblity to case worm insect.

Agronomic and morphological characteristics of Suakoko 8, Suakoko 10 and Suakoko 12 are given in Table C.3.

It is recognised that in Liberia the lowland rice area, with good water and fertilizer management, for which Suakoko 12 is recommended, is quite limited at present. However, through the efforts of various on-going rice development projects, such an area is likely to increase to at least 2-3 thousand hectares or even more during the next 2-3 years. In that situation 20-25 per cent higher yield potential of Suakoko 12 over other recommended varieties should be able to bring significant economic dividends.

In 1976, IR 1416-131-5 (Suakoko 12) was nominated into the WARDA coordinated varietal trials and tested in several West African countries in 1976 and 1977. WARDA results indicated good performance in Mauritania, Upper Volta, Sierra Leone, Ivory Coast, Senegal, Gambia, Niger, Nigeria and Togo under good management.

TABLE C.2: PERFORMANCE OF IR-1416-131-5 IN COMPARISON TO IR-5 AND SUAKOKO 8 IN YIELD TRIALS IN IRRIGATED INLAND VALLEY SWAMPS IN LIBERIA, 1974-78

Season and Conditions	Year	Location	Yield (kg/ha) IR 1416	IR-5	Suakoko 8
Wet season	1974	Suakoko	6559	3993	4891
Good Management	1975	"	6116	4721	5691
	1976	"	4432	3668	3569
	1977	Voinjama	5904	5452	5770
	1977	Foya	6638	6850	6717
	1978	Bong Mines		5444	3670 -
	1978	Foya	7875	8160	6600
	1978	Voinjama	5530	-	4344
		Mean	6062	5216	5369
Wet season	1975	Suakoko	3406	3364	3152
Poor Water Control	1977	"	3350	5086	4936
Newly Developed Swamp and/or Imbalanced	1977	Kolahun	3900	5824	4050
Nutrition	1977	Zleh Town	3813	4376	3357
	1978	Suakoko	2227	3364	3656
		Mean	3339	4402	3826
Dry Season	1975	Suakoko	4774	3611	-
	1975	Foya	6926	5223	-
	1976	Suakoko	4400	4000	3858
	1977	Suakoko	3950	3448	4259
	1978	Suakoko	3500	3520	3380
	1978	Foya	5800	4566	-
	1978	Voinjama	6200	5133	6395
		mean	5079	4214	4473

TABLE C.3: VARIETAL CHARACTERISTICS OF SUAKOKO 8, SUAKOKO 10 AND SUAKOKO 12

Characteristic	Suakoko 8	Suakoko 10	Suakoko 12
Duration (days)			
50% flowering	110	105-110	105-110
maturity	140-145	135-140	135-140
Plant type	Intermediate	Intermediate	Semi-dwarf speading
Height (cm)	120-130	115-120	80- 85
Tillering	Intermediate	Heavy	Heavy
Lodging	Intermediate	Intermediate	Resistant
Panicle Length (cm)	28	25	22
Threshability	Intermediate	Intermediate	Intermediate
Grain Size			
Length (mm)	9.6	8	9
Width (mm)	2.9	2.8	2.8
1000 Grain Weight (gm)	25.8	17	23.2
Husk colour	Straw	Brown spots on straw	Straw
Milling (%)	66.2	66.1	65.2
Grain appearance (dehulled)	Speckled brown	White	Speckled brown
Reaction to:			
Iron toxicity	R	R	I
Leaf blast	S	R	R
Neck blast	I	I	R
Brown spot	I	S	S
Sheath rot	R	R	R
Glume discolouration	R	R	R
Case worm	I	I	S

R: Resistant I: Intermediate S: Susceptible

Thus, for lowland rice cultivation, five improved rice varieties are available which can be recommended according to stage of development of swamp as given below:

Gissi 27 - for traditional cultivation in swamps.

Suakoko 10 - for newly developed swamps during first 2-3 seasons when water and soil fertility management is not adequate.

IR-5 - for swamps and irrigated lowland which have been developed and cultivated for 2-3 seasons where iron toxicity is not a serious problem.

Suakoko 8 - for improved swamps which have been developed and cultivated for 2-3 seasons where iron toxicity is a serious problem. Also for those farmers who prefer long slender grains, better cooking and keeping quality and palatability of Suakoko 8 over that of IR-5.

Suakoko 12 - for improved swamps and irrigated paddy conditions which have been under cultivation for several years and where water and fertilizer management are good. Also for cultivation under good management conditions during dry season where incidence of leaf and neck blast disease is more severe.

APPENDIX D

LIST OF SWAMPS IN GRAND GEDEH COUNTY

D.1 LIST OF SWAMPS IN GRAND GEDEH COUNTY

The following is a list of swamps in Grand Gedeh County as supplied by the south-east Regional Office of the Ministry of Agriculture, Zwedru.

TABLE D.1: LIST OF SWAMPS IN GRAND GEDEH COUNTY

	NAME OF TOWN	LOCATION OF SWAMP
I. TCHIEN DISTRICT		
1	Charlie Gwean Town	Gborbo Section
2	Ziatown	Ziatown Sobaken Highway (Cavalla Road)
	Ziahtown	Gweantown Highway
3	Tuzon Town	Tuzon-Ziatown Highway Swamp
	Tuzon Town	Town (Cattle range site)
4	Gorbo Solo Highway Swamp	Beeken Town, Gorbo Section
5	Gboliken Doelazone Town Highways Swamp	Doelazone Road, Gorbo Section
6	Gboliken Township	Gboliken-Baileyville Township (John Duo's farm)
7	Kparr-Garley Town Swamp	Garleytownship (before entering and after)
8	James Gblah's Village	Gblah Village (Cavalla Road)
9	Francis Town	Francis waterside area
10	Dweayee Town	Dwehtown (Extension Officer Yonly's farm)
TCHIEN MENSION SECTION:		
1	Oldman Kpar-kahn Village	Below Gweanee Greek
2	Oldman Toeday's Swamp	Near Col/Arthur Jolokai's house
3	Gorbo Community Swamp	Near Mr. Friday Freeman's Village
4	Naibo Community Swamp	Near Gbargba Ville
5	Bowen Town Swamp	Between Mandingo quarters and Bowen Town
6	Grebo Community Swamp	Between Grebo Community and Kula bypass
7	New Zwedru area Swamp	Between Old Jail Compound and the football field
8	Jarba Town Swamp	Between Jarba Town Pelizone Highway
9	Gbarbo Town Swamp	From the Dubeh River bridge to Gbarbo Town - thence to Harper Zwedru Highway, etc.
10	Tarluetown Swamp	Town township
11	Kumah Town Swamp	Kumah Town and Jellue Town highway area
12	Cyrus S. Cooper Village Swamp	Cyrus S. Cooper Village (Sinoe Highway)
13	Gbodu Town Swamp	Gbordu Gorbograba Highway
14	Gorbo Gragba Town Swamp	Garduway Ville & Sinoe highway area Swamp, etc.

TABLE D.1: (Continued)

NAME OF TOWN		LOCATION OF SWAMP
TCHIEN MENYEH SECTION		
1	Beh Town	Beh Township
2	Bah-saye Town	Bah-saye Town
3	Geeyah Town	Geeyah Town
4	Toegbadee Town	Toegbadee Town
5	Deh-Suah Old Town	Near Zwedru City (on both sides of the road from Zeyoungtown
6	Sinkor-Town	Sinkor Kparsuahtown highways
7	Gleplay Town Swamp	Gleplaytown-Zwedru highways
8	PTP Area Swamp	On PTP highways on both sides of the road
9	Bangrawa Town Swamp	Near Garlo Ville area on the right from Zwedru
10	Palace of Correction Swamp	On the access road between Konobo and Jarbahtown highways
11	Tofoi Town Swamp	Tofoi Township (Kannah Section)
12	Willie Jellu Town Swamp	Willie Jellu Town (Kannah Section)
13	Gbeabo Town	On both sides of Konobo Road (To NPC Project)
14	Kparsuah Hill	Zwedru City, Kparsuah Hill area
15	Jensenville	Between Jensenville and Naibo Community
16	Gbarba-Ville	Between Gbarbavillee & M.T. Wilson land
TCHIEN DISTRICT, NAIBO SECTION:		
1	Janzon Town	Janzon Township
2	Balabodee Town	Balabodee Town
3	Charlie Breezee Town	C. Gaye Breezee Town
4	George Tarley Village	Janzon highways
II. GBARZON DISTRICT:		
1	B'hai Town	B'hai Town below Cest River
2	Barh Town No. Two	Near Hon. Beh's farm road
3	Blowon Town	Blowon Town
4	Toe Town	Between Toe Town/Ivory Coast Border
5	Senewhen Town	Duogee Town & Senewhen highways
6	Duogee Town	Around Duogee township
7	Bassa Village	Between Bassa Village/Gayetown
8	Tian Town	In Tian Town itself and on Zleh-Town highway
9	Tarfan's Village	Between John Tarfan & Beh Farms
10	Polar Town	Polar Township
11	Jarwondee Town	Jarwondee/Juluzon highways
12	Kparkeh Town	Kparkeh Township
13	Daybleh Town	Daybleh Town
14	Juluzon Town	In Juluzon Township

TABLE D.1: (Continued)

NAME OF TOWN	LOCATION OF SWAMP
III. KONOBO DISTRICT:	
1 Jimmy Bantoe Village	Kannah/Konobo Boundary
2 Sentrudrue Town	Sentrudrue Town near NPC Project
3 Varzon Town	Varzon Town itself & Tuzon Town
4 Dweh Town	Between Varzon/Dwehtowns
5 Ziahtown	Ziahtownship itself
6 Bargloh Town	Between Ziahtown/Bargloh highway
7 Geediglor Town	Between " /Geedigloh Town
8 Pelluken Town	Near Pelluken (Zwedru highway)
9 Pennoken Town	Kweaken Highway from Pennoken
IV. GBEAPO DISTRICT:	
1 Kanweaken	Kanweaken Town behind the comp.
2 "	Kanweaken Town behind the Country Town
3 Dweken	Dweken Road
4 "	" Town
5 Podroken	Podroken Town
6 Fleken	Fleken highway
7 Kanweaken	Behind Central High School, Harper highway
8 Paroken	Paroken Town, Sass-Town highway
9 Klaken	Klaken Town, " highway
10 Pronoken	Pronoken, Harper highway
11 Tartuken	Tartuken highway
12 Putuken	Putuken Township, Harper highway
13 "	Deblehville Township, Harper highway
14 Jarkaken Township	Jarkaken highway
15 Geeken "	Geeken Township highway behind Geeken Town
16 "	Township limits
17 Segborken	" "
V. WEBBO DISTRICT:	
1 Fishtown	Pallipo area
2 Seaken Township	Sarbo Sweaken H/Qtrs.
3 Geeken "	Sarbo Chiefdom, Geeken Township limits
4 "	Sarbo Lovco Campsite, River Ggbeh highway
5 Wosaetuken Township	Nyetianpo, Harper highway
6 Douboyou Toe Town (Wortieken)	Duobo Chiefdom, Harper highway
7 Gbarweleken Township	" " " "

TABLE D.1: (Continued)

NAME OF TOWN		LOCATION OF SWAMP
8	Konowroken, Webbo Chiefdom	Harper highway
9	Nyaake Township (Webbo)	Nyaake Township limits
10	River Gbeh Concession area	Camp site (Kitapo)
11	Production Camp (MWPI)	Glarro
12	Freetown	"
13	Sackor Township	"
14	Nyenawreken	Kiteapo Clan