Land Resource Study

27 Land resources of the Bahamas: a summary

Land Resources Division, Ministry of Overseas Development

Land resources of the Bahamas: a summary

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Land Resources Division

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Land Resource Study 27

Land Resources Division, Ministry of Overseas Development,
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THE LAND RESOURCES DIVISION

The Land Resources Division of the Ministry of Overseas Development assists developing countries in mapping, investigating and assessing land resources, and makes recommendations on the use of these resources for the development of agriculture, livestock husbandry and forestry; it also gives advice on related subjects to overseas governments and organisations, makes scientific personnel available for appointment abroad and provides lectures and training courses in the basic techniques of resource appraisal.

The Division works in close cooperation with government departments, research institutes, universities and international organisations concerned with land resource assessment and development planning.

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*Contributed by W T Gillis

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2. Land capability (1:1 000 000)

Abstracts and keywords

ABSTRACT

The report summarises eight earlier reports, each of which described one or two major islands in the Bahamas. The text is divided into four main parts: Introduction; Natural resources; People and the land; and Recommendations. These are subdivided into Chapters. A confidential annex contains recommendations for each main island. The report is accompanied by three maps: Population (1:1 000 000), Land capability (1:500 000) and Groundwater (1:500 000).

Part 2, Natural resources, summarises the Survey's work and findings on the environment, and outlines the physiographic and planning regions. In Chapter 1, regions are defined mainly by reference to rainfall, vegetation type and depositional regimes, past and present. The planning regions recognised in practice by the Bahamian authorities are also explained. Chapter 2 briefly describes the marine tropical climate and relates it to vegetational differences. Chapter 3 reviews the biogeography and vegetation of the islands. Though having a broad regional similarity, each island has its own characteristics, the Crooked Island Passage acting as a major biogeographic boundary within the region. The vegetation communities of Abaco and Eleuthera are outlined, these being typical examples of a pine island and a coppice island, the two major vegetation types. Land developers are cautioned not to destroy vegetation, particularly in the semi-arid south. Chapter 4 summarises a survey of the pine forests by Henry (1974). It deals particularly with the description of the forest vegetation, the location of land suitable for forestry, stocking conditions, growth rates, exploitation and the future development programme. The importance of the Bahamian forests and their potential for rapid growth are emphasised. Chapter 5 introduces the subject of groundwater. It describes how freshwater occurs as a 'lens' within the limestones and the factors which affect the capacity and extent of different lenses. It is underlined that scientific investigation of wellfields is of relatively recent origin and that comprehensive monitoring of extraction has yet to begin. Chapter 6 discusses the relationship between rocks and landforms. Chapter 7 reviews soils and emphasises that Bahamian soils, though in many cases productive, are poor by world standards. Unusual, locally adopted, practices for improving soil conditions are reported and the most promising soils for modern agriculture are identified. Chapter 8 discusses the lithofacies (characteristic limestones) and associated soils of the pine forested areas, many of which are already in highly productive use. Fourteen lithofacies which give rise to an equal number of distinct land types are described in detail and the scientific basis for distinguishing them is given. Chapter 9 considers the shorelines in detail.

Part 3, People and the land, studies population, wealth, economic activities, communications and the tenure, use and capability of the land. Chapters 10 and 11 describe human aspects and communications. Chapter 12 records that much land still belongs to the State (most of the pine-covered areas) and that there is little pressure on land in the depopulated islands away from Nassau. Land use is discussed in

Chapter 13. The recurrent theme is the rapid creation of plantations which have often failed in times of economic competition. Subsistence cultivation forms the continuing, stable background to these other shorter-lived enterprises. Present agricultural land use is classified under 'no investment', 'low investment' and 'high investment' types. Chapter 14 discusses land capability. Two capability classifications have been used; the first classification centres on agricultural land suitable for mechanised ('high investment') farming whilst the second takes more note of non-agricultural uses in the tourist and construction industries. A scheme for the zoning of land is offered for the use of planning staff.

Part 4, Recommendations, contains general recommendations (Chapter 15) including proposals for the establishment of Government Offices to take advantage of work produced by the Survey and to provide a centralised source of information on related topics. Detailed recommendations are made in Chapter 16 for the large-scale extraction of groundwater.

RÉSUMÉ

Ce rapport résume huit rapports antérieurs, chacun d'entre eux décrivant une ou deux îles principales des Bahamas. Le texte est divisé en quatre parties principales : Introduction, ressources naturelles, la population et la terre, et les recommandations. Une annexe confidentielle contient des recommandations pour chaque île principale. Le rapport est accompagné de trois cartes : population (1:1 000 000), productivité potentielle du pays (1:500 000) et nappes d'eaux souterraines (1:500 000).

La partie 2, ressources naturelles, résume le travail d'inspection et les découvertes sur l'environnement; elle expose également, dans leurs grandes lignes, les régions physiographiques et les régions planifiées. Dans le chapitre 1, les régions sont principalement définies selon les précipitations qu'elles reçoivent; le type de végétation, et les régimes de déposition, passés et présents. Les régions planifiées, reconnues dans la pratique par les autorités des Bahamas, sont également justifiées. Le chapitre 2 décrit brièvement le climat tropical marin et le relie aux différences de végétation. Le chapitre 3 passe en revue la biogéographie et la végétation des îles. Bien qu'étant régionalement largement similaires, les différentes îles ont leurs propres caractéristiques, le passage de l'Ile Crooked agissant comme une frontière biogéographique majeure à l'intérieur de la région. Les communautés végétales d'Abaco et d'Eleuthera sont décrites, celles-ci étant des exemples types d'îles à pinèdes et d'îles à taillis, les deux types principaux de végétation. Il est recommandé aux exploitants de ne pas détruite la végétation, particulièrement dans le Sud semi-aride. La chapitre 4 résume une étude de Henry (1974) sur les forêts de pins. Il traîte particulièrement de la description de la végétation forestière, de la localisation des terres à vocation forestière, du peuplement des forets, des vitesses de croissance, de l'exploitation et du programme de développement futur. L'importance des forêts aux Bahamas et leur potentiel de croissance rapide sont soulignés. Le chapitre 5 introduit le sujet des nappes d'eaux souterraines. Il décrit comment l'eau douce se présente sous forms de "lentille" à l'intérieur du calcaire et les facteurs qui influencent la capacité et l'importance des différentes "lentilles". Il est souligné que l'étude scientifique des champs de puits est de date relativement récente et que le vrai contrôle de l'extraction n'a pas encore commencé. Le chapitre 6 discute les relations existant entre les roches et la topographie. Le chapitre 7 passe en revue les sols et souligne que les sols des Bahamas, bien que fertiles dans beaucoup de cas, sont pauvres par rapports aux normes mondiales. Des pratiques peu connues, adoptées localement pour améliorer les sols sont rapportées, et les sols les plus favorables à l'agriculture moderne sont identifiés. Le chapitre 8 discute les lithofaciès (calcaires caractéristiques) et les sols des zones de forêts de pins qui y sont associés, beaucoup d'entre elles faisant déjà l'objet d'une production intensive. Quatorze lithofaciès engendrant un nombre égal de types topographiques distincts sont décrits dans le détail et les bases scientifiques permettant de les distinguer sont données. Le chapitre 9 étudie les littoraux.

La partie 3, population et pays, étudie la population, les revenus personels, les activités économiques, les communications, la régime foncière, et l'utilisation et la productivité potentielle de la terre. Les chapitres 10 et 11 décrivent les aspects humains et les communications. Le chapitre 12 montre que beaucoup de terres appartiennent encore à l'Etat (la plupart, des zones recouvertes de pins) et que peu de terres sont travaillées dans les îles dépeuplées loin de Nassau. L'utilisation de la terre est discutée dans le chapitre 13. Le thème qui revient souvent est la création rapide de plantations qui ont souvent fait défaut dans les périodes de concurrence économique. Les cultures de subsistance constituent une constante fondamentale par rapport aux autres entreprises sans lendemain. L'utilisation actuelle de la terre agricole est classée en les types suivants : "aucun investissement", "investissement faible", et "investissement élevé". Le chapitre 14 discute la productivité potentielle du pays. Deux classifications sont utilisées; la première se concentre sur les pays agricoles adaptés à l'exploitation mécanisée ("investissement élevé") tandis que la seconde tient davantage compte des utilisations non agricoles dans les industries du tourisme et de la construction. Un schéma de découpage du pays en zones est présenté pur être utilisé en planification.

La partie 4, recommandations, contient des recommandations générales (chapitre 15) renfermant des propositions en vue de la création de bureaux gouvernementaux, pour tirer parti du travail accompli par l'inspection et pour fournir une source centralisée de renseignements sur des thèmes apparentés. Des recommandations détaillées sont faites dans le chapitre 16 pour une extraction à grande échelle des eaux souterraines.

RESUMEN

El informe resume ocho informes anteriores, cada uno de los cuales describe una o dos de las principales islas de las Bahamas. El texto se divide en cuatro partes principales: Introducción; Recursos naturales; la Gente y la Tierra; y Recomendaciones. Estas cuatro partes a su vez se dividen en capítulos. Un anexo confidencial contiene recommendaciones para cada una de las principales islas. El informe va acompañado de tres mapas: Población (1:1.000.000), Productividad potential de la tierra (1:500.000) y Agua del subsuelo (1:500.000).

La Parte 2, Recursos naturales, resume el trabajo y las conclusiones del Estudio sobre el medio ambiente y señala las regiones fisiográficas y de planificación. En el Capítulo 1 se definen las regiones principalmente en cuanto a la precipitación de lluvias, tipo de vegetación y regímenes de sedimentación, pasados y presentes. También se explican las regiones de planificación reconocidas en la práctica por las autoridades de las Bahamas. El Capítulo 2 describe brevemente el clima trópico marino y lo relaciona con las diferencias en vegetación. El Capítulo 3 analiza la biogeografía y la vegetación de las islas. Si bien las islas tienen una gran semejanza regional, cada una tiene sus propias peculiaridades, actuando el Pasaje de la Crooked Island como límite principal biogeográfico dentro de la region. Las poplaciones de vegetación en Abaco y Eleuthera quedan reseñadas y son ejemplos típicos de una isla de pinos y una isla de arbustos y matorrales, los dos tipos principales de vegetación. A los urbanizadores se les advierte que no destruyan la vegetación, en especial en la zona semiárida del sur. El Capítulo 4 resume un informe de Henry (1974) sobre los bosques de pino. Trata en especial de la descripción de la vegetación forestal, la localización de la tierra idónea para silvicultura, las condiciones de densidad relativa y absoluta, el grado de crecimiento, la explotación y el programa de desarrollo futuro. Se subraya la importancia de los bosques en las Bahamas y su potencial de crecimiento rápido. El Capítulo 5 introduce el tema de las aguas de subsuelo. Describe cómo se presenta el agua dulce como una "lente" dentro de las piedras calizas y otros factores que afectan la capacidad y el alcance de distintas lentes. Se señala que la investigación científica de las agrupaciones de pozos es de origen relativamente reciente y que está por empezar la observación global o verificación de las extracciones. El Capitulo 6 trata de las relaciones entre rocas y formaciones fisiográficas. El Capítulo 7 revisa los suelos y destaca que el suelo de las Bahamas, aunque en muchos casos es productivo, es pobre en comparación con los suelos del mundo. Se señalan prácticas poco corrientes, adoptadas localmente, para mejorar las condiciones del suelo y se identifican los suelos más prometedores para la agricultura moderna. El Capítulo 8 trata de litofacies (piedras calizas características) y suelos afines de las zonas pobladas de pinos, muchas de las cuales están ya en alta productividad. Se describen en detalle catorce litofacies que dan lugar a un número equivalente de distintos tipos de tierra y se presta la base científica para distinguirlos. El Capítulo 9 considera en detalle las líneas litorales.

La Parte 3, la Gente y la Tierra, estudia la población, riqueza, actividades económicas, comunicaciones, y la posesión, use y productividad potencial de la tierra. Los Capítulos 10 y 11 describen los aspectos humanos y las comunicaciones. El Capítulo 12 indica que mucha tierra pertenece aún al Estado (la mayor parte de las zonas cubiertas de pino) y que existe poca presión para utilizar la tierra en las islas despobladas lejos de Nassau. El empleo de la tierra queda tratado en el Capítulo 13. Un tema que se repite es el de la creación rápida de plantaciones que han fallado con frecuencia en tiempos de competencia económica. El cultivo de subsistencia forma el marco continuo y estable de estas otras empresas de duración más corta. El uso actual de la tierra de labranza se clasifica bajo los tipos de "no inversión", "baja inversión" y "alta inversión". El Capítulo 14 trata de la productividad potencial de la tierra. Se han empleado dos tipos de clasificaciones de productividad potencial; el primero se concentra en la tierra de labranza adecuada para la explotación agrícola mecanizada ("alta inversión") mientras que el segundo se fija más en los usos no agrícolas que hacen las industrias del turismo y de la construcción. Se ofrece un esquema para la división de la tierra por zonas para uso del personal de planificación.

La Parte 4, Recommendaciones, contiene recomendaciones generales (Capítulo 15) e incluye propuestas para establecer Oficinas Gubernamentales, que puedan aprovecharse del trabajo obtenido del Estudio y facilitar una fuente de información centralizada sobre temas afines. En el Capítulo 16 se hacen recomendaciones detalladas para la extracción a gran escala de agua de subsuelo.

DESCRIPTORS FOR COORDINATE INDEXING

Bahamas, climate, landform, topography, sea, groundwater, water resources, aquifer, Ghyben Herzberg lens, limestone, aeolian sediment, hydraulic sediment, coast, surface water, soil description, lithosol, inceptisol, lithofacies, phytogeography, vegetation, forestry, forest exploitation, forest mensuration, land resources, land use, land capability, land tenure, land settlement, wealth, demography, communications, agricultural practice, subsistence farming, tourism, planning, mapping.

Glossary of terms

Chapter 5 (first appearance of term)

Aquiclude	A dense rock layer more or less impervious to water movement which has the ability to prevent subsurface water migration
Aquifer	A rock formation bearing underground water
Coefficient of storage	A figure by which rock volume must be multiplied to arrive at its volume of available stored water
Crust	Thin (¼ inch) weakly cemented layer of rock of greater strength than material above and below it and capable of acting as an aquiclude
Effective porosity	Pores within the rock able to receive infiltration
Holocene	A part of the Pleistocene which began about 10 000 years ago and continues today
Hydraulic connection	Subsurface holes, voids, etc. allowing the transmission of hydraulic pressure
Miocene	A period in the late Tertiary era of earth history
Palaeosol	A buried ancient soil layer of a previous land surface
Pleistocene	The main period of the Quaternary era
Potable	Drinkable
Tidal fluctuations	Rise and fall of water level in a borehole or bluehole in response to oceanic tides
Tidal response	The degree to which borehole (etc.) water levels respond to the tide (½ tidal amplitude,etc.).
Time lag	The delay in minutes and often hours between oceanic and borehole tidal movement
Transmissibility	The ability of rock containing water to yield its water at a point of abstraction

Vadose	The zone above that saturated by groundwater, i.e. above watertable

Chapter 6

Carbonate sediments	Limestones i.e. with a calcium carbonate composition; also includes dolomite
Oolitic	Of sedimentary limestones composed of millions of spherical grains resembling, in mass, fish roe and owing their origin to precipitation of lime onto continuously moving nuclei
Prior	Ancient, pertaining to an earlier geological phase (in the Pleistocene in this case). Hence prior channels, prior landscapes etc.

Chapter 7

Alkalinity (soil)	A condition opposite to acidity in which the soil contains a preponderance of ionised bases (in this case of calcium)
Lithofacies	Characteristics of a sedimentary rock by which it can be defined, namely composition grain size(s), primary structures, fossils, particularly as they derive from the original sedimentary conditions

Chapter 8

'Castles'	Upstanding remnants of hardened rock resembling castle turrets. A 'coined' word
'Cross-bed rotting'	Of muddy bedded rocks; a tendency to weather across (at right angles to) bedding planes.(In bedded grainstones weathering usually takes place only along the bedding planes)
'Deadrock'	A 'coined' term for all rock in flat land (as described in Chapter 8) which lies above the moist weathering zone. Inert and subject to much slower weathering than rock below in the moist soil zone. An important constraint to land preparation
Grainstone	A term for limestones composed of grains rather than mud
'Granularised'	A form of weathering of microcrystalline muds with grains into fine gravel - a 'coined' word
'Highs', 'lows'	Or high spots etc. Self explanatory term for ground surfaces slightly higher or lower than adjacent areas: may be used for differences of the order 2-3 ft or 4-6 ft
'Microcrystalline mud'	Semi-translucent uniform mass of crystalline carbonate without liminess or visible graininess. May contain a scatter of coarse oolites

'Micromesas'	A 'coined' term for small weathering residuals in limestone terrain, from mesa (a tableland) and micro (very small). Steep sided, flat topped, but irregular areas of rock 12 inches or so high, 2-6 ft wide
'Micropots' ('Micropotholes')	Vertical-sided holes in a rocky surface varying in width from 6 to about 12 inches, and up to 18 inches deep.
Mudstones	Of limestone it means the opposite of Grainstone (see above). All gradations exist between grainstones and mudstones
Primary structures	Structures formed in the sediment at the time of its deposition (such as bedding, or traces of burrowing or churning animals)
'Roofing'	(Over underground voids) of an apparently solid ground surface which because of better weathering below than at the surface develops voids 'roofed over' by rock. A 'coined' term
Shelf limestones	Limestones usually relatively pure formed in shallow seas. Typically those presently forming in the Bahamas
'Steps' and 'pavements'	Self explanatory 'coined' phrases to describe stepped and level limestone surfaces
'Tree throw'	Disturbances of surface rock and soil by trees blown down or otherwise uprooted. A major natural cause of surface physical disintegration

Part 1

Introduction

Introduction

PREFACE

This report contains the results of an investigation into the land and water resources of the Bahamas Islands. The study was carried out by the Bahamas Land Resource Survey between 1969 and 1976 and was guided by a Bahamian Government Project Steering Committee. In addition to the land and water resources (soils, rocks, landforms, shorelines, climate, vegetation, forests and underground water) appraisals were made of past and present land use, primarily from an agricultural point of view. The investigation was reported in confidence to the Government of the Bahamas in eight volumes of the following *Draft Land Resource Study:**

> B G Little, D K Buckley, R Cant, P W T Henry, A Jefferiss, J D Mather, J Stark and R N Young (1971-76) Land resources of the Commonwealth of the Bahamas.

Volume 1	Abaco
Volume 2	Eleuthera
Volume 3	Cat Island
Volume 4	Andros Island
Volume 5	Grand Bahama
Volume 6	Great Exuma, Little Exuma and Long Island
Volume 7	Crooked Island and Acklins
Volume 8	Mayaguana and Inagua

The report was accompanied by a total of 131 separate maps.

An associated report, 'The pine forests of the Bahamas' was published as *Land Resource Study* no. 16 in 1974.

The present *Land Resource Study* is a summary of the previous reports, giving a perspective account of Bahamian resources — the original *Draft Land Resource Study* volumes need only be used as a source of detail on specific subjects or specific areas.

To update the earlier data, new information gained during a resource seminar in Nassau in early 1976 is incorporated in the present report. Four newly prepared, generalised separate maps are intended to give a general picture of Bahamian resources and are not meant to be a substitute for the 131 detailed maps contained in the draft volumes.

Some of the information, especially that summarising water resources, remains confidential and has been presented separately in a confidential annex to this report.

It has not been possible in this summary report to give an island-by-island account of resources, although readers interested in specific islands will find that the separate maps (e.g. the land capability map) are useful in this respect, as are the numerous inter-island comparisons made in text and tables.

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*These volumes may only be consulted or obtained with written permission of the Director of Agriculture, PO Box 3028, Nassau.

This report is intended for Bahamian Government officers (and teachers), but also contains geographical and scientific information which may be of value to organisations and individuals who have not had access to the original reports.

The cost of the survey was paid by the Bahamian Government. A total of seven British specialists and three Bahamian counterparts took part in the investigation which was supported by the technical resources of the Land Resources Division (Ministry of Overseas Development), London, the Institute of Geological Sciences, London, and the University of the West Indies.

ACKNOWLEDGEMENTS

This report summarises work done and results gained during a 7-year project. Consequently, it is not possible to thank all those who have contributed their time and energy or lent their support to the project, though many who have so helped are acknowledged in the relevant volumes of the *Draft Land Resource Study* (Little *et al.)* which preceded this summary report. Special thanks are given to the various Permanent Secretaries of Agriculture and Works, their Directors, and the staff of each office for their assistance; to the Department of Lands and Surveys, to its Directors and field survey staff, and to the Meteorological Office; and to the staff of Bahamas' Water Supply Developments for assistance rendered which was often beyond that specified in their contracts. The Survey also wishes to record its indebtedness to the many inhabitants of islands for their assistance and hospitality.

ORIGIN OF THE PROJECT

Between 1961 and 1966, recommendations had been made by the forestry advisers to HM Government that forestry and land use studies of the Bahamas should be carried out by the Land Resources Division (then part of the Directorate of Overseas Surveys). Proposals for a soil survey were made in 1967 by Dr N Ahmad of the University of the West Indies, and in 1968 recommendations for a groundwater study were made by Mr D A Gray of the Institute of Geological Sciences. Suggestions by Mr C W Lynn, Director of Agriculture, for widening the scope of the study, led to an appraisal visit by Mr M A Brunt of LRD in May 1968. Detailed project proposals were submitted by LRD and accepted by the Bahamas Cabinet in January 1969.

PROGRAMME

Work on Abaco and Eleuthera occupied the period from April 1969 to June 1970. During this time a study was also made of the pine forests of the Bahamas. This first work was referred to as a pilot phase and led into a second phase lasting from November 1970 to January 1972 in which Cat Island and Andros were studied in some detail and San Salvador was briefly inspected in a short visit. Following a period of report and map production, fieldwork recommended in late October 1972 on Exuma, Long Island, Crooked Island, Acklins, Mayaguana and Inagua. Grand Bahama, previously not included in the programme, was studied before the main fieldwork finished in December 1973. Report preparation and map production continued in England.

TEAM COMPOSITION

The team assembled from sources outside the Bahamas consisted of the following:-

B G Little	Hydrological Engineer and Project Manager, Land Resources Division, Ministry of Overseas Development, London
D K Buckley	Hydrologist, Institute of Geological Sciences, London
R Cant	Hydrogeologist, Ministry of Works, Nassau
P W T Henry	Senior Forester, Land Resources Division
A Jefferiss	Agricultural Consultant (formerly Senior Agricultural Officer, Ministry of Agriculture, Nassau)
J D Mather	Hydrologist, Institute of Geological Sciences, London
J Stark	Senior Research Fellow, Soil Science Department, University of the West Indies
R N Young	Geomorphologist/Soil Surveyor, Land Resources Division

The team was joined by L Newton, Agricultural Officer, of the Bahamas Department of Agriculture.

The Lands and Surveys Department in Nassau provided a survey team for precise levelling of borehole locations related to established sea level data. The Ministry of Works continued to provide a driller, Mr D Penn, to carry on lightweight drilling in Mayaguana.

Mr Henry worked with the team in Abaco, and in addition, investigated pine forests throughout the Bahamas. Dr Mather was a member of the Survey team in Abaco and Eleuthera (Volumes 1 and 2 of the *Draft Land Resource Study);* Mr Buckley commenced with Volume 3 (Cat Island) and Mr Cant with Volume 5 (Grand Bahama).

READER'S GUIDE TO THE TEXT

This report is for the use of general readers as well as for those who have professional interests in certain aspects of land resources.

For readers with various professional interests in the report it is suggested that the chapters listed below may be most appropriate to their needs.

To further facilitate a rapid appraisal, each chapter ends with a summary.

1. **Senior decision makers**

Introduction

Chapter 4 Pine forests (recommendations)

Chapter 10 Population, wealth and economic activity

Chapter 15 General recommendations

Confidential annex

1. Specific recommendations for each island
2. Groundwater resources of each island and recommendations for their development

2. **Senior development executives and senior scientists**

Introduction

Chapter 4 Pine forests

Chapter 5 Groundwater

Chapter 8 Rocks and soils of the pine-covered areas

Chapter 10 Population, wealth and economic activity

Chapter 14 Land capability

Chapter 15 General recommendations

Chapter 16 Recommendations for large-scale groundwater abstraction

Appendix Methods used in the survey

Confidential annex

1. Specific recommendations for each island
2. Groundwater resources of each island and recommendations for their development

3. **Officials concerned with local investigations and developments**

Land

Introduction

Chapter 5 Groundwater (summary)

Chapter 6 Rocks and landforms

Chapter 7 Soils

Chapter 8 Rocks and soils of the pine-covered areas

Chapter 12 Land tenure

Chapter 13 Land use

Chapter 14 Land capability

Appendix Methods used in the survey (relevant parts)

Confidential annex

1. Specific recommendations for each island
2. Groundwater resources of each island and recommendations for their development

3. Detailed inventory of tillage land listed by island

Agricultural extension

Introduction

Chapter 2 Climate

Chapter 3 Biogeography and vegetation

Chapter 6 Rocks and landforms

Chapter 7 Soils

Chapter 8 Rocks and soils of the pine-covered areas

Chapter 12 Land tenure

Chapter 13 Land use

Chapter 14 Land capability

Confidential annex

1. Specific recommendations for each island
2. Groundwater resources of each island and recommendations for their development (relevant parts)
3. Detailed inventory of tillage land listed by island

Groundwater

Introduction

Chapter 2 Climate

Chapter 5 Groundwater

Chapter 6 Rocks and landforms

Chapter 16 Recommendations for large-scale groundwater abstraction

Appendix Methods used in the survey (relevant parts)

Confidential annex

2. Groundwater resources of each island and recommendations for their development

Tourism

Introduction

Chapter 1 Regions

Chapter 3 Biogeography and vegetation

Chapter 9 Shorelines

Chapter 10 Population, wealth and economic activity

Chapter 11 Communications

Chapter 14 Land capability (later parts)

Confidential annex

1. Specific recommendations for each island
2. Groundwater resources of each island and recommendations for their development

Regional planning

Introduction

Chapter 1 Regions

Chapter 2 Climate

Chapter 4 Pine forests

Chapter 9 Shorelines

Chapter 10 Population, wealth and economic activity

Chapter 11 Communications

Chapter 14 Land capability (parts of)

Chapter 15 General recommendations

Confidential annex

1. Specific recommendations for each island
2. Groundwater resources of each island and recommendations for their development

Readers whose official status allows them access to Volumes 1-8 of the original confidential island reports *(Draft Land Resource Study,* Little *et al.,* 1971-6) will find in them the items referred to in the present report and also the detailed maps mentioned in the Introduction. General readers wishing to consult Volumes 1-8 and the associated maps may apply to the Director of Agriculture, PO Box 3028, Nassau, for permission.

Part 2

Natural resources

Chapter 1 Regions

PHYSIOGRAPHIC REGIONS

The Bahamas can be divided into purely physiographic regions on the basis of climate, groundwater, vegetation, landform and surface deposits. A clear distinction based on vegetation is that between the pine islands (Andros, New Providence, Grand Bahama and the Abacos) and the remainder of the islands, called the coppice islands. The latter are so called on account of their hardwood vegetation, now largely reduced to thicket form; they may be divided into a number of groups on the basis of rainfall. Inagua and South Acklins usually receive less than 30 inches of rain per annum and have a climate which Holdridge (1967) classifies as capable of supporting tropical very dry forest. Exuma, Long Island, North and Central Acklins and Mayaguana form a group with a wetter climate of 30-40 inches annual rainfall, whilst Big Wood Cay, South Andros, Eleuthera, Cat Island and San Salvador receive over 40 inches. These island groupings based on rainfall also have differences in vegetation, soil, surface deposit and different capabilities for ground water replenishment.

Differences not related to climate are those of landform/depositional type and size of the island and these relate to bank size and other factors which as yet are imperfectly understood. However, a significant environmental distinction can be made between those coralline islands (Mayaguana, Inagua and Plana Cays) which occupy small isolated banks and other coralline islands such as Grand Bahama and Andros which are associated with the much larger Great and Little Bahama Banks. For the geologist, the fact that the depositional lithofacies (see Chapter 8) typical of flat areas of the pine islands are not repeated in the coppice islands is a valuable distinction; similarly the presence of large areas of uncemented surface deposits in Acklins and Inagua.

As the maximum relief between high and low land is only 206 ft, relief cannot be used to define regions (as, for example, into mountains, foothills and plains) although, within islands, it is reasonable to define hilly and flat subregions.

There are climatically influenced sedimentary zones (e.g. depositional areas dominated by coral in the south). However, certain geological features are widespread and bear no relation to climate.

PLANNING REGIONS

Natural resource endowment, dependent to a great extent on climate, has predetermined settlement and regional success, so giving a rough correspondence between natural and human resource regions.

Although island affinities and a number of more complex groupings have been proposed, the one set out in the Regional Development Strategy (p. 49-50 and Map 4) (Bahamas, Ministry of Development, 1974) appears simple and adequate; it groups the islands as follows:

North	Grand Bahama and the Abaco Islands
Central	Biminis, Berry Islands, New Providence, Andros, Eleuthera, Cat Island, the Exumas, Long Island, San Salvador, Rum Cay and Cay Sal

South Crooked Island, Long Cay, Acklins, Mayaguana, Inagua and the the Ragged Islands

The basic information for defining planning regions similar in their human resources is given in Separate Map 1 of this report. The themes for this map are discussed in Chapter 10. Separate Maps 2 and 3* cover the principal physical resources of land and groundwater. Each island is considered a subregion, and its size, shape and relationship with other islands can be derived from the maps. Their relationships and communications with Nassau are also shown in the Regional Development Strategy (Bahamas, Ministry of Development (1974)) pp 11-15, and in Separate Maps 1 and 2. Further information on the actual state of development and development prospects of each island is needed to complete the regional analysis. Some of this can be obtained from annual statistical abstracts produced by the Cabinet Office, Department of Statistics. Relatively few islands in the south have any complex development.

SUMMARY

1. The presence of pine forest is the best single criterion for distinguishing regions.
2. Coppice islands without pine fall into three rainfall zones. Vegetation, agriculture, soils and groundwater availability largely reflect these differences in rainfall.
3. Islands perched on small isolated banks may be geologically distinct from those on large banks.
4. Planners distinguish north, south and central regions.

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*Separate Map 3 in confidential annex.

Chapter 2 Climate

The Bahamas has a marine tropical climate as defined by Miller (1971, pp. 119-122) and described by him as characterised by persistent north-east trade winds, with warm, wetter summers and cooler, drier winters. Within this general regime, there exists substantial variation between the wetter, cooler north-western islands (which may get one fifth more rainfall than Nassau) and the drier, warmer south-eastern islands, some of which get only half of Nassau's rainfall. Depressions and associated rain from the north and north-east affect the northern Bahamas but are less frequently experienced in the south-east. The whole archipelago lies within the North Atlantic hurricane belt.

The volumes of the confidential *Draft Land Resource Study* (Little *et al.*, 1971-6) each give a brief account of climate, particularly as it affects agriculture and groundwater replenishment (recharge). An ecological-climatic ('life zone') classification, set up by Holdridge (1967) is used to characterise each island's climate by reference to its temperature, rainfall and potential evapotranspiration regimes. Abaco (whose rainfall probably equals its potential evapotranspiration) by this classification lies on the transition between 'subtropical moist' and 'tropical dry forest'. Eleuthera and islands as far south as central Acklins are within the 'tropical dry forest' life zone and south Acklins, Mayaguana and Inagua – in Inagua potential evapotranspiration exceeds rainfall by 2½ times – are within the 'tropical very dry forest' zone. Vegetationally, if ground conditions are taken into the reckoning the peculiar environmental conditions in Inagua might suggest that 'thorn woodland' or even 'desert scrub' were more appropriate life zones for this island.

Climatic data used by the survey are derived almost wholly from the Meteorological Office, Nassau, which collects data at one or more stations on most main islands. A review of rainfall records is given in 'Past records of Bahamas rainfall' (Bahamas Meteorological Office, 1971a). Rainfall data used by the survey is mostly based on a 20- year record from 1951. Many of the stations are situated on offshore cays (Green Turtle Cay for Abaco, Dunmore Town for North Eleuthera and Long Cay for Crooked Island and Acklins (Volume 7, p. 11,*) which makes the data collected less applicable to the main islands. A limited quantity of data from recording sites established by the LRD Survey were used in Volumes 1-4*. No new recording sites were established after the work in Andros in October 1971.

Broad regional trends in rainfall distribution are summarised in 'Rainfall distribution over the Bahamas' (Bahamas Meteorological Office, 1071b) in the following words:

> 'These *(monthly maximum, mean and minimum rainfall, 1951-1970)* show for the North West Islands a wet period from May/June to October, with June and October as the wettest months. This gradually changes towards the south east until in the extreme south eastern islands the wet season is from April/May to October/November, with a pronounced drier break in July and August and October the wettest month.'

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*Of the *Draft Land Resource Study* (Little *et al.*, 1971-6), which preceded the current *Land Resource Study*. Throughout the current report, reference to a volume is to a volume of the *Draft Land Resource Study*. A list of the volumes is shown in Part 1 (p. 1) of the current report.

Graphs of monthly rainfall are shown on the land capability map (Separate Map 2) which accompanies this volume.

Table 1 shows mean annual rainfall for each main island together with three measures of statistical probability that emphasise the least annual rainfall expected in 8 years out of 10 and the chance of getting less than 40, 30 or 20 inches in any one year. The islands are listed in order of decreasing rainfall.

TABLE 1 Rainfall statistics presented by island

Island	Mean annual rainfall (in)	Minimum (annual) rainfall expected 8 years out of 10	Estimated % probability of receiving less than		Standard deviation (in)
			40 in	30 in	12.9
Abaco	62.1	51	4.3*	0.62	
Grand Bahama	50.8	42	16	3	11.1
Eleuthera	45	37	12	30	9.6
			30 in	20 in	
Andros	44.8	36	8.5	1	10.8
Cat Island	40	33	13	1.2	8.8
Exuma	37.7	31	19	2	8.8
Long Island	35.7	28	26	3	8.0
Long Cay	34.7	24	35	12	12.6
Mayaguana	34.0	25	35	9	10.4
Inagua	27.5	19	60	23	10.1
*50 in = 17.6					

There is no orographic (mountain - induced) rainfall in the Bahamas (as no hill in the islands rises higher than 207 ft), and there are no rain shadow zones. It has been suggested that the trade winds tend to displace the island cloud (a cloud which forms by mid-day because of heating up of the air over the islands' vegetation), and consequently that the associated convection showers frequently fall either in the sea or to the west of centre in an island. Unlike winter depressions, summer convective rainfall is often very localised (Volume 7, Plate 8), and wide variation in catch at raingauges has been recorded within a small area (20 000 ac) in Abaco (Volume 1, p.9), on a daily, monthly and even yearly basis. As might be expected, the longer rainfall records are characterised by less divergent totals.

Hurricanes and tropical storms are recorded for the period 1871-1963 on tracking charts (Cry, 1965). A count of those which actually crossed each island or passed within 200 miles of it is presented in each volume of the *Draft Land Resource Study* and summarised in Table 2.

TABLE 2 Incidence of hurricanes in the Bahamas

Island	Number passing across an island	Number passing within 200 nautical miles
Abaco	8	91
Eleuthera	6	85
Cat Island	7	39
Andros	9	90
Grand Bahama	16	70
Exuma	5	45
Long Island	7	45
Crooked Island and Acklins	9	45
Mayaguana	5	45
Inagua	3	45

According to records assembled by Cry (p.28) tropical storms are most likely to occur between the first week in August and the last week in October with the maximum hurricane hazard in the second week of September.

Information of interest to the Ministry of Tourism and to regional planners is the monthly variation in temperature extremes. Table 3 shows such values for Abaco, Exuma and Inagua. Note that differences between the north and south are less marked in summer than in winter, that there is an increase in mean monthly maximum temperature from north to south and that even in the northern islands frost is unknown — a factor of critical importance in commercial vegetable growing for the American market.

TABLE 3 **Monthly variation in temperature extremes for Abaco (wet north-west), Exuma (central) and Inagua (dry south-east island).**

Month	Mean maximum temperature			Mean minimum temperature		
	Abaco	Exuma	Inagua	Abaco	Exuma	Inagua
Jan	78.3	79.1	83.7	64.5	69.0	67.5
Feb	76.7	78.5	82.3	62.7	67.4	67.3
Mar	79.5	80.9	84.6	66.0	69.1	68.7
April	81.1	84.1	87.6	69.0	71.9	70.2
May	83.7	86.2	87.6	72.1	74.1	73.8
June	86.1	87.4	89.2	75.1	76.1	75.8
July	87.3	88.7	91.2	76.9	78.1	76.3
Aug	86.9	90.0	91.0	77.1	77.8	75.6
Sept	86.6	88.1	90.6	76.2	77.0	73.8
Oct	84.4	86.1	88.8	74.0	75.4	73.8
Nov	80.9	82.5	86.6	69.6	72.3	70.3
Dec	78.9	79.4	84.1	66.6	69.8	68.3

The climatic factors discussed above have obvious significance in groundwater recharge, water supply, agriculture and tourism. Equally important to the last and to human settlement generally are factors of relative humidity* and local sea and land breezes not discussed here.

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*Humidity and temperature have elsewhere been combined in various ways (Thom, 1959; Hevener, 1959) to yield a 'comfort index'.

SUMMARY

1. The islands have a marine tropical climate, i.e. north-east trade winds, warm wetter summers, cool drier winters.
2. Islands north of Nassau receive up to one fifth more rainfall than Nassau; south-east islands may get as little as half of the Nassau rainfall.
3. The period May/June – October is the north's wettest season.
4. The south is wettest between April/May and October/November (although July tends to be dry).
5. Relief does not affect rainfall.
6. Summer rainfall can be very localised.
7. August to October is the hurricane season. Statistically speaking the time of peak hazard is 7-14 September.
8. The islands are never subject to frost.

Chapter 3 Biogeography and vegetation

BIOGEOGRAPHY

This section on biogeography contributed by W T Gillis, provides a setting for the survey's vegetation studies. Dr Gillis is an expert on the Bahamian flora.

What we know as the Bahama Islands have not long been above sea level — geologically speaking they probably emerged as dry land in the late Tertiary. Consequently the flora and fauna have only occupied the islands 'recently'. The sources of the plants and animals which now occupy the islands must of necessity have been the adjacent regions, chiefly Cuba, Hispaniola (Haiti and the Dominican Republic), Florida, and to a lesser extent the more distant regions of Puerto Rico and Yucatan in Mexico. Affinities of the present plant and animal denizens of the Bahamas bear out this assumption. In addition, there are of course pan-tropic weeds and domestic animals such as field mice and house rats, those organisms which manage to make their way to most regions of the world aided by the activities of man.

To understand the present-day distributions of plants and animals in the Bahamas, one must look at how much of the archipelago was above water during the Pleistocene, the Ice Ages when much of the world's water was fixed in continental-sized glacial ice. At times the sea was about 590 feet lower than it is at present, leaving vast areas of the present shallow banks of the Bahamas exposed as dry land. Whole island groups coalesced on the Great Bahama Bank (Andros, New Providence, Cat, Eleuthera, the Berry Islands, the Exumas, Long Island, and the Ragged Chain), and a smaller mass to the north consisted of the Little Bahama Bank (now Grand Bahama and the Abacos). Crooked and Acklins were together on one bank, but most of the other islands existed as discrete units as they do today, only they were somewhat larger in land area than at present.

Deep water always separated the Bahamas from Cuba, but the distance separating them was less than 35 miles in Pleistocene times, whereas today it is at the least 160 miles. Deepwater channels also separated the Banks from each other within the Bahama Archipelago. The size of water barriers across which any disseminules must pass to the Bahamas from outlying regions was considerably smaller. Hence, by laws of chance, there was greater likelihood that seeds, spores, whole plants, or even animals could traverse the smaller gaps to the Bahamas from Cuba, from Hispaniola, from Florida, etc. Following melting of glacial ice, the seas rose swallowing the shores, the islands shrank and the distances between them grew. Even so, occasional organisms could bridge the gap by long distance dispersal. The occasional transporting of viable seed by birds is quite probable. Furthermore, the frequent hurricanes which rake the islands usually blow in from the south and east, conceivably carrying with them seeds, branches, spores, and occasional rafts of small organisms which have intentionally or passively sought refuge on them. One species of *Fimbristylis* appeared in the northern Bahamas after the 1926 hurricane and is still known there as 'hurricane grass'. Presence of certain species of pygmy boas and owls can be linked to specific storms that probably brought them across to the Bahama archipelago from Cuba in recent times.

Hence the floristic constitution of the islands of the Great Bahama Bank is fairly uniform. Most plant species found on any one island of the Bank are to be found on all. The few exceptions are seven or eight species of Cuban origin which have been restricted to South Andros (a few to Andros in general) having failed to bridge the gap to the other islands. Further, there are some species of plants (e.g., asters, poison-ivy, grape) which apparently entered the Bahamas from the North American continent through Florida and are found only on the north-western islands (Bimini, Andros, Abaco, Grand Bahama, New Providence, and to a lesser extent Cay Sal). The southern islands have their chief affinities with Cuba and Hispaniolo, with Hispaniola influencing the flora of Inagua and the Turks and Caicos Islands more than islands to the north and west where the influence is chiefly Cuban. San Salvador remains an enigma in that, despite its relative distance from Hispaniola, it has more items in its flora and fauna of Hispaniolan and Puerto Rican origin than is readily explained. There are a few plants (e.g., *Mimosa bahamensis*) which have a link with Yucatán; they are, surprisingly enough, restricted to the eastern islands and not the western ones which are nearest to Yucatán today!

The several Puerto Rican species absent in the intervening land mass of Hispaniola but present in the Bahamas have perhaps entered the islands through 'stepping stone' islands located between Puerto Rico and the Turks and Caicos group. These stepping stone islands were above water in the Ice Ages but today are shallow submerged banks (i.e. the Mouchoir Bank, the Navidad Bank, and the Silver Bank).

The deepwater gaps, which have been barriers to plant and animal migration throughout the history of the Bahamas, continue to have an effect in barring interchange between islands today. Most noteworthy is the Crooked Island Passage. Within the islands it is the most significant single barrier to the migration of plant and animal species between northern and southern islands. It forms a biogeographical line of considerable consequence.

There are a few endemic plant species (i.e. species of Bahamian origin), but these amount to only 3–4% of the total flora of about 1 000 vascular plant species. This is a reasonable figure that one could predict would evolve *in situ* within the past few million years since their precursors colonised the Bahamas. Morphological modification of the precursors has caused the orginals to evolve into the distinct species seen today. Among the animals, this is especially noteworthy in the lizards, primarily of the genera *Anolis* and *Ameiva* which have subspecies confined to one or a few islands only.

Each island – even on the fairly uniform Great Bahama Bank – has a different set of dominant species. *Erythroxylum rotundifolium,* for instance, is found on most islands within the archipelago, but is nowhere really abundant. On Mayaguana, however, it becomes the dominant tree species. *Cynanchum bahamense,* a vine which is also present on nearly all the islands but never abundant, can be found on Cay Sal in all habitats (except mangroves) draped everywhere over the vegetation. Quite remarkably it was never collected there (in a botanical sense) until 1976! This particular phenomenon is probably accounted for by the influence of local features and competitors and the proximity to source areas.

Certain other phenomena are evident within the islands. Because of the reduction in rainfall towards the south, species of plants which tolerate dry, even semi-arid, conditions become more numerous in the south (especially south of the Crooked Island Passage). Plants which normally are found on beaches begin to be found in inland sites and inhabit ridgeland areas as well *(Ipomoea stolonifera, Suriana maritima,* and *Hippomane mancinella,* for example). There is an increase towards the south of plants with greyish or hairy leaves, an apparent adaptation to the drier environment. There is a surprising number of species which do not cross the Straits of Florida into the United States, species which are otherwise common throughout the islands (e.g. *Phyllanthus epiphyllanthus, Rhachicallis americana, Baccharis dioica).*

In consequence, each island has a distinct assemblage of organisms. A trained biologist could, if placed on any island within the archipelago, identify the island within an hour by studying its composition of fauna and flora.

One can explain the biogeographic patterns of the Bahamas, therefore, by understanding the biota of the land areas nearest to the Islands and the immediate past 1–2 million years of history, especially the most recent 12,000 years. Therein lies the key to origin, dissemination, and time of arrival on the Bahamas of all the precursors to the species present today.

VEGETATION*

The LRD examined and reported on vegetation communities in Abaco and in Eleuthera. A later visit to Mayaguana and Inagua in 1973 led to a short comparison of Mayaguana's vegetation (representative of a dry south-eastern island) with the vegetation of Eleuthera. Plant identifications on all islands were made with the assistance of G R Proctor, botanical specialist of the Institute of Jamaica. The results are given at Volume 1,[+] pp.12–18, Volume 2,[+] pp.9–14 and Volume 8,[+] pp.24–28. Individual areas occupied by each vegetation community are mapped together with agricultural land use. During field work, specimens were collected and those, dried and identified, form the basis of a small herbarium at the Ministry of Agriculture, Nassau.

It was the original intention of the LRD Survey to use the distribution of vegetation communities as an aid in defining uniform areas of land – a normal approach in land resource survey work. The usefulness of the approach was assessed (Volume 3,[+] pp.10–11) and it was agreed that though valuable in itself it did not advance the Survey's knowledge of landforms and soils and (as the Survey was not set up to pursue the study of vegetation in its own right), the work was suspended. In 1973, a brief private visit by Proctor, Gillis and Jefferiss to Inagua and Mayaguana formed the basis of the comparative notes mentioned in paragraph one. There is thus only a short reference to vegetation in Cat Island (Volume 3,[+] pp.11–12) while the vegetation of Andros and Grand Bahama is described only in *Pine forests of the Bahamas* (Henry, 1974) at p.26 and p.24, respectively.

The account of Abaco vegetation distinguishes 19 communities, each closely related to physiographic units. They include two coastal mangrove communities, two coastal communities established on sand and others on rock, marl flats and coastal hammocks. Each is characterised by one or more prominent species which include mangroves, buttonwood, sea oats, *Casuarina, Salicornia, Strumphia, Bucida* and *Bucida* with buttonwood. Fresh water flooding and high watertable communities include those dominated by reeds and by sedges and others dominated by palms. Two communities on inland sands are described, one with herbaceous vegetation and low shrubs, one with broad leaved, evergreen and deciduous woodland. Communities established on rock include a broadleaved thicket and two types of broadleaved and deciduous woodland, two varieties of pine woodland and a community of mixed broadleaved woodland with scattered pine. In the following lists, numbers identify each community on the original maps of Abaco.

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*For glossary of common and botanical names in this section see end of Chapter 3 & 4

[+] Of the *Draft Land Resource Study* (Little *et al.*, 1971–6 (see Part 1, Preface, of the present report for details of volumes))

Coastal communities

1 Tidal Coastal Rock and Marl Communities (*Salicornia* Community)
2a Coastal Sand Community (*Uniola* Strand Community)
2b Coastal Rock Community (*Strumphia* Community)
3 Poorly developed Mangrove (*Rhizophora mangle)*
4 Dense Mangrove (*Rhizophora, Avicennia, Conocarpus* and *Laguncularia* Communities)
5 Coastal Marl Flats Community (*Bucida* Community)
5a Coastal Hammock Community (*Bucida/Conocarpus* Community)
14 Coastal Sand Community (*Casuarina equisetifolia)*

Freshwater flooding and high water table communities

2c Flooded Herbaceous Communities (*Typha* and *Cladium* Communities)
6b High Water Table Communities (*Sabal/Thrinax* Community)

Inland sand ridge communities

6 Herbaceous Scrub Vegetation (*Coccoloba/Baccharis* Community)
7 Broad Leaved Evergreen Woodland (*Acacia/Metopium/Swietenia* Community)

Ridged rock land communities

8 Broad-Leaved Thicket
9 Lowland Broad-Leaved Woodland (*Acacia/Metopium* Community)
9a Elevated Broad-Leaved Woodland (*Acacia/Myricanthes/Coccoloba* Community)
9b Lowland Broad-Leaved Woodland (South)
10 Lowland Broad-Leaved Woodland with Scattered Pines
12 Pine Woodland on Rockland with High Watertable (Pine/*Sabal/Thrinax* Community)
13 Pine Woodland (*Pinus caribaea)*

The Eleuthera vegetation account distinguishes two communities of evergreen and deciduous bushland, a low scrub thicket and a thicket dominated by thatch palm and silver top. All occur on rock. On sand, the description distinguishes bushland, thicket (probably brought about by farming) and three kinds of dwarf shrubland with cocoplum including communities with thatch palm and with bahamian agave. Fresh water marsh vegetation in Eleuthera is divided into distinct communities dominated by pond top (*sabal palmetto*), sedges and bullrushes, respectively. A variety of mangrove communities, some containing buttonwood, occur both in the coastal zone and inland. There are in addition inland and coastal communities of algal mats with sparse low mangrove. Vegetation communities of Eleuthera were similarly mapped and the following numbers used to identify each community:

Vegetation of rock land

1 *Bursera — Metopium* Evergreen and Deciduous Bushland
1a *Swietenia — Bursera* Evergreen and Decuduous Woodland
2 Depauperate *Xylophylla — Croton* Evergreen and Deciduous Bushland and Low Thicket
4a *Thrinax* and *Coccothrinax* Palm Thicket

Vegetation of littoral sands and dune land

1b	*Bursera — Metopium* Evergreen and Deciduous Bushland
2b	Evergreen and Deciduous Thicket
2c	Dwarf Shrublands with *Thrinax* Palm Stands
3a	Dwarf *Chrysobalanus* Shrubland
3b	Dwarf Shrubland with *Agave bahamana*

Vegetation of inundated and periodically flooded land

4	Undifferentiated freshwater swamp vegetation (Sabal Palmetto Swamp — Sedge Swamp — Bull Rush Swamp)
5	Mangrove
5a	Algal Mats : Seasonally freshwater swampland with sparse low mangrove

The account of Mayaguana vegetation was restricted to observations in the western half of the island. It was noted, for example, that a bushland with mahogany, ratwood and wild tamarind replaced the gum elemi/poison wood vegetation community mapped in Eleuthera, and that low cocoplum scrub similar to an Eleutheran coastal type occurred not only at the shore but also for some distance inland. Thatch palm was absent from the palm thickets and a number of other differences in species composition were apparent.

It is unfortunate that there is no methodical account of the Inagua vegetation which differs markedly from that of Abaco and Eleuthera and, over huge areas, from that of Mayaguana. This vivid distinction is emphasised by Plates 1, 2 and 3 in the present report and by others in Volumes 2 and 8 of the *Draft Land Resource Study*. Vegetation mapping in Inagua, the largest dry island in the Bahamas would provide an interesting subject for research.

A list of academic papers on Bahamian botany is to be found in an excellent natural history paper *'Bibliography of the natural history of the Bahama Islands'* by Gillis,Harrison and Byrne 1975 (pp.17—19). Gillis and Proctor are at present preparing a revised flora of Bahamian vascular plants to replace that section of the original 1920 flora of Britton and Millspaugh (1962).

On the whole, the effect of human interference (cutting, burning, selective felling, grazing, etc) has been to effect a reduction in height of the woodland and a decrease in the number of species. The word depauperate is used specifically to describe this condition in Volume 2 p.11. Not all areas of each island are affected in this way. Some types of vegetation overlie land that has no productive use and has never been burnt even at time of higher population pressure. Some areas are relatively remote (south-east Long Island and much of South Acklins, for example) and therefore little affected. The slow regeneration of vegetation cleared for farming in the dry south-eastern Islands (Volume 2, p.59) has been emphasised by the authors as a caution to potential developers who might undertake haphazard or wanton clearing.

PLATE 1 A section of tall coppice land (Vegetation Community 9) exposed by development near Crossing Rocks Settlement, Abaco. Individual trees are 25-30 ft high, though crowns are small.

PLATE 2 One of several distinctive vegetation communities on uncemented deposits in Inagua. Individual trees are 20-25 ft high but irregularly and much less closely spaced than in the photograph above.

PLATE 3 View from the coastal sand ridge (with Vegetation Community 2c) over a hypersaline pond or lagoon. Beyond the pond the vegetation is classified as Community 1 on rock; central Eleuthera near Governor's Harbour.

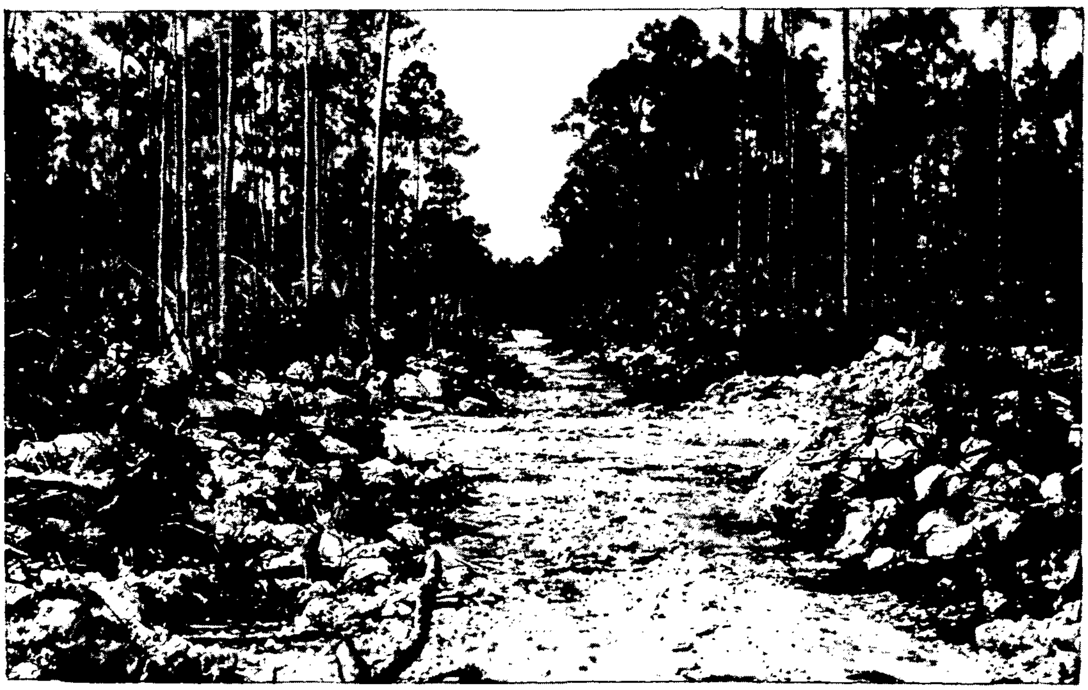

PLATE 4 Bulldozed third-order forest tracks prior to felling of the trees. Note the palmetto understorey. The large blocks of limestone along the roadside, indicate land unsuitable for tillage; block 3a, North Andros.

BOTANICAL AND VERNACULAR NAMES OF PLANTS MENTIONED IN CHAPTER 3

Bahamian agave	*Agave bahamana*
Bucida	*Bucida spinosa*
Buttonwood	*Conocarpus erecta*
Casuarina	*Casuarina equisetifolia*
Cocoplum	*Chrysobalanus icaco*
Gum elemi	*Bursera simaruba*
Jumbay	*Leucaena lencocephala*
Mahogany (madeira)	*Swietenia mahagoni*
Mangrove	Including: *Rhizophora mangle, Avicennia germinans, A. nitida* and *Laguncularia racemosa*
Ratwood	*Erythroxylon rotundifolium*
Sea oats	*Uniola paniculata*

Other plants not given vernacular names:

Salicornia perennis
Strumphia maritima

SUMMARY

Biogeography

1. The Bahamas emerged as vegetated *terra firma* in the late Tertiary geological period and were colonised by plants and animals from adjacent areas. Only about 4% of the 1 000 vascular plants are entirely Bahamian in origin.

2. Plants and animals are derived from those on the adjacent larger land masses of Cuba, Hispaniola, North America, Puerto Rico and Yucatan in Mexico.

3. The floating and rafting in of species from other areas (disseminules) has been aided by hurricanes and transport by birds.

4. At times of extreme low sealevel in the Pleistocene (Ice Ages), the 'moat' of deep water channels around and within the Bahamas was considerably narrower than at the present day. This facilitated the immigration of disseminules. 'Stepping stone' islands, now submerged, must also have helped.

5. There are several cases of locally established species which are absent elsewhere. The appearance of certain species correlates with dated hurricanes.

6. The Crooked Island Passage forms a major barrier to migration — a biogeographical dividing line of considerable importance.

7. Islands even in a comparatively uniform area such as the Great Bahama Bank tend to have different dominant plant species.

8. Plants adapted to the semi-arid environment become more numerous in the south where also they extend their habitats.

Vegetation

9. The survey made a limited study of the vegetation communities in Abaco and Eleuthera which formed the basis of airphoto mapping. Later the survey of vegetation was discontinued.

10. Nineteen vegetation communities were distinguished in Abaco. All were closely related to physiographic units (sands, rockland, high watertable and littoral areas). A further 12 vegetation communities were distinguished on Eleuthera. The two islands were taken as typical examples of pine and coppice islands respectively. Later it was found that coppice vegetation differed in north and south.

11. The limited observations in the south Bahamas (Mayaguana and Inagua) indicated numerous important differences in the nature of the vegetation – a point emphasised in the biogeography section (Summary 8).

12. Vegetation mapping in Inagua is recommended as a suitable research topic.

13. Human interference throughout the islands has resulted in a reduction in the height of the vegetation and in the number of species. Areas more or less affected (and unaffected) by human activities can be recognised.

14. Potential developers are cautioned against haphazard or wanton clearing, especially in the drier islands.

Chapter 4 The pine forests*

INTRODUCTION

The Bahamian forest estate has been exploited throughout its licenced** history with little regard for sound management. Its full potential for rapid growth has probably never been realised and it has been consistently undervalued as a natural resource. The islands of Grand Bahama, Abaco, Andros and New Providence are the natural habitat of *Pinus caribaea* v. *bahamensis,* one of the most important tropical pines being grown in plantations throughout the lowland tropics today. Most of the forest areas have however been exploited for sawn timber or pulpwood in recent years and have a growing stock mostly less than 10 years old.

The LRD study of Bahamian pine forests† (Henry, 1974) covers investigations into the widespread death of pine trees in the four islands mentioned above, fire damage, a reconnaissance survey of regeneration stocking in Abaco and Grand Bahama, an investigation into growth rates, possible silvicultural practices and the costs and benefits of fire protection and silvicultural treatment. It also reviews exploitation methods in use at 1969 in Andros and gives a detailed review of the history of exploitation. The information collected in the four pine islands is then used to update a national forest policy which would, if adopted, ensure sound management of the forests as a profitable continuing industry. The following abbreviated account deals with the appearance of the forest vegetation, land suitable and available for forestry, the stocking condition as observed in 1969, and growth rates. It relates the more important facts in the history of the licence and proposes a programme of development for the islands studied.

CHARACTERISTICS OF THE FOREST

The forest occupies the soily rock plains, rough slightly elevated ground and minor ridges which together make up most of the pine islands; the forest does not occur on higher ridges next to the deep water shore (which tend to support coppice, i.e. narrow stemmed, close-spaced stands of semi-deciduous and evergreen broad-leaved trees) or on sandy areas along the coast. Henry's report (1974) defines two site qualities, good and poor, which it is suggested accord with lower and higher watertables. Yields in Andros and Norman Castle (Abaco) also suggest a relationship with land quality, the tallest forest occupying the land best suited to agriculture.

The better quality sites are dominated by pine woodland (*Pinus caribaea*) although this may be much altered by exploitation and fire damge. Trees may attain a height of 70—80 ft at maturity and may form dense stands. The shrub layer is variable, much influenced by the density of the canopy and by the incidence of fires. At the most extreme it may be up to 9 ft high, the principal shrub species being cinnecord, poisonwood, bastard stopper, pigeon berry, beefbush, horseflesh and *Tetrazygia bicolor.* Pond top, silver top and thatch palm occur, but less frequently in drier sites than in areas of high watertable. Love vine is a commonly occurring creeper.

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*For a list of common and botanical names see end of Chapters 3 and 4.

**This term refers to licencing for commercial exploitation.

†***Land Resource Study 16 (Henry, 1974) Pine forests of the Bahamas.***
This report is the source of the greater part of the information in this chapter and is constantly referred to, either as 'Henry (1974)' or as the 'original report'.

In the lower quality pine woodlands, the pine grows poorly though it often forms a dense thicket. Palms may dominate the ground flora (as, for example, in the Twin Lakes area, Andros) but do not attain more than 8 ft. Pigeon berry, poisonwood, rough varronia, box briar, yellow elder, *Tetrazygia bicolor* and *Ascyrum linifolium* may also occur. A number of herbaceous plants are typical. They include marsh pennywort, sawgrass, southern yellow-eyes grass, perennial marsh fleabane and *Rhynchospora perplexa.* Full lists of species, with common and botanical names are given at pp. 23–24 and Appendix 2 of Henry's (1974) report.

A mixed hardwood pine woodland is found in some ridged areas usually inland from the deep water shore where the surface rock is bedded and blocky. The hardwoods form a dense layer with a fairly uniform canopy from which the pines emerge. The common hardwood trees in this vegetation type are cinnecord, gum elemi, mastic, poisonwood, black torch, pigeon plum, sea grape and paradise tree. The shrub layer is poorly developed but there may be vines together with orchids and airplants which grow attached to the hardwood stems.

Exploited or burnt woodland may contain low shrubs of the original understorey with a preponderance of poisonwood on the more rocky areas and grasses on land with more surface soil. Bracken abounds in burnt areas where the rock/soil profile is deep and loose. Henry (1974) records a number of differences between the vegetation types in Abaco, Grand Bahama and Andros.

THE SIZE OF THE FOREST

Henry (1974) presents information on the location and acreages of the main forest areas (the acreages relate to land which has once carried pine forest and now has a young standing crop). Extensive clear felling for pulpwood since 1957 means that the crop throughout the pine islands is mostly young (Plates 4 and 5). The oldest of the recently regenerated trees are in Grand Bahama. South Abaco in places has no crop at all (Plate 6). Table 6 of Henry's report summarises the position in 1970.

Abaco

Table 18 of Henry's report gives the area of Great Abaco occupied by pine in 1956. This was almost completely clear felled between 1959 and 1967 (Text Map 6 in Henry's report). About 21 150 acres subsequently became the BAIL sugar estate and in the last five years 1 500 acres of Norman Castle have been ploughed for agriculture. Numerous small areas of land have been cleared within Little Abaco, which has 4 200 acres of mature pine. The total forest area of the Abacos on Crown Lands is about 126 763 acres disposed as shown in Table 4.

TABLE 4 Location of forest areas on Crown land in Abaco

Area location	Good pine sites (ac)	Poor pine sites (ac)	Total acreage
Great Abaco south of Crossing Rocks	51 414	6 894	58 308
Crossing Rocks north to the river	22 514	4 584	27 098
The river north to Marsh Harbour less BAIL estate	12 571	1 862	14 433
Marsh Harbour to Treasure Cay	8 294	4 418	12 712
Norman Castle less Key and Sawyer farms	8 487	1 524	10 011
Little Abaco*	4 201	–	4 201
Total			126 763

*Site quality not given but mostly good

PLATE 5 Haitian forest workers cutting and stacking billets of pine, North Andros 1973.

PLATE 6 Mortality of pine seed-trees affected by bark beetle and weevil infestation after the 1962 hurricane and subsequently by fire in South Abaco. View south along the main forest exploitation road which branches to Hole in the Wall and to Sandy Point Settlement.

Grand Bahama

The whole of Grand Bahama was cut for pulpwood between 1956 and 1959 (Text Map 5, Henry, 1974). The boundary between Crown land and Grand Bahama Port Authority land zig-zags north-west from a point on the South Coast about 2 miles west of High Rock village. The Port Authority area therefore occupies all land marked Coupe 1 and two-thirds of land marked Coupe 2a (Text Map 5 Henry, 1976). The remaining forested Crown land totals about 63 200 acres and is disposed evenly in a relatively compact series of blocks for 12 miles to the west and 12 miles to the east of Pelican Point Settlement.

Andros

All accessible areas of North Andros were cut for pulpwood between 1967 and 1975 (see Plates 4 and 5). Mangrove Cay and other areas south of Middle Bight were not cut. A summary of the accessible area occupied by pine forest is given below.

TABLE 5 Location of accessible forest areas on Crown land in Andros

Location	Acreage
North of the latitude of Fresh Creek less BARTAD area (2 200 ac)	98 710
Between Fresh Creek and Middle Bight	54 340
Areas in and adjacent to Mangrove Cay) Areas in South Andros) (Timber-stands still intact))	25 740
Total	178 790

New Providence

Crown forests in New Providence are small, relatively intact and have never been systematically cut over. Table 44 of Henry's report shows that the Crown has 4 924 acres of pure pine forest, 2 300 acres of which occupy poor sites, and 2 624 acres good sites. The forest has suffered considerable encroachment due to urban spread and agricultural expansion between 1958 (the year of the air photography) and 1976.

REGENERATION, STOCKING AND GROWTH RATES

Abaco

A reconnaissance was made of stocking in about 88 500 acres of land that seemed likely to remain part of the forest estate. The youthful stands of pine have been affected by forest fires. Stocking in Abaco as in Grand Bahama was assessed in six classes, each defined by the number of saplings per acre.

TABLE 6 **Abaco: stocking the new crop of pine saplings (from Table 36 of Henry's report 1974)**

Location	Acreage	Acreage
Norman Castle	11 510	Over half poorly or insufficiently stocked; about one quarter moderately or well stocked; one quarter unexploited
Eastern Shore) East Point) Marsh Harbour (N))	5 090	Three fifths fully, adequately or moderately stocked; two-fifths poorly or insufficiently stocked
Marsh Harbour (S)	5 950	Most adequately stocked
Buckaroon Bay	4 600	Half fully or adequately stocked; nearly half poorly stocked
Cornwall	10 160	Less than two-fifths fully or adequately stocked; less than one-fifth moderately stocked; more than two-fifths poorly or insufficiently stocked
Sandy Point	51 200	More than four-fifths insufficiently stocked mostly needing reseeding; one-tenth fully, well or moderately stocked; the rest poorly stocked

The poorly stocked areas of South Abaco which carry no seed trees cannot be improved except by reseeding; about one quarter of the assessment areas were well stocked and, if fire could be controlled, the poorly stocked areas should improve by natural seeds dispersal. Theoretically, by 1969 (after clear felling) regeneration should have been 2—10 years old but fire losses have led to much less advanced regeneration. There is evidence of more and less severe destruction of the forest by fire — 15 ft high saplings being immune to all but very hot fires. A sampling of height growth (Table 35, Henry, 1974) shows that 3 year old saplings may be 3 ft tall, those 5—6 years old may reach 10 ft and those 9 years old, 15 ft, the average height of each age group being 1½, 5, and 8—10 ft respectively.

Andros

The maps of Andros (in four sheets at 1:50 000 scale) in Henry's report show the quality and stocking of virgin forest areas uncut at 1969 as well as details of cut areas, older areas of regeneration and timber destroyed by fire and by saltwater flooding. The time is now right to carry out a post-exploitation assessment of stocking regeneration.

In each of two areas of Abaco, and one of Andros, investigations were made into the relationships between basal area, age, diameter, height and volume of 50 trees. The results show clearly that second growth stands are more vigorous than virgin ones. Also that the greatest development takes place in the early years before the tree grows to more than 4" in diameter, after which growth slows down. The fact that there were taller trees in the northern forest of Andros (also near Norman Castle, Great Abaco) than in much of Abaco is perhaps significant and merits further investigation. In Andros the tallest trees observed were 80 ft high with an average in the same stand of 58 ft and 12 in diameter at breast height. A limited assessment of timber basal areas was made in the uncut stands in Little Abaco. Trees there, though affected by fire, are now of saw-log size.

Grand Bahama

In Grand Bahama, stocking was examined along the larger roads and by aerial reconnaisance. It appears that the area from the eastern margin of the Port Authority Land to The Gap is reasonably well stocked with original 10–12 year old regeneration, some of which reach 18–20 ft. Areas west of the Port Authority boundary in places have 17 year old regeneration following pit prop cutting in the early 1950s – one 17 year old specimen had a height of 32 ft, a diameter at breast height of more than 14". These stands could not be exploited for pulpwood. (Some areas have recently been exploited by the Bahamas Timber Company north of High Rock Village). East of The Gap the timber crop is younger and has sustained more fire damage. In consequence, island-wide pulpwood cutting would have to be put off until the 1980s or 1990s. Fires are less of a hazard in Grand Bahama because of the natural barrier afforded by cross island creeks. August Cay, protected by water from fire in other areas, has undamaged stands up to 20 ft in height.

New Providence

No detailed assessment was made of the stands in New Providence but most of the Crown forest land (measured at 4 924 acres in 1958, subsequently diminished) is mature pine carrying 5–6 cords per acre. The map distinguished between good and poor pine stands. A number of trial plots with 7–22 year old trees were examined and evaluated using volume tables compiled for a comparably poor quality area in Andros. Approximate estimates suggest a mean annual increment of 0.214 cords/acre, which is slightly below the average (Table 21 in Henry's report) calculated from the Abaco pulpwood operation.

RECENT EXPLOITATION

The licence history of the Crown forests began in 1900 when the Governor, Sir Gilbert Carter, granted a number of 100 year concessions to cut lumber on the main pine islands. In the following years there emerged a clear pattern of licences being treated as saleable assets. Licences were commonly sold after amendments which gave the licensee greater freedom. In each case, sale resulted in substantial profits to the licensee and commensurably poor benefits to the Government.

Pulpwood cutting and virtually clear felling was first introduced into the licence by Governor Lord Ranfurly in 1956, after which Owens Illinois of the Bahamas extracted pulpwood continuously between 1957 and 1975 in Grand Bahama first, then in Abaco, and later in Andros. In 1966 the company relinguished their cutting rights in Abaco in consideration of a grant of 21 150 acres of land in fee simple in central Abaco on which they established a sugarcane estate. They have since disposed of their Grand Bahama licence to the Grand Bahama Development Company and are reportedly (p.48, Clarke, (1974)) about to relinguish their cutting rights on Andros.

DEVELOPMENT RECOMMENDATIONS

The Survey strongly recommends that the Bahamas Government should set up a development programme, to protect, manage and harvest the forest on the basis of sustained yield for the good of the Bahamas. Whether the forest is then harvested for lumber or for pulpwood will be a matter of Government policy, although the forestry report leans heavily towards lumber production, which it demonstrates can be socially and economically more profitable. At the time of writing Government management has to be restricted to Abaco, as the other forests continue under licence until 2006.

A recommended programme for Abaco

Six areas outlined on maps accompanying Henry's report are recommended for management. The overall annual cost of managing 70 000 acres (representing the three southern areas plus some land expected one day to be taken into agricultural use) would be about 70 cents/acre; this charge, which is high compared with comparable areas in the United States will have to be faced.

Reseeding of about 50 000 acres in South Abaco would need to be undertaken; a period of 5–6 years is suggested and techniques are discussed in Henry's report. Silvicultural work (thinning, control of hardwood understorey) would be carried out by a permanent labour force also responsible for fire protection. With fire protection, but no silviculture, a 23 year rotation would be required for pulpwood; with silvicultural work the yield after 23 years would be at least one-third greater than without. If the more dispersed northern areas (already two-fifths stocked with mature timber) were added to this 70 000 acre estate, the management costs per acre would be increased considerably. Nevertheless the increased costs could realistically be justified in view of the benefits to tourism, land management and conservation.

If cut for timber (lumber) the annual yield from Abaco alone would just about meet the whole country's annual home requirement (reviewed on pp.71–73 of the Henry's report). The report contrasts the respective benefits of timber and pulpwood production, pointing out that pulpwood production would necessarily have to be exported as there is no possibility of establishing a pulp mill in the Bahamas due to its very high water needs and effluent disposal requirements. Sawn timber, it states has many advantages over pulpwood; it can be processed within the country and would provide a valuable import substitute. It is a higher value crop than pulpwood even though it takes longer to grow, and is a crop which can be exploited at a rate consistent with sound environmental management. The sawn timber industry would moreover create continuing opportunities for the labour force, at the same time reducing the country's dependence on imports. The forestry report therefore disagrees in many respects with the advisory paper by Wendell Clarke, though joins with him in his recommendation for positive Government management of the forests.

Recommendations for Grand Bahama

The present regeneration of Grand Bahama would allow the licensee to take one further crop of pulpwood before expiry of the licence in 2006. If however the licence were to revert to the Crown, it is recommended that the forest be exploited for sawn timber rather than pulp. It would then be possible to integrate Grand Bahama with Abaco in a sawn timber working circle commencing production of its first timber in about 1992. It is meanwhile recommended that the new licensee, the Grand Bahama Development Corporation, should be encouraged to accept licence amendments which promote sound management, the use of a working plan and protection against fire.

Recommendations for Andros

No suggestions can be made concerning the forests in Andros at present, as these remain with the licensee. He should however be persuaded to protect his concession against fire during the period of the licence. Should this forest estate revert to the Crown as suggested elsewhere, its re-acquisition would improve the profitability of managing the other forest areas, particularly as fire protection is more economic when applied to large compact areas.

Recommendations for New Providence

It is recommended that the Crown forest land might form the source of wood for a two-man charcoal burning operation. The use of modern kilns would improve output and reduce fire risk. Meanwhile it should be established whether fire protection in New Providence should be paid for from Forestry funds when the primary use of large areas of the Island's forest is other than forestry.

Other recommendations

Other recommendations in the Henry's report include a Draft Forest Policy (Part 6), proposals for a new forest legislation (Appendix 6), a programme for silviculture research (p.139), and suggestions for promoting seed collection for export (p.132). Details are also given of the techniques, research, equipment and costs involved in the establishment of a reliable system of fire control.

BOTANICAL AND VERNACULAR NAMES OF PLANTS MENTIONED IN CHAPTER 4

Bastard stopper	*Petitia domingensis*
Beefbush (gunwood, above all, white cedar)	*Tabebuia bahamensis*
Black torch	*Erithalis fruticosa*
Box briar	*Randia aculeata*
Cinnecord	*Acacia choriophylla*
Gum elemi (gumbo limbo)	*Bursera simaruba*
Horse flesh (wild tamarind)	*Lysiloma bahamensis*
Love vine (woe vine)	*Cassytha filiformis*
Marsh pennywort	*Centella erecta*
Mastic bully	*Masticodendron foetidissimum*
Paradise tree	*Pluchea odorata*
Perennial marsh fleabane	*Simaruba glauca*
Pigeon berry	*Duranta repens*
Pigeon plum	*Coccoloba diversifolia*
Pond top (pond thatch, hat palmetto)	*Sabal palmetto*
Poison wood	*Metopium toxiferum*
Rough varronia (cocobey)	*Cordia bahamensis*
Sawgrass	*Cladium jamaicense*
Sea grape	*Coccoloba uvifera*
Silver top (silver thatch, bay top)	*Coccothrinax argentata*
Southern yellow-eyed grass	*Hypoxis juncea*
Thatch palm	*Thrinax microcarpa*
Yellow elder (buttercup)	*Turnera ulmifolia*
Other plants whose common name are not given	*Ascyrum linifolium* *Rhynchospora perplexa* *Tetrazygia bicolor*

SUMMARY

1. The north-east Bahamas are the natural habitat of the valuable tree crop species *Pinus caribaea* var. *bahamensis.*

2. About 407 000 acres of pine forest belong to the Crown (and therefore to the Bahamas Government – see Chapter 12).

3. Under various licence arrangements the forests have always been exploited rather than managed and have consistently been undervalued.

4. A major (LRD) survey of the forests was conducted in 1969. The Survey's development recommendations for Abaco include fire protection and are based on sustained yield.

Chapter 5 Groundwater*

INTRODUCTION

The Bahamas require an ever-increasing supply of water as the population increases and living standards rise. Where water is limited, improved methods of exploitation and use are needed.

In the Bahamas, potable supplies are derived from local rainfall. Limited quantities are stored in the ground in the form of thin and destructible bodies (lenses) of freshwater. Water from these sources has always been readily available but there is an ever-increasing demand. Because development must be attuned to resources and because groundwater is by far the cheapest source of freshwater, the LRD Survey's major effort has been to assess each island's groundwater potential. For example, water from the New Providence wellfields costs the Government about $1.50 per 1 000 gallons (1976 prices) whereas desalinated water costs in the order of $6.00. The cost of delivering Andros water to Nassau by barge is $5.00. Obviously groundwater is of great economic importance and must be protected from wastage, pollution and unfair exploitation.

PREVIOUS WORK

In recent years there has been extensive exploratory and supply well drilling throughout the Bahamas though little of this has been properly recorded or critically examined. A high proportion of the recorded early work was based on New Providence, for example, Riddel (1933), Stubbs and Langlois (1954), Ebasco Service Inc. (1964), Garret, Sikes and Walker (1966), and Philpott, Ross and Saarinen Inc. (1966).

Perhaps the most detailed technical report prior to those of the Bahamas Land Resource Survey was the one compiled by Klein, Hoy and Sherwood (1958) for the U.S.A.F. bases on Grand Bahama, Eleuthera, San Salvador, and Mayaguana. Other technical reports on the groundwater of various parts of the Bahamas include that of Guyton and Associates (1966), Howard Humphreys and Sons (1971), McWhorter (1975) and the many consultancy investigations required for large developments (Dean-Saarinen Associates Ltd (1970), Richard Green and Associates (1972), Tanner (1966), and Philpott, Ross and Saarinen (1969)).

Large numbers of government groundwater reports can be located in the Ministry of Works and Utilities files. Some were written before, some after the LRD Survey's studies (e.g. Garret, 1966, 1967; Street, 1968, 1969; and Cant 1974a, 1974b, 1975a, 1975b, 1975c, 1975d, 1975e, 1975f).

Because of poor monitoring and poor data collection, very little is known about the effects of long-term groundwater abstraction. What is more, the government does not require wellfield development reports once a development franchise has been awarded.

However, reports on the New Providence wellfields and notes on some of those in the Family Islands (previously known as the Out Islands) are now regularly produced by the Ministry of Works and allied staff.

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*See Glossary for a number of technical terms relating to water resources.

HISTORICAL AND MODERN USAGE OF WATER

The early importance of water is often reflected in named wells and the names of settlements, (e.g. Columbus Well and Slave Well, both on Long Island, Pirate Well on Mayaguana, and Spanish Wells on St. Georges Cay). Before western settlers arrived, wells dug by the Arawaks must have been situated in unconsolidated sediments as they did not possess the tools to cut through limestone. Settlers in the 18th and 19th century were able to dig wide-diameter wells in rock and many of those known may have been in use for more than 200 years.

Early settlements and great houses (many built on ridges) were not always located near freshwater supplies. Labour was cheap because of slavery and water would have been carried to them from nearby sources.

Good freshwater suitable for the supply of an expanding village has not always been a first priority in settlement location. Many of the early settlements took as their first priority either safe, easily defended harbours, good fishing or natural salinas where a living could be obtained from salt production. Moreover, the land grants given to the earliest settlers were never based on knowledge of an island's resources. More recently, development has come through tourism; Bimini, for example, has developed because of its excellent deep sea sport-fishing and despite its poor water supply.

In the family islands water is still largely obtained from shallow dug wells, some private, some dug by the community, some by the government. Often these have hand or electric pumps. In the south-east Bahamas, bucket abstraction is still the most common technique used (more than 70% of all wells in Long Island use buckets). Some users have a raised reservoir or a pressurized tank to give them domestic running water.

It is the government's aim to provide all major settlements with piped water from government operated wellfields, but the high cost of supplying small scattered settlements causes problems. In addition, where there is no adequate supply near a settlement expensive water mains may be required. In some areas water lenses may be small and scattered, necessitating the construction of a scatter of small wellfields. In the Governor's Harbour – Palmetto Point area of Eleuthera, for example, there will soon be eight separate wellfields altogether producing only 85 000 gallons per day. Water distribution from a central wellfield requires a good water lens and demands high capital costs, but such a system (as at the Bogue Wellfield in Eleuthera) simplifies the problem of maintenance and monitoring.

FRESHWATER LENSES*

The structure and behaviour of a freshwater lens is described in the following diagram, and in the following text.

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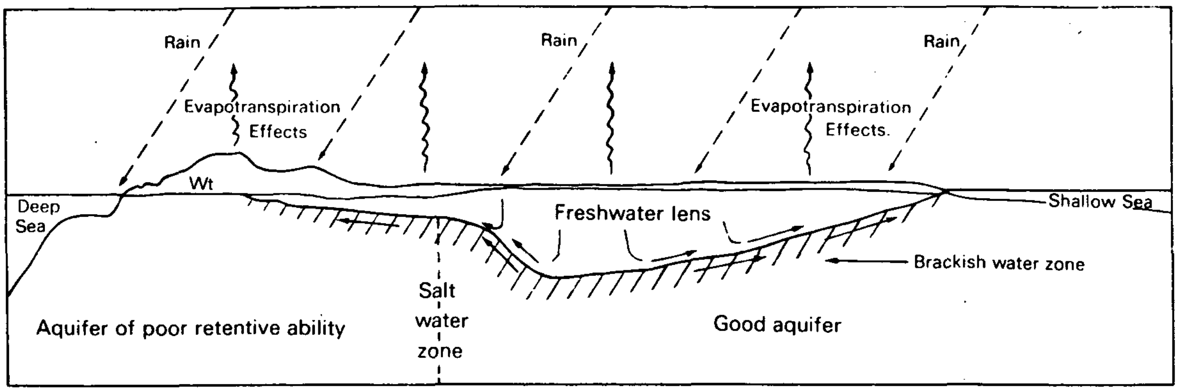
*Freshwater is defined as containing less than a specified proportion of chloride ions. (Salt (i.e. sodium chloride) occurs in water in an ionised state and the World Health Organisation (WHO) recognises 600 ppm of chloride as the maximum concentration in drinking water). In the Bahamas, groundwater contains from about 30 ppm chloride to 12 000 ppm chloride; rarely does it exceed or equal the salinity of seawater. The Survey indicates that a freshwater lens is made up of three layers, (a) the drinkable top layer of varying thickness usually ranging from 100 to 400 ppm chloride; (b) a transition zone, normally about 5 ft thick, in which chloride concentration increases downwards from 400 to 1 200 ppm, and (c) the saline layer through which salinity rapidly increases downwards from 1 200 ppm chloride to become very salty. Ideally, wells abstract water only from the drinkable top portion. If a well is overpumped, the thin transition zone expands and salinities in the top layer slowly increase beyond 500 ppm. Continued overpumping leads to intrusion of the saltwater portion of the lens and is indicated by salinities in excess of 1 200 ppm in the top layer.



Rainwater seeps down through porous rock during times of heavy or continuous rainfall. On reaching the watertable, it slowly spreads outwards toward the sea or, alternatively, downwards to mix with saline water. The top layer is derived from rainfall and is of course fresh. If it is big enough, it is known as a freshwater lens (technically a Ghyben-Herzberg lens) – because of its supposed lens-like shape. Freshwater is slightly lighter than seawater and will float on it within the pores of the rock. The rock impedes the movement and therefore the mixing of fresh and salt water. Freshwater moves outwards from the centre of a lens towards the sea and this flow carries away saltwater that might otherwise enter and spoil the lens. In these two ways the lens is preserved.

In reality the lens includes mixed (or brackish) water i.e. water of any salinity lower than that of the sea, and only the least saline top layer of this can be thought of as a resource of drinking water. Brackish water however is a potential input for desalination plants, and is less expensive and difficult to process than more salty water.

Not all of the rainfall will get to or remain in the lens; indeed, most is lost back to the atmosphere via processes collectively labelled evapotranspiration. In areas of the Bahamas where the rainfall averages about 50 inches per year, about one quarter of this amount enters the lens as recharge; in low-lying areas the proportion is even lower as the ground surface loses more by direct evaporation. Seasonal recharge and the growth of the freshwater lens is also dependent upon the nature of the rock, and the size of the island. Locally, lenses achieve a balanced state and remain in this state until either the volume of recharge changes, abstraction begins, or the effects of evapotranspiration are increased.

CHANGES IN WATERTABLE

Measurable changes in watertable occur as a result of tidal action, rainfall, abstraction, changes in barometric pressure, evapotranspiration, and groundwater discharge at the coast. Perhaps the most obvious and interesting of the changes is the first and occurs as a result of tidal action.

Tidal action

These changes faithfully reflect the oceanic tides, i.e. with two highs and two lows per day. If the size and timing of the tidal fluctuations in different boreholes are compared with those in the sea, the following facts emerge:

1. Size and timing of the tidal response is affected by rock permeability
2. Both size and timing are strongly influenced by borehole depth
3. The response is dependent on the proximity of deep sea

Tidal effects advance from deep water through the rock, as a pressure wave, the amplitude of which is increased where the hydraulic connection between the watertable and deeper, more permeable, zones is best. The measured time lags, and the tidal amplitude in the sea and in boreholes can be used to determine the coefficient of transmissibility* and the coefficient of storage within the limestone aquifer. The rate of outward flow of groundwater can also be calculated.

Rainfall

The rainfall-induced water level changes can be short-term phenomena caused by sudden recharge, or, longer-period seasonal rises and falls (Figure 1); both have been recorded. They relate to the volume of recharge, the depth below ground of the watertable, and the effective porosity of the aquifer. During periods of no rainfall the watertable is slowly lowered as a result of evapotranspiration and discharge at the periphery of the lens.

Abstraction

Pumping lowers the watertable in a borehole almost immediately and the relationship between drawdown (the lowering of the watertable) and the pumping rate, (a value known as specific capacity), provides another means of estimating transmissibility. Figures obtained by pump testing in this way are considered more realistic than those derived by analysis of tidal fluctuations. Long-term abstraction, as practised in production wellfields, must, in theory, permanently lower local watertables as pumping is the equivalent of reducing recharge. Inadequate monitoring has been a characteristic of wellfields and in consequence no such change in watertable level has yet been documented in the Bahamas.

Barometric pressure

Changes in borehole water levels induced by barometric pressure variation probably result from partial confinement of the aquifer – this in turn is caused by variations in permeability in successive beds of rock. This effect has been described from observations by the LRD Survey.

Evapotranspiration and groundwater discharge at the coast

Evapotranspiration and coastal discharge of lens water cause less obvious variations in water level. Though these effects can be identified during dry periods, neither can be isolated.

SURFACE EXPOSURES

Inland water bodies are, in most instances, exposures of groundwater i.e. places where the watertable is at about the same level as the land surface. Seasonal and short-lived ponds that appear after heavy rainfall may have nothing to do with the watertable; they are typically shallow and fresh and do not respond to the tide. They occur where the surface rock is impervious enough to retard infiltration; their standing period may range from a few hours to the full length of the wet season.

Exposures of groundwater include marsh areas, prior creeks (ancient relics of a previous landscape which are no longer functional), blueholes, salt ponds, lagoons, and man-made excavations. There are no true rivers or streams because of the high permeability of the limestone surface and the general flatness (or low relief) of the land. Some tidal creeks, especially in Andros, look like river systems and carry surplus freshwater off the land but are affected by two-way tidal flow.

Surface water is discussed in some detail in Volumes 1-8 of the Draft Land Resource Study (Little *et al.*, 1971-78); the two most unusual types, blueholes and salt ponds, are described here.

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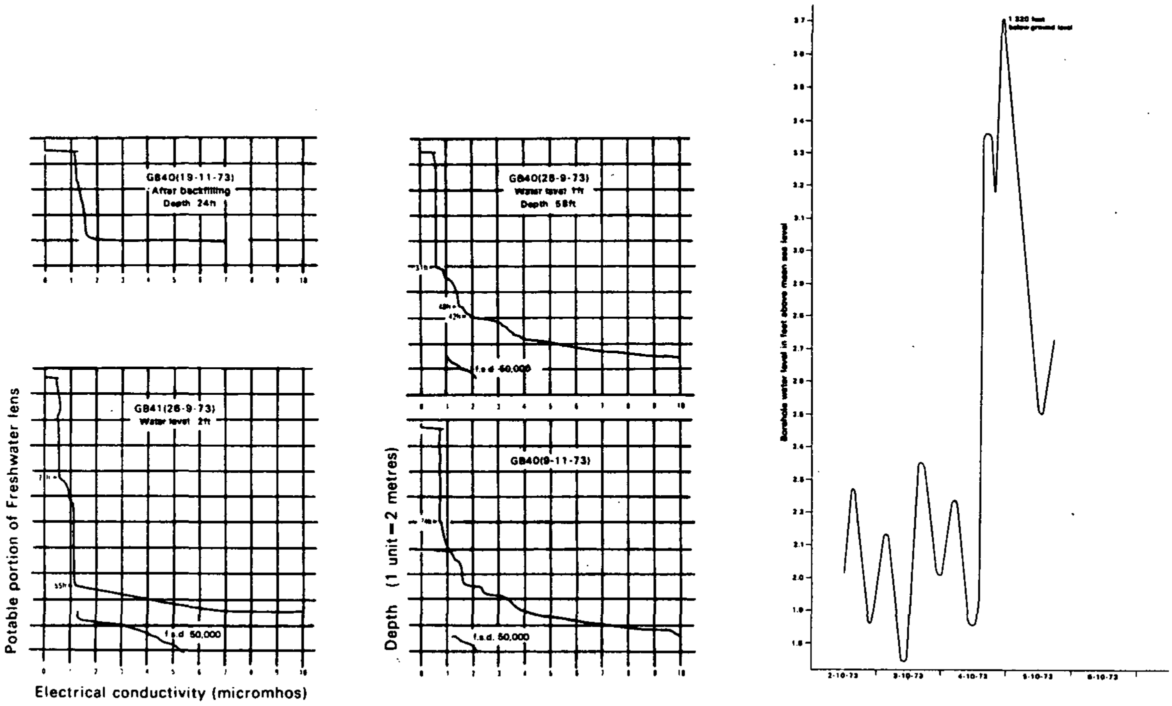
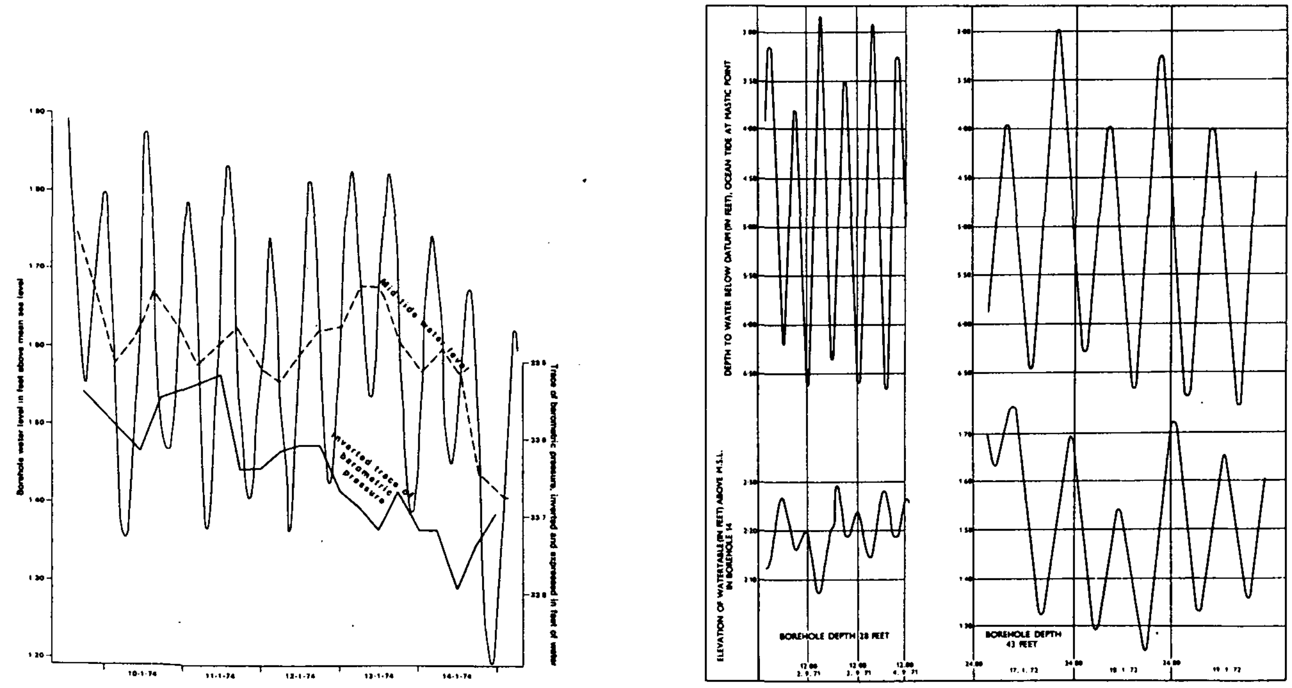
*See glossary.

FIGURE 1



A Examples of two conductivity logs made in hole GB40 before and after backfilling

B Example of rainfall recharging the aquifer (GB39)



C Example of the relationship between borehole water level and barometric pressure (GB65)

D Example of water level fluctuation in hole AN14, related to the ocean tide at two different depths of penetration of the borehole

FIGURE 1 Typical results obtained in the groundwater exploration

Blueholes

Blueholes occur throughout the Bahama Banks and are particularly common in and around Andros where many are strikingly beautiful (Plate 7). Their interest to man is evident in that they are commonly mentioned in scientific and non-scientific literature (including tourist guides). Blueholes owe their existence to subaerial solution of limestone during periods of low sealevel (the Ice Ages). Depths range from about 20 ft to more than 350 ft; many are nearly circular with vertical or overhanging sides and may contain stalactites and other features associated with caves. Most blueholes today are flooded more or less to the brim, some just offshore occur in environments of heavy and continual sedimentation, and that they are still open despite an estimated 5 000 years of infilling can probably be cited as further evidence of their size. One coastal bluehole north of Clarence Town, Long Island, may open to the sea as a cave deep under water. Any connection those on land have to massive underground cavern systems is indicated by larger tidal fluctuations and smaller timelags in the bluehole than occur in the surrounding areas.

On larger islands – those with well developed lenses – blueholes may contain freshwater. Depth sampling in some has indicated that a freshwater/saltwater boundary occurs at the same level as in the surrounding land. Exaggerated tidal response and heightened surface evaporation in blueholes result in greater mixing between fresh and salt water than occurs at the boundary within a rock aquifer, and as a result blueholes may be slightly saltier than surrounding groundwater. In inaccessible parts of Andros drilling costs were saved by bluehole sampling performed direct from a helicopter equipped with floats.

Salt Ponds

In the Bahamas, evaporation exceeds precipitation during the course of a year and a standing body of slightly saline water may become hypersaline or completely dry up in the dry season. Salt ponds are uncommon on the pine islands due to a more widespread presence of fresh groundwater, and to the higher annual rainfall. There are, in addition, relatively fewer closed lagoon sites adjacent to the coast in which salt ponds can develop.

Toward the south-east of the archipelago, the likelihood increases that ponds will dry out completely in each season to leave a salty crust and in the semi-arid conditions of Inagua there are salt flats (the 'sebkha' of geological literature).

Hypersaline ponds vary in colour and may be green, yellow, brown, red or purple depending upon the algal and pigmented bacterial content. At a certain salinity algal growth is favoured but if evaporation continues the salinity increases and it may eventually reach a point that is unfavourable to algal growth. At this point bacteria begin to feed on the dead algae and a pond will start to smell. At this stage the pond becomes strongly coloured because of the pigmented bacteria, solar absorption is further increased, and evaporation is also increased. Eventually a level may be reached where gypsum and salt are precipitated.

This process, variously assisted by man, has been used as the basis of the solar salt industry for many years. Historical examples of the salt industry can be seen at Clarence Town, Long Island; William Town, Exuma; and even as far north as Rose Island just off the north-east coast of New Providence.

Floors of hypersaline ponds described above are commonly sealed by a 1-4 inch thick impervious layer of algae. Tidal fluctuations may be totally dampened by this mat, in which case changes in waterlevel are related to evaporation and precipitation. In consequence there is no reason why a normal freshwater hypersaline lens should not exist below the sealed floor of a pond: the lens being recharged with freshwater from outside the limits of the pond. In fact, just such a situation was discovered at Ridge Pond, 2 miles south-east of Steventon Exuma.

PLATE 7 A circular bluehole 450 ft wide and 125 ft deep within a marsh area of Andros. Note the logging tracks in the background and pine trees on slightly higher land within the marsh.

PLATE 8 A section of coastal terrace composed of cemented coral rubble, Mayaguana. The study of groundwater includes a geological investigation of such water-bearing rocks.

GEOLOGICAL CONTROLS

Introduction

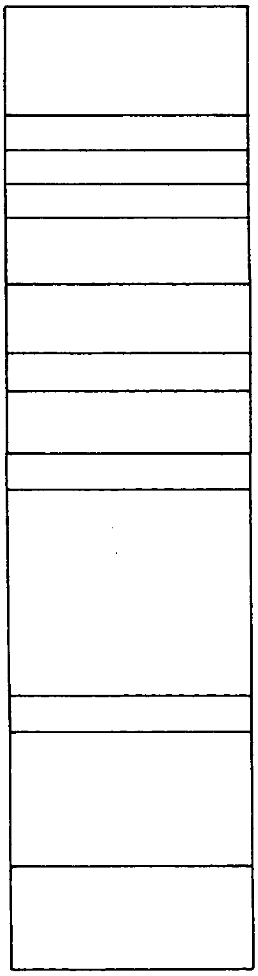
Bahamian freshwater lenses occur in Pleistocene and Holocene limestones and limesands where porosities and permeabilities vary upwards and downwards in the rock and, to a lesser extent, from place to place, as a result of different ancient depositional conditions.

As explained in Chapters 6 and 8, the surface geology consists of large, relatively flat areas of marine deposited sediments. Superimposed on these are patterns of ridges representing ancient shoreline and beach deposits and hillier wind-formed dune ridges. Among the flat lying, mostly marine sedimentary sequences there occur sediments of ancient marsh origin with a characteristic range of lithologies.

The marine deposits which originate in shallow water are probably the most widespread and form the main aquifer. Cores taken from these deposits show that there are four major layers (units) of rock in the uppermost 100 ft and these are separated by three, well-developed and widespread ancient soil zones (Figure 2). Each of the rock beds has characteristic cementation and cavern/fissure development, and these peculiarities together with the 'distorting' effect of the various soil zones are responsible for vertical variations in permeability which in their turn have a strong overall influence on water-holding and transmitting properties of the aquifer (Plate 8).

The individual units differ as a result of the processes by which the loose initial deposits are converted into rock. Younger beds are less affected than older ones by these processes which together are called diagenesis.

Figure 2 Generalised geological section through Bahamas Bank marine sequence



Nomenclature where given	Position relative to sea level (ft)	Description
	+ 10	Flat rock surface (+3 to + 15 ft)
	+ 5	Aerated marine limestone (vadose zone)
	– 0	Watertable
MARINE UNIT 4	– 5	Saturated marine limestone (phreatic zone)
Soil Layer 5	– 10	Palaeosols & crusts
	– 15	Marine limestone (aragonite present)
Soil Layer 4	– 20	
	– 25	Palaeosols & crusts sometimes cavernous
MARINE UNIT 3	– 30	Marine limestone (little aragonite)
	– 35	
Soil Layer 3	– 40	Palaeosols & crusts often cavernous
	– 45	Marine limestone (no aragonite)
	– 50	
Soil Layer 2	– 55	Palaeosols & crusts
MARINE UNIT 2	– 60	
	– 65	
	– 70	Marine limestone (no aragonite)
	– 75	
	– 80	
	– 85	Palaeosols & crusts
Soil Layer 1	– 90	
	– 95	
MARINE UNIT 1	– 100	Marine limestone (no aragonite)
	– 105	
	– 110	
		Large caverns

Aquifer types

The following important aquifer types (in some cases specific to a certain depth) can be identified in the geological sequence of the Bahamas.

Uncemented loose sands

These are the sands (mostly Holocene in age) described from many coastal areas. Uncemented sands, particularly fine-grained ones, are highly porous but because the pores are very small, surface tension is high and this allows little groundwater movement. Despite their relative impermeability they can, because of their water-retaining ability, store freshwater even in close proximity to the sea. Most limestones in a similar situation would, because of their greater permeability, retain their freshwater less well. Consequently, fresh groundwater on a small cay is more likely to be found in sandy areas than among rocks. The sands east of Governor's Harbour, Eleuthera, exemplify the value of fine-grained sands as an aquifer – even though their low permeability causes abstraction problems and wide dug wells replace boreholes, whose low yield would rapidly cause them to be pumped dry.

Marine deposits 15 ft above to 20 ft below mean sea level (m.s.l.) – Marine Unit 4

This rock unit exhibits a wide range of cementation – cementation being the first important diagenetic step in the change from loose sand to fully altered rock. Initially, cementation reduces porosity by filling vacant space between grains. However, water movement continues through holes etched out by water penetrating into depositional burrow structures, roots, casts and bedding planes (primary structures within the rock described in more detail in Chapter 8). Further cementation of the mass is accompanied by increased flows through so called 'secondary porosity' which in Unit 4 comprise a connected system of 1/3- 3/4 inch wide fissures and holes etched out by solution of the rock. The denser and more resistant the mass of rock becomes to groundwater movement, the more these channels develop. Channels which conduct a high proportion of the water moving through the rock are often lined with a red-stained coating of calcite. Channels not actively involved in water movement soon become infilled with coarse granular calcite crystals – calcite being one of the pure crystalline forms taken by limestone.

At approximately 8-10 ft b.m.s.l. in Unit 4, there is a moderately widespread zone of ancient soils and crusts of harder-rock. This zone may be hydrologically important, especially as it occurs at what is commonly the base of many supply wells.

In practice, Unit 4 is usually the only portion of the aquifer from which water is directly abstracted. It has a higher porosity though a lower permeability (connected porosity) than the underlying rocks – this has now been demonstrated by a gamma-ray assessment of the Survey's core specimens by the University of Miami. With notable exceptions, most of the cores have a constant porosity of 40-50% in the uppermost 20 ft – figures which are important in evaluating the total volume of freshwater in any area.

The deeper rock units – Marine Units 3, 2 and 1

Early on in diagenesis, i.e. in the stage-by-stage change of limesand into limestone, the solution of some fossils in the rock (fossils comprising aragonite, a mineral chemically the same as calcite but different in crystal structure) increases the porosity in the older units. However, the limey material taken into solution is soon re-precipitated in another form (calcite) making the local rock 8% less porous overall. This mineral conversion is responsible for the development of dense recrystalline limestone such as described in many of the cores. Additional cementing calcite is provided by limited dissolution of Unit 4 which overlies the other units. In Unit 3 aragonite may still be present: however aragonite is less stable than calcite and none has been observed in the older Units 2 and 1. Complete recrystallization, as evidenced in Units 1 and 2, involves calcite being uniformly dispersed through all primary and secondary pore spaces. Core samples from Units 2 and 1 are dense and appear impermeable; nevertheless within this dense limestone, water movement is made possible – actually improved – by the development of cavern systems formed by further enlargement of a proportion of the early-formed solution channels. In sum, the greater degree of rock alteration results in a decrease in the number of active solution channels, though the few which remain grow very large. It is also accompanied by a decrease in overall porosity.

Unit 3 extends from about 25-40 ft b.m.s.l. and is, in many islands, occupied by freshwater. Cementation is usually variable and aragonite common. Very rarely is water abstracted from this part of the aquifer.

Units 2 (40-85 ft below m.s.l.) and Unit 1 (90-110 ft below m.s.l.) are heavily recrystallised. In several of the larger islands with thicker lenses (Andros, Abaco, Grand Bahama, Eleuthera and Cat Island) they contain freshwater.

Ancient soils and crusts in the subsurface

Sandwiched between the Units 1 to 4 are a number of buried earlier land surfaces that include ancient soils, and cavernous zones. These important layers are often very permeable and as they were once continuous surfaces they extend over wide areas (see Figure 2). The hard caprock/crust layers indicative of surface rock alteration and found on buried land surfaces play an equally important part in the behaviour of groundwater. Few Bahamian rocks are capable of forming a dense barrier to water (an aquiclude) and the buried caprock surfaces are the nearest approach to such a layer. Under certain conditions caprock can create partly confined conditions and separate water of different qualities; for example, a relatively impervious crust and soil layer is reported at the freshwater-saltwater boundary (interface) in many parts of New Providence (Garret *et al.*, 1966). Impervious layers and layers of high permeability distort the shape of the lens; consequently, lenses in the Bahamas deviate from the form which might be predicted for a truly homogenous aquifer. Plate 8 shows rocks wide-spread in the southern islands which are associated with excessive permeability.

Dune rocks or 'aeolianites'

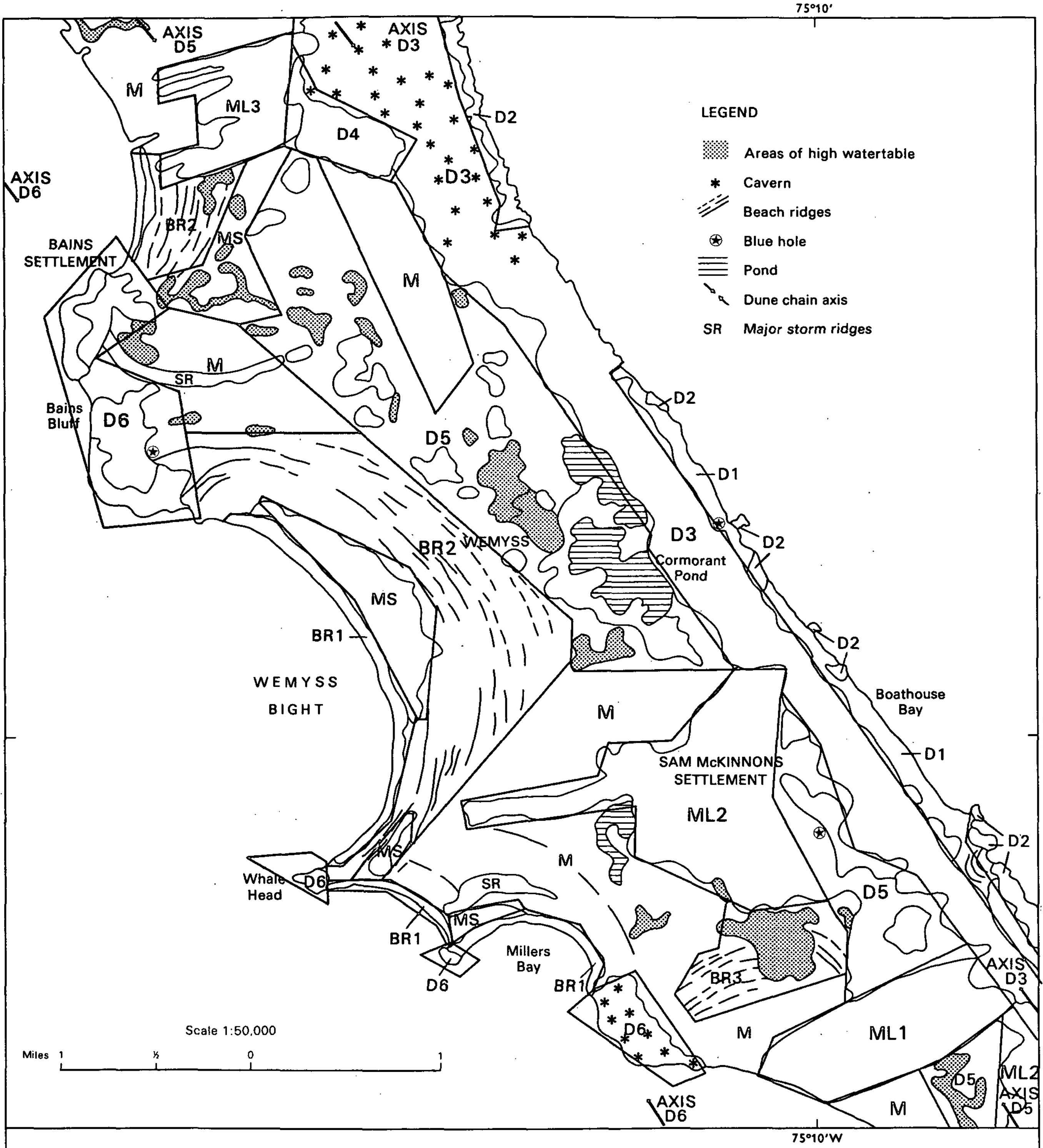
Ancient dune systems of Unit 1 age and characteristics may still be present in the landscape – buried, but partly protruding as hills above later marine deposits (see Text Map 1). These old, much altered, rocks may thus be exposed at the surface (as D4 and D5, Text Map 1) or at the underground level at which freshwater lenses would develop. They are capable of preventing lens development by causing rapid mixing of fresh and saline water. Their high permeabilities encourage rapid flushing away of any recharge.

Younger, less altered dunes (e.g. D2, Text Map 1) would be capable of maintaining a lens in most situations except for the fact that they are often above the level of the watertable. Marine beds underlying them may be occupied by freshwater.

METHODS USED IN THE SURVEY, RESULTS OBTAINED AND RECOMMENDATIONS

Methods are given in the Appendix and results are in Confidential Annex 2 and Confidential Maps 2a-b. General recommendations concerning groundwater are given in Chapter 16.

TEXT MAP 1



The complex outlines in black show the shape of individual landforms identified by airphoto interpretation and checked in the field. The overprinted red lines generalise and simplify this original information to show how each area of land and its landforms originated

Areas D1-D6 are landforms of dune origin; all but D1 (the youngest) are now rock. Whether D6 or D5 is the oldest has not been ascertained. Areas BR1-BR3 are landforms of beach ridge origin; again, all but BR1 (the youngest) are now rock. The BR3 ridges are hardly visible on the ground and can best be appreciated on airphotos. Areas ML1-ML3 are ancient marine lobes originally deposited as sand from currents streaming across the area from the open Atlantic to the east; all are now rock. Geological principles suggest that ML1 is the youngest and ML3 the oldest. Other areas of the map include prior marshes (MS) and prior marine (sea bed) areas (M). An old creek within MS now forms a modern high watertable 'wetline'

Landform origins illustrated from the Wemyss Bight area, Long Island

Summary

1. Water reserves in the Bahamas are contained within the limestone rock where they take the form of freshwater lenses.
2. There is no cheaper source of freshwater in the Bahamas than groundwater: it is four times cheaper than desalinated water.
3. Only in very recent years have attempts been made to evaluate water resources and its exploitation scientifically.
4. Settlements sited for reasons other than an abundance of freshwater may have outgrown their supplies.
5. It is the Government's intention to provide piped water to all settlements – this will commonly involve high capital costs.
6. A freshwater lens comprises fresh, brackish and saline layers; it is fed by rainfall and loses stored water to the sea and to the underlying saltwater on which it floats.
7. Its level changes in response to natural and man-made conditions.
8. Blueholes, ancient caverns now full of water, are of great interest; some contain freshwater.
9. Hypersaline ponds which occur naturally are also used for the production of salt. Some may be underlain by freshwater.

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10. Surface geological deposits in the Bahamas indicate several depositional environments.
11. Below the surface four distinct rock units of increasing age can be distinguished in the Survey's drill cores.
12. Progressive alteration of sand to rock is accompanied by changes in the rock's porosity and permeability.
13. Buried land surfaces, their ancient soils and caverns between the four rock units exert a profound influence on groundwater behaviour.
14. Buried topography of highly altered and less altered dune rocks also exerts a major control on groundwater behaviour.

Chapter 6 Rocks and landforms

INTRODUCTION

Resource surveys typically study landforms with the use of overlapping airphotos to give a stereoscopic view of the land. Airphoto interpretation (AP1) reveals the arrangement of dunes, beach ridges, marshes and plains, any of which can be outlined on the photographs and later transferred to maps in the first stage of landform analysis. API yields a mass of supporting evidence from land use, vegetation, and human occupancy which complements the landform analysis and contributes to a survey's understanding of land.

ROCKS

Many features of the land surface are controlled by the rock base (Young, 1972). It proves very valuable to establish the limestone type (or limestone lithofacies) (see Glossary) at each ground site, and thereby to label landforms and other identifiable areas of land. Limestone identification has been used in Cat Island dune landscapes, and has proved extremely useful in labelling different ground types on the plains of Andros (Young, 1974 and Chapter 8) and other pine islands. It has provided the basis for distinguishing different land types which have no major relief — land which in soil covered landscapes would be differentiated on the basis of soil profile. A knowledge of the variability of limestone types within different landscapes is a valuable aid to mapping land for agriculture or general development purposes. Pages 71—91 of Volume 3 (Cat Island) of the *Draft Land Resource Study* illustrate the kind of results that can be obtained from the landform analysis, rock determination and supporting fieldwork described here. Table 8 and Text Map 2 of the present report illustrate the results gained on rock plains.

Volume 3 contains the most definitive section on landforms and geology of any of the draft volumes; explanatory text is to be found on pp. 63—69 while each Cat Island land facet (typical land type) is given a detailed description on pp. 71—91. Beach ridges and dune landforms are considered in detail as the main relief formation; ridges and elevated land originated in a marine environment are discussed on p. 66 (the Bennett's Harbour marine lobe) and elsewhere, on pp. 24 and 31 in Volume 6, and on p. 61 in Volume 1. Further discussion on the origin of beach ridges is found on pp. 61—62 of Volume 1 and of dune ridges on pp. 53—55 of the same volume.

Flat land areas of the coppice islands, their characteristics and origin, are discussed on pp. 67-68 of the Cat Island report (Volume 3). Information collected in islands further south-east suggests that lagoonal sediment with a high proportion of coralline algae and *in situ* corals occurs more frequently in the south-east and notably in eastern Mayaguana (Volume 8, pp. 32—33) and Inagua (Volume 8, p. 43). Saltwater drawn to the surface in the arid south-eastern islands (Volume 8, p. 33) probably contributes to a great deal of surface hardening of these sediments. Analogous conditions of deposition and late stage hardening may be responsible for the dense and very level rock plains seen, for example, in the south of Abaco (for several miles north from Hole in the Wall); in south Eleuthera (around Millars, for example); in south Long Island (from Hard Bargain to Mortimers, Volume 6, p. 35) and the hard rock plain south-east of Pompey Bay, Acklins.

Level areas with superficial hardening (i.e. caprock) are discussed at p. 66-68 in Volume 2. Caprock is a dense crystalline, often laminated layer, which commonly overlies much less hard rock and has a number of different origins, each involving the digestion of surface rock layers by organisms (particularly algae) humus-charged solutions, etc. Though dissimilar in origin, cappings associated with caliche (Plates 28, 29 and pp. 47-48, Volume 6) may present problems for land preparation, similar to those encountered in land with caprock.

Level areas which include tillage class rockland (soily rock plains of Andros, Abaco and Grand Bahama) are more completely discussed elsewhere (Young, 1974): see also Tables 7 and 8 of the present report. Photographs illustrating a number of tillage and non-tillage pine rockland types are given in Volume 4, Andros, and in Plates 15 and 16 in Chapter 8 of the present report. Figure 3 in Chapter 8 illustrates the 14 characteristic generalised ground surface types found on the BARTAD farm.

A relatively comprehensive series of wetland types is mapped in the Cat Island volume (Separate Map 4, Land capability) at 1:25 000 scale. Considerable attention to the external appearance of extensive marsh areas in Andros (Plate 9) is reflected in the Andros land system descriptions, nine of which refer to marshes. Areas of surface water are described in the groundwater section of each island.

LANDFORM ORIGINS

In the Bahamas it is almost impossible to discuss landforms without reference to sediment and sedimentary origin. Most Bahamian landforms are 'constructional', i.e. more obviously the result of the heaping together of sediments than of sculpturing by destructive erosion. This applies equally to flat land constructed of deposited sands or muds which later harden to rock, as to hills obviously of dune and beach ridge origin. Moreover the Bahamas is a land without rivers, isolated from continental sources of rock and terrigenous waste (clays, mineral sands, etc.) Bahamian limesand and mud is a newly created material precipitated from seawater (only rarely is it a product of erosion). Lime sediment is formed (secreted) by corals, shells and coralline algae in their growth and disintegration; it is produced by a number of organisms which during their lifetime give rise to lime mud, or process it into larger grains; and also from cold Atlantic water: in its tidal flow onto the shallow, warm Bahamas banks, it drops its dissolved lime, thus contributing by precipitation to the growth of oolitic sand grains.

A great proportion of this newly created sediment simply accumulates where it was formed, i.e. it contributes to a deposit. Close to the shore this applies particularly to sediments produced in quiet water. Some newly formed sediment is transported – most typically it moves onshore to a beach. Once above wave reach it becomes a deposit of the littoral or shore zone, a beach ridge whose existence, however, is only guaranteed if, before hardening, it is neither blown inland by the wind nor reattacked by waves. If it is blown by the wind it may move a short distance inland or merely contribute locally to ridges of windblown sand; either way it may later become more or less fixed by vegetation (Plate 10). Dunes up to 75 ft high built up in this way occur along the eastern shore of Eleuthera, for example.

Once deposited on land, sands begin a complex change from loose sediment to cemented, compact and even hard rock (see for example dune types D1-5, Text Map 1). This is brought about by rainfall and by freshwater held between the sand grains. Coralgal sands, i.e. sands composed of grains of coral and algae, go through a more complex process of cementation and hardening as described in a paper based on a study of Bermudan limestones (Land, 1967). The sequence described by Land distinguishes coralgal rocks from oolitic ones whose lithification history is usually simpler.

The chances of either dune or beach ridge surviving is increased in conditions of falling sea level. In times of rising sea level, they are slight. Sea level change, well-established as a scientific fact, is evidence in the Bahamas; by the depth of blueholes (see Chapter 5): and by the terraced nature of the underwater platform surrounding some islands (recorded, for example, in the landform map of Inagua accompanying Volume 8).

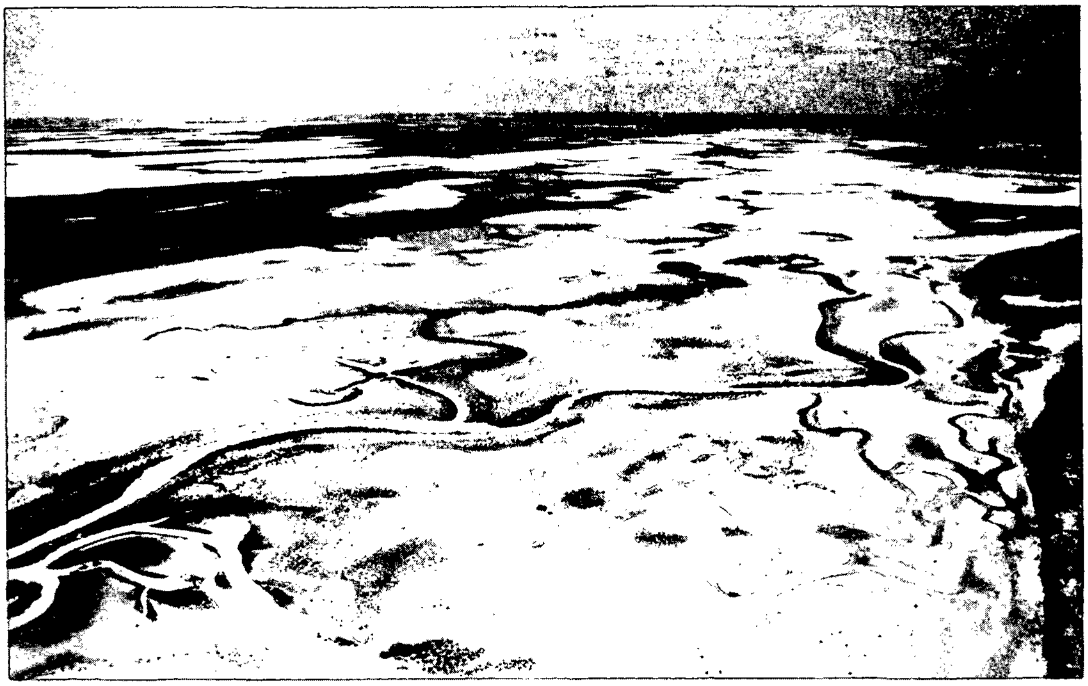


PLATE 9 Marshes near a creek called Wide Opening in western North Andros. Such areas also provide a model for the mapping of lithofacies types in areas which, though of similar origin, are now dry and covered with pine forest.

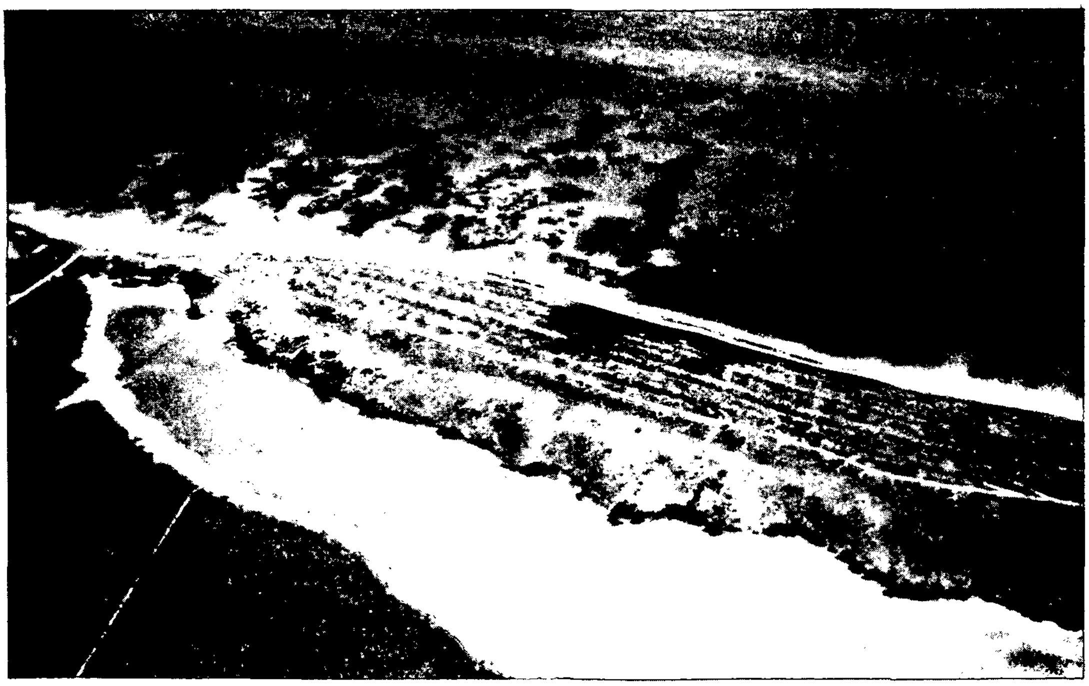


PLATE 10 Beach ridges near the sea and a low dune (adjacent to the pond) form the Greenwood Barrier in south east Cat Island. A maze of small reef knolls lies offshore.

Blueholes and terraced underwater platforms evidence lower sea levels. Higher sea levels are evidenced by fossil coral reefs located on dryland in Mayaguana (Volume 8, Plate 24) and elsewhere, and by the whole range of ancient seabed surfaces now exposed in flatland throughout the Bahamas (displayed and best documented at the BARTAD farm, North Andros, (Young, 1974)).

In conditions of falling sea level the seabed deposits of sand and mud become exposed. After emergence, loose marine and marsh sediment will become fixed by colonising plants, and in places worked over by foraging animals and the wind, before it is finally cemented into rock. Alternatively, as probably occurred in east Central Abaco, it may be heaped up into a series of dune chains by drying winds. Before emerging high and dry, a marine sedimentary environment may become a marsh and acquire its characteristic features, aquatic vegetation and sediment type.

The above is a very brief outline of Bahamian littoral, dune, marine and marsh origin landforms. All begin as sand or mud, some are transported, some washed away; those that remain become cemented and much altered, and all are later attacked to some extent by erosion. An actual example of a typical arrangement of these diverse landform types is given in Text Map 1.

LANDFORM PATTERNS

Landforms in each island are a composite of dunes, beach ridges, marshes and plains (covered in late Pleistocene sediments or bare). Some are in the process of forming at the present day (i.e. they are active forms) and some are the landforms of previous periods of dune building, beach ridge formation or erosion. Steep remnants of hard dunerock on the western side of an island (as for example in Eleuthera and Long Island) are relics of dune building which occurred as long ago as two million years, while toward the sand dunes which commonly occur on the east coast, dunerock hills become progressively more youthful (Plates 11 and 12). An example of such remnants are the isolated hills, strung out in a line between Bains Bluff, Whale Head and Millers Bay (Text Map 1). These are of highly altered coralgal dunerock and probably once formed a continuous dune ridge (Volume 6, p. 32), which was later reduced to a few remnants by erosion, and partly buried under modern sediments (p.42). Such sequences have also been described from Bermuda by Land and others (1967).

Three or four periods of formation are also evidenced (see Text Map 1) by beach ridges. Recognisable beach ridges range from the clearly defined recent sandy forms at the coast, through older rock ridges further inland, to ancient ridges which in some places are so faint as to be discernible only on airphotos, though not from ground observation; the area of Hawks Nest Point and the adjacent tract called Belomel in south Cat Island also provides a good example.

Different marine levels, corresponding to the periods of dune and beach ridge formation, have been investigated in surface rocks and in the subsurface. Episodes of marine deposition and later exposure at the surface (emergence), recorded in the subsurface are illustrated in Volume 8, Figure 3. Different ages of flatland are less apparent in the landscape, unless the flatland has distinctive form (Volume 6, p. 21).

Flat areas demarcated by erosion phenomena and with no obvious veneer of later deposited sediments can sometimes be identified by reconstructing their ancient geographical environment. This may demonstrate that during a period generally characterised by deposition, sediment was excluded from the area – perhaps by physical barriers (dunes, etc.) or by distance from the source of sediment. Land Type 4 in Text Map 2 of Volume 8(Inagua) is of the latter type. Different landforms, which once formed a mutually dependent pattern in the prior environment, are clearly recorded in the present day topography, and their interrelationships are understood through API. In many areas a complete 'prior landscape' of dunes, beach ridges, marshes, channels and the like can be recreated in the landform analysis, (Text Maps 1 and 2).

PLATE 11 Panoramic view near Salt Pond, Long Island. The sloping block-strewn dune rock surface in the foreground will continue to be cultivated for a short period in a pattern of shifting agriculture and then abandoned. In the background a hypersaline pond, a sandy ridge and the sea.

PLATE 12 The north part of saline Cormorant Pond seen from Wemyss Bight Old Estate House, Long Island (the hills are those labelled D5 in Text Map 1). Note tidal notching by the pond water and the poorly developed nature of the vegetation on the hard (old) rock surface.

Similarly, later periods of landform growth have a precise complementary relationship (governed largely by hydraulic laws that control wind and water sediment transport) with older landscapes to which they form successive additions. The following examples, (all but (a) are shown in Text Map 1) illustrate this: (a) advancing fronts of later dunes will plug the lowest point in an earlier dune chain; (b) bays between headlands become sealed by beach ridges, commonly enclosing small level areas of salinised rockland; (c) marine lobes – boat or flame-shaped plumes of sand (Volume 6, p. 21) force through narrow gaps between cays and bury earlier seabed areas; later on emergence, they become fixed as rock; (d) marine flats protected by the growth of some form of natural barrier from winds and waves develop the channels, geology and sedimentary aspects of a tidal marsh.

Constructional landforms such as are described in the four examples above, are dominant, despite the fact that the whole land surface is continually subject to erosion and downwasting (p. 7 of this report).

Blueholes, representing erosion in a vertical sense (Volume 4, Plates Ia, Ib and IIb), cliffs (Volume 3, Plate E1/1), and undercut and dwindling rocky shores – erosion in a lateral sense (Volume 6, Plate 11) are the more obvious landforms associated with erosion. Evidence of the slow, progressive wasting of the limestone surface is apparent in soils, fissures, surface irregularities of the rock and block-strewn land surfaces. Below the surface, groundwater saps away at the initially solid fabric of the rock.

SUMMARY

1. Airphotos are used to identify areas of land which have similar characteristics and origins. The method is most successful in hilly islands e.g. Cat Island.
2. Upstanding landforms (dunes, beach ridges and hilly marine-origin forms) are dominant even though the whole land surface is continually subject to erosion and downwasting.
3. Different types of land within flat areas of the pine islands (plains landforms) can not be differentiated on airphotos and can only be studied on the ground (see Chapter 8).
4. Landforms (hills and plains) are merely deposits of carbonate sediment, variously cemented and hardened. Hence landforms and sediments are best studied together.
5. All sediments have been produced on the spot from precipitated, previously dissolved, lime; they are not the product of erosion in adjacent land areas.
6. The preservation of a wide variety of dune, beach ridge, marsh and marine deposited landforms depends to some extent on geologically recent sea level changes.
7. Prior (i.e. ancient) landscapes can be reconstructed to show an island's growth.

Chapter 7 Soils

INTRODUCTION

A soil can be defined as a rooting medium for plants; it can also be thought of as a residue from the physical or chemical breakdown of rocks, alternatively the material which results from the physical and chemical 'ripening' of uncemented sediments. Some soils are simply accumulations of leafmould and humus. Soils may or may not have distinct layers.

The report of the Cornell University Expedition (Mooney, 1905) contains the classic study of Bahamian soils. A later advisory report (Innes, 1946) described four of the principal soils, discussed their chemical deficiencies and their fertiliser requirements and at the same time touched on the mechanical preparation of rockland and advised on soil conservation practices. Between 1946 and 1969 there were a number of successful attempts to farm various types of soil and rockland but no descriptive studies emerged. The LRD Survey therefore took the 1905 and 1946 studies as its starting point, and produced more precise soil descriptions and soil maps of Eleuthera, Cat Island and parts of Exuma. Soils described in Volumes 1-5 of the *Draft Land Resource Study* were summarised in Volume 6 and certain previously undescribed soils were added to this account. Volume 6 also recorded the most comprehensive account of soil formation and emphasises that Bahamian soils, though in many cases productive, are poor by world standards.

In limestone terrain such as occurs in the Bahamas, soil is scarce because limestone, instead of decomposing as many rocks do into a loose mixture of stone, sand, silt and clay, variously rich in nutrient minerals, simply dissolves away to expose fresher limestone below. Bahamian limestone is so pure (99.5% is often quoted) that only a small amount of insoluble impurity is left in its stead. This, if not washed off downslope by the rain or blown away by the wind, accumulates and, over thousands of years, contributes to a thin residual soil cover. There are, however, good reasons for considering that more impurities may be released than the characteristic '99.5% soluble carbonate analysis' suggests. Possible sources of potential residues are volcanic ash additions, chlorite (a mineral formed directly out of seawater), minor minerals and elements built into corals, algae and sponges, and iron compounds and other impurities caught up in limestones which form in foetid mangrove environments.

Studies of soil and the rock with which it is associated also suggest that different soils (e.g. red, brown, black, etc) are related to subtly different limestone materials. For example, oolitic white limestone is consistently overlain by thin, poorly developed leafmould soils; red (aluminous lateritic) soils are consistently found on the older coralgal limestones (i.e. limestones made up of grains of coral, coralline algae and shells originally derived from the coral reef shore). A variety of interesting correlations have been noted between soil and sediment/rock composition and between soil and rock age. In just the same way there are definite relationships between lithofacies and land type. The reader is referred to pages 63-91 of Volume 3 (Cat Island) where aspects of this subject are examined in more detail, and to a report by Young (1972), which also appears as an appendix in Volume 3.

Bahamian soils may be put into four general classes:

1. Limestone residues (red and brown lateritic soils)
2. Organic soils (leafmould soils on rock; muck soils)
3. Sedimentary soils (sandy soils with humus; sandy soils with caliche; lime-silt soils)
4. Man-made soils (quarry pit soils, artifically augmented soils of Exuma, heaped-up marsh soils of North Eleuthera, prepared rockland soils).

Any of these may by the invasion of salty water, be converted into saline soil, hence saline red soils, saline muck soils, etc.

MAJOR SOILS OF THE BAHAMAS

The main soils of the Bahamas are described below, followed by an account of other soils found only in the south-east Bahamas.

Soils found throughout the Bahamas

Aluminous lateritic soils ('red soils', 'pineapple soils', 'Bahamas red loam')

These occur in low spots or 'valley bottoms' varying from one half to five acres in area, between dune ridges, as in Eleuthera (Volume 2,Plate 7,) and Cat Island (Volume 3,Plate IVa). Similar soils occupy strips of land between beach ridges in Norman Castle, Abaco and Rolle Town, Exuma (Volume 6,Plate 6), and on some flat land as at Williamstown (Little Exuma),east of Deadmans Cay (Long Island) and in eastern Mayaguana. Red soils also occur on hillsides held on an irregular rock surface of coralgal composition as at Cove and Mountview,an old estate area 2 miles south-east of Old Bight, Cat Island. In each case the sediments on which they have been formed are derived from the deep water coralreef side of the island and contain coralgal material. The soils are always associated with hard rock, are usually shallow, and poor at retaining water and holding on to applied fertilisers. Consequently, in their natural state at least, they have few uses.

Immature lateritic soils ('brown mineral soils', 'Bahamas stony loam')

Occasionally found as shallow continuous soils, they are more often interrupted by rocky outcrop and lie on an irregular rock surface. They are of widespread occurrence in coppice islands where they are usually deepest in so called 'banana holes', (steep sided small caves) and at the foot of ridges. In pine islands, the surface layer of leaves comprises pine needles rather than broad leaves, nevertheless these soils are widely distributed in association with many different lithofacies (see p. 65); they are never deep and have low water retention. This is offset by the moisture which can be supplied to them from the surrounding soft rock where soil and rock are intimately associated. They have a low natural fertility and a limited ability to retain applied fertiliser.

Leafmould soils on rock ('black land', 'provision land', 'Bahamas black loam')

These soils largely comprise fine-grained, dark, coloured humus, covered by less rotted and newly fallen leaves, but may also contain a minor amount of mineral soils. Under natural bushland the leafmould may cover the entire rock surface but after cut and burn farming rocky outcrops are exposed. They are traditionally cropped for 1 or 2 years and are then abandoned; they are unsuitable for sustained cropping, land preparation or mechanised farming.

Sandy soils with humus and leafmould ('whiteland', 'bankland')

These soils are of variable character, and depending on the prevailing salinity and vegetation cover, ('which affects the amount of humus incorporated in the soil), and the composition and size range of the sand (e.g. coarse sands drain rapidly, coralagal sands make better land than oolitic sands). Sandy soils provide a continuous planting medium, allow plenty of room for root growth and are suitable for light machinery, alternatively they can be weeded with the hoe. The best sandy land with a high freshwater table is used for mechanised farming at Bahama Palm Shores (Central Abaco). The finely divided state of the limesand poses problems of plant nutrition due to continuing alkalinity and phosphate fixation and numerous areas of sand are subject to salt intrusion.

Soils found only in the south-east Bahamas

In the south-east Bahamas a number of other soils are found. These include the following:

Sandy soils containing concretions of caliche

In Long Island (Volume 6, Plates 28 and 29) and at Smith Bay, Cat Island (Volume 3, Plate Va,) the caliche takes the form of fusions of cemented sand, individual concretions ranging from peppercorn to football size. These occur throughout a rather coarse, sandy soil profile which so far has been identified only on and at the base of certain hillslopes. None have been located adjacent to potential irrigation water supplies. Their agricultural value appears slight.

Sandy soils containing caliche concretions at depth ('level dirt land' of Acklins, 'brown sands' of Inagua)

These soils form a continuous soil cover over extensive areas inland. They have been measured at over 1 ft deep in several pits in Acklins and comprise a humic medium-grade sand in the upper part of the soil succeeded downwards by lighter-coloured fine and very fine sand overlying a rubbly layer of caliche concretions. Although infertile as soon as it is deprived of repeated leaf-fall, such land could be valuable where irrigation water and fertiliser can be made available. It is widespread in Acklins south of Delectable Bay (see Volume 7,Text Map 2) and in parts of south Inagua (areas around borehole IG 41).

Limesilt soils

These soils are largely composed of raw limesilt, relatively little altered by soil processes but supporting various densities of thicket cover. They are found in Inagua and are also interpreted from airphotos as occurring in south Acklins and Mayaguana. They may be partly 'armoured' by limestone blocks; they have no agricultural use.

IMPORTANT MINOR SOILS IN THE BAHAMAS

Muck soils

These deep peaty soils occupy wide hollows which flood periodically. They are often deep, though waterlogged below about a foot, and may smell strongly of sulphide. At Mount Thompson, Exuma (Plate 13) and to the west of Rolleville they have been augmented by rock rubble and sand to make level planting areas. They can be productive if they overlie fresh water and are treated in this way.

PLATE 13 Newly prepared "man made" soils with a crop of maize at Mount Thompson, Exuma. "Shag pond land" on the left of the picture awaits improvement to the same condition.

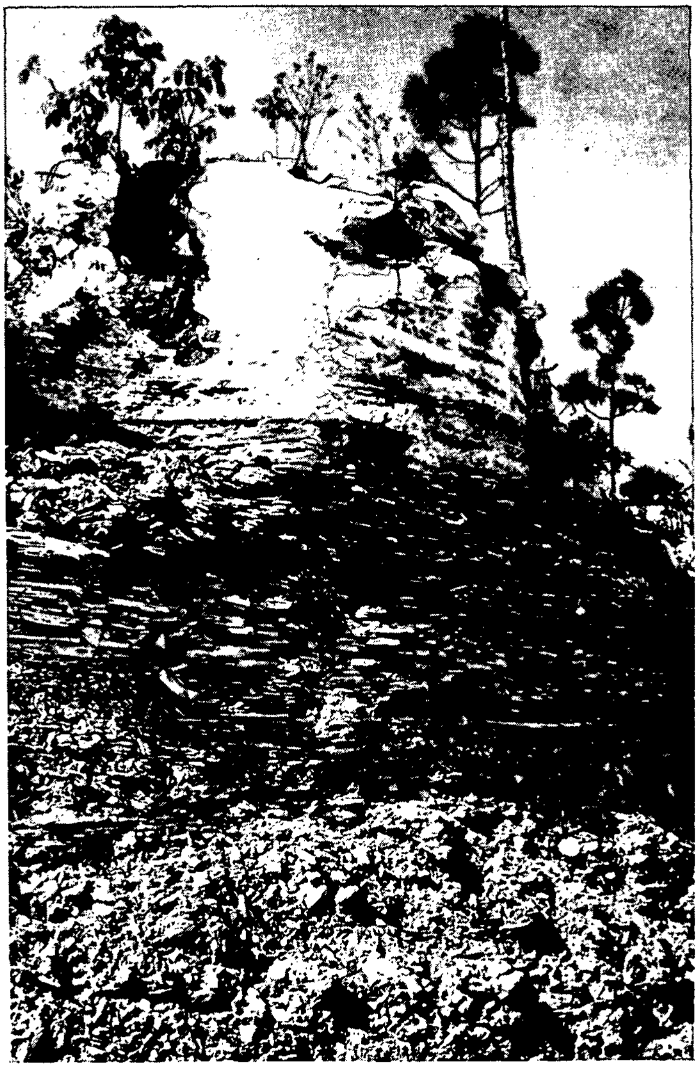


PLATE 14

Two distinct styles of weathering seen in a road cut in the Norman Castle Area, Abaco. Potholed massive limestone (Lithofacies IV) overlies thin bedded fissile limestones (Lithofacies I). Material below the regular bedding is fallen rubble.

Man-made soils

These have already been referred to in connection with immature lateritic soils and muck soils. They include quarry pit soils of Long Island (see Volume 6, p. 65); augmented red soils and muck soils of Exuma (Volume 6, pp. 48-49); marsh soils of North Eleuthera (Volume 2, p. 79). The soils created by mechanical preparation of tillage rockland described in more detail in Chapter 8. (See Plate 13).

AGRICULTURAL SIGNIFICANCE OF THE SOILS

The mineral fraction of Bahamian residual soils, i.e. those of rusty red, brown or yellow clay-like substance, is very poor in nutrients. Consequently growing plants have to depend on fertiliser. A further drawback to the use of these soils is that they rarely occur free of included rock fragments or rock outcrops. This excludes the use of tractors except on land that has been mechanically broken up at considerable expense. The preparation incorporates soil and rock and if the soil: rock ratio is favourable may result in productive land. The main drawback of the sandy soils is the problem of plant nutrition occasioned by the very large surface area of lime presented by the sand. Consequently, sandy soils suffer from alkalinity, although this condition is counter-balanced by a high content of humus derived from leafmould which is in itself acidic, and has the effect of sealing raw lime surfaces. A second shortcoming of sandy soils is that they are located mostly around the coasts and rarely have access to irrigation water. Humic soils on rockland are even more difficult to manage. They rapidly waste away on exposure of the land and are depleted of nutrients.

Modern agriculture therefore looks to residual and sedimentary soils despite the abundant problems they present.

SUMMARY

1. Bahamian soils are of four general types

limestone residues	(red and brown soils)
organic soils	(blackland, etc)
sedimentary soils	(sandy soils, etc)
man-made soils	(quarry pits, prepared rocklands, etc)

2. Any of these may be saline or have a high watertable.
3. 99.5% pure limestone by definition should release 1/200 of its weight of soil-forming residuum on dissolution of the limestone.
4. Soils are consequently thin except in shallow basins of natural concentration.
5. Different limestone types engender different soil types.
6. Sedimentary soils including 'level dirt land' and armoured silts are common in the semi-arid south-east.
7. Agriculturally, the soils suffer from inability to retain nutrients, low natural fertility and alkalinity because of their liminess.
8. The most valuable soils for modern agriculture are those of the flat, pine areas, and the more humic whiteland soils.

Chapter 8 Rocks and soils of the pine-covered areas

ROCKS

Many different limestones occur in the pine flatlands. They are all very young i.e. probably late Pleistocene, and are pure 'shelf limestones' without clay or sand. They have been formed at, just below or just above sea level. In most cases they are not fully cemented and may be relatively soft.

Beneath the pine trees the ground surface varies from place to place. These differences are illustrated in Figure 3. In some places the ground crunches underfoot, feels spongy and has soil mixed with gravelly or platey rock fragments, so that one can dig holes in the ground surface with the heel of one's boot. In other places one has no alternative but to thread one's way between knee-high 'castles' of upstanding rock, although the ground between the 'castles' may be soily and packed with gravelly fragments.

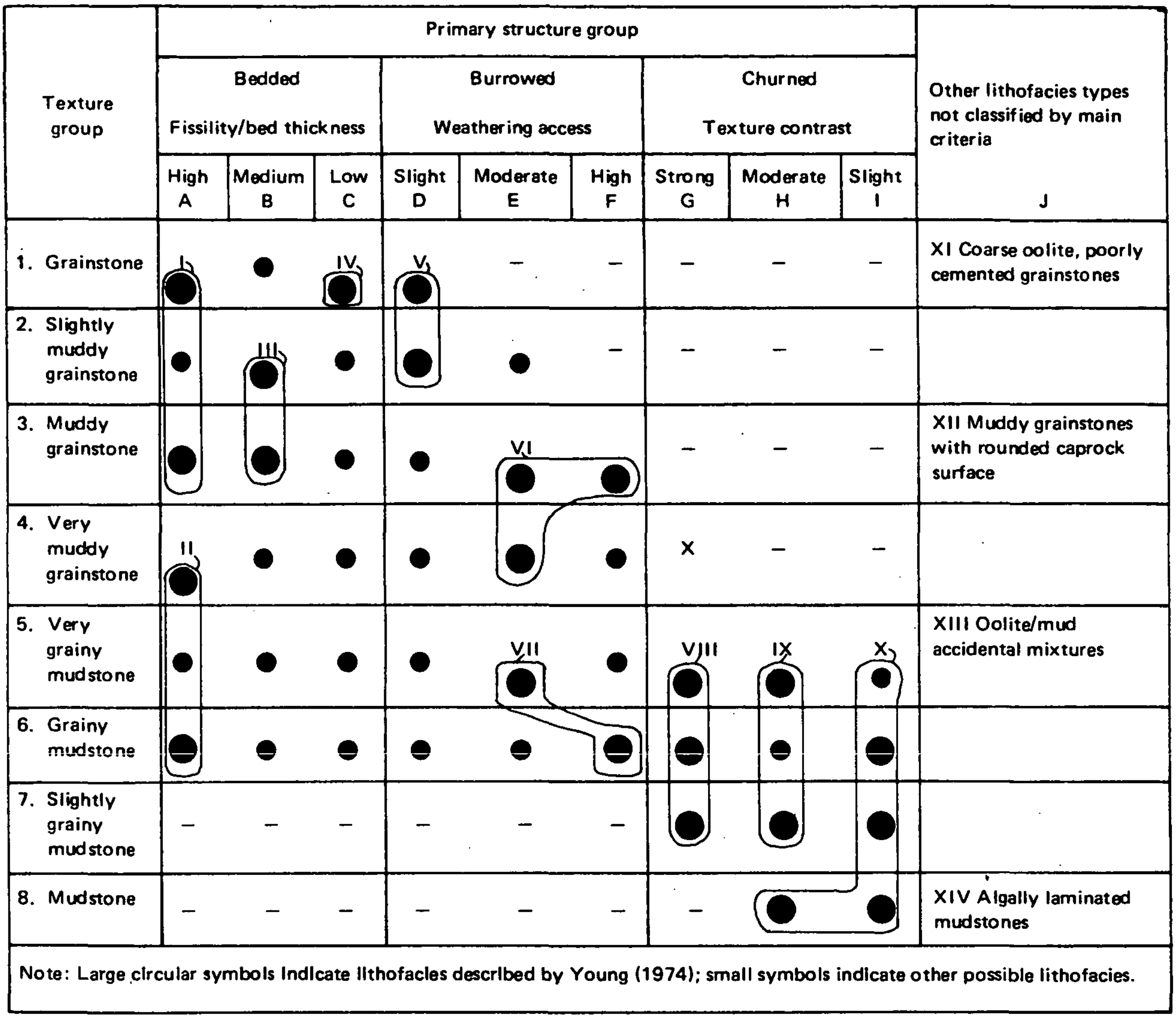
Yet elsewhere walking may be made precarious by an almost continuous series of minute potholes through which, perhaps 12 inches below, the moist underlying soil surface can be seen. There are many other varieties of flatland than those described above (see Table 8). The different qualities of land are a direct reflection of the kinds of limestone which underlie and, in places, outcrop on it.

Another name and the best scientific term for different kinds of limestone in this context is *lithofacies,* and one can refer to different types of pine rockland as areas of different lithofacies. The elements in concert with plants and animals bring about the eventual penetration and disintegration of the surface layer, each lithofacies reacting differently (Plate 14). The physical disintegration is accompanied by solution of the limestone by rainwater leaving insoluble coloured residues that contribute to the soil.

Fourteen different lithofacies which have been mapped and investigated in detail are shown in Table 7. Each has a characteristic texture (shown here as from 1, Grainstone, to 8, Mudstone) and a characteristic structure (more correctly called primary structure) identified as bedded, burrowed or churned (Plates 15 and 16). Each group is divided into three subgroups (columns A-I) depending on the fragment size into which the surface rock has disintegrated. Four of the distinctive types in the pine islands do not fit this classification and are listed under column J and elsewhere there are probably 4 or 5 other types that might go into this column. One of the latter is illustrated with the 14 lithofacies types in Figure 3.

For the same 14 lithofacies, Table 8 gives descriptions of the ground surface with which they are associated (also illustrated in Figure 3) the characteristic rock debris, and the nature of the 'rock/soil profile' and subsurface rock. In Table 7 the main lithofacies types are circled. They are described in detail in Table 8 and Figure 3 and with regard to capability as tillage land in Table 13, Chapter 15.

TABLE 7 The relationship of lithofacies with texture and primary structure groups



Texture group	Primary structure group									Other lithofacies types not classified by main criteria
	Bedded Fissility/bed thickness			Burrowed Weathering access			Churned Texture contrast			
	High A	Medium B	Low C	Slight D	Moderate E	High F	Strong G	Moderate H	Slight I	J
1. Grainstone	I ●	•	IV ●	V ●	–	–	–	–	–	XI Coarse oolite, poorly cemented grainstones
2. Slightly muddy grainstone	•	III ●	•	●	•	–	–	–	–	
3. Muddy grainstone	●	●	•	•	VI ●	●	–	–	–	XII Muddy grainstones with rounded caprock surface
4. Very muddy grainstone	II ●	•	•	•	●	•	X	–	–	
5. Very grainy mudstone	•	•	•	•	VII ●	•	VIII ●	IX ●	X ●	XIII Oolite/mud accidental mixtures
6. Grainy mudstone	●	•	•	•	•	●	●	•	●	
7. Slightly grainy mudstone	–	–	–	–	–	–	●	●	●	
8. Mudstone	–	–	–	–	–	–	–	●	●	XIV Algally laminated mudstones

Note: Large circular symbols indicate lithofacies described by Young (1974); small symbols indicate other possible lithofacies.

TABLE 8 Characteristics of the lithofacies type (read in conjunction with Figure 3)

Lithofacies type	Ground surface	Sub-surface	Comment
Bedded group			
I	Flat or hummocky; thin platey debris over surface; occasional less fissile blocks	Soil often deep and nearly continuous; debris in soil platey, occasional thin slabs; soil penetration deep	Mostly good land but may deteriorate rapidly to III or V; profile deepening potential good
II	Flat or hummocky; very fragile, thin platey debris; cross-bed rotting yielding platey gravel; occasional or frequent castles of hard rock	Soil usually deep and continuous, in-soil debris as at surface and much corroded; soil penetration deep	Rock more fragile than I, also less likely tc release lime due to high proportion of microcrystalline mud
III	Often undulating, also flat; debris tabular, or slabby or slightly irregular; some larger blocks; rock-dominated stable surfaces; common	Soil patchy, mostly medium or shallow depth; debris in soil as at surface; subsurface poorly penetrated beyond 6 in. depth except along cracks etc	Lacks adequate mineral soil; prepares to a limey tilth; often variable quality and may be associated with slightly undulating land
IV	Frequently broken and/or holed blocky or slabby surface; more muddy varieties have micropot surfaces, steps, pavements, underground voids	Soil thin, very patchy, humic, in crevices and holes; sub-surface breakdown poor	Non-agricultural; difficult to re-habilitate once spoiled; may provide building stone

TABLE 8 (continued)

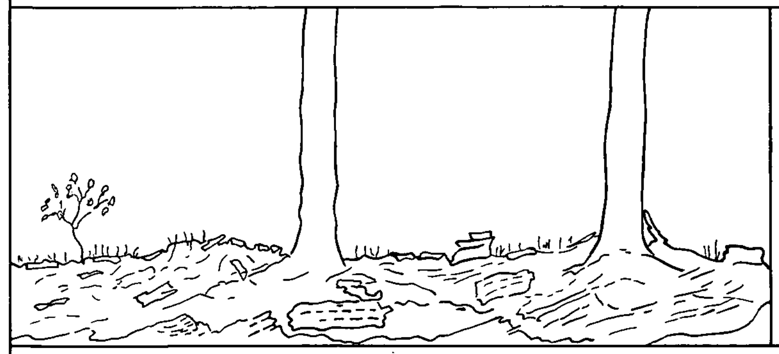
Lithofacies type	Ground surface	Sub-surface	Comment
Burrowed group			
V	*In situ* rock often exceeds debris surfaces; 'roofing' common; micromesas and high volume of dead rock; irregular gravel and tabloid stones	Soil thin, usually discontinuous; may be hidden below roofing rocks; sub-profile base poorly penetrated; breaks naturally to coarse debris	Usually low capability land; similar land occurs at the Central Agricultural Station Gladstone Road, Nassau
VI	Usually flat; *in situ* rock less than gravel; gravel debris medium to fine (1½-½in); coarser surface debris irregular in shape; common semi-attached dead rock	Soil usually abundant and containing close-packed gravelly debris; deep (12-24 in) soil penetration through burrowed rock fabric; sub-surface a plexus of rock with contained soil	Soil profile-deepening potential good; less favourable than more muddy strongly churned lithofacies
VII	Usually flat; irregularly shaped gravel; frequent upstanding vertical remnants of rock; 'castles'	Soils deep between rockier areas; subsurface breakdown good excepting below 'dead-rock' and 'castles'	
Churned group			
VIII	Normally flat; may be hummocky due to the effect of tree throw (c.f. I, II also with deep profiles); debris fretted, often fragile; coarse surface debris rare	Deep, fine and medium gravelly soils spread overall; good subsurface penetration of soil into microcrystalline mud riddled with small holes	Subsurface rock-soil fabric riddled with holes allows rapid and effective profile deepening
IX	Similar to VIII above but having more dead rock at surface, frequently coarser gravel and less effective soil penetration; soil profiles consequently less deep and agriculturally less favourable		
X	Surface flat; debris very fine gravel; may have arrested drainage; supports palms or grasses rather than shrubs or bracken	Soil medium sometimes near continuous with very fine gravel included, or shallow and discontinuous with very little debris at all: structure confined to poorly defined horizontal partings; penetration of soil absent below 3-6 in	Soil profile base flat and regular with very restricted potential for deepening; subsurface rock compact
Other types			
XI	Undulating land; rounded highs and lows (4 ft relief); fragile crushable blocks at surface; localised colluviation	Well aerated soils; grainy soils on highs; generally soft porous rock, may contain denser bands of grainstone	Too uneven for many uses; limey after preparation, highly porous; tree crops have been suggested
XII	Flat or sloping, much bare gray rock; small scale domes and hollows (6-12 in); surficial humic soil; arrested drainage with pools; exfoliated debris	Soil volume low; most soil in areas stripped of caprock where gravel may occur; sticky yellow soils found in narrow holes; rock shielded by capping, limey and white	Frequent around low spots; also evident on some slight rises adjacent to III; unrewarding to prepare
XIII	Flat; very fine, sometimes equidimensional unfretted; gravel; also tabular debris may occur	Soil medium or thick with uniform fine gravel; subsurface penetration good; among mostly granularised oolite/mud mixtures thin grainy beds occur	Very good breakdown, possibly limey land especially in areas of mashed soft oolites
XIV	Very flat; rare surface debris; low profile of weathering includes much *in situ* rock; often with arrested drainage	Soil shallow or exiguous, often wet, with algae; contains little debris; rock dense, resists repeated hammer blows; soil penetration exceptionally poor	A rare type, absolutely the opposite of type XI; rock largely microcrystalline mud; not an agricultural prospect

PLATE 15 Bedded, low-fissility, very muddy grainstone with rare burrows (4C in Table 7). This lithofacies is among those which do not weather to a loose soily surface. It forms low rocky rises. If the heavy crop of deadrock is removed into windrows (as here) the quality of the underlying surface is improved - but remains mediocre.

PLATE 16 Slightly grainy mudstone with moderate or good texture contrast see Table 7, Type 7G or 7H and therefore susceptible to weathering. This lithofacies breaks down to a gravelly surface, littered with fragile deadrock. Here it is seen, prepared and cleared of all but the smaller rock fragments, ready for vegetable production.

FIGURE 3

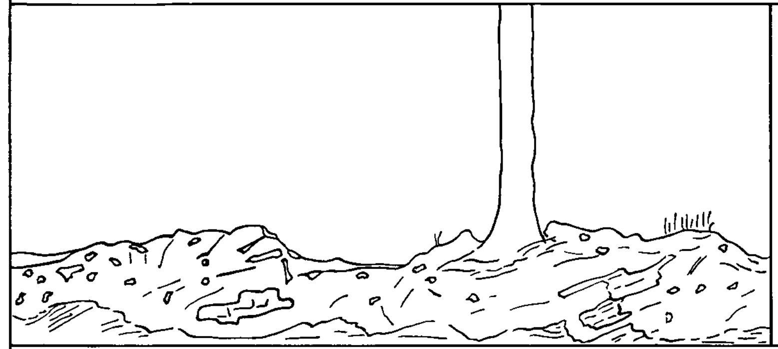
THIN BEDDED FISSILE GRAINSTONES - "PLATEY ROCK"



I

Slightly hummocky, loose soily surface with platey rock debris; soil profile relatively deep; occasional rather fragile blocks in the profile and at the surface

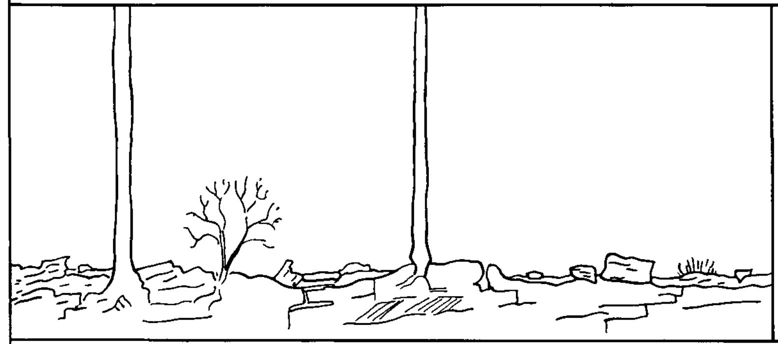
THIN BEDDED FISSILE MIDDLING TEXTURED ROCK - "MUDDY PLATE ROCK"



II

Surface made hummocky by tree throw; loose soily surface with platey rock; differs from I above in the "cross rotting" of plates to produce a fine gravel

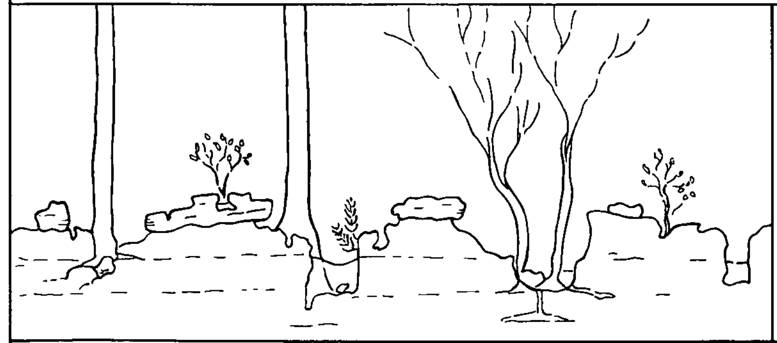
MEDIUM THIN BEDDED "FUSED PLATE" ROCK



III

Shallow, patchily distributed soil; flat *in situ* rock at surface; poorly separated platey rock and thin slabs as surface debris; occasional fissures

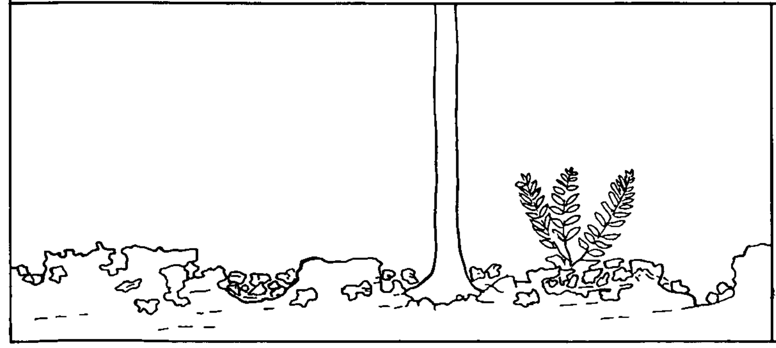
THICK BEDDED GRAINSTONES - "MASSIVE ROCK"



IV

Rocky bare surface irregular in aspect; frequent small potholes and large surface blocks; soil mostly leaf mould; scattered coppice tree species

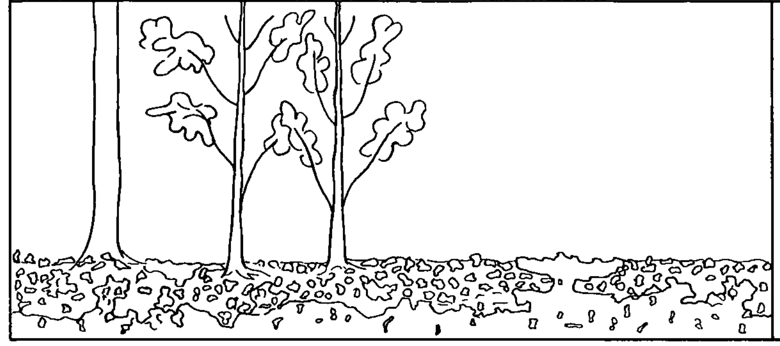
SLIGHTLY BURROWED GRAINSTONES



V

Irregularly shaped, fist-sized surface rock debris; rock surfaces common, "roofing" of rock over soil; commonly supports bracken after a fire

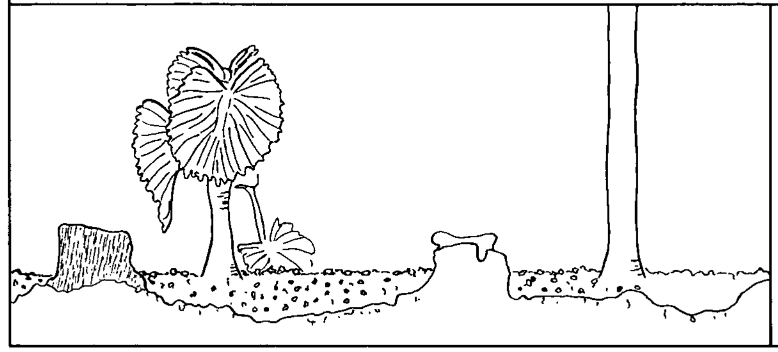
MODERATELY AND WELL BURROWED, RATHER MUDDY GRAINSTONES



VI

More or less level surface, mostly gravelly; medium to fine gravel; some irregularly shaped *in situ* rock; soil moderately abundant; good penetration of less weathered rock below

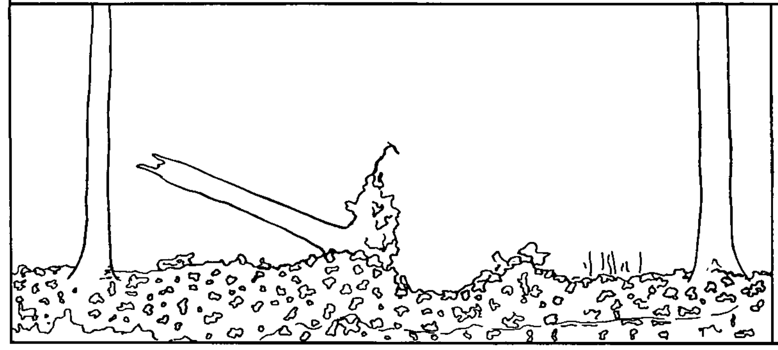
MODERATELY AND WELL BURROWED GRAINY MUDSTONES



VII

Usually flat but with standing vertical rock remnants and "castles" of hardened rock; soils mostly deep with gravel; palmettos common

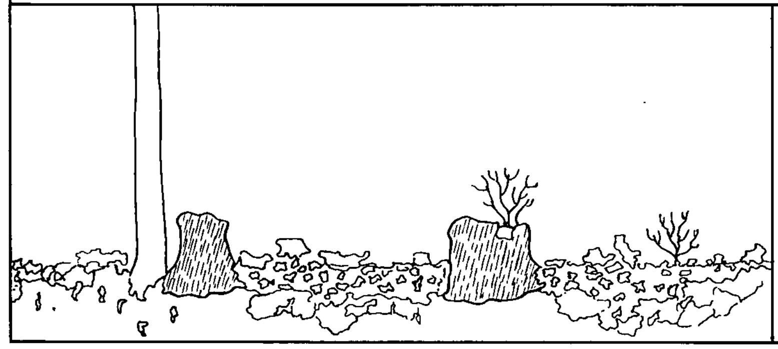
IMPURE MUDSTONES WITH STRONG TEXTURE CONTRAST



VIII

Flat or hummocky due to tree throw; mostly gravelly at surface and through the profile; coarse surface material scarce; exellent penetration of soil into rock below

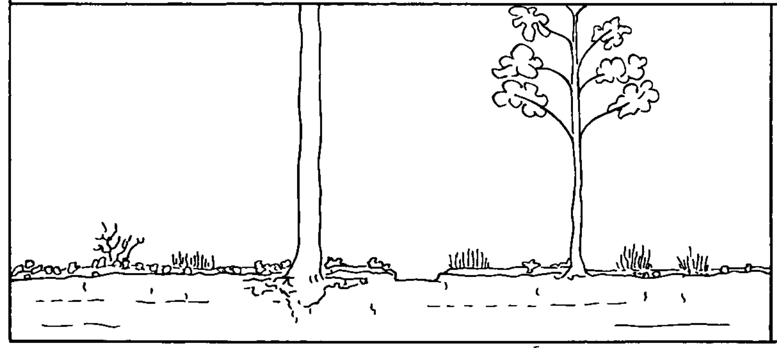
IMPURE MUDSTONES WITH MODERATE TEXTURE CONTRAST



IX

More dead rock at surface than in VIII; gravel coarser; soil less deep; poorer penetration of soil into subsurface rock

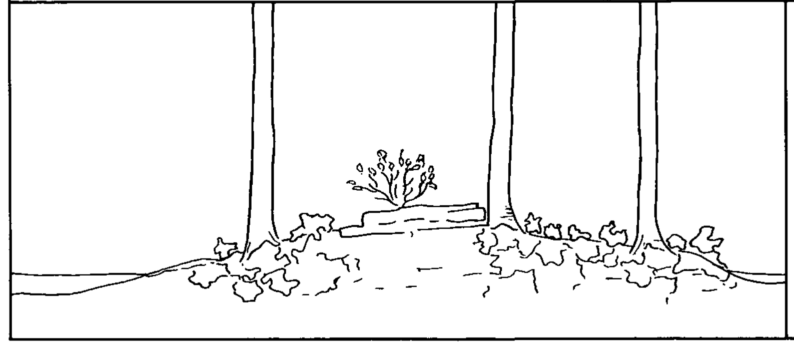
IMPURE AND PURE MUDSTONES WITH ONLY SLIGHT TEXTURE CONTRAST



X

Very flat, relatively uninterrupted surface, partly covered by medium-depth soils; some fine gravel; subsurface rock nearly uniformly resistant with little soil penetration; grasses

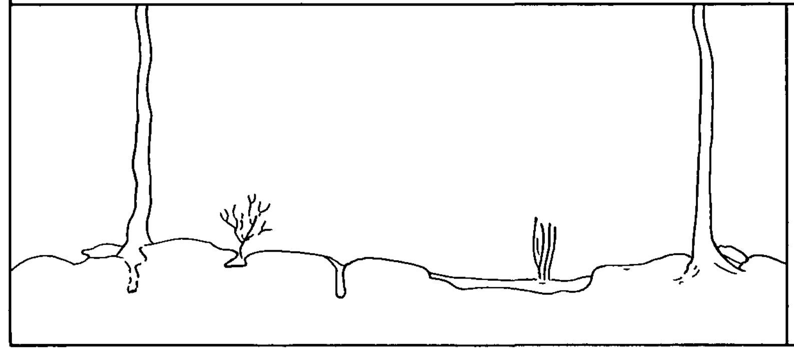
COARSE OOLITE (POORLY CEMENTED GRAINSTONE)



XI

Low mounds and basins, the latter with small soil deposits; fretted and irregular surface rock debris, which breaks easily to release soil and powdery lime; soil scarce on mounds; some bedding

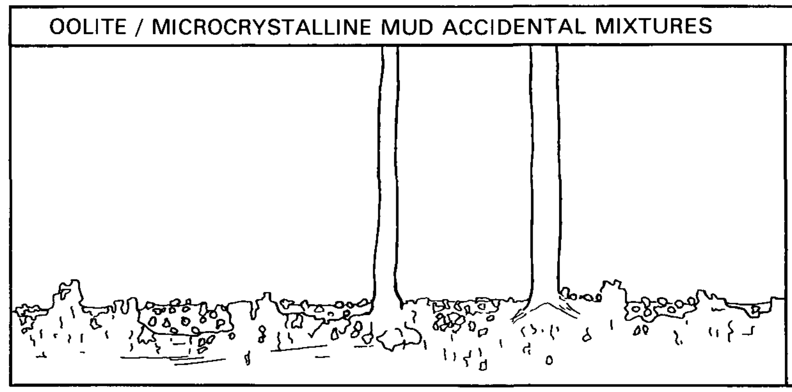
MUDDY GRAINSTONES WITH ROUNDED CAPROCK SURFACE



XII

Smooth, bare surfaces of caprock; land often slightly undulating with small, soil-filled depressions; narrow potholes provide the only penetration of soil into the subsurface rock

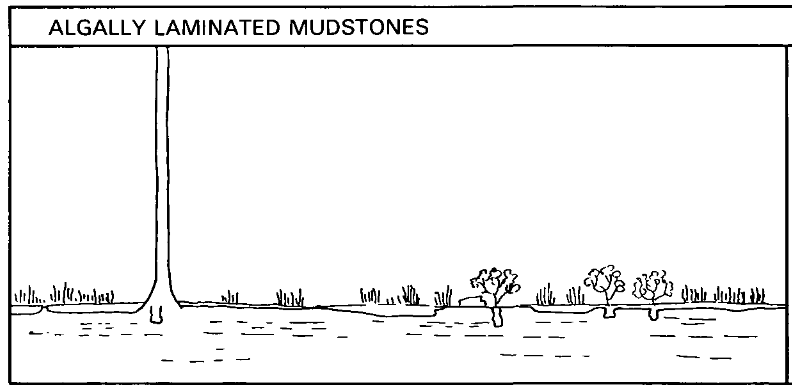
OOLITE / MICROCRYSTALLINE MUD ACCIDENTAL MIXTURES



XIII

Very level land; low fretted remnants of rock stand clear of soily surface; small subangular gravel fragments; subsurface rock breaks to similar size and shape; "white spots" in ploughed land mark concentrations of strongly oolitic rock

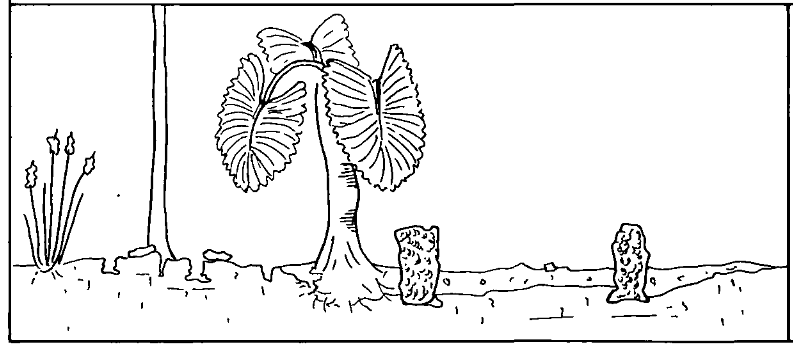
ALGALLY LAMINATED MUDSTONES



XIV

Very flat land; very thin soil; no dead rock; subsurface rock almost unpenetrated, dense and very resistant to impact breaking; grasses

DISTINCTIVE SOILY LITHOFACIES FROM THE TWIN LAKES AREA



Very soily flatland; fine gravel throughout the profile; scattered tall narrow "rock stumps" of hardened rock; abundant silver top palmetto

FIGURE 3 Lithofacies types and corresponding ground surfaces, BARTAD project, North Andros

Each sketch section illustrates about 20 feet of surface

D.O.S. 3249 H

The different lithofacies indicate to a geologist the different conditions in which each was deposited at a time when sea level stood some 5 ft higher. Across North Andros, for example, and specifically on the BARTAD site, there were shallow shoals, tidal channels, tidal marshes and slightly higher 'islands' of dry land surrounded by narrow shoreline zones and mangroves. Each environment had its characteristic deposit of sediment which, left high and dry by a falling sea, is now cemented into rockland and covered by pine forest. The ancient depositional pattern is still discernible (see Text Map 2) as a mosaic of different lithofacies. Indeed, a few of the larger elements of the ancient pattern can be interpreted from airphotos though much becomes apparent only after close inspection of the ground surface itself and of the texture and primary structure of the rock.

More information about texture and primary structure is to be found in a report on the BARTAD site (Young, 1974) which explains how the overall texture and the arrangement of different textures within a rock may act to create various degrees of texture contrast, zones of weakness and lines of access and how these influence the coarse of weathering and the size and shape of the end products of weathering. The BARTAD report also discusses the four most important primary structures, namely various types of bedding, burrows caused by the shrimp *Callianassa,* churning caused by a variety of animals feeding within newly deposited mud, and traces of roots, particularly of mangrove.

SOILS

The character of the agriculturally important surface layer depends very largely on the rock debris within it, hence the expression rock/soil association in Volumes 1 to 4 of the *Draft Land Resource Study.* However, there are four main soils associated principally, but not exclusively, with different lithofacies. These are:

1. Organic soils - dark leafmould soils (associated with lithofacies 1C).
2. Organic/residual soils - well aerated, humic soils with some mineral residues and scattered limesand grains (associated with the grainy lithofacies 2B, 1D, 2D 5D and 5F).
3. Redder limestone residues - more compact red-brown, less humic soils largely composed of mineral residues mixed with rock debris (associated with lithofacies 3E and F, 4E and perhaps 5G and H).
4. Browner limestone residues - a humic or brown soil frequently of sticky consistency (associated with texture groups 6-8) with churned primary structure.

Some profile differentiation i.e. organisation of the soil into horizontal layers can be found. For example, mineral soil profiles are usually redder at the surface and yellower or browner at depth; mineral soils are often of stickier consistency at depth and contain more clay.

SUMMARY

1. Though pine covered islands have identifiable hills and wet areas, airphotos yield no clue as to the nature and surface characteristics of the flat land.
2. This flat land can be divided up into different types based on the nature of the underlying limestone rock and the resultant ground surface characteristics.
3. The best name for the subtly different limestone rock types which underlie this variation is lithofacies.

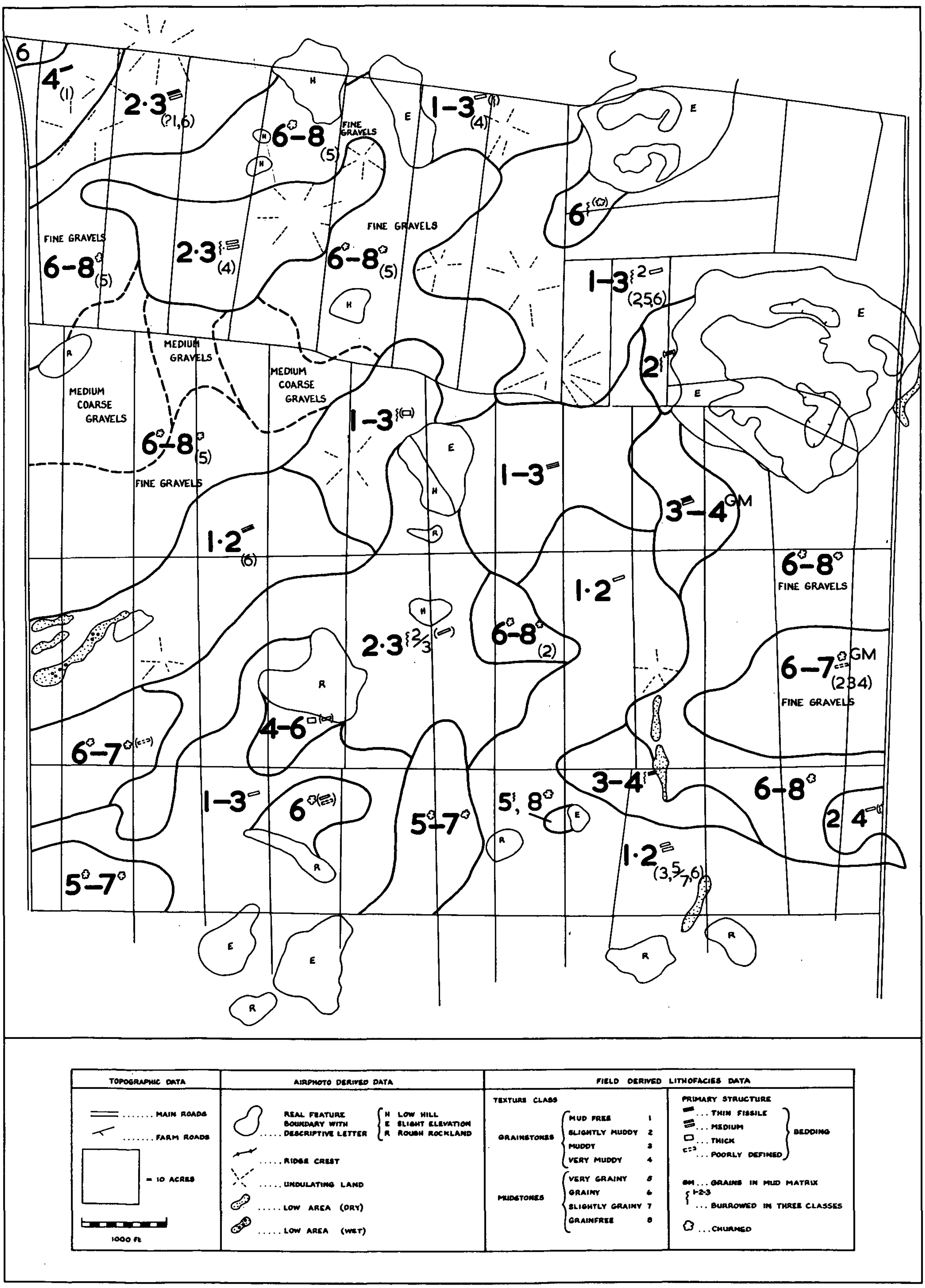
4. Different lithofacies weather in different ways depending on their texture and primary structures.

5. The chapter illustrates 14 lithofacies types which occur at the BARTAD site and one from the Twin Lakes area.

6. The scientific basis for distinguishing them is given. So also is a detailed description. (The relationship of each with land capability for mechanised agriculture is contained in Chapter 14).

7. A map of the BARTAD project area emphasises how lithofacies vary over an area.

8. Four main soils associated with different lithofacies are briefly reviewed.



An example of lithofacies mapping from the BARTAD project, North Andros

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Chapter 9 Shorelines

Whereas it is easy to classify shorelines in textbook fashion (as for example 'submerged', 'volcanic', 'eroding', 'embayed', 'coral reef affected' and so on), such descriptions are inadequate when it comes to portraying local variation at a usable scale. As shown in Volumes 1-4 of the *Draft Land Resource Study,* shorelines can be classified in a more practical way on the basis of features which will prove critical in subsequent land use e.g. sand drift across a potential harbour site. However, any classification (no matter how good) tends to throw together broadly similar shorelines which nevertheless may differ in one or two features that later prove to be critical for development. Consequently the most useful map for Bahamian users is probably one which gives a concise verbal description of each shoreline and indicates its limits. This is the approach followed in Volumes 6-8 for Exuma, Long Island, Crooked Island and Acklins, Mayaguana and Western Inagua. Maps such as these can then be interpreted to give information on hurricane susceptibility, potential harbour sites, locations for inshore commercial fishing and sport diving, scenic quality and the establishment of tourist routes.

Prior to the adaption of the approach used in Volumes 6-8, shorelines had been classified as described in the text and had been illustrated by reference to named areas around the coasts. This approach was most successfully used for Cat Island. Andros, whose shoreline is relatively monotonous, was described more briefly, as also was Grand Bahama.

Each shoreline description on the map describes separate zones of the shore: the backshore—in places characterised in landform terms; shoreline shape—emphasised to highlight significant special features such as creeks, coves, peninsulas, etc, not obvious on the map; and the foreshore—the zone most important to many shoreline users, which may be rocky, sandy or muddy, steep or flat, and may possess distinctive vegetation affecting its use. Because of the excellent quality of the air photography and the great clarity and stillness of the water, offshore features down to perhaps 100 ft are visible on the prints (Plates 17-19). Each map annotation therefore draws attention to underwater geologic materials, corals, marine vegetation where it occurs, the width of the platform (or lagoon if an outer reef is present), the depth of water through reef passes and the steepness of the platform edge. The water depth immediately offshore (i.e. where jetties and harbour facilities might be constructed) has been estimated from diving experience (checked in a few places against the 'Yachtsman's Guide'). Depth groups given are: 'very deep' i.e. water estimated deep enough for super tankers; 'deep' i.e. adequate for most cruise ships and freighters; 'medium' i.e. adequate for mail boats and large yachts and 'shallow' i.e. adequate for dingies and 'Boston whalers'. Where abundant coral heads are present, water depth between heads will not necessarily indicate suitability even for small craft.

Sample descriptions from the Mayaguana map sheet (which it is suggested might be taken, with the Inagua sheet as a model for future descriptions) are as follows:

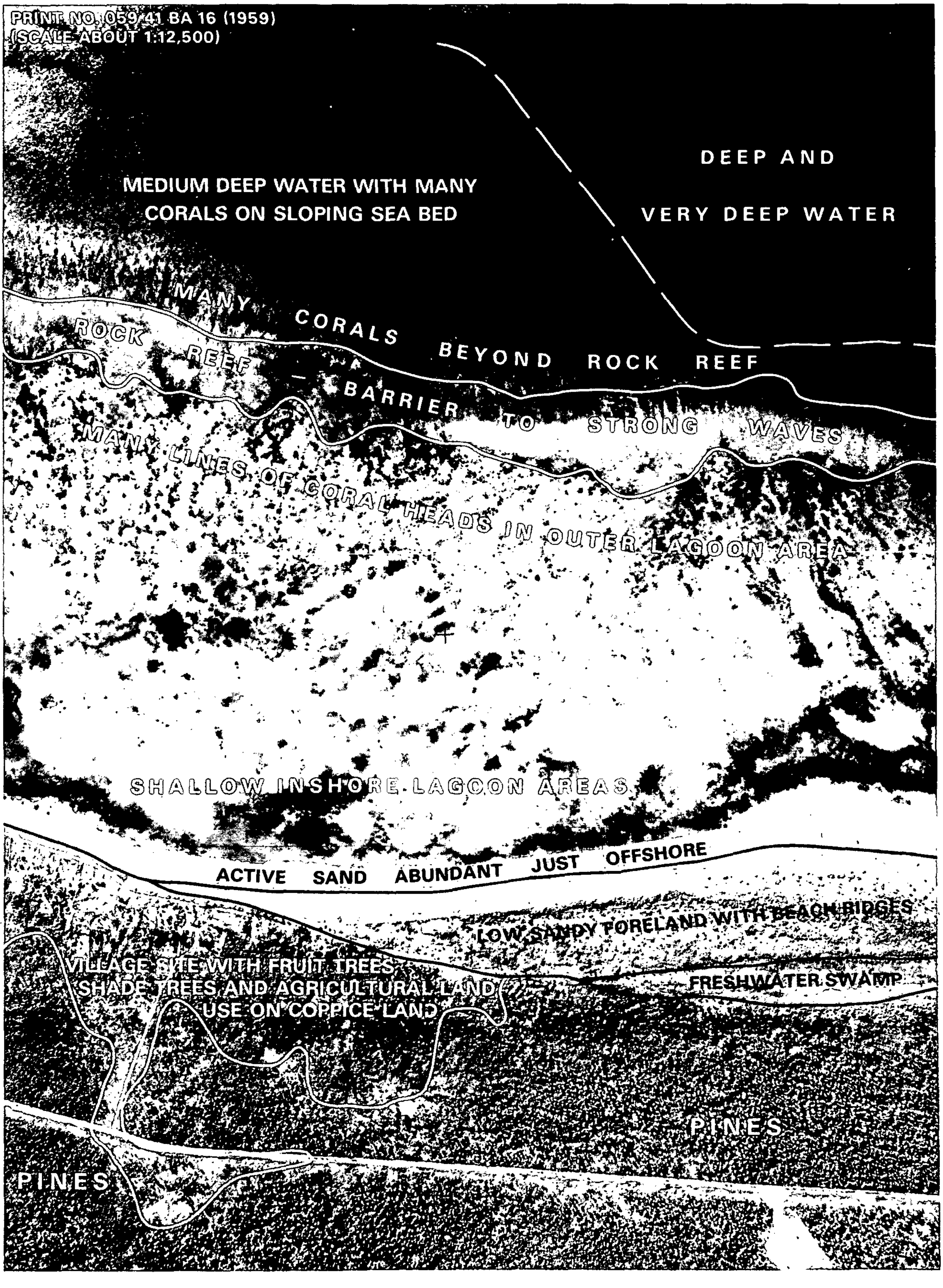

PLATE 17 Shoreline and offshore details on a high quality vertical airphoto of High Rock Village, Grand Bahama. Much of the Bahamas is covered by excellent air photography.

PLATE 18
Coral reef, well developed lagoon and hypersaline ponds behind a narrow zone of sand, along the windward shore of North Acklins.

PLATE 19 Scenic coast: cliffs and a coastal bluehole with corals. The bluehole is deepest at the R.H. side of the picture; 3 miles west of Clarence Town, Long Island.

1. For a section of shore almost 4 miles long, west of Abraham Bay. 'Incised sand-and-soft-rock shore; narrow sandy foreshore; immediate offshore very shallow, muddy sand as far as rock reef 300 yards from shore; lagoon shallow with barely submerged rock reef margin; inner rock reef more broken in west'. Frequently sections are shorter, the shortest being about ½ mile.

2. For a section east of Mayaguana near Booby Cay: 'Accreting sandy shore; medium width beach; offshore shallow-medium depth channel, some coral; currents setting south; shallow rock reef at 500 yards distance from shore, major lagoon beyond'. This refers to a section a little over 1 mile long.

   Shorter descriptions are used where the shore has fewer distinctive features, but is clearly different from the adjacent shorelines. Two such from Inagua describe a ½ mile and a 1 mile section of coast on Inagua's south shore. One is described as: 'Rugged indented low cliff shore; very deep water'; the other, at Conch Shell Point as 'Incised soft-rock shore; beach at west end; abundant creek-derived sand in east; shallow, continuous outer reef'.

PRINCIPAL VARIATIONS IN SHORELINE TYPE

There appears to be an increase in the incidence and vigour of reef growth from north to south within the archipelago. This relates not only to present day reef growth but probably also to fossil corals (see Plate 8). The fact has an important bearing on coastal protection, the sediment types onshore (and their derived rocks and soils), coastal exposure, harbours, scenery and tourist potential.

The most important single distinction is between lee shores facing the shallow water of the Banks, and windward shores facing not only the deep Atlantic but also the 'weather side' of the islands, i.e. their north and east coasts. Windward or weather shores are associated, among other things, with coral growth, good fishing, coralgal pink shelly beaches, deep blue water, rugged rough shorelines, saltspray sand dunes, agriculturally superior whiteland, (see Chapter 7) less groundwater and more attractive scenery. Leeward shores are associated with shallow waters, restricted coral growth, oolitic and muddy sands, mangroves, agriculturally inferior whiteland, beach ridges and more abundant groundwater. There are several exceptions to this general picture as, for example, at Benzie Hill (near Turnball, Long Island) and Port Royal (Cat Island), both on a lee shore, where deeper water and coral patch reefs lie close to the shore, and at Gregory Town (Eleuthera), Bains Town (Long Island) or south of Bluff Settlement (Cat Island) which have bold, cliffed landforms facing to leeward i.e. to the west.

Although the majority of the islands studied are situated on either the Great or Little Bahama Bank there are others, notably Mayaguana and Inagua, which occupy small 'individual' banks completely surrounded by deep water. On these islands reef terraces are common: so also is a coarse, coralline, 'sandy blackland' (i.e. rock-strewn, coarse sand with a content of leafmould), whilst coastal marshes with creeks are rare. In these and other ways their shorelines contrast strongly with those islands on the large Banks further to the north-west.

PRACTICAL CONSIDERATIONS

Land use and the activities that can take place at the shore and in the offshore zone are to some extent determined by the shoreline characteristics. For example, locations with a persistent and strong supply of shoaling sand may prove unsuitable as harbours; exposed rocky shores fringed by deep water are commonly associated with damaging salt spray which may make the immediate inland area valueless for agriculture and property development alike. Water sports make different demands on the immediate offshore area, skiing for example being best carried out where there are no corals and scuba ('tank') diving where there is adequate depth of water and striking underwater scenery (cliffs, gullies, strong coral growth).

Coastal erosion receives considerable attention in Jamaica and a number of other Caribbean countries. Despite the occasional digging of sand for construction work and for stabilising roads sprayed with bitaminous liquid, there appears to be little pressure on coastal sand resources at present nor does the Bahamas have a high population pressure, or potentially vulnerable coastal roads sandwiched between steepland and sea. Planners, developers and local official should, however, be alert to a number of potential problems, namely: (a) erosion of deep gullies ('blowouts') when plant cover is destroyed in exposed areas of the windward shore; (b) ecological damage to creeks and marshes occasioned by real estate development (Little *et al.* 1971); and (c) general spoilage of beaches and shorelines adjacent to dredged areas and industrial sites.

SUMMARY

1. The shorelines of Abaco, Eleuthera and Cat Island were classified into types illustrated by named examples.
2. Andros shorelines, which constitute a relatively poor resource, were treated in a similar fashion.
3. Grand Bahama shorelines were cursorily described. The emphasis of the study there, as in Andros, was on agricultural land.
4. The project steering committee accepted a proposal for more detailed shoreline descriptions for the south-east islands.
5. Hence concise verbal descriptions of each section of the shore form a part of the landform maps for Exuma,Long Island, Crooked Island, Acklins, Mayaguana and west Inagua.
6. These descriptions describe the backshore, foreshore, and the immediate and more distant offshore. They give information which can be interpreted for a variety of purposes.
7. Generalised distinguishing features of Bahamian shorelines include:
    i. The more abundant coral growth (present and the past) around islands of the south-east.
    ii. The distinctive physical characteristics of windward and leeward shores.
    iii. The more truly coral island quality of south-east islands situated on small banks.
8. Shoreline damage by careless practices in industry and real estate dredging operations are seen as more important than sand depletion and coastal erosion.

Part 3

People and the land

Chapter 10 Population, wealth and economic activity

INTRODUCTION

No analysis of population is made in the *Draft Land Resource Study* although discussion in some of the land use sections relates population change to levels of economic activity and the extent of cultivated land. Population matters are discussed in the *Regional Development Strategy,* (Bahamas, Ministry of Development, 1974) which compares the growth rates of Grand Bahama and New Providence in relation to growth rates in the rest of the Bahamas, distinguishes islands showing an increase from those showing a decrease in population between 1963 and 1970, presents two tables on migration, and groups the islands by population size. The same report devotes nine pages to an economic diagnosis, making use of a coefficient of localisation of economic activity. The 1970 census, a very complete compilation, unfortunately has no textual summary.

Separate Map 1, which accompanies this report, presents six aspects of population, money incomes and economic activity of importance in regional planning. They are:

The distribution of population

The male-female age structure of the population in each island

An estimate of each island's income shown in three income groups

Economic activities of the population of each island (in 1970)

The inset map shows:

Migration from family islands i.e. islands other than New Providence to the two urban centres

Net population change of the total and of the economically active population

DISTRIBUTION OF THE POPULATION

An effort has been made to give as true a picture as possible of the clustering (or dispersal) of population. Population circles are accurately located at the centre of a single settlement or at the 'population centre of gravity' of a settlement group. Where settlements enumerated together are widely spaced (enumeration district 71 in Cat Island, for example) a population dot with tie lines to each settlement is given rather than risk misallocating population. In enumeration district 173 in Mayaguana total population is shown equally shared between two settlements, to maintain a sense of village distribution. The population of the Exuma Cays has been allocated to Staniel Cay and Black Point, the main settlements.

POPULATION STRUCTURE

The age-sex pyramid is a way of comparing population structures, a 'normal' population would be represented by two stepped right-angle triangles each a mirror image of the other, one representing males, the other females. Population structure is influenced by factors which include fertility, marriage age, mortality and emigration as well as economic facts such as job availability and specialised employment opportunities. The age-sex pyramid for New Providence shows a vigorous, fertile community; a similar population structure is approached in the age-sex pyramids of Eleuthera and Abaco. The tendency in poor or underdeveloped islands is for a 'waisted' pyramid showing a scarcity of able-bodied economically active people and an abnormally high proportion of old people and children (Plates 20 and 21). Cat Island is the most striking example of this: it has been referred to as a 'nursery island'. Crooked Island, Acklins, Mayaguana and to some extent Andros also exhibit this tendency. The Inagua salt industry probably accounts for the high proportion of people between 20 and 40 in that island while without the salt industry the 'pyramid' might well resemble that for Cat Island. In Exuma there seems to be an unusually large proportion of children without a corresponding imbalance of old people. In Grand Bahama the nursery island situation is reversed i.e. Grand Bahama has attracted large numbers of people aged 20-50. In the Biminis, males exceed females in nearly every age group, perhaps reflecting job opportunities for single men in the male dominated sport fishing industry. In the Berry Islands, there are more than twice as many men as women and the availability (in 1970) of construction work (especially for 20-40 year olds) may be the cause. Correspondingly there are islands where the male population is depleted for example, Cat Island, Crooked Island, Acklins and Mayaguana Islands – where women outnumber men almost 2 to 1 in the economically active (20-50) age group.

AN ESTIMATE OF EACH ISLAND'S INCOME

Relative prosperity of an area as evidenced in new houses, the number and age of vehicles on the road, and living conditions depends on several factors including the proportion of potential and actual wage earners in the community, the size of the population, and the sum of incomes at different levels. On the map crude measure is given of regional wealth and its distribution in three income groups. Incomes are taken from the census report, and a median figure (e.g. $5 500 in place of $5 001-6 001) is used to arrive at an estimate of the total. The three figures distinguish a lower income group (less than $4 000 per annum) from a middle income group ($4 000 – 10 000) and a high income group (more than $10 000). In addition, Island incomes are shown as a percentage of the income received by the whole population throughout the Bahamas. The figures of course refer to 1970.

Income as defined above is not directly related to the capital available for local investment as social factors and personal investment decisions affect the relationship; low income people, for example, may consume all their income simply in living whereas high income people may invest money elsewhere. High and low income communities do however differ both in their outward appearance, in their ability to obtain capital and in their willingness to risk money on new ventures. Where island populations and individual incomes are low, little locally generated capital is likely to be available for projects.

ECONOMIC ACTIVITIES OF THE POPULATION OF EACH ISLAND IN 1970

The percentage of the working populations engaged in various economic activities is shown as a bar graph on Separate Map 1. Category A includes housewives, school children and students while Category K includes retired people and the unemployed. Using the census both might be analysed still further. Category B includes large numbers of traditional farmers in subsistence agriculture, the fourth Category D, those engaged in manufacturing. Two leading economic activities, construction and tourism, come under Categories F and G. Category J, community social and personal services, is made up of people employed by the government (the public sector e.g. teachers, nurses, policemen etc.)

PLATE 20 Children with their father, Mayaguana.

PLATE 21 Many children from the family islands come to Nassau for their secondary education. They live with relatives and often stay on: schoolgirls in Nassau.

The graphs show that the Berry Islands, Biminis and Grand Bahama, in that order, had the largest percentage of the population engaged in private sector development (Categories C—I but not Category B, farmers) in 1970. The full list, which again reflects regional imbalance in development is as follows:

Berry Islands	71%	Exuma	26%
Biminis	54%	Andros	16%
Grand Bahama	54%	Mayaguana	15%
Inagua	45%	San Salvador and Rum Cay	15%
New Providence	42%	Long Island	14%
Abaco	40%	Ragged Island	12%
Eleuthera	35%	Cat Island	6%
		Crooked Island	6%
Harbour Island and Spanish Wells (Island off Eleutheral)	28%	Aclins	4%

Islands can also be listed by the percentage of their population engaged in tourism (Category G).

Berry Islands	22%	Andros	7%
Grand Bahama	21%	San Salvador and Rum Cay	4%
Eleuthera	21%	Long Island	4%
Biminis	18%	Inagua	3%
New Providence	17%	Cat Island	2%
Abaco	11%	Mayaguana	2%
Harbour Island and Spanish Wells	11%	Crooked Island	1%
Exuma	11%	Acklins	1%
		Ragged Island	0%

Islands with a large proportion of the population engaged in farming are the traditional subsistence-farm islands:

Cat Island	43%
Mayaguana	34%
Long Island	29%
Crooked Island	29%

MIGRATION FROM FAMILY ISLANDS TO THE TWO MAIN URBAN CENTRES, NASSAU AND FREEPORT (see inset to the main map)

Young people may wish to leave their island in order to obtain employment in the urban centres. Others who have worked for a period away from home may return, often at a time when, supported by savings, they can start up a small business or simply enjoy their own island's lower costs and slower pace of life. Migration to the two main urban centres accounts for over 70% of all inter-island movement and only 1½% of those migrating come from islands south of Eleuthera. Many migrants who move to New Providence remain there. Despite this, New Providence shows a net loss of population over the period 1963-70 due largely to out-migration of part of its population to the Freeport area of Grand Bahama. (See Plate 21).

NET POPULATION CHANGE (OF THE TOTAL AND OF THE WORKING POPULATION)

This indicates the net number of people moving away or coming to each island in the period 1963-70 (the intercensal period). Outward movement is shown as negative (-), inward as positive (+). The percentage of the total which this represents is shown on the map. Values are given for both total and working populations.

All the figures on economic activity and migration may be distorted by short term local surges of development or increased economic opportunity, and should be scrutinised with this in mind.

SUMMARY

1. This chapter is supported by Separate Map 1 which shows population distribution, the structure of the population in each island, migration trends and net population change.

2. The map also gives island by island details of annual money incomes and economic activities – recorded at the 1970 census of population.

3. Factors affecting each of the above are discussed. It is evident among other things that:

   i. Migration to Nassau and Freeport accounts for over 70% of all inter-island movements

   ii. Only 1.5% of the migrants come from islands south of Eleuthera

   iii. A number of islands have a strongly 'waisted' population structure, i.e. an imbalance of dependents

   iv. Islands in the north-west have absorbed the active working population

   v. Cat Island, Long Island, Crooked Island and Mayaguana, with a tradition of subsistence farming, do indeed have the largest percentage of people engaged in this occupation.

4. Information contained in the map can be used with land capability and groundwater data in establishing regions and locating potentials for and constraints on development.

Chapter 11 Communications

MAIL BOATS

The schedules of the small passenger/freight boats operating between the islands are available from the Ministry of Transport, and the Dock Master at Potters Cay, New Providence. Inter-island sea transport was examined in detail in the 1967 Report by Wallace Evans and Partners (Bahamas) who made recommendations for modernisation of the fleet and rationalisation of routes and cargo handling. The Regional Development Strategy (Bahamas, Ministry of Development, 1974) gives a concise summary of inter-island shipping and notes that none of the recommendations put forward by Wallace Evans have yet been taken up.

Twenty-three mail boats received Government subsidy totalling $ 1.3 million in 1976 ($ 0.75 million in 1967); there are also a number of unsubsidised trading boats. Most routes radiate from Nassau to individual family islands. Exuma and Long Islands are connected along a radial line from Nassau, as are Rum Cay and San Salvador, and Long Island and Inagua. Most boats stop at more than one port of call on the islands they serve. This appears to be a custom carried over from days when no road link existed between settlements. As even today few trucks may be available to carry goods along the newly constructed roads, the custom may not have outlived its usefulness.

Criticisms levelled against the present system are that, despite a heavy subsidy, it provides inefficient carriage of goods, a rather limited service for passengers and is poorly organised.

AIR TRANSPORT

The national airline,Bahamasair,operates regular services to all the main islands except Acklins, whose inhabitants cross by ferry to Crooked Island if they wish to travel by plane. A number of island communities (Ragged Island, Rum Cay and More's Island) have no air service. Some services are twice or three times daily while others are offered only twice a week. Schedules are available from the airline or Ministry of Tourism and up-to-date information about airstrips is available from the Department of Civil Aviation. A comparatively large number of privately operated small planes serve the needs of the more prosperous islands.

ROADS

Many island settlements, which as little as 10 years ago were linked only by sea, have now been linked by road. Major roadworks have recently been undertaken on Grand Bahama, Andros, Abaco, Cat Island, Long Island, Acklins and Mayaguana. This work has included the creation of completely new spine roads in Cat Island and Acklins. A complex network of forest roads, some of excellent quality, has also been constructed in Andros, Grand Bahama and Abaco during the course of forestry operations in the last 20 years. Few populated settlements on the 11 major islands are not linked with others by road. Settlements in most of the islands, with the exception of Exuma and North Eleuthera, are situated in such a pattern as to allow them to be linked by a simple spine road.

Some islands, notably Long Island, are well supplied with side roads, i.e. roads off the spine road which gives access to farm land and to the shore, but such roads are notably absent in several other islands.

Roads in most areas south of Georgetown, Exuma, are unpaved; most of the Government constructed network in Exuma, Eleuthera and Cat Island is paved or has a bitumen-sprayed surface and there are stretches of paved road in Abaco (around Marsh Harbour) and in Andros (Stafford Creek to Fresh Creek, San Andros to Nicholls Town and Lowe Sound). Many of the roads in the Freeport area of Grand Bahama are built to a high standard and a paved Government road exists eastwards through High Rock Village as far as Pelican Point Settlement, its quality deteriorating eastwards. Islands with areas developed for the sale of land (Exuma, Eleuthera and Grand Bahama in particular) have a large mileage of subdivision (i.e. road subdividing residential lots) mostly leading nowhere. A large road mileage is also associated with forestry on the pine islands. It is reported that due to lack of systematic maintenance some roads in Exuma and Eleuthera have fallen into disrepair as also have the heavily used sections of forest road regularly graded by Owens Illinois on Grand Bahama, Abaco and Andros until their departure early in 1975. Ungraded roads deteriorate within months, and within 2-3 years potholes and the encroachment of grass, shrubs and pine trees may make them impassable – though they may be cleared at relatively low cost.

The least satisfactory roads occur in Crooked Island. The main road from the mail boat landing at Landrail Point to Cove (the ferrylanding to Acklins) is narrow and in places rocky and rough.

TELECOMMUNICATIONS

Whereas many private subscribers are individually listed in the Bahamas Telephone Company directory for Eleuthera, Abaco, Exuma and of course Freeport and New Providence, most islands either have no private telephones or very few. Calls are therefore made during set hours at one or two stations throughout each island. This is an inefficient practice, demanding time (queuing is normal) and transport to the operating station. If a 'voice contact' is lost and repairs are not urgently effected, messages are sent by morse code, and both the individual and the community suffer temporary isolation.

SUMMARY

1. Most of the 23 subsidised mail boats operate on routes radial from Nassau.
2. The system has been said to be inefficient, to provide a rather limited passenger service, and to be poorly organised.
3. Despite increasing use of air services, mail boats continue to be indispensable.
4. Air services operate to most of the inhabited islands at frequencies which reflect the profitability of the route and the predicted volume of traffic.
5. Many private planes carry individuals to and from more prosperous islands which were previously linked only by sea.
6. Many settlements have recently been connected by road.
7. Major roads and whole road systems have been created both as public works and in the course of forest exploitation and real-estate development. Roads built for the two latter purposes are particularly subject to deterioration.
8. The least satisfactory roads are in Crooked Island.
9. Except in Eleuthera, Abaco, Exuma and the two main urban centres (Freeport and Nassau)-, most islands have very few or no public telephones.

Chapter 12 Land tenure

PRIVATE LAND

Recorded ownership of land in the Bahamas began in 1629 with the Adventurers. After 1717 (the time of Woodes Rogers) all the land in the Bahamas was vested in the Crown whose agents at various times disposed of parts to private individuals and to companies. The early history of ownership is referred to in Chapters 5, 7 and 10 of *A History of the Bahamas* (Craton, 1968) but is not reviewed here.

Many of the small, privately owned areas previously formed part of much larger estates originally granted to aristocratic early settlers. Areas with no obvious utility for traditional agriculture (namely 'pine barrens', areas of land subject to flooding and excessively dry, rocky or saline land) have for the most part remained with the Crown. Today with a contraction of rural population and a decrease in farmed acreage, there appears to be an excess of land over requirements in many islands and many families own large areas of land which lie idle, but which they are pleased to hold as a security against the possibility of future property sales. In general ownership of quite large tracts of land is relatively widespread except (see later) south of Crooked Island.

In the past, when island populations were larger and most food had to be grown at home, land may well have been in short supply as cut and burn farming* can require 100 acres of land to maintain a yearly cut area of 10 acres. Any large family with only 10 acres would have had great difficulty in surviving by subsistence farming alone. As pine barren land, as the name implied, was not considered agriculturally productive, it was rarely taken into private ownership; coppice land, on the other hand, was.

Table 9 shows the land ownership situation throughout the islands studies. The exact whereabouts of private and other lands is shown on the 1:25 000 and 1:50 000 scale resource maps accompanying Volumes 1-8 of the *Draft Land Resource Study.*

The ownership and location of a proportion of the individual parcels of land can be obtained from the Department of Lands and Surveys' cadastral plans and records.

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*A primitive system of farming widespread in tropical countries in which forest, woodland or other natural regrowth is periodically cleared by axe, fire, cutlass or machete, maintained in cultivation for a number of years (rarely more than 3 or 4) then abandoned for another similar area which is similarly cleared. Growth of weeds and a decline in the natural soil fertility (high at the beginning) necessitates abandonment. As much as 10 or more times the annual cleared area is required to sustain such a system.

TABLE 9 Guide to the distribution of private land, Crown land, and commonage

Island	Present ownership	Remarks
Abaco	21 500 ac owned by the sugar company, more than 60% of all north-east and east facing coastal land within 1 mile of the shore is private	See Chapter 4
Andros	Main private tracts are around San Andros, Mastic Point, Nicholls Town and Andros Town; most coastal land in Mangrove Cay and South Andros also private	Some land grants associated with development of forestry; some with plantation sisal
Grand Bahama	Most land east of Gold Rock Creek still Crown land; many small areas of private land along south coast; most land west of Hawksbill also private; area between Hawksbill and Gold Rock Creek owned by the Grand Bahama Port Authority	Early 19th Century land grants. Grand Bahama Port Authority purchase, 1955
Eleuthera	Little Crown land left unalienated; one large area in North Eleuthera; large areas have been sold to property development companies	Large areas of commonage for Harbour Island, Spanish Wells, Savannah Sound, Tarpum Bay and Rock Sound; early estates
Cat Island	Most land private; the largest areas of Crown land at the Bight airstrip and east of McQueens	Early estates
Exuma	Most land privately owned, some held in common; large areas have been sold into the hands of one or two property development companies	Originally land deeded to inhabitants from the estate of Lord Rolle on his departure from the island
Long Island	Most land privately owned by Long Island families; small areas of Crown land (each of 100-300 ac) throughout the island are mostly wet	Private land owned by descendants of the slave owning class who remained on the island
Crooked Island	Most of the dryland privately owned by Crooked Islanders; sandy Crown lands at Majors Hill and Colonel Hill are subject of traditional farming rights	Early estates
Acklins	Less than 10% of the dryland area is private; most belongs to the Crown which however exercises no right over it and does not exclude farming land use	At least two original 18th century estates are now recorded as Crown land; did not pass to the early inhabitants
Mayaguana	No private land east of Abraham Bay; less than 10% privately held throughout the island	No 18th or 19th century estate lands granted
Inagua	Island at least 95% unoccupied Crown or National Trust land. Small areas of private land occur adjacent to Matthew Town; several square miles of flooded and high watertable land owned by the salt company	No early estates granted

The financial rewards of selling property to development companies and speculators has resulted in the alienation of large areas of private land to North American and European interests. Exuma and Eleuthera have disposed of large areas of land in this way. In other islands, Long Island and Crooked Island for example, very little land has been alienated to outsiders. The very limited extent of private ownership in some islands, Mayaguana, Acklins and Inagua for example, has excluded their inhabitants from the property sales boom of the last decade. Even had there been property to sell it is doubtful whether these more remote islands would have been very attractive to most buyers.

CROWN LAND*

Crown land exists throughout the Bahamas; on some islands more than on others. Overall, Crown lands occupy 70% of the total land area and all offshore areas. The Bahamian Minister of Development is responsible for these lands and with the concurrence of his Cabinet, may dispose of them. In the past they have been alienated under the following forms of tenure; Annual Licence of Occupancy; Leasehold (for periods of 5, 10, 21 or 99 years); Conditional Purchase Lease (for periods of 3 or 5 years); fee simple title (special cases); permission to explore (to conduct feasibility studies for periods up to 2 years).

These forms of tenure are still in effect but have been modified so that lands are no longer leased for periods longer than 21 years and Conditional Purchase Leases are no longer granted for lands intended for agricultural use. Leases for agricultural lands are kept short since better control can be effected in this way. Under the new system, purchase leases are granted for homesteading, for certain types of reclamation and for some large scale developments.

Various forms of tenure are granted on a range of acreages as follows:

Annual Licence of Occupancy		1-5 ac
Leaseholds	(residential)	½-2 ac
	(agriculture - small holding)	2-5 ac
	(agriculture - large holding)	20-50 ac
	(agriculture - commercial)	Up to 2 000 ac
	(industry and resorts)	2-10 ac
Purchase Lease (homestead)		¼-2 ac

Use of Crown lands will in the future be in accord with zoning principles, land being reserved for its best suited use within a wider policy of regional industrial development.

Every effort is made to provide suitable Crown Lands for development for resort, industrial and agricultural purposes by domestic or foreign investors, and it is Government's policy that Crown lands should, wherever it is feasible, be the Bahamas contribution in joint company participation ventures for certain development projects. In such circumstances either a long (21 year) lease is granted or, exceptionally, the whole or part of the land required for a project may be sold to the developer.

GOVERNMENT LAND

Government lands for public purposes (public buildings, schools, official residences, landing places, airfields, playgrounds, parks and roads) are scattered throughout the islands. These lands, which account for about 1½% of the total land area of the Bahamas, vest in the Treasurer. While both Crown and Government lands belong to the people as a whole, Government lands are distinct inasmuch as they are in definite use for the public good. (They also form a much smaller proportion of non-alienated land than does Crown land).

COMMONAGE

The Commonage Act (Chapter 123 of the Law of the Commonwealth of the Bahamas) defines such lands as 'lands held in common'. This includes any lands which have been

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*Land now at the disposal of the Government of the Bahamas retains its traditional name 'Crown land'.

granted to more than 20 people and not partitioned. The Act requires commoners to maintain and keep a register of their members in each settlement in which any land is held in common. It is only on Eleuthera that such registers of commoners have been formed. Other lands which might also theoretically be regarded as commonages but which are never referred to as such occur on Grand Bahama and in Great Exuma (Rolleville and Rolle Town).

LAND REGISTRATION

The Department of Lands and Surveys does not maintain a land register, but has a fairly complete record of all Crown Grants issued since 1786. The Government is (in 1976) about to consider legislation in regard to land registration but no complete register of lands can exist until such time as this is enacted and brought into effect. At the present time all conveyances of land are recorded in the Registrar General's department but this register does not detail the location of individual parcels of land and their history of ownership.

There are numerous areas in the Bahamas for which no clear title ownership exists. Only when a title is actually required (usually on account of a land transaction) does the claimant (or claimants) endeavour to establish one through the Quieting of Titles Act, as this course of action is very costly and time consuming. If a clear Abstract of Title can be provided, no further proof of ownership is required.

SUMMARY

1. From 1717 until the Bahamas assumption of independence in internal affairs, 'The Crown' (lately the Secretary of State for the Colonies through the Governor of the Bahamas) controlled the disposal of all land not privately held.
2. Ownership of quite large tracts of land is relatively widespread.
3. The inhabitants of the pine islands tend to own coppice areas rather than pine covered land; much of the pineland is alienated to companies.
4. The inhabitants of Eleuthera, Cat Island, Exuma, Long Island and Crooked Island are relatively well endowed with land, though in the three islands first mentioned, much has been sold to property developers. The inhabitants of Acklins, Mayaguana and Inagua own little.
5. Land sales have been particularly large in Eleuthera and Exuma.
6. 70% of Bahamian land is defined as Crown land, i.e. owned by the State and the responsibility of the Minister of Development. This land is scattered throughout the Bahamas.
7. Various forms of lease of Crown land, none longer than 21 years, are offered.
8. The government now has a clear policy which it applies to the alienation of Crown lands.
9. Eleuthera, notably, but also Exuma and Grand Bahama, have commonage land.
10. There is no land register.
11. Most Crown grants since 1786 are recorded at the Department of Lands and Surveys.

Chapter 13 Land use

HISTORICAL ASPECTS

Columbus, who landed at San Salvador and visited Long Island, Crooked Island and Long Cay in 1492, described the Amerindian Arawaks occupying the land as pursuing what must have been a cut and burn agriculture, growing maize, cassava, cotton and other crops. Their only domestic animal was a type of barkless dog. These people left little trace of their farming on the landscape.

Settlements were established at Governor's Harbour and Dunmore Town in the 17th Century. Later, before the introduction of the plantation system for the production of cotton by Loyalists after the American War of Independence (1776), many of the islands were periodically exploited for valuable hardwoods such as mahogany, satinwood, horseflesh and *lignum vitae* and for dyewoods such as brasiletto and logwood which were taken to America and to England. Pine lumber from the northern islands was used in the building of ships and houses. Settlement was probably minimal until salt production commenced in the 18th century in Inagua.

Since the 18th Century, the Bahamas has exported valuable hardwoods (small quantities of *lignum vitae* have been exported from Acklins within the last decade); cascarilla bark (sweetbark), used to prepare an aromatic bitter; plait prepared from various types of palm frond, bat guano ('cave earth'), used as a fertiliser; and marine products including sponges, turtle shell, helmet shells used for Cameos, ambergris, etc. The islands have also provided pine lumber planks for boat building, other local uses and for export, and latterly pit props and pulpwood for major industrial corporations. There has throughout the period been a continuation of subsistence farming (either linked with commercial monoculture or as the sole land use).

The most notable agricultural effort between the 1780s and the 1830s was plantation cotton, based on the labour of imported slaves. Large fields were laid out and cleared with little regard to the lie-of-the-land and soil erosion. A great number of dry stone walls were built to enclose and channel livestock, to enclose water points and to mark property boundaries. Most of these walls can be identified, often overgrown, in the present landscape along with the substantial ruins of thickwalled plantation houses, their associated kitchens, storerooms and workers' quarters. Characteristic of this time are large rectangular fields which can be seen in shadowy outline on air photographs taken today. The large rectangular fields of North-East Point, Inagua (Volume 8 Text Map 2) probably originated for different reasons in the 1850s and 1860s (see later) though they have continued in use until recent times.

There is material and written evidence of cotton plantations in Eleuthera, Long Island, Crooked Island and Acklins but not in the pine islands (excepting New Providence) nor in Mayaguana and Inagua. For a short time at their peak, plantations in Exuma and Long Island jointly reached an export of 600 tons of clean cotton lint annually from 4 000 acres of cleared land. McKinnen (1804) wrote of a visit to a plantation house in Acklins; Farquarson (1832) describes one in San Salvador.

Until 1848, much of the salt used in the Newfoundland Cod Fisheries was obtained from the Turks and Caicos Islands. Following secession of these islands from Nassau rule in 1848, the Heneaga Salt Company invested in salt production on Inagua where it organised the pre-existing haphazard layout of pans, laid out a much improved settlement (Matthew Town) and built a light tramway to haul salt from the pans south-east of the town to a jetty on the adjacent west coast. Similar work was carried out at Duncan Town (Ragged Island), Port Nelson (Rum Cay), Williams Town (Little Exuma) and on Long Cay and Rose Island. Some of the salt pans are still in use, some are defunct while those at Inagua, flooded over, form part of the much larger reservoirs feeding the Morton salt operation further north. There are many other places, for example the east coast of Acklins, Cat Island, Clarence Town (Long Island) and until 1965, Mayaguana, where salt pans were established and can still be seen.

The islands have a history of certain cash crops apart from cotton; these include sisal, pineapples, and bowstring hemp. Where crops were plantation grown they appear eventually to have failed either because of overseas competition or changed economic conditions imposed from outside.

Sisal, established as a plantation crop around Mastic Point, Andros in the late 19th and early 20th centuries failed to prove profitable. The sisal plantation in Cat Island in the last quarter of the 19th century suffered severe competition from East Africa and Mexico whose product was cheaper, stronger and better washed, there being inadequate freshwater for retting and washing the Cat Island fibre. The relics of Cat Island's industry are to be seen about 3 miles south of New Bight at Point Tucker where a settlement, now called The Village,was abandoned around 1910. Remains of a small jetty, a tramway right across the island, retting pits hewn out of rock and the ruined fibre preparation room are still easily identified in the landscape.

Areas of Abaco north of Norman Castle were run as a sisal plantation by the Bahamas (Inagua) Sisal Plantation Ltd. Sisal was grown as a cottage industry in Long Island and Crooked Island. In 1908 Long Islanders grew 250 acres of sisal and produced 2½ million lb of fibre which is estimated to have given each family an annual income of about £22 sterling. It is also reported that Crooked Island's only income after the First World War was that derived from sisal. Cottagers not only exported the raw fibre, but also twisted it into various grades of rope using simple wooden windlasses (the remains of one such stands near the shore near Bainstown Long Island). Mayaguana produced little sisal, while efforts to produce the fibre at Blakesfield now a deserted settlement 1½ miles north of the Morton Salt Works in Inagua, failed for lack of fresh washing water.

Pineapples were a very important crop for some years in the 1890s. They were cultivated almost exclusively on the many pockets and hillsides of red aluminous lateritic soil, and were shipped in Schooners to the US and to England. In one year it is recorded that Bahamian pineapples satisfied the whole North American market. Many deteriorated in transit and pineapple canneries were set up on Eleuthera and in New Providence. Little evidence remains in the landscape of the once thriving industry which was stifled in the early 1900s by competition from Hawaii and Cuba. There are, however, a number of areas around the Bight (Cat Island), Gregory Town (Eleuthera), and Buckleys just south of Deadmans Cay (Long Island) where pineapples of excellent flavour are still grown on a small scale.

In the period 1939-45 *Sansevieria* or bowstring hemp - a fibre crop valued for brush and mat making was encouraged in Cat Island (at Bains Town), in Andros and in Exuma, but it came to nothing.

Livestock numbers in certain islands, notably Long Island and Exuma,have been high in the past. In 1913 Long Island carried 5 800 sheep, 850 goats, 314 horses and 200 cattle; in 1937, 7 500 sheep and a lesser number of goats together with other stock including pigs. Exuma in 1937 had 5 963 sheep, 1 800 goats, 330 cattle, 173 horses, 445 pigs and 1 158 turkeys. The number of goats subsequently rose, but sheep declined. Other islands are also recorded as having stock but in much smaller numbers. Until recently, few stock were kept on the pine islands.

CURRENT LAND USE

Land use mapping

In order to establish the present pattern of land use, Volumes 1-8 of the *Draft Land Resource Study* contain an agriculturalist's description of current land use together with maps of all islands except Andros and Grand Bahama. Islands south from Cat Island were investigated via air photography in 1970-1. For Abaco and Eleuthera (mapped in 1969-70), the 1958 photography had to be used. The land use map of Eleuthera is the most complicated inasmuch as it includes eight land use types and 12 vegetation types. The number of types was reduced for Cat Island and still further for islands farther south, when it was realised that vegetation mapping was not important enough to warrant the time spent on it and that a wide variety of land uses were not present except in Eleuthera. For the south-east islands the mapping concentrated on indicating field-by-field those areas with active farms. The land use maps therefore show considerable progression in style and content. The earlier ones (and very soon those from 1970-1 photography) will mainly be of historical value, though a useful record for evaluating later changes.

One way of categorising current land use is on its level of investment. 'No investment' land use would thus apply to the traditional system of cut and burn farming; 'high investment' to modern mechanised farming, intensive livestock units, etc. An intermediate, low-investment style is associated with planting of fruit trees and preparation of land which is later hand cultivated. These terms are used thus in the following account.

Patterns of land use

Village shape and settlement distribution

Village distribution is accurately reflected in Separate Map 1. The majority of villages are coastal with a preference for the western leeshore or in some cases for the southern leeshore as in south Cat Island and Grand Bahama. The opposite coast has been settled where the western shore is mostly marshy; protection for such windward sites may be offered by a chain of offshore cays as in Exuma and Abaco, a barrier reef and rocky shallows (as in the west coast of north Andros) or simply a well-developed reef (northern Acklins, Crooked Island). Few settlements are located wholly inland, the most notable being those in north Exuma and in western Crooked Island. There is a variety of village shapes. The majority of villages are long and narrow, strung out along the shore or a favourable rocky beach ridge. Villages such as Abraham Bay, Mayaguana, lie compactly around a crossroad (Volume 8, Plate 20); Colonel Hill (Crooked Island) lies at successive levels up an inland ridge overlooking the ocean. Other villages as for example Cabbage Hill 2 miles west of Colonel Hill and Rolleville, Exuma are rather dispersed yet still arranged in compact shape. Planned settlements such as Matthew Town, Inagua, and Duncan Town, Ragged Island, and until recently Owens Town, Andros, are arranged about a grid pattern (see Plate 27).

Either immediately adjacent to or within the dispersed village plan, inhabitants of the settlement farm land which is used for domestic animals and fruit trees. Animals include goats, poultry and occasionally a few pigs in makeshift wooden sties. Some islands support sheep. Fruit trees include the full range of traditional species. Both sweet potatoes and a few vegetables (in sandy ground) and maize (on rockland) may also have their place within the village. At the present time with the farming labour force in most islands reduced to women and older men, the amount of food produced or reared within the yard may be a considerable proportion of the total. In parts of Long Island and Crooked Island, houses are set back within a walled garden area containing fruit trees instead of giving directly on to the road. In Long Island, agricultural 'quarry pits' (i.e. small cultivated areas created by partly backfilling, with soil and rock,borrow pits and quarried areas which intersect the water table) are also commonly located within sight of the owner's house. Immediately beyond the village, land may be arranged in a pattern of small walled fields.

At a distance from the village, only a small proportion of the land space is occupied by farming. Once upon a time it must have been much more. Which areas are used depends on accessibility, ownership, land type, land quality and what type of land the family members are youthful enough to prepare. There is evidence that because of the contraction of the work force and of the area of coppice cut down annually, the period of abandonment of the less easily worked or more distant areas has increased, thus allowing coppice to grow to a greater height.

Conversely, farmers tend to cultivate land closer to the village especially when they have no means of transport; this land therefore receives more attention and consequently shorter bush fallowing. Despite this, people who depend to any extent on subsistence farming – who have no adequate alternative means – still walk 3 or 4 times a week in some seasons up to 4 miles to cultivate whiteland soils on the east and north shore of some islands.

For those who have pickup trucks or horses, distance from the village is less important; newly cleared fields are found along new roads up to 5 miles from the nearest settlement. Farmers find themselves free to choose land that suits them best along a number of new roads despite the fact that the land may belong either to the Crown or to an absentee real estate company and its clients.

The size and the shape of individual fields are often characteristic within different types of land. Fields on blackland with relatively few cultivable sites per acre are frequently large and of more or less regular shape. In contrast, many whiteland fields are small; they also tend to be elongated along the swash (a wet area commonly occurring between sandy shoreline ridges and rocky terrain inland). By cultivating areas as low as possible on the sandy ridge, farmers take advantage of moist conditions, thicker vegetation and more leafmould. The same elongated regular fields are found in beach ridge rockland. Similarly the better soil conditions in hollows between opposing hills give rise to characteristic field shapes as do soily zones extending along the base of some ridges.

The landscape of shifting cultivation is one of scattered fields separated by areas of uncultivated bushland. An exception to this is found on land which is prized either for subsistence crops or for commercially orientated low-investment production of crops such as tomatoes (or, previously, pineapples). In such areas a continuous mosaic of fields often develops and land is short fallowed, rather than abandoned. This is true of an area of low flatland 'Rock Sound tomato land' in Eleuthera (Volume 2, p. 60); of some flat whiteland (e.g. north of Colonel Hill and at Port Royal, Cat Island); and of hilly rockland with red soils such as occurs at Mountview Estate, Cat Island. Areas of land in Crooked Island and near Snug Corner, Acklins that have a near continuous sandy profile with rock may have some of the attributes of stable land use, each area being walled off into more or less permanent fields.

Traditional ('no investment') land use

Features of the cut and burn method of farming (shifting cultivation) are well known to most Bahamians. They include the selection and clearing of land with a suitably high growth of coppice or 'scrub' i.e. with a suitable accumulation of surface leafmould. The bush is cut to leave larger trees while medium girth trees are often lopped off at shoulder level. The cut branches are then laid evenly over the field and left to dry (Volume 2, Plate EL8). After the first rain, usually in May, they are fired when sufficiently dry to burn down to ash. If the leafmould is too dry and the 'burn' too hot it may reduce the thickness and value of the underlying leafmould soil. The net effect is to clear the land, to burn up weeds and seeds, to sterilize the ground and to convert the vegetation to ash with considerable fertiliser value. Each field is then planted, usually to a wide variety of crops. The cutlass used for cutting the bush is also used for planting the seeds and each crop type is sited in the place best suited to its needs. The cutlass is used again for weeding.

After using the field for 2 years it is normally easier to shift to new land and repeat the cutting and burning process rather than to contend with the rapid weed growth and the soil's declining fertility. Where youthful labour is scarce the effort of cutting out a new field may be avoided for perhaps an additional year by weeding.

Certain types of land tend to be preferred for certain crops. A list of these is given on p. 17 of Volume 2 (Eleuthera), an island where there appears to be quite a strong tendency to select land type). It is noted that on Crooked Island (Volume 7 p. 64,), which has a much drier environment, farmers plant over a wide range of land types to reduce the risk of total crop failure in unfavourable seasons. In the farming year, men, women and children each have their special tasks, though it is not unusual nowadays (with fewer men around) to find women cutting, sowing, weeding and harvesting.

Where fields are a long way from the village, a farmer may, three or four times a week, set out on foot at 6 a.m. to work from say 8 until 11 and then return. In rare instances a thatched shelter may be erected to provide cover during the day, or at night during critical periods such as planting time and harvesting.

People farming in areas remote from their own villages (as for example on the Plana Cays, on Attwood Cay or (in the recent past) at North East Point, Inagua) may set up temporary camps regularly supplied by a small sailing boat.

Far fewer livestock are kept now than were kept in the recent past. This is particularly true of horses, sheep and goats. A few horses are used for transport in Cat Island, Long Island and Crooked Island. Some goats and sheep are kept within naturally confined and easily fenced areas of land (as at Zanicles, Cat Island and Williams Town, Exuma). Others (Plate 22) are kept penned in feedlots (as in Inagua where the survey recorded about 100 goats), and elsewhere in small numbers. Goats are commonly kept on a shifting tether particularly on grassy roadside verges and weedy lots within the village.

The number of cattle in Eleuthera, recently standing at about 500 head, is now reduced to about 50 head, all at Rock Sound Ranch (see later). Elsewhere, only in Cat Island does the survey record the presence of cattle though it is likely these have now succumbed to their inadequate rations. In Andros, cattle were once kept at the Twin Lakes Farm and some escaped from fenced paddocks and remained loose on the Island when the farm closed down. Now all the island's cattle are located within the BARTAD farm (see later) which also rears sheep and goats and keeps a number of working horses. Dogs which run wild in packs are a menace to small livestock both in Andros and elsewhere. Although pigs and poultry are kept by some households most of the pork and dressed poultry come from intensive units in Grand Bahama, Eleuthera and New Providence. There appears to be no tradition of collecting eggs for eating.

'Low investment' land use

Some farmers have money and are prepared to spend it ahead of time in order to obtain a better farm income. In some cases they employ Haitian labour. They often run a pickup or a car which is used on the farm. This group includes, for example, those farmers of northern Eleuthera who plant citrus orchards and bananas to sell in New Providence. Their farming activity gives rise to a different farm landscape which includes wire fenced pastures of fixed outline, clearly definable, sometimes row-planted orchards and banana groves, and a greater density of small farm roads. Their crop patterns may be more sophisticated than those of the wholly traditional farmer, involving for example 3 years of annual crops followed by 10 years of use for citrus groves, succeeded by several years' use of the land as fenced orchards (Volume 2, p. 17).

PLATE 22 Sheep penned in a feed-lot, North Eleuthera. Their rations may include the cut branches ("bough") of locally available shrubs and trees, jumbay, cinnecord, ram's horn and gum elemi.

PLATE 23 Low-investment land use: ripped high watertable rockland less many of its larger blocks which have been carried off the field or crushed. A commercial farm near Benzie Hill, Long Island.

There are a number of distinct types of 'low investment' farming. Exuma farmers invest money to programme (a) shag ponds (marshy freshwater ponds which, by infilling, can become productive - see Volume 6, p. 59 and Plate 4 & 5 in the same volume) east of Mount Thomson, (b) muck soils (Volume 6, p. 58 and Plate 2 in the same volume) at Rolleville, and (c) red soils at Williams Town, Rolletown, Mosstown, and elsewhere. These areas of more intensive land use may be fallowed but are not abandoned and are in some cases considered of sufficient value to the owner for him to build walls to enclose his own parcel of land. Each of these improved types has a continuous rock-free soil which can be weeded and row-planted. Vegetables (particularly onions) grow well and many are sold in Nassau.

In Long Island and elsewhere, money has been invested in ripping hard rockland but this has only sometimes improved the land's long-term value to the farmer (see Plate 23). Ripping is normally carried out on non-tillage rockland to allow plants to root beneath the otherwise unpenetrated surface into the moist rock zone below. The ripped landscape is characterised by distinctive straight-edged fields which almost always lie adjacent to the road. It is pointed out (Volume 6, p. 65) that the rainfall, which is sufficient to supply a sparsely planted crop on unprepared rockland, is clearly inadequate to sustain a crop planted 5-10 times more densely on land which has been ripped, but which relies on rainfall alone.

Further preparation and removal of blocks of rock from the surface makes ripped land easier to use but may create acute problems of excessive free lime, problems that are far less severe in tillage class rockland. The largest commercial farm in Long Island, which exports bananas, chillies, melons and other products to Nassau, was prepared in this way. In Acklins there has been a certain amount of unsuccessful ripping of land underlain by saltwater. In North Andros money has been invested in poor land along the Queen's Highway, setting greater value on roadside sites than on land quality. Use of ripped poor-quality, non-tillage rockland is commonplace in New Providence where the disadvantages of the land are partly offset by the advantages of proximity to a good market.

Throughout the Bahamas, farmers dynamite holes to give fruit trees room in which to develop their root systems. The alternative method of cross-trenching* or single tyne cross-ripping (Plate 25) sometimes is used while Long Island farmers achieve root-room for their trees by excavating 'quarry pits' – a practice absent from most other islands. Abandoned roadside borrow pits or pits purpose-excavated to the watertable are backfilled with rock debris, plant trash and soil in such a way as to allow the pits to be used intensively for vegetables and fruit trees.

'High investment' land use

'High investment' agricultural land use is confined to Abaco, Eleuthera, Grand Bahama, Andros and New Providence. Islands further south fall into the agriculturally 'low' and 'no investment' classes.

Volume 1 of the *Draft Land Resource Study* discusses the history of large-scale farming in Abaco beginning with the Crockett Development and the Heveatex Plantations in the 1940s. The Scott Matson farms, a Florida company growing fruits and vegetables which succeeded this, is said to have been the first truly commercial operation in the island. It occupied land in the north-east of what is now a 2 500 acre sugar estate. This estate, owned by Bahamas Agricultural Industries Limited (BAIL), was in production when Volume 1 was written (1970) but closed down in 1971. In 1976 it has neither been sold nor reopened. It occupies ploughed unirrigated rockland varying in

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*Cross-trenching is a method of (a) providing 'root-room' for tree crops and (b) securing a favourable position for the roots in relation to the watertable. It involves the excavation and backfilling with soil of two sets of trenches which intersect each other. A less expensive but similar pattern may be created by using a bulldozer to draw a 2-3 ft ripper through the rock. The resultant fractures allow roots to penetrate into moist rocks below the surface.

character between very good and poor Capability Classes* 2-4 on which unirrigated yields of sugarcane, though good in parts, were low overall. Figures are given in Volume 1 for the 1969 and 1970 production.

A later agricultural development which by report is a most successful operation, occupies 1 500 ac of Capability Class 2 and 3 soily rockland in Norman Castle area (the same company—Key and Sawyer Farms—also operates two smaller areas (one sandy) in Central Abaco). It grows vegetables, avocados, bananas and other crops. These are mostly packed in extra-large crates in the field, and exported by sea via Marsh Harbour to Florida. The company was developed and is run and part-owned by two local Bahamians.

The Eleuthera report (Volume 2 of the *Draft Land Resource Study)* discusses the history of the Hatchet Bay Plantation at Alice Town and the poultry farm (a part of the same enterprise) as it was in 1971. The ownership and operation of the enterprise have since changed; it no longer has a milking herd, and since 1975, under the control of the Bahamas Agricultural Development Corporation, has concentrated on poultry (fed on imported rations), and eggs. It also blends milk solids. The report also describes conditions at the Rock Sound Ranch, to the north of Rock Sound. When known as Three Bays Farm under Colonial Development Corporation management it was unsuccessful in producing vegetable and other crops (Volume 2, p. 16) and was subsequently acquired for pedigree cattle rearing. The report points out the poor quality of the farm's rockland and its low watertable as factors adverse to its success. The Ranch now (1976) has only 50 cattle, most of them pedigree Charolais whose best progeny are exported.

Descriptions of agricultural land use in Grand Bahama relate to 1969 when there were six farms housing 167 000 broilers and 76 000 laying hens, also two other farms housing 340 pigs. The skilful management of Grand Bahama Farms Limited, a 25 acre irrigated and mechanised holding producing vegetables, melons, grapefruit and irrigated bananas, was noted. The report also refers to a well managed, one acre hydroponic farm producing high quality salad crops, melons, etc.

The Andros report describes the very specific aims of the San Andros farm, these being to supply the Florida market with cucumbers, crook squash and other vegetables including, lately, tomatoes, at those times when the Florida harvest is adversely affected by frost. It comments on the opportunist nature of such farming, which though highly efficient and well-managed (particularly in its response to market demand) rarely employs the whole prepared acreage of high class soily rockland, provides only winter crops, and harvests the whole crop only in such years as it is profitable to do so. The report gives production figures (p. 33) and contrasts the method and productivity of this operation with traditional farming in the island.

It also describes the ill-conceived Colonial Development Corporation Twin Lakes Farm project which in 1953,despite 'detailed investigation' by an 'agricultural mission', failed,as might have been predicted, on lime 'marls' which it was impossible to drain. The recurrent failure of agricultural efforts in Andros is perhaps linked with the wide variety of entrepreneurial groups experienced in many things but not in farming who have engaged in agriculture on the island.

The BARTAD project was initiated after the production of the Andros report (Volume 4). Its 2 000 acre site, much of it good class tillage rockland, 7 miles south of the San Andros Airport, was selected initially by reference to the project's land capability map (Separate Map 2). The project's aim is to maintain a central research station occupying 500 ac and up to 16 satellite farms which will be leased to competent project-trained Bahamian farmers. At the time of writing, four satellite farms and their farmhouses have been developed. Agriculture already includes vegetables, fruit trees and a variety of livestock, the satellite farmers being obliged to fit in to a cropping pattern prescribed by the project management (see Plates 24-26). The appearance of an Andros 'pioneer spirit' and a growing attachment to the inland site augurs well for the project's future.

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*See Chapter 14 for definition of capability classes.

PLATE 24 Traditional farmers from Andros discussing with Bahamian project staff the advantages of modern, irrigated vegetable-growing techniques at the BARTAD project.

PLATE 25 Establishment of a row of young avocado pear trees in Class 2 tillage rockland at the BARTAD project, North Andros.

PLATE 26 An imported breed of cattle from Texas grazing in carefully prepared paddocks at the BARTAD project, North Andros.

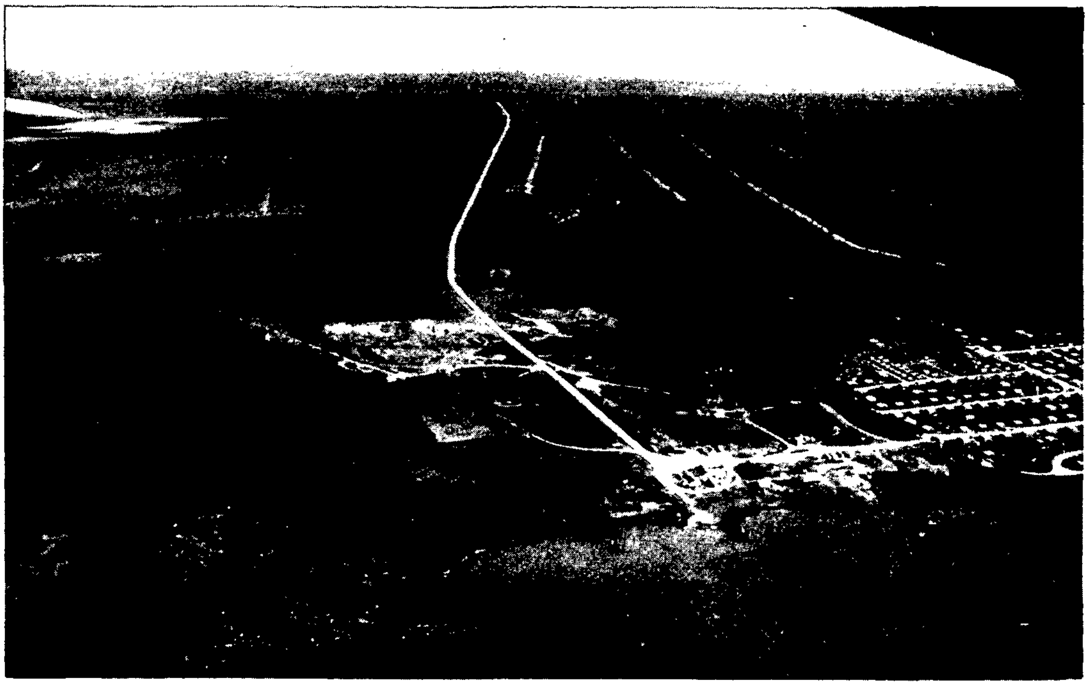

PLATE 27 Owens Town (now dismantled) as it was in 1971. The camp housed several hundred Haitian forest workers for 7 years. The previous phase of timber exploitation is evidenced in the centre of the picture by huge piles of sawdust and ruins of a sawmill.

Gathered products

Gathering has little effect on the Bahamian landscape. Extraction of worthwhile hardwoods is all but a thing of the past. Collection of cascarilla bark (used as a source of aromatic bitters) which gives rise to coppicing of the shrub is only noticeable where areas have been deliberately planted for this purpose. Its effect on the landscape differs little from cut and burn farming. The effect of collecting palm fronds for making plait (for mats, hats and baskets) goes unnoticed. So also does beachcombing which in some islands may provide marketable objects such as large glass fishing floats, sawn timber, rope and articles for use about the house. The digging of bat guano, formerly in widespread use as a fertiliser, has a purely local effect on the landscape.

Along the seashore there are certain customary sites heaped high with the discarded shells of conchs whose meat is a staple food. Offshore conch crawls* in 2-3 feet of water often occur in the same vicinity. Night crabbing (catching land crabs, which are another source of food, 'walking' through the bush after the first rains in May and June) is an important business in Andros and Mayaguana particularly. In Andros, the lamps used (bottles of kerosene with unguarded cotton wicks) are the frequent and predictable cause of widespread forest fires.

Industrial and other uses of land

In the islands studied, there are relatively few industrial uses of land. The two salt companies, the Diamond Crystal Corporation in Long Island and the Morton Salt Company in Inagua, are, however, massive users of low lying areas which have no other economic use. Their operations involve a great deal of earth-moving and the building of causeways which are likely to have a permanent effect on the landscape. By comparison, the associated industrial plant which occupies at most a few tens of acres, is less significant. In more evolved settlements such as Marsh Habour, Abaco, and Georgetown, Exuma, and those with a tourist industry such as Nicolls Town, Andros, and Treasure Cay, Abaco, some land is devoted to public utilities and minor urban uses. Industrial land use in most of the islands, however, amounts to no more than an occasional fuel depot. Throughout the islands a large acreage of land is occupied by major spine roads and airstrips.

In all islands north of Long Island a considerable acreage is criss-crossed by subdivision roads associated largely but not entirely with speculative land purchase. The number of associated dwellings is commonly few. Massive landscape modifications completed or in process are associated with the provision of golf courses and other facilities. Though usually no longer owned by local people the more agriculturally useful land continues in use for subsistence farming.

Forestry land use

Forestry is discussed in Chapter 4 of this report. In scale, it is the most important use of land in the whole of the Bahamas.

Misuse of land

The maps accompanying Volumes 6, 7 and 8 of the *Draft Land Resource Study* show areas of disturbed land which are mostly the result of bulldozer work along the newly constructed roads. This is rightly considered a serious misuse of land likely to impede normal bush growth for scores of years and to be unsightly to the traveller. In some cases disturbed land is associated with accelerated groundwater loss.

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*A conch crawl is a close-fenced area of a few square yards set in shallow water. Conch caught by fisherman are 'stored' live in these enclosures until required for food.

SUMMARY

Historical aspects

1. Cut and burn land use by the Arawaks was replaced by exploitation for natural products before 1776.

2. European/North American settlement established cotton plantations between 1780 and 1840; subsistence farming continued.

3. Salt production flourished from 1848. Many islands were involved and some still are.

4. Sisal, which failed around 1890, was particularly important in Cat Island and Little Abaco. In Long Island it was an important cottage industry.

5. In 1890 Bahamian pineapple growers supplied the entire United States demand, but only a few are now grown.

6. Long Island and Exuma were important for livestock, their numbers were once much higher than today.

Present land use

7. Land use field and documentary investigations were supported by a mapping programme. The emphasis of this programme changed over time.

8. Most villages are coastal and on the lee shore. There is a variety of village shapes including some settlements planned on the grid pattern.

9. A high proportion of food (fruit and small livestock) is produced in house yards within each settlement.

10. Worked areas ('fields') away from each village usually have no fixed boundaries though their situation is determined by factors such as ownership, accessibility, land quality, etc.

11. Only a small proportion of the land is farmed in today's economic conditions.

12. Fields on different land types assume characteristic shapes.

13. Highly prized land may be walled and have the attributes of a stabilised agricultural landscape.

Present-day agricultural systems

14. Three types of agricultural land use are recognised:

    'traditional ('no investment')' land use
    'low investment' land use
    'high investment' land use

15. 'No investment' land use is shifting cultivation (cut and burn):

    i. There is evidence of land selection for certain crops and of the planting or sowing of crops on a wide range of land types to give a higher probability of success
    ii. Limited livestock production uses shifting tether methods, fenced areas of bushland and feed lots (browse is brought in)

16. 'Low investment' land use is associated with sale of produce to Nassau. It results in a semi-stabilised farm landscape including:

fenced orchards
infilled freshwater marshes
marsh islands
quarry pits
ripped land

It is best developed in New Providence, Eleuthera, Exuma and Long Island.

17. 'High investment' land use is comparable with that in North America. It has until recently relied on imported technology and expertise. It includes the:

Abaco Sugar Estate
Norman Castle Farm of Key and Sawyer
Hatchet Bay Plantation
Rock Sound Ranch
Grand Bahama Farms Ltd
San Andros Farm
The BARTAD project

and such failures as the farm at Twin Lakes, Andros.

Gathered products; other land uses

18. As in early days, natural products are still gathered. Cascarilla and palm fronds for plait are important plant products.

19. Land crabs and marine products including conch are important animals.

20. Industrial use of land is limited on most islands - New Providence and Grand Bahama are an exception.

21. Inagua and Long Island have large areas of land used for the production of salt.

22. Land sales are associated with complex patterns of subdivision roads, but few houses.

23. Valuable pine forests cover nearly ½ million acres. Forestry is an extremely important land use.

24. Misuses of land are often associated with thoughtless use of bulldozers.

Chapter 14 Land capability

INTRODUCTION

Once a point is reached where detailed natural resource studies (Chapters 2-9) are complete, ideas for suitable future use of different areas of land can be proposed. Future use will depend partly on present use (Chapter 13).which often indicates what success has been achieved or might be expected on any land type. It will also depend on local needs and Government policy for an area which will to some extent have been guided by interim resource reports. Where government policy is the development of mechanised farming, one set of land criteria will apply. These however would be inappropriate criteria for another type of development, e.g. tourism or industry.

In general the survey has met this problem by focusing on modern agriculture in the pine islands and a variety of non-agricultural development options in islands of the south-east. Two classifications are given in this chapter. In addition there is a scheme for producing land zoning maps for use in regional planning.

The land capability maps that accompany Volumes 1-6 of the Draft Land Resource Study allow the reader to distinguish three classes of land that can safely and profitably be worked as mechanised agricultural farmland (Classes 1, 2 and 3) from all other types of land. Each map also distinguishes and indicates a suitable use for land that is not good enough for mechanised agriculture (Classes 4-7). Separate Map 2 of the present report shows the disposition of the acreages suitable for tillage in sub-regions of each island.

Land in the first two islands studied (Abaco and Eleuthera) was divided into 12 land capability classes, each numbered as below:

Class 1	Small individual areas of deeper red and brown soil together with 'whitelands' (humic sands)
Class 2,3	Intimate associations of soil and rock (occupying the top 3-18 inches of the ground surface) suitable for preparation as ploughland. Class 2 Gravelly; Class 3 Stony
Class 4A	Rockland neither good enough to be worth ploughing nor steep enough to be classified as 4B
Class 4B	Sloping rockland with gradients of 1 in 20 to 1 in 10; also groups of minor rock ridges
Class 5A.	High watertable hardened, rockland of various types
Class 5B	Sandy land excluding:-
Class 5C	Steep sand dunes (and 1 - humic ('whiteland') sands)
Class 6A	Rather bare rockland pitted with caves
Class 6B	The steepest rockland (with gradients of 1 in 10 and more)
Class 7A	Land liable to fresh or brackish water flooding
Class 7B	Areas with saltwater flooding

In this capability classification (Table 10 gives the details), Class 1 land is said to be the most versatile i.e. have the least number of limitations for a wide range of uses. In practise the terms land capability and land suitability are often used as substitutes both imply a potential land use. Land suitability suggests specific use (or even in some cases specific crops). Capability, on the other hand, gives a measure of the versatility of a tract of land for a wide range of uses, and tracts of land that can be used for the greatest number of purposes are given the highest (Class 1) ratings. Mapping land capability from resource maps is very much a matter of informed common sense; on the other hand, considerable experience is required to define the sub-classes of tillage land.

It would have been possible in a series of maps to show the 'top' class, second and third class sites for a whole host of single uses with each use separately displayed – one map showing only Classes 1, 2 and 3 for mechanised agriculture, another map of the same area showing the top three classes for forestry, and a third perhaps the best land for urban development. Inevitably this would yield a very large number of map sheets. In Volumes 1-5, this problem is avoided by placing the greatest emphasis on mechanised agriculture (Table 10).

TABLE 10 **The land capability legend applicable to Abaco and other pine forested islands with considerable agriculture potential**

Tillage land*	Title	Main characteristics
Class 1	Land having an essentially continuous gravelly or fine tilth, nowhere less than 6 inches deep	Sandy land; whiteland Colluvial hollows of red or brown latosols
Class 2	Land which can, at varying but not excessive cost, be reduced by standard heavy tillage implements to a continuous gravelly or finer tilth, nowhere less than 6 inches deep	Coarse oolites, burrowed limestones and lime muds on flat plains
Class 3	Land which can at varying but not excessive cost be reduced by standard heavy tillage equipment to a continuous stony tilth, nowhere less than 6 inches deep	Thin bedded, slightly burrowed and other limestones, flat or undulating ground
Non tillage land †	Title	Suitability
Class 4A	Flat, gently sloping or undulating land: discontinuous soil cover	Production forestry and construction development
Class 4B	Moderately sloping land or land with short moderate to steep slopes, discontinuous soil cover	Production forestry and construction development
Class 5A	Essentially flat, low level, superficially hard land: high water table	Not usually suitable for forestry. Presents problems for construction development in coastal sites
Class 5B	Essentially flat, loose or semi-lithified sand: minor ridges: youthful soil development	Construction development. Amenity
Class 5C	Moderately to steeply sloping sandy land: youthful soil development	Construction development. Amenity
Class 6A	Flat, gently sloping or undulating land: frequent caverns, knolls and fissures	May present terrain problems for all uses
Class 6B	Steeply or very steeply sloping rock land or land containing a complex of moderate to steep slopes	May present terrain problems for all uses
Class 7A	Land subject to inundation by fresh or brackish water	Amenity and conservation only unless reclaimed
Class 7B	Land subject to inundation by saline water	Amenity and conservation only unless reclaimed

* A variety of limitations listed below were used to qualify Classes 1-3 on the map:

c = Climatic limitation
e = Minor erosion risk
ee = Major erosion risk
t = Topographical limitation
s = Adverse soil conditions, minor limitation
ss = Adverse soil conditions, major limitation
w = Limited irrigation water or seasonally high water table
ww = Absence of irrigation water or seasonally high water table

† Slope categories as detailed below were used to discriminate between land of Classes 4, 5 and 6:

a. Level or flat, gently sloping or undulating : slope up to 1 in 20
b. Moderately sloping: slope from 1 in 20 up to 1 in 10
c. Steeply or very steeply sloping: slope more than 1 in 10

Most of the tillage class land (whose characteristics are discussed later in this chapter) is found (see Separate Map 2) in the pine islands (Grand Bahama, Abaco, New Providence and Andros). In other islands Classes 2 and 3 are found only in insignificant amounts though Class 1 may be widespread.

Non-tillage lands have been distinguished on their suitability for forestry, construction development, amenity or conservation via a consideration of physical characteristics – whether the land is wet or dry, sandy or rocky, hilly, cavernous, flat, ridged, etc. (i.e. its characteristic landform). Land that is suitable for many uses is rated highly in this classification (Table 10) while land that has a limited range of use is low rated. The classification is thus based on differences in versatility.

Despite the high rating of agricultural land,it must be recognised that land of Class 4, 5 or 6 in the pine islands as elsewhere, though useless for agriculture, is naturally sought after for residential uses, amenity and tourism – and this despite the fact that it may be more expensive to develop than flat land. Seen in this way, Class 1-3 land is the most versatile, but though capable of supporting a number of land uses (agriculture, forestry, light industry or housing) it should be reserved for agriculture; no other land is good enough and agricultural development has a high priority. On the other hand, Class 1-3 land offers little scenic advantage for residential development, tourism or recreation.

In most of the south-east Bahamas, relatively little land can be considered suitable for mechanised agriculture and it is very important to point out its alternative merits. Many factors (low rainfall, lack of tillage class rockland (see Chapter 11), relative remoteness and low population densities) make the Abaco-style land capability classification based on mechanised agriculture inapplicable in the south-east. The alternative classification presented in Volume 6 (and Table 11) is therefore more suitable for these islands. It accords greater importance to Classes 4-6 and describes their development potentials and limitations in greater detail.

In addition a completely different approach to identification of regional development possibilities is presented in Table 12, distinguishing land which has some economic potential from that which has none. The scheme, under a different name, is contained in Volumes 6 and 7 and is reviewed here for consideration and possible use by Bahamian planning authorities. Economic potential here includes:-

1. Agriculture, afforestation and bases for inshore fishing
2. Water abstraction
3. Industry
4. Amenity (or tourism) and recreation.

The land with no clear economic potential (i.e. land with no obvious use, which can produce no income in its unmodified status and which few people, paying for it, would wish to take into private ownership) is divided into five classes (Z1-Z5 in Table 12) depending either on the degree of difficulty or of hazard involved when its use is unavoidable (as for example when it must be crossed by a new road).

TABLE 11 **The original land capability legend modified for use in Exuma and Long Island but also suitable for Eleuthera and Cat Island**

Tillage land	Title	Typical land
Class 1	Land having a continuously sandy tilth not less than 6 inches deep	Reclaimed freshwater marsh improved by physical addition of limesand from local sources
Class 1/4A	Land of varying capability comprising a number of separate soil bodies notable in the local context; normally deficient in irrigation water	Separate shallow colluvial soil bodies set in undulating rockland; shallow soils improved by physical additions from surrounding area
Non-tillage land	**Title**	**Use limitations and advantages**
Class 4A	Gently sloping or undulating rockland; discontinuous, thin and localised soil cover	No limitations for a wide range of construction/development uses; little natural landscape advantage
Class 4B	Moderately sloping land or land with a complex of gentle, moderate and steep slopes; discontinuous soil cover	Slopes limiting to low cost construction/development; moderate landscape advantage for residential uses and amenity
Class 5A	Flat, low-level, surficially hard rockland; high watertable; often brackish or saline	Rock hardness and high watertable limiting to construction development; no natural landscape advantage
Class 5B	Flat or slightly ridged loose or slightly cemented sandy land; some humic soil development of surface sands	Use limited by salt spray in exposed coastal sites: variable landscape advantage depending on vegetation and setting; may have limited agricultural potential where irrigation water and soil development allow; suitable for recreation and amenity
Class 5C	Moderate to steeply sloping sandy land; some humic soil development of surface sands	Use limited by saltspray in exposed coastal sites; normally high landscape quality; suitable for amenity and recreation; highly susceptible to intrusive development; erosion control may be necessary in much-used area
Class 6A	Flat, gently sloping or undulating rockland; frequent caverns open at surface	The many caves present a major obstacle to construction/development use; some areas may have landscape value for amenity and recreation
Class 6B	Steeply or very steeply sloping rockland; land containing a complex of moderate to steep slopes	Steep slopes severely limiting to low cost but suitable for high cost construction/development; high quality landscape enhances quality of adjacent areas; highly susceptible to intrusive development
Class 7 Class 7A Class 7B	Land subject to inundation; salinity level not specified Land subject to inundation by fresh or brackish water Land subject to inundation by saline or brackish water	Usually limiting to all construction/development; of variable amenity value depending on nature, surroundings location and accessibility. may be irreversibly spoiled by badly conceived land reclamation; some areas may benefit from wildlife conservation measures

TABLE 12 **A scheme for zoning land for the purposes of regional planning**

A. Land with a defined economic potential

1. Agriculture, reforestation and fishing*

AG1 Land with some potential for mechanisation (irrigation water available)

AG2 Land with no potential for mechanisation (irrigation water available)

F Land with relatively high potential for reforestation or woodland conservation

C Shoreland giving direct access to important inshore fishing or conching grounds

2. Water abstraction

W Land underlain by important lenses of fresh water, which land in some cases may have a second potential (e.g. W/F) or coincide with Z1-Z4

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*Classes which can be distinguished on a map as either accessible or inaccessible.

TABLE 12 (continued)

3. Industry

S	*Potential site for industry requiring deep water access

4. Amenity and recreation*

R1	Land well endowed by nature for the subclass activity
R2	Land moderately well endowed by nature for the subclass activity

Subclasses – amenity and recreation

A	Opportunities for enjoying landscapes of notable quality which may include point features (caves, blueholes, accessible vantage points) *or* more extensive features (areas of interesting vegetation)
B	Opportunity for viewing interesting man-made sites i.e. BX (historic or cultural interest); BY (industrial or other interest)
C	Opportunities for enjoying notable coastal scenery
D	Shore suitable for walking, collecting, etc.
E	Shore and offshore suitable for bathing
F	Shore and offshore suitable for skindiving
G	Opportunities for observing birdlife (GV) wildlife (GW)

B. Land with no defined economic potential

Z1	With characteristics allowing relatively lower road and other construction costs
Z2	With no characteristics positively adverse to road and other construction
Z3	With characteristics incurring relatively higher road and other construction costs
Z4	Wet land or land with seasonal/occasional flooding characteristics
Z5	Wet land or land with twice daily flooding characteristics

Land capability of tillage class rockland (Classes 2 and 3 of Table 10)

Few areas of tillage class rockland are suitable for mechanised farming without prior preparation, though some areas even in the natural state may have a fine gravelly surface or be covered with fragile tile-like fragments of limestone. Different types of pine flatland (at least 14 distinct types have been mapped by Young (1974) at the BARTAD Project) have different potentials.

The main characteristics of the three tillage classes are listed below:-

Class 1

No rockland has been classified as Class 1 despite the fact that relatively deep-soil (i.e. 12 inches of soil with rock debris) land with tiley or gravelly fragments has all the characteristics originally used in setting up the class (Table 10). It was decided that it would be misleading to class even the best rockland as Class 1 because of the rapid, unpredictable worsening of the surface from place to place. Class 1 has therefore been reserved for two types of land: level sands (in which in nearly all cases it is accompanied by some limiting subscript letter) and areas of uninterrupted soil.

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*Classes which can be distinguished on a map as either accessible or inaccessible.

Class 2

This represents what seems to be the best rockland i.e. land, usually in pine forest areas, which can be prepared at a comparatively low cost into a continuous gravelly tilth nowhere less than 6 inches deep. At the BARTAD Project $185 per acre has been quoted as the minimum cost for efficient preparation of Class 2 land (Land Preparation Report 2a, BARTAD). The word gravelly here only implies a certain size; it has no implication for shape. The implication is that gravelly tilth comprises soil and rock fragments less than 2 inches across. Plate LC/4 and LC/5 in Volume 1 illustrate the different relative rock fragment sizes.

Class 3

This represents what seems to be less good rockland which nevertheless could still, but at greater cost, be prepared as tillage land. The prepared land would be inferior to Class 2 land despite the higher cost of preparation. In practice the land would finish up with a stony tilth, i.e. rock pieces larger than 2 inches, and commonly with pieces 3-6 inches maximum dimension. Table 13 shows the general lithofacies types (see Chapter 8) commonly included in Classes 2 and 3.

TABLE 13 **Lithofacies types, their colloquial names and typical capability class (see also Figure 3 and Table 7)**

Lithofacies type	Colloquial name	Constituent lithofacies	Typical (but not inevitable) capability class
I	Thin bedded fissile grainstones – 'platey rock'	1A, 3A	2
II	Thin bedded fissile middling textured rock – 'muddy plate rock'	4A, 6A	2
III	Medium thin bedded 'fused plate rock'	2B, 3B	3s, 3ss
IV	Thick bedded grainstones – 'massive rock'	1C	4a, 4b
V	Slightly burrowed grainstones	1D, 2D	3
VI	Moderately and well burrowed, rather muddy grainstones	3E, 3F, 4E	3 and 2
VII	Moderately and well burrowed grainy mudstones	5E, 6F	2
VIII	Impure mudstones with strong texture contrast	5G, 6G, 7G	2
IX	Impure mudstones with moderate texture contrast	5H, 7H	2ss
X	Impure and pure mudstones with only slight texture contrast	6I, 7I, 8I, 8H	3s
XI	Coarse oolite (poorly cemented grainstone)	1J	3st
XII	Muddy grainstones with rounded caprock surface	3J	3ss
XIII	Oolite/microcrystalline mud, accidental mixtures	4J	2s
XIV	Algally laminated mudstones	8J	4a

Criteria used to subdivide Classes 2 and 3

A survey of land capability in Andros done in connection with site selection for the BARTAD project (Young, 1973) distinguished subclasses of Classes 2 and 3. They involved the following limitations: s (shortage of soil, t (uneven topography) and x (a large content of hardened rock) – combined with numerical indices as below:

2^2, 2s′, $2s^2$, $2s^3$, 2ss, 2t, 2ts, 3s, 3ss, 3x, 3sx, 3t, 3sxt

The same criteria were used to classify observations in Grand Bahama (Volume 5) though the map was simplified into more basic classes. Examples are given by Young (1973) of the correspondence of subclasses with land capability indices described in 'Methods' (Appendix).

SUMMARY

1. Land capability is an aid to planning for the future use of land.

2. Different criteria are appropriate for different types of development (agriculture, tourism, industry etc.).

3. The Survey focused on modern agriculture for the north-west islands and on non-agricultural development options in the south-east.

4. The capability classification in Table 10 indicates land suitable for modern mechanised agriculture. The classes are based on the idea of decreasing versatility (impediments).

5. Non-agricultural classes are distinguished on suitability for forestry and other uses. Landform and rock type is the governing criterion.

6. An alternative classification (Table 11), which places less emphasis on agriculture, emphasises landscape values and recognises planners' preferences for landscape variety, has been used for Exuma and Long Island. It is considered better suited for coppice islands than the classification described in Table 10.

7. A zoning scheme based on four types of economic potential and various degrees of disability or hazard is also proposed.

8. There are two classes (2 and 3) of tillage rockland. Of these, Class 2 can be prepared to a gravelly tilth whereas Class 3 can at best only result in a stoney tilth. Size of rock fragment in the prepared surface is the distinguishing criterion.

9. Additional sub-classes of 2 and 3 (Class 2 divided into seven sub-classes, Class 3 into six) were devised for detailed work in Andros.

Part 4
Recommendations

Chapter 15 General recommendations

LAND RESOURCES AND LAND USE PLANNING

1. The Bahamas Government now has, in the form of the various LRD Survey reports and maps, a substantial volume of information which should be put to work in development. It is therefore strongly recommended that a small Office of Land Resources be set up, probably within the Department of Land and Surveys and answering to its Director, to interpret and use the resource surveys. The Office should preferably be staffed by two Bahamian graduates, one holding the senior post. Alternatively, if assistance is required until a second graduate becomes available, a suitably qualified expatriate should be engaged to support the Bahamian.

   The functions of this Office would be:

   i. To maintain a complete, fully accessible store of all the information produced by the Survey including maps, reports, photographs and scientific papers. It would also search out, collate and store all new information

   ii. To serve the needs of development by means of *ad hoc* advice as well as being involved in the planning of future land use. The Office would maintain the strongest possible links with planners, and with the Ministry of Works

   iii. To set up an orderly programme of study of aspects of land (sand and rock types, soils, and land use) critical to its successful development. In this it would need to maintain the closest cooperation with the BARTAD Project and the Ministry of Agriculture

   iv. In furtherance of the above aim, to establish links and cooperate with outside academic bodies in setting up projects of real practical value to the Bahamas

   v. To extend the reconnaissance survey work done by the LRD Survey (as detailed island by island in Confidential Annex 1)

2. It is recommended that the Regional Planning Office should investigate the possibilities of producing land zoning maps as outlined in Table 12. These maps should be relatively simple to produce using the Survey's work together with a limited amount of local and historical enquiry. An estimated 1-3 weeks might be required to produce a draft map of each of the islands in the south-east.

AGRICULTURAL EXPANSION AND FORESTRY

3. Most settlements in the Bahamas lie on the coast. The emphasis on agricultural expansion on tillage class land and the new move into interior land at BARTAD strongly recommends inland pine areas as sites for new, agriculturally based settlement. Specific recommendations to this end are given for Andros in Confidential Annex 1.

4. Although it is inevitable that the acreage of forest land will diminish because of the encroachment of agriculture, settlement and industry, it is considered essential that such encroachment should be carefully controlled. Destruction of valuable tree crop potential can only be considered where:

i. Such clearing could be said to advance the general welfare of the people of the Bahamas

ii. All alternative sites (in the case of industry and residential expansion) have been examined and rejected on sound principles

iii. The land which it is proposed to sever from the forest estate has been surveyed for its suitability for the proposed new use.

It is conceded, however, that agricultural settlements will usually need to be sited within and not remote from their lands. Such settlement should be considered an unavoidable encroachment.

ROADS AND PUBLIC WORKS

5. The information provided by the Survey should allow road alignments to be planned in a much more rational fashion than has been the case up till now. When such matters, or indeed any land development proposal, arise it is most important that the Survey's maps should be consulted.

6. Members of the Survey importing earth-moving equipment into various more remote islands have noticed that it is used usually only on one job and then it is expensively exported before it has been used to the full benefit of the local populace. Although amplified use of heavy plant often hinges on a question of funding it would be very valuable if prior notice were given of the arrival of such equipment in the less developed islands. There could thus be benefit to the contractor and to the island alike if a programme of important work could be drawn up.

7. When bulldozers are used for development work, every effort should be made never to allow wanton destruction of either rock surfaces or of the freshwater lens (by exposing it in excavations) or of vegetation. The two latter cautions are especially important in dry islands whose water lenses are thin and destructible and whose vegetation once removed will take many years to become re-established.

TOURISM

8. Although originally set up to investigate potential agricultural land, the Survey became more involved with the aesthetic qualities of landscape as it moved south-east where agriculture was climatically and otherwise at a disadvantage. A number of specific recommendations have therefore been made for tourism (see Confidential Annex 1). To these are added the following general recommendations:

i. That the Ministry of Tourism should use the Survey reports in order to prepare small factual guides (of 8 or 16 pages perhaps) to each island. At present, hard geographical facts are rarely found in tourist booklets despite the fact that a proportion of tourists find these very valuable and might well be attracted to the relatively disadvantaged islands if more such information was offered them

ii. That the Ministry of Tourism, cooperating with others should use the shoreline and slope maps of the south-east islands to produce relatively accurate smaller maps showing areas of scenic interest. The possibility of having an outside mapping company prepare sophisticated tourist maps at 1:100 000 scale should not be ruled out

iii. Signposts and informative notices; most islands in the Bahamas and especially islands such as Long Island and Exuma would benefit from the establishment of simple signposts (settlement names and distances) and more informative ones giving information about side roads to the

Atlantic shore. The latter might describe the quality of the track and what the visitor might expect to find at the end of it in terms of scenery and recreational resources such as listed in Table 12.

9. Many Bahamian islands are rich in historical associations including actual buildings, old sites, rail lines and tramways, Arawak mounds and old walls and wells. No complete account of these has ever been attempted nor is there any map giving their locations. It is therefore strongly recommended that the relevant ministries should combine with the Historical Society to encourage and perhaps support one or two people to research this subject. The use of air photographs allows sites now remote and overgrown to be pinpointed. Similar work should also be undertaken on natural sites such as caves and blueholes that would provide a focus of interest for the tourist and become a source of national pride for Bahamians generally.

10. A major recommendation of the Survey is that a government Groundwater Section should be formed. As groundwater is and will be the cheapest source of water for the forseeable future, this resource must be fully and correctly exploited before turning to other sources. A permanent data collection and research organisation should be incorporated into the branch of Government responsible for water supplies – currently the Ministry of Works and Utilities. This body should be able to improve the present state of knowledge of the hydrological cycle in the Bahamas, which would lead to more accurate estimates of recharge, evapotranspiration, and the possibilities of multiple land use. Besides basic research, the Section will need to monitor producing wellfields and ensure that these wellfields receive proper management. Most of the abandoned and dilapidated wellfields in the Bahamas are a result of mismanagement and there is still no routine sampling programme.

    The Groundwater Section requires a minimum of two professional grade officers in the fields of hydrology and/or hydrogeology, plus a full supporting staff of technical assistants. Allied or counterpart staffing is also required in the Ministry of Agriculture and the Meteorological Department.

    Considering the scarcity and vulnerability of the Bahamian freshwater resources there is a need for proper groundwater legislation. The water resources should be a part of the public domain. At present preliminary drafts are being prepared to this effect and no further discussion is warranted here.

    Detailed recommendations for large scale groundwater abstraction are contained in Chapter 16.

11. In order to obtain some long-term practical data, presently non-existent, a test wellfield is needed. With correct monitoring from the undeveloped state, many characteristics can be tested to evaluate the relationship of hydrogeologic theory to practice, for example, the relationship between recharge and lens thickness. Also, information such as the lateral extent of the effects of pumping can only be obtained by this method. The Barging Scheme wellfield on north Andros could, and will be, used for this purpose. There are 18 monitor wells in the vicinity of that wellfield and the necessary facilities for recording pumping rates, volumes, and salinities have been designed into the installations.

Chapter 16 Recommendations for large scale groundwater abstraction

The following guidelines are recommended for all instances of large scale groundwater abstraction.

1. There should be preliminary drilling and pump testing to confirm the volume and availability of the water resources to be exploited. Test wells drilled through the freshwater/saltwater interface should be preserved for monitoring the movement of the interface.

2. Based on the results of the above and on the nature of the environment, a decision should be made as to the best technique or means of removing the water. In some areas trenches are cheaper and safer to use than boreholes and on New Providence they have proved far easier to monitor. Factors that should be taken into account for this decision are listed in Table 14. One of the main reasons for utilising trenches is that there is less penetration of the horizontal, stratigraphic and structural controls on vertical water movement. Deeper holes tend to link abstraction to the higher rock permeabilities that occur at depth and up-coning of unsuitable water is facilitated.

Table 14 Should boreholes or trenches be used for a water supply?

Factor under consideration	Preference and reason	
	For boreholes	For trenches
Economics: general	-	Trenches usually cheaper
(a) Depth of watertable	High areas make boreholes cheaper	-
(b) Specific capacities	-	Too many boreholes needed when permeability is low
(c) Quantity wanted	When the demand is low a single borehole will suffice	-
Environment		
(a) Rock hardness	Hard rock can make trenching difficult	-
(b) Sand or loose material	Trench sides may cave in	-
(c) Seasonal flooding	-	Trenches make good use of flooded areas
Resource: general	-	Trenches make better use of resources available
(a) Thin lenses	-	Trenches can be very shallow
(b) Patchy lenses	Being widespread,trenches are more likely to hit a bad spot	-
(c) Risk of up-coning	-	Trenches are shallower than boreholes and safer
(d) Recharge	Trenches may aid recharge but increase evaporation losses	-
Monitoring & maintenance, general	-	Trenches simplify both
Pollution: general	Trenches more prone to pollution	-
(a) Access	Access should be restricted in trench areas	-
Multiple land use: general	-	Many more fittings etc needed for boreholes. Trenches can leave land relatively clear

3. Rainfall records in the wellfield area should be studied and from these a figure for annual recharge should be estimated. Using the Henry equation (see Volume 1 of the Draft Land Resource Study), which relates lens thickness to recharge, the amount of water available for abstraction can be calculated and the net theoretical change in the freshwater resource known in advance. Examples involving the above are given in Table 15. Having calculated a realistic daily abstraction rate and knowing the yield potential of the rock (i.e. the specific capacity) the size of wellfield and spacing of the abstraction points can be decided.

Table 15 Rainfall and recommended abstraction rates — for years of average precipitation

Island	Mean annual rainfall (in) *	Estimated recharge - based on 75% evapotranspiration loss (in)	Water available if lens reduced by half (in) †	Equivalent in gal/day/ac †	Abstraction rate in gal/day/ac if lens is to be reduced by 1/3 †
Abaco	60.9	15	11.2	680	516
Acklins	32	8	6	350	276
Andros	50	12.5	9.4	570	431
Cat Island	42	10.5	7.8	460	361
Crooked Island	34.6	8.5	6.4	380	293
Eleuthera	44.7	11	8.25	490	379
Exuma	39.7	10	7.5	440	345
Grand Bahama	58.9	14	10.5	630	482
Inagua	27.4	7	5.2	300	241
Long Island	35.6	9	6.75	400	310
Mayaguana	34	8	6	350	276

† It may not be possible to reduce thin lenses by this proportion and so abstraction rates would need to be even lower.

* These figures differ in some instances from those given in Chapter 2. They are however those currently in use at the Ministry of Works and can be taken as reliable for their purposes.

Figure 4 can be used to determine spacing if boreholes are to be used. It is generally recommended that 24 hour pumping be maintained and drawdown limited to 0.1 ft. Boreholes should always be as shallow as possible. The minimum depth for a given pumping rate can be established from the preliminary pump tests. Trench spacing and lengths can also be established by pump testing.

4. Once the wellfield starts operating the following data should be recorded: production, salinity, recharge, and changes in the natural condition.

   i. **Production.**

   The total amount of water abstracted at each pump should be recorded on a weekly basis. Pumping rates at each should be noted at the same time. If a pump is turned off for more than a day it should be indicated in a diary kept on day-to-day operations.

   ii. **Salinity**

   Salinities should be checked once a week. Samples are to be taken from sampling cocks designed for that purpose. Checks should be made periodically along the length of trenches for lateral variation.

   iii. **Recharge**

   A rain gauge is needed in the supply area. This can be sited at a convenient location for daily reading. The data obtained must be carefully and conscientiously recorded.

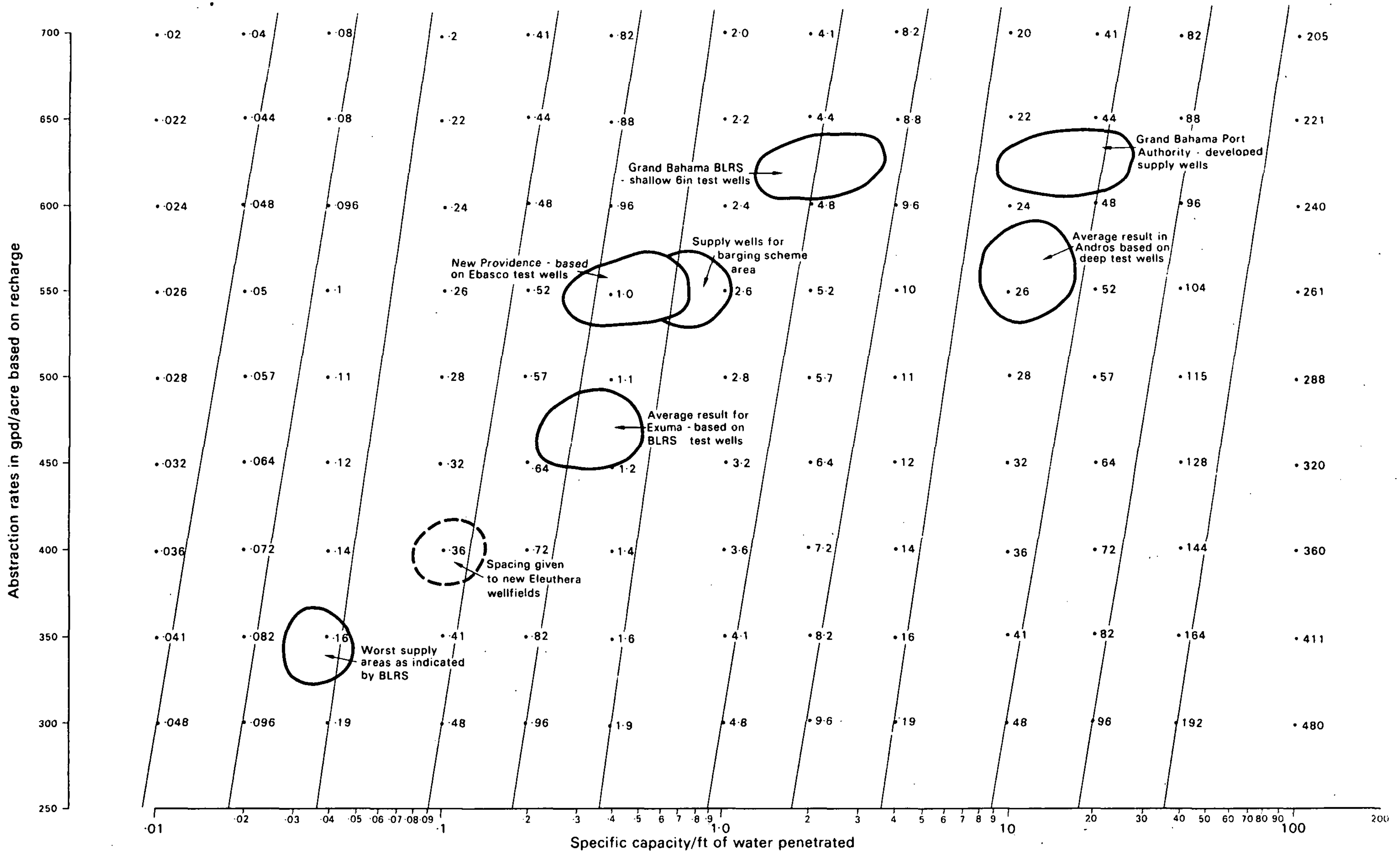

FIGURE 4 A guide to correct spacing of supply wells and safe abstraction rates in a wellfield in which individual wells penetrate 10 feet into the water and drawdown never exceeds 1/10th foot

The abstraction rate (in gallons per day on the vertical axis) has to be governed by specific capacity per foot of water (horizontal axis)

The number of acres required for a well in each type of aquifer is shown by the acreage values laid out in a grid pattern on the figure

FIGURE 4

iv. **Changes in the natural condition**

Before pumping starts, all of the monitor wells should be logged with a recording conductivity meter; once pumping has started this should be done once every 2 months until a new equilibrium is achieved. Thereafter the monitor wells can be depth sampled once or twice a year depending upon how much seasonal variation is indicated and how constant the rate of abstraction remains.

The data from i., ii., and iii. as outlined above can be collected and recorded by the permanent wellfield staff; iv. should be monitored by a Government hydrologist and his staff. Other more exotic data such as variations in the watertable level and the effects of reduced discharge can be obtained by the hydrologist when required. At least once a year all the information gathered should be presented in a report along with a discussion on the significance of this material.

5. Changes in wellfield production rates should be compensated for in the design and operation of the wellfields; i.e. if an area becomes brackish with use then an equal area of wellfield should be put into use in compensation. Pumping in the 'good' area should not be doubled up in order to meet demand. Malfunctioning pumps should not result in increasing pumping rates in any one specific area. It is assumed in this section that the spacing and abstraction rate in the wellfield is an optimum one based on the recommendations given above.

Part 5

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Appendix
Methods used in the survey

Methods used in the survey

A description of the methods used in each section of the survey gives the user insight into the working of the survey and the likely accuracy of each observation. It also allows for adaptation or amendment of methods as seems most desirable for future work.

CLIMATE

The emphasis of the study was on rainfall. All available records were examined and evaluated statistically by a number of orthodox procedures. A number of rain gauges were established in the first four islands studied. A recording rain gauge was positioned towards the centre of Andros and a small weather station recording temperatures, sunshine hours, rainfall, open pan evaporation and windiness was set up close to the sugar factory in Abaco. A limited amount of data was generated in this way.

VEGETATION

The consultant botanist and one of the Survey team visited a number of characteristic sites where they recorded the result of an intensive site examination identifying all species encountered. Specimens were collected and dried and field observations were consolidated into a series of vegetation types. Some of these types corresponded with others in the biogeographical region. The vegetation types thus defined were mapped on air photographs during the land use photo interpretation.

PINE FORESTS

Methods used by the forester included visual estimation of regeneration stocking and height after some initial sampling; also growth studies based on various conventional methods of measurement. An investigation of the Andros pulpwood cutting operation was conducted by field observation and enquiry, while the history of licenced exploitation was obtained from Crown land documentation and other records.

GROUNDWATER

Hydrogeology depends a great deal on sophisticated methods and instruments, hence the exceptional length of the following section.

Fieldwork for the groundwater phase of the Survey continued from April 1969 to March 1973 and involved several different persons. Hardly surprisingly, the techniques employed evolved with the survey as more knowledge on the groundwater environment was gained. Fieldwork was divided into two main parts; (a) exploratory, and (b) testing. Exploratory work involved locating and quantifying the freshwater resources of each island and the testing involved assessing the nature of the aquifer where these resources occurred to evaluate their full potential.

Exploratory work

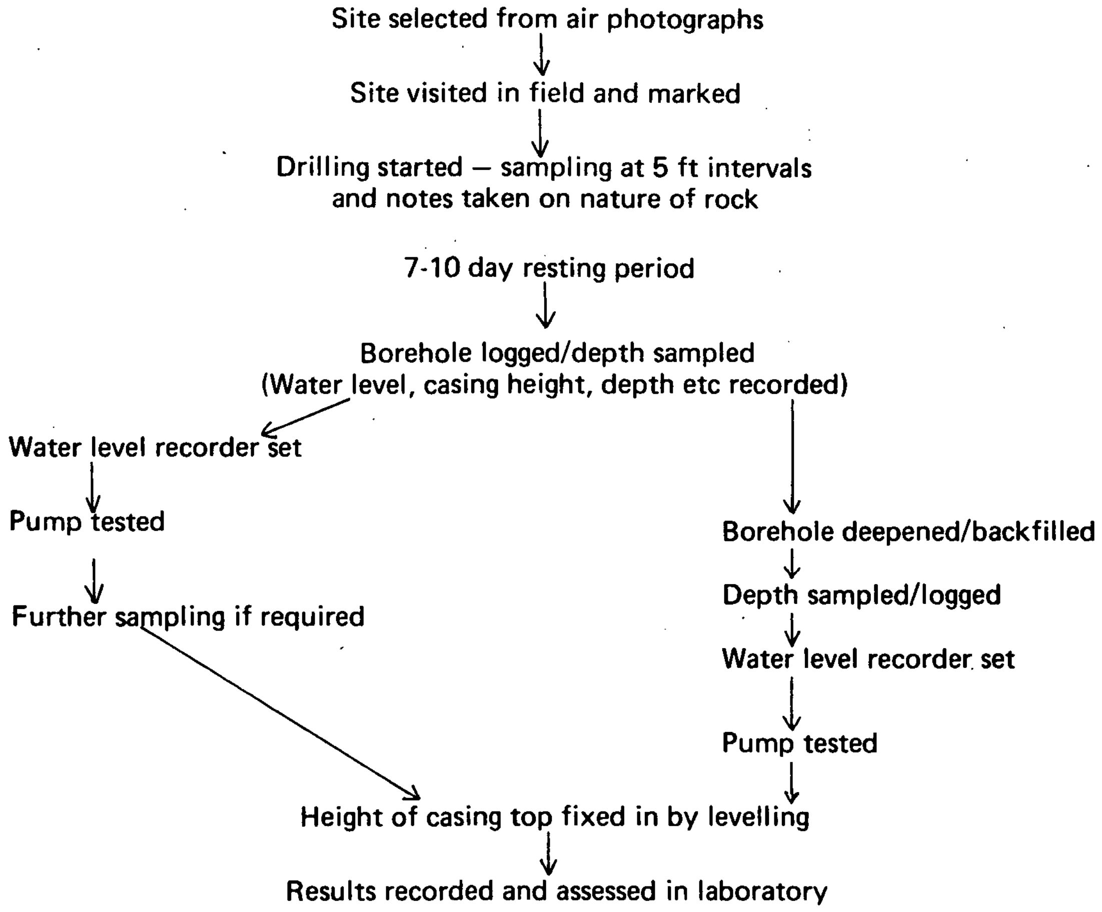
The exploratory programme was based largely on air photograph interpretation; test drilling; supplementary resistivity analysis; and a sampling phase of pre-existing boreholes, wells, and ponds.

Air photo interpretation (API) Air photograph studies were made to locate boreholes and other test sites on most islands, and also to evaluate the potential of each island as a whole before starting the groundwork. On some islands such as Grand Bahama and Andros the air photographs were not so useful and test locations were selected from the 1:25 000 scale maps.

Drilling 6" percussion holes were drilled by contract, and 4" and 2.5" holes were drilled by seconded staff from the Ministry of Works. Percussion boreholes were favoured because they were thought more likely to give true results when tested than rotary drilled boreholes where the sides are smeared. The contract 6" boreholes were generally drilled through the change from fresh to saline water, and chloride content (a measure of salinity) was tested every 5 ft, by the driller until a predetermined level was reached or exceeded (usually 250 or 500 mg/l).After a 7-10 day resting period the boreholes were depth sampled by the project staff using either a 200 ml Munro sampler, or a 10 ml mini-depth sampler. The mechanisms of both of these are described in the earlier reports. They function by lowering a collecting device to the required depth and then trapping a water sample. Chloride analyses were carried out on the samples in the field using a titration method (Hach Kit) or an Orion Specific Ion Meter, Model 407, equipped with the prescribed specific ion electrodes.

Salinities were also gauged from logs of conductivity obtained by lowering a temperature compensated probe down into the boreholes. The probe used covered a range of 0-50 000 μmhos. The outputs from the bridge network were directed through an electronic avometer and readings were obtained from selected depths. On Grand Bahama the output was coupled to an electronic recording chart mechanism and continuous profiles of conductivity were collected. Detailed information of groundwater quality can be obtained using such equipment and on Grand Bahama the instrument proved very successful. Examples of completed borehole logs are given as Table 16(A). Figure 5 summarises the procedure employed for each borehole.

FIGURE 5 Flow diagram showing the process of groundwater investigation



4" cores were collected from all of the islands except Acklins. This work was done on contract. The purpose of the coring was to investigate the nature of the aquifer in terms of its mineralogy, constituent composition, stratigraphy, porosity, and permeability. The coreholes were also used for groundwater exploratory purposes. Samples obtained by coring were checked and described in the field and these descriptions are given in the reports. At present 11 of the cores are at the Institute of Geological Sciences in London, and the remaining 16 are at the University of Miami Comparative Sedimentology Laboratory. Further detailed work is now being undertaken by two acknowledged limestone experts, R N Ginsburg (Miami University) and R G C Bathurst (Liverpool University) who will make the results of their work available to the Bahamas Government.

A limited number of 4" exploratory boreholes were drilled using an air flush rotary rig belonging to the Ministry of Works. This machine was only used by the survey on Mangrove Cay, Andros.

A small mobile drill rig, 'The Minuteman' was used on all but the first four islands. Operated by the Ministry of Works staff, this rig was useful for investigating the margins of the freshwater lens and other areas with less freshwater potential. The rig was powered by a 5 HP petrol engine and holes were drilled by continuous flight augering. The auger rods were 3 ft long and the bit 2½ inches in diameter. The maximum depth, 30 ft, could be drilled in approximately 60 minutes in soft limestone areas. In some hard cap-rock locations in the SE Bahamas the rig proved ineffective. The augered holes had to be cleared of slurry before sampling; this was achieved by using an improvised bailer or by blowing the hole out with compressed air. Unless saline at the watertable the minuteman test wells were drilled to a predetermined depth and then sampled with the 'mini depth sampler' after a 10 day resting period.

In order to allow full exploratory coverage of the islands with a limited road system, access tracks were made. These rough tracks were constructed with either a D7 or D8 and were considered acceptable once the project vehicles could pass over them.

Other sampling work Pre-existing boreholes, blue holes, and any other groundwater exposures were sampled in the exploratory phase of the programme using the same techniques as employed for the contract boreholes. In some islands like Long Island and Cat Island large numbers of shallow domestic wells were tested and these gave a clear indication of where the groundwater was saline. Sampling shallow dug wells on the islands with abundant fresh water was not so valuable in terms of information gained as they were always fresh. However such wells should be routinely sampled to monitor pollution. Water level recorders were set on certain ponds and bodies of water to establish that they were connected to the ground water; the water samples were collected from a wide variety of sources for full chemical analysis of their tritium content.

Resistivity analysis Many measurements of electrical resistivity were made on Abaco, Exuma, Long Island and Grand Bahama. In this technique, current is passed through the ground via two metal stake electrodes hammered into the rock, and the drop in potential after the current is passed through the ground is recorded at two other electrodes placed in line with the two first at specified distances either side of the centre. The ratio of drop in potential to applied current is read as the specific resistance; the units of resistivity are the ohm meters (ohm-m). The value of resistivity obtained (the apparent resistivity) is a weighted average of the real resistivity of the rock and that of the contained pore-fluid down to a depth appropriate to the electrode spacing used. By increasing the horizontal separation of the four electrodes the depth of penetration of the current can be increased and the apparent resistivity at different depths can be measured.

Changes in the apparent resistivity of the aquifer in the Bahamas are largely due to changes in the salinity of the groundwater with depth; i.e. because freshwater overlies saltwater. The combination of increase in permeability of the aquifer and salinity of the pore fluid with depth produce depth curves which show a rapid reduction in resistivity downwards. Resistivity curves are normally analysed quantitatively, the field curve being compared to a set of standard curves prepared for specific combinations of horizontal layer resistivities and depths. This technique using Mooney-Wetzel curves, produced no significant guidelines in terms of layer thicknesses when applied to resistivity data obtained by the survey: and at present only qualitative interpretation of the curves seems satisfactory. Where brackish or saline water is encountered near the surface, it would be expected that most of the current would pass along this layer rather than penetrate further, and, in general terms, there is no simple relationship between electrode spacing and depths of penetration of the current.

In Volume 5 of the *Draft Land Resource Study*, a relatively detailed discussion is given on the interpretation possibilities of the resistivity technique. In summary it is not nearly as effective or useful as test drilling.

An ABEM Ac Terrameter, Type 5310, was used for the resistivity traverses. Each traverse took between 60 to 90 minutes. Results are given as plotted curves or in table form.

Testing phase

Tests were made on the aquifer by closely monitoring changes in water level and relating these to the several factors that could cause them. Tests were also made by sampling certain boreholes at fixed interval to evaluate how the changing tide could affect salinity and how drilling affected salinity.

Records of water level changes in boreholes or ponds were obtained by the use of clock-driven water-level recorders or by direct measurement using an electronic water level indicator. One water level recorder was usually set for the full period that the island was under observation in order to detect any seasonal change. This borehole was also equipped with a rain gauge and depth sampled every month. Recorders were set on all the remaining boreholes for periods of 3-7 days, and on these it was possible to monitor changes in water level that resulted from the tides, rainfall and barometric pressure change. For correlation purposes a tide gauge, rain gauge, and a recording barograph were kept in continuous operation. Examples of the effects of these three influences on a recorder chart are shown in Figure 1.

Changes in water level resulting from abstraction were recorded by direct measurement (with a water level indicator) during pump tests. The water-level indicator used allowed for accuracies of up to 1/50 ft. Standard pump tests of 30 or 60 minutes duration were made with the suction intake placed 5 ft below water level.

Pumping rates were measured by recording the time taken to fill a drum of known volume. Salinites were checked during the test at fixed intervals. A completed pump test form is shown in Table 16A as also is a graph (Figure 6) of the changes in water level plotted against time. In some pump tests a conductivity probe was positioned at the freshwater/salt water interface to monitor the effect of pumping on the base of the lens. In one case (Grand Bahama Borehole No. 4) the borehole was blocked off between the pumped section and the interface, but usually it was left open.

During several pump tests, water levels were monitored in nearby holes in order to observe the shape of the resulting cone of depression. High transmissibilities usually made these tests unsuccessful though an immediate pressure-wave effect could be detected when the pump was turned on or off.

Boreholes that were backfilled were tested before and after backfilling and the results were compared to give an indication of the variation of aquifer permeability with depth. Shallow boreholes gave very different results from the deeper boreholes. Backfilling was required so that tests on the aquifer gave results that were true for the potable portion. The effects of backfilling on salinity are shown in Figure 1.

The heights of the casing of all boreholes above mean sea level was established, by a survey team, so that mean groundwater levels could be calculated from the recorder charts.

TABLE 16A **Example of completed pump test form**

Groundwater investigation pump testing

Island Grand Bahama	Borehole GB45	Date 14.12.73	Duration of test 30 mins	Pumping rate 95 gpm
Drawdown .048	Specific capacity 1978 gpm/ft			

Actual time	Elapsed time	Water level
12.40	0	1.920′
12.45	5	1.907′
12.50	16	1.886′
12.51	pump on	–
12.52	12	1.931′
12.53	13	1.920′
12.54	14	1.920′
12.55	15	1.918′
13.00	20	1.900′
13.06	26	1.880′
13.10	30	1.870′
13.15	35	1.854′
13.20	40	1.840′
13.21	pump off	–
13.22	42	1.782′
13.23	43	–
13.24	44	1.768′
13.25	45	1.768′
13.30	50	1.760′
13.35	55	1.740′

Pumping rate guide: time taken to fill drum of volume 47.82 I.G.	
First filling	31 secs
Second filling	29.7 secs
Third filling	29.9 secs
Mean filling time	30.2 secs

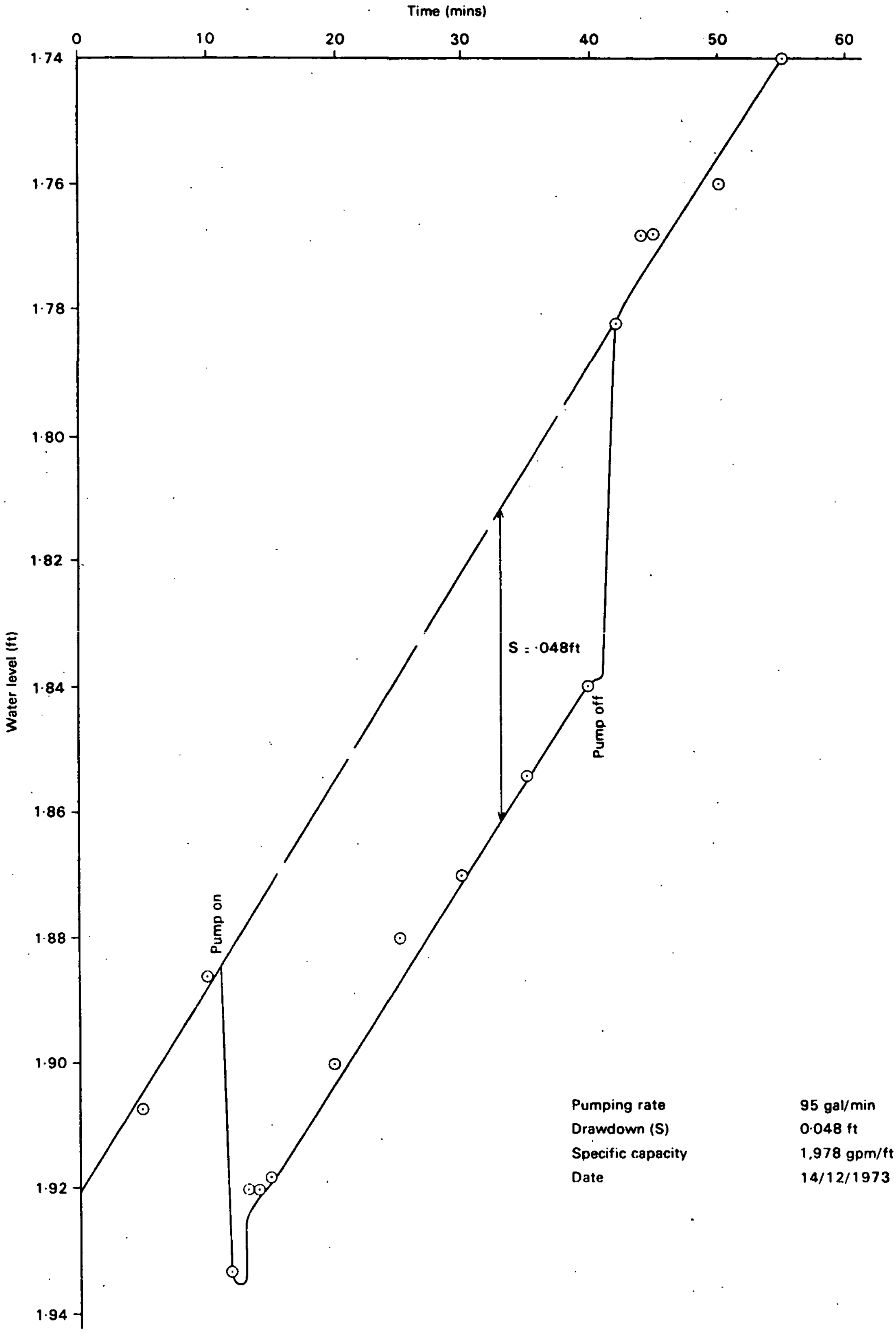
Chloride during test		
After 2 mins	–	ppm
After 10 mins	180	ppm
After 15 mins	180	ppm
After 30 mins	180	ppm
After 60 mins	–	ppm

TABLE 16B **Example of a completed contract borehole record**

Island Long Island	Hole No. LN-35	GR 292668	Elevation (ft) 12.54	Depth (ft) 36.52
Water level (ft) 10.1	Casing above ground (ft) 0.14	Date drilled 1.2.73	Water level recorded 19-21 March 1973	Pump tested 4.4.73

Sample depth below top of casing (ft)	Chloride content during drilling (mg/l)	Sampled after drilling at 27.2.73		Sampled after drilling at 4.4.73	
		Chloride content (mg/l)	Conductivity (micromhos) 4.4.73	Conductivity (micromhos) *	Conductivity (micromhos) *
5					
10					
15		303	905		1 315
20		242	1 415		6 250
25	177	272	2 980		10 550
30	177	757	5 800		10 800
35	197	1 818	6 350		10 450
40	532			* After pump testing	

FIGURE 6



Pumping rate	95 gal/min
Drawdown (S)	0·048 ft
Specific capacity	1,978 gpm/ft
Date	14/12/1973

FIGURE 6 Example of pump test results showing drawdown superimposed on the effect of a rising tide at hole GB45, Grand Bahama

Having obtained the field data as described above (see also Plates 28 and 29) and shown in the flow diagram (Figure 5) a number of calculations and assessments could be made. These included:-

1. An assessment of changing lens thickness and groundwater level as a result of rainfall;
   - i. in the long term seasonal context, and
   - ii. in a short term context.

   An approximate figure for annual recharge could also be obtained by reviewing the local rainfall records
2. Calculation of mean water level above sea level in each borehole. In several reports these are plotted against the thickness of the lens
3. Calculation of time lag and fluctuation ratio of the tidal responses in boreholes as compared to the sea. From these results an estimate of aquifer transmissibility can be made
4. Calculation of barometric efficiency in boreholes where these effects were observed
5. Calculation of specific capacity in the pump tested boreholes. Specific capacity is obtained by dividing the pumping rate, in gpm, by the observed drawdown, in ft. Aquifer transmissibilities can be evaluated from these data
6. Calculation of maximum safe daily abstraction rates based on the amount of annual recharge, the thickness of the lens, and the specific capacity of the aquifer.

LAND, LANDFORMS AND ROCKS

Typically landforms of the long narrow islands of the Bahamas can be mapped with the aid of air photographs, by which characteristic sites are selected for observation in the field.

In order better to understand the geological/landform variation in Eleuthera, 11 profiles of the island, shore to shore, were surveyed and examined (Figure 5, Volume 2 of the *Draft Land Resource Study*).The observed differences are partly explained by reference to Text Map 3 in the same report but the full import of the findings were not clarified until the landforms of Cat Island had been studied.

Air photographs are much less useful in the mapping of pine-covered flat areas. In Abaco, for example, close attention had to be paid to minor details of topography (rocky knolls 3 ft high, tiny wet spots, minor undulations, etc) in order to build up a broader picture. In flat areas it was found necessary to use methods which rely on an understanding of limestone depositional environments and lithofacies (a term explained in Chapter 8). These methods enable the investigator to make broadly accurate predictions of the nature of the ground surface. In Abaco the above method was combined with systematic touring of the mapped areas – the observer seated in a chair on the roof of a moving pick-up so as to obtain a higher viewpoint and a less obstructed view of the ground surface. An experiment in detailed site recording was carried out by probing the ground surface with a crowbar along 2 120 foot traverses set to intersect at right angles. The method and results are presented after p. 112 in Volume 1 of the *Draft Land Resource Study.* The results are expressed as a soil/rock ratio which ranged from 3/100 in some areas dominated by rock to 569/100 in highly soily areas.

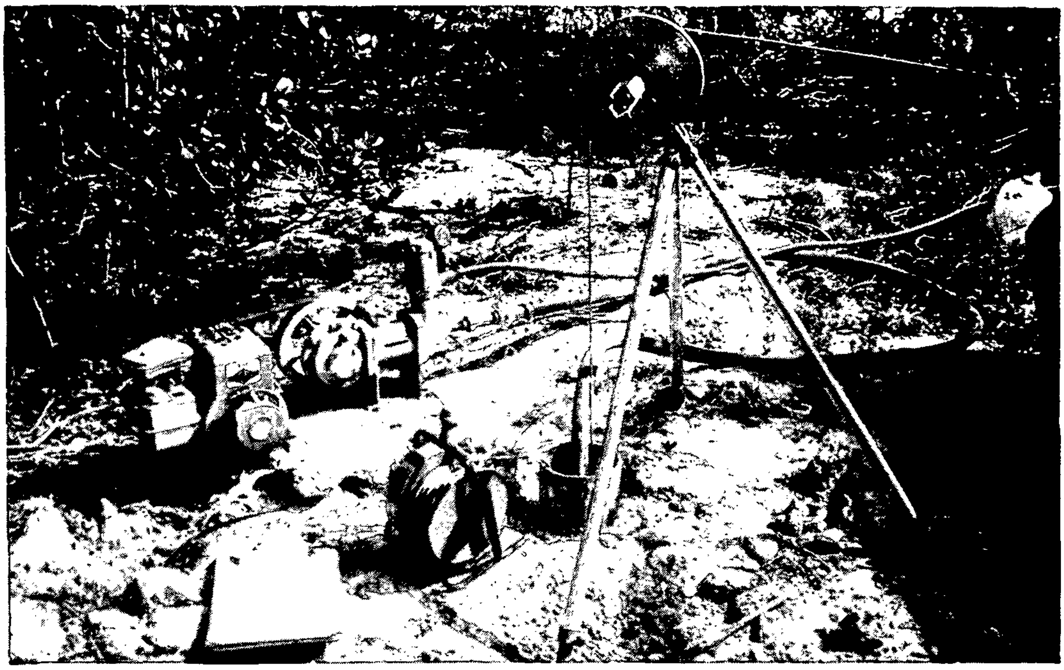


PLATE 28 Typical arrangement of equipment and instruments for testing low specific capacity boreholes; a low-capacity pump, a water level indicator and a conductivity probe suspended over a tripod.

PLATE 29

View of the equipment used for conductivity logging. The apparatus in the vehicle (L H side) records a plot of electrical conductivity against time (alternatively against depth); this information is derived from the conductivity probe which is lowered into the borehole.

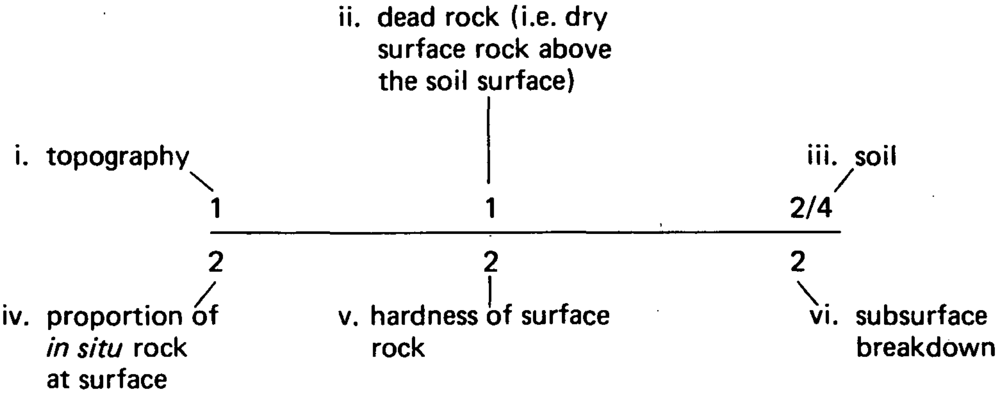
Different types of beach ridge formation in Norman Castle, Abaco were shown to contain land of widely varying capability. These were investigated by means of carefully measured profiles across the beach ridges – on each profile the ground surface details were recorded. Airphoto analysis of the height, the spacing and the sharpness of beach ridges at several hundred points throughout the area supplemented the field traverse information. The traverse results are shown in Figure 10 of Volume 1 of the *Draft Land Resources Study* and all the findings were used to draw the final map. Rock hardness originally evaluated using a 'rebound hammer' was later equally well assessed by dealing the rock a series of smart blows with a wrecking bar.

A new system was devised for Andros. It was backed by the knowledge gained in the first year's work. Airphotos showed relatively few relief features in the survey area so it was necessary to visit and inspect a network of some 1 200 points, as when the survey began in 1971 the only air photographs available showed the land fully covered in pine trees – the minor topographic details hidden.

At each point an L-shaped walk approximately 50 paces long was made into and out of the forest block. The surface was explored by walking on the land, inspecting the surface visually and 'with the feet' (or with a wrecking bar where the surface was covered with vegetation), by digging a series of small grub holes, probing the regolith, by any method in fact by which it was possible to examine the surface and subsurface materials.

The results of this inspection were summarised in a six-figure index in which each characteristic has a bearing on the potential of the site as ploughed rockland.

The index was arranged as follows:



The various terms are explained below:

i. Overall shape of the surface 'minor topography'

ii. Volume of inert, mostly soil-free rock lying above the moist weathering level

iii. Total estimated relative volume of soils

iv. The percentage of the surface occupied by non-fragmented (i.e. firmly-seated) rock

v. The hardness of the rock as a whole *or* of agricultural limiting elements ('castles', 'pavements', etc)

vi. The normal size of pieces of rock from the subsurface, estimated from rocks heaped alongside the road, and material in tree roots.

Arabic numbers 1-4 identify shape, volume of inert soil-free rock, volume of soil etc. Low numbers, e.g. 1 and 2, indicate favourable site conditions; higher numbers, e.g. 3 (and in the case of soil, 4) less favourable conditions. Class 2^1 for example has an index

$\frac{111}{121}$ or $\frac{111}{122}$ (Young, 1973). Lower classes (worse tillage land) contain more high numbers: 3sxt for example, is represented by the index $\frac{232}{132}$.

The land evaluation did not rely on soil pitting, which was inadequate for mapping out the complex ground surface changes. Details of how to process the indices and to prepare the land capability maps is contained at pp. 76-79, Volume 5 of the *Draft Land Resource Study*, which also discusses the reliability of the map boundaries at different observational densities.

Soils

The soil programme overlapped with that of landforms and land capability and in may instances the nature of the rock soil surface precluded the use of conventional soil survey methods. Air photographs however were scanned for clearly defined soil areas whose agricultural potential was later inspected in the field. There were no detailed case studies or chemical analyses.

Land use

The land use reports were based on 5 years of touring experience by the senior agricultural officer, Ministry of Agriculture, Bahamas (seconded to and later consultant with the Survey).The historical land use section resulted from research into contemporary newspaper articles, published works, and commissioners' and other government reports. Mapped land use boundaries and area measurements (in Volumes 6-8) were prepared in the cartographic section of the Land Resources Division from detailed airphoto interpretation checked by a team member conversant with the land.

Publications of the Land Resources Division

These publications have a restricted distribution and are not available to booksellers. The Division makes a report on each completed project. The report is published as a *Land Resource Study* or *Technical Bulletin* only with the consent of the government concerned.

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