Institute of Offshore Engineering

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A STUDY TO ASSESS THE FEASIBILITY OF USING A GEOGRAPHICAL INFORMATION SYSTEM TO MANAGE AND MONITOR CORAL AND SAND MINING IN THE REPUBLIC OF MALDIVES

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ABSTRACT

The Republic of Maldives, is a least developed nation, situated in the South - West Indian Ocean. It covers a total area of 90,000 km^2, although its land area is only 298 km^2. As an atoll nation, the Maldives has few natural resources and has to import most of its goods. The majority of its foreign exchange is earned from a highly successful tourist industry. To build resorts for the tourist industry and accommodate a fast growing population, the Maldives has exploited one of its few resources. Coral and sand are mined indiscriminately, causing possibly irrevocable damage to the reefs and exposing the fragile coastline of the islands to global climatic changes, such as sea level rise.

Geographic information systems (GIS) are the latest computer systems that allow analysis of spatially integrated data sets. They have been proven to be useful in the management of land resources and are now being adapted to regulate marine situations. This report examines the application of a GIS to the management of coral and sand mining in the Maldives and takes into account the difficulties that a developing nation might have in the acquisition of such a system.

INTRODUCTION

1.0 INTRODUCTION

The Maldives are a small island, atoll nation, that is situated in the Indian Ocean. As with many such nations (Lieu 1986), the Maldives have many problems relating to their size, location, population and resource base. In fact apart from the marine resources, the Maldives are reliant on other countries for imports of all goods. Consequently, the accumulation of foreign exchange is of extreme importance. Being a tropical island country, has enabled the Maldives to exploit their marine environment in favour of the tourist industry. This has led to a rapid expansion in the number of resorts that have been built in the last decade.

The Maldives also have a rapidly growing population, with the average growth rate standing at 4.1 % for 1990. This means that more houses must be built in order to accommodate the rise in the number of people. A recent survey has also found that more people are likely to live in houses constructed of coral and coral aggregates than ever before.

Coral blocks, coral sand and akiri (coral rubble) are the traditional building materials and one of the few natural resources that the Maldives possess. In the past, coral and sand were used for construction purposes on a subsistence basis by the local island populations. However, due to the recent expansions in the building industry as a direct result of the population and tourist increases, coral and sand have been exploited to keep pace with the commercial demands.

The direct removal of live corals from the reefs has meant that the Maldives are now faced with a number of potentially serious environmental problems that could affect not only their future safety, but also their economic health.

The Maldives are extremely low lying islands, with non being greater than 3 m in height above sea level. They are therefore extremely vulnerable to any rise in sea levels that might occur and that have been predicted in the next few decades. The reefs that surround the islands and the atoll rim act as natural breakwaters and reduce wave impact on the beaches. The reefs also support a variety of fish species, which form an important constituent of the fishing industry.

Coral and sand mining is still at the present time a disorganised and piecemeal industry. There are few records of the volumes of coral rock and coral aggregate that have been extracted over the last few years. Consequently, the only indicator of the possible reef damage is an estimation based on the building that has occurred and environmental impact assessments of reefs that are known to have been heavily mined. However, there is a serious lack of base line data concerning the marine environment in the Maldives, which makes even this approach difficult.

The Maldives are also not mapped accurately and knowledge about depths, reefs locations and bottom types is restricted.

The advent of computers has changed the way in which information is dealt with. There have been rapid advances in computer technology over the last thirty years and computers have now become integral pieces of office equipment. In natural resource studies, much of the data are of a spatial nature, for example the distribution of fisheries resources in coastal waters, or alternatively the location of reefs that are damaged due to mining activities. However, until recently the available software have only been able to perform analysis of a non spatial nature.

Geographical information systems (GIS) are specialised computer assisted mapping systems that allow data to be analyzed in a spatial context. Previously requiring very large computers, GIS can now be used from work stations and microcomputers and so are now within the financial reach of most large organisations.

The main uses for GIS is as a tool for resource assessment, planning and management because they carry out a number of analytical functions, are integrative and spatial and most importantly can be updated both in terms of data acquisition and software functions.

This report aims to assess whether the use of a geographical information system would be a worthwhile investment to aid in the management and monitoring of coral and sand mining in the Republic of Maldives. It has been written with two different parties in mind. On the one hand, it aims to establish for the Maldivian Government the benefits that such a system would bring to the management of coral and sand mining, whilst highlighting the organisational changes that would necessarily result from its installation. The report has also been written to hopefully enable an " expert " in GIS to make a judgement about which GIS and software package would be most suitable for the Maldives, should the Maldivian Government decide to obtain one.

The report starts by placing coral and sand mining in context with the Maldivian environment and the economy. It then discusses the major aspects of geographical information systems and their uses. Finally, an attempt is made to consider the changes that a GIS would make to coral and sand mining and the Maldivian Government should one be implemented.

The research for this project was conducted in the Maldives and through interviews with various members of the Maldivian Government. Some sections are therefore written with the authors own experience of the Maldives in mind.

CHAPTER TWO

2.0 THE MALDIVE ISLANDS

2.1 General

The Republic of Maldives is a chain of coral islands situated to the South - West of the Indian Sub - Continent. There are 26 atolls which lie along the 73 ^{o} E meridian between 7 ^{o} 06 ' N and 0 ^{o} 42 'S in the Indian Ocean (fig. 1) . These atolls are made up of approximately 1200 islands but the exact number varies in the literature by about one hundred. Of these 1200 islands only 205 are used for habitation and industrial needs and these will be referred to as inhabited islands in this document. There are 70 tourist islands which are set aside solely for use by tourists and the major travel operators all have connections in the Islands. The total land area of the Republic of Maldives is about 298 km ^{2} and thus only represents a fraction of the total area of the state which is about 90,000 km ^{2}. In 1977, the Maldives declared an Exclusive Economic Zone, thereby increasing marine resources under its juristriction by another 200 miles in all directions.

2.2 Administration

For administrative purposes, the 26 natural atolls are divided into 19 regional atolls (fig.2). The atoll chain is about 870 km in length and 130 km wide at the widest point. The capital, Male, occupies the whole of one island in the central atoll of North Male Atoll and is 2 km ^{2}. The total population in 1990 was 210,000 and 25% live in the capital. Each atoll has a chief, who represents the government authority. Each Inhabited island has an island chief who answers to the atoll chief. However, communications with the capital are limited to a radio telephone and contact by boat.

The atoll and island chiefs have the responsibility for the maintenance of public order, the implementation of government policies and the collection of statistics.

2.3 Formation of the Maldive Islands

The Maldive Islands are one of the largest groups of coral atolls in the world. However,

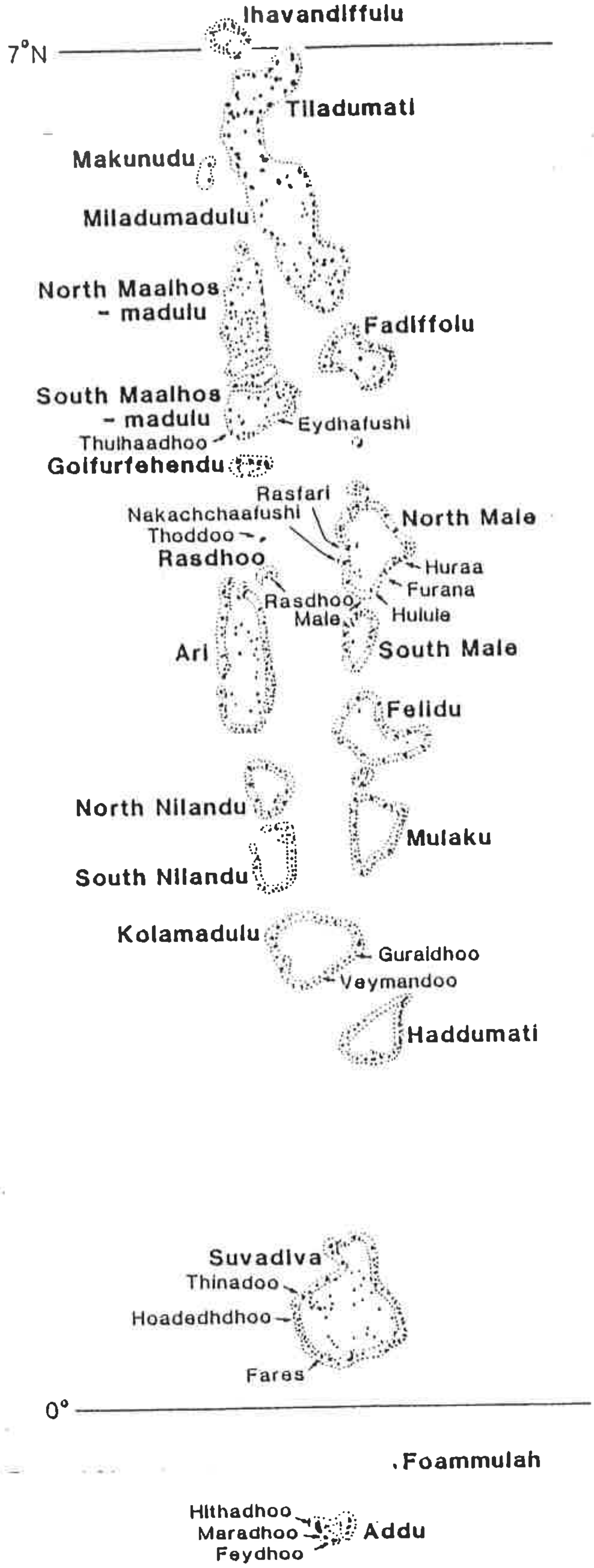


Figure 1. The Republic of Maldives

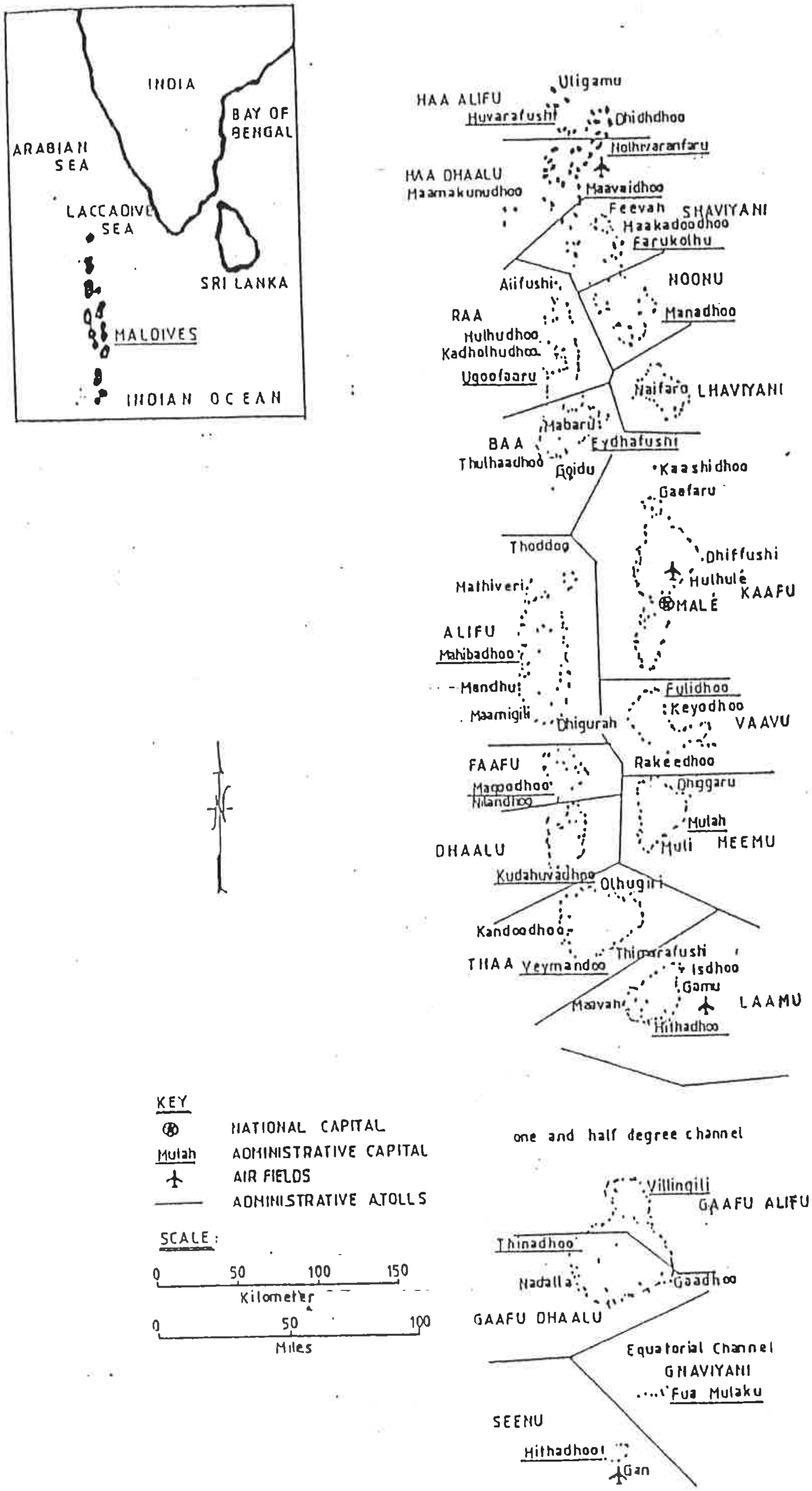


Figure 2. The Administrative atolls of the Maldives

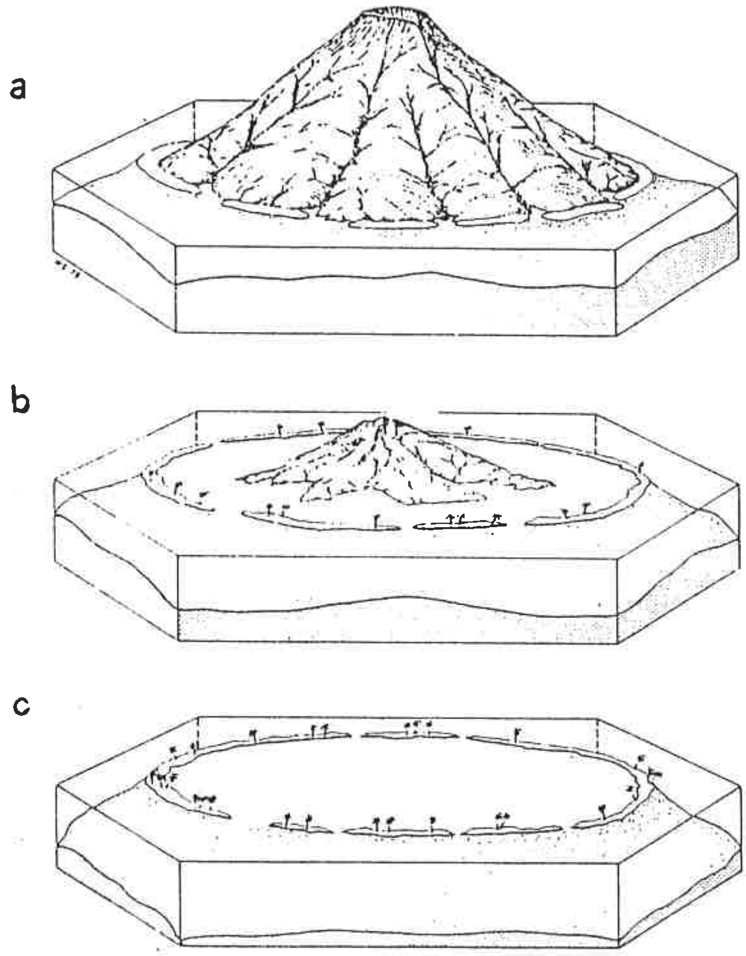
according to Woodruff (1989) their formation is difficult to explain solely in terms of the traditional Darwinian theory for atoll formation.

Darwinian theory, the most widely accepted, is based on the recognition of three types of reef. These reefs are the fringing reef, the barrier reef and the coral atoll. Theory suggests that they are formed sequentially following subsidence of the volcanic basement upon which they are formed. Thus, when a volcanic island forms in mid ocean, a fringing reef should form around it. This island will gradually subside and the reef should grow vertically by the deposition of coral skeleton and biogenic carbonate. The growth should be greatest on the outside due to better water circulation and so nutrient supply. This then results in the formation of a lagoon and a barrier reef. With continued subsidence, the volcanic core will sink further to leave a coral atoll. Coral growth then continues around the outside of the atoll and eventually an atoll reef forms (figure 3).

The Darwinian theory of atoll formation can also be incorporated into plate tectonic theory (Woodruff 1989). It is thought that the ageing and contraction of the ocean floor together with tangential movement of the plate can explain the subsidence of the atolls. Evidence for the existence of the volcanic base layer was provided by the results of a borehole taken by the Elf petroleum company. This drilling encountered Eocene volcanic basement at a depth of about 2000 m, which would seem to confirm the Darwinian theory.

However, Purdy (1981) has interpreted the archipelago formation as the subsidence process being interrupted with episodic northward expansion and the coalescence of the shallow water reef environment.

This theory would explain why although coral atolls appear to have the same overall structure, as explained by the Darwinian theory, groups of atolls vary considerably throughout the world. These differences can also be partly explained in some cases by regional weather patterns. For example the atolls of the Pacific are subject to frequent



a) Fringing reefs, b) barrier reefs and c) coral atolls showing the evolution from one to another by gradual subsidence as proposed by Darwin (after Hopley 1982)

FIGURE 3 The theory of atoll formation

and powerful storms and hurricanes. These can move large volumes of material and so cause a build up in land mass. Alternatively, storms may degrade reefs and strip land away from islands.

Not only are there differences between atoll groups, but significant variation can be seen in the geomorphological structure of one atoll chain. In the case of the Maldives, the atolls can be seen to vary from North to South.

The atolls to the North are broad banks with lagoons of 50 - 60 m in depth. These are discontinuously fringed by reefs with small reef islands and with numerous patch reefs and faroes (ring shaped reefs, plate 1). In the South of the archipelago, the lagoon depths increase to 80 - 100 m. In this area it is found that the atoll rim has greater continuity and a larger proportion of the perimeter of the atoll is occupied by islands.

This difference in morphology suggests, according to Woodruff, that the variable climatic trends between the North and the South may play an important part in contributing to the development of the reef system (figure 4).

This could be a plausible explanation as the Maldives' weather system is dominated by two monsoonal systems. The North - East monsoon runs from the beginning of December to the end of March and the South - West monsoon from the end of April to the start of October.

The impact of storms is more widely felt in the North than in the South although annual rainfall is 1500 mm in the North compared to 2000 mm in the South.

The Maldives are amongst the few coral atolls which exhibit the phenomena of faroes. These are horseshoe shaped islands that have their convex sides facing the sea. Guilcher suggests that this is a result of the surf generated by the alternating monsoonal winds, as the faroes in the centre of the atoll are almost symmetrical. Stoddart (1971) on the other hand feels that differences between the frequency of faroes in the North and South of the archipelago is due to the differences in rates of reef growth. The infilling of faroes

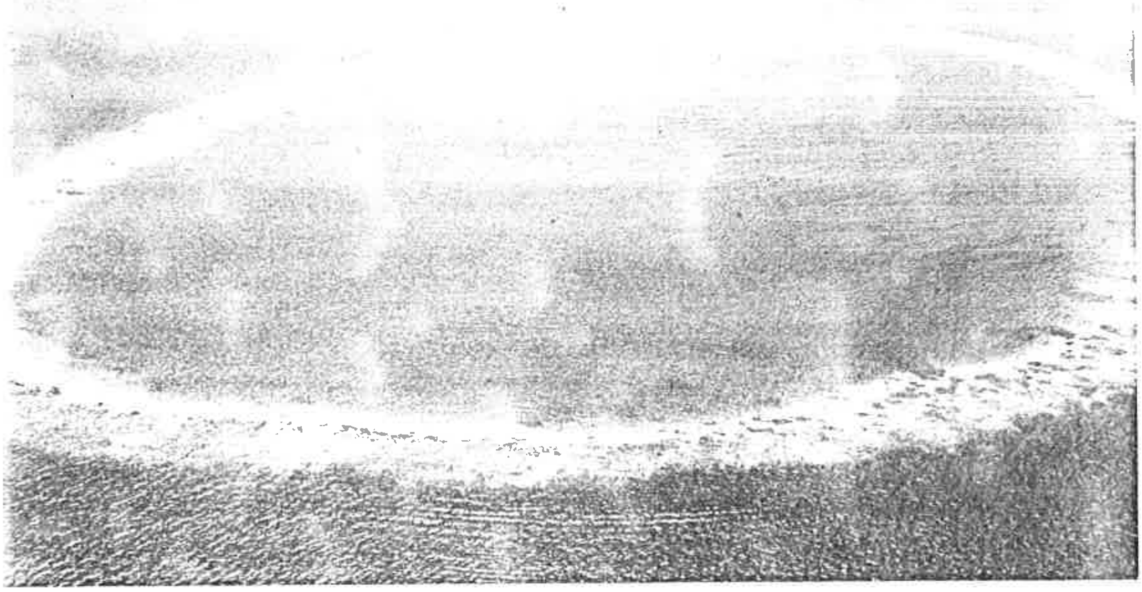


Plate 1. Ring Reef or Faro in North Male Atoll

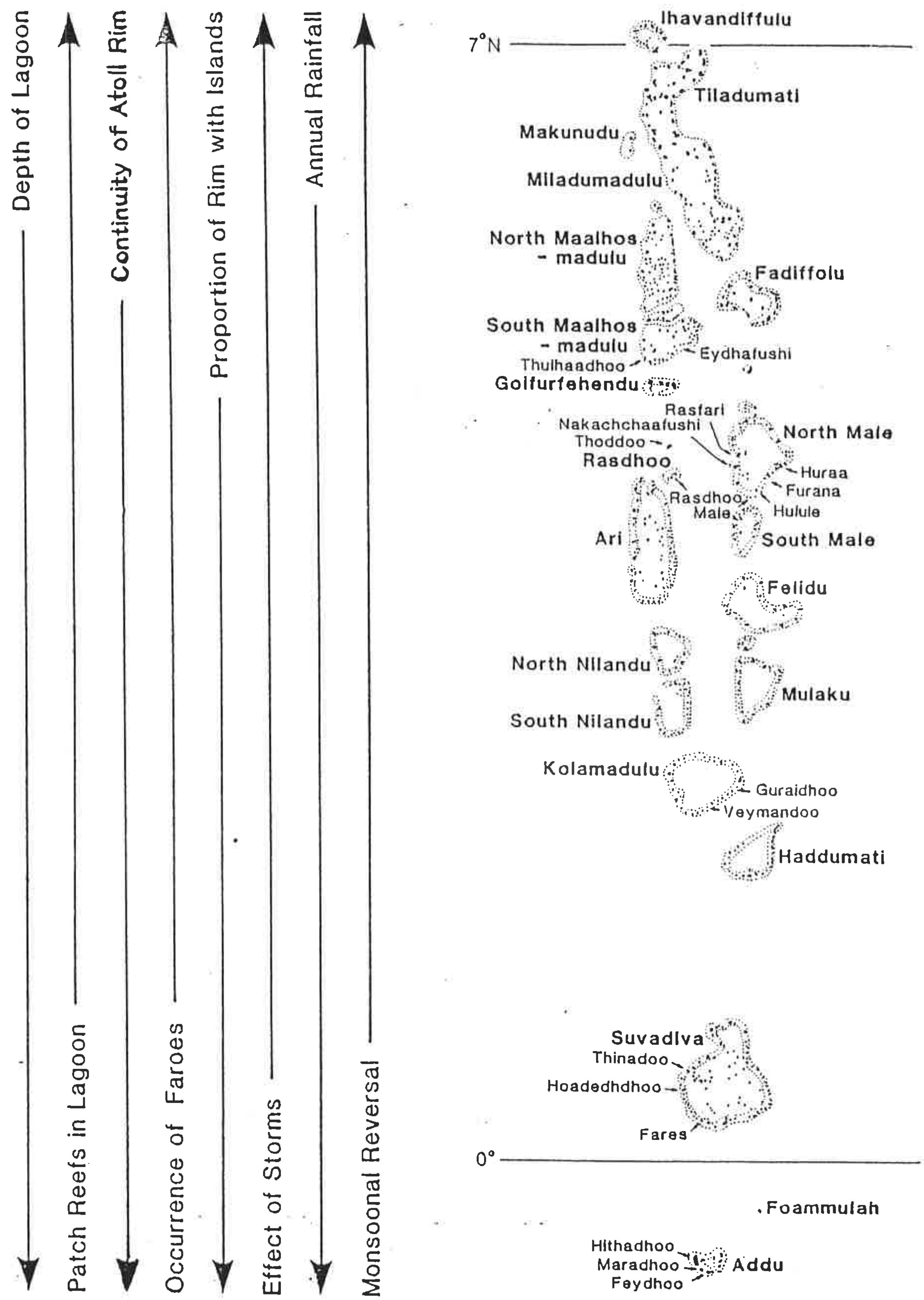


Figure 4. The Morphological Changes that occur from North to South through the Islands. (Woodruffe 1989)

with sediment leads to the complete filling of a ring shaped reef and the development of a sand cay on that reef to the lee side. This process may in time lead to the formation of a new island.

CHAPTER THREE

3.0 THE SYSTEM OF GOVERNMENT IN THE MALDIVES

3.1 Political History

The Maldives have always been an independent political entity apart from one brief period for 15 years between 1558 and 1573 when the Portuguese gained control. In 1887, the Maldives agreed to become a protectorate of the British government and allowed them to take responsibility for the defense and foreign relations whilst maintaining for itself all internal control and decision making.

In 1553, when the ruler at that time, Sultan Mohammed Ibn Abdullah was converted from Buddhism to Islam, the people of the Maldives adopted that faith. The only religion allowed in the Maldives now is Islam.

The Maldives gained their independence in 1965 and ceased to be a British protectorate. In 1968, the Sultanate was abolished, the first President, Nassir, was elected and the Maldives became a republic.

3.2 The Present Government Structure

The present President, Maumoom Abdul Gayoom, is serving his third term in office, having been re-elected as the only candidate in 1988.

The President, is the head of state with ultimate power. At the top is the President and all important decisions are taken by him or on his behalf by the Presidents Office. Below this are the various Ministries, each dealing with a different aspect of state affairs.

At the head of each ministry is a minister and a deputy minister. Below them come the directors of different sections and these are followed by an under secretary.

The Maldivian civil service is mainly comprised at the lower levels of people serving their government bond, which is a form of national service. There are opportunities for further training and those members of staff with sufficient qualifications may enter tertiary education in Western or other universities. However, in doing so they " bond " themselves for a further period of time, proportional to the amount of training they have undertaken. In general, these opportunities are fairly restricted and not many staff have the necessary qualifications. This is due in turn to the lack of higher education facilities in the Maldives. In Male there is one institution, the S.E.C., where A levels may be taken. There were 68 places here during 1990 and this has risen to 79 in 1991. There is severe competition for these places and people who get the places will probably have 8 O levels with grade A. Alternatively, those who can afford it go abroad to study, but this is a very limited number.

At the moment there is also full employment in the Maldives, but this situation is expected to change over the next few years as the increases in population catch up to the school leaving age. When this occurs a situation of competition for employment will arise and the bond process will not be as necessary. This situation will hopefully encourage those people who are interested in government affairs to join the civil service and therefore increase efficiency and the motivation of the staff.
However, beyond the initial top layers of management within the government and civil service, which exist as we would recognise it, the hierarchical system of organisation management breaks down. There maybe certain divisions, for example, the surveying department in the Ministry of Public Works and Labour, but within the division there is no formal upward ladder, with members at the bottom answering to a higher authority, other than the director of the division.

This lack of structure makes the working environment extremely difficult. Initially, people do not have well defined job definitions and thus within one department or ministry it is often difficult to know exactly who is responsible for a particular aspect of a project. It therefore follows that staff have problems in tracing people in other departments than their own. A further problem then arises when contact details are not available when people leave their offices.

It is not difficult to see that in this chain of events that information quite often goes astray or is incorrectly filed. This causes considerable problems in terms of communications, the recording of information and locational whereabouts of members of staff, factors that are naturally taken for granted when one aims to achieve an efficient and integrated governmental system.

3.3 The Ministries.

There are individual ministries responsible for such areas of government as Health, Tourism, Public Works and Labour, Industry, Transport, Atolls Administration, Fisheries and Agriculture, Planning and Environment, Foreign Affairs and Education.

In order to ascertain the state of coral and sand mining in the Maldives several of these departments were visited as each has specific responsibility for certain areas where mining is carried out. The following text gives a brief summary of the role of each Ministry within the system of government. It is worth remembering at this stage that the Ministries have very insular roles and communications between them normally only occurs through the circulation of a directive from the President's Office.

1) The Ministry of Tourism

The Tourism Ministry, as its name suggests, is responsible for all the tourism related concerns in the Republic. This includes all matters concerning the actual islands used for resorts. Initially, islands were purchased from the government and then turned into resorts. However, this process was stopped and Islands are now let to resort owners. The ministry manages the leases and these are periodically reviewed. If a resort has problems or is deemed to be managed incompetently, then the lease may not be renewed. All environmental issues, dredging and mining activities carried out by the islands are under the authority of the Ministry. However, the tourist resorts do not have a very healthy environmental record, which The Ministry of Planning and Environment are trying to change.

2) Atolls Administration

Atolls Administration bears the responsibility for all matters concerning islands in atolls other than North Male Atoll, where the capital is situated. Direction to the islands is passed on through communications with the atoll chiefs and then to the individual island chiefs as explained in chapter 2. However, many issues, such as dredging of harbours, are referred to the relevant ministry rather than being dealt with by Atolls Administration. Figure 5 lists all the atolls of the Maldives, both by geography and by administrative area.

3) The Ministry of Planning and Environment

The newly created Ministry of Planning and Environment (MPE) eas formed in 1988 from the existing Ministry of Planning and Development. The Ministry is supposedly responsible for all environmental affairs and has sections that include the environment and surveying departments. It also is the centre where development planning is carried out and the National Development Plan is created. The statistics section of MPE deals with all the country's national statistics data and publishes them annually.

Recently, the Environmental Research Unit (ERU) was created.

The ERU has been set up in order to " carry out all research work relating to the environment, and making available all relevant data for programming, planning, enforcing and regulating environmental matters ". However, the exact role of this unit is as yet unclear and this issue will be discussed more fully in chapter 5.

4) The Ministry of Fisheries and Agriculture.

The Ministry of Fisheries and Agriculture oversees all aspects of administration concerning both fisheries and agriculture. Tuna fish is one of the biggest exports in the Maldives and is the main source of protein in the Maldivian diet and consequently is of extreme importance.

The Marine Research Section (MRS) is a separate division of this Ministry and is housed

Administrative Atolls (Capitals)	Geographical Atolls
1. Haa Alifu (Dhidhdhoo)	1. Ihavandhippolhu
	2. Thiladhunmathi (North)
2. Haa Dhaalu (Nolhivaranfaru)	Thiladhunmathi (South)
	3. Makunudhoo
3. Shaviyani (Farukolhufunadhoo)	4. Miladhunmadulu (North)
4. Noonu (Manadhoo)	Miladhunmadulu (South)
5. Raa (Ugoofaaru)	5. Alifushi
	6. North Maalhosmadulu
6. Baa (Eydhafushi)	7. South Maalhosmadulu
	8. Goifehenfulhadhoo (Horsburgh)
7. Lhaviyani (Naifaru)	9. Faadhippolhu
8. Kaafu (Thulusdhoo)	10. Kaashidhoo
	11. Gaafaru
	12. North Male'
	13. South Male'
9. Alifu (Mahibadhoo)	14. Thoddoo
	15. Rasdhoo
	16. Ari
10. Vaavu (Felidhoo)	17. Felidhu
	18. Vattaru
11. Meemu (Muli)	19. Mulakatholhu
12. Faafu (Magoodhoo)	20. North Nilandhe
13. Dhaalu (Kudahuvadhoo)	21. South Nilandhe
14. Thaa (Veymandoo)	22. Kolhumadulu
15. Laamu (Hithadhoo)	23. Hadhdhunmathi
16. Gaafu Alifu (Villigili)	24. Huvadhu (North)
17. Gaafu Dhaalu (Thinadhoo)	Huvadhu (South)
18. Gnaviyani (Foammulah)	25. Foammulah
19. Seenu (Hithadhoo)	26. Addu

Figure 5. A list of Atolls by Administrative and Geographic Division

on the other side of Male to the main governmental offices. The MRS is the primary centre of research concerning the marine environment in the government of the Maldives. At the present time its structure is as shown in figure.

MRS is unusual within the governmental set up of the Maldives in that there are a large proportion of expatriate advisors seconded to it. These advisors are all supplied by different funding agencies, such as the British Overseas Development Administration, and have their individual remits to adhere to.

The structure of MRS is such that there are 3 distinct sections. The fisheries section deals with all aspects of fisheries research including the tuna fishery and stock assessment of reef fisheries, which is now becoming an important extension of the fishing industry due to demand by tourists. There is also a section set up to monitor corals, reefs and associated factors in the Coral Reef Research Unit (CRRU). Separate, but associated with research into corals, is the ODA coral reef rehabilitation programme. This is investigating the possibility of creating artificial reefs using concrete blocks and thus alleviating the detrimental effects caused by coral and sand mining in the atolls, which will be discussed more fully in the next chapter.

The third main area of research is also ODA funded. This research explores aspects of beach erosion, turtle breeding grounds, and the effects of coral and sand mining on the marine environment.

5) The Ministry of Public Works and Labour

Ministry of Public Works and Labour (MPWL) has responsibility for all building works throughout the atolls, and are especially responsible for harbour works and dredging activities. This includes some surveying works for specific islands, although this is done solely at the request of the Atolls Adminstration.

They are also responsible for all mining that is carried out in North Male Atoll.

3.4 Population and Future Growth

The Maldives suffers from the same problems as many small island nations. Not only does it have an extremely limited resource base but it also has a small population compared to the area of its land mass. This population is also extremely unevenly distributed with a quarter of it living in the capital and the rest being scattered around the 202 inhabited islands in 26 atolls.

Figure 6 shows the population of the Maldives at the time of the census in 1985 and the MPE estimates for 1990. The inter - censal period 1977 - 1985 registered a high population growth rate of 3.2% and the five year period after this to 1990 had an even higher growth rate of 4.1 % (Binnie and Partners Report 1991). This high rate was sustained by a corresponding fall in the death rate due to better medical care.

When these figures are analyzed more closely, it is found that the average household in the Maldives rose from 6.1 people per house in 1977 to 6.4 in 1985. In Male there were 12.7 persons per house.

The last two housing censuses indicate that more families are living in permeant houses with walls made of cement blocks or coral. The rates of increase at which this occurring is 4.6 % for the atolls and 7.1 % for Male.

3.5 The Economy of the Maldives

Male is the centre of the Maldivian political and economic life. A disproportionate share of government expenditure directly benefits Male and ensures its residents a standard of living substantially higher than in the atolls (World Bank 1980). The income derived from the government sector, shipping and tourism are all concentrated in Male and this means that there is a disparity of economic and social progress between the atolls and Male.

The Maldives is a small island state and though it covers 90,000 km^2 its total land area

Maldives' Population in 1985 and 1990

Year	Total	Male	Female
1985	180,088	93,482	86,606
1990	212,200	109,100	103,100

Source: 1985 Census and MPD estimates

Figure 6.

is only 298 km ^{2}. Due to its limited land mass, lack of mineral reserves and the fact that coral atolls are not very fertile for agriculture, the Republic of Maldives has a very narrow resource base (de Kadt 1979).

The main natural resources are marine and these include the well established tuna fishery, the growing reef fishery and the small mariculture industry of giant clams. Coral and sand are the only available building materials at the present time, although efforts are being made to replace these with sand blocks.

The GDP, which is the best indicator of growth rate of the economy, was an average of 9.2 % from 1985 until 1990 (figure 7). The GDP per capita at 1985 constant prices has increased substantially from Rf2,300 in 1981 to Rf 3,000 in 1985. It is estimates that the GDP per capita was Rf 4,200 in 1990 and this reflects growth rates of 9.4 % for the early part of the decade and 5 % for the latter half. However, these figures are misleading in that they conceal variations. It is estimated that 60 % of the population had an income of Rf 1,900 in 1985 and in Male the average income at the same time was Rf 5,370 (Binnie and Partners 1991).

The biggest contributors to the Maldivian economy are without doubt the fishing and tourism industries.

Traditionally, the fishing industry has been the biggest earner in the economy for foreign trade. However, in recent years, since 1984, the tourist industry is now the largest contributor to the gross domestic product (fig 8). It now accounts for 17.4 % of the total GDP in the Republic (1988) compared to 15.2% in 1984. Tourism statistics from the period 1972 to 1988 are shown in figure . It can be seen from this table that there has been a rapid expansion in the industry during the eighties, both in the number of beds but also in the actual number of resorts. According to the Binnie and Partners Report into Coral Mining (1991), the expansion of the tourism sector has stimulated other parts

	1982	1983	1984	1985	1986	1987	1988 Est.		
	(Millions of rufiyaa; constant 1985 prices)							Percentage share of GDP	
								1984	1988
Gross domestic product	347.4	415.5	527.5	600.3	651.9	709.7	771.6	100.0	100.0
Primary sector	150.4	156.0	168.3	188.1	196.6	207.6	218.0	31.9	28.3
Agriculture	68.6	69.3	72.3	69.5	76.0	77.9	79.9	13.7	10.4
Fisheries	72.2	76.3	85.0	106.9	108.1	116.5	124.1	16.1	16.1
Coral and sand mining	9.6	10.4	11.0	11.7	12.4	13.2	14.0	2.1	1.8
Secondary sector	59.4	64.2	73.0	82.4	88.8	97.7	107.5	13.8	13.9
Construction	33.4	34.4	40.8	49.0	52.8	58.1	63.9	7.7	8.2
Manufacturing	26.0	29.8	32.1	33.5	36.1	39.7	43.6	6.1	5.7
Tertiary sector	137.6	195.3	286.2	329.8	366.5	404.3	446.1	54.3	57.8
Distribution	49.5	69.4	87.7	97.2	103.6	115.5	128.8	16.6	16.7
Transportation	-16.3	-11.2	12.1	13.9	33.7	37.1	40.8	2.3	5.3
Tourism	56.0	64.9	80.4	108.9	111.9	122.4	133.9	15.2	17.4
Real estate	16.2	17.5	20.9	26.0	28.3	30.9	33.7	4.0	4.3
Other services	10.0	17.1	42.3	38.0	33.4	37.9	42.9	8.0	5.5
Government administration	22.2	37.6	42.8	45.9	55.5	60.5	66.0	8.1	8.6

Figure 7. Gross Domestic Product by Sectorial Origin, 1982 - 1988

Source: MPD

Year	Tourist Island Resorts (nos.)	Accommodation Capacity (beds)			Visitor Arrivals (nos.)	Inter'al Tourist receipts (Rf million)	Gov't Rev. from Tourism (Rf million)
		Resorts	Others(1)	Total			
1972	1	280	n.a.	280	1097	n.a.	n.a.
1975	8	908	n.a.	908	9013	n.a.	n.a.
1978	17	1300	n.a.	1300	29325	n.a.	n.a.
1979	25	1690	n.a.	1690	33124	n.a.	2.6
1980	32	2402	n.a.	2402	42007	n.a.	6.6
1981	37	3226	687	3915	60358	113.3	13.5
1982	44	3984	1066	5050	74411	162.2	24.0
1983	51	4450	1272	5722	74163	162.2	24.0
1984	53	4724	739	5463	83814	218.6	27.7
1985	55	5375	555	5936	114554	291.0	39.2
1986	56	5559	865	6414	113953	286.0	44.4
1987	57	6203	1121	7324	131399	461.2	60.3
1988	58	7119	896	8015	155757	552.9	74.3
Growth Rates (% p.a.)							
75-80	32.0	21.5	n.a.	n.a.	36.0	n.a.	n.a.
80-88	7.7	14.5	3.9	10.8	17.8	25.4	24.2

Note: (1) Hotels, guest houses and vessels.

Source: Annual Statistical Report on Tourism in Maldives 1989, Ministry of Tourism.

Figure 8. Tourism Statistics 1972 - 1988

of the economy and in particular the construction industry in the central atolls, where the majority of the resorts are situated close to Hulule International Airport.

Fisheries on the other hand made up 16.1% of the GDP in 1984 and this had not changed in the 4 years to 1988. In 1985, fisheries achieved a growth rate of 25.7 %, second only to that of the tourism sector and the growth rate over the period of time from 1984 - 1988 was 9.9 %.

The construction industry accounts for 8 % of the GDP and has reflected the growth in the tourist industry and the number of new resorts that have been built during the eighties. The average growth rate between 1985 and 1990 was 10 % .

It must be remembered that the construction industry consists of two components, one of which represents the external companies that import all their own equipment and materials for large construction projects and the other side which accounts for private sector building, including work for resorts.

Both the fishing and the tourism industries rely on healthy reefs for their success. The fishing industry is mainly a tuna fishery, but the bait that is used to catch the tuna comes from the reefs. Recently, there has been an increased demand for reef fish from the tourists and this has created a new market which it is hoped can be developed further.

3.6 Examination of the Contribution of Coral and Sand Mining to the Economy of the Maldives

Coral and sand mining contribute the least to the national economy in terms of rufiya out the 10 main services indicated and this has dropped in the last few years to only 2 % of the GDP in 1990 (Binnie and Partners 1991).

The market for coral rock, aggregate and sand has traditionally been determined by five main factors.

1) The historic demand for local construction materials

2) Government regulations and environmental impact

3) Development of competing construction materials

4) Construction techniques and the impact of international aid projects

5) Price structure for raw materials and finished construction

(Binnie and Partners 1991)

Figure 9 shows the estimated use of coral rock, coral aggregate and sand during the period 1980 to 1990. It was calculated from Ministry of Public Works and Labour records in the Binnie Report that approximately 570,000 m^3 used in this time period for various construction projects through out the Maldives. The average annual consumption rose in the later half of the decade, again reflecting the increase in construction due to the boom in the tourism industry. The Binnie and Partners Report estimates that 67 % of materials were used in the construction of houses, 12 % on tourist resorts and 21 % for other structures such as breakwaters.

3.7 Employment Figures

The spread of employment in all sectors is shown in figure 10 and it can be seen that coral and sand mining only accounts for a very small part of employment in the Maldives. Approximately 36 % of the workforce engaged in coral and sand mining are based in Male, with the rest located in the atolls. This seems sensible because the larger amount of population will require more building materials and also most of the tourist resorts are based within a short distance of the capital and the largest number are within North Male Atoll itself.

The actual distribution of miners and boats between the atolls is shown in figure 11 and this shows that the majority of miners and boats do in fact originate from the atolls of Ari and North Nilandhe mainly, even though the bulk of mining may be carried out in Male Atoll.

	1980-1985		1986-1990		Total 1980-90	
	Total	Annual Av.	Total	Annual Av.	Nos.	%
Coral Rock						
Malé	2325	390	1055	210	3380	16.8
Malé Atoll	1230	205	970	195	2200	10.9
Ari Atoll	710	120	1050	210	1760	8.7
Other Atolls	5610	935	7220	1445	12830	63.6
Total	9875	1645	10295	2060	20170	100.0
Coral aggregate (akiri)						
Malé	495	80	875	175	1370	38.7
Malé Atoll	269	45	181	35	450	12.7
Ari Atoll	89	15	137	25	226	6.4
Other Atolls	648	110	842	170	1490	42.2
Total	1501	250	2035	410	3536	100.0
Sand						
Malé	3138	525	4218	845	7356	34.6
Malé Atoll	1198	200	905	180	2103	9.9
Ari Atoll	556	90	878	175	1434	6.7
Other Atolls	4521	775	5848	1170	10369	48.8
Total	9413	1570	11849	2370	21262	100.0

Figure 9. Estimated Use of Coral Rock, Coral Aggregate and Sand 1980 - 1990 (000 ft^3)

Source: Binnie and Partners 1991

Sectors	1985 (Base) Workforce (Atoll)	Workforce (Male')	1990 (Projection) Workforce (Atoll)	Workforce (Male')
1. Agriculture and Atoll Industries	11,941 (32.6)	0	11,837 (29.6)	0
2. Fisheries	11,436 (31.3)	908 (6.1)	12,117 (30.3)	913 (5.2)
3. Coral and Sand Mining	403 (1.1)	223 (1.5)	480 (1.2)	263 (1.5)
4. Construction	1,866 (5.1)	745 (5.0)	2,119 (5.3)	825 (4.7)
5. Manufacturing (urban) & Electricity	1,427 (3.9)	2,249 (15.1)	1,280 (3.2)	2,843 (16.2)
6. Distribution	256 (0.7)	2,294 (15.4)	400 (1.0)	2,931 (16.7)
7. Transport	1,646 (4.5)	1,758 (11.8)	2,079 (5.2)	2,000 (11.4)
8. Tourism	2,853 (7.8)	209 (1.4)	3,639 (9.1)	246 (1.4)
9. Finance and Insurance	109 (0.3)	343 (2.3)	80 (0.2)	281 (1.6)
10. Services including Government Administration	4,646 (12.7)	6,166 (41.4)	5,959 (14.9)	7,248 (41.3)
TOTAL	36,583	14,895	39,990	17,550

Source: 1985 Census and MPD estimates

Figure 10. Distribution of Domestic Workforce in Male and the Atolls in 1990

Atoll/Island	1985 Census Pop. (nos.)	1985 Census Labour Force (1) (nos.)	1990 Census Pop. (nos.)	Coral & Sand Mining (2) Employment (nos.) 1985	Employment (nos.) 1990	Vessels (nos.) 1985	Vessels (nos.) 1990
Raa (North Maaphosmadulu)							
Vaadhoo	223	75	271	6	6	1	1
Ugoofaaru	607	205	716	6	6	1	1
Innamaadhoo	355	120	374	6	6	1	1
Kaafu (Malé Atoll)							
Dhiffushi	582	195	759	6	6	1	1
Maafushi	730	245	824	6	6	1	1
Alifu (Ari Atoll)							
Feridhoo	386	130	449	6	6	1	1
Omadhoo	417	140	523	6	6	1	1
Fenfushi	357	120	430	84	90	14	15
Maamigili	817	275	979	120	150	20	25
Faafu (North Nilandhe Atoll)							
Biledhdhoo	496	165	718	66	90	11	15
Magoodhoo	328	110	352	48	60	8	10
Dharaboodhoo	178	60	231	30	30	5	5
Nilandhoo	668	225	894	60	90	10	15
Sub-total	6144	2065	7520	450	552	75	92
Total	180088	51429	219780	643	743	107	124

Note: (1) Estimates based on Source (i).
(2) Estimates based on Source (iii). Vessels (mas dhonis) carrying coral rock and sand normally have a crew of 6 men.

Sources: (i) Population and Housing Census of Maldives 1985.
(ii) Population and Housing Census 1990 - Preliminary Results, March 1990.
(iii) Study interviews and Consultants' estimates.

Figure 11. Estimates of Miners Serving Male and Male Atoll

Source: Binnie and Partners 1991

3.8 Economic Development

The First National Development Plan outlined three major long term objectives for the future growth and expansion of the country.

These were to improve the standard of living of the population, to balance the economic progress between Male and the atolls and to obtain greater self - reliance for the future.

The Maldives has just completed their second two year development plan that ran from 1988 to 1990. In this plan, " Decentralisation and diversification of economic activity (were) the central themes of Maldives' development strategy ".

The central point of the development plan was the Public Investment Programme (PIP). This included some 170 projects costing about $283.5 million. More than 80% of this investment was in foreign currency, reflecting the need to import most equipment, material and personnel. Fifty eight percent of the expenditure was allocated for infrastructure investment, twenty seven percent for the social sectors and fifteen percent for the productive sectors including fisheries, agriculture and tourism. This pattern of expenditure highlights the government's role as that of an underwriter for private sector participation in the productive sectors of the economy.

3.9 Future Growth

The Maldivian economy is expected to remain buoyant through out the 1990's, with tourism continuing as the leading growth sector, supported by modest expansions in manufacturing and fishing.

Figure 12 shows the expected tourism numbers to the year 2010. The projections are in line with the investment commitments of the private sector and Government expectations. Beyond 1995, the projections are indicative only, based on more modest rates of growth. Visitor arrivals are forecast to increase from 189, 000 (estimate) in 1990 to 285, 000 and 383,000 by 2010. Over the same period the number of resort beds are expected to rise from 8,788 in 1990 to 12,000 in 2000 and 15,000 by 2010 (Binnie and

Year	Maldive Islands	Malé	Malé as % of Total
Census (nos. 000)			
1985	180.1	45.9	25.5%
1990	219.8	58.9	26.8%
Projections mid-year (nos. 000)			
1990	222.0	60.0	27.0%
1995	267.0	75.0	28.1%
2000	317.0	93.0	29.3%
2010	418.0	131.0	31.3%
Growth Rates (% p.a.)			
1985-90	4.1%	5.1%	
1990-95	3.8%	4.7%	
1995-00	3.5%	4.3%	
2000-10	2.8%	3.5%	

Sources: (i) Statistical Year Book of Maldives 1989.
(ii) Ministry of Planning and Environment.
(iii) Study estimates.

Figure 13. Maldive Islands - Population Projections

Year	Visitor Arrivals (000s)	Resort Beds (nos.)	Capacity Utilization (%)	Av. Length of Stay (days)
Actual				
1987	131.4	6203	56.0	9.7
1988	155.8	7119	58.0	9.6
1989 (est.)	171.2	7631	59.0	9.6
Projection				
1990	189.2	8788	59.0	10.0
1995	235.0	10383	62.0	10.0
2000	285.0	12000	65.0	10.0
2010	383.0	15000	70.0	10.0
Growth Rate (% p.a.)				
1985-89	10.5	9.2		
1990-95	4.5	3.5		
1995-00	4.0	2.9		
2000-10	3.0	2.3		

Sources: (i) National Development Plan 1988-1990, Ministry of Planning and Environment.
(ii) Ministry of Tourism and private resort developers.
(iii) Study estimates.

Figure 12. Maldive Islands - Projected Tourism Indicators

Partners). However, in looking at these figures it should be remembered that they were calculated before the onset of the Gulf War. There were considerable reductions in tourist numbers due to the event
(personal communication) and this may have caused some concern in the Government, resulting in a reduction of future resort expansion plans. It should also be remembered that holiday destinations are also a fashion that change over time.

Fishing and manufacturing are also expected to do well providing the internal market remains buoyant and the Government provides constructive support. Other sectors of the economy, such as construction, distribution, transport, real estate and services will directly benefit from the growth in tourism, manufacturing and fishing (Binnie and Partners 1991).
The population is also expected to continue growing at a high rate in the future (figure 13). This table indicates that the population in Male could increase by more than 50 % in the next ten years. The Government is aware of this problem and there are plans to use nearby islands as satellites to accommodate this growing number of people. The two islands, Villingili (one mile to the West of Male) and Meerufenfushi (25 miles to the North) have been designated as the potential islands to take the Male overspill.

With the projected increase in tourism and population growths, coupled with trend for families to live in coral or cement block walled houses it is expected that there will be a strong demand for coral, coral aggregates and coral sand in the future.
Figure 14 shows the projected used of coral sock, coral aggregate and sand from 1991 to 2010. The total demand for coral rock through out the Maldives is projected to increase from 60,000 m^3 in 1986 - 90 to 76,000 m^3 in 1996 - 2000, at an average growth rate of 2.8 % per annum. The main reason for the decline in use of coral is because it is expected that concrete blocks will be used instead.

Atoll	1980-85	1986-90	1991-95	1996-00	2001-10
Coral Rock					
Malé	385	210	175	156	94
Malé Atoll	205	195	145	109	109
Ari Atoll	120	205	315	329	207
Other Atolls	935	1445	1895	2128	1235
Total	1645	2055	2530	2722	1645
Coral Aggregate (Akiri)					
Malé	80	175	282	668	862
Malé Atoll	45	35	52	63	87
Ari Atoll	15	25	54	97	107
Other Atolls	110	170	361	528	763
Total	250	405	749	1355	1819
Sand					
Malé	525	845	1400	2400	2958
Malé Atoll	200	180	214	225	297
Ari Atoll	90	175	270	408	398
Other Atolls	755	1170	1786	2412	2747
Total	1570	2370	3670	5445	6400

Figure 14. Maldive Islands - Projected Use of Coral Rock, Coral Aggregate and Sand 1991 - 2010 (000 ft^3 per year)

Source: Binnie and Partners 1991

CHAPTER FOUR

4.0 CORAL AND SAND MINING

It has been explained in previous chapter that the Maldives lack natural resources of their own and those that exist are exploited to their fullest potential. Coral and sand are two such natural resources that are exploited.

4.1 Uses of Coral and Sand in the Maldives.

The main uses of coral and sand are in the construction industries, that is in road construction and building development.

1) Road Construction

At the present time there is a development project to pave all the roads in Male. There is a problem, however, in that the only fresh water on the islands exists in the form of a fresh water aquifer below ground level. Due to the high population density in Male, this aquifer is gradually being compressed and reduced to critical levels. There is also a growing risk of saltwater intrusion which is exacerbated by the compression problems (Ali and Mahir, 1987). The roads are the sole remaining open areas that allow a reasonable volume of water to pass into the lens.

This problem has been compounded by the traffic increases in the last decade. There are now a considerable number of motorised vehicles, including cars, pick up vans, lorries and motor bikes that exert far more weight and so pressure on the aquifer than the traditional bicycle. The roads are getting more compacted and water sits for a longer length of time before being absorbed. This in turn means that much of the water is lost due to evaporation. It is therefore of extreme importance that the roads are constructed in such a manner to allow any falling rainwater to permeate down to the water table.

The method of construction that has been devised is to use crushed coral rock as hard core to fill the road bed and coral slabs to pave the roads. Recently, cement blocks have been used inplace of the coral for paving (plate 2) and are fitted together in a way that allows water to sink down between them.

However, it was noticed during a recent visit to Male, that even on newly paved roads that water stands for quite a length of time after a particularly heavy rainfall.

2) Building Development

All buildings apart from "special" buildings are constructed from coral blocks (Office of Physical Planning and Design, OPPD). Special buildings are the larger ones with important usage, for example the new hospital being built by the Indian Government in memory of Indhira Ghandi. All other buildings are mainly constructed from the traditional materials of coral blocks and more recently, sand and cement blocks. Plate 3 shows the construction of a large building using traditional materials. This building is to be a new science laboratory. Figure 15 shows the OPPDs building and design programme for 1991 and outlines the type of materials used for constuction.

An important use of coral rock is also in the building of boundary walls between properties, which are necessary features to prevent neighbourly disputes over property ownership.

4.2 Shingle Rampart Debris

Coral debris or akiri, is composed of dead broken coral and is used as an aggregate in the construction industry particularly in the manufacture of lime. As an aggregate it is also a constiuent of reinforced concrete frames. Lime has now generally been replaced with cement.

4.3 Coral Sand

Coral sand is used both in it's fine and coarse stages in the production of cement and for the creation of hollow sand concrete blocks.

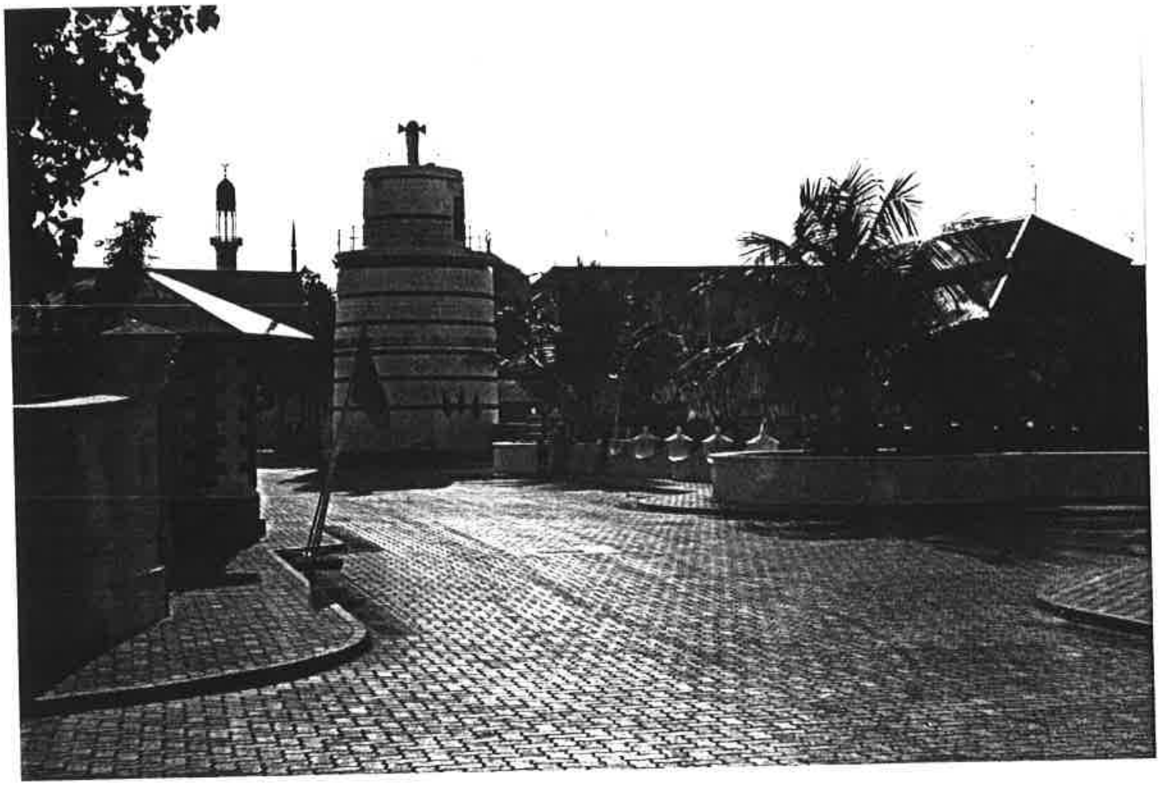


Plate 2. Paved Roads in Male, the Capital.

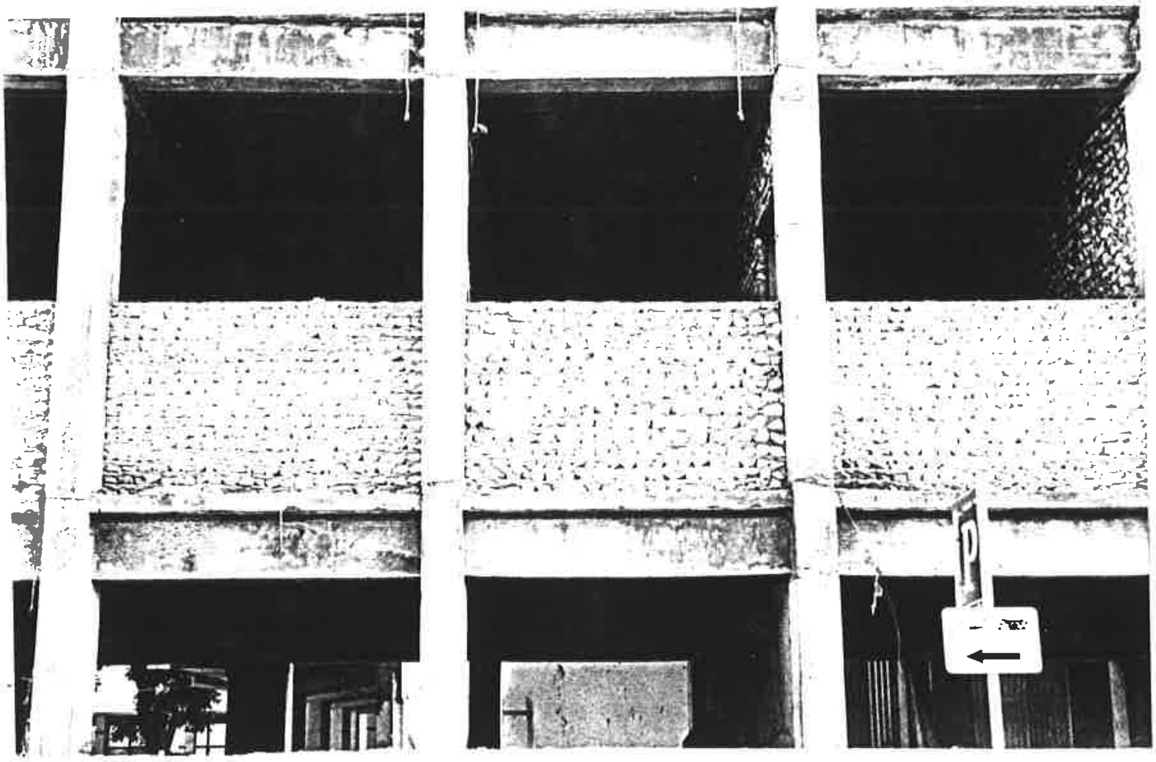


Plate 3. A " Special Building ", a new Science Laboratory

OFFICE FOR PHYSICAL PLANNING & DESIGN

News Conference 1991
14-07-1991

Projects undertaken and designed by OPPD in 1991

January in July 1991 ah OPPD gai kurevifaivaa muhimmu baeh masakkaiy

1. Design, Detail design, Bid Document thayyaaru kurun
   - 1.1 EPSS aa (imaaraaiy) building
   - 1.2 MES aa (imaaraaiy) "
   - 1.3 Allied Insurance
   - 1.4 Arabiyyaa School Phase II
   - 1.5 Regional School Furniture
   - 1.6 Addu Primary School
   - 1.7 Ministry of Finance ge gudhan
   - 1.8 MMA Chandhanee Magu
   - 1.9 Aa Regional Hospital
   - 1.10 Hulhule Miskiiy

JUMLA ANDHAAZAA AGU (Total Cost) Rf 34.0 million

2. Construction Supervise Kurun Project under construction
   - 2.1 Majeediyya Lab
   - 2.2 Aminiya Lab
   - 2.3 MTCC ge OBC
   - 2.4 Galolhu Stadium
   - 2.5 Thaajuddeen Phase II
   - 2.6 Iskandhar Phase III
   - 2.7 Arabiyya Phase I
   - 2.8 Regional Secondary School, Hithadhoo
   - 2.9 Airport Admin Block
   - 2.10 Allied Health Imaaraaiy
   - 2.11 Coast Guard Imaaraaiy (imported aggregate)
   - 2.12 Indoor Stadium
   - 2.13 Muleeaage Extensions
   - 2.14 TV Maldives Extension
   - 2.15 UN Building (imported aggregate)

JUMLA ANDHAAZEE AGU Rf 45.0 million

3. Plan Kurun
   - 3.1 Villingili Alternate Design

4. Survey Kurun
   - 4.1 Mulhi raajjeyge chart kurehun

FIGURE 15 A summary of the work carried out by the Office of Physical Planning design in 1991

4.4 Other Uses

Corals are also removed from the reef in small amounts for decorative reasons. It is now illegal to export black coral, but red and other types of coral can still be found as jewellery around Male.

Many of the tourist resorts have used coral species such as Acropora hyacinthus and the organ pie coral Tubipora musica in interior design.

4.5 Method of Extraction

All mining activities in the Maldives are carried out manually. The local boats (dhonis), select a suitable place for coral extraction, that is suitable for coral type and location and coral rock will then be collected by hand (plate 4). This involves the breaking of live corals if necessary using iron bars and picks, from the reef bed. Manageable size pieces are then loaded into the boats and sailed to their destination (Brown 1986).

The coral blocks or aggregate is then left for a time in the sun and rain to clean it of salt and living material. Subsequently, the rocks are broken by hand into smaller pieces of approximately 4 x 4 x 3 inches which is the size used for construction (Brown 1986). Plates 5 and 6 how larger coral boulders and smaller pieces of broken coral lying on reclaimed land near the harbour in Male.

4.6 Environmental Effects of Coral and Sand Mining in the Maldives

Coral reefs are extremely important in small island states such as the Maldives, both economically and environmentally (Lieu 1986). The economics of the Maldives have been discussed in the previous chapter and this section will deal with the implications of reef degradation and those due to coral and sand mining in particular.

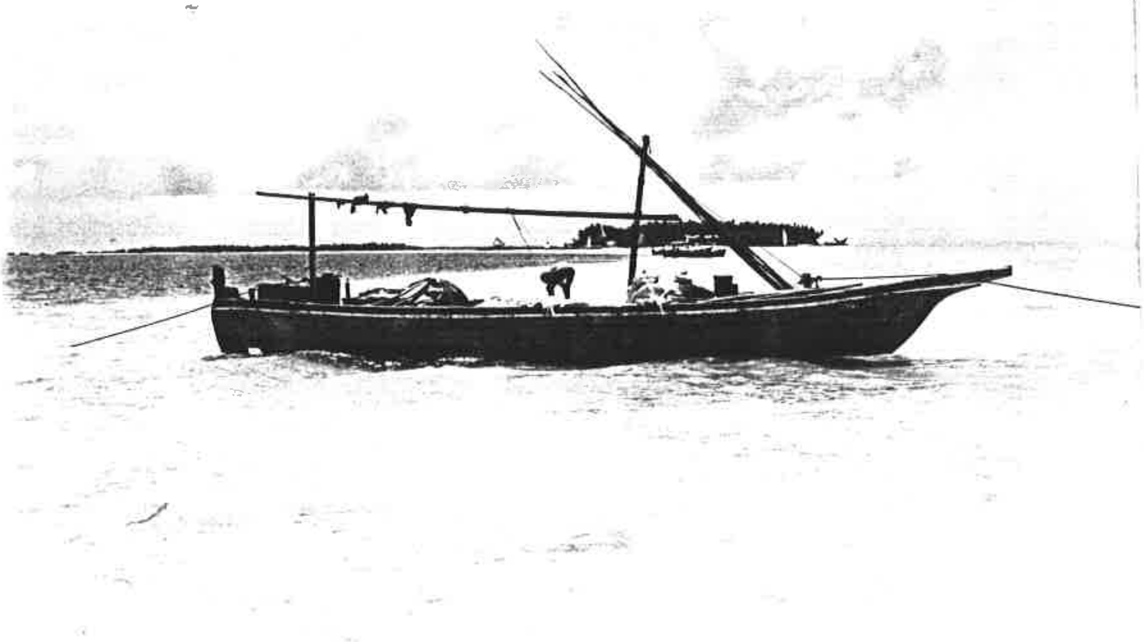


Plate 5. Large Coral Boulders on Reclaimed Land in Male

Plate 6. Coral Rubble on Reclaimed Land in Male

Coral reefs are extremely sensitive and fragile environments. They are therefore susceptible to damage which may be due to naturally occurring phenomena or to human activities (Kuhlman 1988, Grigg and Dollar 1990). Natural phenomena, over which there is no human control, can cause devastating effects. Pearson (1981) lists these perturbances as cyclones, red phytoplanktonic tides, the crown of thorns starfish, volcanic activity, extreme temperature changes and catastrophic low tides.

However, in addition to these climatic and biological disturbances which the reef may adjust to and compensate for in its lifecycle, are those caused by anthropogenic interactions. Human induced damage to the reef may occur due to pollution both by chemicals and human waste, blasting (nuclear and normal), tourism related activities, dredging and of course mining. A fuller list of impacts due to human activities is shown in figure 16.

4.7 Environmental Effects of Reef Degradation

1) Impacts due to Climatic Changes

The Maldives are low lying islands with none being greater than 3 m above sea level. This means that they are at considerable risk of flooding, will be affected by changes in mean sea level height and will be susceptible to any changes in wave patterns and wave actions upon the coast line.

In recent years there has been considerable concern about the climatic changes that are occurring globally and as the Maldives are so low lying, any changes in sea height present a real threat of flooding.

Coral reefs act as naturally occurring breakwaters and reduce tidal impacts apon coastlines. They therefore help mitigate the effects of coastal erosion, which is a naturally occuring process where any stretch of land meets the ocean, but is a particularly severe problem for island nations such as the Maldives with vast amounts of coast to

IMPACTS ON CORAL REEFS

Reference	Source of stress	Medium	Mechanism	Result
Cortes & Risk (1985)	Soil erosion due to deforestation			
White (1987)	Coastal construction	Suspended sediment	Reduction of light, clogging, imposition of clearance work load	Weakened or dead corals, silted surfaces
Bak (1978)	Dredging			
Neudecker (1987)	Power and desalination plants	Hot water	Exceeds thermal tolerances	Weakened or dead corals
Loya & Rinkevich (1987), Cubit & Burgett (in press)	Shipping, industry	Oil	Poisoning, algal growth	Weakened or dead corals, excess algae
Marszalek (1987)	Human habitations, including ships	Dissolved nutrients from sewage		
	Agri- and aquaculture	Dissolved nutrients from fertilizers, wastes	Enhanced growth of free-living algae, which overgrow corals, trap sediment and block recruitment	Excess algae, dead corals
Woodley (in press)	Over-fishing	Removal of herbivores		Loss of fishes, excess algae, dead corals
Endean (1987)	Excess *Acanthaster planci*, ?due to predator removal	Predation	Tissue loss	Dead corals

Figure 16. Impacts on Coral Reefs (Woodley and Clark, 1989)

protect. At the present time coastal erosion in the Maldives is already a cause for concern.

Plates 7 and 8 show the same stretch of beach on one of the tourist islands, Ihiru, in North Male Atoll, during the different monsoonal seasons.

As seen in the pictures dramatic changes in beach morphology occur with the change in wind direction during the different monsoonal seasons. With each monsoonal shift more beach erosion occurs.

The recent climatic changes have affected the Maldives' weather patterns as much as the rest of the world. The traditional distinct monsoonal seasons now seem to be less specific. For example there were particularly severe storms during 1987 and at the beginning of June this year, which resulted in out of season beach shifts (Personal communication).

Hurricanes are well documented as having detrimental effects on reef habitats in all parts of the world (Moran and Reaka - Kudla 1990).

Storms are known to cause damage through wave damage, scouring, sedimentation and reduced salinity (Woodley et al. 1989).

Apart from causing freak weather conditions, the climatic changes that are occurring at the moment due to the greenhouse effect and ozone layer depletion, are also resulting in a sea level rise by causing melting of the ice caps.

There have been several predictions for sea level rise (Houghton et al 1990) ranging from millimetres to centimetres per year. Figure 17 shows a summary of sea level rise predictions for up to the year 2100. It is worth noticing that all predictions are for an accelerated rise. This means that any action to be taken in establishing long term preventative measures should be carried out while there is still time to think clearly about the problems and issues involved. At the moment there is little evidence to suggest that sea level rises are a problem for the Maldives

(Woodroffe 1989, Delft Hydraulics). However, if sea levels did rise considerably, the problems of coastal erosion that have been discussed will be exacerbated and the two

Plate 7. The Beach at Ihuru Resort during the North - East Monsoon

Plate 8. The Same Beach during the South - West Monsoon

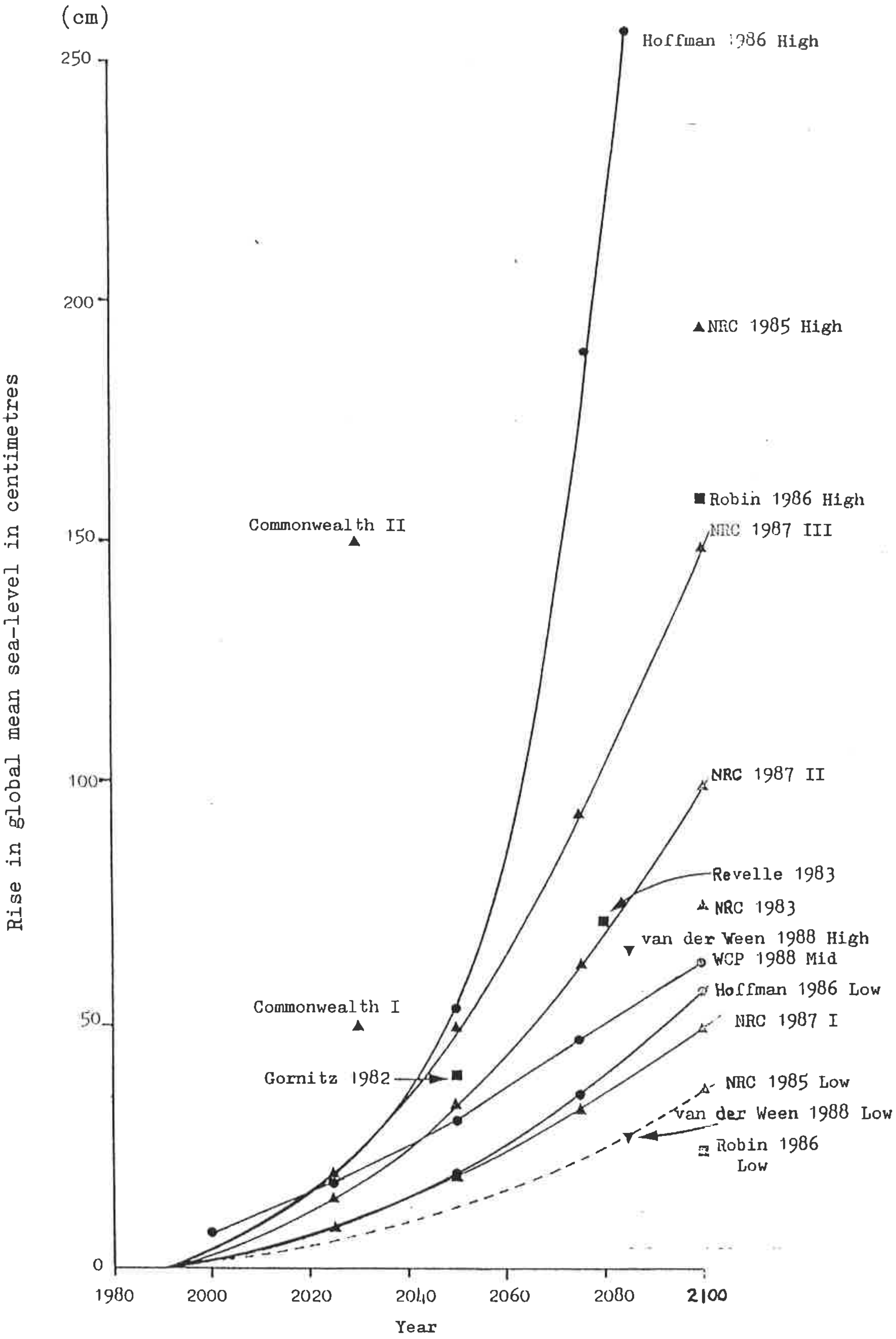


Figure 17. A Summary of Sea Level Rise Predictions to 2100. (A. J. Edwards)

main economic markets of tourism and fishing will be threatened.

2) Degradation Due to Tourist Activities

Degradation due to tourist related activities is also becoming more of a problem in the Maldives with the rapid rise of the tourist industry in the last decade. In 1989, 1,588,488 tourists visited the Maldives (Statistical Year Book 1990) . The problems which result from the influx of large numbers of tourists have been seen in many parts of the world, particularly now in Australia, where whole sections of the Barrier Reef have been completely destroyed due to negligence, boat anchors and divers. There is no published data on environmental impacts of tourism related activities in the Maldives, and unfortunately many of the resort owners themselves do not seem particularly concerned at the present time. However, there are definite signs of reef damage due to dive boats, divers, snorkellers and sewage related problems (Dawson Shepherd, personnel communication).

3) Damage Caused by the Crown of Thorns Starfish, Acanthaster planci

The starfish, Acanthaster planci, is a natural predator of coral and has been seen to cause devastating effects on the reefs of the Barrier Reef. It has particular preference for hard corals, the same that are preferentially mined for construction purposes. In some cases, the extent of predation has resulted in a 90 % destruction of the hard corals on a reef (Endean and Cameron 1990).

4) Detrimental Effects Due to Coral and Sand Mining

Coral and sand mining contributes to these environmental and so economic disturbances because it results in the direct removal of large amounts of material from the reefs. Mining in reef areas has been well documented as causing detrimental effects in several parts of the world (Salvat 1987, Gabrie et al. 1985). If one particular area is mined then that site becomes more sensitive to any future damage that may occur and it aggrevates the situation in reefs that may already be suffering due to natural perturbances. Plate 9 shows a typically mined reef in the Maldives in North Male Atoll. Note the one remaining table coral, Acoropora, that has been left behind. This is in total contrast to the healthy branching corals shown in plate 10 .

Coral and sand mining have three major impacts on the environment.

1) Beach Erosion

The first and probably most important effect is the increase in beach erosion due to the higher wave impact as a result of the removal of the reef ajoining the islands.

Studies have been carried out by the Marine Research Section and the Ministry of Planning and Environment which have found that there is a definite likelyhood that beach erosion could occur in some islands due to mining of the associated reefs. One such study was at Kaashidhoo, carried out by the ERU in March of this year.

Infact, the recent report by Delft Hydraulics reached the conclusion that " the Maldives are undermining their safety with considerable speed " and points out that " more and more coral will be mined to accommodate the fast growing population that will need to defend it's eroding shorelines with ever increasing speed, using more coral for shoreline defense works etc."

This report has estimated that a lowering of the reef top may be occurring in the range of 10 - 20 mm per year and this is in the range of predicted sea level rises for the next decade.

The problems are particularly severe in North and South Male Atolls where the majority of the mning is carried out. The problem is made worse in these areas by the collection of akiri, which collects on the east sides of the islands due to storm deposition. It's removal not only reduces sea defences, but also the source of natural acretion that enable the islands to develop as part of their natural formation (see chapter 2).

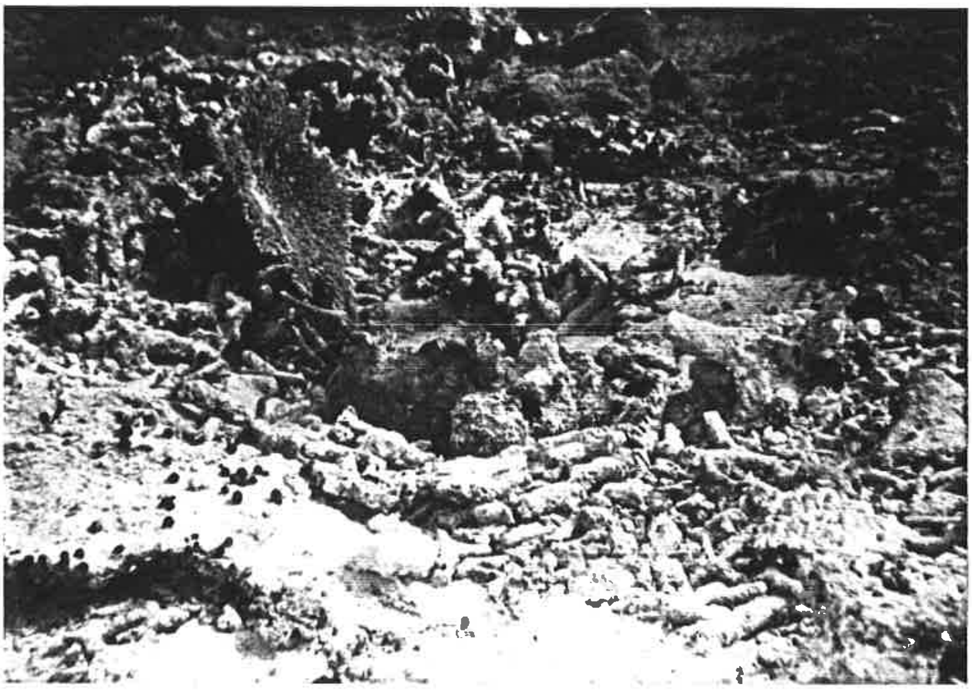


Plate 9. A Mined Coral Reef in North Male Atoll, with One Table Coral Remaining. Courtesy of Dr. Susan Clark

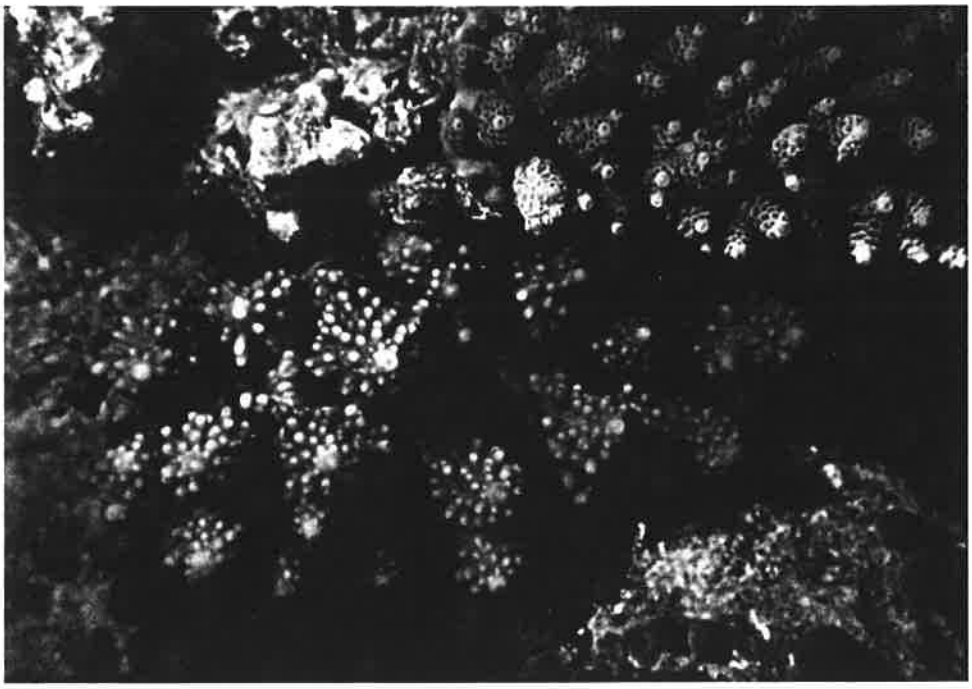


Plate 10. Healthy branching Coral

2) Reduction in the Diversity and Abundance of Reef Fish

" Cluster analysis of abundance data from various sites demonstrates a sharp division between mined and unmined reefs "

The abundance and diversity of reef fish is known to be closely correlated to the complexity of the habitat. A relationship was demonstrated at sites where mining has significantly reduced the topographical complexity and caused a corresponding reduction in fish numbers, during the environmental assessment part of the Binnie and Partners study into coral and sand mining.

3) Loss of Wildlife Habitats

Certain areas of beach that may be exploited for akiri or sand collection are the habitat for at least one species endemic to the Maldives. The Central or Paler Maldivian Little Heron, Buteroides stiatus didii, is known to be unique to the Maldives.

In 1985, an Economic and Social Commission in Asia and the Pacific (ESCAP) report concluded that coral mining and souvenir collecting are the major causes of coral reef degradation in the Maldives so far.

CHAPTER FIVE

5.0 THE CURRENT STATE OF CORAL AND SAND MINING IN THE MALDIVES

5.1 Responsibility for Coral and Sand Mining at the Present Time.

At the present time, responsibility for coral and sand mining and to which authority permission must be applied to in order to carry mining out is confused.

For mining in North Male Atoll, where the majority of the mining is carried out, jurisdiction and permission for mining belongs to the Ministry of Public Works and Labour.

Mining that is undertaken in the atolls is the responsibility of Atolls Administration. However, this a an area where localised decisions are made. In practice, permission is sought from the island chief by islanders if they wish to mine in the vicinity of an inhabited island. The Island Chief then informs the Atoll Chief and Office that mining is being carried out.

Any mining or dredging around tourist islands is the responsibility of the Ministry of Tourism. In reality, however, the resort owners are able to undertake mining and dredging in the vicinity of their island without seeking permission of another authority.

If mined materials are required from an area that is not classified within one of the above three categories, then it is the Ministry of Fisheries and Agriculture whose permission must be sort for work to be carried out. However, in practice, it is found that the Ministry will be informed after the mining has begun, and in some cases no indication of work in progress is ever given.

5.2 Current Legislation for Mining in the Maldives

Appendix one shows the most recent government directives concerning permission to mine coral in the Maldives form the 12 th of February 1990 until the 30 th June 1991. In February of 1990, the Presidential Letter, stated that mining was to be stopped from the House Reef of inhabited islands (the reef immediately associated with the island, see plate 11) due to the damage occurring from such activities. However, so that islanders living far from fringing reefs were not inconvenienced too much, permission was given to mine the reefs of close by uninhabited islands. This was on the condition that the Atoll Office should supervise proceedings and note any damage to the island. However, this Letter did not make any recommendations as to the action to be taken if large amounts of damage did result from such activities.

This situation was modified slightly by a following Presidential Letter in October of 1990, which defined to greater extent the areas where mining was allowed and the action to be taken over damaged reefs. In this letter, mining was forbidden from House Reefs, any fringing reef close to an inhabited island and reefs on the Atoll Rim.

A further step was also taken in a positive direction when mining to build boundary walls between adjacent properties was also banned.

Any damage to reefs was to be reported to the Ministry of Atolls Administration and the Ministry of Planning and Environment.

The situation has recently been altered again, however, as internal disputes between islanders have arisen due to the time taken to erect suitable boundary walls between properties. In a Presidential Letter of June 30 th 1991, permission was renewed to allow the mining of coral for boundary walls and outer walls of buildings.

Plate 11. A Tourist Island with House Reef

5.3 Proposed Controls For Future Coral and Sand Mining

Discussions are on going at the moment to decide upon effective action for mining in the future. Two main meetings dealing with the issues of coral and sand mining and how the situation was to be regulated were held in June. The proposal was that suitable sites for the mining should be designated by the Marine Research Section of the Ministry of Fisheries and Agriculture and that monitoring of these sites would be carried out by the Ministry of Planning and Environment.

However, in order to designate sites, suitable ones need to be approved in the first instance.

5.4 Selection of Sites Suitable for Mining.

The problems associated with coral and sand mining was first recognised in a report by Dr. Barbara Brown and Dr. R. Dunne in 1986, carried out on behalf of the Maldivian Government.

1) The Binnie and Partners Study

In 1990, funds were made available by the ODA for a team of consultant engineers, Binnie and Partners, to carry out a study (Coral Mining Study Preliminary Report) into the possibility of finding one site that would supply all the Maldives coral and sand requirements for the next fifteen years with the intention of minimising damage to any more reefs.

Ten sites were selected for investigation in North and South Male Atolls. However, out of these sites only two were chosen for further investigation, in a fuller programme carried out later in the year.

The final results of the study (Binnie and Partners Final Report, the Maldives Coral Mining Study) concluded that the site referred to as Faroe 7 in South Male Atoll, was both financially and economically viable as a means to provide coral for building purposes for ten years and up to 50% of the sand requirements for the whole of the

Maldives. The report concluded that this method of coral extraction would also be acceptable on environmental and social grounds.

This report has only just been concluded, and as of yet no decision has been made by the Maldivian government as to the action that might be taken on the future of coral and sand mining.

2) Studies by Dr. Dawson Shepherd

During this same period of time, further work has been carried out by Dr. Alec Dawson Shepherd into possible sites for sand mining. His work has been concentrated in the North and South Male Atolls and Ari Atoll also in the centre of the Maldives archipelago. He first has to identify possible sites from the 1969 aerial photographs and then transfer this data to a copy of the relevant British Military map of the area (mapping data about the Maldives is discussed in chapter 9). A boat survey then ensues to check these sites out accurately. Criteria for selection include the following,

1) the site must be part of a reef of an uninhabited island.

2) the sand must be part of the lee slope of the island or reef, so that the natural protection will not be removed.

3) there must be a suitable entrance channel to the site.

4) the site must not be a known fish breeding ground (this is ascertained by sending questionnaires to local fishermen).

5) the sites must be within reasonable distance of the inhabited islands which require the sand.

To date, three atolls have been examined in this way. They are North Male Atoll, South Male Atoll and Ari Atoll. Figure 18 shows an example of a map that has been produced detailing possible sites in South Male Atoll. Dr. Dawson Shepherd thinks that it will have taken approximately a years worth of work to obtain this data and produce accurate maps of the sites. If it is remembered that there are 26 atolls, this a very labour intensive method of approaching the situation of site designation. It is difficult to recommend a

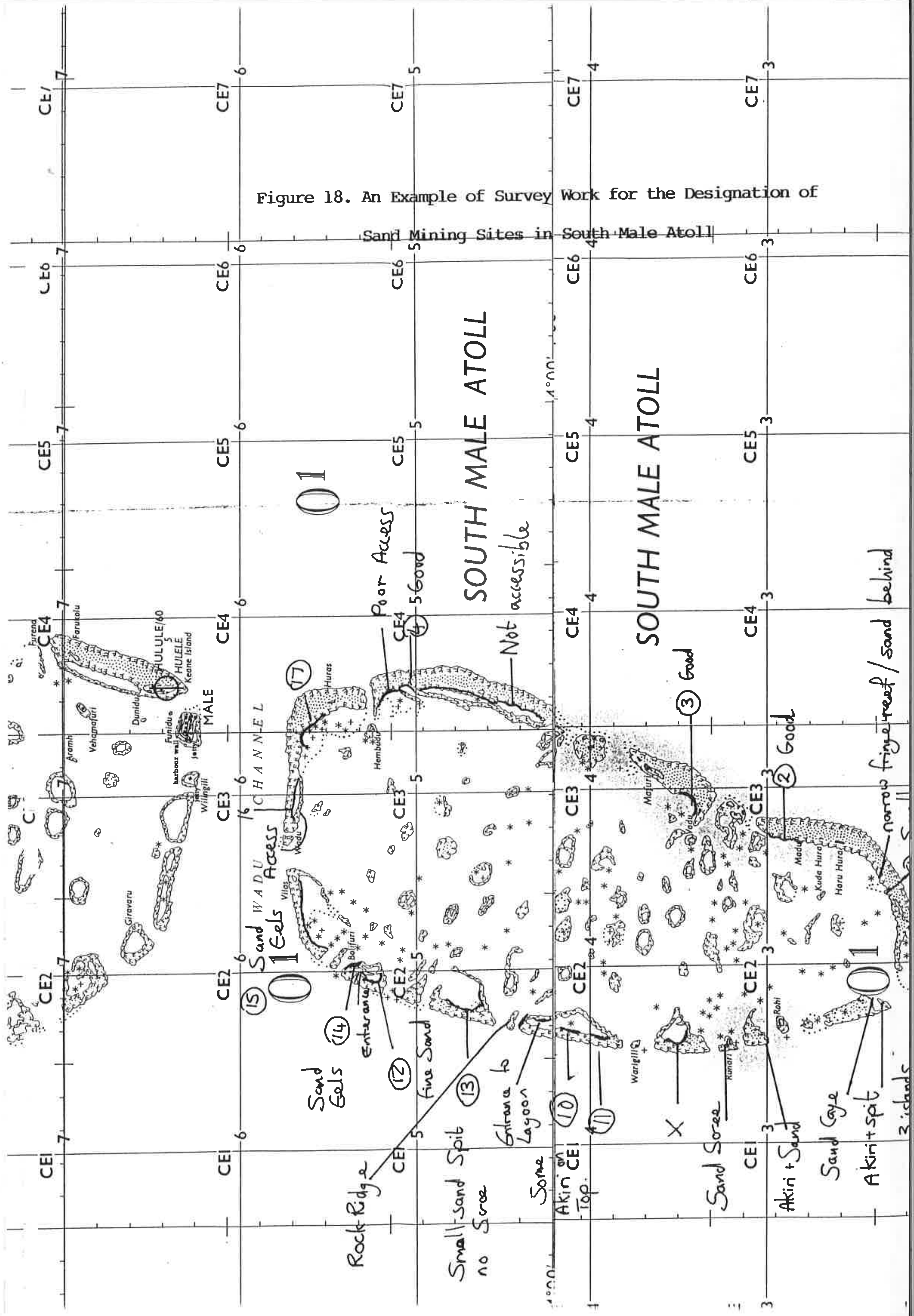


Figure 18. An Example of Survey Work for the Designation of Sand Mining Sites in South Male Atoll

site because it has to be one that is also easily identifiable and one that can be monitored in the future.

The surveying work for both studies has been extremely time consuming due to the lack of accurate geographical data about the Maldive Islands. This issue will be considered more fully in chapter 9.

The next chapter is devoted to explaining the workings of GIS and is followed by a section that considers the requirements which are specifically needed for the development and monitoring of coral and sand mining. This section includes the aspects of organization that would need to be improved before effective implementation of a GIS could be carried out.

CHAPTER SIX

6.0 GEOGRAPHICAL INFORMATION SYSTEMS

6.1 Introduction

Geographic information systems (GIS) are computerised systems that are use to store and manipulate geographic information. A GIS is designed for the collection, storage, and analysis of objects and phenomena where geographic location is an important characteristic or critical to the analysis. While handling and analysing data that are referenced to a geographic location are key capabilities of a GIS , the power of the system is most apparent when the quantity of data involved is too large to be handled manually (Aronoff 1989). There may be hundreds or thousands of features to be considered, or a very large number of factors to be taken into account for each location. These data may exist as maps, tables or lists, forms which are difficult and time consuming to handle manually and so expensive to analyse. A GIS, however, will manipulate the same data in a much smaller space of time therefore releasing personnel and resources for other activities and so reducing costs.

The applications for GIS are numerous and diverse. They have been used typically in the finding of coincident factors such as the areas with a certain combination of soil type and vegetation, or the areas within a city with high and low crime rates. Alternatively, GIS can be used to update geographic information such as forest cover maps to recent logging operations, or updating land use maps to show recent conversion of agricultural land to residential development. In fact, there are many diverse ways in which GIS can be used for aiding planning developments, managing services and monitoring changes in the environment.

Despite the analytical power of this technology, a GIS, like any other system does not and cannot exist on its own. There must be an organisation of people, facilities and equipment responsible for implementing and maintaining the GIS. Ultimately, a GIS is

used to produce information that is needed by a user or a client and its design will be specifically
tailored to that need .

6.2 Definition of a Map

As a GIS is a computerised system that is used to represent and analyse geographical data it is useful to have a definition of an ordinary map. A map is a set of points, lines and areas that are defined by both their location in space with reference to a coordinate system and by their non spacial attributes (Burrough 1986).

6.3 The Operations of a Geographical Information System

The roots of geographic information systems date back to the mid eighteenth century with the development of cartography and the introduction of the first base maps. Before that time, the graphic depiction of spatial attributes could not be accurately drawn. Thematic mapping, that is the definition of attributes to a given geographical area, came about soon after, with maps portraying magnetic variation with isohalines and wind direction by means of arrows. The idea of recording different layers of data on a series of similar base maps originated with strategic planning during the American War of Independence (Parent and Church 1987).

Computer generated maps were first utilised by meteorologists, geophysicists and geologists in the late 1950's and resource inventory and modelling of physical processes were developed during an increased environmental awareness in the 1960's. Thus, by the middle of the twentieth century, there were three critical components available for the development of cartography into a GIS. These were improved technology in the shape of digital computers, improved analytical techniques and a greater awareness of the environment.

6.4.0 The Components of a GIS

Geographical information systems have three important components - computer hardware, sets of application software models, and a proper organisational context. These components need to be in balance if the system is to function properly (Burrough 1986).

6.4.1 Computer Hardware

The general hardware components of a GIS are the central processing unit (CPU) or computer which is linked to a disk drive storage unit. Data is converted from maps, lists or tables into digital form by a digitizer and are sent to the computer. A plotter or other display device is used to show the results of the data processing and a tape drive is used for storing data or programmes or for communicating with other systems. The user controls the computer and peripherals through a visual display unit (terminal). The terminal may be a microcomputer, or it might incorporate special hardware to allow the quick display of maps. The major hardware components of a GIS are shown in figure 19.

6.4.2 GIS Software Modules

The software package for a geographical information system has five basic technical modules. These are sub systems for data input and verification, data storage and database management, data output and presentation, data transformation and user interaction (Burrough 1986).

Data input is the procedure of encoding data into a computer in computer readable form and writing the data to the GIS data entry base. Data entry is usually the bottleneck in implementing a GIS (Aronoff 1989) and the creation of an accurate and well documented data base is critical to the operation of a GIS. It is important to remember that accurate information can only be generated if the data input is itself accurate in the first instance.

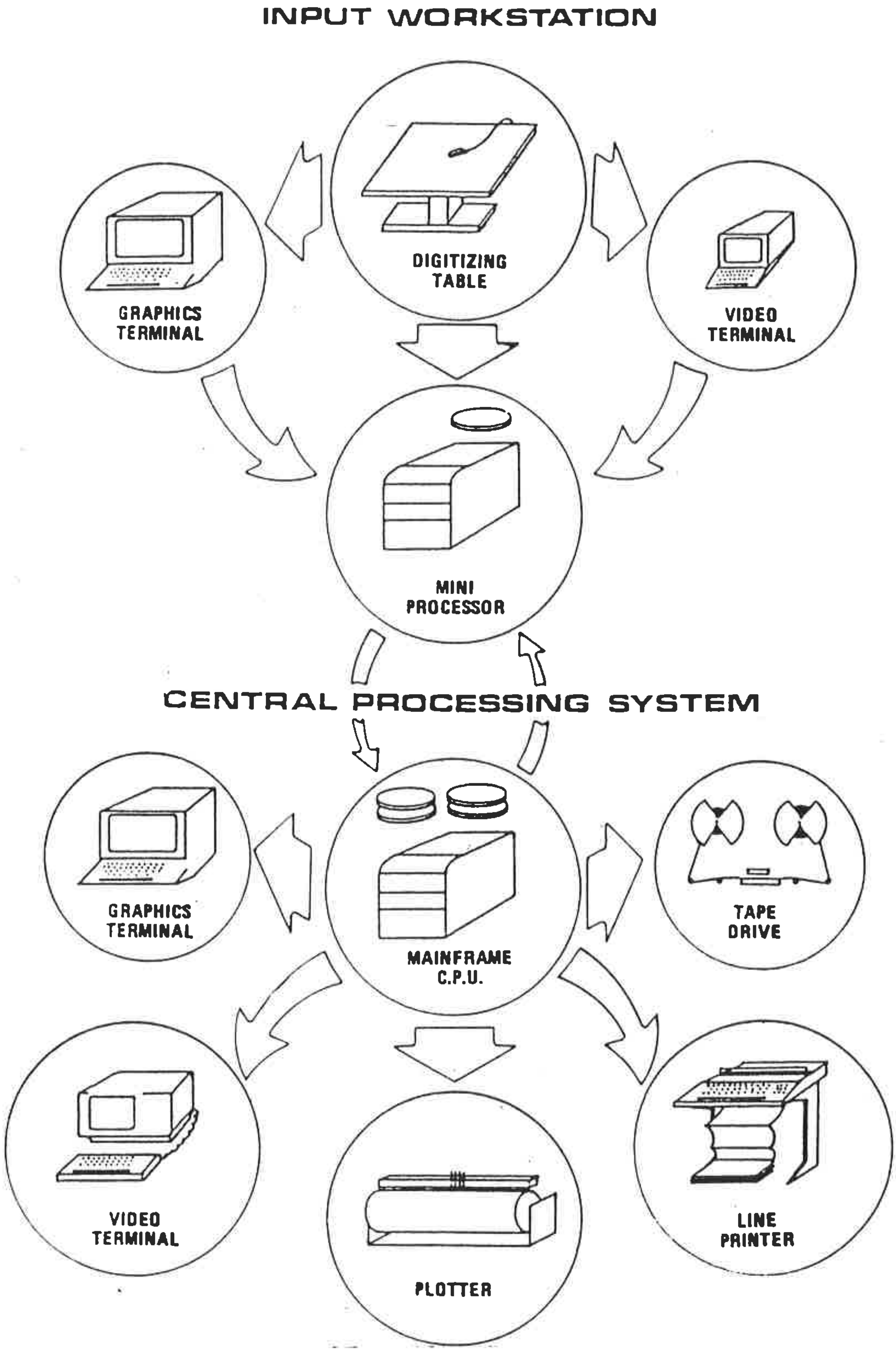


Figure 19. The Hardware Components of a GIS

(Butler et al., 1986)

There are two main types of data that need to be down loaded into a GIS. These are spatial data and associated non spatial attribute data. The spatial data represents the geographical location of features. For example, points, lines and areas are used to represent specific geographical features like a lake or forest. The non spatial attribute data provide descriptive information, like street names, water salinity and soil composition. This data type must be entered and correctly and logically linked with the spatial data for any sense and judgements to be made in the future.

There are two fundamentally different but complementary ways of representing spatial data on a computer. These two ways are known as raster and vector formations. A raster representation is when an object is built up from a set of points on a grid which is also known as a raster. The computer knows that the points all belong to the same object because they are given a code and so are all displayed at the same time, represented by a numerical value or colour or grey scale, forming a picture.

The vectorial representation of data uses lines that are defined by a start and an end point. These lines are vectors and the computer uses pointers to link the vectors together to illustrate an object.

There are also other differences between the two systems. For example, the vectorial system requires fewer numbers for representation, thus needing less storage space. The vector image is more aesthetically pleasing to the eye and the resolution of the raster based image needs to be improved, requiring more coordinates and so memory storage space, to achieve the same quality of picture. The linkage between the vector lines also allows searches to be spatial searches to be made. However, it is far quicker to change the shape or size of an object using the raster representation as alterations or changes in data composition merely involves deleting certain values or adding in new ones. In the vector representation the coordinates must be updated and relinked.

It should be realised that there is not necessarily a connection between the structure of the data base and the means by which the data is expressed. That is, the data may be raster or vector based but the display may be the opposite. In many computer aided design and mapping systems information is expressed from a vector structured data base on a raster colour display or a vector plotter.

a) Data Inputing

There are five types of data entry systems commonly used in GIS and these are keyboard entry, coordinate geometry, manual digitizing, scanning and the input of existing digital files (figure 20).

i) Keyboard Entry

Most attribute data are entered using a keyboard and are obtained from an existing data base into which they were keyboard entered. Keyboard entry can be used during manual digitizing to enter attribute data. However, this is normally more efficient if it is handled as a separate operation and the attributes are entered with a code to indicate the spatial element that they describe.

ii) Coordinate Geometry

A second data entry method involves the calculation and entry of coordinates using coordinate geometry procedures (COGO). These procedures are mainly used to enter land data entries. It is an accurate technique because the original information comes from the use of land surveying instruments. This is especially important when maps must represent information exactly for legal purposes. Because of the high precision nature of this method of data entry, the costs are also extremely high and can be up to twenty times more than other methods, although on average the cost is in the range of six times more expensive (Aronoff 1989 and Dangermond 1988).

iii) Manual Digitizing

The vast majority of data entry is now done using a manual digitizer. This is for a variety of reasons. For example, it may not be possible to remove maps to where a scanner is

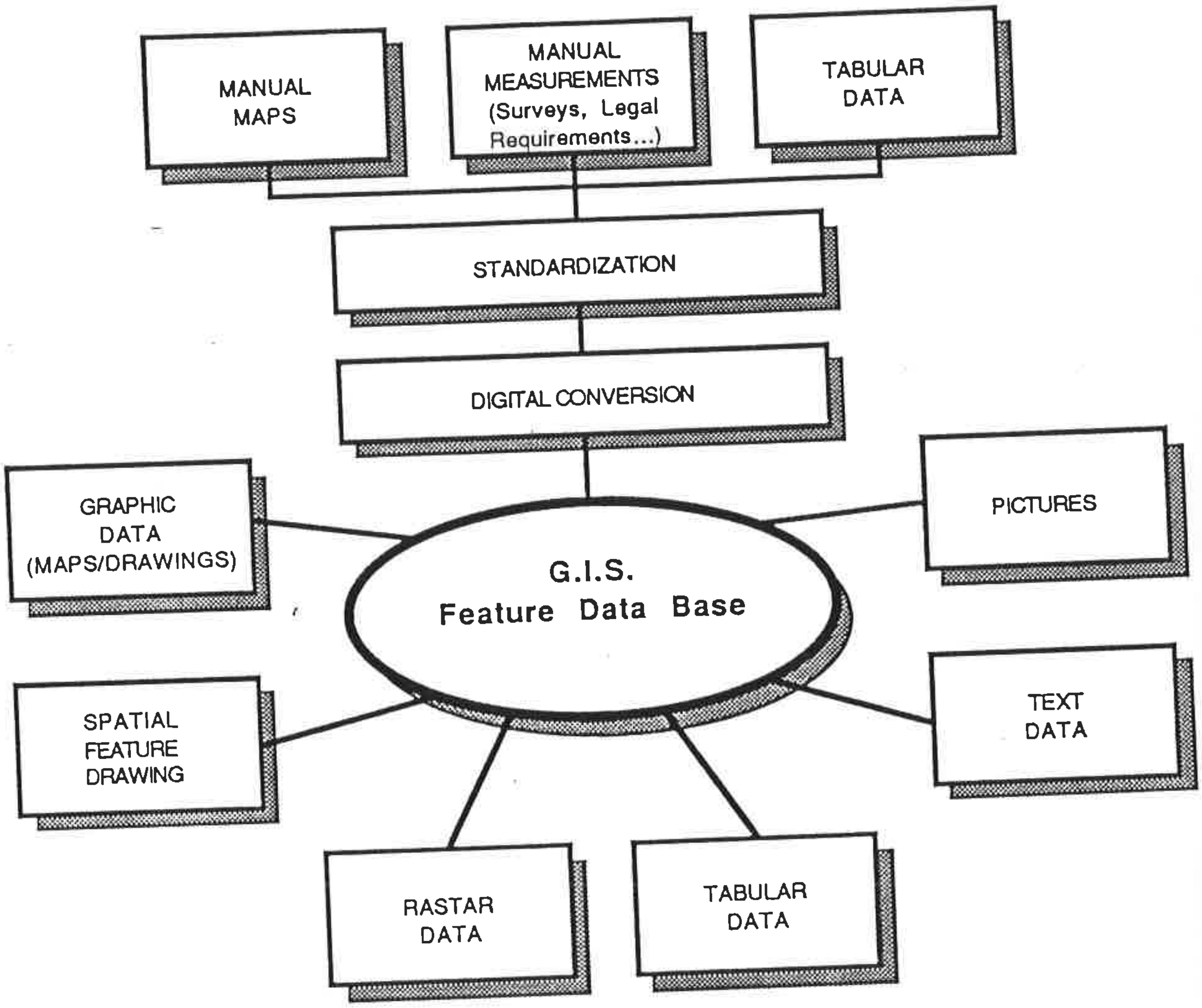


Figure 20. The Software Features of a GIS

(Butler et al., 1986)

available for doing the actual conversion automatically, or records may be in such poor repair (ancient documents) that scanning is impossible. It is also possible that a scanner may not be able to distinguish features distinctly enough to translate them accurately.
However, manual digitizing has many advantages. It has a low capital cost, low labour costs and is very flexible and adaptable. Whilst the procedure of manual digitizing is labour intensive the techniques can be taught to new users within hours. There are, however, greater possibilities for mistakes to be made, but these will be reduced with practice and there is software available for error checking. Any mistakes that are discovered can be updated easily. It is thought that until scanners become more cost effective and flexible that manual digitizing will remain the prelevant method of data entry.

iv) Scanning

Scanners are expensive in the initial outlay for their acquisition and upkeep although they are obviously cheaper to run than employing a large number of people for specialised data entry.
It has been found at the Environmental Systems Research Institute (ESRI) that scanners work best when the information for input is kept simple, for example, maps drawn from photointerpretation or other maps or drawings.
Scanning is most appropriate for maps which contain large volumes of cartographic feature information, that is maps with 1,000 or more polygons and maps whose cartographic feature definitions require substantial amounts of x,y co ordinate definition. Maps which are not clean and require interpretation or adjustment during the automation process or which have small numbers of cartographic features are simply not worth scanning
(Dangermond 1988).

v) Input of Existing Digital Files

There are over a dozen standard types of digital cartographic files that can be used for building GIS systems (Dangermond 1988) that are at present currently available in the United States and Canada. These data sets are currently used for nation wide statistics and census data. Sets are also being made up to provide records of land ownership and to provide information about natural resources.

As digital data sets become more widely available their format will become more standardised. Private companies are also beginning to provide off the shelf data base products. As the cost of existing data sets are the fraction of the cost of creating a new data set, it is hoped that in the future the availability of inexpensive data sets will make GIS technology more attractive and easier to implement (Aronoff 1988).

b) Data Verification

There is considerable scope for error during the data entry process.

The spatial data may be incomplete or doubled. The spatial data may be in the wrong place. The spatial data may be in the wrong scale or may be distorted or linked to the wrong non spatial data. The non spatial data may be incomplete.

The best way to check that the spatial data have been correctly digitized is to get the computer to draw them out again on translucent paper so that they can be placed over the original and checked.

Non - spatial data is best checked by eye or by using special programmes that identify gross errors such as numbers in place of text or numbers out of range.

c) Data Storage

Because building a digital data base is both a time consuming and expensive process, it is vital that the information is stored in a manner that will stop the information degrading. To do this, it is necessary to transfer the digital map data from the local disk memory of the computer to a more secure environment such as a magnetic disk or tape.

Digital databases for topographic, castral and environmental mapping van be expected to have a useful life of 1 - 25 years (Burrough 1986).

However, at the present time there seems to be no exact way of determining the best method of ensuring that information is preserved. For example, the Ordnance survey which started to build up plans of Britain in 1971 follows strict back up procedures laid down by British Government Codes of Practice.

These involve keeping multiple copies of each plan on tape and two copies of the tape are made. One of these copies is then copied to produce a third and these first three tapes are then later supported. After 6 months they are cleaned and rewound. After 12 months they are copied to produce a fresh data bank tape (Ordnance Survey).

In America, on the other hand, the EROS data centre have not found degradation over a seven year period and so find it sufficient to clean and rewrite tapes on a tape cleaner apparatus before reading them on a computer.

Obviously whichever method of ensuring data storage is used, it is important to keep computers in the proper environment for their use. In the Maldives this has already been found to be difficult, with average temperatures around 30 °C and humidity of approximately 85% coupled with inadequate air conditioning facilities, computer maintenance is not easy.

Figure shows the possible damage to magnetic tape exposed to temperature extremes.

d) Data Management

There are three broad approaches that can be used to implement data management within a GIS.

1) This approach is a hybrid system that uses a commercially available DMBS for storage of the non - spatial attributes. The DBMS is normally related to the software for the management and analysis of the spatial data and thus can be used to link the attribute data to the spacial data.

2) The second method uses the DBMS as the main core of the GIS. It allows both attribute and spatial data to be managed and if software is added to the DBMS then spatial functions and graphics displays needed in geographical analysis are available.

3) It is possible to develop an individual, integrated spatial and attribute data base for a specific system from basics (Aronoff 1989).

e) Data Output and Presentation

Information and analysis can be generated out of the system in a number of ways. It can either be viewed on screen in black and white or colour, or can be produced as a hard copy in a variety of ways. For example, different printing and plotting devices are available, with a variety of complexity and colour capabilities. Information viewed on screen or the softcopy as it is known, can be seen in a number of ways.

GIS output capabilities include those listed in figure . In fact, output is only limited by the size of the screen, although this is partly overcome by the use of windows and the accuracy of the information initially used for the data base. It is obviously not sensible to zoom into part of a map at a greater scale than that of the original, because resolution will be lost and accuracy will be reduced.

Both plotter and VDU outputs can be classified as to whether the display is produced by a raster scanning technique or a vector line drawing technique.

Figure 21 shows a comparison of raster and vector display devices and highlights some of the advantages and disadvantages of each.

f) Data Transformation and User Interaction

Geographic data describe objects from the real world in terms of their position within a known coordinate system, spatial relationships with one another and in terms of their attributes. GIS are designed to manage data gathered using widely disparate methods (figure 22). They are able to integrate data, provide analysis and map the results. A GIS

1. Use VECTOR data structures for data archiving phenomenologically structured data (e.g. soil areas, land-use units, etc.).

2. Use VECTOR methods for network analyses, such as for telephone networks, or transport network analyses.

3. Use VECTOR data structures and VECTOR display methods for the highest quality line drawing.

4. Use RASTER methods for quick and cheap map overlay, map combination and spatial analysis.

5. Use RASTER methods for simulation and modelling when it is necessary to work with surfaces.

6. Use RASTER and VECTOR in combination for plotting high quality lines in combination with efficient area filling in colour. The lines can be held in VECTOR format and the raster filling in compact RASTER structures such as run length codes or quadtrees.

7. Preferably use compact VECTOR data structures for digital terrain models, but don't neglect altitude matrices.

8. Use RASTER-VECTOR AND VECTOR-RASTER algorithms to convert data to the most suitable form for a given analysis or manipulation.

9. Remember that DISPLAY systems can operate either in RASTER or VECTOR modes independent of the DATA STRUCTURES that are used to store and manipulate the data.

Figure 21. Recommendations for the Use of Vector and Raster Data Structures in GIS (Burroughs 1986)

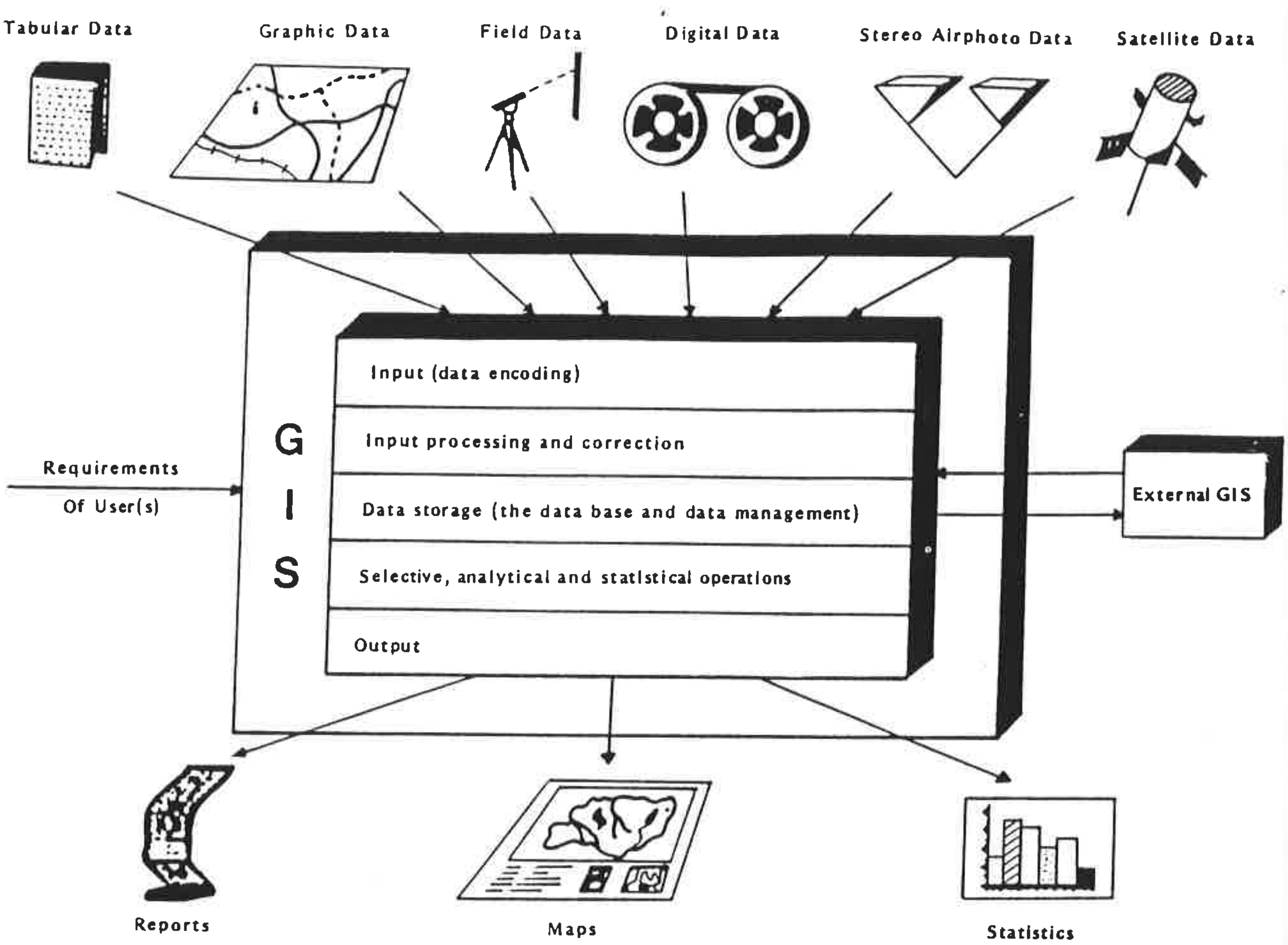


Figure 22. The Different ways in which Data can be Collated for GIS

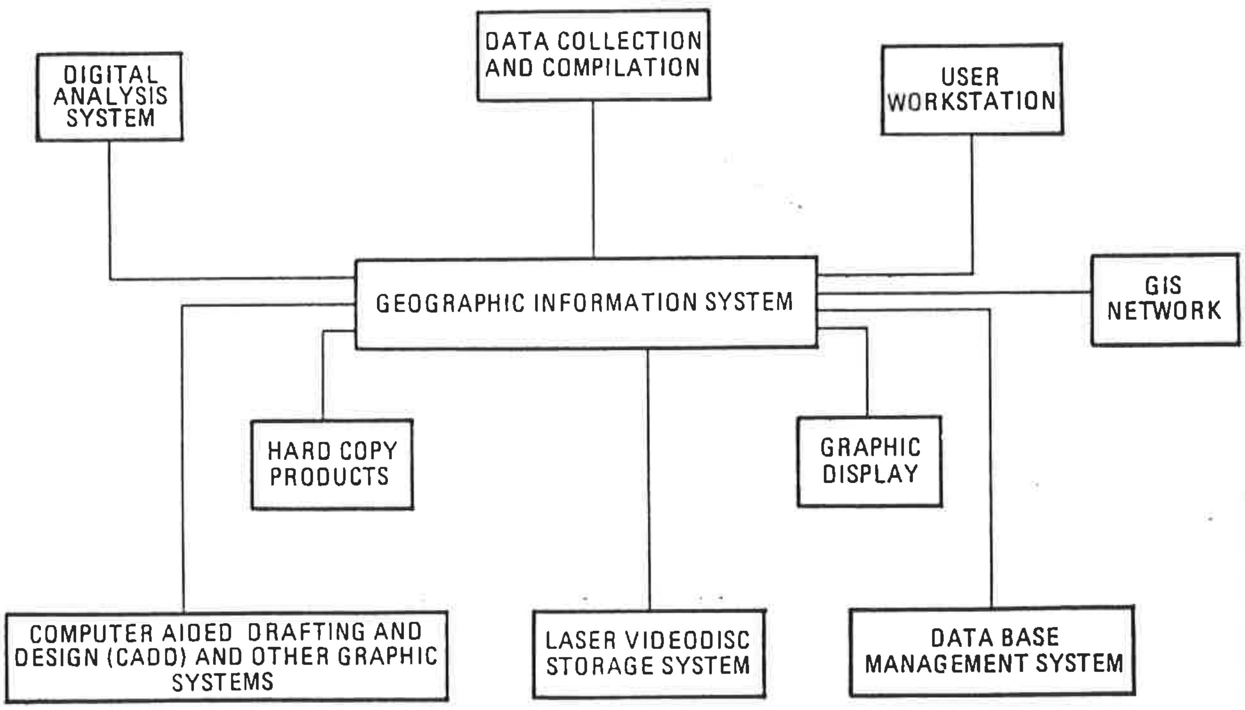


Figure 23. The Functions that can be used for Decision Making Processes and as a Management Aid. (Butler et al., 1986)

is also supposed to be able to answer a broad range of questions about these data. However,it is worth remembering that a GIS is in the end only as good as it's operator. To achieve reasonable answers to questions, data from different sources must be linked together in logical steps.

The ability of a GIS to integrate raster data from a satellite sensor with vector data from a digitized map sheet is one of its strengths, as well as the source of many problems in data storage and management (Robinson et al 1987). In other words, the integration of spatial data from a variety of sources means that problems of locational registration must be solved by the GIS so that all data are located within a common frame of reference.

This ability to provide the capability for answering queries is in fact the major difference between a GIS and computer assisted cartography (figure 23).

The answers to questions from a GIS can be categorised into three types (Aronoff 1989). For example, an answer can be the presentation of data about a certain topic or the number of objects being investigated which fall into a certain defined category (i.e. the number of licences within a certain area of seabed granted, for a specific type of mineral extraction).The third type of answer is a predictive answer, such as the calculation of the volume of a certain type of aggregate that might exist at specific place on the seabed at a specified depth.

The functions used to provide these answers can similarly be divided into three categories.

1) storage and retrieval functions

2) constrained query functions, and

3) modelling functions

(Aronoff 1989).

Geographic information in a GIS is entered into the system as a set of thematic maps. The different types of thematic information are represented as different map layers on paper maps and also as different data layers within the GIS system.

A data layer, consists of a set of logically related geographic features and their attributes. The features to be grouped in a single data layer are chosen for the users' convenience. Examples of data layers that might be used in a marine oriented GIS would include bathymetry and sediment type. They also might include licences for dredging of aggregates and shipping transport lanes, depending entirely on the final requirements of the user.

g) Analysis Functions

A GIS can, within reason be programmed to do what ever is required of it. Aronoff has, however, used a simple classification of analysis functions in order to clarify some of these capabilities. He maintains that the way in which a GIS function is carried out depends upon such factors as the hardware, speed of analysis required, the specific data model being used (raster or vector) and the exact nature of the user requirement.

Using Aronoff's method of classification, analysis functions can be broken down into four main divisions. These can then be further subdivided to give types of functions. The four main classes are therefore as follows,

1) Maintenance and analysis of the spatial data

2) Maintenance and analysis of the attribute data

3) Integrated analysis of spatial and attribute data

4) Output formatting.

An explanation of these four classes is provided by the diagram provided in figure and some of their subdivision functions are shown.

It is not within the scope of this report to discuss in detail all aspects of the working of a GIS, however, some of the more widely used functions will be expanded upon.

1) Maintenance and analysis functions

These are used to transform spatial files, edit them and assess their accuracy. They are primarily concerned with spatial data and need very little reference to attribute data. All GIS systems must have the power to transform source data into the structure used within the particular system.

2) Maintenance and analysis of non spatial attribute data

This type of function are used to edit, check and analyse the attribute data. Editing attribute data allows information to be loaded into the system, retrieved and examined. Many systems allow attribute data from different data sets to be mixed and matched according to need, using a common data field. This process is known as " file" or "address matching".

Security functions can also be programmed into many systems on request, so that the attribute data is only changed if certain codes are used. This is useful as it reduces the possibility that valuable information is lost through error and also acts as protection to stop important information being changed purposely and false or misleading data being entered in its place.

3) Integrated analysis of spatial and attribute data

The third major class of functions deals with the integration of the spatial and attribute data and is what makes a GIS different to other computer cartographic systems. For example, it is possible to retrieve and alter attribute data without affecting the spatial data associated with it. This set of functions also includes the ones that enable classification of a set of features to a particular group.

a) Neighbourhood Functions

Not only will a GIS integrate attribute and spatial data on one data layer, but it will also link data layers together and can perform arithmetic functions between layers.

This class of functions are known as neighbourhood functions, as a point is being related to its neighbours. Other subdivisions within this class include the search function, which is carried out in the region of interest, or window.

b) Topographic Functions

Another important subdivision within this class of functions is the topographic one. The topography of a land surface can be represented in GIS by digital elevation data. This data set consists of a large number of sample points distributed throughout the area being represented. These sample points are commonly organized as a grid of points, as in a raster formation. However, it is also possible to achieve the same effect using a vector based system. This form of representation is known as the Triangulated Irregular Network (TIN). Topography can be used to study any characteristic that has a continuously changing value over a specific area. For example, pollution levels within a lake.

c) Thiessens Polygons

A concept that is commonly used in the analysis of climatic related data is the use of Thiessen or voronoi polygons. A polygon is constructed around a point, and every point within that area of polygon is affected by the same characteristics. For example, data from a single point (the rain gauge) is used to predict the rainfall of associated points in a similar area up to the limits of the next calculated Theissen's polygon and thus the total amount of rainfall within a particular area can be calculated.

4) Output Formatting

Output formatting is the preparation of analysis results for output.

This includes the preparation of tables, map annotation, text labels and graphics for display either on screen or to the printer for hard copy production.

6.4.3 Using a GIS within an Organisation

The five technical sub systems of GIS govern the way in which geographical information can be processed, but unless they are used in the right context their value is limited (Burrough 1986). In order to ensure effective utilisation of a particular GIS, the right organisational environment must be maintained.

As in all new process, new tools can only be used effectively and efficiently if they are fully integrated into the work process and not tackled as an after thought. This requires a full commitment to the system in terms of resources, trained manpower and hardware and software.

The next chapter gives an example of a GIS that is currently in use in the U.K. as a mangement tool for marine aggregate extraction. This is then followed by a section concerned with the specific requirements that must be available for setting up a GIS. Chapter 9, puts the requirements in context for the Maldives and the last chapter discusses the changes that would need to be made if a GIS were to be installed in the Republic.

CHAPTER SEVEN

7.0 AN EXAMPLE OF A GIS USED FOR THE MANAGEMENT OF MARINE AGGREGATE EXTRACTION IN THE U.K.

7.1 Procedures for Aggregate Extraction in the U.K.

In the U.K., the sea bed up to the low water mark is owned by the Crown and is administered by the Crown Estate Commissioners. Aggregate extraction is regulated for the Crown by their agents, Posford Duvivier. In order to mine or dredge for aggregates, companies must first apply for a speculative licence to the agents and then a full licence to carry out their actual mining. It is a condition of mining that all information gathered about the sea bed in these searches is released to the Crown Agents, who then add new relevant data to the data base they are collating. However, this information is restricted to Crown use only, so that companies do not gain unfair advantages over each other.

7.2 The Management of Aggregates using a GIS

At the beginning of 1990, Posford Duvivier acquired a geographical information system, ARC/INFO, so that they could efficiently manage the licensing of aggregate extraction around the coast of England and Wales, whilst retaining information about the type and volume of reserve being exploited.

The system is set up so that licensing areas around speculative bore holes can be seen on screen and information concerning the reserve can be found in a number of different ways. Information about the licence and reserve type, is integrated so that a search under the permit number, Crown Estate Commissioners File number, or dredger owner will reveal the same data.

In this way, it is possible to identify all activities around the coast and it is possible for accurate assumptions to be made about the volumes of reserves left at a particular site.

7.3 The Type of Data Sets Used

In order to make a decision for a licence to be granted, the agents have to consider various factors. To make this process easier, as much data as possible about the marine environment that could possibly affect the extraction of any aggregate has been included in the database of the system. There are eighteen data sets present, which have been set up to integrate with each other and the function and spatial analysis software.

The data sets have been listed, with their source of reference, in figure 24. As it can be seen the data sets have been obtained and collated from a variety of sources. Most of the geological data has been obtained from the British Geological Survey and is supplemented by the confidential data supplied by the dredging companies.

7.4 The ARC/INFO System

The geographical information system, ARC/INFO, was designed by the Environmental Studies Research Institute (ESRI) in Redlands, California in the late eighties. It is a vector based system, composed of two primary components. ARC was written by ESRI to store coordinate data and perform all operations on that type of data. INFO is a relational database management system (DBMS) developed by the Henco Corporation. INFO is used under licence from Henco to store and perform operations on attribute data (Peuquet and Marble 1990). The software consists of several subsystems such as ARCPLOT. This programme allows interactive cartography and mapping processes to be achieved and will allow a hard copy of the map to be printed out.

The Crown Agents use the ARC/INFO system for three reasons. Initially, it is considered to be the best system on the market at the moment and is updated at fairly regular intervals (the next system up is due out at the end of February 1992). The hardware that is used consists of a Sunspan Work station with a 150 mega bite tape drive. There is also a printer and colour plotter.

To be able to run the ARC/INFO software, a licence must be obtained that costs about £2000. This is for the basic package that can be enlarged upon. It is possible to buy customised packages and then develop them to the specific requirements of the user, as Posford Duvivier have done. However, the development of technology then becomes the

FIGURE 24. THE DATA SETS USED TO CREATE THE OVERLAY MAPS OF THE G.I.S. USED BY THE CROWN AGENTS IN MANAGING MARINE AGGREGATES IN THE U.K.

MAP DATA SET	SOURCE OF INFORMATION
Coastline	Ordanance Survey/Admiralty
Bathymetry	British Geological Survey
Geology	British Geological Survey
Sediments	British Geological Survey
Aggregates (coarse and fine sands)	British Geological Survey
Fines and Clays	British Geological Survey
Palaeovalleys	British Geological Survey
Holocene Sediments	British Geological Survey
Bore and Grab Samples	Dredging Companies
Admiralty Features ◊ explosive zones ◊ submarines ◊ fishing limits	Admiralty
Cables and Pipes (gas, oil and B.T)	Crown Estates Commissioners
Cable buffers	Crown Estates Commissioners
Fisheries	M.A.F.F
Historic Wrecks	Admiralty
Latitude and Longitude (automatic to 5' intervals - cost effctive)	Admiralty
Current Licenses	Admiralty
SSSI's	NCC

property of the developer and can be marketed as such. When an updated software is produced by the manufacturers of ARC/INFO, it is automatically made available to older systems.

7.5 Ease of Use

The Arc/Info system is also extremely user friendly. It can be used by a person with fairly limited computer knowledge both to input and extract information, using the " window " function and mouse in place of the keyboard.

7.6 Other Available Systems

There are a number of other systems on the market at the present time. These are predominantly manufactured in America, as this is where GIS has developed and become most popular. Other systems include VITec, ERDAS and GeoVision.

There is also an Australian system available, the BRIAN (Barrier Reef Image ANalysis). The methodology used was developed in response to the needs for very large area remote sensing by Landsat (Jupp et al. 1985).

The BRIAN is not, however, such an integrated system as ARC/INFO, as its main aim is to provide descriptions of images in land cover terms. That is the system provides a tool for incorporating digital image data into regional surveys.

CHAPTER EIGHT

8.0 REQUIREMENTS FOR IMPLEMENTING A GIS

8.1 General

It was explained in the introduction, that the overall aim of this report is to enable an expert in geographical information systems to decide, without too much of their own back ground research, upon the best GIS system for the Maldives, providing that this is a government requirement.

This chapter will explain the process of assessing the factors needed to ensure the successful implementation of a GIS.

Initially, the intended user and user requirements for the system need to be defined. In the case of this report, the intended user of the GIS will be a part of the Maldivian government and the user requirement is to apply GIS techniques to the management of the coral and sand mining industry.

8.2 Personnel Available

All specialised systems require suitably qualified staff to run them in the most efficient and effective manner. It is also very important that with an expensive system the maximum usage possible is made from it in order to achieve the best returns in terms of cost benefits.

This means that if the purchasing organisation does not process the appropriately trained and experienced staff it must be prepared to invest in retraining programmes.

Burroughs (1986) has made an estimate of the types of commonly used GIS functions and the skill levels of personnel required to operate each. This is summarised in figure 25 . " Low skilled " is not a derogatory term used in the GIS context, but refers to typists, computer operators, persons digitizing maps and draughtsmen working on the last stages of the final printed products. On the other hand, " high skilled " refers to managerial, technical, liaison and scientific personnel.

GIS operation	Cost	Personnel			
			Highly skilled		
		Low-skilled	Technical	Scientific	Managerial
Off-line digitizing on microcomputer	low/mod.	+	–	–	(+)
On-line digitizing on interactive graphics system	high	+	+	–	(+)
Off-line scanning (high quality) + vector conversion	very high	(+)	*	–	(+)
Entering attributes in ASCII file	low	+	–	–	(+)
Building topological networks in database	low/mod.	(+)	+	–	(+)
Linking graphic and non-graphic data	low	(+)	+	–	(+)
Inputting satellite images	low	+	+	–	(+)
Geometrical transforms of satellite images	low (software) high (hardware)	+	+	–	(+)
Checking database and archiving	low/mod	+	+	(+)	+

Explanation of symbols in Tables 9.2–9.6: – not necessary; + necessary; * absolutely necessary; (+) desirable, but not essential.

Figure 25, Investment and Personnel needed for Data Input to GIS
(Burrough 1986)

Good managers are necessary for both for the harmonious interaction between the GIS and the rest of the organisation. Liaison personnel are needed to act between users and technical staff and are necessary to ensure the smooth operation of the hardware. Scientific staff may be environmental scientists, using GIS for their work, or computer scientists working on the technical advances of the system.

Burrough (1986) identifies four mixes of people that may exist in an organisation prior to the implementation of a GIS.

1) Plenty of low skilled workers and no high skilled workers. This situation will require the acquisition of high skilled personnel or it will be impossible to operate a GIS.

2) Plenty of low skilled workers, some high skilled scientific and technical staff. This situation will need to train up the low skilled staff to high skilled status.

3) Some low skilled staff and some high skilled staff. This is a good mix of skills, especially if there are enough staff available.

4) None or few low skilled staff and some high skilled scientific and technical staff. This is the usual situation in most universities.

The Maldives, however, does not fall into any of these categories exactly, being a mix of low skilled and high skilled scientific staff that both lack computer technical expertise. This will be discussed more fully in the next chapter.

8.3 Available Finance

Sufficient financial backing is an important factor in determining the success or failure of a GIS. Very few organisations will have access to unlimited funds for a GIS, although the military might be the exception.

In most cases funding will be limited and it is therefore important to get the best system on the market at the time in question to suit the purposes of need. The Maldives is in the lucky position of being able to request finance from inter - governmental organizations

for such an enterprise
(with a suitably argued request), unlike many educational institutions with funding limitations.

8.4 Organisational Requirements

A serious commitment to GIS implies a major impact on the whole organization. This means that the whole organization will need to plan the way in which its data collection and distribution methods will operate in tandem with the GIS over several years.

Also staff will need to be allocated to the GIS on a permeant basis, to up date information and give technical support in daily operations.

It also must be decided who will access the information generated by the GIS. Factors such as security controls can be built into a system so that only certain people can access the whole data base. However, care should be taken that the GIS does not turn into a political power tool. Information may be power, but it is also the foundation of knowledge.

8.5 Planning and Management

When the organisational aspects of the GIS have been defined, it will be necessary to plan the day to day management of the system. Systems managers will be the coordinators between the users, the data suppliers and the hardware and software suppliers in case of technical hitches.

A work plan will need to be developed so that scientists and other users
do not all need to use the system at the same time.

It should be remebered that a GIS is a useful tool to help planning and development decisions, but at the end of the day it is the user that makes the real decision and committment to a course of action.

CHAPTER NINE

9.0 MALDIVIAN RESOURCES THAT WOULD BE REQUIRED TO IMPLEMENT A GIS

9.1 Possible Sources of Finance

Before an expensive system such as a GIS could be considered as a viable proposition for a developing country such as the Republic of Maldives, it is necessary to ascertain whether funding would be available from donor agencies.

It is difficult to put a price on the amount of funds that would be allocated, because the acquisition of a geographical information system is not a short term investment. Apart from the hardware, software and parts that make up the actual system, factors such as building location, staff retraining and cost of data sets need to be considered.

The hardware components of computer systems are reducing in price all the time. For example, the hardware for the ARC/INFO system which was bought last year for the Crown Agents cost in the region of £ 20,000. A similar system that was bought two years earlier by the parent company cost

£ 80,000 for similar components (Posford Duvivier, personnel communication).

The licence for the software of ARC/INFO is approximately £ 2000, but it is impossible to make an estimate on the amount that would be needed to create the right system for the Maldives. This could only be estimated by a GIS vendor when more specific details of the system have been established by a GIS expert.

There will have to be one major investment in the shape of the employment of a systems manager, to run the system full time and deal with any technical problems which might arise. It will also be necessary to employ a person to programme the system to the users requirements, which will change with time, so this would be a short term contract arrangement.

The Maldives has a hot and humid climate most of the year round, with temperatures averaging 30 ^{o}C and humidity levels of about 85 %. This is not the type of environment that computers thrive in, so a location with adequate air conditioning would have to allocated or created for the system. This will be a singular investment.

There are several possible sources of finance for a GIS. The Economic and Social Commission for Asia and the Pacific (ESCAP) run a regional remote sensing programme (reference RAS/86/141), that is involved in trying to aid developing countries in acquiring the technology to run their own remote sensing programmes. As this sort of information is being linked closely to GIS to provide mapping data, the aspects that connect the two are also covered by the programme. Member countries offer some free training courses to foreign nationals at their remote sensing institutes.

The United Nations Environmental Programme (UNEP) also run a programme specifically associated with GIS. This is called GRID, the Global Resource Information Database. An example of the type of work carried out by GRID is the cooperative programme in Samoa which is designed to build a GIS based on the coastal area of Upolu and includes the mapping of the reefs and lagoons (UNEP information letter).

A third inter - governmental organisation that may provide funding for a GIS in terms of hardware and especially data collection is UNESCO. This organisation runs a programme called Training, Education and Mutual Assistance in Marine Sciences, TEMA, under its Oceanographic Commission. An outline of the action plan is provided in appendix 2 . " The Commission's role is important not only to provide motivation, but also as an active promoter of project proposals, particularly in obtaining endorsements of funding organizations and recipient Member States. "

The United Nations Development Programme also has a budget allocation for the Maldives. This is a sum of approximately $ 5 million for a five year cycle. However, if funding for a GIS were to come out of this budget, the Government would have to define the need for one in its National Development Plan (Shazeem Razee, UNDP representative to the Maldives).

Figure 26 shows an outline of current expenditure by various bodies at the present time,

UNITED NATIONS DEVELOPMENT PROGRAMME

Project of the Government of the Republic of
MALDIVES

PROJECT REVISION

Number and title: MDV/88/011/D/01/99 - Capacity Enhancement in Environmental Management and Planning

Duration: 30 months

Project site: Male' and Selected Field Sites in Maldives

UNDP sector and sub-sector: Natural Resources
Planning and Management

Government sector and sub-sector: Environment and Planning

Government Implementing and Executing Agency: Environment Section, Ministry of Planning and Environment

Starting date: January 1991 (Revision C)
June 1991 (Revision D)

Government inputs:
(in kind)
(in cash)

UNDP & Cost-sharing financing	
UNDP	
IPF	$ 572,979
Australia	100,920
Canada	50,000
UNDP & cost-sharing Total:	723,899

This project revision comprises a comprehensive programme for the strengthening of the capacity of the Government of Maldives in environmental management and planning, initial work in developing environmental management tools, including environmental impact assessment, solid waste disposal for rural islands, and population programmes, as well as public awareness activities.

On behalf of:	Signature	Date	Name/Title
The Government:	________	________	________
UNDP:	________	________	________

United Nations official exchange rate at date of last signature of project document: $1.00 = 9.5 Ruffiya

Figure 26. **An Example of a Funding Allocation Programme for the Environment of the Maldives.**

including contributions from the UNDP, for environmentally orientated projects such as " initial work in developing environmental management tools ".

Alternatively, a proposal can be worked out to obtain a loan from the World Bank, which is the case for the Fisheries III project under way at the moment.

Other possible sources of funding would be the British Overseas Development Administration. To obtain funding from this direction, a suitably argued proposal would have to be put forward.

9.2 Availability of Geographical Data Concerning the Maldive Islands.

1) Admiralty Charts

Unfortunately, considering that the fundamental property of a GIS is that it is a geographically based system, there is a lack of accurate maps and geographic data about the Maldives.

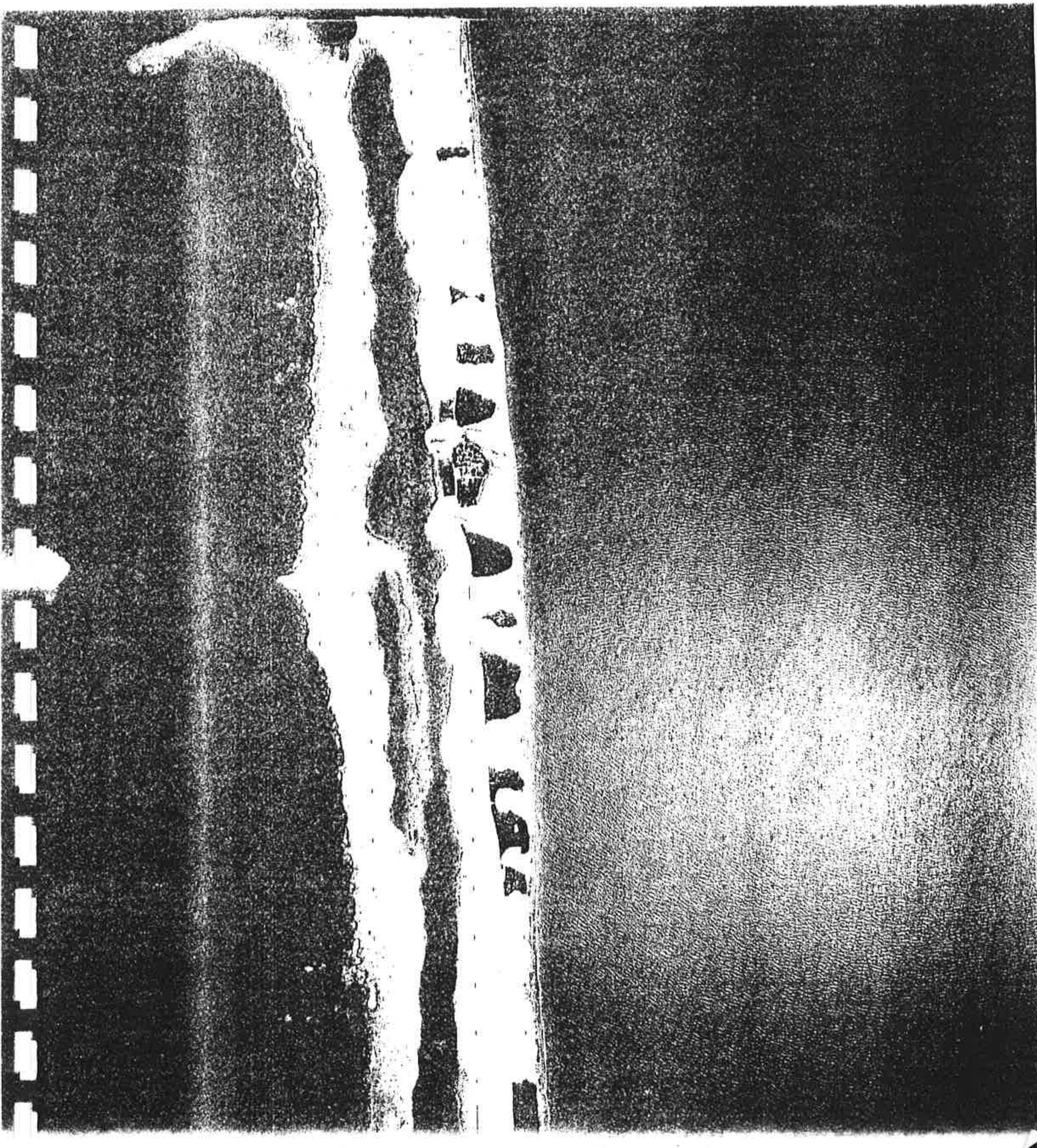
During the time that the Maldives was a British Protectorate, the Admiralty surveyed and charted the area. These charts give the approximate positions of the islands relative to each other and their outlines. However, they are not very accurate but have been updated by means of the Pilot whenever Admiralty vessels have been in the area. The scale of these charts is in the region of 1: 292,000. In fact, when the charts were compared to the aerial photos discussed in the next section, they were only found to have an accuracy of 30 % (Lantieri).

2) Aerial Photographs

In 1969, before the RAF finally left the Maldives, they undertook an aerial reconnaissance of the sea area encompassing the Maldives. This resulted in the production of approximately 7000, nine inch by nine inch, black and white photographs, in two scales of 1: 25,000 and 1: 80,000. These photographs are taken vertically so that the minimum of error is introduced for mapping purposes. A photocopied example of one in the 1: 25,000 scale is shown in plate 12 .

Plate 12 An aerial photograph taken vertically at a scale of 1:25,000

(photocopy)



These photographs were then used to construct the British Military Maps or " Aeronautical Approach Charts ", of which there are eight covering all the islands at a scale of 1: 250,000.

The photographs, as with all aerial photographs are labelled by their film number and their frame number along the bottom edge for identification purposes.

It is possible to see from the photographs the outline of the islands, the reef edge and potential sand screes to the leeward side of the island.

Even though the photocopy is not as clear as the original photographs, they are still difficult to interpret accurately and practice is required by comparing them to the ground to identify features precisely. However, if a really accurate assessment is needed of an area, then the most reliable way is to conduct a ground survey by boat.

Some colour oblique photographs were taken at the end of 1986 in sample areas of Laamu atoll by a consultancy team whilst visiting the Maldives, however, these are only of limited use.

3) Other Available Survey Data

i) Surveys by the Ministry of Public Works and Labour

In recent years, there have been other marine surveys of islands carried out for specific purposes. These have mainly been done by the Ministry of Public Works and Labour when surveying parts of islands that need dredging or improved harbour works. Recently, MPWL, have undertaken specific surveys for the Ministry of Planning and Environment. This has been of tourist islands, for example, Rannali Island in South Male Atoll, to give an indication of the sorts of problems that they might be facing in terms of beach erosion.

The survey of Rannali Island took one week to ground survey using an electronic distance measuring machine (EDM), which gives an accuracy of 1 - 2 cm. It then took a further three weeks before the calculations had been completed to produce a map. It was estimated that two islands per month could be surveyed accurately in this way, giving a measure of the reefs immediately surrounding the island, the vegetation line which meets the sand beach, the line of wave cut and the areas of new coral growth. Appendix 3 shows the islands that have been served to date by MPWL. It shows their location by atoll, the type of survey and scale of survey.

It should be noted that while these islands are mapped accurately to themselves, they will not be accurate relative to one another.

MPWL undertake surveying work for islands outside of North Male atoll also when asked to so by the Ministry of Atolls Administration.

ii) Surveys by the Ministry of Municipality

The Ministry of Municipality map islands, using a theodolight transverse survey, up to their vegetation lines. To date they have mapped approximately fifty islands in all atolls this way and estimate that it takes a week to do one island. This Ministry is marked to become the Maldives' main land survey office in the future.

iii) Surveys by the Office of Physical Planning and Design

The Office of Physical Planning and Design has also carried out some survey work for the Atolls Administration and for the Islands Development Unit.

So far, they have surveyed about five islands, including Kelaa in North Male Atoll, Mamagili in Ari Atoll, Thodda in Ari Atoll and Mafilifishu in Laviana Atoll. This has also included the coast and associated reef of the island using a false datum. Again these islands are not mapped accurately to any others.

iv) Surveys carried out under the Ministry of Planning and Environment

Some islands have also been surveyed by Colin Woodruff and Mohammed Ali of MPE in 1989. Details of their work is shown in figures 27 and 28 and more transects of other islands are available from MPE.

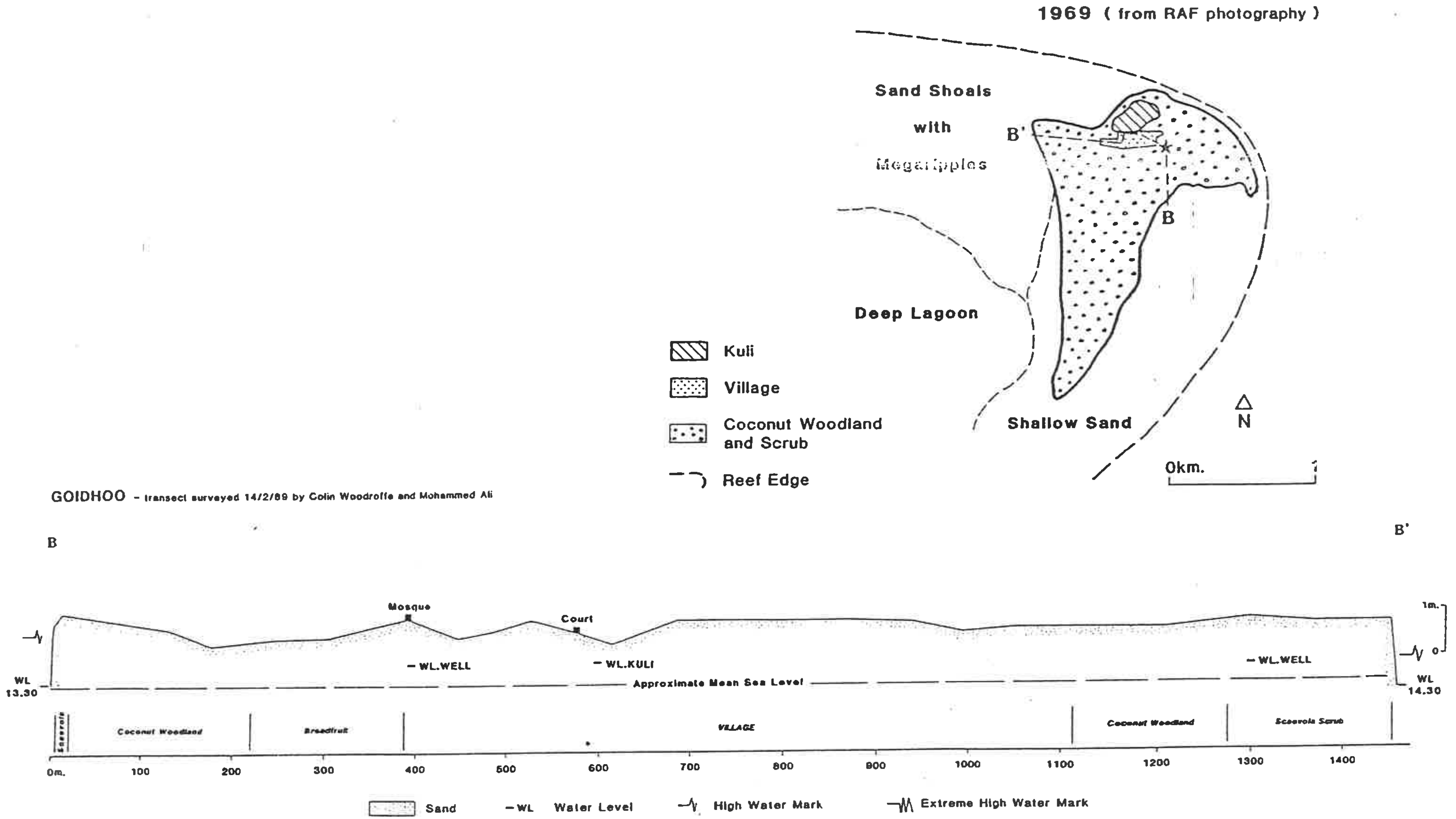


Figure 27 A transect across Goidhoo, South Maahlosmadulu

(Woodruffe 1989)

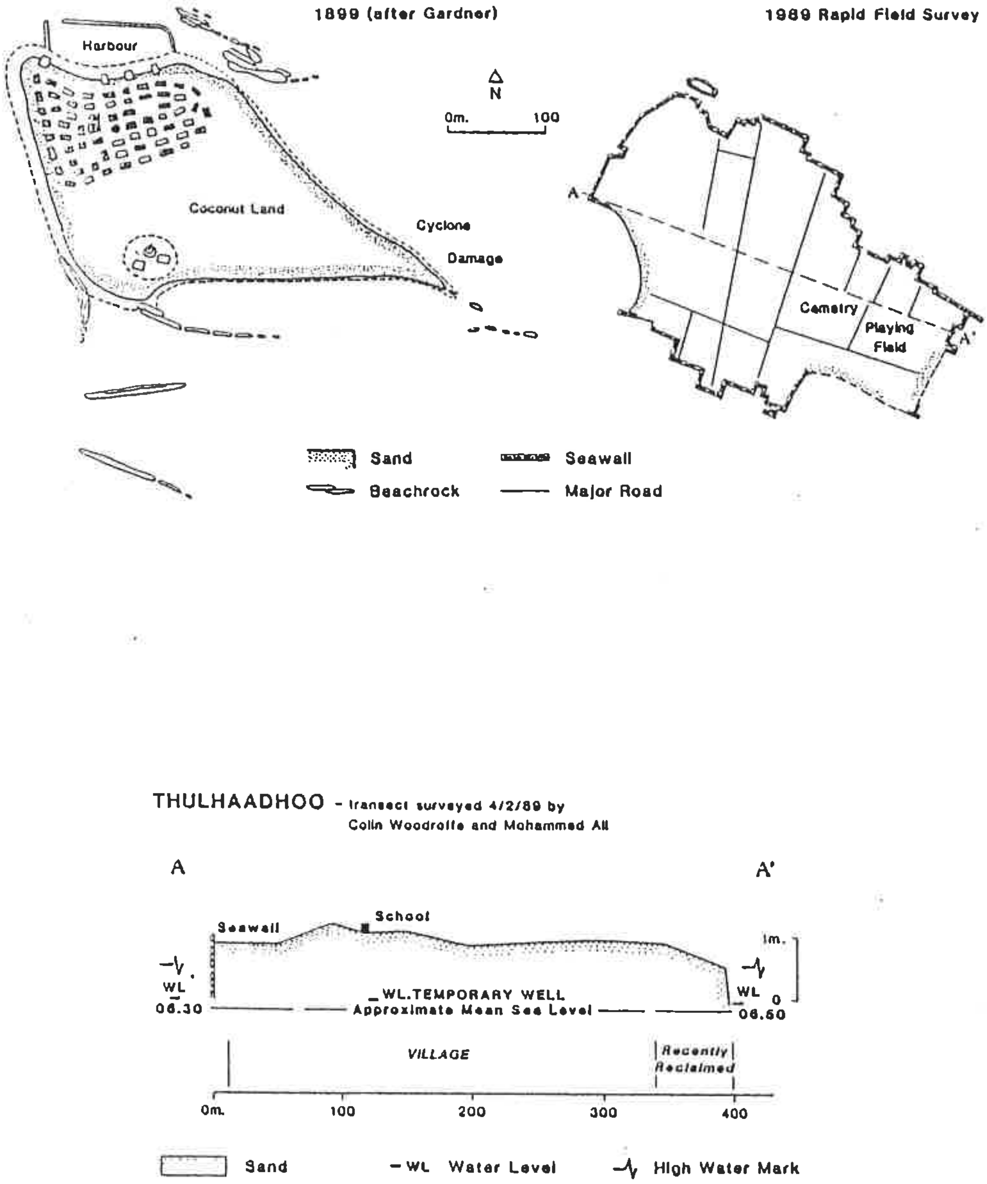


Figure 28 A transect across Thulhaadhoo, South Maalhosmadulu

(Woodruffe 1989)

Figure 29 SPOT digitally enhanced image, North-East of Laamu Atoll (scale 1:40 000)

(Lantieri 1987)

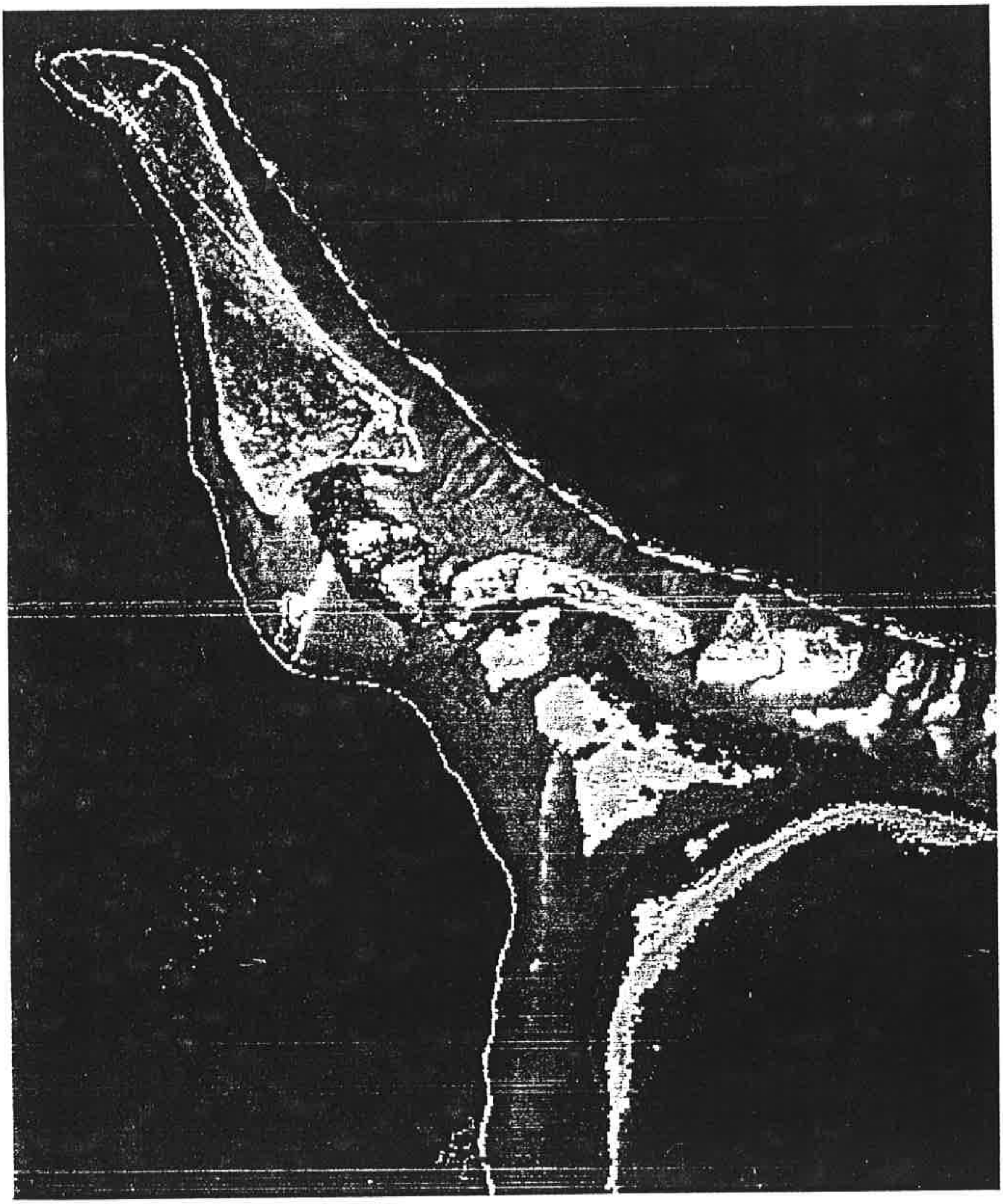
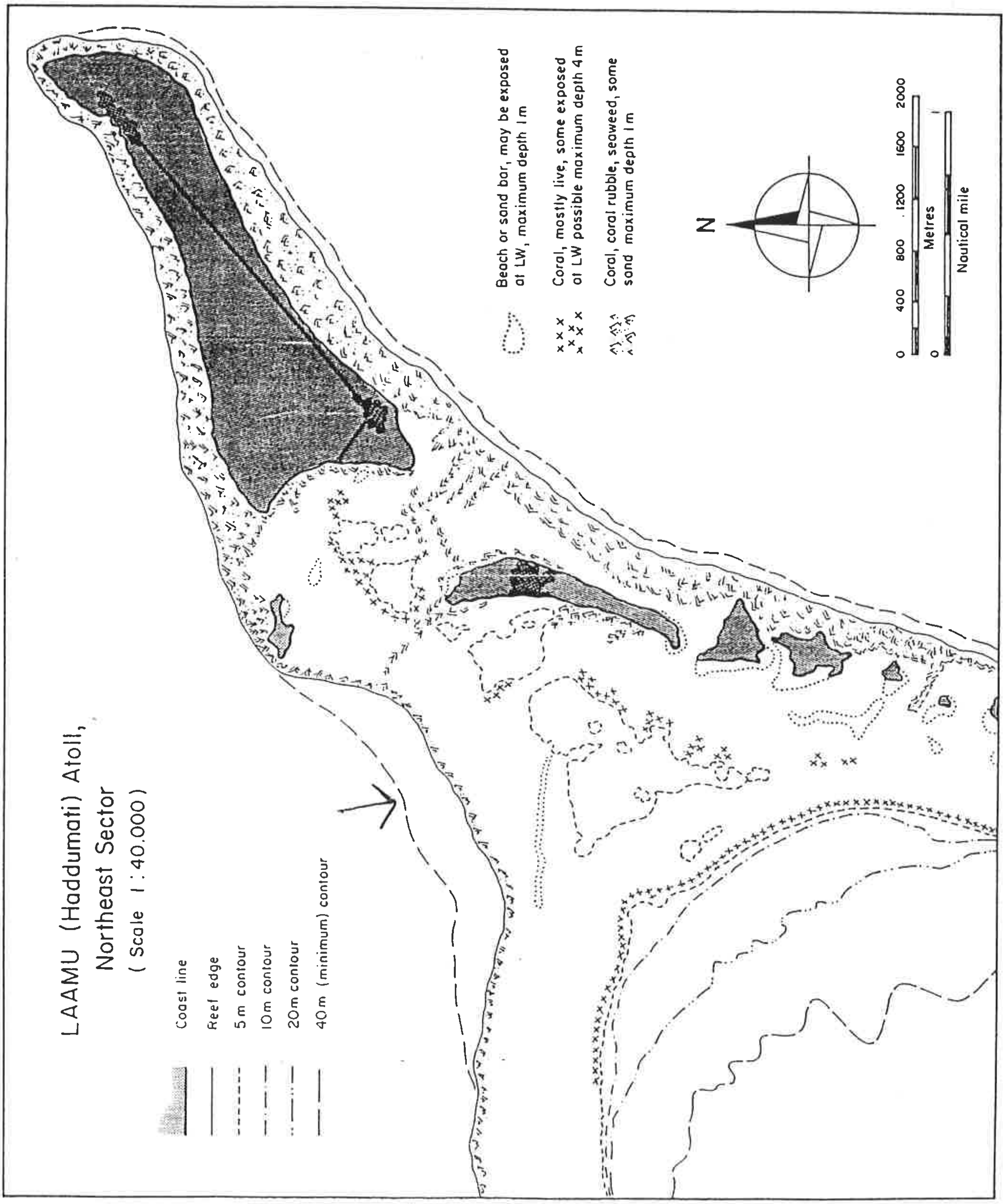


Figure 30 MARITIME CHART OF NORTH EAST LAAMU ATOLL (Scale 1:40 000)

(Lantieri 1987)



v) Attempts at Mapping using Remote Sensing

There have been two attempts to use remote sensing in the Maldives for mapping applications. The first of these was carried out by D. Lantieri for the FAO in 1987. The study concentrated on Laamu Atoll and had three main areas of interest; the use of remote sensing for agriculture and land use, for nautical chart evaluation and for fisheries studies. This study used the Landsat Thematic Mapper (Landsat TM) with a resolution of 30 m and the SPOT satellite with resolution of 20 m to investigate the possibility of accurately mapping the atoll in question.

Figure 29 shows a photocopy of the SPOT digitally enhanced image taken North East of Laamu Atoll at a scale of 1: 40,000. Figure 30 shows a chart prepared from the image at the same scale. However, as impressive as this seems, satellite imagery can also not be relied upon for total accuracy, as factors such reflection from the sea surface can give errors like false bottom depths. In this example, the marked 40 m contour (arrowed) is placed in the wrong place. In the text associated with this report, depth is one of the few features that the author claims to have accurately portrayed using remote sensing. However, on a recent trip to the named area, Dr. Charles Anderson of the Marine Research Section, reported that there was a straight drop - off from immediately next to the edge of the coast to well over 60 m in depth.

The Lantieri report covered the question of accurately mapping the Maldives by considering the use of remote sensing techniques, aerial photography and traditional survey methods. A copy of his findings in this area is produced in appendix 4.

The second study involving remote sensing was carried out by a Chinese contingent in 1988 (Caixing et al.) and this unfortunately did not add any thing new to the Lantieri study, apart from the fact that remote sensing in the Maldives is possible.

Remote sensing has become irrevocably linked with geographical sensing and the acquisition of base line data for accurate amp formation over large areas. Several studies have been done using remote sensing in a variety of applications. A recent report by the

FAO (FAO Technical Paper 287, 1987) used a combination of GIS and remote sensing to plan for aquaculture in Costa Rica. This study found that questions such as " what areas remain for subtidal mollusc culture if shelter is reduced from 2 nm to 1nm ? " can be evaluated.

Various texts exist which evaluate and explain the use of remote sensing in marine science applications (Curran 1985, FAO Technical paper 295 and a UNESCO Report in Marine Science (Van. R. Claasen) 1986). However,most of the applications refer to the use of the satellites SPOT and LANDSAT. A more accurate method of position fixing has been developed by American defence services in the shape of Global Positioning System satellites

(GPS). This system has the highest resolution of all available remote sensing systems currently in operation. Its has such a high accuracy that the American Department of Defence wants to keep the built in error in the system for civilian use. The major advantages it pocesses over the other systems, is that it provides continuous, all weather, 24 hour, world wide positioning (Stansell 1981). The disadvatage at the moment is that it is very expensive. However, it is definitely the answer to accurate mapping in the future (Brown 1991).

9.3) Available Computing Skills and Facilities

In order for an assessment of the staff training requirements needed to operate a GIS it was necessary to ascertain the extent of the computing facilities within the departments most likely to house the GIS and the level of computer literacy amongst the staff within those departments.

The two most likely departments to house the GIS would either be the Marine Research Section (MRS) of the Ministry of Fisheries and Agriculture or the Environmental Research Unit (ERU) of the Ministry of Planning and Environment.

1) Computer Facilities within MRS

The Marine Research Section is situated away from the main government buildings in Male and therefore is quite isolated in terms of it's facilities and although it's staff have access to other departments, this is not easy or convenient in most circumstances.

There are four PC's within MRS that are mainly used for data storage and word processing. The word processing package is Wordperfect (5.0 and 5.1)

and there are four different types of data base management packages in use.

These range from DBMS 4, to a specially prepared package that a VSO prepared during his time in the section.

At the present time there are four Maldivian staff that regularly use the systems for data entry. In addition there are two recently returned staff from doing degree courses in the U.K., who would be expected to have a good grasp of word processing skills. A new member of staff is also being trained to word process and data enter.

2) Computer Facilities in the ERU

The ERU is situated in the Ministry of Planning and Environment and the main governmental building, the Ghazee Building. It therefore has access to the computing facilities there.

On the actual MPE floor, there is an NEC Multisync PC that is IBM compatible and has programmes such as Coral Draw and Map 2000 CDR on it. At the present time this system is being used to a certain extent as a GIS, in that a rough map of the Maldives has been down loaded onto the system, by means of a Hewlett Packard Scan Jet, and features such as airports and anchorages can be added. The map base is of extremely limited value as it has only been drawn by hand from the Admiralty charts and therefore only gives an approximate positions of the islands (figure).

Also associated with MPE is the Computer Centre, that produces the Statistical Year Book annually. This section is the most computer orientated governmental department. It has a variety of independent microcomputers (PS 2) and also has one 286 and 386 for experimental processes only.

As a department it has identified two types of work that it undertakes. These are occasional assignments and routine tasks. Occasional assignments are carried out on behalf of other government departments, and include such activities as surveys and census information analysis.

Routine tasks include systems cataloguing and hard disk structuring, listings of software, manuals and texts, hardware maintenance and software maintenance.

The Computer Centre has it's own development plans over the next five years. It intends to develop a data base and information system network that will supply information to other departments through terminals from the main work station in the Centre. It also intends to develop an application programme. However, before this system can be set up it has to be decided what type of information will be generally available and what security needs to be included.

As this is the computer centre, the staff have more wide ranging experience than are found in other governmental departments. There are twenty members of staff who are in training at the present time to use statistical packages, data base management and to learn hardware maintenance and programming. There are five members of staff who have had degree level training in some type of computer studies and these members are involved in training the others. The centre also has the benefits of expatriate experience who give their support to the department at periodic intervals, under contracts from bodies such as the United Nations. As the computer centre is the main one for the government it also provides in house training for staff from other departments. They run short courses two or three times a year for about 40 people at a time and give introductory lessons in word processing and basic word skills.

9.4 Summary of Resources Available for the Installation of a GIS

The Maldives has a very good chance of obtaining funding for a geographical information system should it decide to obtain one. However, there is a definite need to improve the general mapping data about the marine environment and a previous study by Lantieri (1987) recommended the use of remote sensing and satellite data for this purpose. There are various limited computing facilities within the two departments most likely to be concerned with a GIS. They will not be adequate to cope with a fully integrated GIS if the maximum potential of the system is to be achieved. The final chapter in this report deals with these factors in more detail and offers a solution as to the organizational structure that would have to be created to get the full benefit of a geographical information system.

CHAPTER TEN

10.0 DISCUSSION - IS THE ACQUISITION OF A GIS A WORTHWHILE PROPOSITION FOR THE MALDIVE ISLANDS?

10.1 Introduction

This report was concerned with the feasibility of using a geographical information system for coral and sand mining in the Maldives. It can be seen from this report, that the coral and sand mining industry at the present time is an unregulated and irratic. The lack of attention that has been afforded it in previous years has only recently been overturned in the shape of the Binnie and Partners Report. However, it is impossible to know the extent of damage to the islands' beaches and the increased vunerability to sea level rises that this neglect may have caused.

It is easiest to decide whether or not the acquisition of a GIS by the Maldivian Government for the management of coral and sand mining would be a sensible proposition through considering the implications of changes that will occur as a result.

The planning and establishment of a geographical information system relates to it's context and intended use. There are three main areas which should be considered before choosing to enter into a contract and committment to a GIS. The first is the environment in which the system will operate. The second is the overall aim of the system's intended use and the third is the means by which the operation will be carried out, in terms of finance, policy and people.

10.2 The System in its Environment

In the previous chapters it has been explained that the key to a successful and effectively used GIS is the state of the environment in which the system is housed.

" Above all, the organisational setting of the proposed GIS should be the point of departure of it's planning and establishing a GIS is intended to cope with the prevailing uncertainties in this planning process. " (W. H. E. De Mann 1988).

In other words, the development of a GIS is intricately linked to the organisational structure and the establishment of a GIS should solve the problems and questions that arose from the decision to install it.
It is possible to fit the GIS to the user requirements, but the organisation will inevitably need to change to acommadate the system and the potential user needs to be fully aware of this fact before obtaining a GIS.

Thoughts have already been turned towards information systems, although not necessarily a GIS, in both the Ministry of Planning and Environment and in the Marine Research Section of the Ministry of Fisheries and Agriculture.
The 1988 - 90 National Development Plan states that " A sound data base is a prerequisite for national planning, for improvement of economic and social welfare of the people. "

As part of the National Environmental Action PLan, it was recommended that a concerted effort be made to establish an environmental data base.

" Numerous reports have stressed the need for the establishment of an environmental database in the Ministry of Planning and Environment. Few such recommendations have distinguished between primary and secondary data sources. There exists a substantial amount of published information concerning the natural environment of the Maldives, which is currently not available in the country. Unpublished data sources such as aerial photographs, satellite imagery and maps and charts and navigational data are also available elsewhere. Published and unpublished information within the country is not really accessed since it ,is held in a variety of departments and no centralised system exists to record what is and what is not available. " (National Environmental Action PLan).

It has also been recommended recently in the Fisheries Sector Review Report, that the Marine Research Section should also reappraise its data storage facilities.

" There is an urgent need to assess the future computing needs of MR, select a comuter capable of satisfying these needs and implement a standardised hardware and software acqusitions programme that builds the capability of computing to support MR activities. " Wright, 1991.

This recommendation is made with a proposal for a fairly radical structure change for the MRS, but this is deemed necessary if the long term future efficieny of the section is to be achieved and worthwhile reseach is to be carried out.

Both MRS and ERU of the Ministry of Planning and Environment have already been ear marked to monitor the mining situation. However, the Ministry of Public Works and Labour, which deals with mining and dredging in the North and South Male Atolls, and has had responsiblity for mining in the past, will also need to be involved. The links between mining and this department may well become stronger in the future, as it has been found that dredged sand is the best composition for making sand cement blocks for construction purposes. MPWL has certain records as to the volumes of sand that were extracted in the past and these would be needed to compile the beginnings of a data base on the subject.

If the present proposals are followed, that MRS advises ERU where mining can occur and ERU issues licences, then effective control of the mining situation passes away from MPWL.

The issues of which department are responsible for housing the GIS are further complicated by the proposals outlined in the Binnie Report, which propose a radical change in the way coral mining is carried out.

At the time of writing, the attitude of the Maldivian Government to the future of coral and sand mining is unclear. It seems at the present time that they have three choices over the development of commercial operations concerning mining. The first is that nothing is done and the industry muddles along as it does now. The second is that the development of one faro to provide most of the requirements for coral, sand and coral aggregates, as suggested by Binnie and Partners, is undertaken. The third option is the designation of smaller sites within each atoll, to accommadate all the atoll requirements, as suggested by Dr. Dawson Shepherd.

The option of doing nothing about the situation is clearly not advisable,
as although there is no direct evidence that mining has caused gross detrimental effects under the present system of operations other than the death of reefs, the predicted sea level rises could have far reaching consequences for the low lying Maldives.
This means that option 2 as suggested by Binnie and Partners may be followed. It has been calculated that the mechanised mining of one faro in South Male Atoll could supply all of the coral requirements and 50 % of the sand requirements for 10 years. If this approach to mining is adopted then a centralisation of the industry to Male will inevitably occur, which is the opposite of the governments stated policy for long term development in the atolls.
Binnie and Partners suggest that the social impacts of mechanising the mining will be countered by using the dhonis purely as transport boats.
However, it seems reasonable to assume that the mechanised mining will be undertaken by a set number of vessels and that the rate at which coral is extracted will be more or less constant. It seems unlikely that there will be enough demand to keep all the boats presently employed in the mining and transportation of coral fully occupied.
The third option is to regulate the industry by the allocation of several specific mining sites in each atoll. These sites could be allocated and monitered by MRS, as has been suggested, with dhoni owners applying through MPWL to ERU for licence applications. Apart from licensing considerations, there are other issues to be taken into account. No one knows exactly how much coral is mined each year and who mines it. This means that no taxes or duty are paid upon the landing of coral, even for commercial operations such as resort construction. There is also no accurate way of acertaining the extent to which the reefs are being degraded and how changes in reef structure affect island defences to

wave attack.

If this situation were to be altered and a full regulatory programme of mining activities installed, then a monitoring and surveillance system could be introduced. This would be possible under options 2 and 3 where specfic sites are designated. With these sites, controlled observation experiments could be intiated at the onset of mining and at the start of proceedings to determine the extent of effects of the mining activities on the surrounding reef areas over a period of time.

It seems therefore that the main application of a GIS within the coral and sand mining industry would be threefold. It would be used to regulate the activities of the different dhonis. Each dhoni would be licenced and could therefore be identified and allocated a specific area to work in. Secondly, the volume of coral, sand or akiri landed per dhoni could be kept on file. Finally, information about the marine environment could be collated and filed when the allocation of sites is investigated, thus establishing the beginnings of much needed base line data. These sites can then be studied for changes over a long time period, with a view to finding out exactly how sea level rise and mining is affecting the Maldives.

The question then arises as to which department will house the system. ERU has access, through its close links with the Computer Centre, to a wider base of computing knowhow and the regulation of environmental matters are within its remit. However, MRS will be suppling all the environmental data and MPWL all the volume figures. Unfortunately, due to the fact that all three departments are situated within separate buildings, a work station approach with terminal links to each, would not be a feasible proposition.

The best approach would be to create a new section purely for the GIS. This section would however, have a dual purpose. It would serve initially as the management tool for the coral and sand mining industry, but its long term aim would be to provide the Maldives with a spatially integrated data base of its marine resources.

10.3 Institutional Arrangements

Once the actual location of the system has been decided upon, the institutional details must be decided. The creation of a new departmental section will result in the reorganisation of staff and the allocation of new staff specifically to maintain the system in terms of data input and technical supervision. Access and availability of the system to those from the three departments who will need to use the system must also be considered.

It has been established that the main intended use of the GIS will be for the management and regulation of coral and sand mining. However, for this to occur with any degree of success, a large number of data sets about the Maldivian marine environment will need to be down loaded onto the system.

It is known that at the present time very little data exists compared to the actual size of the designated marine environment (90,000 km^2). In chapter 7, it was shown that the Crown Agents use 18 data sets for their ARC/INFO system. The first of these is the most important for a geographically based information system and is an accurate map of the coast line. Although the Maldives has several accurately mapped islands thanks primarily to the efforts of MPWL, it lacks an accurate outline of its coast and very few of the lagoon and ring reefs are marked. The islands are also not charted accurately relative towards one another, or to the rest of the world. If individual sites that were under surveillance were mapped accurately, data from the same site taken at different points in time could be analysed with confidence. This means that surveys,like those carried out by MPWL, could be used and the maps that they produce could be manually digitized for entering into the system. This would be useful as they can map at a very large scale (1 : 500), which is the scale that would be needed to study the effects of beach erosion effectively (Dawson Shepherd, personnel communication). However, if the environment needed to be looked at over a wider area, for example to study the migratory patterns of tuna fish, then larger maps would have to be produced. This could only be achieved through a large scale mapping programme using remote sensing techniques or aerial photography. Obviously, such an operation would be expensive but would yield long term benefits. The application of remote sensing to mapping the marine environment has been discussed in chapter 9.

10.4 Costs and Benefits

There has been very little in the way of formal acounting of GIS operations, largely because in most cases they are largely experimental (Tomlinson 1987). It is difficult to assess the product of a GIS in terms of output in the terms of maps, diagrams and figures that are produced compared to the cost of establishing the system in the first place. The Crown Agents, Posfo Duvivier, already feel from having their system only one year, that they have benefitted greatly from increased efficiency, saving of man hours and the security such a system generates in terms of safety of data storage. The main benefit they identified, was the increased confidence in decision making, as the machine can be relied upon to integrate all the data it contains relevant to a particular subject. Although they will only be able to truly judge the performance of the system retrospectively, the feeling is that the more data sets that are down loaded and integrated in the software, the greater are the final benefits and end results.

CONCLUSIONS

11.0 CONCLUSIONS

The coral and sand mining industry in the Republic of Maldives needs to be regulated and managed correctly, in order to protect the reefs and so the economy of the country. A geographical information system would be capable of carrying sufficient data, that could be analyzed in a spatial manner, to make this process relatively simple. The Maldives, however, are severely lacking in base line data and the government departments that are concerned with environmental matters do not have adequate information systems to process the data that they have collated.

The Maldives also have a serious lack of accurate maps about their coastline and marine environment, which for a predominantly marine nation is strange. As also suggested by others (Lantieri 1987 and Woodruff 1989), the author would recommend a mapping programme to remedy the situation.

A long term mapping programme could be the start of establishing a geographical data base for use in a GIS. The programme could start with the accurate surveying of sites for coral and sand mining and use this information to observe the direct effects of mining. If surveillance of designated sites was carried out on a scientific basis and was initiated at the onset of mining, it might be possible to gain a clear picture of the effects of the mining in the Maldives. In particular, a controlled experiment could be set up on an uninhabited island to see the effects on beach erosion.

The real value of a GIS for use in the coral and sand mining industry would really depend on the future course of action the government takes after reviewing the Binnie and Partners 1991 Report. If single faro sites are designated, then the spatial nature of the information about mining will have little importance. The regulatory aspects of of dhonis transportation of aggregate could be contained with a normal data base management system.

However, this situation would not detract from the importance of producing a long term data acquisition programme for the marine environment and a GIS would be an invaluable management tool should such a programme be initiated.

APPENDIX 1

12th February 1990

Presidential Letter

No. 30/90/39 A-1

Attn. Minister of Fisheries and Agriculture
Hon. Abdulla Jameel

The President has requested me to bring to your attention that he is aware of the damage and erosion caused by accsessive coral mining from the main reefs.

He has also had the chance to see the damage and talk to the people during his trip to some of the inhabited islands in Male' Atoll in december and to Mulaku Atoll and Felidhu Atoll early January.

Considering this, the President has banned coral mining from the main reef of the island.

However, a complete ban on coral mining from island reefs might cause a convenience for those living in islands far from fringing reefs. ~~So in~~ So in such cases he has also asked to permit coral mining from reefs of close uninhabited islands. The permit should also be on condition that the mining should in no way could cause any damage -

- to the island. The Atoll's Office should supervise, and ~~take~~ ~~almost~~ see if it's causing any damage to the island.

The President also request you to confirm the Atoll's office to impliment this law. All persons leasing uninhabited islands and the people who ~~take~~ ~~new~~ lease new uninhabited islands should also be informed of this new law.

12th February 1990

Your Sincerely

Mohamed Hussain

6th October 1990

Presidential Letter no. 30/90/249/ A-1

Attn: Min. of fisheries and Agriculture,
Hon. Abbas Ibrahim

Refer to your letter no 30/90/39 A-1
(12th February 1990)

1. The regulations restricting coral mining on that letter is causing a great deal of inconvenience to the islanders who require coral for their own private purposes.

The President has therefore permitted to mine coral from the areas listed below, if the Atoll's office sees it feasible.

a. from distant lagoons, where bait fish are not available.

b. from big reefs / lagoons

c. fringing reefs

when mining in the above mentioned areas, the Atoll Office must with the help of the Atoll Developing Committee supervise and see that no damage is caused, to the island. If seen that damage is being caused the committee should inform your ministry, Min. of Atolls Administration —

- and Min. of Planning and Environment and ~~put~~ ~~a~~ ban mining from the damaged area.

2. The President wants a complete ban on ~~from~~ coral mining from the areas listed below.

   a. The ~~natural~~ protective reef around islands and ~~b.~~ the shallow area beyond that reef.

   b. fringing reef close to islands.

   c. Reefs on the Atoll ridge.

3. To reduce coral mining, the President has also banned coral mining for the purpose of building outside walls in government buildings and private homes.

4. The President also requests you to enforce and implement ~~these~~ laws and inform the Atoll Offices and lessons of uninhabited islands.

Yours sincerely

Abdul Rasheed Hussain
Min. of state for Presidential Affairs.

no. 1A / 84 / 91 / 258 <u>Presidential letter</u>

To the Minister of Atoll's Administration.

Please refer to your letter no. 84B / 1 / 91 / 477 (2nd June '91) and our letter 1A / 84 / 90 / 381 (on 26th sept. '91)

In the third point of our letter to your ministry no. 1A / 84 / 90 / 381 regarding the difficulties the islanders face without the availability of corals and giving the permission to extract coral from distant lagoons where baitfish is not found and from big fringing reefs it was decided not to give permission to take corals for building outerwalls of the government and private owned places. But it is slowing-down the construction of outer walls leading to problems with boundary lines of the private homes and it's also resulting the straightness of the roads and island's beauty. Also in most of the islands there are no arrangements for manufacturing the cement bricks, the President has decided to give the permission from the permitted areas to take corals for building the outer walls too.

30th June 1991.

APPENDIX 2

ATOLL	ISLAND NAME	DESCRIPTION	SCALE
ALIFU	MIRIHI	BEACHLINE SURVEYS	1:500
ALIFU	UKULHAS	TOPO & HYDRO SURVEY OF PORT FACILITIES	1:1000
ALIFU (ARI)	MAHIBADHOO	TOPO & HYDRO PORT FACILITIES	1:1000
ARI	MAALHOS	PLAN & PROFILE PROPOSED JETTY SITE	1:500
ARI	MAALHOS	WATER WELL SURVEYS (LEVELS)	N.T.S
BAA	HITAADHOO	TOPO & HYDRO PORT FACILITIES	1:1000
BAA	THULADHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
BAA (SOUTH MALOSMADULU)	DHARAVANDHOO	TOPO & HYDRO PORT FACILITIES	1:1000
BAA (SOUTH MALOSMADULU)	EYDAFUSHI	TOPO & HYDRO SURVEY OF PORT FACILITIES	1:1000
DHAALU (SOUTH NILANDU)	KUDA -HUVADHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
FAAFU	NILANDHOO	TOPO & HYDRO SURVEY OF PORT FACLITIES	1:500
FAAFU NORTH (NILANDU NORTH)	BILEHDHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:500
GAAFU ALIFU	DHANDHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
GAAFU ALIFU	KOLAMAAFUSHI	TOPO & HYDRO SURVEY OF PORT FACILITIES	1:1000
GAAFU ALIFU	VILLINGILY	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
GAAFU ALIFU (NORTH HUVADU)	GEMENEFUSHI	TOPO & HYDRO SURVEY OF PORT FACILITIES	1:1000
GAAFU DHAALU	FARES	TOPO & HYDRO SURVEY OF PORT FACILITIES	1:1000
GAAFU DHAALU	GADHDHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
GAAFU DHAALU	MADHAVELI	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
GAAFU DHAALU	RATHAFANDHOO	TOPO & HYDRO SURVEY OF PORT FACILITIES	1:1000
GAAFU DHAALU	THINADHOO	TOPO & HYDRO SURVEY OF PORT FACILITIES	1:1000
GAAFU DHAALU (SOUTH HUVADU)	HOADEDHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
GNAVIYANI (FORMULAKKU)	NO MAPS AVAILABLE		
HAA ALIFU (NORTH TINADUMATHI)	TAKANDHOO	TOPO & HYDRO SURVEY OF PROP.PORT FACILITIES	1:500
HAA ALIFU (NORTH TINADUMATI)	HOARAFUSHI	TOPO & HYDRO SURVEY OF PROP.PORT FACILITIES	1:2000
HAA ALIFU (NORTH TINADUMATI)	IHAVANDHOO	TOPO & HYDRO SURVEY OF PROP.PORT FACILITIES	1:800
HAA DHAALU (SOUTH TINADUMATI)	HANIMAADHOO (AIRPORT)	TOPO & HYDRO SURVEY OF PROP.PORT FACILITIES	1:4000
HAA DHAALU (SOUTH TINADUMATI)	MAKUNUDHOO	TOPO & HYDRO SURVEY OF PROP.PORT FACILITIES	1:800
HAA DHAALU (SOUTH TINADUMATI)	NAAWADHOO	TOPO & HYDRO SURVEY OF PROP.PORT FACILITIES	1:500
* ← HAA DHAALU (SOUTH TINADUMATI)	NELLAIDHOO	TOPO & HYDRO SURVEY OF PROP.PORT FACILITIES	1:500
KAAFU	DIFFUSHI	TOPO & HYDRO SURVEY OF PROP.PORT FACILITIES	1:1000
KAAFU	DUNIDHOO	TOPO & HYDRO SURVEY OF ISLAND SHORELINE	1:1000
KAAFU	FUNADHOO	TOPO & HYDRO SURVEY OF ISLAND SHORE ZONE	1:1000
KAAFU	GAAFARU	TOPO & HYDRO SURVEY OF PROP PORT FACILITIES	1:2000
KAAFU	GULHI	TOPO & HYDRO SURVEY OF PROP.PORT FACILITIES	1:800
KAAFU	HULULE'	PROPOSED SITE FOR MPWL WORKSHOP & QUARTERS	1:200
KAAFU	HULULE'	PROPOSED SITE-2 FOR MPWL WORKSHOP & QUARTERS	1:500
KAAFU	HULULE'	TOPO & HYDRO SURVEY -ISLAND SHORE ZONE	1:1000
KAAFU	HURA	TOPO & HYDRO SURVEY OF PROP.PORT FACILITIES	1:800
KAAFU	KAARSHIDHOO	REEF & LAGOON LANDING FACILITY SURVEY	1:1000
KAAFU	MAAFUSHI	ASBUILT SEAWALL & CHANNEL TOPO SURVEY	1:1000
KAAFU	MALE'	CONSTRUCTION OF NORTH SEAWALL & BREAKWATER	1:1000
KAAFU	MALE'	MPDP- SOUTH WEST HARBOUR	1:500
KAAFU	MALE'	MPDP-MARINE DRIVE/KABA AISA ACCESS ROAD MAP	1:1000
KAAFU	MALE'	MPDP-TOPO & HYDRO SURVEY -SOUTH WEST HARBOUR	1:1000
KAAFU	MALE'	MPDP-TOPO SURVEY COMMERCIAL HARBOUR	1:500
KAAFU	MALE'	ROAD & REEF BOUNDARY OF MALE' ISLAND	1:2500
KAAFU	MALE'	TOPO & HYDRO MAP-BERTHING AREA INFRONT MPWL	1:200
KAAFU	MALE'	TOPO & HYDRO SURVEY ALONG COASTLINE OF MALE'	1:1000
KAAFU	MALE'	TOPO SURVEY OF SAARC HALL	1:500
KAAFU	MEERUFENFUSHI	TOPO & HYDRO SURVEY OF PORT FACILITIES	1:1000
KAAFU	RANNALHI	SHORE LINE AND REEF TOPO SURVEY	1:500
KAAFU	UDAFUSHI	TOPO & HYDRO MAP OF SHORELINE (NEWLY FORMED)	1:500
KAAFU	VILLINGILY	HYDRO SURVEY OF CHANNEL BETWEEN MALE'& VILLIG	1:1000
KAAFU	VILLINGILY	SHORE LINE x SECTIONS	1:500
KAAFU	VILLINGILY	TOPO & HYDRO SURVEY-COASTLINE (WEST&EAST)	1:1000
KAAFU (MALE')	MALE'	TOPO & HYDRO MAP OF PROP. HOTEL SITE	1:500
LAAMU	FONADHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
LAAMU	HITADHOO	TOPO & HYDRO SURVEY OF PORT FACILITIES	1:500

LAAMU	ISDHOO/KALAIDHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
LAAMU	KALAIDHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
LAAMU	KUNAHANDHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
LAAMU	MAAMENDHOO	TOPO & HYDRO PORT FACILITIES	1:500
LAAMU	MAAVAH	TOPO & HYDRO PORT FACILITIES	1:1000
LAAMU (HADDUMATI)	MAABAIDHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:500
LAVIYANI	MAAFILAFUSHI	TOPO & HYDRO MAP OF SHORELINE OF ISLAND	1:1000
LAVIYANI	NAIFARU	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
LAVIYANI (FADIPOLU)	HINNAVARU	TOPO & HYDRO PORT FACILITIES	1:1000
MEEMU (MULAKKU)	KOLHUFUSHI	TOPO & HYDRO SURVEY OF PORT FACILITIES	1:1000
NOONU	HOLHUDHOO	TOPO & HYDRO SURVEY OF PROP. PORT FACILITIES	1:200
NOONU (SOUTH MILADUMADULU)	MANADHOO	TOPO & HYDRO MAP OF PROP.PORT FACILITIES	1:600
NOONU (SOUTH MILADUMADULU)	VELIDHOO	TOPO & HYDRO MAP OF PROP. PORT FACILITIES	1:600
RAA	MADUVVARI	TOPO & HYDRO PORT FACILITIES	1:1000
RAA	MEEDHOO	TOPO & HYDRO PORT FACILITIES	1:600
RAA	RASMADHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:500
RAA (NORTH MALOSMADULU)	ALIFUSHI	TOPO & HYDRO PORT FACILITIES	1:1000
RAA (NORTH MALOSMADULU)	UGOOFARU	TOPO & HYDRO PROPOSED PORT FACILITIES	1:1000
SEENU	FEYDHOO	SHORELINE SURVEY	1:5000
SEENU	HANKADA & HITADU (PART OF)	SHORELINE SURVEYS	1:5000
SEENU	HITADHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
SEENU	HOLUDHOO	TOPO & HYDRO MAP OF PORTT FACILITIES	1:1000
SEENU	MARADHOO	SHORELINE SURVEYS	1:5000
SEENU	MARADHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
SEENU	MEEDHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
SEENU (ADDU)	GAN	SHORELINE SURVEY	1:5000
SHAVIYANI	FARUKOLU FUNADHOO	REEF & LAGOON LANDING FACILITIES	1:2000
SHAVIYANI	GOIDHOO	REEF & LAGOON LANDING FACILITY SURVEY	1:2000
SHAVIYANI	KOMANDHOO	TOPO & HYDRO MAP PROP.PORT FACILITIES	1:800
SHAVIYANI	MAAKAGOODHOO	SHORE PROTECTION SURVEY	1:1000
SHAVIYANI	MADIDHOO	SHORE LINE SURVEYS	1:2000
SHAVIYANI	MAROSHI	REEF & LAGOON LANDING FACILITY SURVEY	1:2000
SHAVIYANI (NORTH MILADUMADULU)	KANDITHEEM	TOPO & HYDRO SURVEY PROPOSED PORT FACILITIES	1:800
THAA	DHIYAMIGILI	TOPO & HYDRO PORT FACILITIES	1:500
THAA	GURAIDHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:500
THAA	THIMARAFUSHI	TOPO & HYDRO MAP OF PORT FACLITIES	1:500
THAA (KOLUMADULU)	VILUFUSHI	TOPO & HYDRO SURVEY OF PORT FACILITIES	1:500
VAAVU	FELIDHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:500
VAAVU	KEYODHOO	TOPO & HYDRO MAP OF PORT FACILITIES	1:1000
VAAVU	RAKIDHOO	TOPO SURVEY OF RAKIDHOO ISLAND	1:500
VAAVU (FELIDHOO)	RAKIDHOO	TOPO & HYDRO MAP OF PORT FACLITIES	1:1000

APPENDIX 3

Restricted distribution

IOC/TEMA-V/9
Paris, 2 January 1991
Original: English

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
(of Unesco)

Fifth Session of the IOC Committee for
Training, Education and Mutual Assistance in Marine Sciences (TEMA-V)
Paris, 25 February - 1 March 1991

DRAFT TEMA ACTION PLAN FOR 1991-1995

The Draft TEMA Action Plan was prepared by the Secretariat, and reflects consultations with experts and the Chairman of the Committee.

The Committee is requested to review the Draft, comment on it, revise it as required during the Session, and adopt it.

SC-91/CONF-209/COL-5

management; V. data management and information acquisition; and VI. continuing education and retraining. Each addressed the same subject areas and questions.

18. The working group on sustainable development and management, as an example, considered the training and education needs in the following areas of major concern: sea-level rise; coastal processes; disruption of coastal equilibrium; land-sea and ocean-atmosphere interactions in the coastal zone; water pollution of coastal zones; management of deep ocean. In several of these reference was made to IOC activities and need for involvement. The recommendations included the need for the establishment of long-term monitoring and baseline programmes at regional and sub-regional levels, the call for in-corporation of coastal zone management and planning courses in university curricula, and the development of public awareness and information programmes.

19. The workshop as one of its three recommendations on major issues emphasized the need for initiation of support for and participation in programmes of formal and continuing education and training for effective coastal area management, and also called for organization of training courses and workshops and preparation of appropriate educational material for education.

20. In considering the TEMA Action Plan for the period 1991/1995 the results of the workshop should be appropriately taken into account. Several aspects are covered in specific matters through activities within the subject area and regional programmes of the Commission. However, two areas are proposed in this Action Plan, partly on the basis of the results of the workshop, to be addressed through an interdisciplinary or problem area approach: coastal zone management, related observations and developments; and marine environmental education.

6. GENERAL OUTLINE OF THE ACTION PLAN

21. The implementation of the Comprehensive Plan should focus attention on the following aspects, as proposed at the Twenty-third Session of the Executive Council (Doc. IOC/EC-XXIII/8, Annex 6):

(i) preparation of a **Marine Science Country Profile** that should provide, *inter alia*, information for a given country on the scope of marine scientific research, ocean services, management and related needs for appropriate development;

(ii) establishment of an adequate **national co-ordinating structure** for effective co-ordination of marine research related services and activities at the national level; promote effective linkage between producers and users of marine scientific knowledge and data, and managers; interact with IOC and liaise with regional and international organizations involved in marine research and development; and assist the Government in the formulation of marine science policy;

(iii) promotion of **regional co-operation** (including the creation of regional pooling of facilities such as instrumentation, research vessels), to contribute, on the one hand, to the integrated development and management of a shared environment and its resources, as well as to address common problems of the region, and on the other hand, to benefit from mutual co-operation in fostering transfer of knowledge and technology and thus provide feed back to the development process at the national level; and

(iv) preparation of **technical assistance projects** at the national, regional and sub-regional levels for extra-budgetary funding in support of national and regional initiatives to enhance marine research capabilities;

6.1 MARINE SCIENCE COUNTRY PROFILES (MSCP)

22. The following actions are considered to initiate a set of MSCPs:

(i) Upon the request of a Member State that a national MSCP be prepared with the assistance of designated national institutions or experts, IOC should provide guidance and assistance for the compilation of basic information for Marine Science Country Profiles; and

(ii) MSCP thus prepared by appropriate national authorities, IOC will, if required, assist in the preparation of the standard software, the camera-ready manuscript of the translated version and then proceed with printing.

6.2 NATIONAL ORGANIZATIONAL STRUCTURE

23. The following actions should be taken by national authorities of Member States and/or the IOC Secretariat to strengthen national co-ordinating bodies:

(i) IOC Secretariat will continue to invite Member States which do not have established co-ordinating bodies to consider creating such bodies and provide advice when required;

(ii) IOC Secretariat will continue to invite Member States, as an alternative, to establish suitable national co-ordination mechanism for specific programmes of regional and global scope, and provide advice, as appropriate, through IOC regional/technical subsidiary bodies;

(iii) the national co-ordinating body may help identify in co-operation with expert advice, national needs in relation to the country's priorities and interests in relevant IOC programmes; and

(iv) IOC and/or other relevant bodies should provide, upon request, advice to Member States on relevant aspects of such a national organizational structure.

6.3 TECHNICAL ASSISTANCE PROJECTS

24. A recent significant trend is the increase of IOC's involvement in extra-budgetary projects. The Commission's role is important not only to provide motivation, but also as an active promotor of project proposals, particularly in obtaining endorsements of funding organizations and recipient Member States. The following actions are required:

(i) identification of problem areas in individual Member States and the region through visits of experts and through the IOC regional subsidiary bodies;

(ii) drafting project documents with assistance of national/regional experts, as well as relevant governmental authorities;

(iii) seeking support from and negotiating with potential funding organizations and seek national commitment to prioritize such projects; and

(iv) upon receipt of necessary funding, implementation of these projects with proper co-ordination.

7. TRAINING ACTIVITIES

25. Training activities include group training (IOC-organized or co-sponsored training courses and workshops) and individual training through study grants, shipboard training and the Fellowship Research Scheme (IOC-FRS).

26. At its Twenty-third Session, the Executive Council referred to the IOC regional and global programmes which offer a unique opportunity for developing and strengthening co-operation amongst the participating Member States. It emphasized that TEMA activities should form an integral part of those programmes and that all IOC subsidiary bodies should play a decisive role in both defining TEMA needs

TABLE II

LIST OF IDENTIFIED TRAINING NEEDS

	Proposed By	Applicable Regions
A. OCEAN DYNAMICS AND CLIMATE		
- Equipment Handling and Data Analysis for Continental Shelf Circulation Studies	WESTPAC	WESTPAC IOCEA IOCINDIO
- Continental Shelf Circulation Modelling	WESTPAC	WESTPAC
- Marine Meteorology and Physical Oceanography	IGOSS	All Regions
- Coastal Water Dynamics	IOCINDIO	All Regions
B. OCEAN SCIENCE IN RELATION TO LIVING RESOURCES		
- Collection, Processing and Analysis of Oceanographic Data and Phytoplankton Samples	IOCINCWIO	All Regions
- Collection, Processing and Analysis of Zooplankton/Ichtyoplankton Samples	IOCINCWIO	All Regions
- Larval/Post Larval Identification	WESTPAC	All Regions
- Qualitative and Quantative Chemical Analysis of Blooms associated Bio-Toxins	WESTPAC	WESTPAC IOCINDIO
C. OCEAN SCIENCE IN RELATION TO NON-LIVING RESOURCES		
- Preparation and Interpretation of Data Maps for Palaeogeographic Studies	WESTPAC SWATL	WESTPAC SWATL IOCARIBE
- Data Compilation and Analysis for Palaeogeographic Mapping	WESTPAC SWATL	WESTPAC SWATL IOCARIBE
- Interpretation of Marine Geological/ Geophysical Data	WESTPAC	WESTPAC IOCARIBE IOCINDIO
- Monitoring Coastal Erosion	OSNLR	All Regions
- Marine Geological Survey Technique and Sediment Budget	OSNLR	All Regions

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This list of training activities such as course, workshops, seminars, is based on needs identified by IOC regional and subject area subsidiary bodies.
IOCEA

TABLE II (Cont'd)

	Proposed By	Applicable Regions
- Continental Margin Environment and Mineral Resources	OSNLR	SEPAC SWATL IOCEA
D. OCEAN MAPPING		
- Bathymetric Mapping for Marine Studies	OSNLR	All Regions
E. MARINE POLLUTION AND MONITORING		
- Methods of Monitoring, Processing and Interpretation of Petroleum Pollution	IOCINCWIO	All Regions
- Inter-Calibration Techniques	WESTPAC	All Regions
- Monitoring River-Inputs of Pollutants	WESTPAC	WESTPAC IOCINDIO
- Application of Remote Sensing Techniques for Coastal Environmental Monitoring		All Regions
- Oceanography in Relation to MARPOL		
F. INTEGRATED GLOBAL OCEAN SERVICES SYSTEM		
- Compilation, Analysis and Interpretation of IGOSS Data	IGOSS	All Regions
G. OCEAN OBSERVING SYSTEM		
- Observation and Analysis of Sea Levels	IOCINCWIO	All Regions
- Storm Surge Prediction	IOCINDIO	WESTPAC IOCARIBE IOCINDIO
- Remote Sensing Technique for Ocean Observation		All Regions
H. INTERNATIONAL OCEANOGRAPHIC DATA AND INFORMATION EXCHANGE		
- Managing and Handling Oceanographic Data	WESTPAC	All Regions
- Marine Science/Information Mangement	IOCINCWIO	All Regions
- Compilation and Processing of Oceanographic Data for Micro Computors		All Regions
I. INTERNATIONAL TSUNAMI WARNING SYSTEM		
- Tsunami Warning Practice	ITSU	WESTPAC SOUTHEAST PACIFIC

APPENDIX 4

CHAPTER III. NAUTICAL CHART REVISION AND FISHERIES CHART

A. NAUTICAL CHART REVISION (Figures 10 and 11)

1. RESULTS OBTAINED FROM SPOT AND LANDSAT TM ANALYSIS

The usefulness of SPOT and Landsat TM for Nautical Chart (NC) revision was evaluated by comparing the satellite data and the original NC (Figures 7 and 10) with a reference map obtained from interpretation of aerial photos. Islands, shallow water and deep water features analysable on the satellite imagery were the following:

1.1 Island features

a) Coastline mapping

The existing Nautical Chart shows large errors in coastline mapping, due, as previously mentioned, to the fact that most of the coast was mapped from marine surveys at the end of the last century. Thus, when compared with a reference map made from 1:25 000 aerial photos, the mapping accuracy of land areas on the NC was revealed to be only 30% or less. Landsat TM or SPOT satellite images were found very accurate for updating the coastline on the NC, providing a mapping accuracy of 99% when compared to the reference map. In the context of the Maldives, the revision of the coastline map is certainly a first priority, and the simplest and most useful output that could be provided by visual analysis of high resolution satellite images.

b) Inland feature mapping

On the existing Laamu NC, information on land features is very poor, being restricted to indicating the presence of palm trees and some shrubs on six islands. None of the areas reported on the reference map as cultivated fields, swamp (Hitadu island), roads (13 islands) or villages (17 villages identified) is reported on the NC.

Once again, enhanced satellite imagery appears to be a valuable tool for updating vegetation, geomorphological and artificial features on the NC. Thus, it was found that the presence of cultivated fields, palm trees and shrubs could be discriminated on Landsat TM and particularly on SPOT enhanced images at a high mapping accuracy (over 90%). Land use features such as swamps were also visible on the SPOT colour composite. Most of the artificial features found in Laamu Atoll are also mappable on SPOT or Landsat TM imagery. The mapping accuracy for paths, of which 23 were recorded, reaches 66% for semi-enhanced Landsat TM and 75% for SPOT enhanced images. For villages (17 recorded), the mapping accuracy is 77% for Landsat TM semi-enhanced image and 85% for SPOT enhanced imagery. It should be noted that neither SPOT nor TM raw data colour composites were found useful for mapping vegetation, geomorphological and artifical features.

1.2 Shallow water features (Figure 11)

The annular coral complexes which characterize the atolls are recognizable on aerial photos not only by their rings of islands but also by the circular band of shallow sea bottom, whose light tones contrast with the darker tones of the deeper sea. In Laamu Atoll these circular bands are mapped on the NC as annular strips enclosed by dotted lines (intended as 2-3 fathom or 5 metre depth lines) and filled in most cases with very small dots (for sandy bottom). The mapping of these shallow water areas is very important for navigation.

a) Updating of the NC to record all areas of shallow sea bottom can be done with very high mapping accuracy (almost 100%) with the enhanced SPOT or Landsat TM imagery. In fact, the so-called SPOT shallow water color composite image (see p.8, b_3) was found to correspond exactly to these shallow bottom areas on the NC. It was also noted that the lower depth limit of these shallow sea and bottom areas to be mapped on the NC corresponds to the maximum depth penetration of the red band of SPOT (or Landsat TM).

b) In these shallow water areas, four classes could be discriminated with confidence on the SPOT enhanced image (see Figure 11). These are defined by both a bottom cover type and a bathymetry range, and are as follows:

a. Beach and sand bars, at a maximum depth of 1 metre, most probably exposed at low tide;

b. coral, coral rubble and/or seaweed and some sand at a maximum depth of 1 metre;

c. dense coral, mostly live, at a maximum depth of 4 metres;

d. sand with scattered coral or seaweed at depths ranging from 1 to 5 metres.

In the area covered by class d) the different tones of blues seen on the SPOT enhanced image correspond generally to different depths in the 0-5 m range (the deeper, the darker). However, it was not possible to attribute with acceptable confidence a depth range for each blue tone, as the colour tone also depends on the bottom cover type (density of seagrass or coral rubble).

c) It should be noted also that, generally speaking, tide variations reported on the NC are very low (about 1m average tidal range) in the class d. area. However, SPOT imagery can be useful for mapping at 1:50 000 scale the sand bars under tide movements.

1.3 Deep water features (Figure 11)

In the deep water areas, several parameters could be identified on the satellite images. These concern:

a. Bathymetry

An attempt was made to correlate to depth ranges each of the 9 solid colours produced on the deep water part of the SPOT image. It was found that after grouping some colours together, several bathymetric lines could be mapped on the image with reasonable confidence: these are: 5-metre (limit between shallow water and deep water image), 10-metre (yellow and orange colours) 20-metre (light yellow green and bright green colours). It was also possible to identify a line beyond which the depth is greater than 40m. (At this line, taking into account the image colour boundary between indigo and black, the depth may be greater than 40m, and also within the line many areas may be more than 40m deep; however, it was confirmed that image black always indicates a depth of over 40m.)

b. The mapping of maritime dangers:

All the isolated circular areas rising up inside the water of the lagoon at depths ranging from 0 to 10 metres (blue, yellow and orange in the black part of the image) were assessed as maritime dangers on the images.

All the features appearing on 1:25 000 panchromatic aerial photos could also be identified on the enhanced SPOT imagery (mapping accuracy over 99%). On the other hand, very few of these dangers (only 6) could be linked with those mapped on the existing version of the NC, confirming yet again its low accuracy. In conclusion, it appears that SPOT imagery can be used with high accuracy for updating the mapping of maritime dangers. However, it should be noted that very small coral outcrops of less than one pixel size cannot be seen on the satellite imagery, although they still represent a danger for navigation. This is one reason why maritime transport cannot rely completely on maps obtained from satellite image interpretation.

c. Note on Sea Bottom type

In deep water areas, it was not possible during the sea truth exercise to get information on the sea bottom type and therefore this parameter could not be properly analysed on the SPOT imagery.

It should be noted that, according to other ongoing research, it may be possible to map from SPOT data up to 3 different bottom cover types using special digital processing techniques (use of textural analysis). However, it seems that sea bottom type mapping must rely a great deal on sea measurements.

d. Discussion:

Several remarks can be made on SPOT mapping capabilities in deep water areas:

1. There is an overlap in the depth range corresponding to adjacent colours which increases for deeper waters (e.g. dark green 20-34m, sapphire blue 25-56 m, indigo 26-63 m). Overlap may be related partly to factors which in this study could not be adequately analysed, especially

in higher depth ranges, such as differences in bottom cover and shape. In addition, radiance values are less accurate and significative as the area becomes deeper.

2. Depth ranges corresponding to certain colours change from one area of the atoll to another. For example, the range of sapphire blue in the Northern area of Isdu/Danbidu is 25-35 metres, but in the Hitadu area this range was 43-56 metres. Indigo corresponds to 26-39 m in the North, and 47-63 m in the South. However, the deeper readings for the southern areas should be considered with caution, since they far exceed the results of similar studies conducted in other areas. Further study would therefore be needed to determine if the figures result from atmospheric or surface phenomena rather than from the sea bed. However, the figure for the northern part should be considered fairly reliable, since for 20-39 m range the image presents clear contours of dark green, sapphire blue and indigo. Finally, it can be said with confidence that all black areas on the image are deeper than 40 m.

3. A distinct wave pattern of sapphire blue and indigo can be observed on the image in the southern areas of the atoll and west of Mamendu Island. Various possible explanations have been considered for this phenomenon; it could either be the result of high surface waves (observed in the area during sea truth collection) or the results of a wave pattern on the sea bottom (in some areas, the echo-sounder recorded many valleys and irregularities in the bottom contours). Further research would provide an answer.

1.4. Geographical accuracy

None of the documents used for the above study, such as satellite imagery, the aerial photo "reference map" and the Nautical Chart, were produced according to cartographic projection (e.g. UTM) as there are no available geodesic points in the Laamu atoll area (or even for the Maldives). Therefore, the estimation of mapping accuracy presented is of necessity relative to the reference map constructed from aerial photos. However, geometric distortions of this reference map are negligible when compared to the mapping error observed on the Nautical Chart, therefore the comparison is still of value.

In the case of the implementation of a national programme for Nautical Chart revision, the NC would have to be corrected in a geographical reference system and therefore geodesic points would have to be taken all over the country. The number of geodesic points which would have to be surveyed depends on the method used (aerial photos, satellite imagery or only sea survey) but would be minimum for a method based on satellite data, thanks to the possibilities of spatio triangulation.

1.5 Conclusions

It was shown in this study that high-resolution satellite data could be very useful for updating several of the features usually reported on the Nautical Chart. However, the complete revision of the Nautical Chart could not rely exclusively on remote sensing techniques, as much information usually reported on the NC cannot be extracted from satellite data. In fact, the implementation of a national programme for NC revision would always require an intensive maritime survey.

In conclusion, the use of satellite data for Nautical Chart revision could be considered in two modes:

1. either for a quick updating of some features of the Nautical Chart where satellite imagery was found to make a positive contribution, such as for mapping the coastline or various islands and maritime features as described above. In this case, the campaign could be reduced to a minimum (e.g. 2 months for the whole of the Maldives),

2. or for a complete revision of the Nautical Chart. In this case, satellite data would be used first to update some land and sea features and secondly to orient the necessary intensive sea campaign required (several years).

2. COST/BENEFIT ANALYSIS (see Figure 5)

A cost benefit evaluation of high resolution satellite data for Nautical Chart revision can be made in different ways according to the level of revision to be achieved (quick updating or complete revision). This section deals with a cost-benefit analysis for a complete revision of the NC, where the final map would be produced in a cartographic reference projector (such as UTM).

2.1 Cost Analysis

Complete revision of the NC can be achieved by different methods. The most traditional is based on an extensive sea measurement campaign using specially equipped research vessels. Other methods would be based on a combination of sea measurements and interpretation of remote sensing data (satellite or aerial photos). In the latter case, remote sensing data are used mainly to orient the maritime campaign.

The cost of Nautical chart revision as indicated above was established taking into account discussions held with the "Service Hydrographique et Océanographique de la Marine", competent in the field of Nautical Chart revision, and the following estimate was reached:

2.1.1 <u>Traditional method based on sea measurements</u>:

Sea measurements for all the Maldives would rely on a very intensive campaign which would include:

- purchase of equipment for sea measurements... US$ 670 000
  - localisation equipment.................. US$ 170 000 (theodolithe, receptor, etc...)
  - sounding equipment...................... US$ 150 000
  - geodesic system......................... US$ 150 000
  - research vessel......................... US$ 180 000
- personnel: 4 consultants for 8 years (minimum) = 32 m/years

  4 years x US$ 332 500/year................ US$ 2 660 000

  In the end, the total cost for the traditional method would reach .... <u>US$ 3 330 000</u>

2.1.2 <u>Method based on maritime campaign and photo-bathymetric restitution of aerial photos</u>

a. <u>Acquisition of aerial photos</u>

Hypothesis A: Use of an old vertical aerial photo coverage

- reproduction of vertical AP coverage (1:25 000)........ US$ 5 000
- acquisition of 36 mm sample aerial photos (inland feature updating) (see Chapter 2, para III)................. US$ 47 000

<u>TOTAL</u> <u>US$ 52 000</u>

Hypothesis B: Use of a new vertical AP coverage

- acquisition of vertical AP is estimated at a minimum cost of US$ 300 000 US$ for all the Maldives.

b. <u>Interpretation of aerial photos</u> would include land area <u>interpretation</u> and bathymetric line mapping from stereoscopic analysis of 1:25 000 aerial photos. Work for the whole of the Maldives can be estimated at 2 to 3 man/years for a minimum total cost, including renting of photogrammetric material and drafting of map, of .... US$ 300 000

c. Sea campaign

The main difference from the traditional method would be a reduction of the sea campaign period:

- purchase of equipment: would be the same as for the traditional method............ US$ 670 000
- personnel: 4 consultants would have to be employed during a period of 2 to 3 years, representing a cost of around .... US$ 830 000

In conclusion, the total cost of the Nautical Chart revision based on aerial photos would be around US$ 2.000.000 (Hypothesis A) or US$ 2.248.000 (Hypothesis B).

2.1.3 Method based on maritime campaign and satellite remote sensing data

a. Acquisition of remote sensing data

- acquisition and processing of print of SPOT data...................................... US$ 160 000
- acquisition of 36 mm aerial photos.......... US$ 47 000

Total cost of remote sensing data is .... US$ 207 000

b. Interpretation of satellite imagery and aerial photos (3 man/months)......................... US$ 30 000

c. Sea campaign (bathymetry, geodesy, other) would still be important and would include:

- purchase of equipment...................... US$ 670 000
- personnel: 2 years of consultancy for 4 specialists, making a total of........... US$ 655 000

NC revision using a remote sensing technique would cost a total of US$ 1.562 000, and appears to be by far the cheapest of the three proposed methods.

Note: Cost of quick updating: Although a quick NC updating as defined on page 28 was not covered by this cost/ benefit analysis study, it should be noted that its cost would be considerably lower than that of a complete revision of the NC, and should not exceed US$ 300 000.

2.2 Benefit analysis

= Compared to the method based on aerial photo interpretation, the method based on satellite remote sensing techniques is preferable, as it is quicker (total of 2.5 instead of 5 years) and much cheaper (US$ 1 560 000 instead of US$ 2 000 000), even if aerial photo interpretation can provide greater accuracy in mapping coral outcrops between 1 and 10 metres in diameter.

= Compared to the method based only on a maritime campaign, the satellite remote sensing method presents considerable advantages, namely:

- a lower cost (benefit of US$ 1 800 000)
- a shorter time for the production of the revised NC (2.5 instead of 8 years)
- a large increase in the quality of the final product: thus, interpreted satellite data permit extensive mapping with high accuracy of:

  . the coast line
  . bathymetric lines up to 30-40 metres depth
  . coral outcrops bigger than 10 metres in diameter

In conclusion, it appears that the best method for NC revision is, unreservedly, that based on high resolution satellite remote sensing techniques.

B. **FISHERIES CHART** (Figure 11)

Figure 11 has been drawn from visual interpretation of SPOT enhanced imagery. Such a chart could be of use in predicting fishing grounds which may harbour certain species and sizes of fish, as well as in choosing fishing methods and gear to be tried out in certain areas. The relative gradients of slopes of different areas, depth ranges, and the density of coral or seagrass can help a fisherman to decide how to fish. On clear bottom he may try gillnets, but where some coral exists a better choice may be certain types of longlines, pots or hook-and-line. Additional information from a more thorough field survey could allow the addition of much more detail to the fishing chart. For example, this mission saw abundant sea cucumbers on extensive sandy shallows about 0.5-2m deep. On shallows covered by sea grass and coral, several species of juvenile reef fish were abundant, and in deeper waters, adult snappers, groupers and rays were sighted. Dhonies were observed catching bait fish in several areas of the atoll.

Information about bottom cover and area can also be useful to the fishery biologist or development planner. For example, the Government of the Maldives is involved in a project aimed at opening 2-metre-deep channels, requiring substantial data processing and ground truth or sea truth activities on site.

Whereas a one-week survey covering an entire atoll, conducted by persons unfamiliar with the area, obviously cannot permit reliable mapping of resources and fishing grounds, a more extensive field survey incorporating interviews with more fishermen should allow development of a fishing chart with much more information about resource distribution and abundance.

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