COMMONWEALTH SECRETARIAT

THE IMPLICATIONS OF SEA-LEVEL RISE FOR THE REPUBLIC OF MALDIVES

by

Alasdair J. Edwards

Centre for Tropical Coastal Management Studies
University of Newcastle upon Tyne

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Centre for Tropical Coastal Management Studies
Department of Biology
The University
Newcastle upon Tyne NE1 7RU

Tel: (091) 232-8511

EXECUTIVE SUMMARY

1) A working envelope for projected sea-level rise is proposed for planning purposes. This should be updated for every three year plan and preparation for sea-level rise should form part of every three year plan.

2) The proposed working envelope predicts a rise in mean sea-level of 4.7 ±1.5 cm within 15 years, 6.7 ±2.2 cm within 20 years, and 18 ±7.5 cm by 2030. These interim values should be used for planning until such time as new information becomes available and the working envelope can be updated.

3) The next 15 years should be used by Government of Maldives to develop the infrastructure and skilled manpower to cope with the demands that sea-level rise will place on society and the economy.

4) Vertical growth of coral reefs of up to 7-10 mm per year may mitigate some of the worst impacts of sea-level rise by maintaining offshore sea defences and providing a continuing source of sediments for beach accretion. This mitigation has considerable potential until 2030-2050.

5) The Maldives have a unique and ancient culture, language, writing and way-of-life. Relocation would almost inevitably destroy these.

6) Sea-level rise will place severe strains on the narrowly based and already precarious economy of the Maldives. A coherent programme of research, training and infrastructural development should be established and international aid to implement this should be sought from those industrialised countries primarily responsible for global warming.

7) Mapping and survey data are currently inadequate for planning purposes and a primary task of the Environment Section should be to collate existing topographical data and make use of aerial photographs and field surveys to build up an environmental database. This would be of use to many government departments.

8) The Maldives lies almost entirely within 3.5 m of mean sea-level. Most of its human habitation, industry and vital infrastructure lie within 0.8-2.0 m of MSL.

9) The population is scattered over 203 administrative islands, many of which are very small (<10 ha) and not defensible economically. Although about 40% of the population are to be found on only 8 islands, almost 50% are scattered over 177 islands. Early next century some rationalisation of the distribution of this scattered population will have to be considered. Certain atoll capitals may have to be relocated.

10) Population growth is proceeding at an exponential rate of 3.1% per year (doubling time 22 years). This high rate is placing severe strain on both the economy and natural resources of the Maldives. Child-spacing and other measures need to be promoted urgently.

11) Some islands have already exceeded their carrying capacity following rapid population growth and others are approaching theirs. Such islands can be particularly vulnerable to sea-level rise because of concomitant damage to their natural resources. Carrying capacities with respect to groundwater and land use need to be established for inhabited islands, particularly those selected for development or scheduled for accelerated development.

12) Current education and training programmes must give adequate priority to providing personnel with the specific skills in engineering, economics, planning and science needed to meet the challenge of rising sea-level.

13) The remit of the Department of Meteorology should be widened to cover oceanographic monitoring and it should be renamed the Department of Meteorology and Oceanography to recognise this. Long-term tide gauge data must be collected at Male', Gan and preferably Hanimaadhoo (H. Dh.). Meteorological stations should be developed at Hanimaadhoo and Kadhdhoo (L.). The feasibility of gathering wave data should be investigated.

14) Until 2030 corals should be able to adapt to the slow increase in sea surface temperatures. Temperature anomalies of 1-2°C will still cause "bleaching", however.

15) Reliable fisheries statistics will provide the best warning of any effects of global warming on fish stocks. At the moment these are not predictable.

16) Agricultural statistics are unreliable, cultivation is largely mixed and on small plots. Economic effects of sea-level rise on agriculture are thus difficult to quantify. Taro cultivation in the southern atolls may be particularly susceptible.

17) Tourism accounts for about 17% of GDP and 21% of government revenue. This sector of the economy will be particularly vulnerable to sea-level rise in the longer term on account of the small size of resort islands and the vulnerability of Male' International Airport.

18) The runway of Male' International Airport on Hulule is only 1.2 m above mean sea-level. At present the airport's sea defences are barely adequate. The future of the airport should be reviewed on the basis of the working envelope of sea-level rise projections and plans for its future development drawn up.

19) The implications of sea-level rise should be considered in the siting of industrial developments.

20) In the short- to medium-term, sea-level rise appears to be the least of the problems facing groundwater in the Maldives. Excessive extraction is likely to be the primary cause of salination until 2030.

21) Reclaimed land is at risk of inundation even now, primarily because it is low (<1 m above MSL) and in creating it reefs offshore are likely to have been degraded. Reclamation should be strongly discouraged. Costs of protecting reclaimed land, even in the short-term, are likely to be in the order of $ 1000-1800 per metre of coastline.

22) Mining of corals from reef flats should to be stopped. Before this can be done, either a hollow concrete block manufacturing industry or the mining of a complete faro to produce coral rock needs to have been established. Both options should be investigated as a matter of urgency.

23) Environmental legislation and a procedure for Environmental Impact Assessment need to be set up to prevent avoidable damage to the environment which will further increase the vulnerability of the Maldives to sea-level rise. The Environment Section should play a central role in this.

24) Recommendations are summarised in Section 4.2.6.

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1. INTRODUCTION

1.1. Background to the study

On the 15th October 1987 at the Commonwealth Heads of Government meeting in Vancouver, His Excellency Mr Maumoon Abdul Gayoom, President of the Republic of Maldives, requested that a detailed study of the implications of projected sea-level rise for the low lying countries of the Commonwealth be undertaken. This request led to the formation of the Commonwealth Expert Group on Climate Change and Sea-Level Rise. The Group has: (a) reviewed the scientific evidence for global warming and sea-level rise, and (b) commissioned case-studies of the possible socio-economic impact of sea-level rise for Bangladesh, Guyana, Tonga, Tuvalu and Kiribati. The present case-study of the implications for the Republic of Maldives was commissioned in March 1989.

> "I would suggest to my distinguished colleagues around this table that we request the Secretary–General to set up a group of experts to do an indepth study of the problem with a particular emphasis on the effects of the projected sea level rise on low–lying countries of the Commonwealth and the dangers it poses to the physical infrastructure and resources of those countries and identify effective, practical and feasible protective measures that could be taken to safeguard the territories, the economies and above all, the peoples of those countries."
>
> – President Maumoon Abdul Gayoom to the Commonwealth Heads of Government Meeting, Vancouver (15 October 1987)

The study was carried out by Dr Alasdair Edwards with assistance from Dr Barbara Brown and Dr Susan Clark of the Centre for Tropical Coastal Management Studies of the University of Newcastle upon Tyne. The Newcastle group has been working in the Maldives on coastal natural resource management problems since January 1986 and has six members with field experience in the Maldives. This expertise led to our involvement in this study. The original Terms of Reference are listed in Annex 1.

Prior to the Commonwealth study, the Government of Maldives had already received three reports on the implications of sea-level rise (Woodroffe, 1989; Pernetta & Sestini, 1989; Hulsbergen & Schroeder, 1989), three on environmental management (Kenchington, 1985; Brown & Dunne, 1986; Engineering Geology Ltd & Tropical Coastal Management Consultants Ltd, 1987), and one on disaster preparedness (Oakley, 1988). These reports contain a great deal of useful information and many recommendations with which we entirely concur. In later sections we review some of the recommendations of these reports in the light of our own experience in the Maldives. Where possible we have compiled and analysed the available information in novel ways and tried to avoid duplication, though naturally this will occur where we are in full agreement with previous consultants.

In view of the previous work it was decided to devote a significant part of the study to preparing an outline action plan to move the discussion of sea-level rise beyond the problem identification stage to the problem solving stage. Dr Edwards visited Maldives from 23rd April to 3rd May 1989 (Annex 2) both to seek for key information and to discuss feasible strategies for implementing a series of recommendations and proposals.

1.2. Review of global warming and sea-level rise projections

We have reviewed a considerable volume of recent literature on sea-level rise (Annex 3) but found a few publications particularly useful (Hoffman et al., 1986; Titus, 1986; NRC, 1987; van der Ween, 1988; Warrick et al., 1988; Jaeger, 1988). The primary aim of this review has been to establish an up-to-date consensus estimate for the sea-level rise likely to effect the Maldives by 2030 and thus place the originally suggested 0.5 m and 1.5 m Commonwealth scenarios in perspective.

In the case of the Maldives where the maximum elevation above mean sea-level (MSL) is about 3.5 m and most human habitation appears to be 0.8-2.0 m above MSL, the exact magnitude of projected sea-level rise is critical. In such a low-lying nation planners will need projections for up to 25 years ahead with 95% confidence intervals in the order of $\pm$5 cm or better if they are to plan effectively. The natural sea defences of the Maldives are coral reefs and a key consideration in sea-defence planning for the future is whether reef growth can keep up with sea-level rise. Accurate projections of the rates of sea-level rise are needed in order to assess this. These three points illustrate the importance of a well-defined projection with which planners can work. While the levels of uncertainty remain too high, planners cannot plan effectively, policy makers will be reluctant to take decisions, and society will remain sceptical.

At this point it must be said that there is not yet unequivocal evidence of "greenhouse" gas build up causing global warming and thus sea-level rise. However, the consensus among atmospheric scientists is that "greenhouse" gas build up does cause global warming and consequently sea-level rise. We accept this and are primarily interested in finding an envelope of projections which can provide a useful basis for planning. The working envelope can be updated and refined year by year as new data become available; the important thing is that there is an acceptable basis for planning and action.

Before discussing the scenarios for sea-level rise considered, we will briefly outline the basis of the links between greenhouse gases (carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons [CFCs]), global warming and sea-level rise, and the various levels of uncertainty involved. The first level of uncertainty involves the projections for greenhouse gas emissions. The use of CFCs is already being curbed following signing of the Montreal protocol and the central issue is how fossil fuel (coal, oil, gas) burning - the primary source of greenhouse gases - will develop over the next decades. Once the greenhouse gases are released to the atmosphere they act to trap heat. The second level of uncertainty involves how much warming will accompany a given increase in greenhouse gas concentrations and how long this warming will take to reach a steady state. Once the atmosphere is warming it can affect sea-level by (a) warming the sea and causing thermal expansion of the seawater, (b) melting mid- and high-latitude small glaciers and ice caps (Alps, Rocky Mountains, Andes, Himalayas, etc.), and (c) melting the Greenland and Antarctic ice sheets. The third level of uncertainty involves how fast heat will be transferred vertically downwards through the ocean and how glaciers and polar ice sheets will respond to global warming. As research progresses and political initiatives are taken in respect of CFCs, fossil fuel use and deforestation, so the amount of uncertainty at all levels is reduced and it is important to realise that the projections available should become significantly better year by year.

TABLE 1. Various scenarios for the rise in sea-level (in centimetres) until 2100. All figures refer to rises from a 1986 zero baseline.

Author	2005	2010	2025	2030	2050	2075	2100
1. Hoffman 1986 - High	6.2	8.6	19.4	23.9	53.5	190.6	366.0
2. NRC 1987 - III	6.1	8.9	20.6	25.6	50.6	93.8	150.0
3. NRC 1987 - II	4.7	6.7	14.8	18.1	34.9	63.3	100.0
4. WCP 1988 - Mid	9.1	11.3	17.8	20.3	30.5	47.1	63.2
5. Hoffman 1986 - Low	3.6	4.8	9.2	10.9	19.5	35.4	57.7
6. NRC 1987 - I	3.3	4.5	8.9	10.7	19.1	32.8	50.0

Sources: 1. Hoffman et al. (1986). Appendix A. High Case. Adjusted to 1986 baseline by interpolation.

2. NRC (1987). Using $E(t) = 0.12t + 0.01049t^2$ where $E(t)$ is eustatic rise in sea-level in cm in t years since 1986.

3. NRC (1987). Using $E(t) = 0.12t + 0.0064t^2$.

4. Jaeger (1988) - World Climate Programme (WCP): Impact Studies. Based on Figure 1(b), adjusted to 1986 baseline.

5. Hoffman et al. (1986). Appendix A. Low Case. Adjusted to 1986 baseline by interpolation.

6. NRC (1987). Using $E(t) = 0.12\ t + 0.00279t^2$.

Figure 1 and Table 1 summarise various scenarios for sea-level rise to 2100. The projections of NRC (1987) are somewhat arbitrary (0.5, 1.0 and 1.5 m rises by 2100 described by simple quadratic equations) but nevertheless provide a useful working envelope within which most recent predictions are contained. Hoffman et al. (1986) revised earlier projections (Hoffman et al., 1983) in the light of better projections of glacial responses and we consider only the revised estimates. The middle scenario of Jaeger (1988) assumes present trends in emissions of greenhouse gases (except CFCs) and a moderate climate sensitivity. Several authors have given estimates of rises by specific dates, e.g. Revelle (1983) - 71 cm by 2085, van der Ween (1988) - 28-66 cm by 2085, and these point estimates are included. The work of Robin (1986) is discussed in detail both by NRC (1987) and van der Ween (1988). There has been a tendency for more recent studies to revise downward earlier estimates of the rates of sea-level rise, however, an unexpected interaction (e.g. large releases of methane from thawing tundra) could alter this welcome trend.

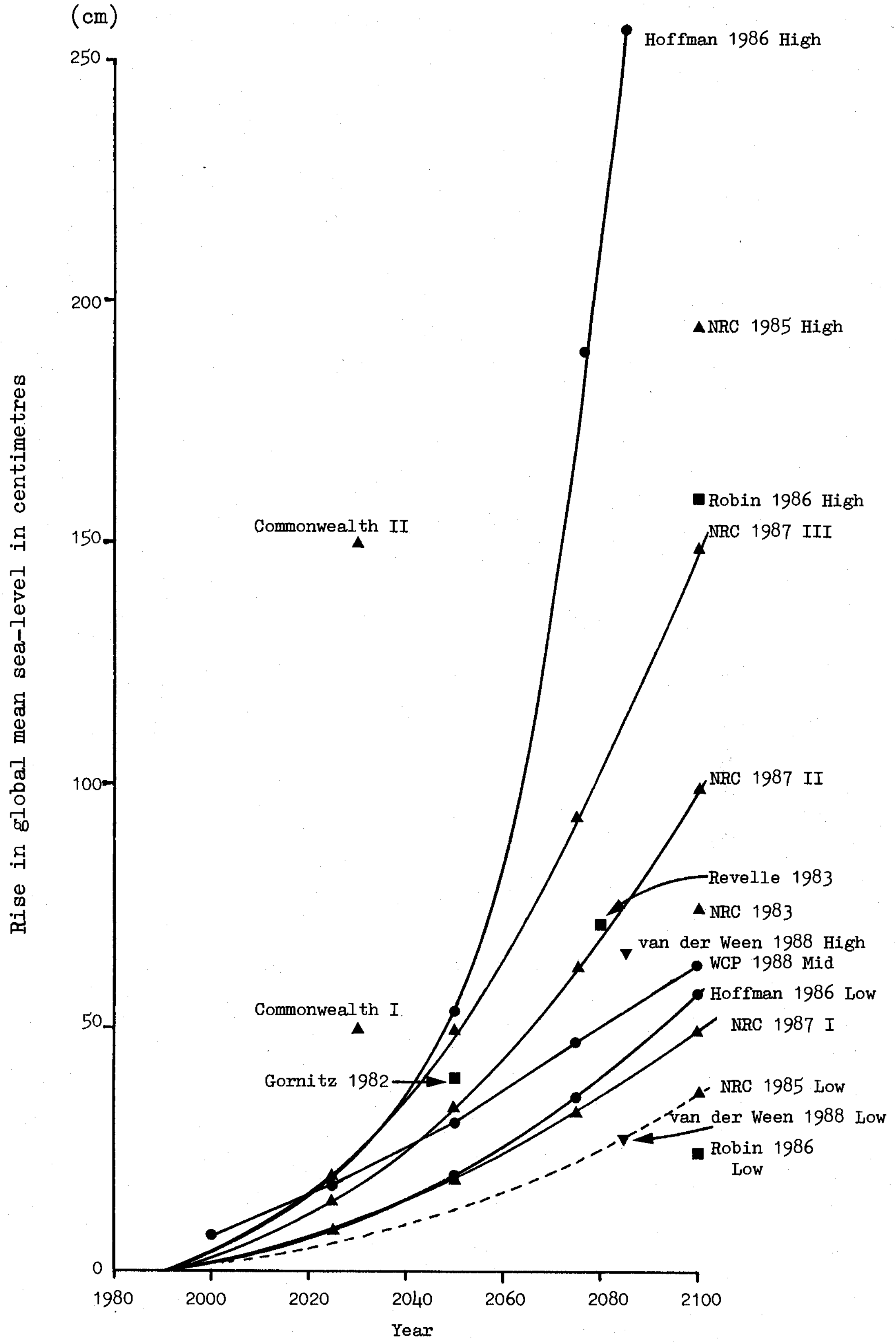


FIGURE 1. Summary of recent projections for sea-level rise to 2100.

The key points to emerge from Figure 1 are:

1) Almost all projections considered fall between the Hoffman (1986) High and van der Ween (1988) Low.

2) Up until 2040-2050 the NRC (1987) I and NRC (1987) III scenarios provide a useful working envelope and more or less coincide with Hoffman et al. (1986) Low and High scenarios respectively.

3) Beyond about 2025 the degree of uncertainty inherent in the projections makes them of limited use in the Maldives context but still leaves a 35 year period for which sensible contingency planning can and must be carried out.

4) The rise in sea-level by 2030 is likely to be about 18 $\pm$7.5 cm (10.7-25.6 cm).

5) If a 15 year period from 1990 were allowed by Government of Maldives for infrastructure preparation, research and planning, by the end of this time sea-level would have probably risen by 4.7 $\pm$1.5 cm (although possibly as much as 9 cm).

6) If a 20 year period from 1990 were allowed for infrastructure preparation, research and planning, by the end of this time sea-level would probably have risen by 6.7 $\pm$2.2 cm (although possibly as much as 11 cm).

7) A rise of 50 cm would be extremely serious for the Maldives (see Sections 2.3, 2.10 and 3). Such a rise is anticipated by about 2050 on a likely worst case scenario, by 2065 on a middle of the road scenario, and by 2100 or later on best case scenarios.

Three important conclusions are:

(1) There is time a) to gather the necessary data to allow planning for sea-level rise, b) to develop the governmental infrastructure and manpower to implement plans, and c) to build up social awareness of the demands that sea-level rise will place on society.

(2) There will be half a century of technological and scientific progress before the situation in the Maldives is likely to become critical.

(3) It should be possible to spread the economic demands, that combatting sea-level rise to 2030 will entail, over 25 years or so if forward planning capabilities are developed, national political will is strong and international aid is forthcoming.

1.3. Response of coral reefs to rising sea-level

When it comes to discussing sea-level rise, tropical islands have the important asset of living growing coral reefs. These reefs in the case of low-lying sediment based islands are the primary reason for the existence of the islands in the first place. It is their wave energy absorbing capacity which has allowed sediments derived from their own erosion to accumulate and be shaped by waves and currents into dry land. Once islands are established it is primarily the offshore protection provided by the reefs which maintains the islands' integrity. Due to the dynamic nature of the system, although the coastlines of the islands may appear fixed they are likely to be continually moving if looked at over periods of tens to hundreds of years. On small islands even seasonal changes will be apparent.

Coral reefs tend to grow up to just below mean low water level and as mean sea-level rises they will tend to grow to keep up with it. In the Maldives they have grown 10-20 m upwards within the last 10,000 years as sea-level has risen following the last glaciation (Woodroffe, 1989). A key question is how reefs will respond to the accelerating rate of sea-level rise being predicted. This issue is reviewed in some detail in Annex 4 and a summary presented here.

Individual corals, particularly branching species like those in the genus Acropora, can grow many centimetres in a year. However, what we are interested in is net vertical accretion rates averaged across whole coral reefs. References to growth and growth rates which follow are to such vertical growth by whole reefs.

Very few studies have considered the growth of coral reefs in relation to sea-level rise; those that have (Cubit, 1985; Buddemeier & Smith, 1988; Hopley & Kinsey, 1988) predict similar growth responses. In the short-term, up until 2030, the response of coral reefs is likely to be generally beneficial although the actual response of different parts of the reef community will vary considerably. For sea-defence purposes we are concerned only with the reef flat.

In large areas of protected reef flats where coral growth is currently constrained by exposure to low tides (e.g. areas such as where Woodroffe (1989) collected his microatoll), growth will accelerate as sea-level rises until maximal growth rates are attained. Reef flats in areas of heavy seas and strong wave action, i.e. sites on the outsides of atoll rims, may unfortunately not display such an immediate response to sea-level rise as protected sites. Reef growth at such sites is usually limited by wave action and as sea-level rises increasing wave heights and wave energy may counteract any response by corals. The reversing monsoon system and relatively benign seas in the Maldives may work in the corals' favour but it is unclear which way the balance between erosion and sediment disturbance and coral growth will swing. Site specific information is needed on coral growth rates in the Maldives before any detailed discussion of likely responses can be made.

In the absence of such information a general response envelope for coral growth has been formulated using available data. A consensus of the various methodologies for estimated coral growth gives a "best estimate" of 10 mm/year as the sustained maximum growth rate. The highest sustained rates deduced from the geological record are 12-14 mm/year. Studies on present day reefs using a technique known as alkalinity depression reveal modal growth rates of 3-7 mm/year depending on the types of reefs. Reefs in the clear sediment free waters of the Maldives might be expected to be able to grow at rates towards the higher end.

These growth rate estimates are examined in relation to rates of sea-level rise based on Hoffman et al. (1986) and the pragmatic working envelope of NRC (1987). Figure 2 shows how the various estimates of coral growth rates compare to projected rates of sea-level rise until 2030. Table 2 indicates the years when sea-level rise rates outstrip the various estimates of coral growth rates. In these years the potential benefits of having living and growing offshore sea-defences cease.

FIGURE 2. Projected rates of sea-level rise up until 2030 compared to rates of vertical growth of coral reefs. (ADT = Alkalinity Depression Technique).

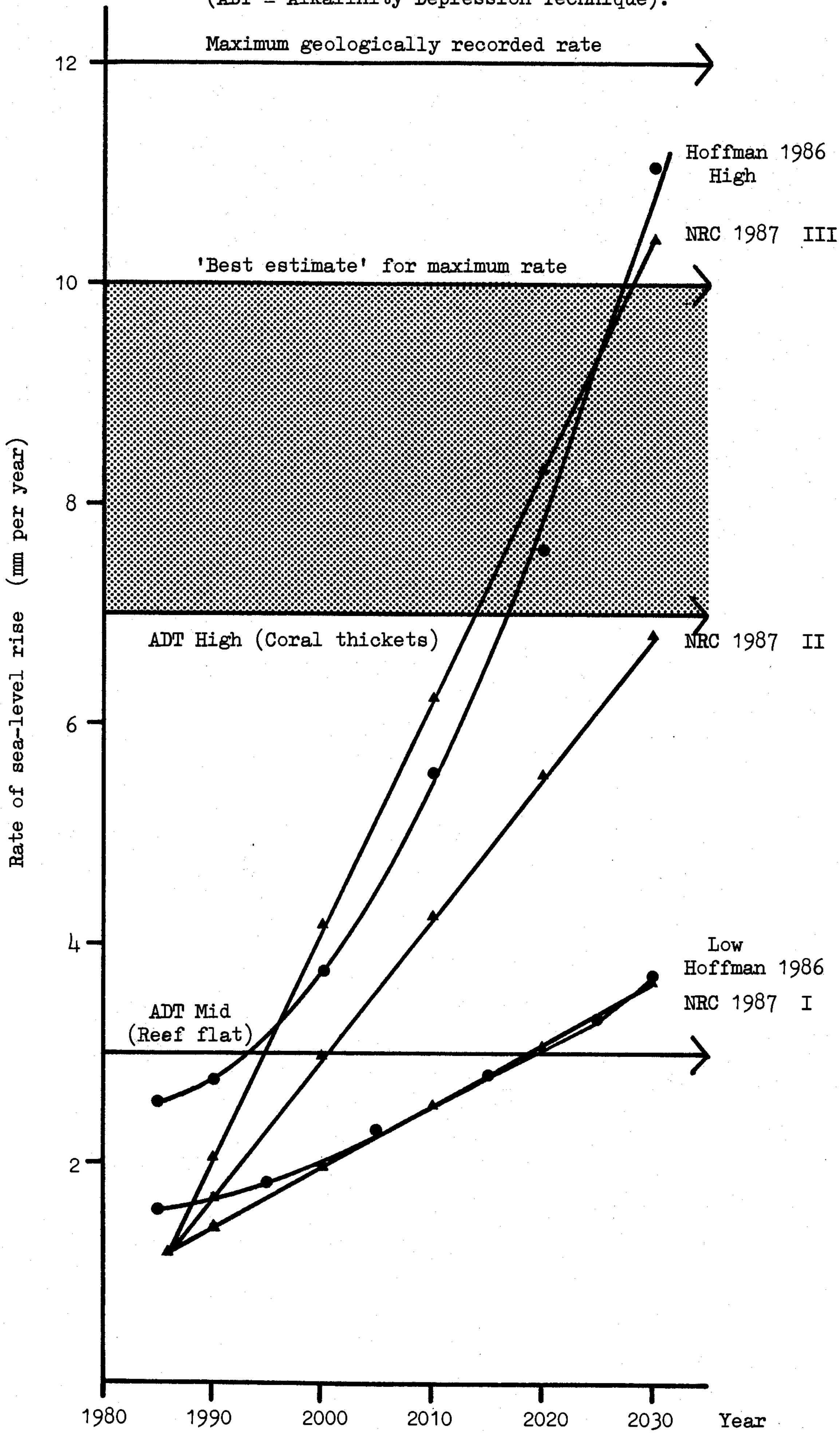


TABLE 2. The year in which sea-level rise will exceed coral growth rates of 3, 7 and 10 mm/year for Hoffman et al. (1986) and NRC (1987) sea-level rise scenarios.

Sea-level rise scenario	Year in which sea-level rise exceeds coral growth rate of:		
	3 mm/year	7 mm/year	10 mm/year
NRC (1987) I	2018	2090	2144
NRC (1987) II	2000	2031	2055
NRC (1987) III	1995	2014	2028
Hoffman et al. (1986)			
Low case	2020	2070	2100
High case	1994	2016	2027

From Figure 2 it can be seen that if coral growth rates are at the low end (3 mm/year) then even the low sea-level rise scenarios would leave coral reefs behind at an early stage. Woodroffe (1989) suggests that 3 mm/year would be a minimum growth rate for Maldivian reefs. Taking the perhaps more likely scenario of 7 mm/year, then only the high scenarios for sea-level rise are likely to outstrip coral growth by 2030.

In any event it seems unlikely that the potential sea-defence protection offered by coral reefs will be of much use beyond 2050. This is of serious concern as once higher wave energies begin to impinge on the islands' beaches their survival becomes in doubt. At such a time there will clearly have to be retrenchment to larger defendable islands. In the meantime coral reefs have considerable potential to delay the worst effects of sea-level rise by both their sea-defence and sediment generating functions. Only research on coral reef growth rates and erosion rates in the Maldives will allow this potential to be quantified.

For both a 0.5 m and 1.5 m rise by 2030 the coral reefs would rapidly be left behind by rising sea-level and the heights of waves impinging on the islands' shores would increase steadily with probably disastrous consequences.

2. NATURAL RESOURCES, ENVIRONMENT AND ECONOMY OF THE MALDIVES

2.1. Introduction

The Republic of Maldives (Dhivehi Raaje) consists of a chain of 26 coral atolls lying along the 73°E meridian between 7°06'N and 0°42'S in the Indian Ocean (Figure 3). The area of the state is about 90,000 km^2 but only about 298 km^2 of this is land. There are approximately 1300 islands in the archipelago of which 275 are used for habitation, for tourist resorts, or for industrial purposes. Of the uninhabited islands some 972 are used for agriculture or forestry in some way or another.

For administrative purposes the Republic is divided into 19 administrative atolls which are given letters of the Dhivehi alphabet (Table 3), and the capital Male'. Each administrative atoll has an atoll capital and an atoll chief appointed by the President. In addition, each of the 202 administrative islands within the atolls has a government appointed island chief, or khateeb. The atoll and island chiefs are responsible for the maintenance of public order, the collection of statistics and the implementation of government policies. The atoll chain is about 870 km long and the capital Male' is situated about 600 km south-west of the southern tip of India. Maps prepared by Novelty Printers and Publishers (1979) give the names and positions of all significant islands.

Archaeological evidence indicates that the islands have been inhabited for up to 2,500 years. Heyerdahl (1986) suggests that early settlers were from the Indus valley civilisations and linguistic evidence suggests a common ancestry with the Sinhalese who settled Sri Lanka. The people originally appear to have been sun-worshippers, later Buddhists and were converted to Islam in 1153. Maldivians belong to the Sunni sect.

The distinctive Maldivian language, Dhivehi (based on Elu, an offshoot of Sanskrit), was written down as early as the 12th century and originally written from left to right. The modern script, Thaana, was invented in the 16th century, is based on variants of 9 arabic numerals, and is written from right to left. The Maldives thus boast an ancient culture and their own language and script. A whole unique culture and way of life may thus be put at risk as a result of rising sea-level.

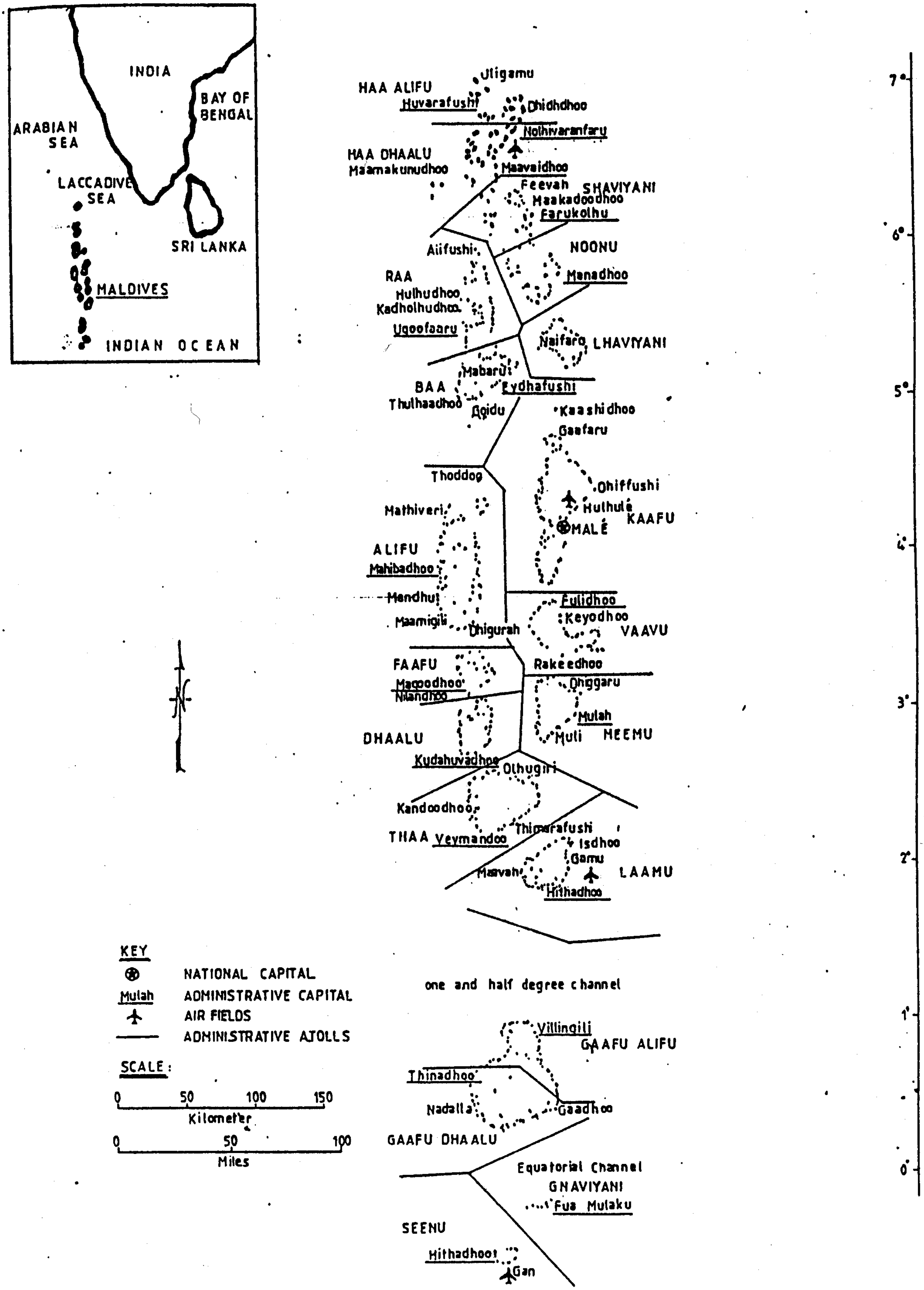


FIGURE 3. The administrative atolls of the Maldives.

TABLE 3. A listing from north to south of the 19 administrative atolls and their capital islands and the corresponding 26 geographical atolls of the Maldives.

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

Male' Island is a separate administrative unit in North Male' atoll (Kaafu).

The four cornerstones of the Maldivian economy are fishing, tourism, somewhat limited agriculture, and international shipping. The Gross Domestic Product (GDP) has grown by an average of 10.8% p.a. since 1977. Based on 1987 figures, tourism (17.2% GDP) is a strongly growing sector (300% of 1981 level), fisheries (16.4% GDP) have also grown well (140% of 1981 level), agriculture (10.9% GDP) has been fairly stagnant (115% of 1981 level) and international shipping (5.2% GDP) after a period of heavy losses in 1982-1983 has almost recovered to 1981 levels. Manufacturing has increased rapidly following the setting up of garment and fish processing and canning factories, and construction has increased due to urban development and infrastructure build-up. The services sector has had exceptional growth led by the rapid expansion in tourism. There has been a major structural shift in the economy from the primary to the tertiary sectors (UNDP/ILO/ARTEP, 1988). The annual growth rate for 1986-1987 was 8.9% and GDP per capita for 1987 was Rufiyaa (Rf) 3,637 (approx. US$ 440).

The principal exports are fish products and ready-made garments and these exports are largely managed by the State Trading Organisation (STO). Total exports in 1987 were valued at US$ 35.3 million. However, the value of total imports in 1987 was $ 73.9 million creating a trade deficit of $ 38.6 million. Also government expenditure of Rf 365.5 million exceeded government revenues and grants by about Rf 20 million.

Sea-level rise is likely to impose economic demands which will exacerbate the already precarious overall balance-of-payments situation unless substantial foreign aid is made available. Any damage to agriculture is likely to push up food imports, whilst sea-defence works will add to construction material import bills (particularly for cement) and also to government expenditure on public works. At the same time any damage to tourism will reduce revenues. Careful planning will help to minimise the strain on the economy.

2.2. Geology

The relatively limited information available on the geology of the Maldives is reviewed comprehensively by Woodroffe (1989). We have nothing to add to his report but will summarise a few of his key points.

The submarine ridge on which the Maldives are sitting is aseismic and may be gradually subsiding. The thickness of coral limestone on the ridge appears to be about 2000 metres. The upper 10-20 m of reef limestones have grown up in response to post-glacial sea-level rise, with reef growth at up to 3 mm/year or more. Reef islands have developed in the last 3000 years while sea-level has been fairly stable. Study of a single microatoll indicated a 6 mm or less net change in sea-level over the last 20-30 years

2.3. **Topography**

2.3.1. Mapping and survey data

Remarkably little is known of the topography of the islands of the Maldives. Data on heights above sea-level, outlines and areas of islands are scanty and derive principally from Admiralty Charts (U.K. Hydrographic Department) and the sterling efforts of Dr Colin Woodroffe and his Maldivian co-workers (Messrs. Mohamed Ali, Abdullah Saeed and Hassan Maniku) from February 4th-13th 1989. The report of Woodroffe (1989) contains diagrams illustrating features of the topography of 13 islands and a summary of his transect information is reproduced as Table 4.

Transect	Name of Islands	Date	Time of water level reading	Length of transect (m)	Maximum Height above MSL (cm)	Height of oceanward beach crest above MSL (cm)	Height of lagoonward beach crest above MSL (cm)	Average height of village above MSL (cm)	Lowest point in island interior *
A	Thulhaadhoo	Feb 4	0830	394	135	115 (seawall)	105	105-120	100
B	Goidhoo	"	1330	1408	160	160	130	90-125	85
C	Ras dhoo	Feb 5	1400	461	160	160	135	105-130	90
D	Hithadhoo	Feb 7	0815	936	320	320	80	80-110	80
E	Maradhoo	"	1045	411	150	150	120	110-130	100
F	Feydhoo	"	1145	493	150	150	110	100-120	90
G	Foammulah	Feb 8	0600	1048	300	300(W)	210(E)	60-100	55
H	Fares	"	1330	267	105	90	90	90-100	90
I	Thinadhoo	"	1815	571	160	140	80	80-150	80
J	Veymandoo	Feb 9	1000	591(+457)	220	220	110	100-160	95
K	Guraidhoo	"	1600	309	155	155	105	105-125	80
L	Furana	Feb 11	0730	251	160	160	110	110-120	85
M	Huraa	Feb 13	1200	950	150	150	85		40

* excepting Kuli/laro pits/excavations

TABLE 4. Topographical data of Woodroffe (1989).

Larger scale Admiralty Charts such as 66a, 66b and 66c (1:292,000) and to a lesser extent 3324 (1:144,486) are not good guides to island sizes and shapes, and in South Thiladhunmathi in particular aerial photographs show that the actual position of islands, their sizes and shapes differ considerably from those charted (Chart 66a). Four charts are sufficiently small scale to provide reasonable outline and area data:-

No. 2036	Horsburgh Atoll	- 1:18,140
No. 2067	Addu Atoll	- 1:25,000
No. 2068	Ihavandiffulu Atoll	- 1:40,000
No. 3323	Male' Anchorage and Approaches	- 1:25,000

Male' Island was surveyed by Binnie & Partners (1975) and their data has been redrawn as Figure 4 with contours expressed as metres above mean sea-level. The map shows that the original habitation on Male' lay between 1.0 and 2.0 m above MSL, the 1950 coastline of the island coinciding more or less with the 1.0 m present day contour (compare Figure 4 and Figure 5). All the reclaimed area is one metre or less above MSL.

The shallow inshore areas and shore of Hulule Island on which Male' International Airport (see also Section 2.10) stands were surveyed in detail by Kocks Consultants Gmbh. of Koblenz, Federal Republic of Germany (Topographic and Hydrographic Survey of Island Shore Zones - Chart H-01). Maldives Civil Aviation Authority landing chart data indicate that the elevation of the runway is 1.2 m above MSL (cf. Section 2.10., Figure 19).

Maafilafushi in Lhaviyani Atoll, which is one of the 9 islands selected for development under the Selected Islands Development Scheme, does not appear to be more than 1.2 m above MSL (Figure 6), is about 52 ha in area and is less than 150 m wide in places.

The report of Farook (1985) that the island of Faridhoo (Haa Dhaalu - population 118) is about 6 m above sea-level needs to be investigated. If true this anomalous island warrants study by scientists.

The picture that emerges is of a nation lying almost entirely within 3.5 m of mean sea-level and with its human habitation, industry and vital infrastructure within 0.8-2.0 m of MSL. Assuming a half tidal range of a maximum of 0.7-0.8 m (cf. Section 2.6.7), it can be seen that the nation lies almost entirely within 2.7-2.8 m of highest astronomical tide (HAT), and most economic and social activity occurs within 1.2-1.3 m of HAT.

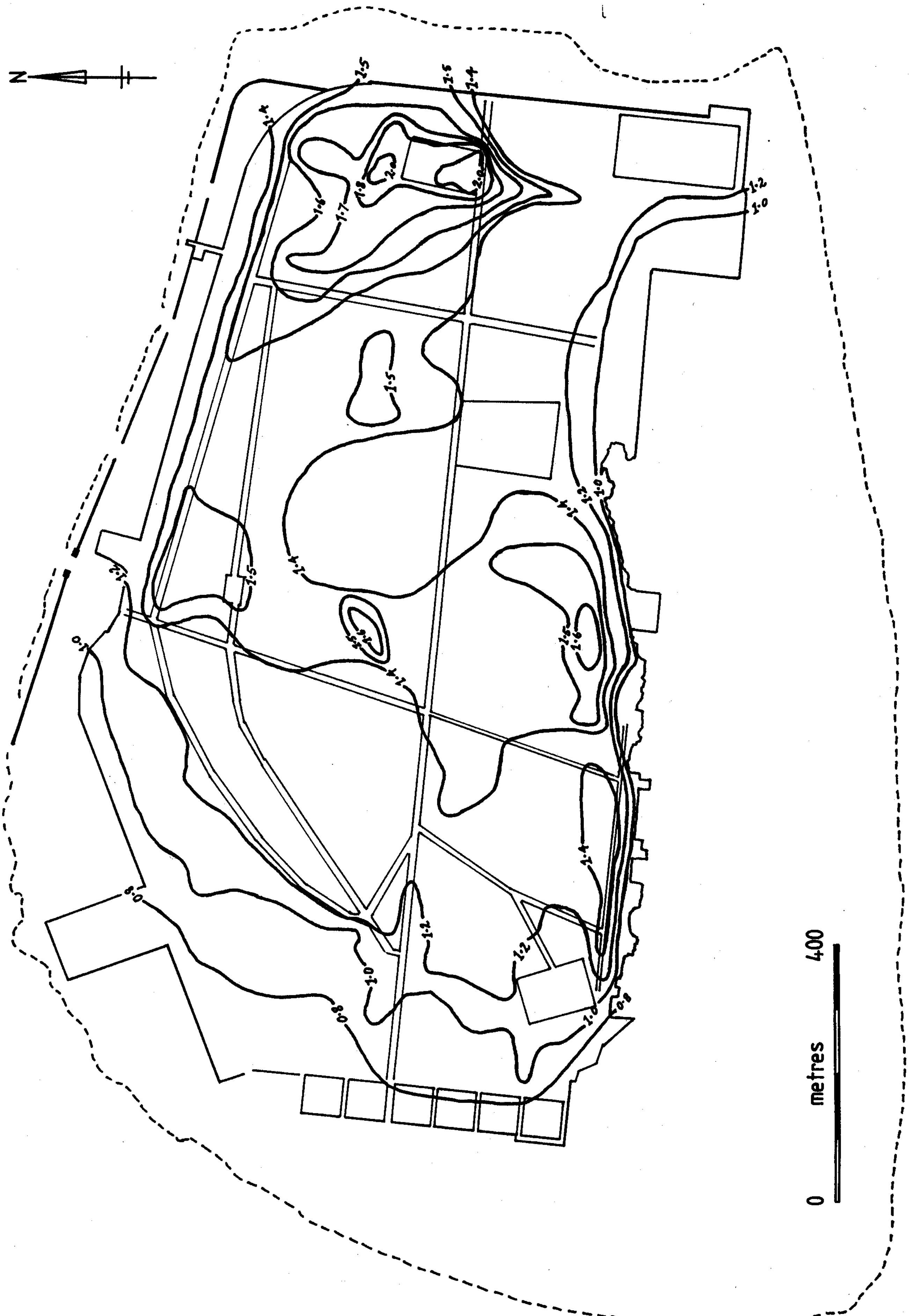


FIGURE 4. Contour map of Male' Island based on survey by Binnie & Partners, 1975. Contours are heights in metres above mean sea-level.

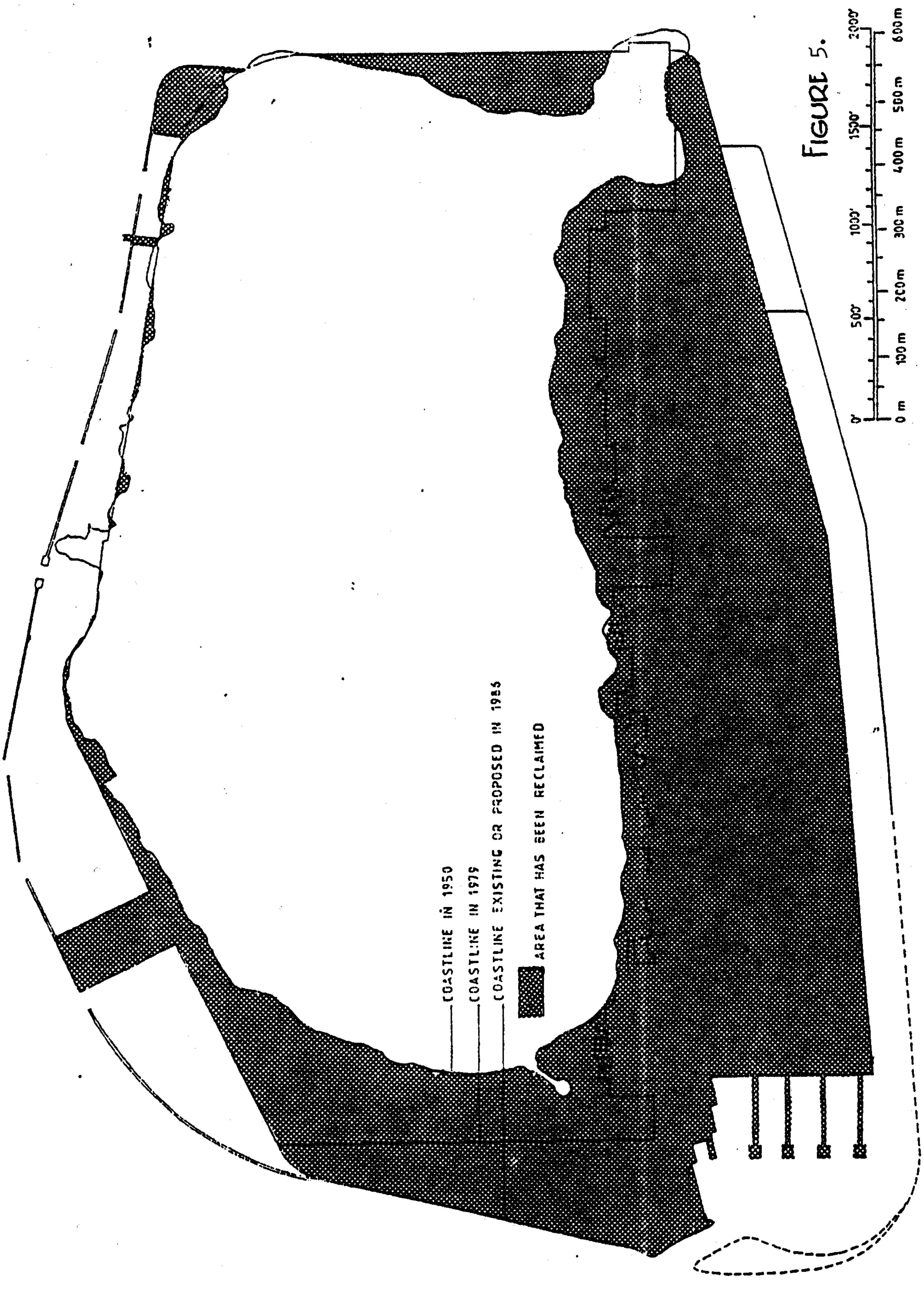
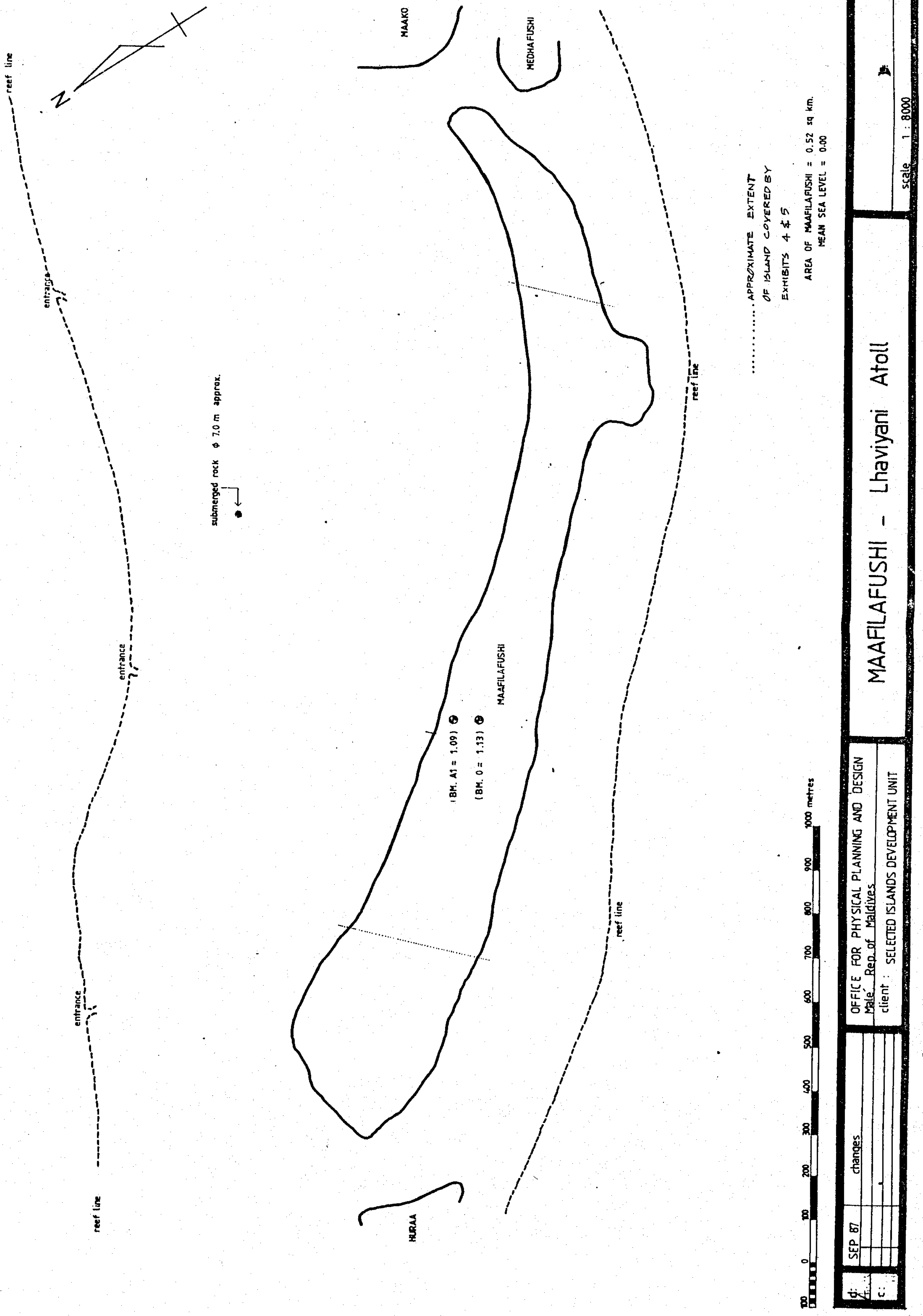


FIGURE 5. The changing coastline of Male' Island as reclamation has proceeded. (Source: Engineering Geology Ltd & Tropical Coastal Management Consultants Ltd, 1987)

FIGURE 6. Maafilafushi (Lhaviyani), one of the islands selected for development.



Not surprisingly, there are already sea-defence problems (Section 3) and these will be exacerbated by any rise in sea-level.

2.3.2. Aerial photographs

A set of aerial photographs of the Maldives is available in the Agriculture Section of the Ministry of Fisheries and Agriculture. It is not known whether the set of prints held comprise all that are available or what the precise extent of coverage is. However, it was indicated to us that most of the archipelago was covered. We are currently investigating the whereabouts of the negatives to these prints to clarify these points.

The aerial survey was carried out in February-March 1969 by the Royal Air Force (RAF) of the United Kingdom. Most photographs were taken at 12,500 ft (3,810 m) and a few at 40,000 ft (12,192 m). Sample reference data from the photographs including code numbers are as follows:-

(a) V13M-RAF1419 250755Z FEB69 C.151.80 MM 40000FT PX16/86 SFDAP CROWN COPYRIGHT.
(b) V13M-RAF1413 240435Z FEB69 C.152.13 MM 12500FT PX16/86 SFDAP CROWN COPYRIGHT.
(c) V13M-RAF1442 040400Z MAR69 C.152.14 MM 12500FT PX16/86.

These photographs along with SPOT (Système Probatoire de l'Observation de la Terre) satellite panchromatic High Resolution Visible (HRV) scanner imagery (10 m pixel size) would provide a good starting point for mapping and surveying the islands of the Maldives to provide the topographic information needed by planners if they are to meet the challenge of sea-level rise.

Like Woodroffe (1989) we suggest that these photographs are handed over to the Environment Section of the Ministry of Planning and Environment and used as a base for mapping and surveying the Maldives.

2.4. Population

2.4.1. Distribution

The population of the Maldives was estimated at 180,088 in the 1985 census. It is scattered over 202 administrative (residential) islands and 73 resort and industrial islands. Approximately one quarter of the country's population (25.5%) is concentrated on Male' Island and about 40% of the population are to be found on only 8 islands (Table 5). The 20 most populated islands contain 50% of the population.

TABLE 5. List of the 25 islands which house populations of over 1000 people. Population figures are for 1985.

Size Class	Island (Atoll)	Population	Cumulative %
10,000 +	Male' Island (Kaafu)	45,874	25.5%
5000-9999	Hithadhoo (Seenu)	6,704	29.2%
4000-4999	Foammulah (Gnaviyani)	4,983	32.0%
3000-3999	Kulhudhuffushi (Haa Dh.)	3,688	
	Thinadhoo (Gaafu Dh.)	3,030	35.7%
2000-2999	Naifaru (Lhaviyani)	2,772	
	Feydhoo (Seenu)	2,525	
	Hinnavaru (Lhaviyani)	2,147	39.8%
1500-1999	Hulhudhoo (Seenu)	1,957	
(7)	Dhidhdhoo (Haa Alifu)	1,805	
	Kadholhudhoo (Raa)	1,777	
	Eydhafushi (Baa)	1,773	
	Hoarafushi (Haa Alifu)	1,650	
	Villigili (Gaafu Alifu)	1,550	
	Maradhoo (Seenu)	1,526	46.5%
1000-1499	Thulhaadhoo (Baa)	1,487	
(10)	Meedhoo (Seenu)	1,422	
	Gadhdhoo (Gaafu Dh.)	1,375	
	Gan (Laamu)	1,200	
	Ihavandhoo (Haa Alifu)	1,181	
	Alifushi (Raa)	1,174	
	Velidhoo (Noonu)	1,157	
	Thimarafushi (Thaa)	1,117	
	Komandhoo (Shaviyani)	1,044	
	Holhudhoo (Noonu)	1,011	53.3%

Table 5 lists all administrative islands with over 1,000 inhabitants in 1985. These number only 25 and accommodate 53.3% of the population. The remaining 84,159 people are scattered over 177 administrative islands.

Outside of Male' Atoll the principal centres of population are in the northern geographical atolls of Thiladhunmathi and Miladhunmadulu which harbour 17.0% of the population, and the southern atolls of Addu and Huvadhu which harbour 16.6% of the population (Table 6 and Figure 7). Thirteen islands among the 80 residential islands in these four geographical atolls have over 1,000 inhabitants. Other important centres of population are the isolated island-atoll of Foammulah with 4,983 inhabitants and Faadhippolhu Atoll (Lhaviyani) which has only four residential islands, two of which have over 2,000 inhabitants (Table 5). Addu Atoll in the far south is noteworthy in that 5 of its 6 administrative islands are among the 20 most populated islands in the Maldives.

TABLE 6. Distribution of population in geographical atolls. (1985 Census figures).

Geographical Atoll	Population (%)	Cum. %	No. of islands with >1000 population	No. of residential islands
N. & S. Male' (inc. Male' Is.)	53,068 (29.5%)	29.5%	1	8
Thiladhunmathi	16,122 (9.0%)	38.4%	2	25
Huvadhu	14,959 (8.3%)	46.7%	3	20
Addu	14,957 (8.3%)	55.0%	5	6
Miladhunmadulu	14,373 (8.0%)	63.0%	3	29
N. Maalhosmadulu	8,242 (4.6%)	67.6%	1	15
Hadhdhunmathi	7,212 (4.0%)	71.6%	1	12
Kolhumadulu	6,949 (3.9%)	75.5%	1	13
Ari	6,705 (3.7%)	79.2%	0	16
Faadhippolhu	6,414 (3.6%)	82.7%	2	4
S. Maalhosmadulu	6,363 (3.5%)	86.3%	2	10
Foammulah	4,983 (2.8%)	89.0%	1	1
Total	160,347		22	159

Note: Remaining 11% of population is distributed among 44 islands in 13 geographical atolls. Only three of these islands have over 1000 inhabitants: Ihavandhoo and Hoarafushi in Ihavandhippolhu Atoll, and Alifushi in the small atoll of the same name.

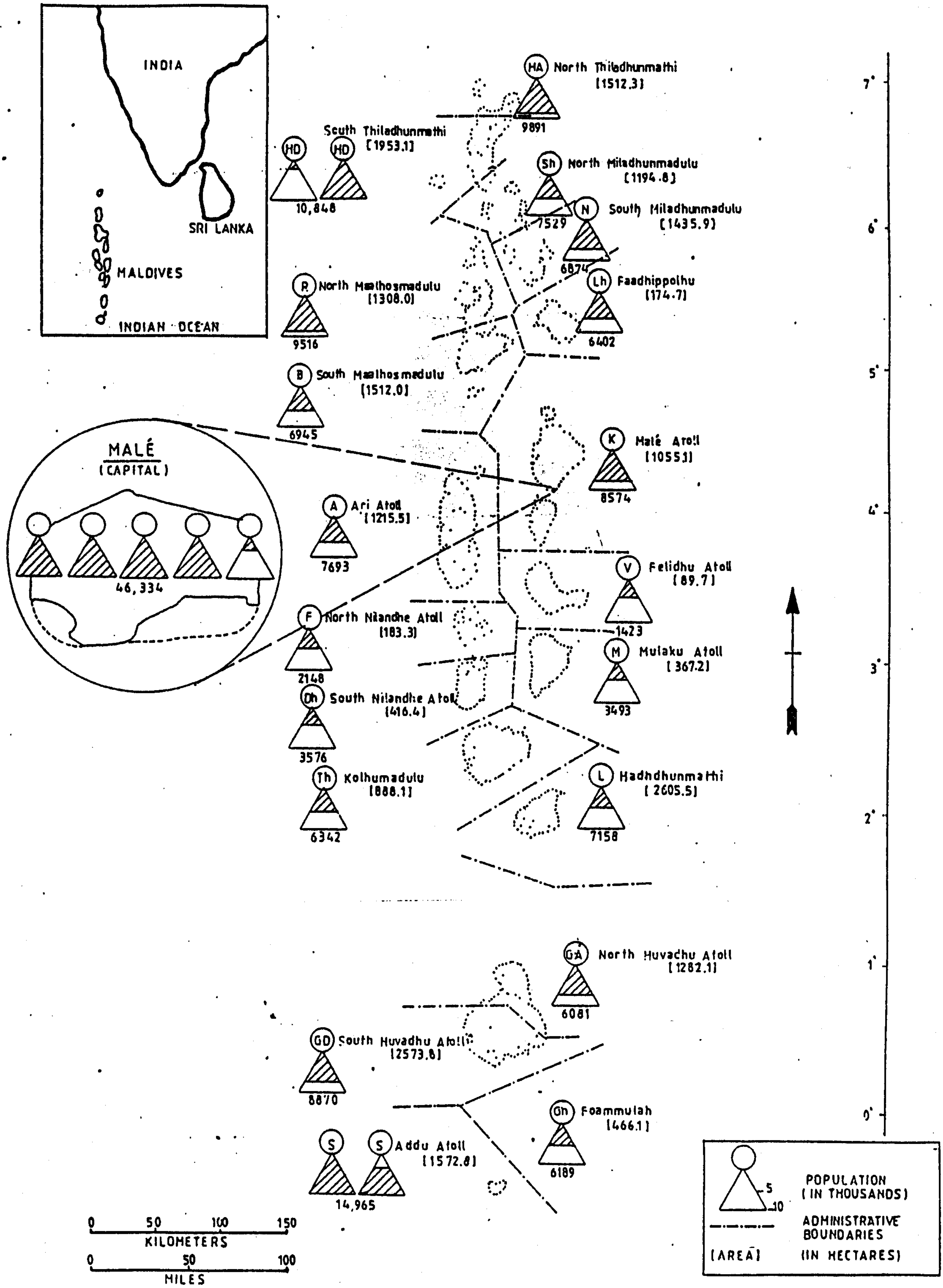


FIGURE 7. Distribution of population in the Maldives. (Source: Oakley, 1988)

The profusion of very small communities on small islands (average size about 0.7 km^2) scattered over about 90,000 km^2 of ocean clearly presents major logistical problems for those involved in planning to deal with sea-level rise. Further, communities tend to be closely-knit and bound to their island homes by strong bonds forged over hundreds of years. Traditionally mobility is low although education, employment and other opportunities attract considerable numbers of Maldivians away from the atolls to the capital Male'. Attempts to relocate a very small community (mustering less than 40 adult males at Friday prayers) and merge it with a larger community in the recent past met with considerable resistance.

Any proposals to rationalise the distribution of the population in the face of rising sea-level will have to take full account of this social resistance and the social impacts of disruption and economic dislocation of the small communities which may be affected. As soon as it becomes clear which islands may be especially vulnerable to rising sea-level, education and awareness programmes should be instigated to prepare communities for possible resettlement and thus minimise social problems. These should preferably be started well in advance (10+ years) of the absolute need to relocate. Maintenance of social cohesion and cultural identity in the face of community upheavals must be a major concern.

2.4.2. Growth

From 1911 to 1964 the population of the Maldives grew slowly from 72,237 to 93,960 with one brief burst of rapid growth from 1957 to 1960 (exponential annual rate of growth 3.5%). Since 1965 growth has been exponential at an average annual rate of approximately 3.1% over the 20 years to 1985 (Table 7 and Figure 8).

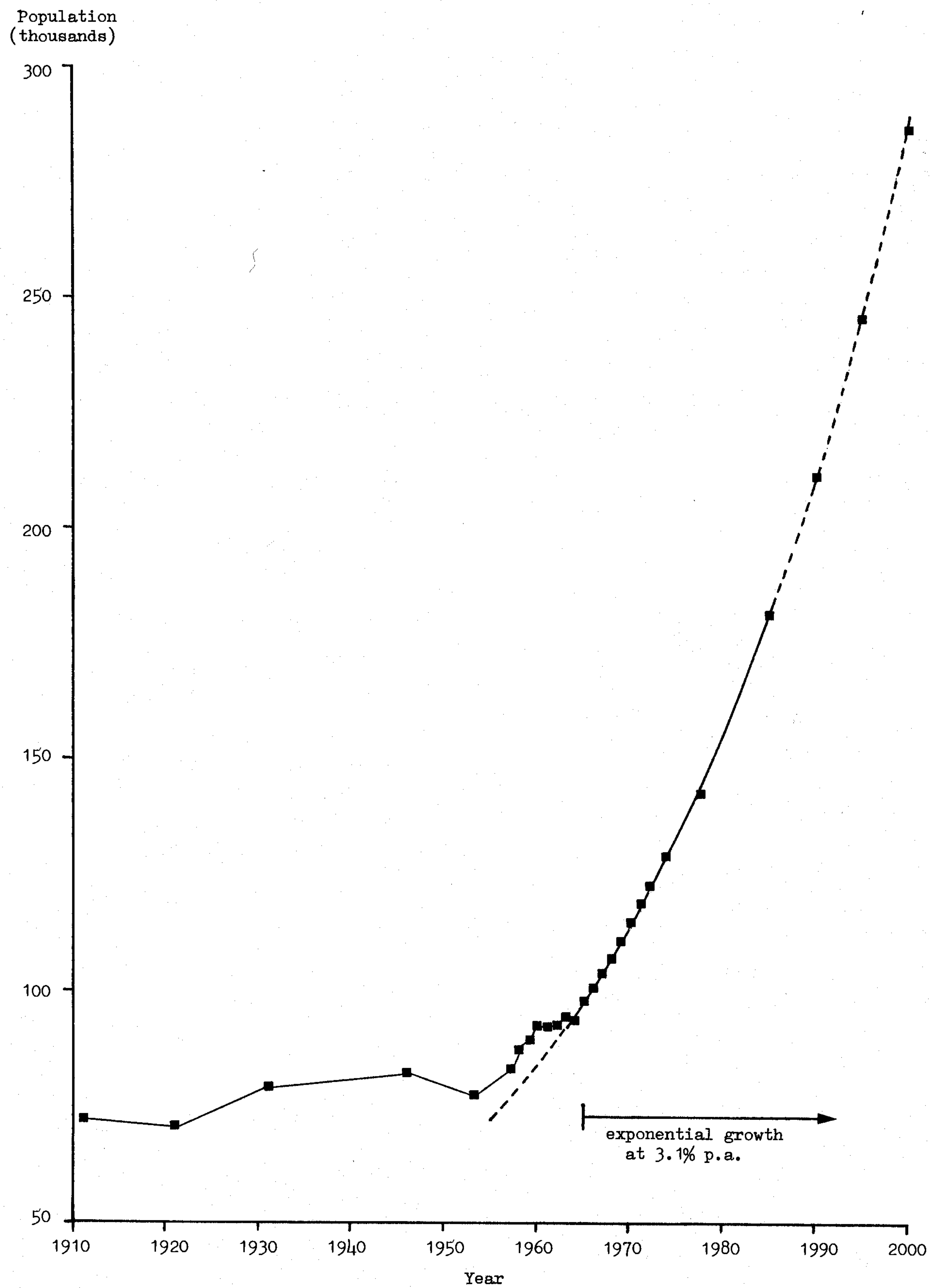


FIGURE 8. Population growth in the Maldives from 1911-1985 with a projection to 2000 assuming continuing exponential growth at 3.1% per year.

TABLE 7. Population growth in the Maldives from 1911 to 1985. Source: Ministry of Planning and Development 1985 census.

Year	Date	Total Population (N)	$Log_e N$	Male' Island Population
1911	October	72,237		5,236
1921	March	70,413		6,127
1931	April	79,281		5,902
1946	June	82,068		8,431
1953	June	77,273		8,484
1957	June	83,075		8,484
1958	June	87,582		10,110
1959	June	89,290		9,471
1960	June	92,247		11,672
1961	June	92,793		11,849
1962	June	92,744		10,875
1963	June	94,527		10,039
1964	1 June	93,960		9,775
1965	28 June	97,743	11.490	10,894
1966	24 June	100,883	11.522	11,297
1967	30 June	103,801	11.550	11,453
1968	28 June	106,969	11.580	12,097
1969	27 June	110,770	11.615	13,336
1970	26 June	114,469	11.648	13,610
1971	25 June	118,818	11.685	15,129
1972	30 June	122,673	11.717	15,279
1974	28 June	128,697	11.765	16,246
1977	31 December	142,832	11.869	29,522
1985	29 March	180,088	12.101	45,874

Predicted population assuming exponential growth rate of 3.1% p.a.

1990	29 March	210,281
2000	29 March	286,703
2030	29 March	726,650

Figure 9 shows the extraordinary close fit of the 1965-1985 census data to the exponential model with growth rate of 3.0833% per year (correlation coefficient = 0.9996) when account is taken of the month of the censuses. Since the exponential growth rate has not varied significantly for 20 years it seems to provide a reasonable basis for future predictions of population increase in the event that there is no government action to decrease population growth. Predictions of the population in

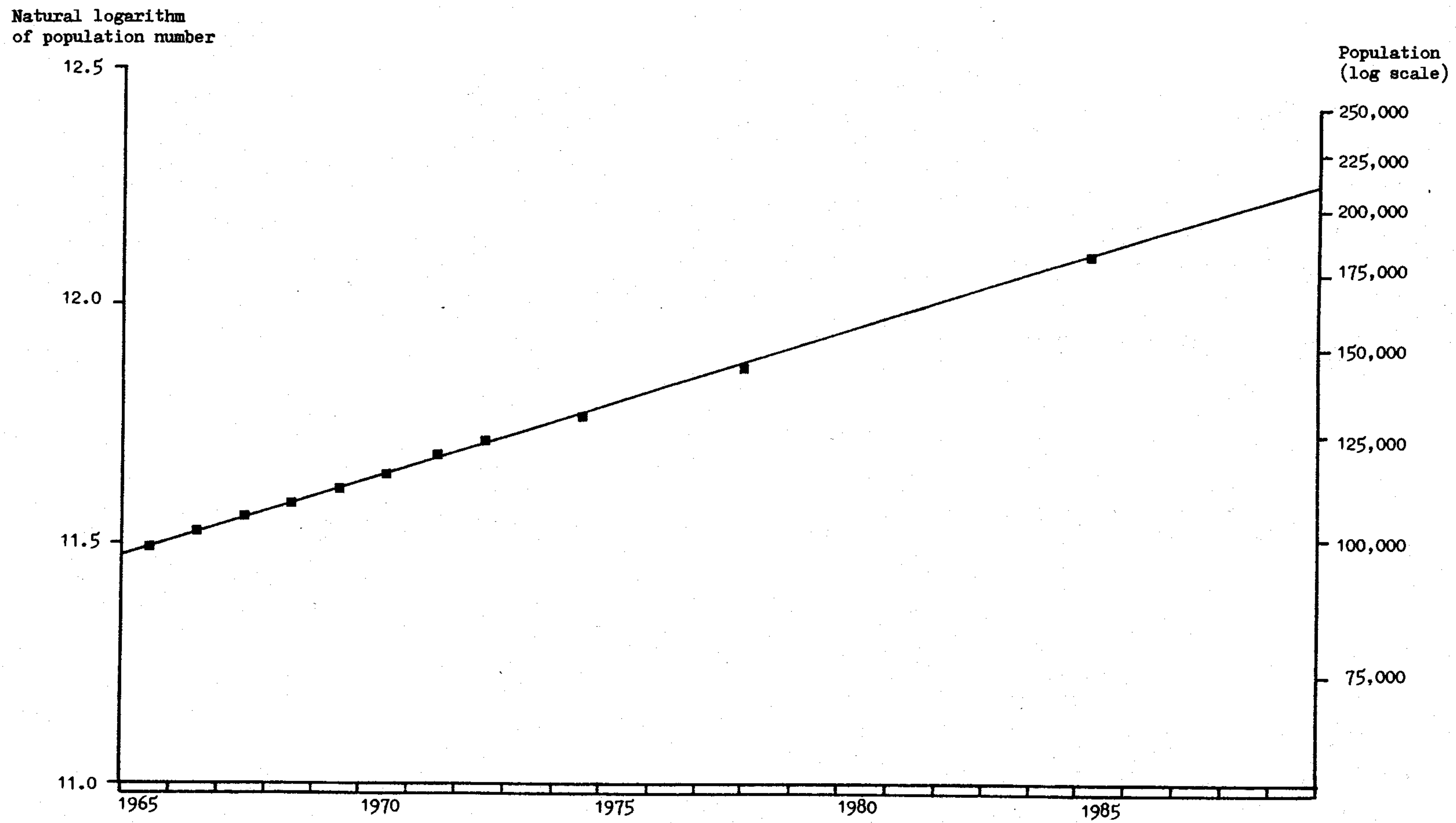


FIGURE 9. Graph of the natural logarithm of the Maldives population aginst time to show the almost perfect fit to an exponential growth model since 1965. Growth rate = 3.0833% p.a. r = 0.9996.

1990, 2000 and 2030 on the basis of a continuing 3.1% exponential growth rate are given in Table 7. The doubling time at this growth rate is approximately 22 years. Unless social attitudes change there is the frightening prospect of a population of 726,650 by the year 2030, approximately four times the present population.

The population of Male' Island has increased about fourfold since 1965 (Figure 10). Slightly over half the increase in population appears to have been due to the influx of people from the atolls seeking educational and employment opportunities. Binnie & Partners (1975) made three projections for the growth of the capital's population but even their high projection underestimated the actual growth. Using a projection which incorporates a decline in growth rate as their proposed saturation level of 75,687 is approached, a population of over 65,000 by 2000 (Figure 10) and saturation by 2030 is predicted. However, it was suggested by Maldives Water and Sanitation Authority that the Male' population is already approaching 60,000 in which case the straight line projection in Figure 10 appears more appropriate. Factors which will influence both the rate of population growth on Male' and the saturation level are a) the development of Villingili, and b) the increase in multistorey house building.

The principal reason for the rapid growth in population over the last 20 years has been the provision of steadily better health care facilities and sanitation. This has led to a dramatic decline in infant (less than one year old) and childhood (1-4 years old) mortality rates. From 1978 to 1987 infant mortality rates declined from about 130 per thousand to 50 per thousand. From 1981 to 1987 childhood mortality declined from approximately 22 per thousand to 7 per thousand. Maternal mortality rates have also declined. These factors between them account for almost all the decrease in overall death rate. Unfortunately, the crude birth rate appears to have shown little decline (at least in recent years), with that for 1980 estimated at 44.2 per thousand and that for 1987 at 43.7 per thousand.

The government has instituted a programme to provide help and advice to married couples on child-spacing methods via the Male' Central Hospital and regional hospitals (National Development Plan 1985-1987). It is not clear how effective this programme is. If increasing population is not to produce unacceptable pressures on both the natural resources and economy of the Maldives, then both the child-spacing programme and awareness programmes need to be promoted by the government to encourage smaller families and

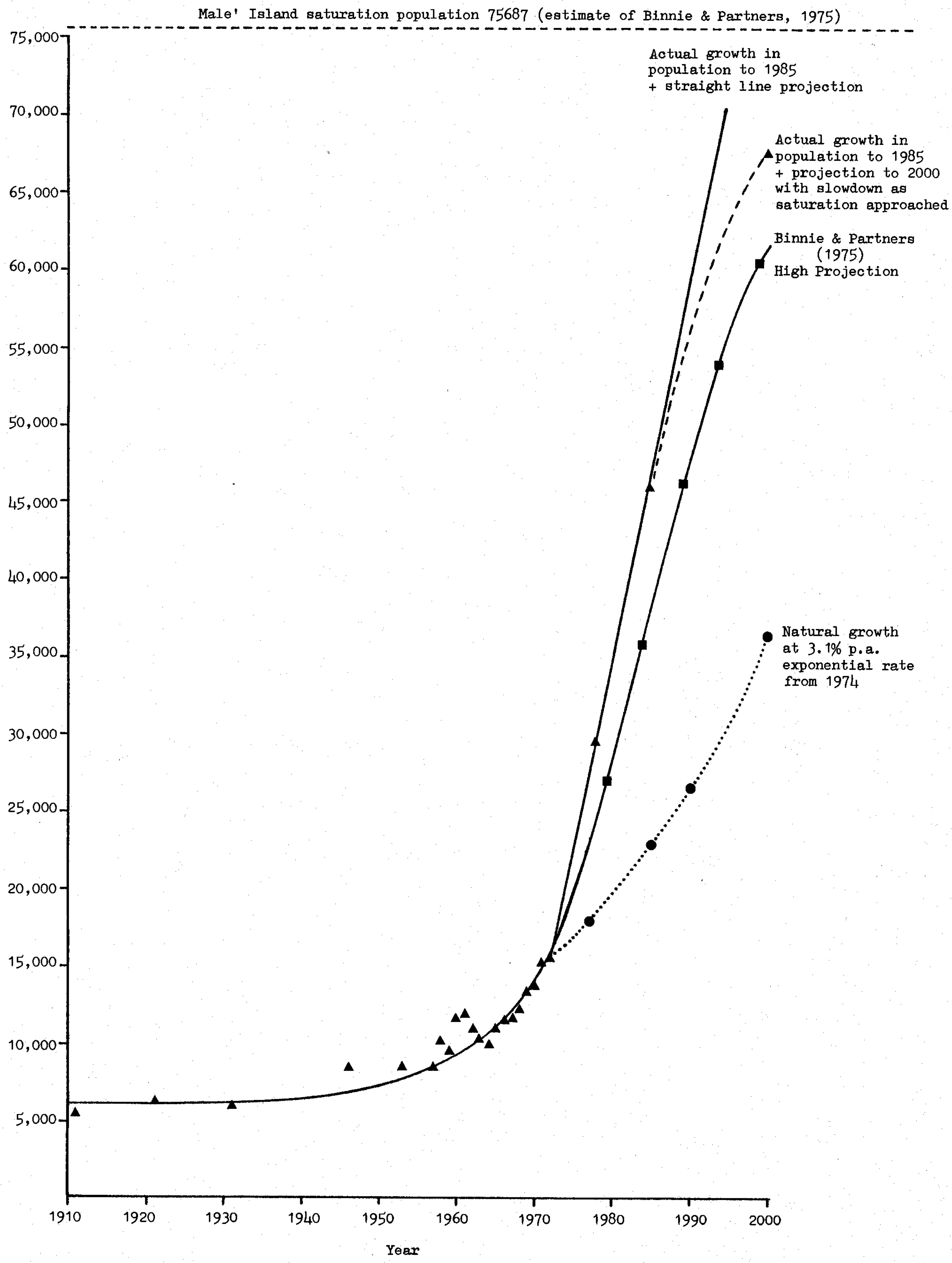


FIGURE 10. The growth of the population of Male' from 1911-1985 with various projections of future growth. It now seems not unlikely that the saturation population could be as high as 90,000.

an older age at first marriage. There is some evidence that the crude birth rate in Male' is below the national average and declining (45-57 per thousand in 1965-1970, 37 per thousand in 1980, 27 per thousand in 1987). Whether this apparent decline is significant, or an artefact of the changing population structure of Male' due to migration, needs to be investigated.

2.4.3. Density

The total land area of the Maldives is estimated to be about 298 km^2. In 1985 the average density of people was $604/km^2$. In the year 2000, if the population continues to grow at its present rate, the density will be $962/km^2$ and by 2030 it will be $2438/km^2$ (about 25 people per hectare of land area).

Male' Island itself was originally about 108 ha in area; by 1979 it was about 123 ha and following completion of the extensive reclamation programme from 1979-1986 it is now about 183 ha. In 1985 about 153 ha were inhabited giving a population density of about 300/ha. Binnie & Partners (1975) estimated the saturation population of Male' at 75,687 which equates with an average density of about 415/ha.

On other islands the density is generally much lower. There is little information on island areas but using estimations of these from charts and the diagrams of Woodroffe (1989) one can calculate very approximate densities for the following islands:-

TABLE 8. Approximate estimates of population densities on a range of islands.

Island (Atoll)	**Approximate size (ha)**	**Population in 1985**	**Population density**
Ihavandhoo (Haa Alifu)	80 ha	1181	15/ha
Thulhaadhoo (Baa)	6 ha	1487	248/ha
Goidhoo (Baa)	120 ha	339	3/ha
Naifaru (Lhaviyani)	30 ha (?)	2772	90/ha
Veymandoo (Thaa)	22 ha	483	22/ha
Thinadhoo (Gaafu Dhaalu)	44 ha	3030	69/ha
Foammulah (Gnaviyani)	460 ha	4983	11/ha
Meedhoo-Hulhudhoo (Seenu)	200 ha	3379	12/ha
Hithadhoo (Seenu)	540 ha	6704	12/ha
Maradhoo (Seenu)	94 ha	1526	16/ha
Feydhoo (Seenu)	56 ha	2525	45/ha

Although these islands (with the exception of Thulhaadhoo) have on average population densities an order of magnitude less than that of Male' one cannot assume that these islands can necessarily support much higher populations on a sustainable basis. Male' has effectively had to sacrifice its coral reef and groundwater resources to support its present population. As a consequence it has major sea-defence and salination problems developing. Thulhaadhoo also has sea-defence problems due in part to reclamation activities. The carrying capacities of other islands need to be assessed urgently if they are not to suffer the same fate.

2.5. **Manpower and education**

The labour force (15 year olds and above) comprised 28.6% of the total population in 1985. The participation rate among the working age population is about 78% for males and 24% for females (UNDP/ILO/ARTEP, 1988). The latter study analysed employment in detail and only a few key points will be considered here.

The Maldives has a high level of functional literacy - 93.25% in 1986 for the age group 15-45 years. However, only about 11% of the population achieve a primary level of education or better and only about 1% achieve secondary school or university qualifications. Those with middle school level or higher levels of education are bound to work in the public sector for a specified number of years, with a minimum of 2 years for middle school graduates. This tends to create excess employment in the public sector (particularly at the lower educational levels) and a complementary shortage of educated manpower in the private sector.

Despite these measures, because the educational pyramid narrows so fast, there is overall a shortage of adequately skilled manpower in the public sector, particularly at higher educational levels. Also the nature of public sector employment (low wages, many people with secondary employment as a result, short office hours to facilitate the latter) conspire to ensure less than optimal utilisation of the talent available. It also ensures that a lot of trained manpower is lost to the private sector at the first opportunity because of disillusionment and the wage differential. Given the need to keep the public sector wage bill down it is difficult to see any easy solution to the problem.

In responding to the challenge of rising sea-level a critical factor will be the engineering, economic, planning and scientific skills of personnel in those government departments which will have to deal with the problems which will inevitably arise. To help build up the necessary personnel, current programmes of overseas training need to be directed to provide personnel with the specific skills needed by those departments (Section 4.2). Further, once people are trained their skills must be properly utilised and their value to the country recognised.

2.6. Meteorology and oceanography

The weather is dominated by two monsoon periods: a dry NE Monsoon period from December to March and a wet SW Monsoon period from April to November. Transition between monsoons occurs gradually during April with the onset of SW Monsoon rains in May. The end of the SW Monsoon tends to occur later further south and the NE Monsoon tends to be less well established in the southern atolls.

2.6.1. Air temperature

At Male' mean monthly maximum temperatures range from 29.7 to 31.4°C and mean monthly minima from 25.3 to 26.4°C. Figures for Gan (Addu) are similar. The global warming generating sea-level rise is predicted to be least in low latitudes. Following the middle scenario for global warming in Jaeger (1988) one would predict an increase in mean temperatures of 0.8-1.1°C in the Maldives by 2030.

Various authors have suggested increased demands on power generating plant as a result of increased used of air-conditioning units as temperatures rise; in the Maldives it seems likely that rising social aspirations and living standards will be the overwhelming factors driving any such increased demand.

2.6.2. Rainfall

The mean annual rainfall at Male' is 1977.3 mm whilst in the south at Gan (Addu) it is 2470.9 mm. Five years data (1984-1988) from Kelaa in North Thiladhunmathi Atoll indicate a mean annual rainfall of 1867.8 mm in the north of the archipelago. These latter data recently collected by the Department of Meteorology confirm earlier suggestions that rainfall increases from the north to the south of the Maldives.

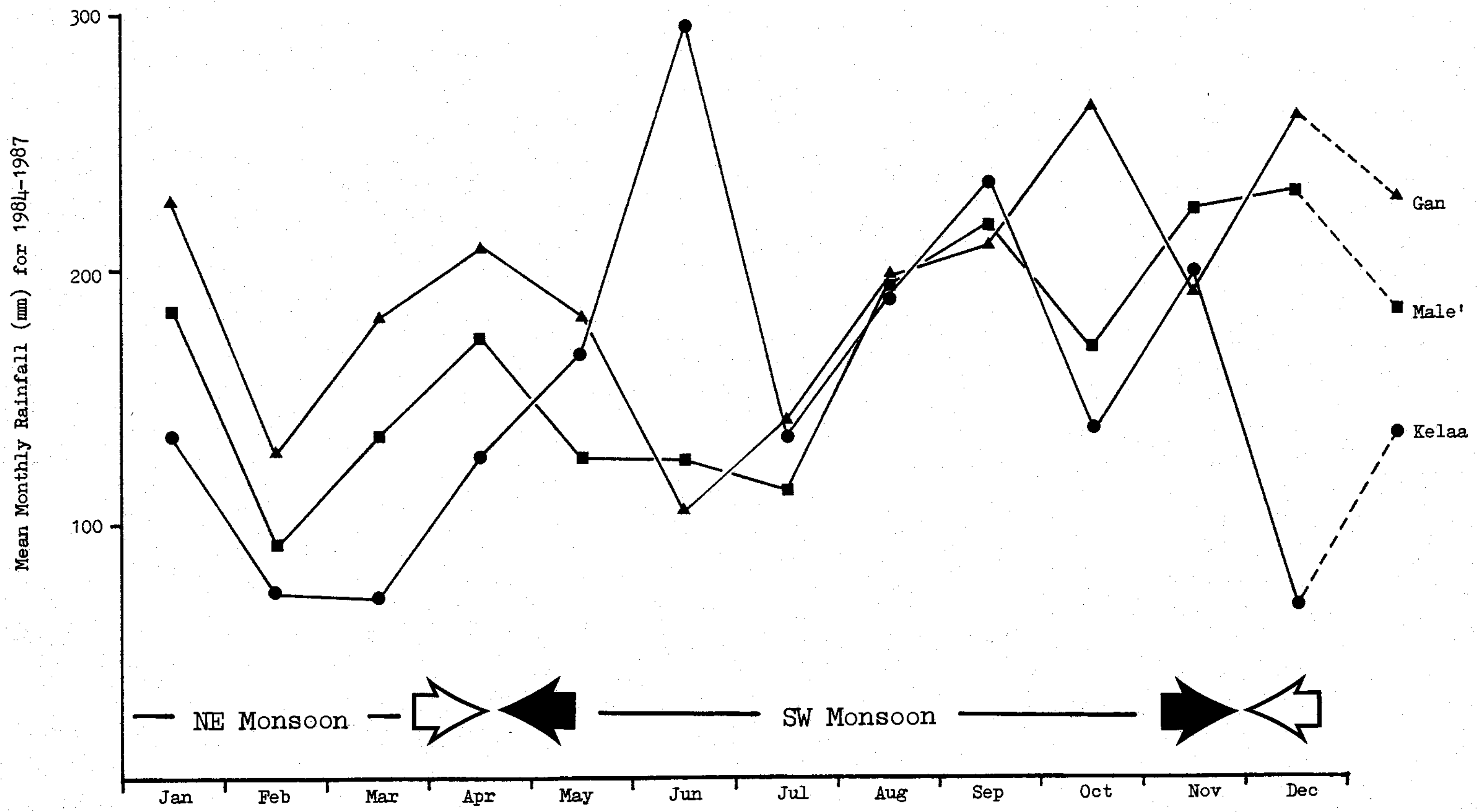


FIGURE 11. Mean monthly rainfall of Kelaa (Haa Alifu), Male' (Kaafu) and Gan (Seenu) to show the north-south variation in rainfall distribution during the NE and SW Monsoons.

The differences in rainfall between the northern and southern atolls are primarily due to the NE Monsoon period and April being much drier in the north (nearer the influence of the Indian subcontinent) than in the south (Figure 11). During June when tropical storms are frequent in the Arabian Sea as the SW Monsoon sets in, rainfall is very high in the northernmost atolls (more than double that further south).

In the northern atolls in particular, January to March can be very dry during the NE Monsoon and towards the end of the dry season groundwater resources (where present) can become badly depleted and noticeably saline, especially on small islands.

Although precipitation in semi-arid tropical regions is predicted to decline, that in humid tropical regions is predicted to increase by perhaps 5-20% by 2050 due to global warming (Jaeger, 1988). There may thus be an increase in average annual rainfall in the Maldives. However, seasonal variability in rainfall may be enhanced as well leading to a more pronounced dry season. In addition, global warming will increase potential evapotranspiration. These latter two effects may counteract potential benefits to groundwater resources as a result of increased rainfall.

2.6.3. Wind

Lying entirely within 8° latitude of the equator, the Maldives are not subject to cyclones due to the negligible Coriolis force at these latitudes. Winds are seldom over Beaufort Force 5-6 (8.5-14 m/s) but gale and storm force winds are recorded on rare occasions. The highest wind speed recorded is 62 kts (32 m/s), recorded in November 1978 (Department of Meteorology, 1988). The windiest time is generally June-July when tropical storms and gales are most frequent in the Arabian Sea to the north of the Maldives and the SW Monsoon is well established in the region. Also in late October and November tropical storms may track westward just to the north of the Maldives from the Bay of Bengal at the end of the SW Monsoon period (Figure 12).

It is predicted that tropical storms will become both more frequent and more intense with increased ocean temperatures. The northernmost atolls of the Maldives are likely to be most affected by the passage of these storms and experience increased wind and rainfall.

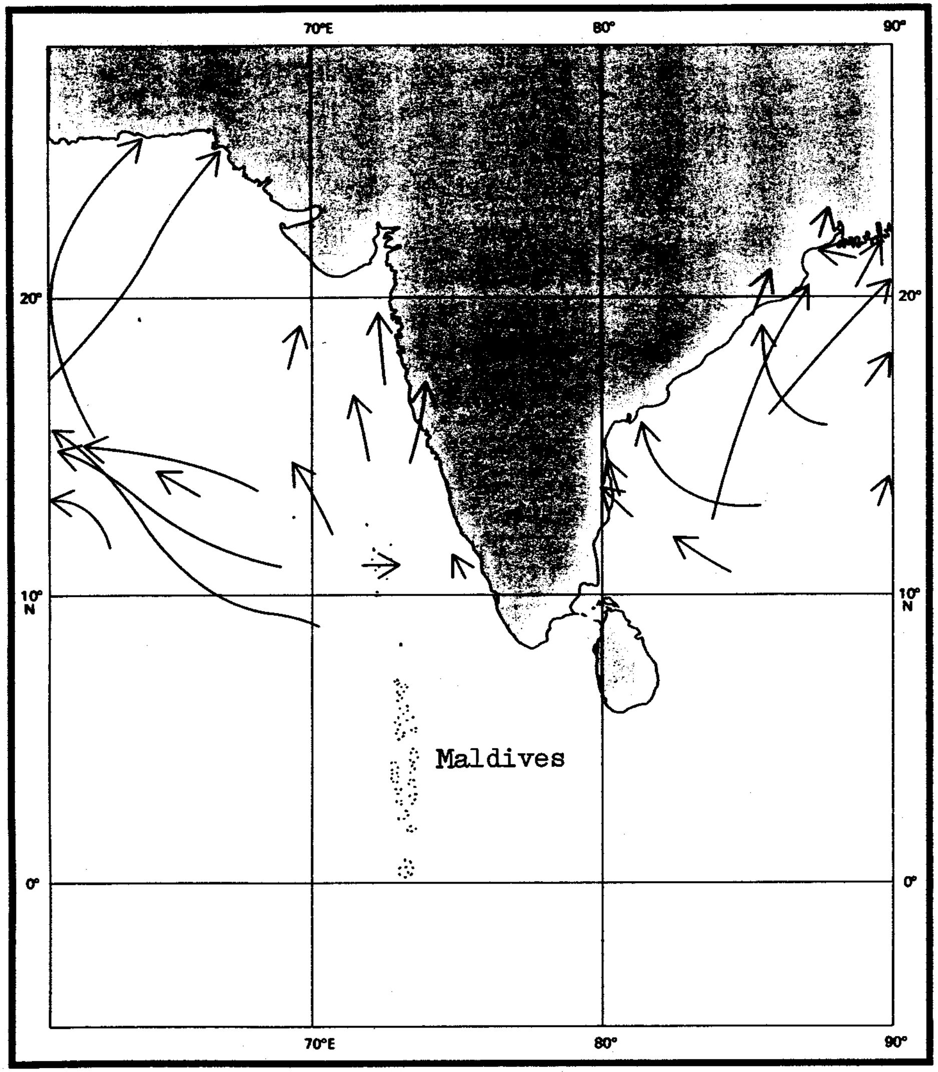


Diagram 15. Tracks of severe Tropical Storms and Cyclones May 1901-1975.

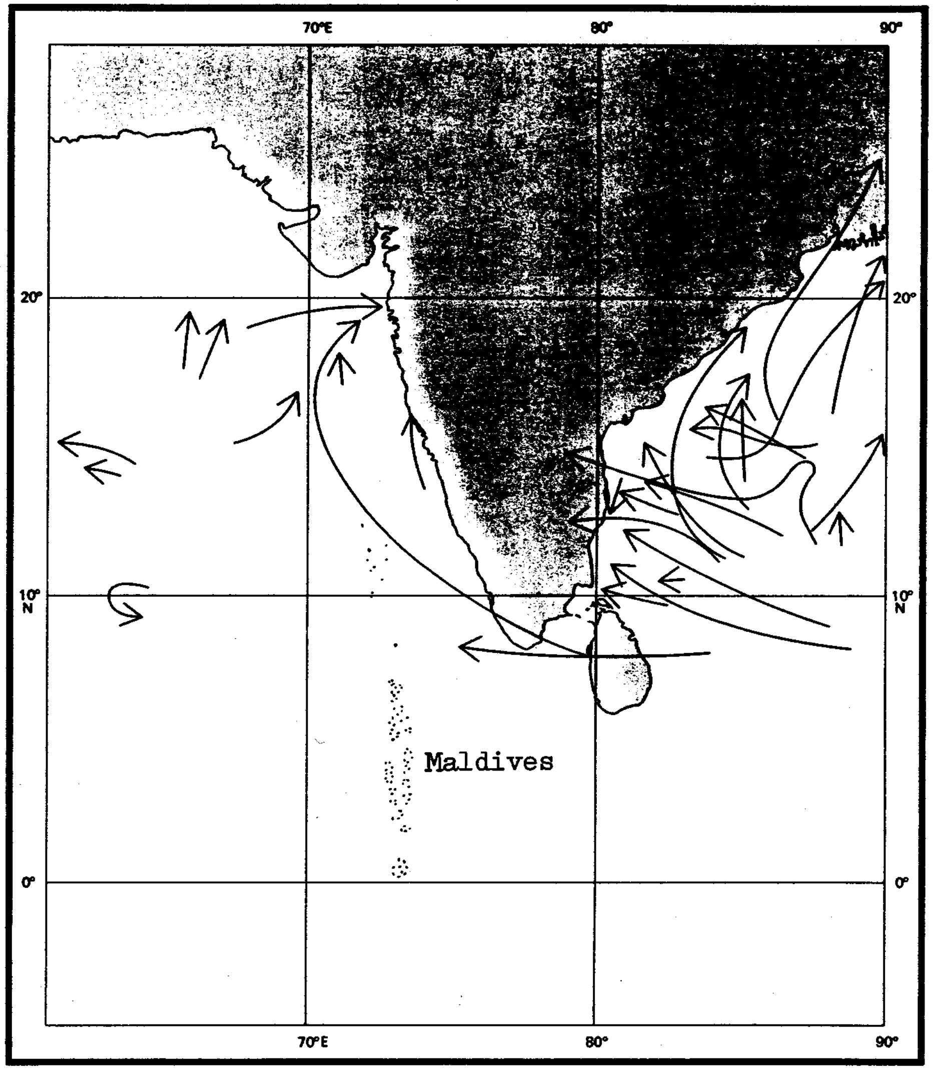


Diagram 16. Tracks of severe Tropical Storms and Cyclones November 1901-1975.

FIGURE 12. Tracks of severe Tropical Storms and Cyclones in the central northern Indian Ocean. (Hydrographic Dept., 1986)

2.6.4. Sea surface temperature

Mean sea surface temperatures range from a low of about 27.5-28°C in January to a high of about 29°C in May. They are thus close to the upper limit (approximately 29°C) for healthy coral growth, particularly in the summer months. Mean sea surface temperatures (SSTs) in the latitude of the Maldives may increase by 0.8-1.1°C (using the middle scenario of Jaeger, 1988) by 2030, leading to January mean SSTs of 28.3-29.1°C and May ones of around 30°C.

Short-term rises in sea temperature of only a few degrees Celsius are known to have deleterious effects on reef building (zooxanthellate) corals. "Bleaching" of corals (loss of symbiotic zooxanthellae and/or the chlorophyll they contain) and considerable subsequent mortality occurred in response to sea temperature rises of 2-3°C following the El Niño event of 1983 at numerous localities all around the globe.

In the Maldives in 1987 a +1.5°C sea surface temperature anomaly in May-June was correlated with bleaching of both reef building and soft corals at various sites in Male' Atoll (Kaafu), Ari Atoll (Alifu) and Felidhu and Vattaru Atolls (Vaavu). The bleaching and associated coral death aroused considerable concern, not least in the tourist industry, and Engineering Geology Ltd and Tropical Coastal Management Consultants Ltd (1987) carried out a study of the bleaching at the request of the then Department of Public Works and Labour. Their report documents the extent and effects of bleaching at a number of sites in Male' and Ari Atolls. Clearly a major concern is that rising sea temperatures may trigger similar bleaching events and widespread coral death.

A warming of about 1°C over 40 years would bring temperatures back to approximately where they were 120,000 years ago during the Eemian interglacial. Corals survived then and it is probable that they and their symbiotic zooxanthellae will be able to adapt to higher ambient sea temperatures until 2030. The response of reef building corals to either faster rates of increase in sea temperature (>0.3°C per decade) or to greater net increase in mean sea surface temperature (>1°C) cannot be predicted with any certainty. Perhaps the only certainty is that the probability of thermal stress induced bleaching events and coral mortality will be higher as global warming proceeds.

Results of work in progress in Hawaii (Hunter and Kinzie in Jokiel and Coles - in press) suggest that there is considerable variation in thermal responses of corals of the same species at the same location, with some coral genotypes being particularly sensitive to higher temperatures while others are more tolerant. There is also a possibility that corals may harbour 'heat-shock' proteins which are produced in response to high temperatures and which convey increased tolerance to further temperature stress by preventing denaturation of vital cell organelles (Miller, 1989). Such research is in its infancy but it provides evidence that corals and their symbiotic zooxanthellae may well be able to thermally adapt in response to a gradual increase in seawater temperature.

2.6.5. Currents

The principal ocean currents flowing through the Maldives are driven by the monsoon winds. From January to March the Indian NE Monsoon current is dominant and westwardly flowing currents of 0.5-1.5 knots (0.25-0.75 m/s) pass through the archipelago. By April winds have backed round to the west and westward currents are weak and in the south the eastwardly flowing Equatorial Countercurrent has moved northwards to Addu. From May to November the Indian SW Monsoon current is dominant and eastwardly flowing currents of 0.5-1.5 knots (0.25-0.75 m/s) pass through the atolls. During December winds veer to the north-east, the Indian NE Monsoon current developes, and the Equatorial Countercurrent moves southward as the predominantly westwardly setting currents return. Locally currents may be much stronger, particularly in the W-E channels between atolls where currents of 4-5 knots (2-2.5 m/s) are often reported (Hydrographic Department, 1986).

2.6.6. Waves

Studies by Lanka Hydraulic Institute Ltd (1988a, 1988b) indicate two major types of waves on Maldivian coasts: waves generated by local winds and storms with periods of 3-8 seconds and swell generated by distant storms with periods of 14-20 seconds. Waves of the latter type, generated by a severe storm thousands of kilometres from the Maldives in the southern Indian Ocean, have been suggested as the cause of the severe flooding of southern Male' Island on 11-12 April 1987 (Goda, 1988).

In the low latitudes in which the Maldives are situated waves over 3.0 m in height are rare. Based on visual observations from ships, the greatest wave height recorded in the area is 6.5 m (Hogben & Lumb, 1967). Using this figure the offshore significant wave height can be calculated as 4.1 m (JICA, 1987). The design wave height for a given sea-defence or other coastal structure can be calculated from a knowledge of the offshore wave height, the height of highest high water (HHWL), and the detailed topography of the site where the structure is to be emplaced. This method was used by JICA (1987) to calculate the design wave height for the detached breakwaters to protect the south coast of Male'. Video footage of the swell waves which caused flooding in April 1987 indicated a period of about 14 seconds. Using this figure for wave period and assuming a HHWL slightly above the highest level of flooding in April 1987 the design wave height for the breakwaters was calculated at 2.0 metres (JICA, 1987).

In the absence of long-term wave rider or other local measurement data on the heights of incident waves in the Maldives, the offshore significant wave height of 4.1 m used by JICA (1987) provides an interim basis for design wave calculations.

Along with the predicted increase in intensity and frequency of tropical storms as a result of global warming, it is probable that the incidence of large waves on Maldivian coasts may become more frequent. Events such as those which caused the April 1987 inundation of Male' are thus likely to become more common. Direct effects of the storms are only likely to impinge on the northernmost atolls and the increased incidence of swells (with periods of 14-20 s) generated by distant severe storms may pose a greater hazard.

2.6.7. Tides

Tides in the Maldives are mixed diurnal and semi-diurnal with the semi-diurnal components dominating (Figure 13). The Department of Meteorology has since February/March 1987 been operating tide gauges at Male' and Gan (Addu) as part of the international TOGA programme. There have been operational problems due to boat damage but useful data are already emerging. Also Lanka Hydraulic Institute Ltd (1988b) installed tide gauges on Male', Hulule and Bandos (North Male' Atoll) for periods of 4-6 months during February-August 1988. These data and Admiralty Tide Tables (1988) predictions give an approximate general picture of tides in the Maldives.

APRIL 1987 TIDE GAUGE RECORD
(Source: Department of Meteorology)

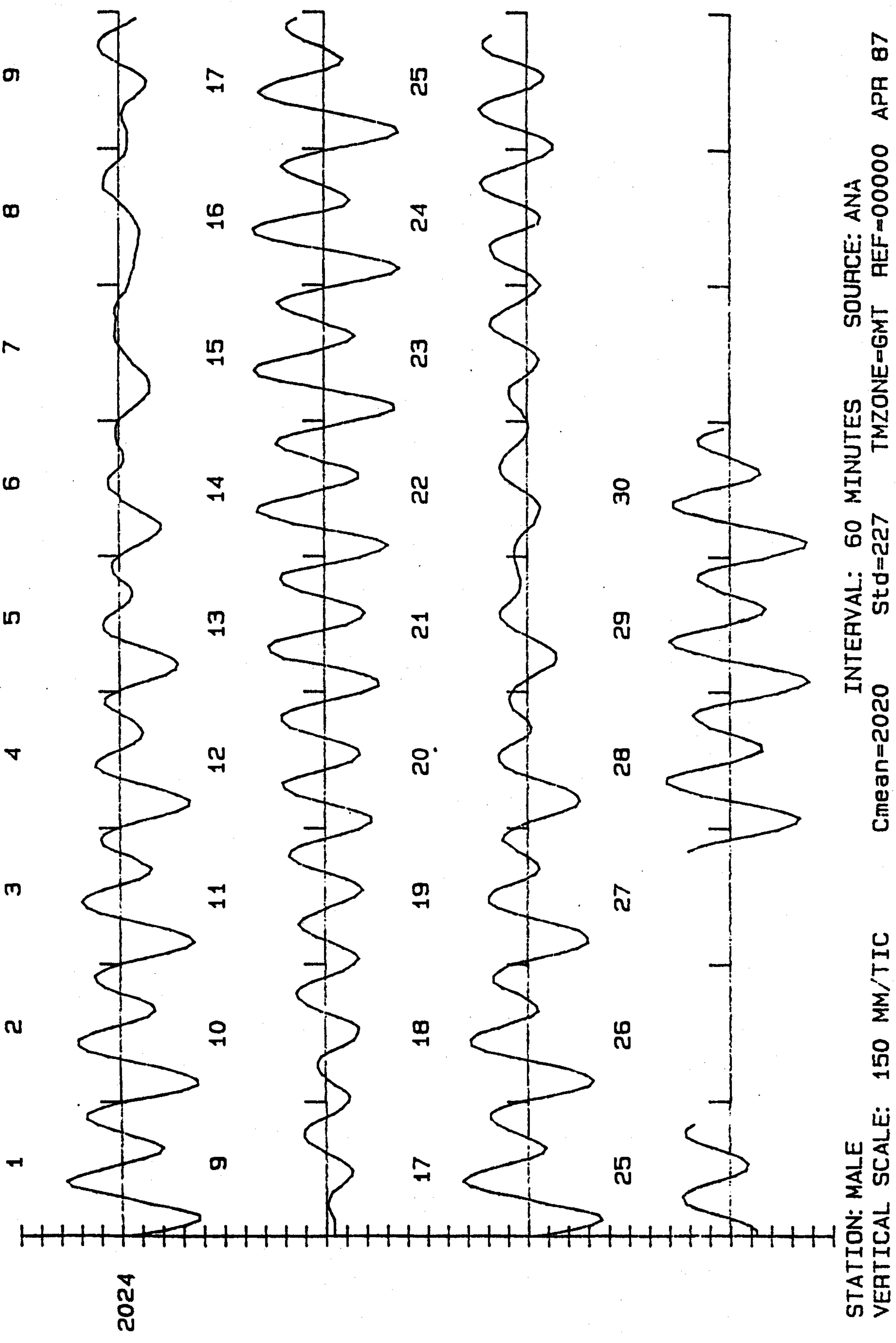


FIGURE 13. A typical monthly tide gauge record from Male' to show mixed diurnal and semi-diurnal tides.

TABLE 9. Summary of tide gauge data gathered by Department of Meteorology at Male' and Gan (Addu). The 1988 Male' data appear to be based on a datum about 29 cm above that used for the 1987 measurements. Readings corrected to the 1987 datum are given in parentheses. All measurements are cm above staff zero.

Male'

	Max	Min	MSL	Range
1987				
February	245	149	193	96
March	253	146	201	107
April	256	145	202	111
May	253	137	203	116
June	261	149	211	112
1988				
January	226 (255)	113 (142)	172 (201)	113
February	218 (247)	116 (145)	167 (196)	102
March	221 (250)	117 (146)	170 (199)	104
April	226 (255)	111 (140)	172 (201)	115
May	225 (254)	120 (149)	175 (204)	105

Mean monthly range = 108 cm. Greatest monthly range = 116 cm.
Total tidal range = 119 cm. Monthly variation in MSL = 11 cm.

Gan

	Max	Min	MSL	Range
1987				
March	205	87	146	118
April	208	86	148	122
May	213	85	150	128
June	223	96	161	127
July	207	91	154	116
1988				
April	215	91	155	124
June	216	82	152	134
July	215	95	156	120
August	213	94	159	119
September	220	87	152	133
October	207	91	151	116

Mean monthly range = 123 cm. Greatest monthly range = 134 cm.
Total tidal range = 141 cm. Monthly variation in MSL = 15 cm.

Results of tide gauge measurements at Male' by the Department of Meteorology are summarised in Table 9. The mean monthly tidal range is 1.08 m and the greatest monthly range is 1.16 m. Correcting for the 29 cm datum difference apparent between the two Male' datasets in Table 9, the highest high tide was +256 cm above datum level (Zo) and the lowest low tide was +137 cm, giving a maximum range for the January to June period of 1.19 m. JICA (1987) in a short period of tidal observations found a maximum tidal range of 1.12 m at Male'.

Admiralty Tide Tables (1988) indicate a 0.2 m seasonal fluctuation in mean sea-level at Male' with MSL in the months of September to November being 0.2 m lower than that in February to April. Adding in this seasonal variation one gets an estimate of maximum tidal range of 1.4 m. Binnie & Partners (1975) give mean sea-level at 8.6 m relative to their zero datum (set at 10.0 m) and highest astronomical tide (HAT) at 9.4 m, giving a maximum tidal range of 1.6 m. This latter figure which takes account of longer term (> 1 year) astronomical factors influencing tides would be the safest to use in calculating highest high water levels due to tidal factors, and thus risks of inundation.

In addition to tidal effects, other factors which might locally affect the height of highest high water in the Maldives are a) barometric pressure, b) wave setup, and c) seiching of water inside the atolls.

a) Mean barometric pressure at Male' was 1010.2 mbar for 1974-1987 (Department of Meteorology, 1988). The lowest barometric pressure recorded was 1004.7 mbar at 00.00 h GMT on 12 May 1977. The maximum depression likely at Male' is therefore 5.5 mbar. The maximum additional sea-level rise which might be expected from the coincidence of a very high tide with a lower than normal barometric pressure is thus about 5.5 cm at Male'.

b) Wave setup is the super-elevation of mean water level shoreward of the breaking point caused by wave action. Wave setup may be considerable and in the design study for the detached breakwaters on the south side of Male', JICA (1987) estimated that it could generate an elevation of as much as 1 m (for 4.1 m waves of period 14 s). Wave setup was probably a major factor in the flooding of the Male' reclaim in April 1987.

c) Studies by Lanka Hydraulic Institute Ltd (1988b) indicated negligible seiching (about 1 cm) within North Male' Atoll.

As mean sea-level rises so obviously will the height of highest high water. In addition large swells and significant wave setup may become more frequent. In the northernmost atolls barometric pressure depression effects may be significant when storms and cyclones pass to the north, however, no data are currently available.

2.7. **Fisheries**

Fisheries are one of the mainstays of the Maldives economy accounting for 16.1-22.5% of GDP over the 1981-1987 period, providing about 60% (Rf 12.5 million in 1987) of export earnings, employing about 25% of the workforce and providing the primary source of protein for the people.

The fishing industry is artisanal in nature and centres around a live bait pole-and-line fishery for small surface-swimming tunas. It has been steadily developed with a programme of mechanization of fishing vessels (masdhonis) begun in 1979, the setting up by the State Trading Organisation (STO) of collection centres for fish and also of fuel distribution points in the atolls, the construction of a cannery on Felivaru (Lhaviyani) and of freezing facilities and ice making plants. This development has led to a doubling of the total annual fish catch from slightly less than 30,000 tonnes in the late 1970s to around 60,000 tonnes at present (Figure 14).

The main fish caught is Skipjack tuna (Katsuwonus pelamis). Catches of this species have approximately doubled during the last decade from around 20,000 to over 40,000 tonnes per year and their percentage contribution to the total catch has risen from about 50% to 75%. The second most important species is Yellowfin tuna (Thunnus albacares) which accounts for just over 10% of the total annual catch (Figure 15).

Exports of fish products have more than doubled over the last decade and in 1987 about 66% of the catch was exported. The principal export is frozen skipjack tuna (62% by weight, 45% by value); next in importance are canned fish (8.8% by weight, 22% by value), dried skipjack (5.5% by weight, 10% by value), salted dry fish - primarily scombrids (13% by weight, 9.3% by value) and salted dry reef fish (6.6% by weight, 5.7% by value). Other marine products exported include dried shark fins, shark liver oil, cowries, sea cucumber, fish meal, aquarium fish and red coral.

Fig 14 : Fish catch

(1977-1987)

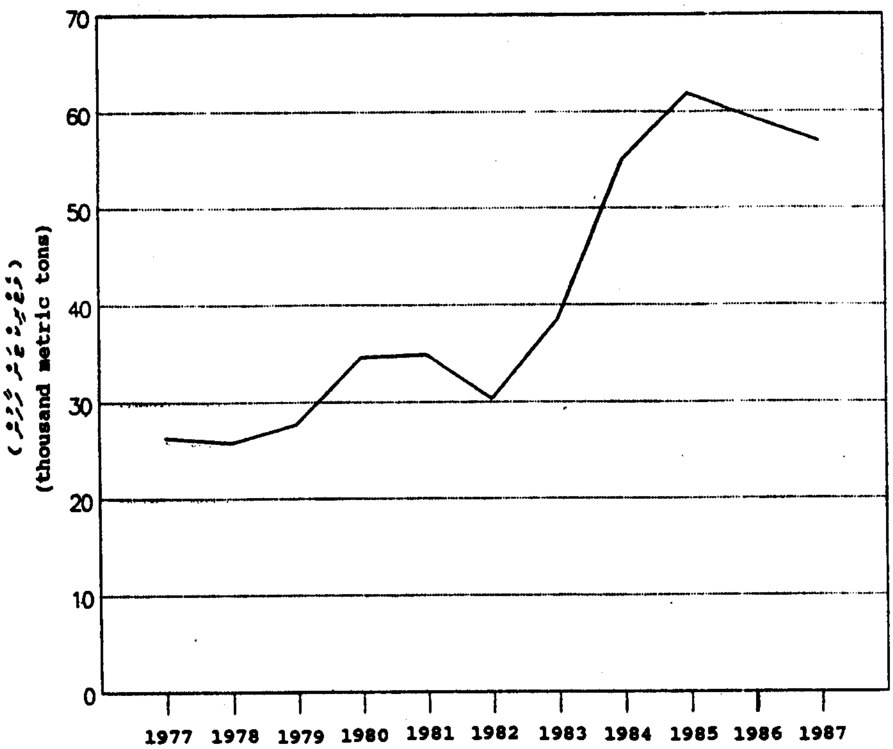
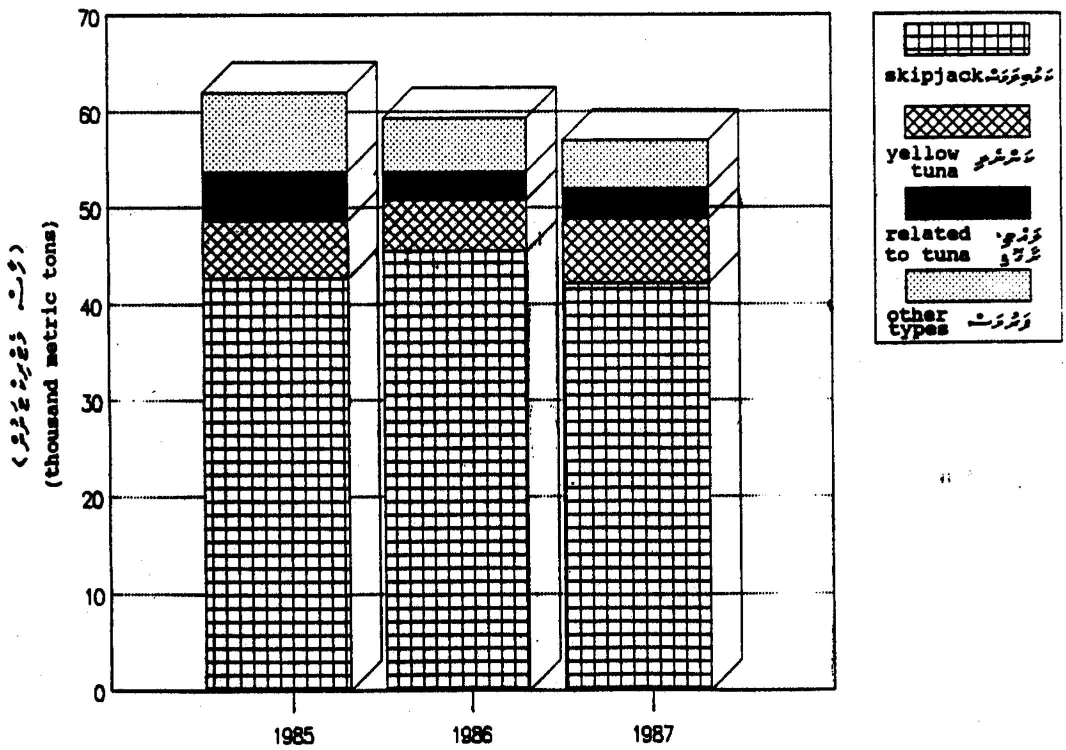


Fig 15 : Fish catch by type

(1985-1987)



FIGURES 14 and 15. Fish catches. (Source: Statistical Yearbook 1988)

Principal fishing atolls are North Thiladhunmathi (Haa Alifu), North and South Maalhosmadulu (Raa and Baa), Faadhippolhu (Lhaviyani), Male' (Kaafu), Kolhumadulu (Thaa), Hadhdhunmathi (Laamu) and Huvadhu (Gaafu). Between them these atolls account for almost 75% of the total fish landings.

It is not anticipated that rising sea-level per se will have any adverse effects on fisheries. It is possible that predicted rises in sea temperatures could have indirect effects on tuna stocks and migration patterns. Temperature induced "bleaching" (loss of symbiotic algae) and death of corals could affect baitfish stocks. The availability of good fisheries statistics should allow effects, if any, to be detected and appropriate research and management measures to be taken. Changing weather patterns may slightly increase the incidence of rough seas and thus fishing days lost. Such effects would be expected to be most marked in the northernmost atolls.

2.8. **Agriculture**

Primarily because of the small area of land available, generally poor soil and limited supplies of freshwater, agriculture is a comparatively small sector of the Maldivian economy. The 1985 census figures indicated that only about 6% of the total workforce were employed in agriculture and forestry. Agriculture accounted for only 11% (Rf 77.9 million) of GDP in 1987 and its contribution to GDP appears to have been declining steadily since 1981-1982 when it accounted for 18.3-19.7% of GDP (using 1985 constant prices). The total area of cultivated land was estimated at 2780 ha by Butany (1974), that is about 10% of the total land area. The total land area which could be cultivated has been estimated at 18,926 ha (about 64% of the total land area).

The numbers of people employed in agriculture and forestry and the numbers of hectares under cultivation in each atoll along with a list of principal agricultural islands are given in Table 10. It can be seen that the principal agricultural atolls are in the north (Haa) and south (Laamu, Gaafu). The two largest inhabited islands, Gamu and Isdhoo (Laamu), are reported to have the largest cultivated areas in the Maldives. Foammulah (Gnaviyani) apparently exports over half its agricultural produce to Addu and is a major supplier of bananas to the Male' market.

TABLE 10. Principal agricultural islands of the Maldives with the details of the agricultural and forestry workforce and cultivated land area in each atoll. Source: Ministry of Fisheries and Agriculture, 1985 census of Ministry of Planning and Development, and Butany (1974).

Administrative Atoll & Agricultural Islands	**Agric. Workers**	**% Total**	**Cultivated Land (ha)**	**% Total**
Haa Alifu	268	9.2	364	13.1
1. Kelaa 2. Maarandhoo				
3. Muraidhoo 4. Baarah				
Haa Dhaalu	138	4.7	344	12.4
5. Faridhoo 6. Nolhivaramu				
Shaviyani	172	5.9	244	8.8
7. Noomaraa 8. Feydhoo				
9. Feevah 10. Foakaidhoo				
11. Narudhoo				
Noonu	73	2.5	116	4.2
12. Hebadhoo 13. Maalhendhoo				
14. Landhoo 15. Lhohi				
16. Miladhoo 17. Holhudhoo				
Raa	83	2.8	234	8.4
18. Kinolhas				
Baa	89	3.0	77	2.8
Lhaviyani	30	1.0	50	1.8
19. Kurendhoo				
Kaafu	62	2.1	19	0.7
20. Kaashidhoo				
Alifu	262	9.0	73	2.6
21. Thoddoo 22. Rasdhoo				
23. Ukulhas				
Vaavu	3	0.1	0	0.0
Meemu	23	0.8	0.4	-
24. Veyvah 25. Mulah				
26. Muli				
Faafu	18	0.6	12	0.4
27. Feeali 28. Nilandhoo				
Dhaalu	39	1.3	21	0.8
29. Kudahuvadhoo				
Thaa	90	3.1	59	2.1
30. Buruni				
Laamu	282	9.7	434	15.6
31. Isdhoo 32. Kalhaidhoo				
33. Gan 34. Fonadhoo				
35. Hithadhoo				
36. Maamendhoo				
Gaafu Alifu	77	2.6	261	9.4
37. Kondey 38. Dhiyadhoo				
Gaafu Dhaalu	634	21.7	291	10.5
39. Madaveli 40. Hoadedhdhoo				
41. Gadhdhoo 42. Vaadhoo				
Gnaviyani	415	14.2	81	2.9
43. Foammulah				
Seenu	162	5.5	98	3.5
44. Meedhoo 45. Hithadhoo				
46. Feydhoo				
	2920	100.0	2780	100.0

Of the 2780 ha of cultivated land, 1792 ha are on inhabited islands and 988 on uninhabited islands. Land belongs to the state but can be leased by individuals. Agricultural plots on inhabited islands are leased for indefinite periods by arrangement with island chiefs (katheebs). People wishing to carry out agriculture on uninhabited islands have to lease whole islands and pay an annual rent of Rf 1 per coconut palm per year (total revenue Rf 383,240 in 1987). Once someone has the lease on an uninhabited agricultural island he can generally retain that lease indefinitely although a few such islands have been transferred to the tourism sector. In 1987 some 972 uninhabited islands were leased for agricultural purposes.

The present system of agricultural land allocation does little to stimulate agricultural development and productivity appears low with little active management of these resources. On many islands the resources appear to be left to look after themselves, the owner merely collecting coconuts and firewood at intervals. The Ministry of Fisheries and Agriculture has put forward proposals to remedy this situation. These involve trying out a new system of fixed term (20-25 year) leases with a requirement for an agricultural management plan and a more realistic rent on 8 islands. Implementation of these proposals would be a first step towards better utilisation of agricultural resources.

Soils are sandy, young, shallow and highly alkaline. They are deficient in nitrogen, potassium salts, manganese, alumininium and iron and rich in calcium, phosphorus and magnesium. The excess of calcium (from coralligenous sediments) interferes with the uptake of potassium salts by plants and iron tends to be converted into an insoluble form in the soil. This means that a lot of nitrogen and potash is needed to grow crops successfully.

Principal crops include coconuts, taro (Colocasia), bananas, Alocasia (taro-like root), millet, maize, arecanut (betel), cassava, onions and chillies. Also grown are sweet potato, breadfruit (Artocarpus), mango, pineapple, cabbage, aubergine, green beans, papaya, guava, jackfruit, lemon, custard apple, passion fruit, pomegranate, screwpine, lime, sapodilla, water melon, pumpkin, carrot, turnip and sugar cane. Most crops are grown in house compounds (backyards) and in small plots on inhabited islands and apart from deeper rooted trees rely on SW Monsoon rainfall. There have been some successful attempts at groundwater irrigation during the drier NE Monsoon (e.g. in Lhaviyani); whether this groundwater irrigation is sustainable does not appear to have been assessed.

Coconut production was estimated at 10.5-12.5 nuts per tree (Butany, 1974). This low yield, about a fifth of what is achieved on some estates in Sri Lanka, is partly due to overcrowding of trees and partly due to pests such as rhinoceros beetle, bats and rats. In an effort to control the beetle by biological means, virus infected beetles have been released into the wild. Warfarin is being used to control the *Rattus rattus* population. It was hoped that these measures would increase nut yields by 20% during 1985-1987. The estimated coconut yield given above may be an underestimate, with yields of 20+ nuts per tree per year being suggested as more probable. Application of management measures such as thinning of dense coconut stands would not only improve yields but also reduce demands on the groundwater of agricultural islands by decreasing transpiration losses. STO has recently been involved in the development of some coconut estates on three uninhabited islands leased for the purpose. These are Maandhoo (Laamu), Beresdhoo (Laamu) and Hulhudhuffaaru (Raa) and have 1680, 3000 and 1800 coconut palms respectively (STO Annual Report, 1986).

TABLE 11. Average annual production of major crops based on 1980-1986 figures of Saini (1987) with an indication of market values at 1989 prices.

Crop	**Average Production (metric tonnes)**	**Market Value (Rufiyaa)**
Coconut (No. of nuts)	10,365,714	20,731,429
Maize	7.5	-
Sorghum	0.5	-
Finger millet	12.3	123,033
Italian millet	7.0	70,500
Colocasia (taro)	1056.6	6,339,823
Alocasia	91.6	732,731
Cassava	17.3	(Rf20 each)
Arecanut (Betel)	15.2	(Rf1 each)
Banana	834.1	(Rf190/bunch)
Onions	1.6	6,406
Chillies	142.9	(Rf0.10 each)

The importance of the traditional staple foods such as taro and breadfruit has decreased as a result of the import of rice and wheat flour, however, in the southern atolls where taro is grown it is still preferred to rice. Table 11 provides estimates of average annual production for 1980-1986. However, the production figures reported for various crops fluctuate by one to two orders of magnitude from year to year and it is unclear what level of confidence can be attached to the figures on which these averages are based. To remedy this situation the Ministry of Fisheries and Agriculture are implementing a project to improve the collection and analysis of agricultural statistics.

Clearly salination of groundwaters which may accompany rising sea-level will pose a threat to agriculture. Already there are problems with aquifers on several islands including Male', where mango trees are beginning to die. Salination of groundwaters will affect deeper rooted trees and vegetation on the island periphery first. Particularly affected will be trees such as mango and breadfruit. In the medium term (<25 years), excessive extraction of groundwater due to increasing population is likely to cause far greater salination than rising sea-level.

The crop which is perhaps most vulnerable to rising sea-level will be taro which is grown in the southern atolls. This is grown in taro pits dug about 40 cm above mean sea-level (e.g. in Feydhoo (Addu) and Foammulah (Figure 16): Woodroffe, 1989). These pits are thus even now below highest tidal levels. Flooding of pits by seawater has already occurred on Foammulah when sluice gates in drainage channels from the pits to the sea have been accidentally left open at high spring tides. Rising sea-levels would a) increase the risk of inundation, and b) lead to the need to raise the level of taro pits as the groundwater table rises.

There are conflicting predictions concerning the affect on rainfall patterns which global warming may have. It seems probable that monsoonal rains may increase in the Maldives. Such a scenario may be beneficial to groundwater recharge and agriculture (cf. Section 2.6.2) but the situation is not clear.

2.9. **Tourism**

Tourism started in 1972 with the opening of the Kurumba Village resort on the island of Vihamanaafushi just north of Male'. By the end of the decade there were 25 resort islands and by the end of 1983 there were 51 resorts. Currently there are 58 tourist resort islands and plans to develope a further 12 in Ari Atoll (Alifu).

Uninhabited islands are developed for tourism purposes. This serves to largely isolate tourists from the local communities of the atolls and minimise the disruptive economic and cultural

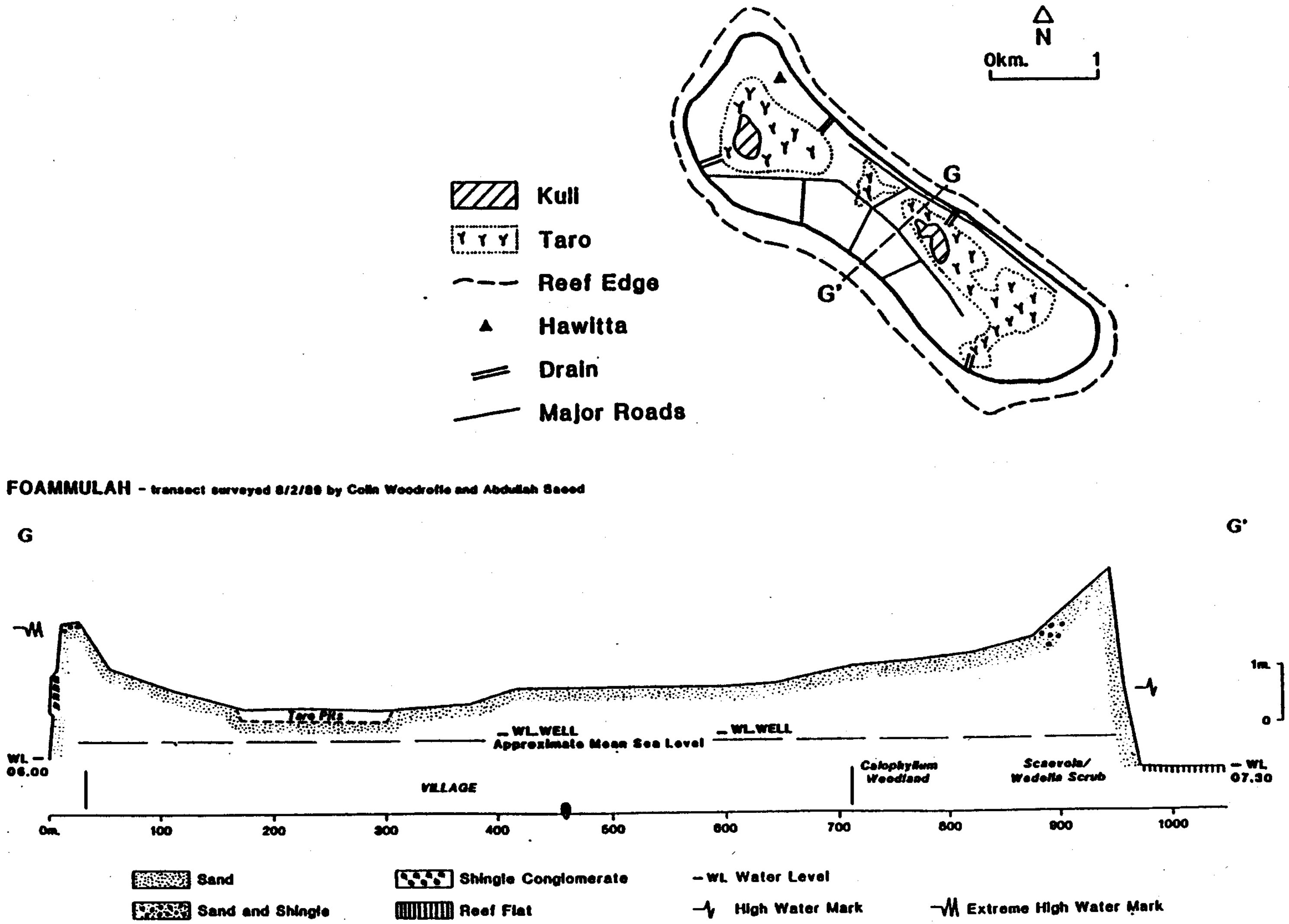


Figure 16. A transect across Foammulah (Source: Woodroffe, 1989)

impacts that tourism can have (Domroes, 1985).

Tourism is one of the mainstays of the Maldivian economy accounting for approximately 17% of GDP and approximately 21% of government revenue. It is an expanding sector of the economy (Figure 17) and a major source of foreign exchange. The number of tourists visiting the Maldives rose from 42,007 in 1980 to 155,758 in 1988, and bed capacity increased from 2418 to about 6383 in the same period. The utilisation of bed capacity has markedly improved in recent years rising from 43.6% in 1980 to 61.1% in 1988. Highest utilisation rates are in January-February at 84.7-85.6% and lowest in June at 33.9% (1988 provisional figures).

The majority of tourists are from Europe with Germany accounting for 26.2%, Italy 18.2%, United Kingdom 6.7% and Switzerland 6.3% in 1988. Japan is also an important country of origin for tourists, accounting for 7.1% of tourist arrivals in 1988. 64.5% of tourists are currently from these five countries.

Resorts are centred around Male' and their operation is entirely dependent on Male' International Airport. At present there are 27 resort islands in North Male' Atoll, 16 in South Male', 9 resorts in Ari, 2 in Rasdhu, one in Baa, one in Lhaviyani, and 2 in Vaavu (Figure 18). No resort island is more than 130 km from the international airport and most are less than 60 km from it. Male' Atoll has now reached saturation as far as tourist development is concerned and Ari Atoll has been designated as the Second Tourism Zone. In Addu Atoll in the far south there is also a resort (Gan Holiday Village) situated close to Gan Airport.

Islands developed for tourism either have their infrastructure developed by Government of Maldives (GOM) and are then leased to operators who manage the resorts, or are leased totally undeveloped to the operators. In 1987, ten tourist islands were government owned, 40 were owned by Maldivians, four were owned by foreign/Maldivian partnerships, and three were foreign owned.

For islands developed by GOM an annual "lease rent" is collected from the resort operator which is reported to be about $2000/bed in Ari Atoll and $3000-4000/bed in Male' Atoll. For islands developed by the operators an annual "land rent" is charged which is calculated on the basis of the number of rooms, number of beds, distance from airport, facilities provided, etc. Improvements made to an island, for example, the planting of trees on a bare island reduce the land rent chargeable, thus providing operators with an incentive to enhance the natural

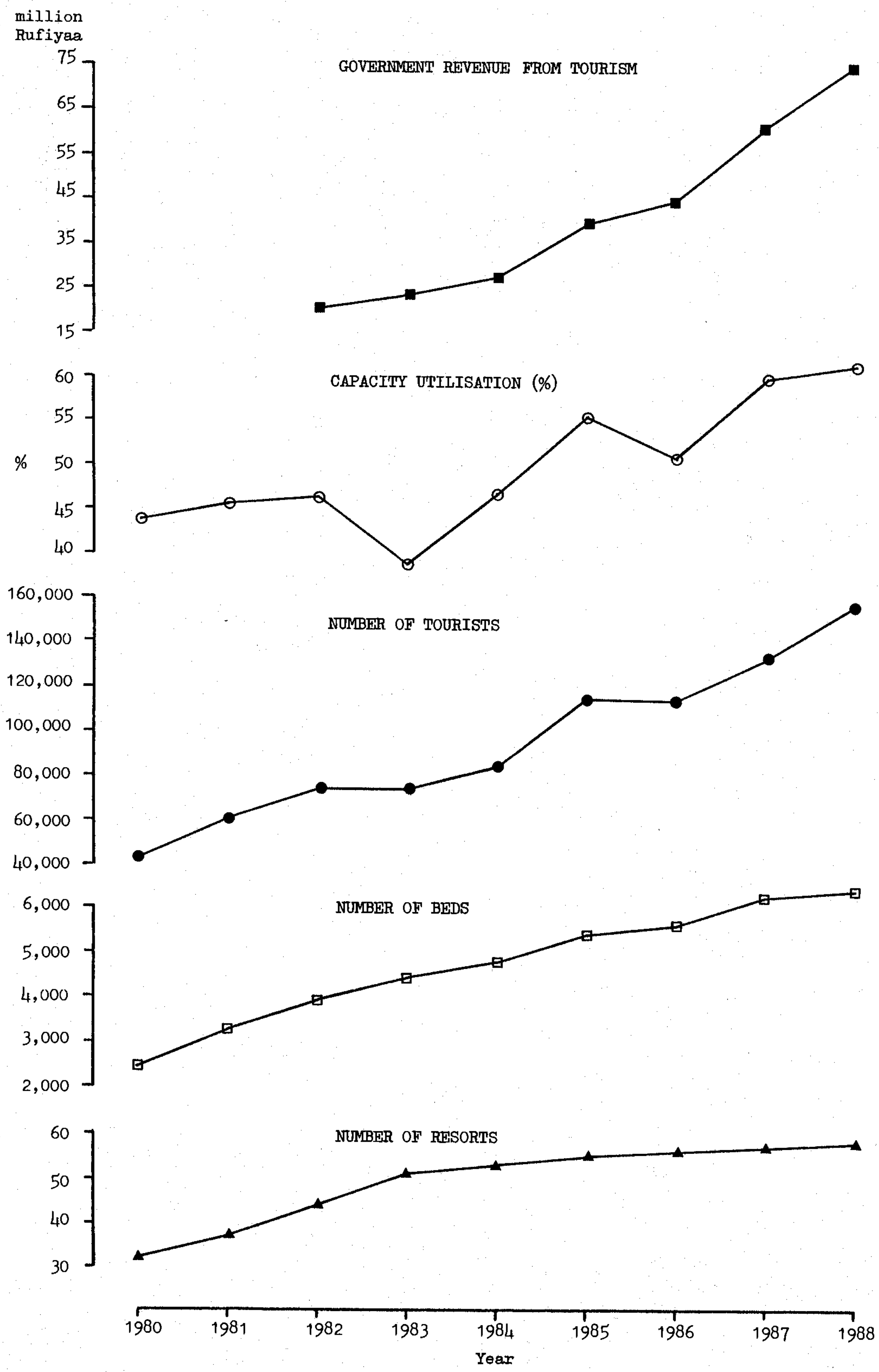


FIGURE 17. Development of tourism from 1980-1988. Compiled primarily from Ministry of Planning and Development Statistical Yearbooks 1985-1988.

resources of their islands. In addition a bed tax of $6 per night is levied for each tourist.

Provisional figures for 1988 indicate that 63% of the government revenue from tourism was derived from the bed tax (tourism tax), 33% was derived from lease rent, only 2.7% from land rent and the remainder from other sources. The total revenue from tourism in 1988 was Rf 74.3 million, equivalent to approximately US $8.25 million at an exchange rate of Rf 9 = US $1.00.

The Ministry of Tourism have a set of guidelines for resort development. These guidelines specify the maximum percentage of the area of an island which can be devoted to accommodation, the percentage which can be occupied by central facilities, the minimum beach length per bungalow, etc. The carrying capacity of each island is thus effectively (if arbitrarily) dictated and all plans for development have to be checked by the Office for Physical Planning and Design to ensure they satisfy the guideline criteria.

The Ministry of Tourism is well aware of the fragile nature of the small island environments and strongly discourages developments which may damage the coral reef or interfere with water movements around islands. New developments are required to have desalination plants to prevent groundwater depletion and several have saltwater flushing sewerage systems. Unfortunately a number of early resort developments were subject to little control and less enlightened management and many examples of groynes and jetties built of coral, severely depleted groundwater resources and reef damage exist. Few tourist islands treat their sewage but the small volumes of sewage from most resorts can probably be safely discharged untreated if discharge pipes are correctly sited.

Tourism is vital to the Maldivian economy and clearly any threat to this industry as a result of rising sea-level will be a major concern. Tourist islands tend to be be small and low and thus are likely to be particularly vulnerable to rising sea-level. In addition, their lifeline to the outside world - Male' International Airport - is only about 0.5 m above highest high water level. This sector of the economy should thus be of prime concern in studies to gauge the likely effects of sea-level rise. At present all that can be said is that serious problems are not anticipated for more than 20 years so the investment potential remains good.

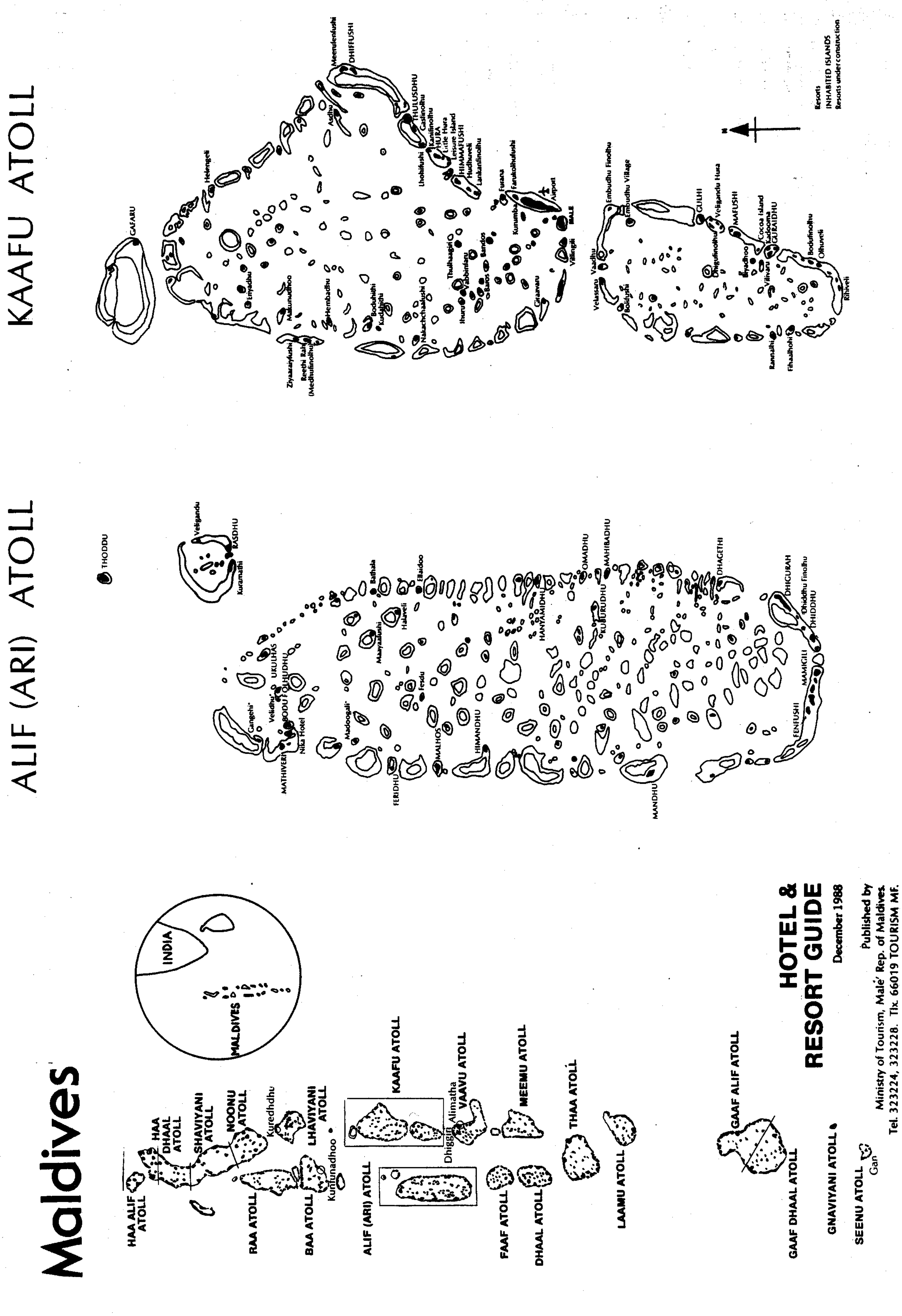


FIGURE 18. Location of tourist areas within the Maldives and location of tourist resorts within Kaafu and Alifu. (Ministry of Tourism)

2.10. Airports

There are three airports in operation and one under construction in the archipelago. The principal airport is Male' International Airport on the island of Hulule about a kilometre from Male'. The two provincial airports in operation are Gan in Addu (Seenu) built by the British originally as an RAF base and Kadhdhoo in the south-east of Laamu which was formally opened in 1986. The fourth airport, at Hanimaadhoo in Haa Dhaalu in the north of the archipelago is under construction at the moment.

The Maldives Airports Authority (MAA) run Male' International Airport but only provide air-traffic control and fire services to the other airports. Gan airport is run by the Addu Development Authority and Kadhdhoo is run by the State Trading Organisation as will be Hanimaadhoo. The Civil Aviation Authority is responsible for setting the standards of operation and ensuring compliance with international aviation conventions.

We were unable to obtain data on the heights of the Gan and Kadhdhoo runways above MSL or the proposed elevation of the Hanimaadhoo runway. However, data on Male' International Airport were available. This airport is the gateway to the Maldives for tourists and in 1987 the airport handled about three aircraft a day (1170 over the year) taking about 140,000 people both in and out of the Republic. The airport also handled about 3,000 tonnes of freight and almost 50 tonnes of mail and is clearly a key installation as far as the economy is concerned with at least 30% of government revenue dependent on its continuing operation.

A detailed survey of the coastal area and shore of Hulule has been conducted by Kocks Consultants Gmbh. of Koblenz, Federal Republic of Germany. Their survey was conducted with respect to a datum at approximate Lowest Low Water (LLW) set at 100.00 m. A benchmark was made at 102.11 m marked by a circular concrete monument 30 cm in diameter. Ground level nowhere appeared more than about 1.7 m above highest high water level. The height of the runway is 1.2 m above mean sea-level and thus has only about 0.5 m clearance at highest high water (Figure 19). The total investment in the airport to date is estimated at almost Rf 200 million.

The runway length is 2840 m and width only 45 m. There are two 7.5 m wide hard shoulders of coral boulders covered in asphalt to give the 60 m width needed by large jets. However, the outer jet-engines of Boeing 747s tend to blow these apart and they have to be patched regularly with concrete.

LANDING CHART-ICAO

04°11'29"N
073°31'59"E

MALE'/ International
MALDIVES

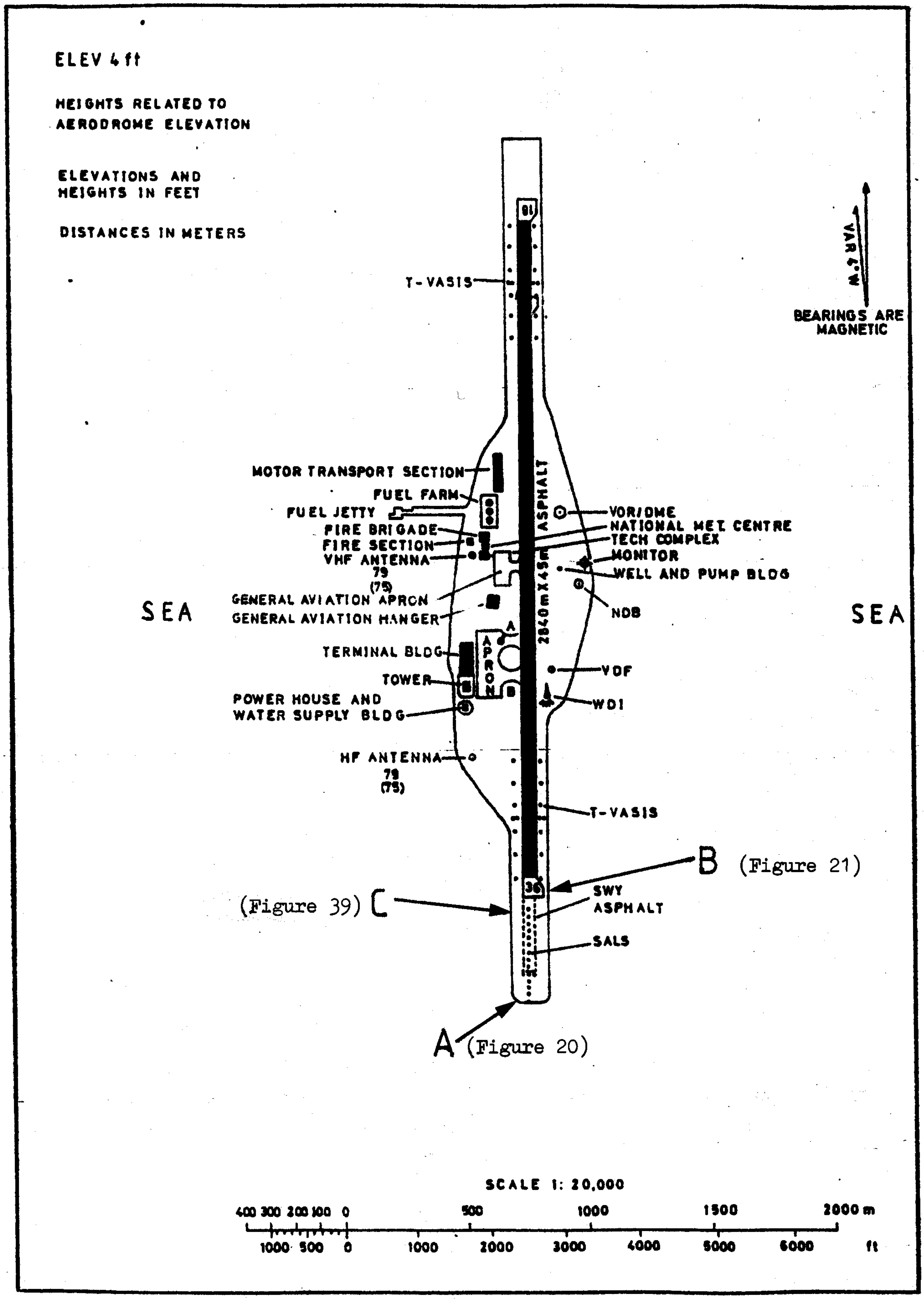


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FIGURE 19. Hulule Island and Male' International Airport. (Source: Maldives Airports Authority).

The retaining seawall is even now not particularly effective and on relatively calm days at high water wave run-up and overtopping can occur (Figure 20). The edge of the turning apron and hard shoulders are lapped by the sea at high water in several places (Figure 21) and on the north-east end which is comparatively sheltered the retaining wall consists of loose piled coral blocks.

Upgrading the sea-defence of such a long thin island is a considerable undertaking and likely to be expensive (probably a minimum of $ 2-3 million just to ensure secure sea-defence to the year 2000). However, the island is of porous coral rock and as sea-level rises so will the water table (be it a freshwater lens or saltwater seepage). Thus at some stage it seems likely that the whole runway will need to be raised. This may not be for 50 years but even now this eventuality should be included within development plans as this future need may impose constraints on the siting of other developments at the airport. Decentralisation to reduce the economic dependence on Hulule should perhaps also be considered.

2.11. **Industry**

Two notable successes in industrial development have been the fish processing and canning factory at Felivaru (Noonu) and garment manufacturing on Gan (Seenu). These are part of the drive to diversify the economy, reduce its dependence on tourism and make better use of the fish resources. Canned fish now form 13.4% of exports by value and garments form 39.3% of exports by value.

From the point of view of sea-level rise the localisation of major investment facilitates protection should this become necessary and makes sea-defence more cost-effective. Investment in the Felivaru complex is estimated at $ 80 million. We have no data on the vulnerability of this investment to sea-level rise. For future industrial or other infrastructural investments the siting must be carefully considered with sea-defence in mind. Also the impacts of construction should be carefully assessed to ensure that poor environmental planning does not put the investment at risk.

FIGURE 20. Retaining wall at south end of Hulule (marked A on Fig. 19) on a relatively calm day at high tide. Even in these conditions spray splashes over and water pools on the inside.

FIGURE 21. Retaining wall by south turning apron of Male' International Airport runway (marked B on Fig. 19). The toe of the wall is eroded so that seawater passes underneath at high tide, lapping right to the runway edge.

2.12. Groundwater

Groundwater is one of the central natural resources of the Maldives. It is rain derived and on small islands in particular is an easily over-exploited resource. Once exhausted it may take decades to re-establish groundwater of reasonable quality. Most of the data on groundwater relates to Male' (Binnie & Partners, 1975; 1986; 1987).

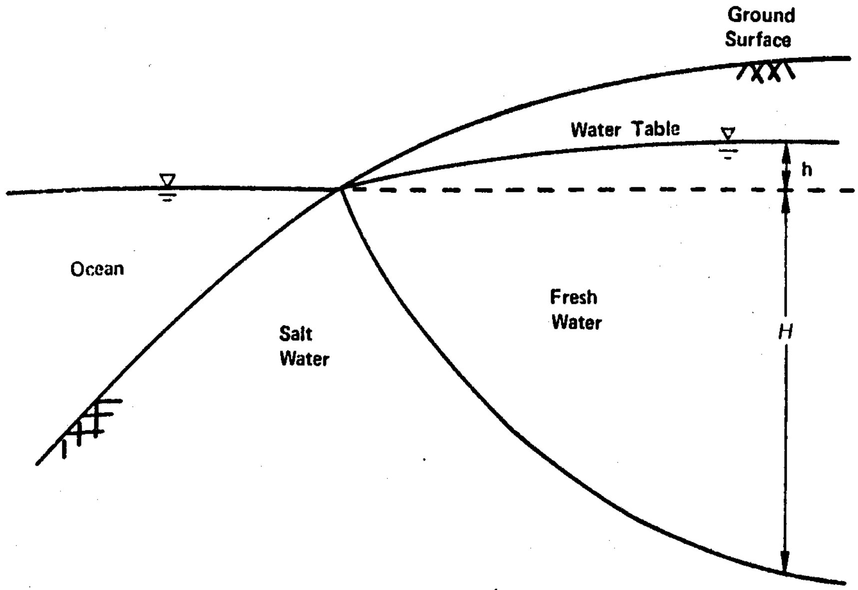


FIGURE 23. Simple density balance view of a coastal aquifer. $1.025 \times H = 1.0 \times (h + H)$ or $H = 40 \times h$.

The groundwater is in the form of a freshwater lens which effectively floats on top of the seawater which permeates the porous coral rock, coral sand and coral rubble which make up the islands. On smaller islands and particularly at sites near the coast the freshwater lens (water table) goes up and down with the tide though its oscillation lags behind the tidal one and is progressively damped as one moves away from the sea (Figure 22). Taking Well 21 in Figure 22 as an example, one finds the mean water level there is 0.4 m above mean sea-level during the same period. Assuming a simple density balance as predicted by the Ghyben-Herzberg principle (Figure 23), where h = 0.4 m then H should be about 16 m. Such a depth for the freshwater lens at this fairly central well in 1974 would have been approximately correct. This simple principle may provide a cheap way of estimating lens sizes from well-level:sea-level differentials.

Source: Binnie & Partners (1975)

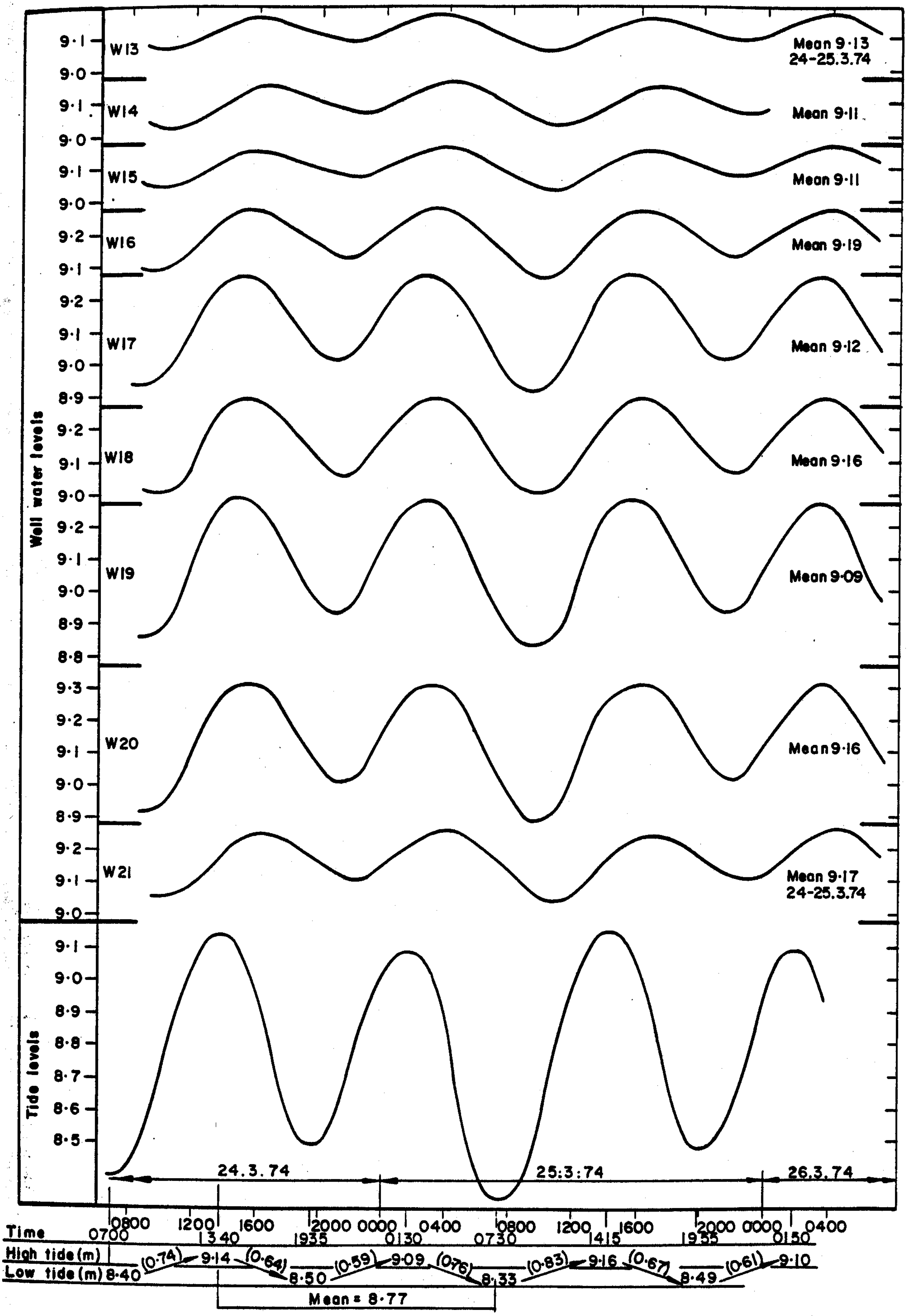


FIGURE 22. Tidal oscillations of water levels in 9 wells on Male'. The time lag and damping is progressively greater as one moves further from the sea. Mean well water-levels are 0.3-0.4 m above MSL.

Probably the least of the problems facing groundwater resources is sea-level rise. With adequate recharge, as sea-level rises so should the water table. On Male' the water table is generally less than 1.2 m below ground level and rising water tables may create problems, particularly in urban areas. One might expect some saltwater intrusion along island rims and relative to ground-level there will be a decrease in the depth of the transition zone between the freshwater lens and underlying saltwater. However, in the medium term these problems are minor in comparison to the damage to groundwater resources caused by excessive extraction. On Male' and on several of the early resort islands groundwater is fast becoming saline or is largely so already. Groundwater resources over a considerable part of Male' are expected to become too saline for drinking purposes by 1990.

In the southern atolls where rainfall is higher the groundwater quality tends to be better whilst in northern atolls where the effects of the dry NE Monsoon are felt most strongly (Section 2.6.2) many wells become brackish then but produce good water during the wet SW Monsoon. The seasonal effects could become more pronounced in the event of global warming but the situation is not clear and will only be revealed by long term monitoring.

There is a clear need for groundwater management and for establishing what the maximum sustainable extraction rates are for inhabited islands, particular those selected for development. On Male' various steps have been taken including 1) collection of roof rainwater for drinking in house water tanks with excess being fed to soakaways to recharge the aquifer, and 2) development of concrete roads with drainage to soakaways to replace impacted earth roads where rainfall collected in pools and evaporated.

Without groundwater management the alternative is desalination plants. One 200 m^3 per day plant has been built with DANIDA help on Male' at a cost of Danish Kroner 4,169,139. It uses 26 litres of diesel per hour to produce 8.4 m^3 of water using the reverse osmosis process. Diesel currently cost Rf 3 per litre. To bulk commercial users water is sold at Rf 50/m^3 at what is considered an economic price (covers costs such as depreciation of plant and manpower as well as fuel). A 1200 m^3 per day multi-effect desalination plant is planned. It is intended that this plant will make use of waste heat from a new generating station.

Between 1983 and 1986 it has been estimated that 560,000 m^3 per year of groundwater were extracted on Male'. At economic prices this was worth Rf 27 million per year (cost of replacement with desalinated water). Other groundwater resources should be considered in this light before deciding to sacrifice them.

3. SEA-DEFENCE AND COASTAL ENVIRONMENTAL PROBLEMS

3.1. Background

The natural sea-defences of the Maldives are the coral reefs which surround the islands and, to a lesser extent, the mangrove and other vegetation which help to stabilise sediments at the shoreline on some islands. The reefs absorb most of the energy of incident waves and provide often extensive areas of shallow waters around islands and at the atoll rims which restrict the heights of waves which can reach the shores of the islands. Typically the coral reefs are covered by about 1.0 m of water at high tide. The energy of a wave is a function of wave height and increases as the square of wave height. Thus a wave of 1.0 m height carries four times as much energy as one only 0.5 m high.

Where population pressures have led to extensive coral mining (Section 3.3) or reclamation (Section 3.2), the coral reef is severely degraded and up to 0.5 m lower than it would otherwise have been. From the point of view of the energy of the waves breaking on the shore this lowering of the reef by 0.5 m is equivalent to a mean sea-level rise of 0.5 m. As an example of the effects of such a change, if a reef flat was covered by 1.0 m depth of water at high water before mining and now has 1.5 m depth of water over it at high tide then the wave energy at the shore will be about 2.25 times what it was before it was mined. With increasing wave energy, sea-defence structures need to be commensurately stronger and therefore cost more. There are thus indirect but tangible economic costs (on top of the environmental ones) associated with severe reef degradation, be that degradation a result of coral mining, sedimentation caused by dredging activities, dynamiting of channels or sewage pollution.

Coral reefs essentially provide offshore sea-defence. In a rising sea-level environment there is reason to hope that the reefs will respond by upward growth of up to 10-12 mm per year and thus continue to provide useful offshore sea-defence for 50 years or more (Section 1.3). They can clearly only do this if healthy. In addition the continuous erosion of the growing reefs generates sediment which will tend to be deposited inshore and ensure that lagoon floors will also accrete and beach profiles will be maintained.

On the shores of the islands themselves (particularly those suffering from population pressures and exceeding their natural carrying capacity) where valuable infrastructure is located close to high water, a second level of sea-defence is often needed such as seawalls and retaining walls. The size and cost of these is determined by how much wave energy has been absorbed offshore.

On the whole the sediments on the shore will be in dynamic equilibrium with those just offshore in the lagoon areas and may migrate on and off the beaches and back and forwards along the shore with seasonal changes in mean sea-level and monsoon wind directions. These processes, or at least their effects, are well-known to islanders and resort operators and underline the delicate dynamic balance which maintains the integrity of the islands. Unfortunately, any disturbance to the dynamic equilibrium which acts to trap sediment at particular locations or causes net loss of sediment to the system, for example, construction of groynes, solid jetties, solid helicopter pads in lagoons, solid causeways, or extension of natural coastlines by reclamation, tends to upset the balance and lead to net erosion at some point on the shoreline.

3.2. Reclamation

Minor reclamation has been carried out on a few islands, usually when they have become crowded (e.g. Thulhadhoo, Baa). The substantial reclamation on Male' is an interesting case history which is worth examining.

The original size of the island (1951 coastline) was 108 ha. By 1979 some 15 ha, principally on the western side had been reclaimed (Figure 24). During the 1970s an acute housing shortage developed on Male' and also the need for space to construct schools, a new hospital, a power plant, etc. In 1979 the Male' Land Reclamation Project was officially launched with the target of reclaiming the lagoon and inner reef area on the south (exposed) side of the island to add another 60 ha. This involved dredging and blasting to produce approximately 905,000 m^3 of infill. Some of the blasted coral rock was used to construct a breakwater along the outer reef. The reclamation was entirely Maldivian government funded, was carried out over 8 years, and cost a total of Rf 47,115,000 (Dept. of Public Works & Labour, 1986). Using the exchange rates prevalent at the time the cost of the reclamation was about US$ 8.25 million or $ 137,500/ha.

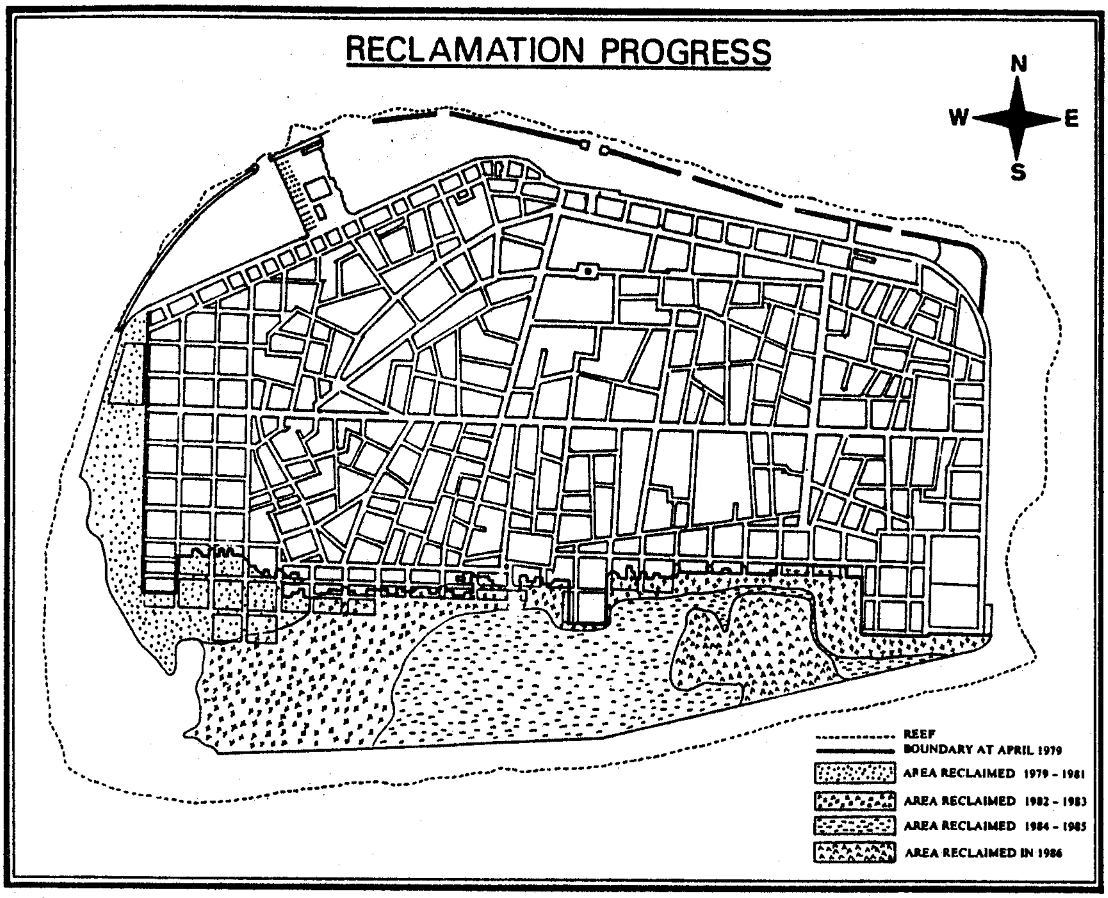
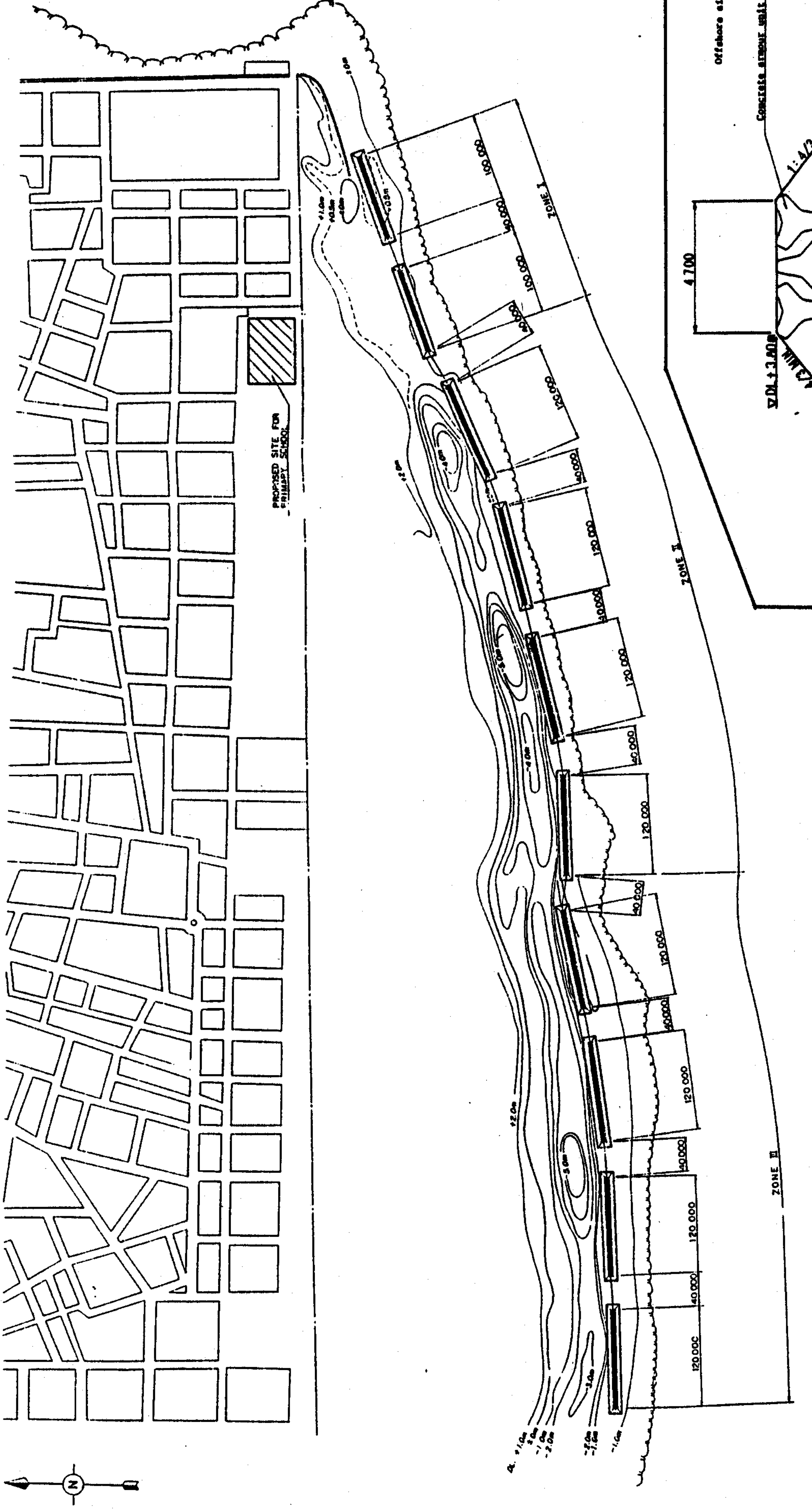


FIGURE 24. Progress of reclamation on Male'. (Source: DPWL, 1986).

A significant amount of infill was lost during three days of high waves in April 1987 and the coral boulder breakwater was more or less destroyed. The Japanese International Cooperation Agency (JICA) agreed to build a series of detached breakwaters. These were constructed either entirely of 3 tonne tetrapod armour units or with coral rock cores with 3 t tetrapod armouring (Figures 25-27). The cost of this protection for the reclaimed area, which is being born by JICA, is about $ 12 million. The total length of coast protected is 1.52 km which works out at $ 7,895/m. This figure incidentally provides an upper limit estimate for a shadow price for coral reefs in respect of their sea-defence service.

Any substantial reclamation is likely to entail sea-defence costs and if these are included in the costs for Male' reclamation (the sea-defence is primarily necessary because of the reclamation) the cost per unit area becomes $ 337,500/ha. The Ministry of Public Works and Labour estimate the average cost of reclamation at Rf 14,000 per plot (2000 ft^2) which roughly equates to $ 132,000/ha.



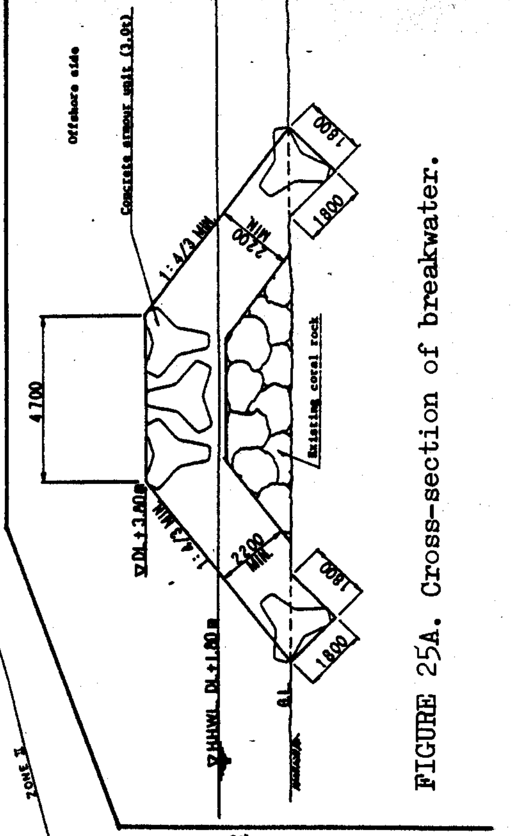


FIGURE 25A. Cross-section of breakwater.

FIGURE 25. Arrangement of detached breakwaters on the south coast of Male'. Retaining wall for reclaim lies approximately along DL 0.0 m.

FIGURE 26. Face on view of one of the ten detached breakwaters on the south coast of Male' to show arrangement of the 3 tonne tetrapod armour units.

FIGURE 27. Detached breakwaters on south-east side of Male' with retaining wall for the reclaim on the left.

A few plots of land on Male' are apparently still in private ownership and provide an indication of a market price for land. This is reported to be about Rf 200,000 per plot (2000 ft^2) which is equivalent to $ 720,000/ha. There is perhaps a premium attached to such a rare commodity as privately owned land.

In the absence of a market, since land is owned by the government, these figures can perhaps provide a basis for assigning a value to land on Male'.

3.3. Coral mining

The corals of the reef flat not only act as the natural offshore sea-defence and as a habitat for baitfish but are also the primary source of building material. Coral extraction in North Male' Atoll has been comprehensively reviewed by Brown & Dunne (1986, 1988).

Coral is used not only in buildings (Figures 28 and 29) but also as hardcore in road construction. Its use has accelerated as the country has developed and the population has rapidly grown. Coral and sand mining account for just under 2% of GDP.

Estimates of coral extraction in North Male' Atoll for 1980-1985 are summarised in Figure 30 and the projected needs of the atoll in the absence of alternative materials are shown in Figure 31.

The principal problem with coral extraction is the way in which it is done. It is removed from the shallow reef flat (1-2 m water depth) using iron bars to break up the living coral into lumps of manageable sizes. This activity is primarily performed by the islanders of Maamigili (Ari Atoll) and strips approximately the top 0.5 m of reef away leaving a bare relatively smooth surface. Using the figures of Brown and Dunne (1986) the yield from one hectare of reef flat can be calculated to be about 500-750 m^3 (not all the reef flat is suitable). The method seems to ensure the maximum destruction of coral reef resources for the minimum return in coral and in a country so reliant on healthy coral reefs this is of serious concern. An additional problem is the poor recovery of some mined reefs, for example, a reef mined almost 20 years ago near Male' anchorage shows almost no sign of recovery.

FIGURE 28. A pile of coral blocks mined from the reef flat at a building site in Male'. An internal coral wall is in the process of being built from broken up pieces of these blocks.

FIGURE 29. Close-up of a coral built wall. Note the large quantity of mortar required to bind the irregular coral nodules together.

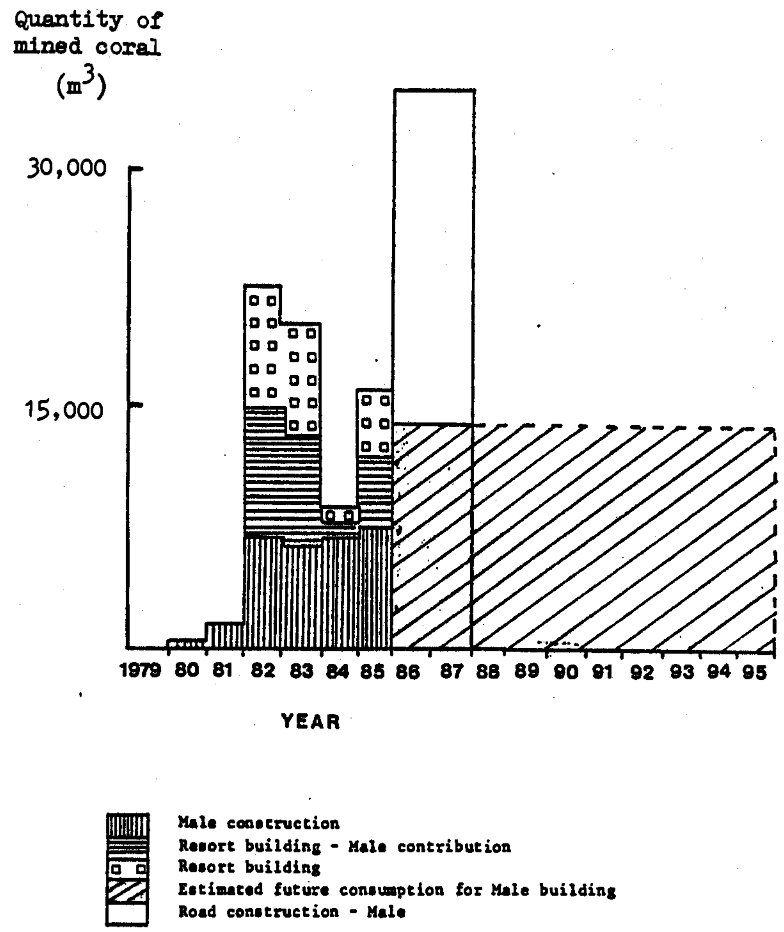


FIGURE 30. Coral extraction in North Male' Atoll 1980-1995. (After Brown & Dunne, 1986)

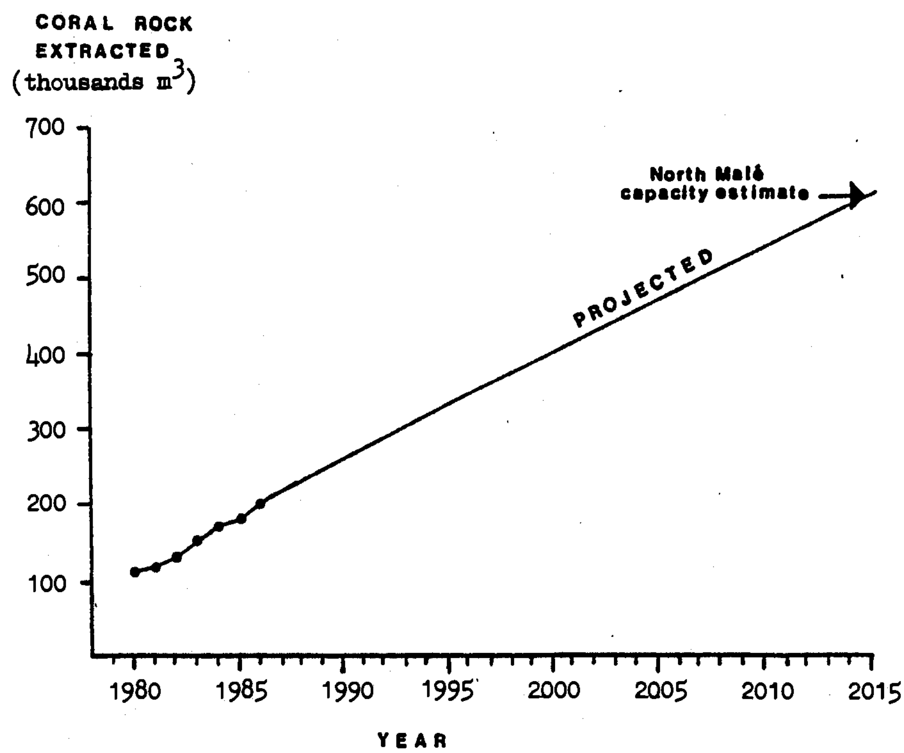


FIGURE 31. Projected coral rock needs of North Male' Atoll with an estimate of the capacity if current mining techniques continue to be used.

Two solutions to the problem were proposed by Brown & Dunne (1985):-

(1) Establish a carefully regulated hollow concrete block manufacturing industry. A concrete block making plant was successfully established in Gan (Addu) by the British in the 1950s to provide the materials to construct the RAF base. In order to manufacture blocks of adequate strength the sand:cement mixture must be 3:1 for outside foundation blocks and 5:1 for blocks which will be faced (Berenschot-Moret-Bosboom, 1980). In addition coral sand must be thoroughly washed to remove salt impurities and groundwater used must not be saline. Blocks should also not be allowed to dry too quickly. A study by the Architectural Section of the Office of the President indicated that hollow concrete blocks were cheaper than coral nodules in all building uses (on average 80% of cost).

(2) Blasting and dredging of a single faro (submerged reef). An average size faro of about 30 ha would yield about 1.5×10^6 m^3 of coral rock if dredged to 15 m, or 10 million m^3 if dredged to the lagoon floor. The 60 m wide rim of such a faro would yield only 5000-7500 m^3 of coral if mined by traditional means. In terms of pure natural resource utilisation efficiency the yield per unit area of destruction is improved by up to 1000 fold and the projected demand (Figure 31) of coral rock for a century or more is satisfied for the loss of one faro (rather than the stripping of all suitable reef flats in N. Male' Atoll!). The increased sea-defence needs due to sea-level rise will probably substantially increase projected demand for coral rock.

The feasibility of this latter approach has yet to be determined but is under active consideration by the British Overseas Development Administration.

3.4. Causeways, jetties and erosion problems in Addu

During the period when the British Royal Air Force operated from Gan, piled causeways were built to link the islands of Gan, Feydhoo, Maradhoo, Hankada and Hithadhoo. Between 1965 and 1969 the piled causeways between Hithadhoo and Feydhoo were progressively replaced with solid coral-rock filled causeways which blocked water flow between the islands and caused several several north-east facing beaches to erode (Kenchington, 1985). In 1982 construction of a solid causeway between Gan and Feydhoo accelerated erosion.

Accompanying the erosion of Feydhoo (Figure 32), Maradhoo and Gan there has been accretion on the north-east of Hithadhoo and on the open ocean sides of the blocked channels between islands (Figure 33). The south-west facing coast of Maradhoo suffered quite extensive flooding in 1984.

Kenchington (1985) discusses the problem in some detail and recommends re-establishing piled causeways which will not obstruct current flows between the islands. It is understood that the Addu Development Authority will be submitting a proposal to replace the solid causeways by box culvert or piled structures and that the British government may help with implementation. Such action should stop or at least slow down further erosion. The costs for the four box culvert/concrete slab causeways are estimated at Rf 23 million for 9 m roadwidth and 1 m walkway or Rf 13.5 million for 4.5 m roadwidth and 1 m walkway. Costs for the same options but using encased steel pile instead of box culverts are estimated at Rf 17 million and Rf 12 million respectively.

In addition to erosion/deposition problems the reduced water exchange between the atoll lagoon and open ocean has led to a dramatic decline in the availability of species used for live-bait and also to coral degeneration.

Construction of solid jetties on Hithadhoo, and at Meedhoo and Hulhudhoo (in the north-east of the atoll) have led to accretion around the jetties as they act to trap sediments. The filling up of Hulhudhoo harbour with sand has been accompanied by erosion of the southern part of Hulhudhoo (Kenchington, 1985). The recommendations of Kenchington (1985) for replacement of solid jetties by piled ones should be implemented as soon as the money can be found.

Causeway construction in Laamu has caused similar predictable problems (Oakley, 1988).

3.5. **High waves and flooding**

Various incidents of high waves and associated flooding have occurred in the Maldives in recent years. The first such event was on 10th-12th April 1987 and caused significant damage to the capital Male', the international airport at Hulule, and to Gulhi, Guraidhoo, Thulusdhoo, Dhiffushi and resort islands on the south-east facing sides of North and South Male' Atolls. The total cost to the Maldives of repairing the damage caused by the April 1987

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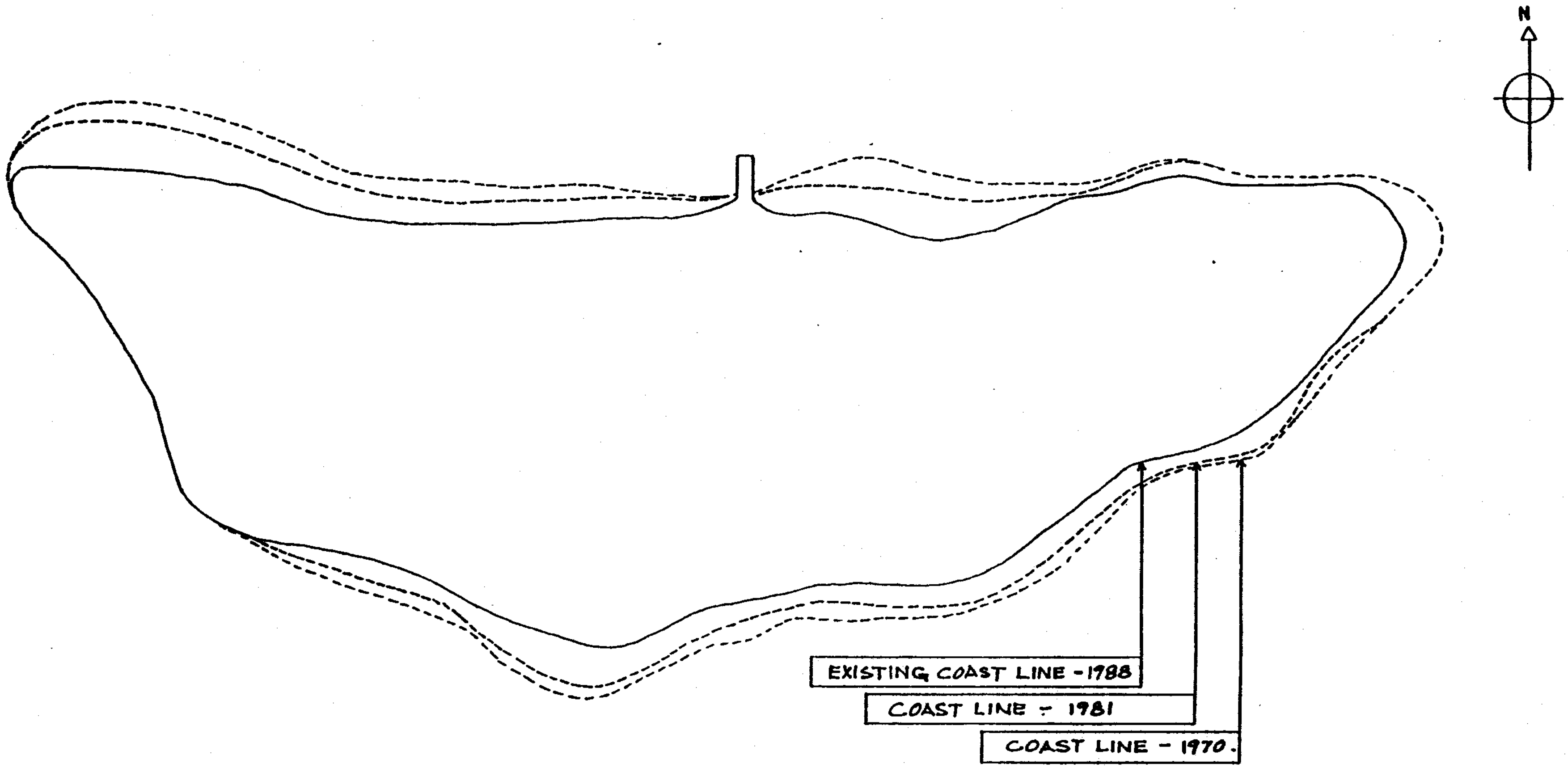
FIGURE 32. Map of Feydhoo, marking the coastlines. 1970, 1981 and 1988.



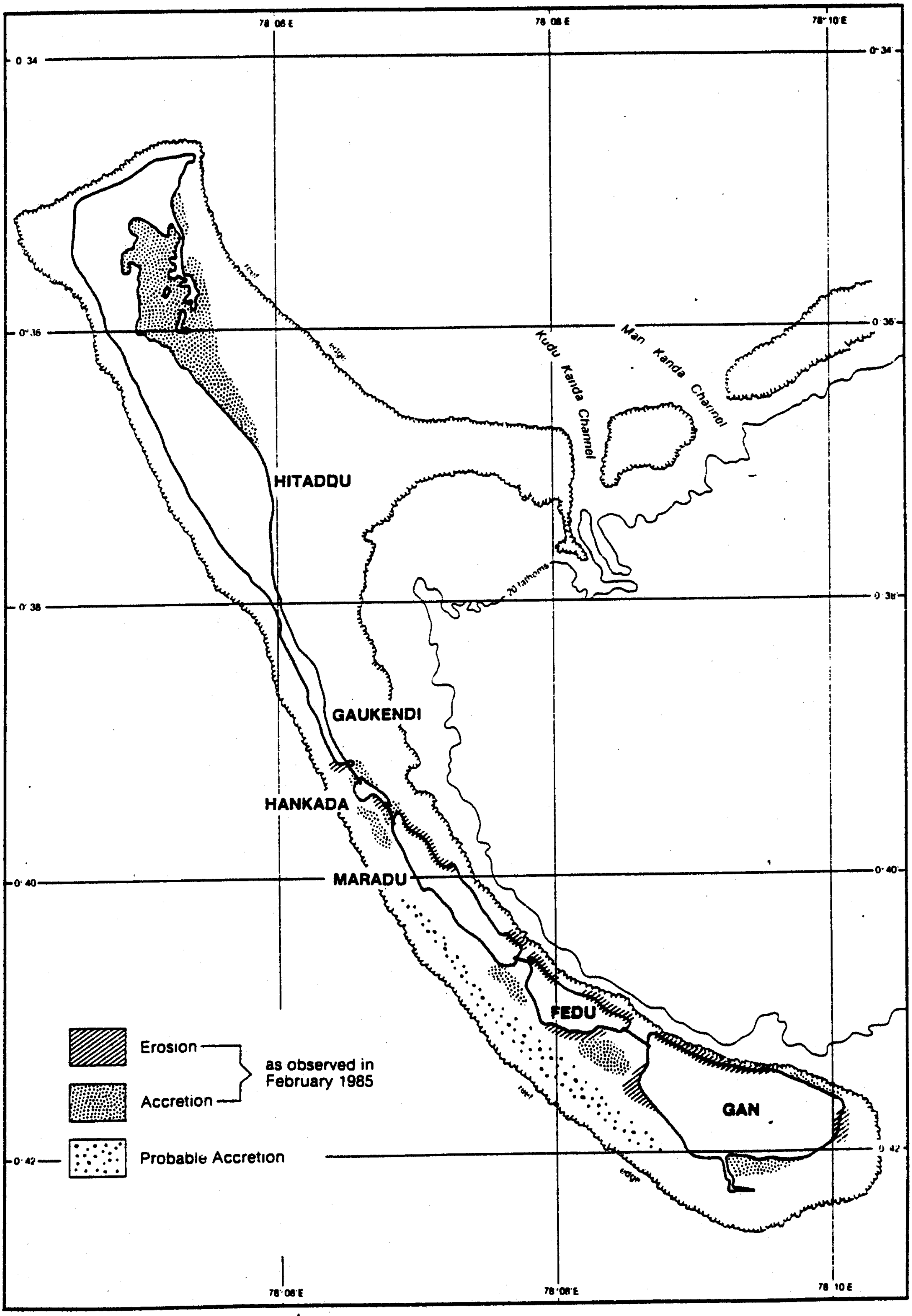


FIGURE 33. Erosion and accretion problems in Addu Atoll. These are largely a result of the construction of solid causeways between islands. (Source: Kenchington, 1985).

waves has been estimated at Rf 90,976,730.

3.5.1. Male' damage (April 1987)

On the sheltered north side of the island the breakwaters (coral rock cemented with concrete) were damaged particularly at the ends at the entrances to the harbours. On the southern and south-western side of the island the loose coral boulder breakwater which was built to protect the reclaim area was more or less destroyed. On the eastern side the containment wall was partially destroyed (van der Weele, 1987). In addition some walls and houses on the seafront were destroyed or severely damaged, and a significant proportion of the reclaimed area on the south side of Male' was washed out to sea (Figure 34, 35).

The exact extent of the loss of reclaimed land is unclear. Van der Weele (1987) suggested 300,000 m^3 of material was lost and JICA (1987) suggested 360,000 m^3 were lost. The total amount of material used in the reclaim is estimated at 906,240 m^3 so these losses would represent 33-40% of the reclaim, equivalent to a loss of approximately 19-23 ha (assuming a fairly even thickness of material laid across the reef flat. MPWL sources suggest that these estimates may be rather high and that losses were in the order of 10-20%. Van der Weele (1987) estimated the costs of breakwater repairs and rebuilding at $ 5 million.

3.5.2. Hulule damage (April 1987)

The south end of the runway was partly flooded and many of the approach landing lights ($ 100 each) on the southern end were damaged. The protective containment walls on the southern and eastern side of the runway were either destroyed or severely damaged. On the western side the breakwater protecting the harbour was badly damaged as was the oil jetty. Almost 4000 m of containment wall and breakwater required renewal (van der Weele, 1987). Estimated costings for this work were $ 4.5 million.

3.5.3. Causes of the April 1987 damage

The cause of the damage has been investigated by Goda (1988) and Merrill, Olsen and Wimbush (1988). Goda (1988) suggested that a storm in the south-east Indian Ocean about 4000-5000 km south-south-east of Male' on April 4th-7th generated the waves (Figure 36). His predictions indicated that the storm would have

FIGURE 34. Edge of the reclaim area on southern Male' Island, showing damaged retaining wall, lost infill and work in progress on the construction of the detached breakwaters to protect the reclaim.

FIGURE 35. South-west coast of Male'. This area will eventually be protected by the breakwater enclosing the proposed port here. Currently, shore protection is provided by these sacks of coral rubble.

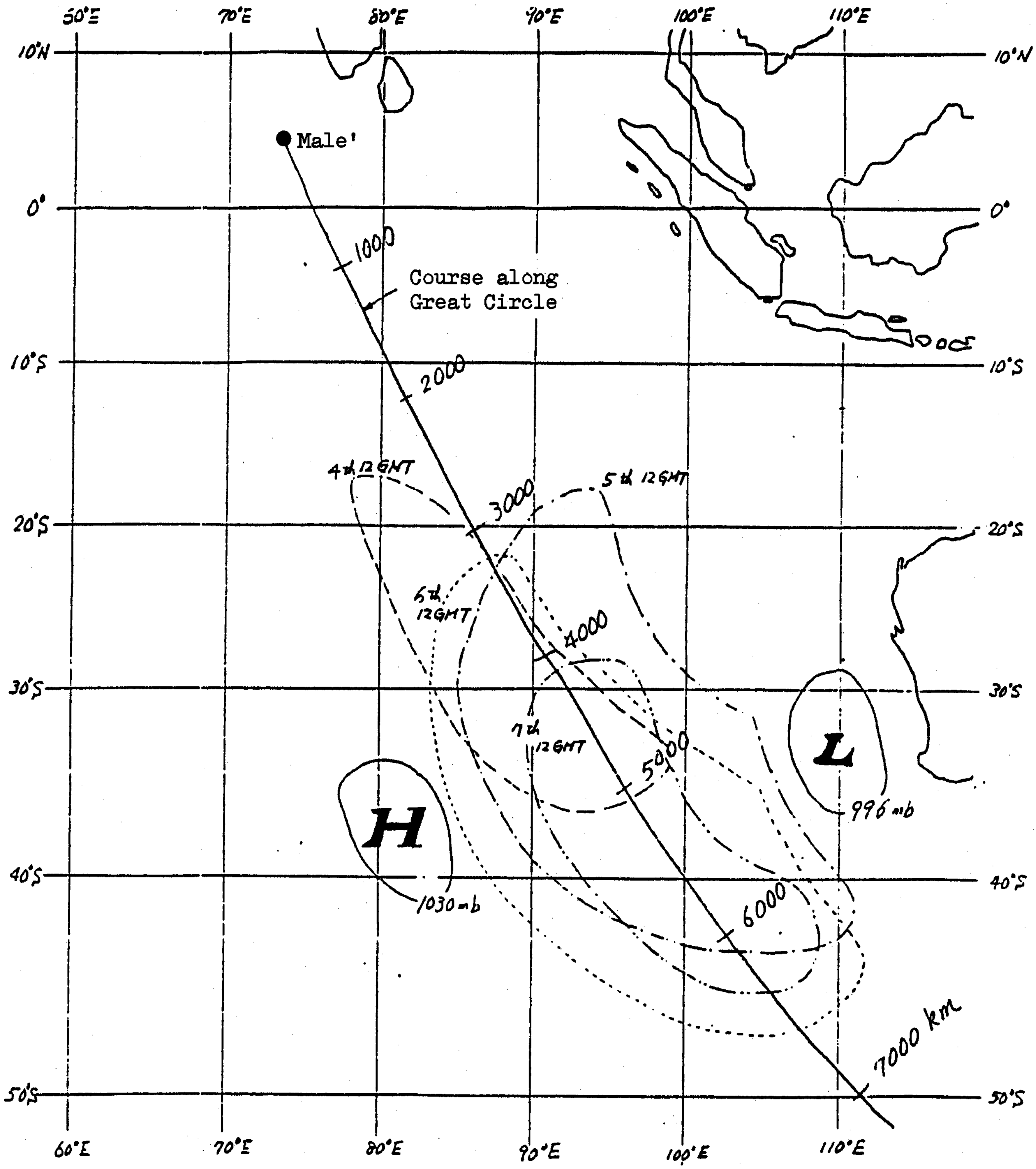


FIGURE 36. Possible source of high waves which damaged Male' on 10th-12th April 1987. (Source: Goda (1988)).

generated a swell of about 3.0 m peak significant height and about 16 second period at Male' on 10th-12th April.

Estimates of the maximum wave heights at the time were 2.5-5.0 m and periods of 9-11 s and 14 s were estimated from video footage (van der Weele, 1987; JICA, 1987). An estimate of probable wave setup for 3.0 m waves on the south coast of Male' would be about 0.75 m (using same method as JICA, 1987). Tides at the time were normal (Figure 13) rising to only about 0.4 m above MSL but wave setup of 0.75 m would cause a highest high water level inshore of about 1.15 m above MSL. At high tide this would have been adequate to cause the flooding observed and would reach the level of the trace marks (labelled A, B and C on Figure 37) reported by JICA (1987) at about 1.09-1.22 m above MSL.

Basically the reclaim is only 0.7-1.0 m above MSL and had poor offshore sea-defence. As such it was prone to inundation at the first set of adverse sea conditions. The original south coast was only built on at elevations over 1.0 m above MSL and had up to 250 m of coral reef and a lagoon to protect it.

Reclamation has also extended parts of Hulule Island beyond its natural coastline. It is low-lying and the areas flooded were within 1.0 m of MSL. Even on a fairly calm day at high water, modest swell waves can throw spray over the south end retaining wall (Figure 20).

3.5.4. June-July 1988 damage

In June-July 1988 there were reports of flooding and wave impact damage principally on the western side of the archipelago (Pernetta & Sestini, 1989: Figure 19). Among islands impacted was Thulhaadhoo (Baa, 6 ha, population 1487), an overcrowded island where reclamation has occurred.

During the SW Monsoon on 2nd July 1988 at around high water the southern (reclaimed) part of Thulhaadhoo was flooded for up to 30 metres inland and 32 houses had to be evacuated. About 3-5 m of land was lost at the beach on the south side. The flooded area appears to have been only about 0.7 m above MSL and about 0.2 m above the high tide of the day (Lanka Hydraulic Institute Ltd, 1988c). Swell waves of 2.0-2.5 m height were breaking at the time and a combination of wave setup of 12-15 cm and wave mass transport across the reef giving a rise of up to 15-20 cm, riding on the back of the high tide would account for the flooding observed. Protection of the shore was by an unconsolidated wall

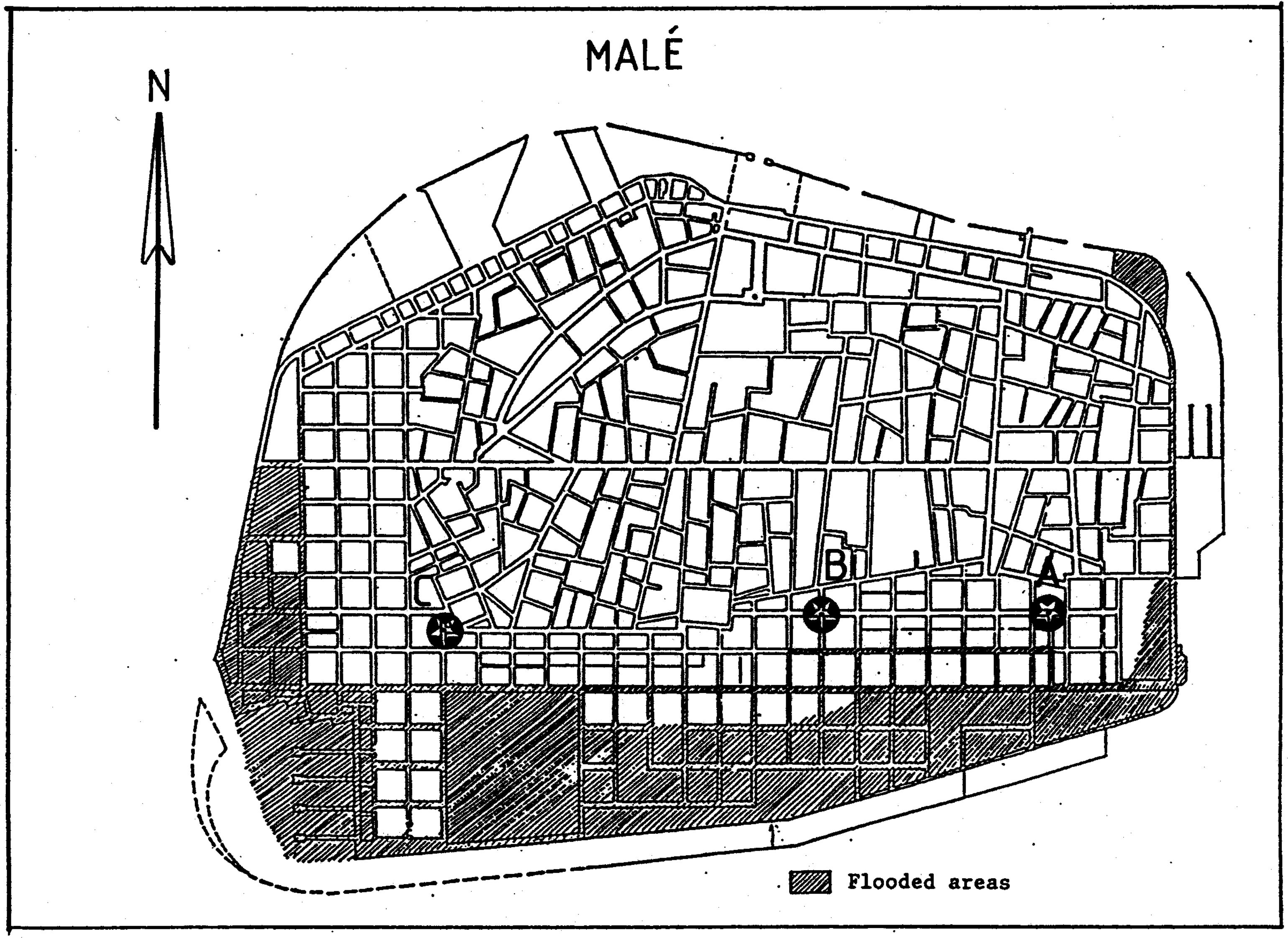


FIGURE 37. Areas of Male' flooded in April 1987. Points A, B and C mark the highest spots where flood traces were found by JICA (1987), these points are 1.02–1.22 m above MSL.

of coral blocks.

Thulhaadhoo has a history of instability and following storms in 1896 and 1898 was reduced to half its previous size (Gardiner, 1903). The highest point measured by Woodroffe (1989) was about 1.35 m above MSL (Figure 38). This island appears to be barely tenable at the moment and would be difficult to defend in the face of rising sea-level.

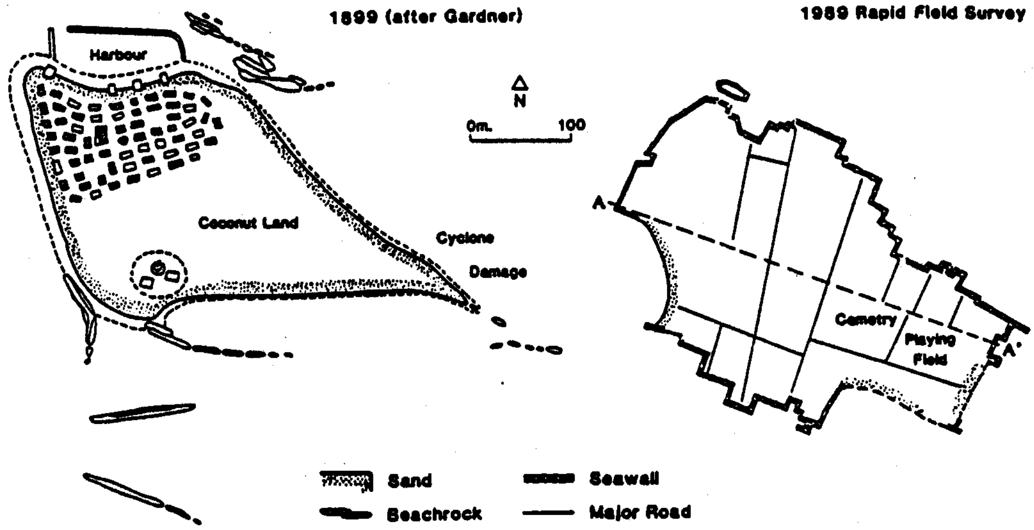
3.6. Costs of seawalls of local construction

Local seawall construction is done primarily by coral miners from Maamigili Island at the south end of Ari Atoll (Alifu) who supply their own coral material. They work under the direction of the Ministry of Public Works and Labour (MPWL). They are paid Rf $4/ft^3$ (Rf $141/m^3$) of wall built and are provided with cement (Rf 60/50 kg), sand (Rf $2/ft^3$ = Rf $70/m^3$) and gunny bags to form the wall base. The latter are filled with a 6 parts sand to 1 part cement mix and laid dry in the water at the wall base. MPWL indicate that approximately 100 kg of cement is used per m^3 of wall. The core of the wall is coral blocks which are faced by a layer of concrete which is supposed to be about 30 cm thick (Figure 39).

Calculations based on the current western seawall design (Figure 40) indicate an approximate cost of US$ 400/m for labour and materials at 1989 exchange rates. The wall has recently been improved by the addition of an overhang on the seaward side to reduce overtopping, however, there are still problems of erosion at the toe and the steep smooth profile promotes wave run-up.

The suggestions of Godage (1988) for further improvements to the western seawall to reinforce the toe, add rip-rap to dissipate wave energy and raise the height still further to reduce overtopping should be seriously considered. His estimates of costs work out at about $735/m for the improvement works.

Given the importance of secure sea-defence it would seem prudent for a structural engineer specialising in sea-defences to review the local construction techniques and advise on how they might be improved or indicate cost-effective alternatives. Expensive solutions are obviously available but are of little use if neither funding nor manpower with the appropriate skills are.



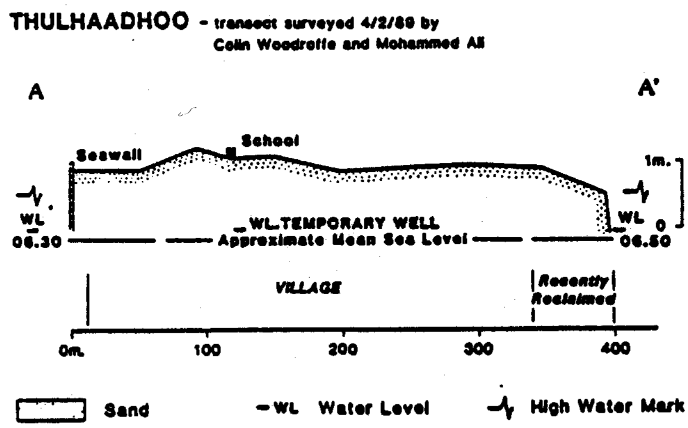


FIGURE 38. Thulhaadhoo island (Baa), population 1,487 in 1985. (Source: Woodroffe, 1989).

FIGURE 39. Part of the retaining wall on the south-west of Hulule (marked C on Fig. 19). This traditional design wall appears to have been undermined leading to collapse from within.

FIGURE 40. Western seawall of Male'. Overhang deflects wave run-up and reduces overtopping. Backwash continually sucks at toe of wall and toe reinforcement and rip-rap are needed to protect the toe.

4. RECOMMENDATIONS

4.1. Introduction

There are two separate but linked issues which need to be dealt with. Firstly, there is no effective mechanism for environmental impact assessment (EIA) so that environmentally unsound projects are allowed to go ahead every year. Secondly, there is neither adequate data nor adequate governmental manpower to cope with the challenges posed by sea-level rise. The first issue needs to be dealt with now, the second can be dealt with over 15-20 years (cf. Section 1.2).

Degradation of the environment, particularly (i) activities damaging coral reefs and thus affecting offshore sea-defence, and (ii) coastal engineering developments which lead to shore erosion (Section 3.4), will add to the cost of dealing with sea-level rise and may render untenable islands which would otherwise have remained habitable for many more years. Because of this, a possible framework for ensuring sustainable (and in the long term cost-effective) development is outlined in Section 4.3.

4.2. Action plan to establish the information base and skilled manpower to deal with sea-level rise

As discussed in Section 1.2 it would appear from current estimates of sea-level rise that the Maldives has at least 15 years to prepare itself to deal with the resultant problems. This period can de devoted to establishing cadres of trained personnel in key government departments and to building up the information base (database) needed by planners and decision makers. The fields in which training will be needed are: engineering, planning, economics, marine biology, oceanography, agriculture and geology.

The parts of government which will be at the forefront of research, planning, sea-defence engineering and decision making are likely to be:-

Ministry of Public Works and Labour
Marine Research Section (Min. of Fisheries and Agriculture)
Ministry of Planning and Environment
Office for Physical Planning and Design
Agriculture Section (Ministry of Fisheries and Agriculture)
Department of Meteorology

Nuclei of skilled manpower already exist in these departments of government and we propose that these should be developed substantially, where necessary with expatriate input while training proceeds. The burden of building up the information base needed for planning should ideally be a joint effort between Maldivian government departments, skilled expatriate workers (e.g. VSOs), interested overseas universities (e.g. Wollongong, Newcastle upon Tyne), foreign governmental aid agencies (e.g. USAID, DANIDA, ODA, JICA) and international agencies (e.g. UNEP, CFTC, EEC).

An important element at the Maldivian end will be the coordination of these activities so that all form part of a coherent programme.

4.2.1. Marine Research Section (MRS)

MRS was originally set up by the Ministry of Fisheries to deal with tuna stock assessment and research work. As needs arose its activities were expanded to encompass all marine environmental matters. Currently, MRS has projects investigating the effects of reef degradation on reef fisheries, the potential for developing reef fisheries, coral reef taxonomy and seasonal variation of live-bait for pole-and-line fishing. A project on the rehabilitation of reefs degraded by coral mining is about to start and various other environmentally orientated research proposals are in the pipeline. MRS have also been charged with the responsibility for long-term monitoring of reefs.

MRS has for a long time recognised the need for well-qualified manpower and is already training personnel at degree level abroad. In addition, the value of working with overseas scientists and thus obtaining on-the-job training has also been recognised and successful Maldivian-expatriate partnerships have been forged with FAO, VSO and ODA scientists working in the Maldives on three year contracts. To some extent one might regard MRS as a model both in successful manpower development and in building up the information base on marine resources. However, the experience of this section also underlines the long time need to develop expertise. The unit has been gradually built up over about 10 years; if all goes well, in another five years or so it will have attained the level of trained manpower and internal capabilities it should have in order to fulfill its role effectively.

The important lesson here is that a 15 year preparation period to build up trained personnel is likely to be barely adequate under present conditions.

With the merger of the Ministries of Fisheries and Agriculture there is a clear opportunity for developing agricultural research and statistics collection along the lines that the Ministry of Fisheries had done. It has already been arranged for a VSO worker to be assigned to help with a programme to improve gathering of agricultural statistics. This programme relies on the statistical expertise of the Administrative Section of MFA and the agricultural expertise of the Agricultural Services section and is a good example of synergism making the best use of available manpower.

Agriculture have several hectares of land on Feridhoo (Ari Atoll, population 386 in 1985) and MRS have for a number of years been considering the possibility of establishing a Marine Research Station (also recommended by various consultants e.g. Oakley, 1988). Feridhoo is primarily a tuna fishing island and reefs in the area, including several large unimpacted faroes, are in good condition. Feridhoo could thus provide the base for both marine and agricultural research. The island is within easy reach of several resorts and twelve more resorts are scheduled for development within Ari in the near future. There is thus also a possibility for developing a botanic garden, aquarium and fishing museum on the same site to attract tourists and offset some of the running costs. Such a <u>Marine and Agricultural Research Station</u> could provide a base for overseas Ph.D. and M.Sc. students as well as postdoctoral scientists carrying out basic research on Maldivian natural resources.

The case for Feridhoo as a research station site thus appears good. However, the practicalities of working effectively so far from Male' need investigating. If qualified Maldivian staff do not wish to reside on Feridhoo the station could become a "white elephant". Also the greatest impacts on marine natural resources have occurred on North Male' Atoll and monitoring programmes on effects of impacts and recovery from damage arguably need to be located there. A case can thus also be made for the marine side of the research to be located in North Male' Atoll, perhaps on Meerfenfushi or Villingili. Before any decisions are taken a detailed study needs to be undertaken to determine the relative merits of the Feridhoo and North Male' options.

Sea-level rise is going to create heavy demands for detailed information on coral reef and agricultural resources. To make best use of scientifically trained manpower it would be expedient to formally redesignate the research arm of MFA as the Natural Resources Research Section and widen its remit to terrestrial as well as marine resources. At least five additional qualified staff will be needed.

4.2.2. Environment Section

The recently formed Environment Section of the Ministry of Planning and Environment (MPE) does not have the manpower needed to fulfil its proposed role either as coordinating body for environmental impact assessment or as a major force in creating the information base needed to plan for sea-level rise.

Present structure:

Director of Environmental Affairs	- Hussein Shihab
Assistant Undersecretary	- Mohamed Ali (Degree)
Assistant Surveyors (2)	- Abdullah Saeed (A-level)
(Environment)	- Mohamed Zahir (O-level)
Programme Officers (2)	- Aiminath Shameem (O-level)
(Trainee)	- Ibrahim Haneef (O-level)
Secretary	- Aishath Asima

We are in agreement with Woodroffe (1989) and Kenchington (1985) on the roles which should be adopted by Environment Section, namely:-

(i) Responsibility for environmental legislation and the implementation of this through environmental impact assessment requirements.

(ii) Coordination of environmental monitoring and establishment of an environmental (natural resources) data base.

(iii) Overseeing of public awareness and educational initiatives with respect to environmental issues and sea-level rise.

Such a set of roles will demand staffing by qualified personnel at a minimum of three times the present level. Among the staff reporting to the Director, there will need to be at least two people with degree level and three with A-level or equivalent qualifications. Until such time as qualified staff can be trained, use should be made of expatriate (e.g. VSO) workers.

Section 5.2 of Woodroffe (1989) spells out in detail the specific needs for an environmental database. We reproduce this below (Figure 41) as we find his approach admirable. We have two minor caveats: (a) Landsat MSS imagery is unlikely to be of much use in the Maldives context due to the poor resolution (79 m), and (b) use of Geographical Information Systems (GIS), although superficially attractive, should be approached with caution less it prove counterproductive. However, we note that MPE already has a Computing Section which is an advantage as far as developing GIS capability is concerned.

Development of environmental legislation and implementation of this through environmental impact assessment in which Environment Section must play a central role is discussed in detail by Kenchington (1985) and in Section 4.3 below.

After strengthening we envisage the complement of Environment Section to include a Director, Deputy Director, 2 Assistant Directors, 3 Senior Project Officers, 6 Project Officers, 6 Assistant Project Officers, 2 Secretaries. At least one of the senior posts should be administrative. Such a team could hopefully tackle the EIA management, environmental database and survey work and public awareness programmes. The Environment Section should be developed as 3 functional units: one concerned with environmental legislation and environmental impact evaluation procedures; one with mapping, topographical surveying and the establishment of an environmental database; and one with educational and public awareness programmes on environmental issues.

Within the main part of MPE, the economic planning capabilities will need strengthening so that there are people who can make use of the information base created.

4.2.3. Department of Meteorology

The Department of Meteorology has a central role to play with respect to preparing for sea-level rise. It already operates tide gauges under the TOGA programme and has thus taken its first steps into oceanography. It has collected the first of the data which will eventually allow the reality of sea-level rise in the Maldives to be demonstrated unequivocally. Data on mean sea-level and the rate of change in mean sea-level are fundamental to all planning and when it comes to convincing Maldivian society of sea-level rise, these data, collected in the Maldives by Maldivians, will be critical.

FIGURE 41. Environmental database recommendations of Woodroffe (1989).

5.2 Need to establish an environmental database

It is necessary to strengthen and expand the Environment Section of the Ministry of Planning and Environment so that it can carry out its role in accordance with the recommendations of Kenchington (1985). The Environment Section should develop in the following directions; it should take responsibilty for the development of environmental legislation; it should co-ordinate environmental monitoring and research; and it should oversee public awareness and educational initiatives (Kenchington 1985). The Section is already active in several areas within these broad headings.

However, in order to proceed further it is going to be particularly important to gather together existing information, and to undertake further environmental studies, to form an environmental database upon which marine and terrestrial resource management can be based.

The following steps appear necessary:

a) Draw together existing maps, charts, aerial photographs and environmental data (land use, vegetation, soils, rock types, sand spit erosion/deposition etc., as outlined in Section 4), and store in a way that they are readily accessible.

b) Synthesise and collate data already available in other ministries (i.e. survey maps from Ministry of Public Works and Labour; resort maps from Physical Planning, maps from island offices)

c) There will be particular need for close cooperation between the Environment Section of the Ministry of Planning and Environment and the Marine Research Section of the Ministry of Fisheries and Agriculture, in order that results of marine research can be incorporated in environmental management plans and zoning proposals. Much of the library and photo material will be important to both sections.

d) Central to the development of a database should be the 1969 RAF vertical black and white aerial photographs. These need to be reorganised and catalogued, and should be transfered from the Ministry of Fisheries and Agriculture to the Environment Section of the Ministry of Planning and Environment. Preliminary maps of vegetation, island shape, topography could be drawn from these photographs, as long as it is recognised that they are 20 years out of date. They will also provide an important record of change when newer information (ideally up-to-date colour vertical aerial photography) becomes available.

e) The environmental data should within the next few years be transfered to a computer-based geographical information system (GIS), with compatible computer-aided draughting and design (CAD) capabilities. Expert advice should be sought in each of the selection, setting up and staff-training phases.

f) Resource surveys of islands and adjacent reefs will be needed, collecting data on island characteristics and stability and change (as outlined in section 4).

These could be done using a variety of techniques, including:

1) Field-based surveys: some kind of field-based surveys will be necessary for surveying heights of islands, and for recording field conditions (i.e. water salinity etc.)

2) Aerial photography: the 1969 photography can fulfil a role. However an

FIGURE 41 (continued).

up-to-date colour vertical aerial photographic coverage would be especially useful.

3) Satellite imagery: some prints of satellite imagery exist for North Male atoll, Suvadiva, Haddumati and Kolamadulu (Landsat MSS and Landsat TM). In addition a remote sensing project is underway (Lantieri 1987; and project with China). Some analysis of SPOT imagery has been undertaken, and SPOT Image have acquired a series of 1987-8 scenes over the Maldives. These data sources will represent important records for subsequently determining change of island characteristics.

4) Some data may be drawn together by sending out questionaire surveys to outer islands, to establish factors such as the extent of pollution, areas from which coral is collected, bait-fish areas, the extent of coastal erosion, the extent of reclamation and coastal protection works.

Of these options, the most useful in terms of the detail of information will be aerial photographic coverage. Satellite imagery (even SPOT with 20m resolution) will not permit the scale of delineation of sand spits, taro pits, individual trees and so on. Colour vertical aerial photographs at either 1:10,000 or 1:25,000 will allow detailed assessment of ground conditions,and will be useful to other ministries (i.e. Public Works and Labour; Physical Planning, Atoll Administration, Fisheries and Agriculture, and perhaps others). It will be necessary to supplement any such remote sensing with detailed field analysis of selected islands. The capability to analyse satellite imagery and particularly to process digital satellite data should be phased in over a period of several years. It would be feasible to plan to acquire a microcomputer-based image analysis system and software for inhouse analysis of satellite digital data. A system such as the Australian produced microBRIAN system, directly developed for mapping shallow water reef environments, would be entirely adequate to analyse and store the satellite imagery, and to undertake mapping and interpretation as required.

g) It is clear that an integrated approach needs to be taken to the further expansion of the Environment Section, and to the development of environmental legislation. While some broad recommendations on an environmental database have been made here, it is clear that this needs to be developed not solely to monitor any changes that are attributable to sea-level change, and to assess the impact of that change, but to address a whole series of environmental issues, pollution, coral mining, reclamation, tourism, etc, and upon which to base marine and terrestrial environmental management. It is strongly recommended that a more detailed study be sought on an integrated approach to environmental monitoring and management, with particular input from those nations with experience in reef and reef island management.

Global warming may have other effects which will need to be monitored (Section 2.6):- (a) increasing frequency of high waves, (b) altered rainfall patterns, and (c) increased frequency and power of storms passing close to the northernmost atolls. All these factors will need to be monitored to try to determine trends which can be used in planning.

To carry out these critical monitoring activities the Department of Meteorology will need to be strengthened, particularly on the oceanography side. In recognition of this wider role the department should be redesignated the Department of Meteorology and Oceanography. The World Meteorological Organisation (WMO) may provide short- to medium-term training in oceanography for staff.

At the moment tide gauges are in operation at Male' and Gan (Section 2.6). Continuous tidal records are needed from now indefinitely. With the airport developments at Kadhdhoo (Laamu) and Hanimaadhoo (Haa Dhaalu) there will be a need for good meteorological reporting at these sites. Meteorological stations, comparable to those at Hulule and Gan, should be established at both airports and in addition a tide gauge should be set up at Hanimaadhoo to get data on tidal regimes in the north. Barometric pressure and wind speed and direction data from Hanimaadhoo will be particularly useful with respect to gauging the likely effects of tropical storms and cyclones passing to the north.

With respect to rainfall patterns, recent steps by the Department of Meteorology should allow changes in these to be monitored adequately. Since 1984 local recorders have been collecting rainfall data for the Department at Kelaa (Haa Alifu), Farukolhufunadhoo (Shaviyani), Dharavandhoo (Baa), Feridhoo (Alifu), Muli (Meemu), Kudahuvadhoo (Dhaalu), Veymandoo (Thaa), Villigili (Gaafu Alifu), Thinadhoo (Gaafu Dhaalu) and Foammulah (Gnaviyani). By 2000 these data may allow some analysis of annual trends. The longer records for Male' and Gan which go back to the 1940s should be placed on a computer and reanalysed for temporal trends as each years's new rainfall data is added.

Data on wave heights is clearly needed (cf. Section 3.5) and advice should be sought on obtaining wave-rider (or similar) data of the type obtained by Lanka Hydraulic Institute Ltd (1988a, 1988b) over a longer timescale. Ideal sites for recording wave data would be off Kelaa (H.A.), Feridhoo (A.), Gan (S.) and Hulule. Rainfall is measured at the two former sites, full meteorological services are in operation at the latter two; Feridhoo may host a Marine and Agricultural Research Station and

Kelaa is one of nine islands selected for development; between them the sites cover all quadrants. Such data are likely to be expensive to obtain and need skilled analysis, however, given the need for accurate design wave calculations by Ministry of Public Works and Labour, this expense would seem justified.

The increased demands on the Department of Meteorology would require at least a 25% increase in staffing levels (currently about 45 in total) as well as additional training of existing staff.

The Department needs to liaise more closely with Ministry of Public Works and Labour, Marine Research Section, Environment Section and Agriculture to ensure that its data are made full use of.

4.2.4. Ministry of Public Works and Labour (MPWL)

MPWL have the unenviable task of trying to carry out sea-defence works on a budget that is not really adequate. They will have to spearhead coastal engineering projects to contain sea-level rise and assess cost-effectiveness and environmental impacts of different engineering solutions. They are already developing their own design capability but urgently require (a) a Geotechnical Unit, and (b) a resident hydraulic engineer who can assess the impacts of coastal structures on sediment transport and wave and current regimes at the shore, as well as advising on design criteria. Whilst coral mining is still practised MPWL should coordinate the maintenance of accurate records of coral extraction rates as they have done in the past.

Engineering Geology Ltd and Tropical Coastal Management Consultants Ltd (1987) presented detailed proposals for the development of a Geotechnical Unit as well as defining its role at some length. Implementation of these proposals should be considered an integral part of strengthening the Maldivian government infrastructure in preparation for sea-level rise. In addition, such a unit is needed for short-term development planning, e.g. Selected Islands Development. Hydraulic engineering and shore processes expertise is needed if any credible attempt at assessing the environmental impacts of coastal engineering projects is to be made. Expatriate advice could be sought whilst Maldivian personnel are trained.

4.2.5. Office for Physical Planning and Design (OPPD)

OPPD has been building up personnel trained in architecture, urban planning, structural engineering, civil engineering, and draughtsmanship for some time. Several members of the Office are overseas engaged in training at the moment and will bring back additional planning and architectural expertise. OPPD provides a service to other government departments and if it is to cope with the steadily increasing volume of work it will need to continue its steady development. Close liaison with MPWL and Environment Section are to be encouraged.

4.2.6. Summary

Marine Research Section

(1) MRS should form the nucleus for building up skilled scientific manpower and the necessary information base on natural resources of the Maldives.

(2) It should be redesignated Natural Resources Research Section to recognise its wider role and agricultural responsibilities.

(3) A Marine and Agricultural Research Station should be set up on Feridhoo (Alifu) or a site in North Male' Atoll to provide a base for vital long term research on coral reef growth and agricultural development (particularly in the context of sea-level rise). Long-term monitoring of permanent sites should be initiated and growth rates, settlement, reproductive biology and ecology of corals, and reef-sediment relationships studied in order to be able to predict the responses of reefs to both sea-level rise and degradation.

Environment Section

(1) The Environment Section needs to be considerably strengthened and expanded.

(2) It should establish an environmental database for the Maldives (including mapping from the 1969 RAF aerial photographs and survey of island topography and natural resources).

(3) It should paly a central role in developing environmental legislation and implementing EIA requirements.

(4) It should oversee public awareness and educational initiatives dealing with environmental issues and sea-level rise.

Department of Meteorology

(1) The Department of Meteorology should be strengthened in the area of oceanography and redesignated the Department of Meteorology and Oceanography.

(2) It should continue the vital tide gauge measurements at Male' and Gan and start them at Hanimaadhoo (H. Dh.).

(3) It should establish meteorological stations comparable to those at Hulule and Gan at Kadhdhoo (L.) and Hanimaadhoo (H. Dh.).

(4) It should investigate the feasibility of collecting several years wave data off Hulule, Gan, Feridhoo (A.) and Kelaa (H. A.).

Ministry of Public Works and Labour

(1) MPWL should establish a Geotechnical Unit.

(2) It should develop in-house capability for assessing physical environmental impacts of coastal structures particularly with respect to water movements.

(3) It should monitor coral mining activities.

Office for Physical Planning and Design

(1) OPPD should continue development of its capabilities to cope with a steadily increasing workload.

4.2.7. Conclusion

These recommendations seek to build on the existing expertise within Maldivian governmental departments and try to avoid creating any new bodies. With an acute shortage of skilled manpower every attempt should be made to make best use of available nuclei of skilled personnel. Creation of additional bodies outside the mainstream executive branches of government will merely tend to suck manpower away from these and reduce the effectiveness of these arms of government. For this reason we are against the proposal for a Maldives Institute (Oakley, 1988). We consider that the primary aims of the Maldives Institute set out by Oakley (1988) (aims which we whole-heartedly support) can be accomplished by developing existing administrative structures. However, the aims will only be achieved if these structures receive the funding priority, imaginative management, and political support at the highest level that they require.

4.3. Action plan to establish natural resource and environmental management

4.3.1. Introduction

The recommendations of Kenchington (1985) go into this subject in more detail and should be consulted. The following framework for discussion was prepared for the Select Committee for Drafting an Environmental Law for the Maldives at their request.

To be successful, the management of natural resources and the environment must be based upon a strong legal foundation which clearly defines the functional and philosophical basis of management - HOW management is to be achieved and WHY it is necessary.

To achieve balance in the consideration of the inter-linked issues of natural resources, the environment and economics, a strong legal and administrative system is proposed which provides for stewardship by the government of the natural resources and environment of the Republic of Maldives.

The essence of stewardship is that the use of or impact upon natural resources or the environment should be approved or expanded only where it can be demonstrated to be reasonable within defined environmental standards.

The key to cost-effective consideration of natural resource and environmental impacts is for these to be included at the initial stages of the development process, not as an afterthought. Planning to minimise impacts on natural resources and the environment does not necessarily increase costs of implementation of projects, it promotes sustainable development, and in the longer term is almost invariably cost-effective. Non-sustainable development merely passes the economic burdens to the next generation. They will have enough problems dealing with sea-level rise and its economic demands.

Legislation to provide a mechanism for environmental management must ensure that the mechanism does not act as a block to development (otherwise it will be by-passed) but rather becomes part of the development and planning process itself.

4.3.2. Why is legislation necessary?

The Maldives are a particularly fragile complex interlinked series of ecosystems. Changes to any of the component ecosystems have effects on the other linked systems. Two primary groupings of systems can be identified, one primarily marine and one primarily terrestrial. The dividing line between the two is thin.

1) The islands of the Maldives owe their existence to localised dynamic equilibria between coral reefs, sediments and water movements (waves, currents, etc.) which maintain the islands' integrity.

2) Groundwater owes its existence to a dynamic equilibrium between rainfall, evaporation, transpiration by vegetation, runoff, seepage to the sea, and extraction by man.

The land itself is thus dependent on undisturbed marine systems whilst its habitability and vegetation are dependent on rain derived groundwater which particularly on small islands is a very easily damaged resource.

Disturbing either set of equilibria can have profound effects. If a development necessitates the upsetting of these balances, the consequences of doing so should at least be quantified so that the benefits of the development can be weighed against the natural resource and environmental costs.

With predictions of rising sea-level it becomes imperative economically to plan now with due regard to natural resource and environmental implications. The future economic viability of the Republic could be at stake. The most cost-effective way to achieve environmental regulation is to integrate the consideration of environmental and natural resource impacts within the planning process at as early a stage as possible.

4.3.3. Objectives of legislation

The objectives of environmental legislation are to ensure:

a) that natural resources are used wisely and that avoidable and, in the long-term, costly damage to the natural resources and environment of the Republic of Maldives is minimised,

b) that the developments are sustainable in the long-term (over periods of 25 years or more).

The alternative, without stewardship by the government, is to pass down to succeeding generations not only damaged natural resources but a large national debt arising from the costs of protecting, repairing and replacing unwise developments and the services and goods once provided by natural resources. Examples are the replacement of degraded coral reefs by breakwaters, or groundwater by desalination plants.

4.3.4. Proposal

To ensure that due consideration is paid to the impacts of development projects on the natural resources and environment of the Republic of Maldives, it is suggested that all projects which potentially have impacts on:

a) Groundwater resources.
b) Coral reefs (e.g. sea-defence capability).
c) Sand and other sediment resources.
d) Water movements along the shores and in the vicinity of islands.
e) Fisheries resources.
f) Agricultural resources.
g) Sediment movements around islands.
h) Seawater quality (e.g. temperature, nutrient levels, salinity, bacteriological status).

have an Environmental Impact Assessment (EIA) study made as part of their planning process. The results of this EIA study should be submitted as an Environmental Impact Statement (EIS). The EIS needs to be subjected to scrutiny and review by technically qualified experts. A summary of the EIA findings of not more than five A4 typed pages should be placed at the beginning of each EIS. Figure 42 summarises a possible procedure for environmental impact assessment. This is discussed in more detail below.

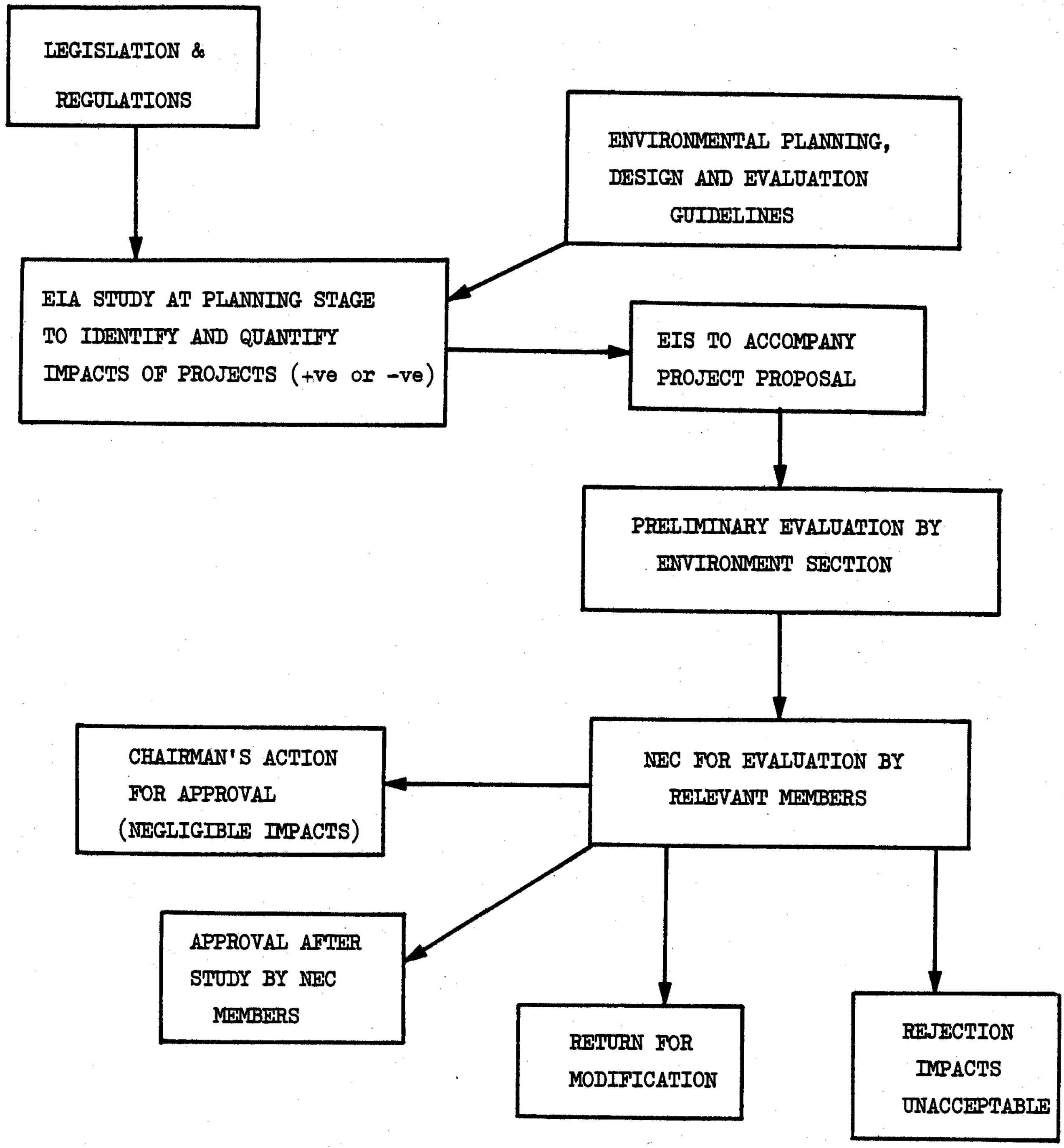


FIGURE 42. A possible procedural mechanism for EIA.

To this end it is proposed that the National Environment Commission (NEC) be reconstituted as a technical committee with the prime function of evaluating, approving or rejecting EIS submissions.

It is proposed that such a reconstituted NEC should be smaller than the original Commission and comprise technically qualified representatives from:

Ministry of Planning and Environment (Environment Section) (CHAIRMAN)
Office for Physical Planning and Design
Marine Research Section (Ministry of Fisheries and Agriculture)
Ministry of Public Works and Labour
Agricultural Services (Ministry of Fisheries and Agriculture)
Maldives Water and Sanitation Authority
Ministry of Tourism
Atolls Development Advisory Board (Ministry of Atolls Administration)
[Department of Meteorology - if this is expanded to provide oceanographic advice]

It should be within the powers of the Chairman of the new NEC to approve by Chairman's Action non-controversial minor projects deemed by the Environment Section as being unlikely to have any significant effects on natural resources and the environment. Members of the Commission should be notified in writing of approvals so made and the accompanying EIS should be available for inspection at Environment Section by Commission members if requested.

The EIS should in the first instance be submitted with the other project documents to the Environment Section of MPE for initial study prior to evaluation by the NEC, if required, or Chairman's Action if not. If necessary, foreign experts should be consulted on controversial technical points and to this end it would be expedient to set up a standing panel of such experts who should both be known to members of the Commission and familiar with the Maldives. Facsimile links make such an arrangement feasible.

The EIA must seek to <u>quantify</u> the impacts of the project to which it refers. If impacts are not adequately quantified the NEC should be given powers to withold approval of the project until the extent of likely impacts are quantified to the satisfaction of the NEC.

To aid project planners it is necessary that some guidelines (Environmental Planning, Design and Evaluation Guidelines) be prepared. Thes guidelines for sustainable development, natural resource management, design and construction should cover:

Jetties
Groynes
Causeways
Retaining seawalls
Breakwaters
Reclamation
Coral mining
Coral rubble extraction
Sand dredging
Sewage disposal
Solid waste disposal
Oil exploration, drilling, and production operations
Industrial outfalls
Buildings
Roads
Carrying capacity calculations for islands
Groundwater utilisation
Introduction of alien species

Guidelines existing in other countries (e.g. Manual of Environmental Impact Evaluation Guidelines of the National Environment Board of Thailand) should be examined and modified as appropriate for Maldives.

Drawing up such a set of guidelines is a major task and should be coordinated by Environment Section with help from MPWL, MRS, OPPD, and MWSA and, if required, also expatriate advisers with experience in a) coastal engineering and hydraulics, b) natural resources management, and c) public health engineering.

These guidelines should be made available to any organisation proposing a development project and should identify broadly acceptable and unacceptable practices and indicate what types of factors should be quantified in an EIA study.

Construction and design guidelines must specify such criteria as the offshore 'design wave' height for coastal protection works and should also consider sea-level rise implications for siting and design of domestic, business, governmental and industrial buildings and plant. Guideline criteria for these should ensure that financial investment is not at short-term (less than 25 years) risk or, if it is, then a statement of plans and costs for protection should be provided.

An alternative approach to environmental impact evaluations is used by the National Environment Board of Thailand. This approach is a two stage one with first an Initial Environmental Examination (IEE) being prepared for each project. This is reviewed by the National Environment Board and if a follow-up study is required a full EIS is asked for. This approach has some good points but might prove a more cumbersome procedure in practice. Figure 43, the preface to the NEB Manual of Environmental Impact Evaluation Guidelines of Thailand, summarises the Thai approach to EIA.

FIGURE 43. Preface to National Environment Board Manual of Environmental Impact Evaluation Guidelines of Thailand.

PREFACE

The attached NEB Manual of Environmental Impact Evaluation Guidelines has been prepared by NEB for issuance to all agencies or individuals, in both the public and private sectors, who propose to undertake (i) construction of any new project in Thailand which significantly alters the existing natural and man-made environment in the area effected by the project, or (ii) construction of major alterations or changes in existing projects which will significantly alter the existing environment.

An initial step, to be taken in the first or preliminary stages of project planning, is to carry out an Initial Environmental Examination (IEE) for submittal for review by NEB. This is a preliminary examination for determining whether or not the project is likely to involve significance environmental effects. If this determination is negative, then the IEE itself will usually be the only environmental analysis which is needed.

If the IEE indicates a follow-up study is needed, then an appropriate EIS (Environmental Impact Statement) report is to be prepared by the agency or individual who proposes the project. This is to be prepared in sufficient scope and detail to enable the NEB to evaluate the overall worth of the project in terms of economic benefits versus possible impairments to precious environmental resources or values

Based on this evaluation NEB can make its recommendations to the RTG on whether the project is meritorious in the overall balance and thus should be allowed to proceed, and (a) if so to delineate the properly applicable environmental constraints, and (b) if not to enumerate the reasons for this decision and where feasible to indicate what additional environmental protection measures need be included in order for the project to be reconsidered.

The agencies of the RTG concerned with project development include those Ministries and other branches of the RTG with operational responsibilities in the areas of jurisdiction affected by the proposed project. It is NEB's desire to work in close cooperation with all Ministries and other agencies concerned, especially those with leading role responsibilities, in order to expedite planning of and concurrence on all projects needed for the continuing development of the country.

FIGURE 43 (continued).

It is recognized that the state of the art in preparing EIS reports is still in the evolutionary stage, even in the USA where an intensive effort has been underway in developing an appropriate technology and methodology for almost 10 years. Hence procedures for preparation of EIS reports have not been standardized and considerable latitude may be in order to preparing the EIS report for any particular project. The main requirement is to present enough information on all sensitive environmental questions to permit NEB to arrive at a fair and objective judgment.

Experience in the USA and other countries where good progress has been made in environmental protection has shown that the EIS report represents the most valuable tool yet developed which can be used by government for assessing the worth of projects in a manner that (a) protects the proper interests of all agencies and people concerned, and (b) will permit continuing economic growth in the country while at the same time protecting and preserving essential environmental values, so these will be perpetually available for meeting both standard of living and quality of life purposes. Careful attention has been given to utilize concepts and criteria on environmental values which are appropriate for Thailand, so that realistic environmental protection can be achieved within realistic economic and other constraints.

The intention of these guidelines is to initiate an appropriate system of environmental protection in Thailand. The Manual includes guidelines for preparing Initial Environmental Examinations, for preparing Environmental Impact Statements, and for preparing Terms of Reference for inviting proposals from consulting firms or other agencies interested in carrying out EIS studies for particular projects. It is planned to update reissue the Manual periodically as experience is gained in this field of work in Thailand.

(Kasem Snidvongs)
Secretary General
National Environment Board

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