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# Environmental Planning, Climate Change and Potential Sea Level Rise: Report on a Mission to the Republic of the Marshall Islands

John Connell
and
Matakite Maata



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**SPREP**

# ENVIRONMENTAL PLANNING, CLIMATE CHANGE AND POTENTIAL SEA LEVEL RISE: REPORT ON A MISSION TO THE REPUBLIC OF THE MARSHALL ISLANDS

SPREP REPORTS AND STUDIES No.

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July, 1992

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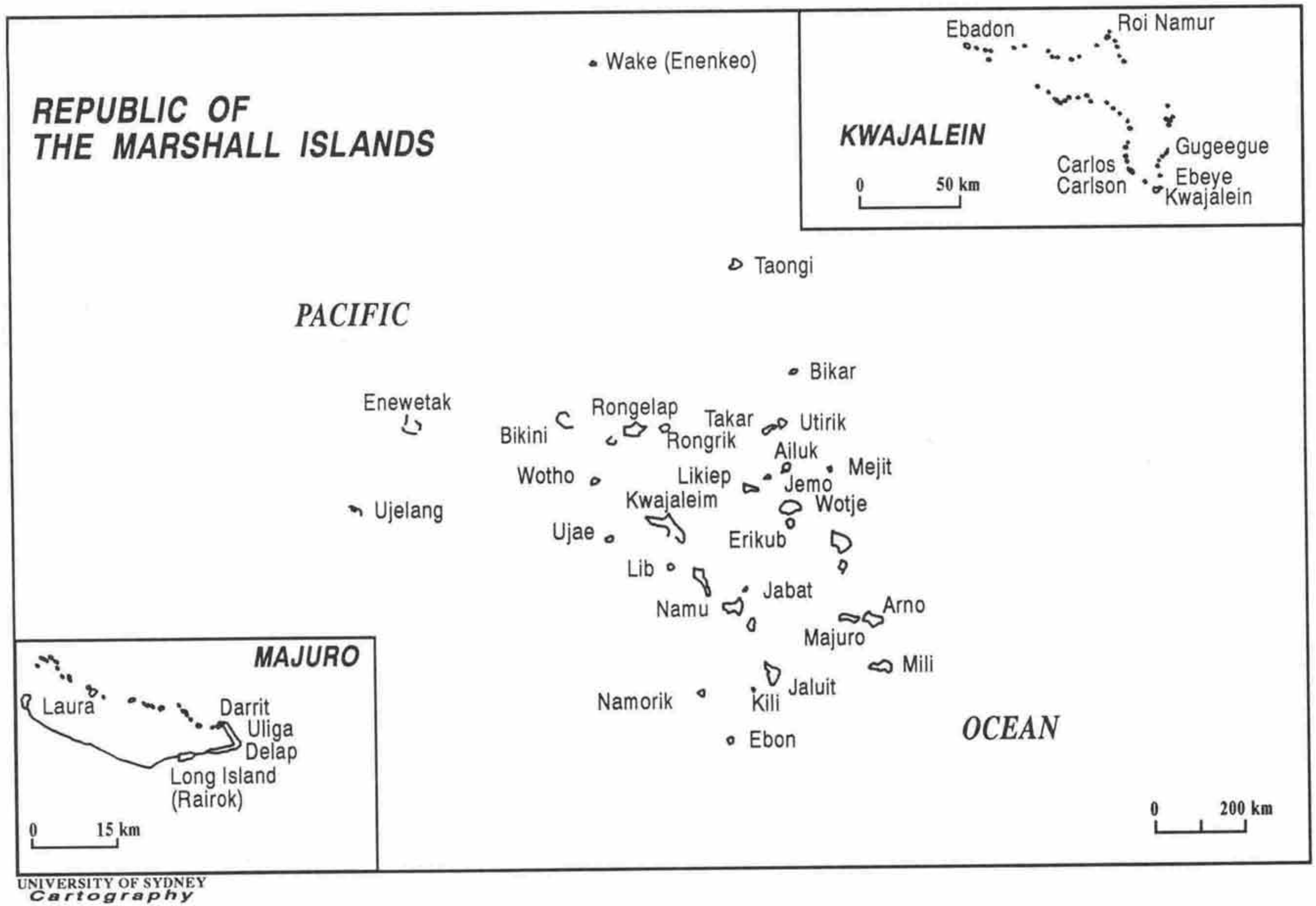
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Lib
Jabat
Namu
Arno
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UNIVERSITY OF SYDNEY
Cartography

## INTRODUCTION

### 1.1 Background

A number of island states have been perceived as being under short-term threat of major environmental changes should potentially significant greenhouse-induced climatic warming and sea-level rise occur. The problems identified for the countries of the South Pacific region have been set out into two collections of papers (Pernetta and Hughes 1990; Hughes and McGregor 1990; cf. Roy and Connell 1991). In these reports, the four atoll states - Kiribati, Tuvalu, Marshall Islands and Tokelau - were identified as the Pacific Island states that were most vulnerable to any sea-level rise because with the sole exception of Banaba island (Kiribati), no part of any of these states was even five metres above sea-level. An article published in Pacific Islands Monthly in 1989 (Connell and Roy, 1989), which drew attention to these issues, was given the dramatic cover title 'Say Goodbye to Kiribati, Tuvalu, Marshall Islands and Tokelau' and led to considerable concern in those states. Sometime afterwards, the President of the Marshall Islands, Amata Kabua, stated

> It is truly frightening to think that our ocean will turn against us. We have been sustained by the ocean for two millennia. It has been bountiful and continues to yield to us its bounty. We have learned that this harmony may be interrupted by the actions of nations very distant from our shores. I hope that the appeal of the peoples of the Pacific can help convince the industrialized nations to discontinue their profligate contamination of the atmosphere (SPREP, 1989:48).

When the Republic of the Marshall Islands was admitted to the United Nations in September 1991, Amata Kabua, in his address to the United Nations, stated that global warming was the most formidable problem that the country faced; though it could do nothing to alleviate the problem itself, other than continue to raise the issue in the international community, it could respond by developing a series of contingency plans which response would be possible (Marshall Islands Journal, 4 October 1991). This report therefore seeks to contribute to this process. Early in 1991 the Republic of the Marshall Islands Cabinet created a national task force on environmental management and sustainable development to oversee the production and development of a National Environmental Management Strategy. This has produced two useful reports on the scientific background to environmental management in the Marshall Islands (Crawford 1992; RMI Taskforce 1992), which have been invaluable for the production of this report, and should be read in conjunction with it.

It is apparent that climatic warming and consequent sea-level rise is simply one, and not necessarily the most urgent, of a number of environmental problems facing small island states. Within the next half-century the probability of economic and nutritional distress, coupled with a growing shortage of fresh water, are much greater than those of physical destruction (Brookfield 1989). Other forms of environmental degradation, including soil erosion and waste disposal problems, may become critical in certain circumstances. Consequently proposals to deal with climate change must be seen in the context of other, more immediate environmental planning issues. This report therefore considers wider environmental issues than climate change alone.

## 1.2 Mission Brief

The brief for this mission was developed by SPREP following early studies of the Maldive Islands (Pernetta and Sestini 1989) and Kiribati (Sullivan and Gibson 1991). The terms of reference, agreed upon by SPREP and the Republic of the Marshall Islands were as follows:

1. Under the general supervision and guidance of the Chairman of the Association of South Pacific Environmental Institutions (ASPEI) a two person mission will visit the Republic of the Marshall Islands for approximately 7 days. The main purpose of the mission is to prepare, in close consultation with national counterparts identified by the host Government, a proposal for a programme of assistance to undertake an in-depth study of the potential impact of expected climatic changes (primarily sea-level and temperature rise) on the natural environment and the socio-economic structures and activities of the host country, including the identification of response options which may be suitable and available to avoid or mitigate the expected negative impact of climatic changes.

2. Specifically, while in the host country, the mission, consisting of two senior experts of the ASPEI/UNEP/SPREP Task Team on climatic change, will:

   (a) examine and evaluate the available information affecting the physical and biological environment (terrestrial and marine) of the islands comprising the country;

   (b) examine and carry out a preliminary assessment of the available demographic, social (including archaeological and cultural) and economic data;

   (c) present, via a public lecture or radio broadcast as appropriate, an overview of the current state of knowledge concerning the greenhouse effect and its possible consequences for Pacific Island nations;

   (d) present to the national authorities, organisations, institutions and experts the results of UNEP-sponsored studies, specifically those conducted in the South Pacific (eg Kiribati) and South Asian Seas areas, outlining the potential applicability of these studies to the host country;

   (e) discuss with the regional authorities, organisations, institutions and experts which may participate in the in-depth study expected to follow the mission and determine the modalities of co-operation between the legal and administrative structures of the country with the team which will assist in the implementation of the in-depth study.

3. On the basis of the activities referred to in paragraph 2 above, as well as information collected by the experts prior to their mission to the host country, the experts will prepare a joint report containing:

   (a) a general overview of the climatological, oceanographic, geological, biological and socio-economic factors which may be relevant to or affected by potential impacts of expected climatic changes;

(b) a preliminary identification of the most vulnerable components and sites of the natural environment, as well as the socio-economic structures and activities which may be most critically affected by expected climatic changes;

(c) an overview of current environmental management problems in the country and an assessment of how such problems may be exacerbated by climatic changes;

(d) a detailed proposal for a joint programme of assistance to the host country for the in-depth evaluation of potential impacts of expected climatic changes on the natural environment and the socio-economic structures and activities of the country including the identification of policy or management options suitable to avoid or mitigate the impact of climatic changes; the proposal should identify the workplan, timetable and financial requirements of the in depth evaluation as well as the possible institutional arrangements for carrying out the evaluation.

4. Prior to leaving the host country, the mission will present to and discuss with the authorities identified by the Government of the country, the outline of the proposed programme, as well as the major findings of the mission. The comments and suggestions of the authorities identified by the Government of the host country will be duly taken into account in preparing the final report of the mission.

5. The final report of the mission, prepared as the experts' joint report and as specified in paragraph 3 above, will be simultaneously submitted to the Chairman of ASPEI, the Director of OCA/PAC and the SPREP Director for clearance. The final report of the mission will be transmitted by SPREP to the Government of the host country together with the comments of SPREP, UNEP and ASPEI and will be used as the basis for subsequent assistance to the Government of the country in formulating and implementing suitable response options to the expected impacts of climate change.

### 1.3 Programme of Mission

The mission to the Republic of the Marshall Islands (RMI) took place between 11th and 20th December 1991. The programme was organised with the assistance of the RMI Environmental Protection Authority (RMIEPA) and was primarily conducted in Majuro, although the experts were able to visit briefly the outer island of Mili.

## 2. THE MARSHALL ISLANDS-HISTORY, SOCIETY AND ECONOMY

### 2.1 History and Society

Like Kiribati to the south, with which there are many traditional ties since both are Micronesian countries, the Marshall Islands consists entirely of atolls and reef islands; there are some twenty six populated islands (most of which are atolls) distributed into two rough groups, the eastern 'Ratak' (Sunrise) chain and the western 'Ralik' (Sunset) chain dispersed over a huge area of the central Pacific. The Marshall Islands have also claimed Wake Island (Enenkeo) to the north, currently an American possession and never occupied by Marshallese in historic times.

As in other parts of Micronesia to the west, Marshallese society is matrilineal, based on a structure of exogamous clans (jiowi or jou); these are non-localised with members on several atolls and are similar to those of the central Caroline Islands. The most important corporate descent group is the matrilineage (bwij) whose head (alab) is the custodian of lineage land and whose influence on land tenure remains of prime importance. Political and legal structure remains partly traditional, based both on matrilineal principles and on principles of 'aristocracy' with chiefs (iroij) who are largely hereditary. In pre-contact times chiefs were occasionally able to extend their influence and control over wide areas (Alkire 1977:70; Kiste 1983) but only in colonial times was there joint authority over the whole of the Marshall Islands and in pre-colonial times there were often rival chiefs on the same island. The iroij still have considerable influence; they are respected and feared and many believe in their ability to exercise supernatural sanctions (Kiste 1983:27). A Council of Iroij acts as an advisory council to the unicameral national parliament (the Nitijela) on matters of traditional and customary law. Complex resource shortages historically resulted in competition, conflict and warfare and also in inter-island exchaoges and the redistribution of both resources and population (Alkire 1978:136). In pre-contact times population densities may have been extremely high on some atolls to the extent that food shortages prompted conflict and localised migration.

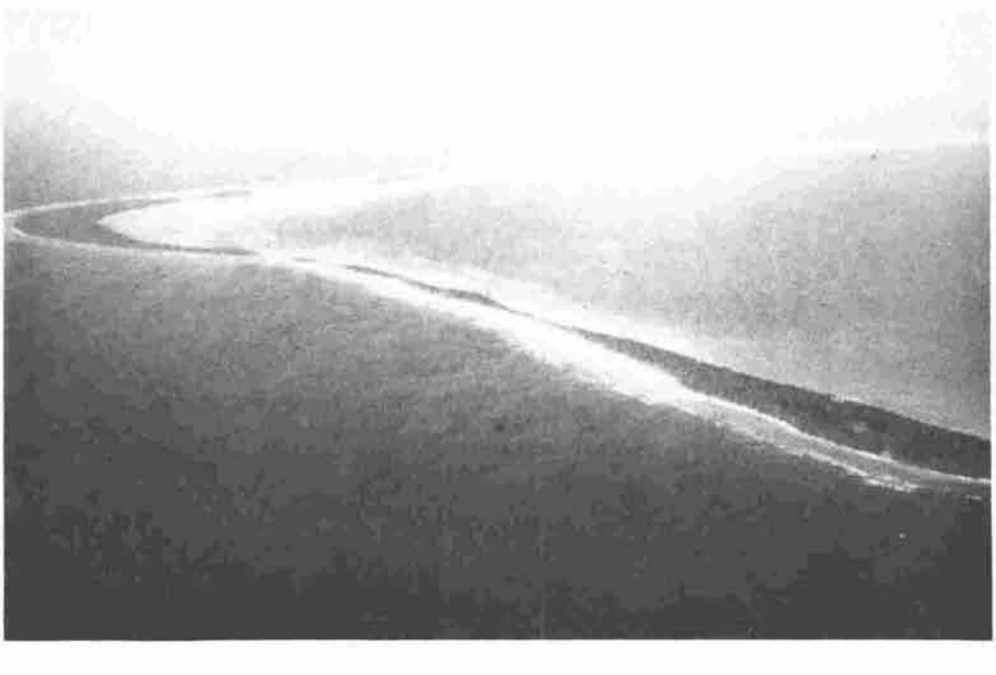
Little is known of the prehistory of the country although the original Micronesian settlement was probably around 3000 years ago. Spanish voyagers 'discovered' the Marshall Islands in the Seventeenth Century; traders, whalers and missionaries came to the islands in the Eighteenth and Nineteenth Centuries, amongst them Captain John Marshall whose name was later given to the islands. In 1835 the Marshall Islands and the eastern Carolines became the centre of Pacific whaling for England and the U.S.A. German traders encouraged the commercial planting of coconuts in the Nineteenth Century. The first missionaries arrived at Ebon in 1857. In the 1870s the Marshalls became very briefly the northernmost extent ofthe labour trade to Fiji (Browning 1981). In 1878 a German consul was appointed to Jaluit and in 1885 the Marshall Islands became a German protectorate. Kili and Ujelang were both uninhabited until the Germans established plantations there (Douglas 1969). During the First World War the Marshall Islands were occupied by Japan and after the war were mandated to Japan. In both German and Japanese times Jaluit was the administrative centre. The Japanese presence was largely commercial, and copra production was stimulated (Rynkiewich 1981) until the mid 1930s.

After 1935 the islands were fortified but were captured by the Americans and, after the war, became part of the U.S. Trust Territory of the Pacific Islands (TTPI). In 1946 the populations of Bikini and Enewetak were resettled so that those two atolls could be used for atomic bomb tests and tests continued until 1962; meanwhile Kwajalein was developed as a missile testing base. The Marshall Islands had become crucial to the United States strategic interests in the northern Pacific. Kwajalein remains important as a missile testing site and is to a large extent outside Marshallese jurisdiction. From 1974 separatist tendencies emerged in the country and in July 1977 the Marshall Islands voted in favour of separation from the remainder of the Trust Territory. In May 1979 the Marshall Islands declared self-government under its own constitution and in March 1982 proclaimed itself a Republic. During 1982 and 1983 there was a series of discussions between the Marshall Islands and the U.S.A. on the terms of agreement of the Compact of Free Association (CFA) between the two countries, the future leasing of the Kwajalein missile range and specific compensation for inhabitants of the islands of Bikini, Enewetak, Rongelap and Utirik who had experienced severe social and medical problems as a result of nuclear testing. The CFA, initially signed by the President of the Marshall Islands in May 1982, was approved by a referendum within the country in September 1983 in which about 60% of the population voted in favour of the Compact which was and finally signed in October 1986. The CFA established a special economic and political relationship between the U.S.A. and the Marshall Islands, providing a high level of economic support to the Marshall Islands, though this declines steadily until the Compact terminates in 2001. The financial assistance provided by the U.S.A. amounts to US$41 million for financial year 1992, that is 61 percent of the national income, a proportion that has fallen from the late 1980s. The RMI became a member of the United Nations in September 1991.

## 2.2 Economy

The land area of the Marshall Islands is no more than 120 sq. km. although the lagoon area is 6,500 sq. km. The traditional economy was oriented to both land and sea although land areas are much more critical than lagoon areas as an influence on atoll population size and density (Williamson and Sabath 1982:78-9). In contemporary times sea area has become more important; the RMI has an Exclusive Economic Zone (EEZ) of more than 1.2 million sq.km.(750 000 sq. miles) and the potential economic value of the fisheries resources of the EEZ is considerable. Soils are thin and porous and continuous salt spray restricts the planting of some species to atoll interiors. Variable rainfall (both seasonally and from year to year) is also a constraint to agricultural development. The northern atolls have as little as 6 inches (15 cm) of rain per year and a number are uninhabited (apart from sporadic fishing and foraging trips from other atolls). The northernmost atolls of Enenkeo (Wake) and Bokaak (Taongi) are too dry to support coconuts and on Bikar mature coconuts are not produced during dry periods (Wiens 1962:365). The constraints to agricultural development in the RMI are considerable and are typical of atoll economies. Hazards are not uncommon, including droughts (especially in the north), tropical storms and storm surges, each of which have caused damage in recent years.

Plate 1· A Fragile Environment: Mili



Land tenure in the Marshall Islands is related to social organisation. All land is considered to be the property of the paramount chief, who holds the primary right to land. Lesser chiefs, and matrilineages, have rights to the produce of the lands, whilst commoners also have claims to the produce. Land is divided into strips (weto) which run from the lagoon to the ocean, hence most landholding units have access to the complete range of land and marine resources. Most land is inherited matrilineally. Land may also be given as gifts by paramount chiefs and, increasingly, land can be bought and sold. The legislative and executive branches of a highly centralised government have the power to over-ride any aspect of the customary law or traditional rights that is not convenient to the needs of government, a situation especially true of land tenure, which is becoming more individualistic (Mason 1977).

The traditional agricultural system developed around the combination of three principal tree crops (coconut, breadfruit and pandanus) and the cultivation of taro in pits, but there are wide variations from north to south in crop combinations. In the northern atolls, from Enewetak east to Utirik, taro and breadfruit cultivation is unknown because of limited rainfall. More recently a small quantity of papayas (pawpaws), sweet potatoes, limes and other vegetables have diversified the agricultural system. In the northern atolls arrowroot and pandanus were both important. By contrast, on the five southernmost islands rainfall is heavy and vegetation diverse and a much wider range of food plants is available including some introduced in the German and Japanese eras. Agriculture was everywhere supplemented by fishing. In the northern atolls fishing was much more important than agriculture, because of the latter's limited potential. A variety of fishing techniques was used, including nets, lines, traps and fish poisoning and hundred of different species of fish were available from the reefs, lagoons and ocean. There was a sexual division of labour. Men built houses, fished, gathered food and cultivated gardens; women were responsible for cooking and storing food, caring for children and weaving.

The traditional agricultural system has declined substantially. On many atolls, such as Namu (Pollock 1974) and Lae (Alexander 1978:67), pit taro cultivation has declined significantly and almost ended. On Arno, Cyrtosperma taro was already quite scarce by the early 1950s; the last taro pit was probably dug in the first decade of this century and only a tenth of the pits prepared for its culture were planted with significant amounts (Stone 1951). On Mili, only a few square metres of taro remain at the edge of a vast abandoned taro patch.

Arrowroot cultivation has ended. On the densely populated atolls of Ebeye and Majuro (with the exception of a small area at Laura) traditional agriculture no longer exists. On those atolls, which contain nearly two-thirds of the national population, many young people have never seen or experienced the traditional Marshallese agricultural economy. Consequently, in the last three decades diets have incorporated a large quantity of imported foods. Crude estimates suggest that about 90 percent of all food is imported. These changes have occurred as Marshallese have become more involved in the cash economy, in a similar manner to that of other parts of the Pacific region; the significance of government employment, the dominance of men (formerly the fishermen and the agriculturalists) in formal sector employment, high wages and substantial compensation payments have accentuated the transition in the RMI. By contrast fishing has declined to a much lesser extent, because of technological changes in fisheries (e.g. gill nets, spears, torches and, especially, fibreglass boats and outboard motors) and continued preferences for fresh fish. Overfishing has however depleted some reef areas. No islands are now primarily dependent on local resources.

Under the aegis of the TTPI administration, no concerted effort was made to improve island agriculture in the Marshall Islands although there have been agricultural stations at Jabwor (Jaluit) and Ejit (Majuro) where attention was generally concentrated on increased copra production. The principal (and virtually the sole) domestic source of revenue is copra. A copra-processing mill was constructed in Majuro in the late 1970s; copra prices have been generally unstable so that the mill has often been closed and prices have scarcely encouraged domestic copra production. However the Marshall Islands was the principal copra-producing state in the Trust Territory area and there is potential for future copra development though this is dependent on world prices; currently prices are extremely low and unlikely to rise significantly in the foreseeable future. Output has also declined significantly in the 1980s because of senile trees, minimal replanting, drought (1983), poor storage facilities and migration from the outer islands. Prices are currently subsidised by the government, copra is exported to Fiji and soap produced locally. In November 1991 the copra price rose from 8.5 cents a pound to 12.5 cents per pound on Majuro and from 7 to 11 cents per pound on the outer islands. On those atolls closest to Majuro, that is Aur, Arno and Mili, production per capita is significantly greater, whereas on the most remote atolls, Ebon, Lae, Lib, Ujae, Ailuk and Utirik, production is lower. On Jaluit too, production is lower than might have been expected. The relative dependence of the outer islands, especially in the drier north, on sources of income other than copra sales is considerable. Without copra production most outer atolls would be subsistence economies almost entirely dependent on remittances and government employment for cash incomes yet copra production alone is an inadequate base for an agricultural economy.

Development policy has favoured a movement towards self-sufficiency in agriculture (although it is recognised that total self-sufficiency is impossible given demand for foods like beef which cannot be produced locally). The attainment of self-sufficiency in basic foods, for both economic and health reasons, was the first priority of the Marshall Islands National Development Programme (1981-1995). Two strands of this were the rehabilitation and replanting of copra plantations and the development of vegetable production. In 1981 a Taiwan Agricultural Technical Mission established a farm on Laura and in 1982 a second farm on Wotje both of which were supplying vegetables to urban Majuro by mid-1982. However, by 1983 there was little marketing of agricultural produce and grave concern that the experimental farms were heavily dependent on fertiliser inputs (and hence that production was both expensive and likely to decline over time). After the Chinese agriculturalists departed the farm system declined. The UNDP Integrated Atoll Development Project has sought to encourage agricultural development in the outer islands, focused on Maloelap, but with only intermittent success mainly because of transport problems (UNDP 1991). Overall 'there is a general lack of awareness of the potential of small-scale agriculture in the Marshall Islands' (Marshall Islands 1991:15). Very little agricultural production is marketed from the outer islands, because of transport costs, irregular services and limited production, other than occasional bananas, much of which comes from Laura or Long Island (Rairok). Chickens and pigs are also occasionally sold. A pilot poultry project has recently been established on Majuro, with Israeli support, but is unlikely to become economically viable. There are considerable constraints to increased agricultural production: land shortage (and land tenure constraints) in the urban areas, high labour costs, an educational system oriented to 'white collar' occupations rather than agricultural development, consumer tastes oriented to imported goods (which are often of lesser nutritional value), minimal taxation on imported goods (even those which are also produced locally), limited marketing infrastructure, inadequate and expensive transport and none or few skilled agriculturalists. Given these constraints few effective developments in the agricultural economy are likely.

The commercial exploitation of marine resources is limited, despite a massive investment of time and money, especially since the signing of the CFA in 1986. A fishing base was constructed in Majuro in 1984, with Japanese government assistance. In 1991 the fish base operation was being supplied by about seven long liners and fish were airfreighted to Hawaii and Japan. Large-scale commercial fishing in the EEZ is mainly carried out by Japanese fishing boats; in recent years lease payments have reached more than US$1 million and were $1.2 million in 1988. In that year Japanese fishing vessels caught 19167 metric tons of fish, mainly skipjack tuna, in Marshallese waters. The problems of establishing large scale fisheries, in competition with large Pacific fringe nations and with a lack of relevant skills, have hitherto limited development, but tuna transhipment and canning is possible if such problems as water supply can be overcome. A cannery is currently under construction on Jaluit. The construction of a cannery will put further pressure on fresh water resources, and could contribute to the degradation of water quality, if waste water is inadequately treated; solid waste and smells may also cause environmental problems. There are no adequate data on artisanal fisheries production, hence the extent of change in this sector and the potential role of fisheries in sustainable development are difficult to estimate.

Mariculture (aquaculture) is regarded as having considerable potential in the RMI, especially for giant clam, small clam species and trochus (Marshall Islands 1991: 9). Giant clam cultivation has begun through a joint venture of the RMI government and a local private business; a private giant clam venture also exists. No mariculture ventures in the Pacific have yet been commercially successful hence future success in the Marshall Islands cannot be guaranteed. A pilot project on Callalin Island (Majuro) is investigating the economic potential of seaweed production for the food and pharmaceutical industries, and this may have greater viability.

Tourism is considered a future development possibility, especially because of the location of the Marshall Islands west of Hawaii and between U.S.A. and Japan. There were less than 3000 tourists in 1988 though this is an increase on previous years. Facilities and tourist attractions are currently limited and expansion depends principally on the structure of air fares. Moreover because of the dependence of the Marshall Islands on imports (especially of foodstuffs and beverages), currency introduced by tourists would largely be exported. It would however generate employment in the service sector.

Manufacturing of anything other than copra is conspicuous by its absence. The prospects of establishing further manufacturing industries, even for import substitution, are poor because of high wage levels, limited natural resources (including fresh water), a small domestic market, low import tariffs and other factors. The Marshall Islands EEZ is considered to be relatively rich in metallic nodules but commercial exploitation remains far into the future (Callies and Johnson 1989).

One of the major constraints to social and economic development is the large size of the country, and the small numbers of people outside Majuro and Ebeye. It is, for example, 1100 kms from Majuro to Enewetak. Since 1982 the Airlines of the Marshall Islands (AMI) have provided an expanded service to the populated atolls, and now have international services to Fiji and Hawaii. The RMI has demonstrated a commitment to air transport rather than the expansion of shipping services, and some additional international services have been proposed. The extent to which the cost of air transport will justify such a policy remains to be seen. In 1978 there were only four usable piers or jetties in the country. Field-trip ships visit the outer islands no more than about four times per year and do not run on regular schedules due to such factors as diversions, breakdowns, lack of outer island load centres and docking facilities and climatic disruptions. Only three atolls - Majuro, Kwajalein and Jaluit - have generated electricity though Utirik has solar energy. Wotje and Jaluit have super-dispensaries; Jaluit has a high school. Otherwise the high schools and hospitals are on Ebeye and Majuro, and almost all 'modern' facilities are concentrated on those two islands.

The Marshall Islands is typical of other atoll states, such as Kiribati, in having an extremely limited resource base from which to generate economic development. The thinly scattered population and limited infrastructure are not the only constraints to development. There are limited skills (for construction, technical activities or simply development planning), shortage of agricultural and fisheries manpower in outer islands (following migration) and the combination of a wage structure which discourages private sector employment (see below) and an import policy which effectively discourages local production.

Without substantial changes it will be difficult to reverse the current trajectory of development. Whilst the RMI has achieved almost complete political independence it has moved further towards economic dependence, especially since the signing of the CFA; the value of imports grew from $30.6 million in 1986 to $44.4 million in 1989 whilst the value of exports grew from $1.2 million (a record low) to $2.3 million, resulting in a negative trade balance of $42.1 million. There have been widely expressed sentiments on the necessity for greater self-reliance, yet the reality of achieving this is increasingly improbable, despite the proposed termination of Compact funding in 2001. The principal difficulty of development in the Marshall Islands is not simply one of re-allocating resources towards improved infrastructure, agricultural investment, etc., but is that of producing a fundamental change in attitudes, demanding wage restraints, raised taxation (on imports and perhaps wages) etc, that is extremely difficult to achieve in a small, democratic country where the majority of the population are now urban dwellers.

A significant proportion of all employment is in the government sector. Between 1973 and 1988 the labour force grew from 7558 to 11488; at that time half of all formal sector employment was in the public sector, the majority of that being with the RMI government and the remainder with the municipalities and statutory authorities. Private sector employment is almost entirely in the service sector, especially in retailing. Unemployment increased significantly in the 1980s; the 1988 census recorded a total unemployment rate of 12.5 per cent compared with 9.7 per cent in 1980. Unemployment was highest in Majuro (17 per cent) and Ebeye (14.6 per cent), especially amongst men between the ages of 15 and 29, since the subsistence sector is largely absent on those two islands. Formal measures of unemployment disguise a significant amount of under-employment.

## 2.3 Population and Migration

The early population history of the Marshall Islands is not well-known but attempts to review it have been made elsewhere (Rynkiewich 1972a, 1972b; Connell 1983). Until the second World War the Marshallese population was actually declining and it was not until around 1960 that it reached its pre-contact level. Since then however population growth has been extremely rapid and, in approximately twenty years, between 1960 and 1980, the population doubled. At the 1988 census the population totalled 43,380; by the end of 1991 the population had probably passed 48,000. The population growth rate has been estimated to be around 3.8 per cent per annum. If this is correct, and there are some grounds for speculation, it is the highest growth rate of any South Pacific island state and one of the highest growth rates in the world. At the present population growth rate the population will double in approximately 17 years and will have reached a total of 100,000 around the year 2010. This population growth rate thus places considerable pressure on the limited land and sea resources of the RMI.

There are a number of reasons why population growth has been rapid. Traditional controls over population growth have broken down following mission influence and colonialism; improved medical care and sanitation have contributed to more rapid population increase (especially through the reduction of infant mortality rates and deaths in childbirth); adoption is common in Marshallese society, as elsewhere in Micronesia; there has been limited response to the availability of modern methods of family planning, since women usually play a limited role (other than motherhood and home-making) in contemporary society. However in the past two decades, although there appears to have been little change in the birth rate, the fertility rate has declined from 7.9 to 7.2 (hence women are having slightly fewer children than hitherto) and there is some degree of optimism that implementation of the National Population Policy (1990) will increase the awareness of population issues at both the local community level, and amongst senior politicians and enable more success with the implantation of Norplant contraceptive devices. However, in the short-term, there is no reason to believe that there will be any significant reduction in the population growth rate this century, as a large number of children enter the fertile age groups. Indeed just over half the population (51 per cent) are aged 14 or under; this too is one of the highest percentages in the South Pacific regions and demonstrates the potential for further growth.

The overwhelming migration trend in the Marshall Islands is the concentration of populations on the two atolls of Majuro and Kwajalein where, since the mid-1960s, population has grown much faster than elsewhere in the country. In 1980 some 60 per cent of the population were on those two atolls; by 1988 that proportion had reached 65 per cent. However on Ebeye (Kwajalein) the rate of growth has now slowed to that of the RMI as a whole, whereas in Majuro the annual growth rate was about 6.3 per cent in the last inter-censal period.

Majuro, which now has a population of over 20,000 had a population of less than 12,000 in 1980. This degree of concentration is much greater than in any of the other Pacific atoll states. It has resulted in extremely high population densities; Ebeye's population density in 1988 of approximately 23,500 per square kilometre is one of the highest in the world, though in urban Majuro (Delap-Uliga-Darrit) the density was half that. Such rapidly growing, high-density urban populations have led to environmental problems (e.g. waste disposal, pollution of water lenses, inadequate sanitation, noise, etc), health and nutrition problems, associated with poor water and sanitation (e.g. infectious and parasitic diseases, skin diseases, gastro-intestinal diseases and malnutrition) and some social problems. In the recent past some of these problems were particularly severe, especially in Ebeye (Connell 1983: 24-25), but better environmental management there has now reduced their severity. The built-up nature of the urban areas has meant that there is little replenishment of freshwater lenses and that the two urban areas are much more vulnerable to natural hazards. The large number of children, especially in the two urban centres, places a great burden on the working population, through the establishment of a high dependency rate, and on educational (and other) services; this pressure, most obvious in the urban centres, in turn emphasises the need to improve urban services, exacerbating the urban bias in service provision (and thus wage and salary employment) which accentuates migration from the outer islands. Nevertheless there is a severe, and increasingly visible, employment problem in the urban areas.

There have been some historic attempts to encourage what the National Population Policy now refers to as 'a more desirable population distribution' or 'spatially integrated development'; these early attempts, which mainly focused on Ebeye, had limited success (Connell 1983: 25-26). Present policies seek to encourage more rapid development in the outer islands, to some extent in association with the UNDP Integrated Atoll Development Project (IADP) which has been based in Maloelap, and also through attempts to develop Jaluit and Wotje as regional centres, with secondary health and education services, superior to those on other outer islands. However population growth on both those islands has been only half that in the RMI as a whole. Indeed in the last inter-censal period only two atolls, Jabat and Ujae, experienced a population growth that was more rapid than that of the nation. All the available evidence therefore suggests that population decentralisation is no more successful now than it has ever been and thus that Majuro is likely to continue to grow at a

Plate 2: Urban Majuro: Rairok (above) and Uliga (below)

rate significantly faster than that of the RMI as a whole. Current planning strategies are unlikely to ameliorte this situation (Gorenflo 1990).

Until the signing of the CFA almost all migration in the RMI was internal. International migration was confined to those moving to the USA for tertiary education and most of these graduates subsequently returned to the RMI, although this is now less true. The signing of the CFA gives all Micronesian citizens unrestricted access to the U.S.A.. The Compact provides that citizens 'may enter into, lawfully engage in occupations and establish residence as a non-immigrant in the United States and its territories and possessions'. This has already encouraged a movement of some of those with skills who cannot find government employment, more permanent overseas residence of students and some migration to Saipan and Guam. There is also a small but significant movement into the US military forces. There are, unfortunately, no data on international migration from the Marshall Islands though many Marshallese are overseas (especially in Hawaii and the west coast of the USA); in time there may become a more obvious skill and brain drain, as government employment opportunities within the Marshall Islands decline, as they are likely to do in parallel with the decline in Compact funding. Emigration to the U.S.A. is thus viewed as a necessary future 'safety-valve', and was deliberately provided for in negotiations with the U.S. government over the CFA hence 'future emigration...far from being seen as a menace that threatens to deplete the islands' human resources, is counted upon as an essential element in the Micronesian states' strategy for economic and political survival' (Hezel and Levin 1989). If environmental conditions worsen, especially through greenhouse-induced sea level rises, there may also be some migration of 'environmental refugees'. It is readily apparent, at the very least, that international migration to the USA provides one response option to any deterioration of social, economic and environmental conditions.

## 2.4 Health and Nutrition

The health status of the RMI population is difficult to assess because of the absence of adequate data. The main causes of mortality in the mid-1980s have been influenza and pneumonia, diarrhoea and intestinal disease, diabetes and heart disease, and there has been a relatively high but falling infant mortality rate (estimated at 63 per 1000 in 1986). Chronic health conditions, associated with the epidemiological transition, have become increasingly significant. The main reported causes of morbidity are respiratory diseases, diabetes, injuries and accidents.

Deaths among children aged five or under have averaged more than a quarter of all deaths in recent years, and more than a quarter of all births are to women under 19 years of age. The main causes of infant mortality are prematurity, diarrhoea and other intestinal diseases, influenza and pneumonia, birth-related conditions and nutritional deficiencies. Deaths due to prematurity have been related to an increasing number of high risk pregnancies (including very young mothers and short births and to poor maternal) nutrition, whilst deaths due to prematurity are often related to malnutrition. Infant malnutrition seems to be the result of two factors: a significant increase in recent years in the consumption of imported foods of limited nutritional value and a switch from breast-feeding to bottle-feeding. Food and nutrition are thus major health issues in the RMI.

The increasing number of malnourished children admitted to Majuro and Ebeye hospitals, and rising proportions of illnesses associated with multiple vitamin deficiencies in the outer islands, led to a National Nutrition Survey being undertaken between September 1990 and May 1991. The survey revealed that amongst children aged less than seven, some 58 per cent were underweight and 39 per cent had anaemia; for children aged between 7 and 14 the comparable proportions were 60 per cent and 16 per cent. Some 3-4 per cent of children had evidence of Vitamin A deficiency; a proportion of more than 1 per cent is usually regarded as of epidemic proportions (although Chuuk (FSM) has a higher proportion). The incidence of malnutrition was higher than had been anticipated, and was attributed to an inadequate calorie intake, though inappropriate habits, including faulty food preparation, unsuitable infant and child feeding patterns and the consumption of non-nutritious food, were also causative factors. This structure of under-nutrition amongst children occurred at the same time as the over-nutrition of women; 30 per cent of all women in the reproductive years 15-49 were overweight and 31 per cent were obese. This situation is probably also true of many men. Significantly the highest prevalence of malnutrition was on Enewetak; the people of this island are completely supported by USDA-Food. Otherwise nutrition appeared better in the outer islands than in the urban centres, posing the question 'why would one choose to be unemployed and live in a crowded urban centre rather than live on an uncrowded outer atoll where local foods could be grown and where fish are abundant?' (Palafox 1991). The partial outcome of this situation is that children have poor intellectual development, high rates of school absenteeism and women have poor pregnancy outcomes. The resultant low educational achievement and high rate of sickness reduces the development of a productive workforce, lowers the quality of life and puts considerable pressure on health services in the RMI.

Malnutrition is associated with changing patterns of food consumption, partly associated with urbanisation. The RMI has an exceptionally high volume of imported foods and drinks (contributing substantially to the deteriorating balance of trade); in 1988 food, beverages and tobacco represented 44 per cent of the value of all imports, one of the highest proportions in the world. Significant components of these food imports were rice, flour, tinned and frozen meat and sugar. A by-product of this import situation is the volume of waste materials that sometimes present environmental problems. Diets have been transformed in the post-war years, away from one based on local foods (breadfruit, taro, banana, coconut and pandanus) to one in which rice has now become a staple; even in the outer islands imported foods are now the major component, a situation that was firmly established by the mid-1960s (Pollock 1974, 1975). Poor diets, especially in urban areas, are related to poverty since rice and flour are the cheapest foods and turkey tails, which are virtually solid fat, are the cheapest 'meat'; local fish costs more in stores than imported chicken, hence there is a disincentive to the expansion of artisanal fishing. In advance of other parts of the TTPI area the Marshall Islands imposed import taxes on foodstuffs, soft-drinks and alcoholic beverages in an attempt to increase self-reliance and diminish worsening nutrition levels, but this has not significantly reduced imports.

Because of the magnitude of food dependency and the significance of malnutrition, the high level of urbanisation and unemployment, and the difficulties of agricultural development on atolls, the tasks of increasing family food production and improving nutrition 'are the most difficult in the Pacific region' (Schoeffel 1991: 9). Unless government at national and local levels gives greater priority to increasing food production for domestic consumption, the situation will be unchanged. Otherwise the main problem facing the health situation is the inadequate level of services provided, especially in the outer islands, where there are no doctors or dentists. These disadvantages cannot easily be overcome without very substantial injections of income, new priorities and adequate training programmes.

## 3. THE ENVIRONMENTAL CONTEXT

### 3.1 The Atolls

The RMI is made up of 29 atolls and five low-lyiog islands - atolls without lagoons - that are typical of island environments in other parts of the Pacific, and especially similar to those of Kiribati to the immediate south (Sullivan and Gibson 1991). Atolls are accumulations of the remains of calcareous reef-forming organisms usually arranged into a rim around a central lagoon, which is largely distinct from the open sea. They are found in tropical ocean waters within $20^{0}$ latitude of the equator. Drilling results from a number of atolls essentially confirm the early speculations of Darwin (1842) that the reef deposits accumulated on the peaks of submerging mid-ocean volcanoes (Scott and Rotondo 1983a and b). As an island sinks under its own weight the reef organisms build upwards in an attempt to keep pace with the relative rise in sea-level. As part of the environmental studies made in the Marshall Islands in connection with atom-bomb testing, the U.S. Navy drilled a series of deep test holes on Enewetak atoll. Two of the test holes went through a 3,936 foot (metres) cap of shallow-water reef limestone and bottomed in basalt. The age of fossils in the deepest limestone is Eocene, indicating that Enewetak atoll is the top of a coralline accumulation that began growing upward about 60 million years ago (Schlanger, 1963). Drill holes dug on Uliga, Majuro appear to have so far yielded only preliminary results on geological structures (Yonekura 1988). Much of the detailed knowledge of the geology of the Marshall Islands is contained in a series of monographs (Emery et al 1954; Fosberg et al 1956), the details of which are of limited significance here.

In Quaternary times the slow upward growth of the biogenic pile has been interspersed by glacio-eustatic fluctuations in sea level (Stoddart 1973; Steers and Stoddart 1977; Bloom 1980; Wiens 1962). For long periods when sea levels fell, the atolls were exposed to subaerial weathering and a karstification of the limestone deposits (Brook and Ford 1978; Emery et al 1954). At times of high sea level they were submerged and corals recolonised the atolls' surfaces (Hopley 1982; Davies and Hopley 1983); during the Pleistocene era each atoll was affected by four or more such fluctuations. Such Pleistocene unconformities have been reported for both Bikini and Enewetak (Emery et al 1954; Ladd and Schlanger 1960). Thus, the broad geological structure of coral atolls comprises a succession of old weathered limestones that form an irregular substrata on which the most recent (Holocene) deposits have accumulated. For the Marshall Islands this geology is well described for Laura, Majuro (Hamlin and Anthony 1987). Intertidal and shallow subtidal areas that form the atoll rims and reef flats are composed mainly of coarse coral detritus; these deposits reach thicknesses up to 25 metres (Wheatcraft and Buddemeier 1981; Davies and Hopley 1983), but in some cases may be as thin as five metres. Reef-rim detritus becomes finer towards the lagoon (e.g. Ayers and Vacher 1986) where the main sediment types are biogenic sands and calcareous muds (Figures 1a and b).

The reef systems of Taongi and Bikar atoll to the north, are unique in the Marshall Islands, and unusual generally, in that they almost completely encircle the atoll, have only one very narrow pass and have an unusual 'stepped' windward reef structure with an elevated lagoon and elevated reefs sloping leeward. Lagoon waters are shallow, with depths not exceeding 100 ft (30 m), and the higher lagoon water levels, sometimes up to 3 ft (1 m) above ocean water levels are maintained at such consistently high levels by the influx of wind driven waters over the windward ocean reef. Unable to escape easily due to the lack of reef channels, the water rushes out of the lagoons through the narrow winding channels creating pressure waves of up to 3 ft (1 m) and making small boat passage hazardous except for the short slack tide period. Water also flows like a waterfall over the coral covered rims and flats of the sloping leeward reefs. The lagoons have fine sediment bottoms with many coral heads and patch reefs, some reaching to the surface. Another unusual feature is the presence of overhanging ribbon reefs in the lagoon, probably due to the stable elevated lagoon levels and dampened tidal effects (Thomas 1989: 33).

Variations in coral assemblages and growth styles reflect exposure of atoll margins to prevailing trade winds (Wiens 1962; Hopley 1982). Typically, atoll rims are higher and narrower and reef flats are better developed on high-energy windward coasts (Wiens 1962). These are constantly scoured and planed off by wave action, and dissected by seaward-trending surge channels. Here too, storm waves deposit coral rubble that progrades lagoon-ward in washover lobes (Wiens 1962). Storm ridges and spits of coarse rubble that build above sea level act as nuclei around which grow small islands (motu) (Figure 1c; Plate Five).

Radiocarbon dating studies (Davies and Hopley 1983; Hopley 1982; Hopley and Kinsey 1988; Marshall and Jacobsen 1985) show that, in most cases, upward reef growth lagged behind rising sea level during the Postglacial Marine Transgression (PMT). It was not until one or two millennia after sea level stabilised that reef building corals reached shallow sub-tidal depths; here living corals became vulnerable to storm erosion, at least on wider coasts. Much of the rubble that the storms generate is washed landwards. This rubble, together with in situ reef, becomes cemented in the intertidal zone to create reef flats (Figure 1b), forming the foundation for islands of calcareous sand and coral rubble build above sea level (Hopley 1987).

Precise radiometric dating of the time of formation of coral reefs is made extremely difficult by the absence of in situ organic material and the rapidity with which diagenetic processes - chemical and bio-chemical dissolution, biological abrasion and accretion, reprecipitation and cementation - act on the detrital carbonate. The same phenomena inevitably reduce the accuracy with which relative sea levels can be determined. Nevertheless, there is a large body of data to show that intertidal reef flats typically have radiocarbon ages less than 5000 years BP and coral islands are mostly younger that this age (Figure 2). Atoll islands are therefore amongst the most recent of geological formations and are also the youngest in terms of colonisation by humans and by fauna and flora.

Islands on atoll rims vary enormously in size aod shape but all are composed of mixtures of coral/algal rubble and calcareous sand and rarely rise more than three metres above mean sea level (Wiens 1962). In the Marshall Islands the highest point is usually assumed to be 3 metres at Laura, Majuro. Cementation in the intertidal and even supratidal zone undoubtedly contributes to their stability (Montaggioni and Pirazzoli 1984). However, the occurrence of exposed and eroding outcrops of beachrock/coral conglomerate on the one hand and newly formed boulder ridges and sand spits on the other indicate that islands are constantly changing shape (Wiens 1962; Hopley 1987).

Island morphologies are diverse. They include narrow, elongated land-forms aligned parallel and relatively close to reef crests, termed 'motu' by Stoddart and Steers (1977), series of small islets separated by the tidal channels and relatively large 'triangular' land areas located at bends in the atoll rim where

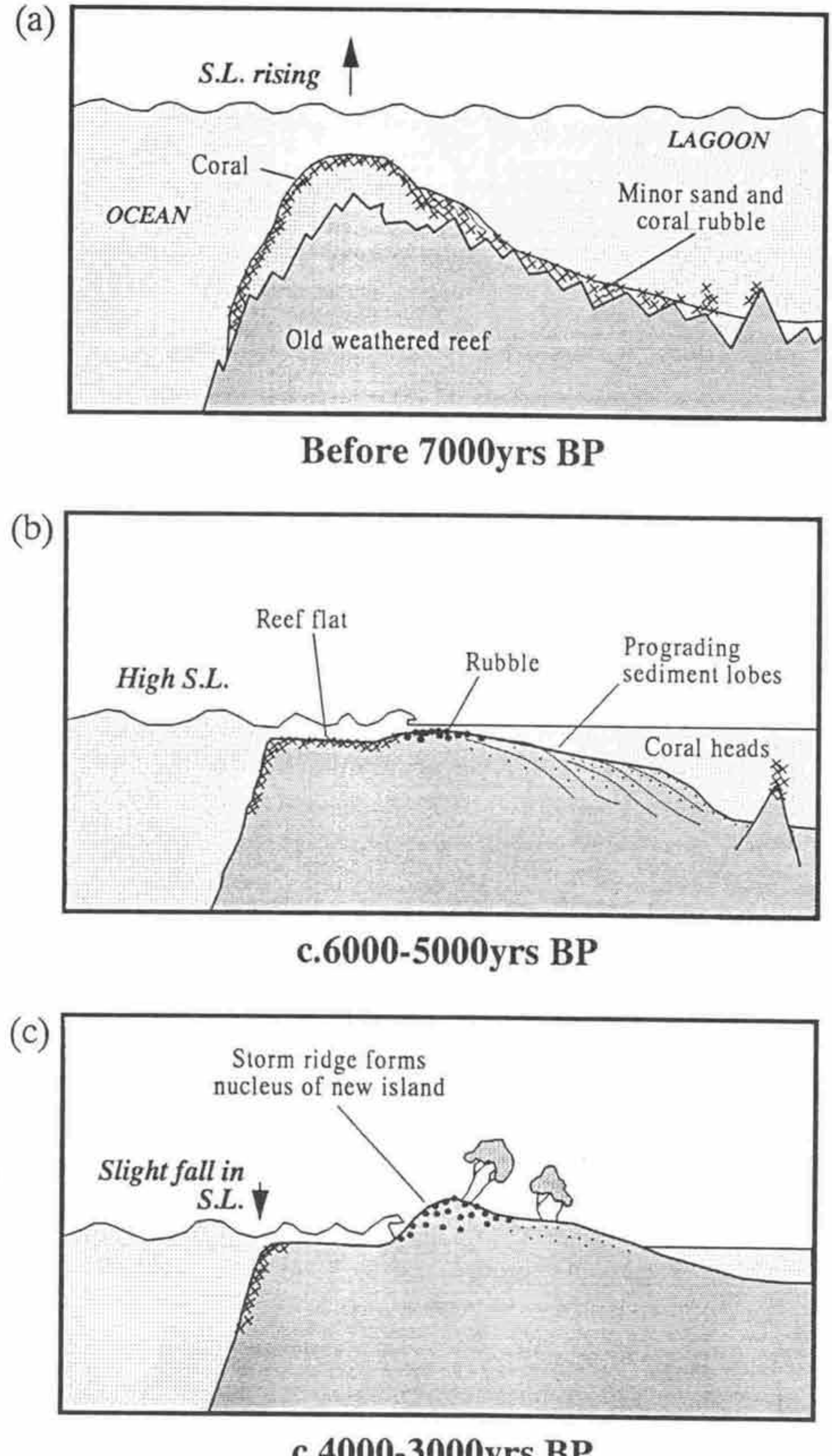





Figure 1: Atoll Formation and Modification

(a) During the PMT, corals colonised old limestone surfaces, but in most cases their upward growth lagged behind the rapidly rising sea surface.
(b) Shortly after sea level stabilised, coral reefs grew up into shallow depths and rubble accumulated to form planar reef flats in the intertidal zone.
(c) A slight fall in sea level during the late Holocene promoted the formation of storm rubble mounds that became the nuclei for island growth.
(Source: Roy and Connell 1991: 1060)

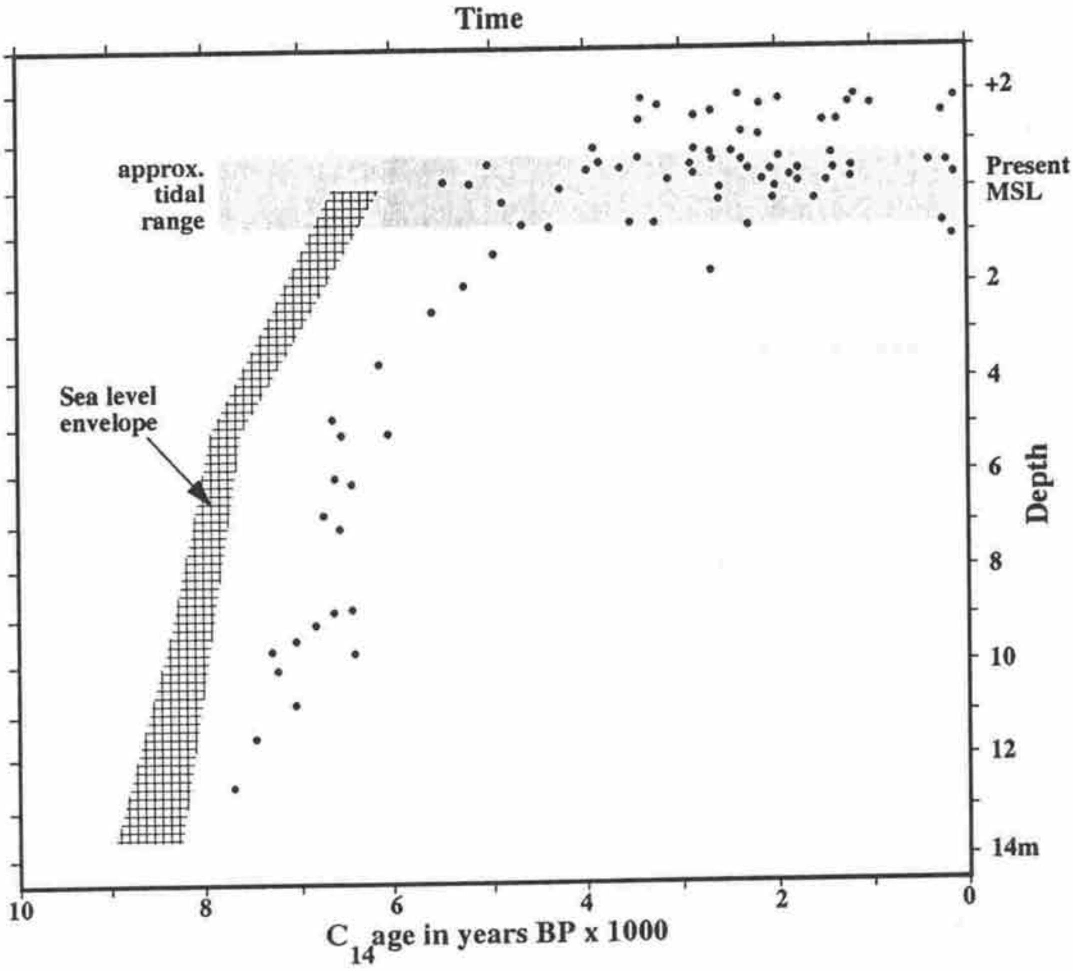



Figure 2: Atolls, Tidal Ranges and Time

Radiocarbon dated material from the supra-tidal parts of atoll islands are mostly less than 4000 years old. Here data from a number of sources is shown in relation to the sea level envelope for SE Australia.

(Source: Roy and Connell 1991: 1062)

reef flats are particularly wide, termed 'vegetated sand cays' by Stoddart and Steers (1977). These triangular islands show beach ridge patterns that indicate the action of convergent waves. The significance of narrow, elongated islands and series of small islets (often located on the same atoll) is unclear. In some cases the small islets seem to be erosional remnants of a larger continuous island that has disintegrated (see Stoddart and Steers 1977: 65); in other cases, the islets appear to be accretionary and may eventually amalgamate to form a larger landmass. In the case of Majuro, the small islets (now linked by causeways) that link D-U-D to Laura were a result of disintegration after the 1905 storm; since then, before the causeways were constructed, an accretionary phase took over. Measurements by Emery and others (1954) show that most reef islands in the Marshall Islands are less than 1000 metres long and 500 metres wide. In other atoll groups, islands may reach considerable lengths but only triangular islands exceed widths of one km, and then rarely.

The building of atoll superstructures, especially islands, results from a combination of processes of small scale erosion and accretion, that can be observed on a day to day basis, interspersed with catastrophic changes caused by extremely violent storms (cyclones and hurricanes) that occur quite rarely. Alkire (1988), Wiens (1962) and McLean (1980) document a number of historical storm events in which waves passed across islands at depths up to 8 metres above the land surfaces, hundreds of islanders died and whole island habitats were destroyed - either washed away or buried in rubble. Series of beach ridges and recurved spits show that islands with these features have undergone a net building or accretionary phase at some time during the last 2000-3000 years. In contrast, features that indicate contemporary erosion include tidal channels intersecting islands and 'makatea' (uplifted cemented coral reef) surfaces around island margins and on reef flats. The ubiquitous problems of dating transported materials that make up the islands have delayed development of meaningful models of island evolution. Based on evidence from the case of Ontong Java, Solomon Islands (Bayliss-Smith 1988), it would seem that very rare and large storms (hurricanes) are critical in generating the new stores of coral rubble on reef flats, and these are subsequently redistributed to maintain islands and infill lagoons. Bayliss-Smith (1988) follows Stoddart et al (1978) in interpreting these changes in terms of 'dynamic equilibrium' (rather than stages in an evolutionary progression) with periods of island accretion alternating with (and largely balancing) erosion. The periodicity of this cycle depends firstly on the 'relaxation time' or rate of recovery of the land form and, secondly, on the recurrence interval of major rubble-generating storms. (Rates of coral regrowth may exert an independent control on rubble-production). The recurrence intervals of these two processes are different with the former being shorter than the latter.

It is reasonable to propose that a particular equilibrium state or condition will vary from atoll to atoll, and even within a single atoll, and will be manifested in terms of island size and spacing. Clearly, not all islands are presently in equilibrium. Larger islands may approximate to this condition (quasi-equilibirum) but small sand and shingle cays on exposed reef flats probably do not. The latter are commonly remnants of large rubble ridges related to single storms; they are subject to constant fluctuations in size, shape and elevation and many have short life spans.

A state of disequilibrium may arise if eovironmental conditions, such as relative sea level or storminess, change with time. For example, island morphologies can be expected to differ depending upon whether an atoll is undergoing slow submergence or emergence. The theoretical effect of slow changes in relative sea level can be predicted: negative movements would tend to promote the accumulation of sediment masses while positive movements should increase erosion. Many of the early observations of atoll islands did in fact infer a slight fall in sea level (Wiens 1962: 95). While this trend has been confirmed by C14 dating in some areas (Hopley 1982; Chappell et al. 1982) it is disputed by others (Newell and Bloom 1970; Bloom 1980; Curry et al. 1970; Montaggioni and Pirazzoli 1984). These differences are mainly because of the radiocarbon dating problems mentioned above, but also because the eustatic changes are so slow (0.1 to 0.2 mm per year) that they are masked or modified by local tectonic trends (Spencer et al. 1987).

A major control on the quasi-equilibrium state of atoll islands is storm intensity and variations in this factor will almost certainly be reflected in island morphology. In a spatial sense, McLean (1980) has shown that cyclone frequency varies latitudinally, generally increasing away from the equator; it is therefore conceivable that atoll islands will show progressive morphological changes in the same direction - a hypothesis that remains to be tested through the careful documentation of island heights and morphologies over a wide range of latitudes. In a temporal sense, Bayliss-Smith (1988) has suggested that storms in the mid-Holocene were more frequent and intense than at present and, at this time, motu islands slowly increased in size. He believes that the trend has reversed during the late Holocene and islands then slowly reduced in size. Regional studies to document island morphology, size and location on atoll rims and the nature of inter-island channels, reef flats etc., such as were undertaken by Wiens (1962) and others in the 1950s, need to be initiated to test the above relationships. In several parts of the Pacific, including the Marshall Islands, there are a number of aerial photographs, dating back to the war that would enable such studies to be undertaken for the past half century.

There is growing evidence that the impact of greenhouse-induced sea level rises will not be the same everywhere. Bryant (1988) has shown how past sea level changes have been influenced by local climatic and oceanographic factors - factors whose variability may increase as the greenhouse effect becomes more apparent. The nature of existing coastlines - whether cliffed, sandy, swampy etc - will also determine the impact of the Greenhouse effect (Thom and Roy 1988) as will the diversity of coral island types (Wiens 1962: 41-44). A number of factors influence the size, morphology and positions of islands around the atoll rim. Storm patterns control the size of gravel ridges and determine how frequently they are formed; tidal ranges transport reef flat material away from islands and into lagoonal sinks; rainfall affects cementation/dissolution processes within the coral rubble pile; and biological processes, such as particular coral or algal growth styles, influence the generation of material to form the islands. These dynamic factors operate within a broad framework determined by the local eustatic history and inherited geology of individual atolls or atoll groups.

## 3.2 Climate, Hydrology and Oceanography

The Marshall Islands has a hot and humid climate, influenced by its oceanic equatorial setting, wholly within the tropics, and dominated throughout the year by easterly winds. The average annual temperature is 81$^{o}$F (27$^{o}$C), with monthly means scarcely varying from 80.7$^{o}$F to 81.4$^{o}$F. The maximum daily variation is about 12$^{o}$F (7$^{o}$C). Temperatures are much the same throughout the country. Relative humidities are also much the same throughout the country, ranging from around 83 per cent at night to 76 per cent at midday. However meteorological records are inadequate on most atolls and much of what can be said about the climatic pattern must be inferred from the vegetation (Fosberg 1990) and, because of human-induced changes, this is an insensitive indicator.

There is some climate seasonality, marked by changes in rainfall and windspeeds; there are also significant regional variations in rainfall. The southern atolls, including Majuro, where long-term weather data exist (Table One) have high rainfalls that average between 3000-4300 mm (120-170 inches) whereas the northern atolls receive 1000-1750 mm (40-70 inches). The general relationship between latitude and annual rainfall for the Marshall Islands is well-known (Arnow 1954; Fosberg 1956). Wake (Enenkeo), where there are also long term weather records, has an annual rainfall of 936 mm (37 inches). The northernmost atolls, Wake, Taongi and also Bikar, are even drier, support a very limited flora and fauna and have not been occupied in recent times by Marshallese populations. Annual rainfall in Majuro (Delap) averages 3500 mm (130.4 inches) and there are seasonal variations between the dry months of December - April, with February having an average rainfall of 158 mm (6.09 inches), aod the wet months of April-November, with October having an average rainfall of 390 mm (13.96 inches). Similar seasonality of rainfall probably exists throughout the country. Rain usually occurs in brief storms, hence sunshine hours are everywhere long. Trade winds prevail in the dry months whereas weaker winds, and occasional doldrum conditions, prevail in the wetter months. Droughts are relatively infrequent, other than in the 1982-83 period, when drought occurred in many parts of Micronesia, in association with a major shift in the El Nino-Southern Oscillation (ENSO), and in early 1970 (Fosberg 1990). On most of the southern atolls water shortages were historically infrequent.

Table 1: Rainfall and Temperature

(Recorded at Majuro in the period 1955-79)

| Month | Average rainfall | Average | Temperature Maximum | Minimum |
|---|---|---|---|---|
| | cm | °C | °C | °C |
| January | 20.3 | 27.0 | 29.2 | 24.8 |
| February | 15.8 | 27/3 | 29.5 | 25.0 |
| March | 23.2 | 27.3 | 29.3 | 24.9 |
| April | 30.7 | 27.1 | 29.5 | 24.7 |
| May | 30.8 | 27.2 | 29.7 | 24.8 |
| June | 31.3 | 27.2 | 29.7 | 24.7 |
| July | 32.2 | 27.2 | 29.7 | 24.7 |
| August | 28.9 | 27.3 | 29.9 | 24.8 |
| September | 33.3 | 27.4 | 30.0 | 24.7 |
| October | 39.0 | 27.3 | 30.0 | 24.7 |
| November | 34.7 | 27.3 | 29.8 | 24.8 |
| December | 28.5 | 27.2 | 29.4 | 24.9 |
| Annual | 348.7 | 27.2 | .... | .... |

(Source: Laird 1989: 381)

The Marshall Islands is to the east of the main typhoon (cyclone) belt in the northern Pacific, hence major storms are relatively rare. However because the islands are atolls storm damage can be severe, and storm surges can have a substantial impact. The most recent typhoons to have a impact in the Marshall Islands were in 1905 and 1918; the typhoon of 1905 formed several breaches on the southern side of Majuro atoll, which was previously continuous between Delap and Laura, demonstrating the instability of atoll environments. In 1958 a typhoon destroyed several buildings in the old capital of Jabwor on Jaluit. Tropical storms have caused problems in recent years. In January 1988 Tropical Storm Roy, with winds gusting to 52 miles per hour (83 km per hour) struck Ebeye, resulting in waves of 2 to 3 metres; one person died and more than a quarter of homes on the island were destroyed. In November 1991 Tropical Storm Zelda battered the lagoon shore of D-U-D; major portions of newly infilled lagoon areas were washed out and part of a new lagoon 'sea wall' was damaged (Plate Three). On Ebeye many houses were damaged and the population re-housed in the school. By Pacific standards neither Roy nor Zelda were significant storms. Though the Marshall Islands has never experienced a tsunami, tidal waves and storm surges have caused damage. In 1979 a series of tidal waves inundated urban Majuro, and caused damage running into millions of dollars, over a two week period; land, houses and government buildings were destroyed. There is some indication that global warming could contribute to the increased incidence of hazard events of this kind. With the exception of drought conditions in northern atolls, high energy storm waves, especially in the period October-December when sea levels are highest, represent the most significant natural hazard that the Marshall Islands experiences.

The capacity of atolls to support populations is closely related to rainfall, and to the existence of a permanent groundwater system (Wiens 1962). Islands above a certain size, about 1.5 hectares or 200 metres in diameter, typically contain a permanent lens of freshwater surrounded by salt water (Figure 3) The lens - like shape of the freshwater body is governed by the Ghyben - Herzberg principal which is primarily a function of density differences between salt and fresh water. The volume of the lens is roughly proportional to the surface area of the atoll. Freshwater moves radially outwards under gravity head towards the coastal margin of the island to discharge into the sea. Some of the freshwater mixes with underlying seawater to form a transition zone of mixed, or brackish water. The freshwater with a density of 1,000 grams per cubic centimetre (g/cc) displaces the underlying saltwater with a density of 1.025

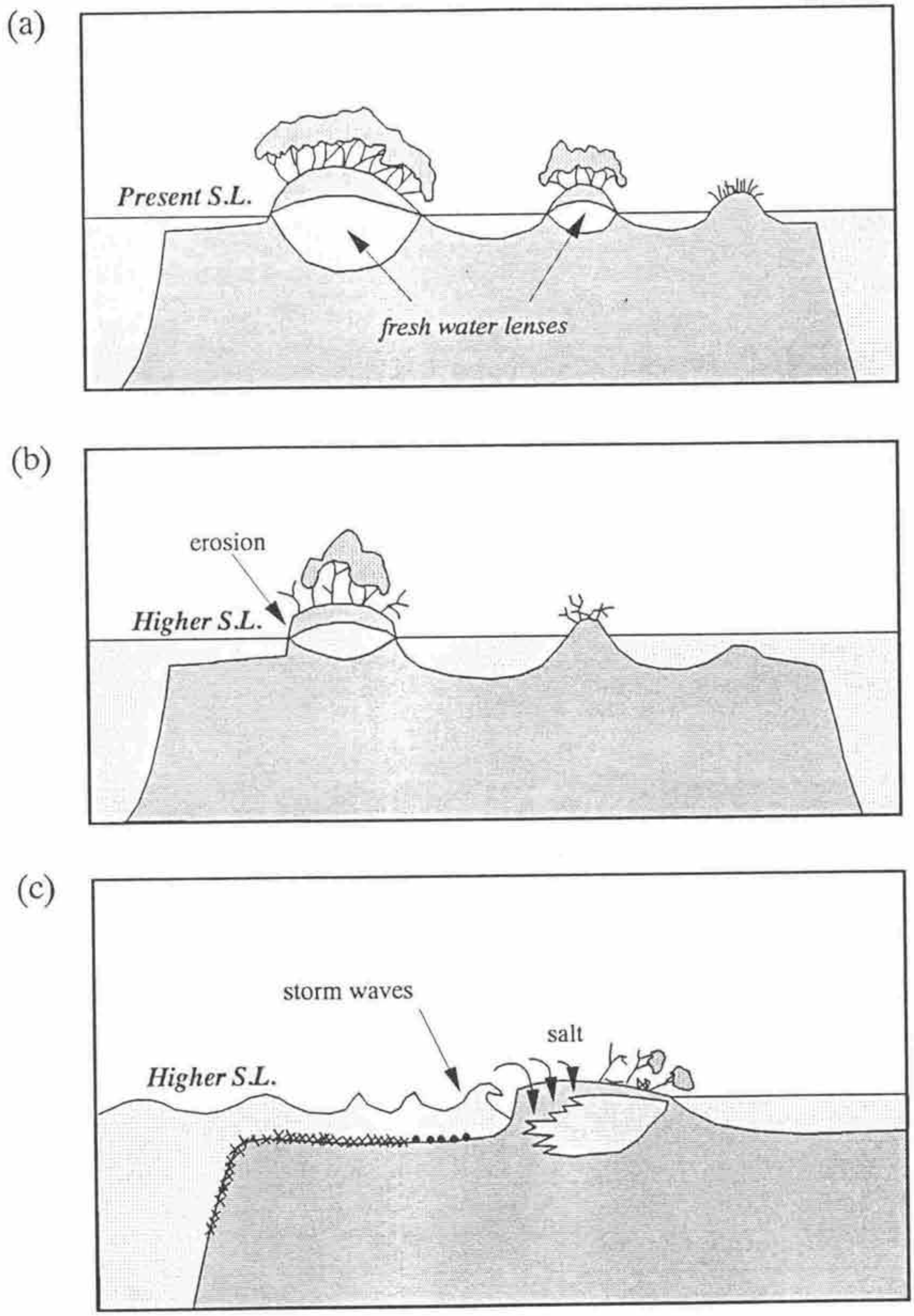





Figure 3: <u>The Changes in Freshwater Lenses</u>

The Ghyben-Herzberg freshwater lenses vary in size under present - day islands (a). They will be significantly reduced or even disappear if sea level rises and island shorelines erode (b). Because of the loss of "Freeboard", storm overwash of the islands will cause salt intrusion into the groundwater to occur more frequently (c).
(Source: Roy and Connell 1991: 1065)

Plate 3: Uliga: Lagoon 'Sea Wall' and Storm Damaged Restaurant

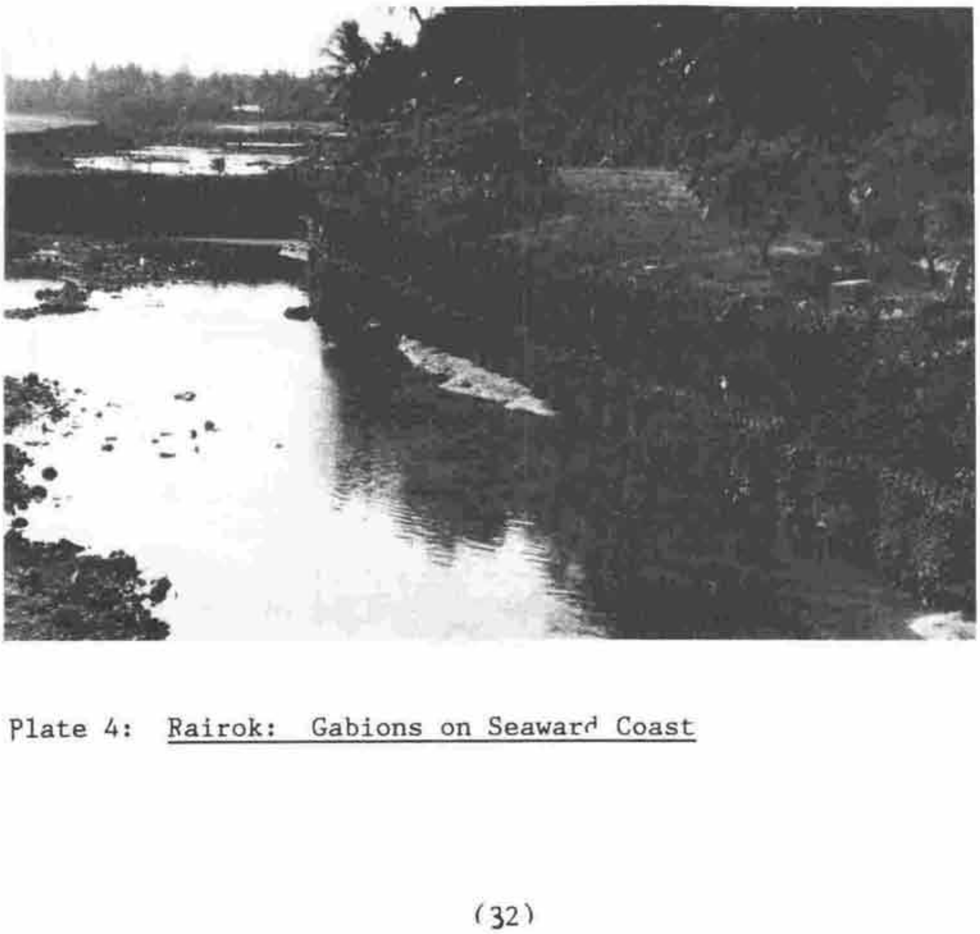


Plate 4: Rairok: Gabions on Seaward Coast

g/cc, to a depth roughly 40 times the elevation of the lens surface above sea level. This is known as the Ghyben-Herzberg relation. The actual thickness of freshwater is influenced by the recharge and discharge rates, size and shape of the island and the hydraulic characteristics of the aquifer. The thickness of the transition zone is affected by mixing induced by tidal fluctuations, variations in recharge rate, and the rate and direction of groundwater flow. Other factors influencing the character and behaviour of the freshwater lens include annual rainfall, permeability of the rocks beneath the island and mixing due to storm or tide induced pressure gradients (Buddemeier and Holladay 1977; Ayers and Vacher 1986; Jacobson and Taylor 1981). Rainfall is the sole source of recharge for lenses. Rainfall events of sufficient intensity and duration recharge the lens, as is apparent in the case of Laura, Majuro (Figure 4). Thus, for example, recharge derived from a significant rainfall event in the first week of January caused a rapid water-table rise, followed by a exponential decline as the recharge-discharge balance was restored. Fresh water bodies are normally absent on atolls. In the Marshall Islands, only one atoll, Mejit, has a brackish fresh water lake, though several have central depressions, where taro patches are often little different from swamps. Milkfish occur in some of these ponds. Such surface water supplies are of no use for potable water.

Evapotranspiration (ET) diminishes the amount of rainfall that reaches the lens as recharge. ET is a collective term for the evaporation of rainfall and transpiration of soil moisture by plants. Hunt and Peterson (1980) have determined that the ET loss was between 40 and 60 per cent of the rainfall at Kwajalein atoll. Similar calculations for Laura, Majuro, based on an average rainfall of 140 inches (3600 mm) give an ET value of about 50 per cent of rainfall, or about 70 inches per year. For 70 inches of recharge per year and a catchment area over the potable lens of about 1.4 sq. km., the average annual recharge to the freshwater lens at Laura becomes 1.83 million gallons per day. This is an average figure and varies with rainfall and discharge from the lens (Hamlin and Anthony 1987: 19).

In most small atoll islands, a relatively small ground-water flow and continuous tidal fluctuation result in a relatively thick transition zone and a thin lens of potable freshwater, as on Kwajalein (Hunt and Peterson 1980). In general, the freshwater lens is thicker on the lagoon side of the atoll because of the lower permeability of lagoon side sediments relative to ocean side sediments. This characteristic of the atoll freshwater lens was first described by Cox (1951) in

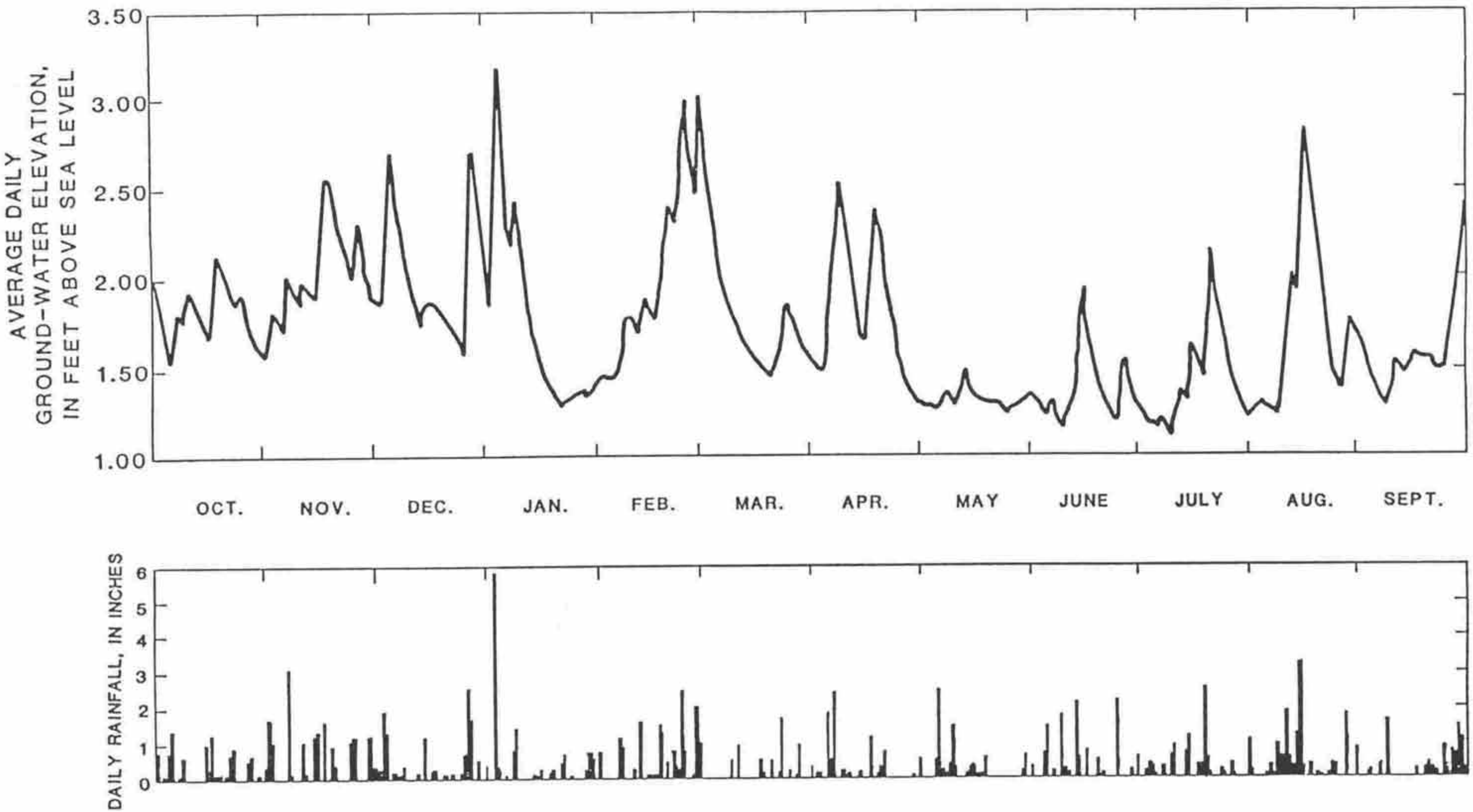



Figure 4: Rainfall and Groundwater Level Change at Laura (October 1984 to September 1985)

(Source: Hamlin and Anthony 1987: 20)

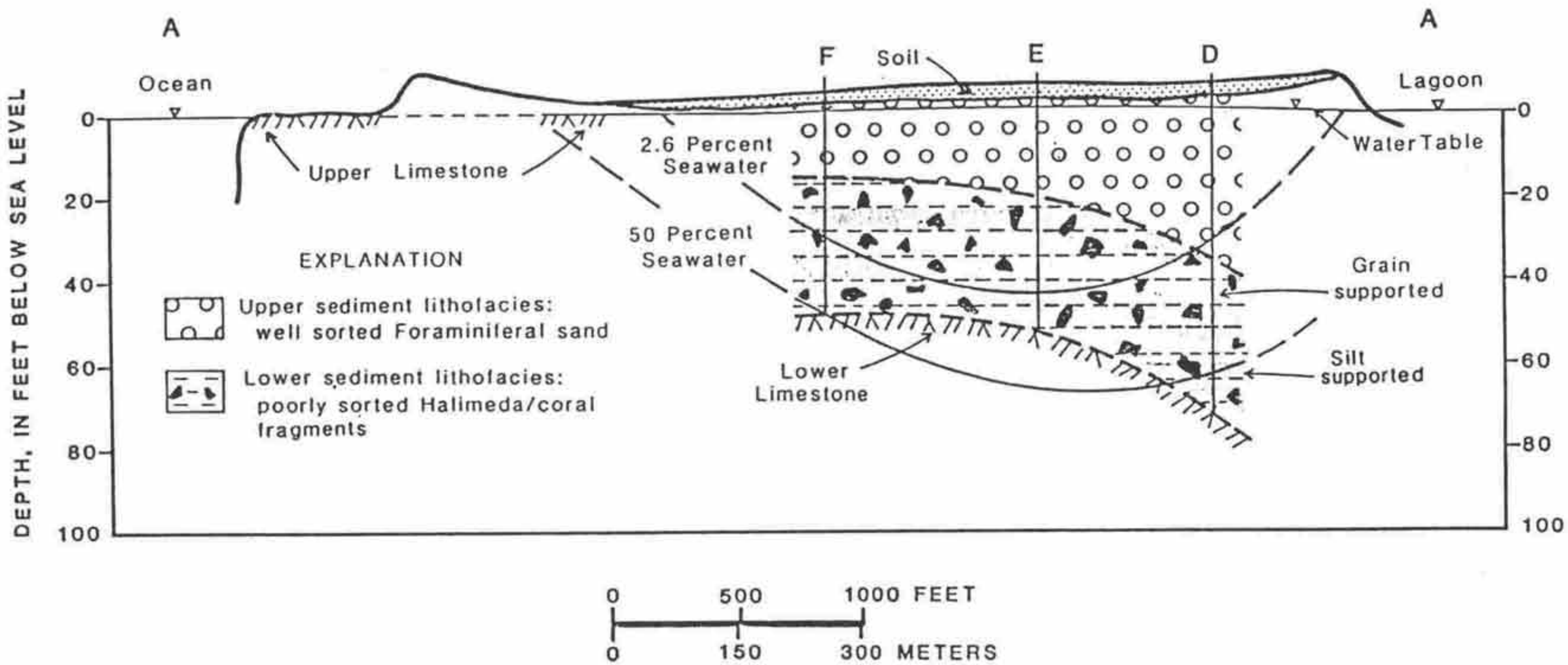



Figure 5: Hydrogeological Section of Laura Showing Lines of Relative Salinity

(Source: Hamlin and Anthony 1987: 12)

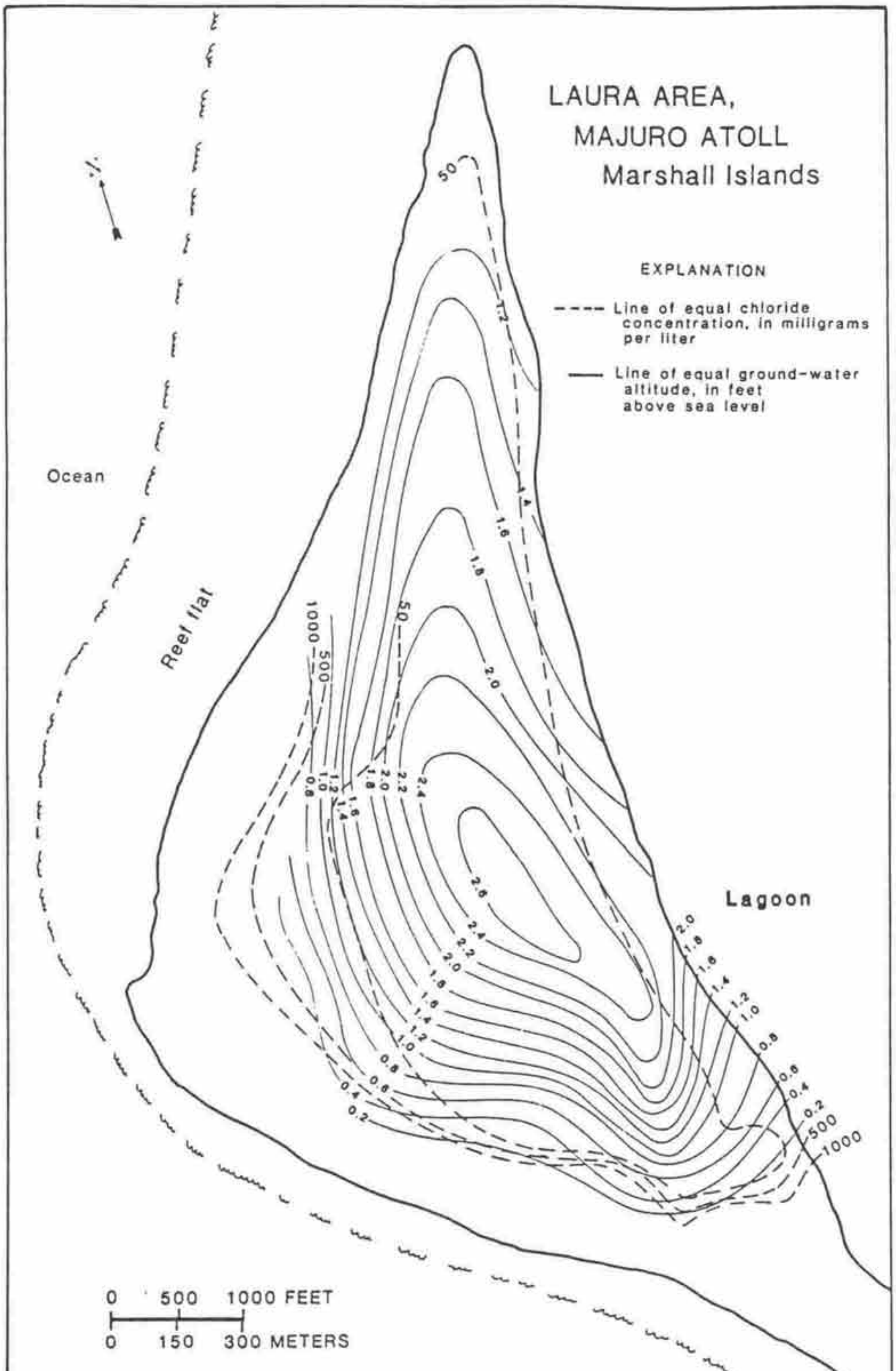


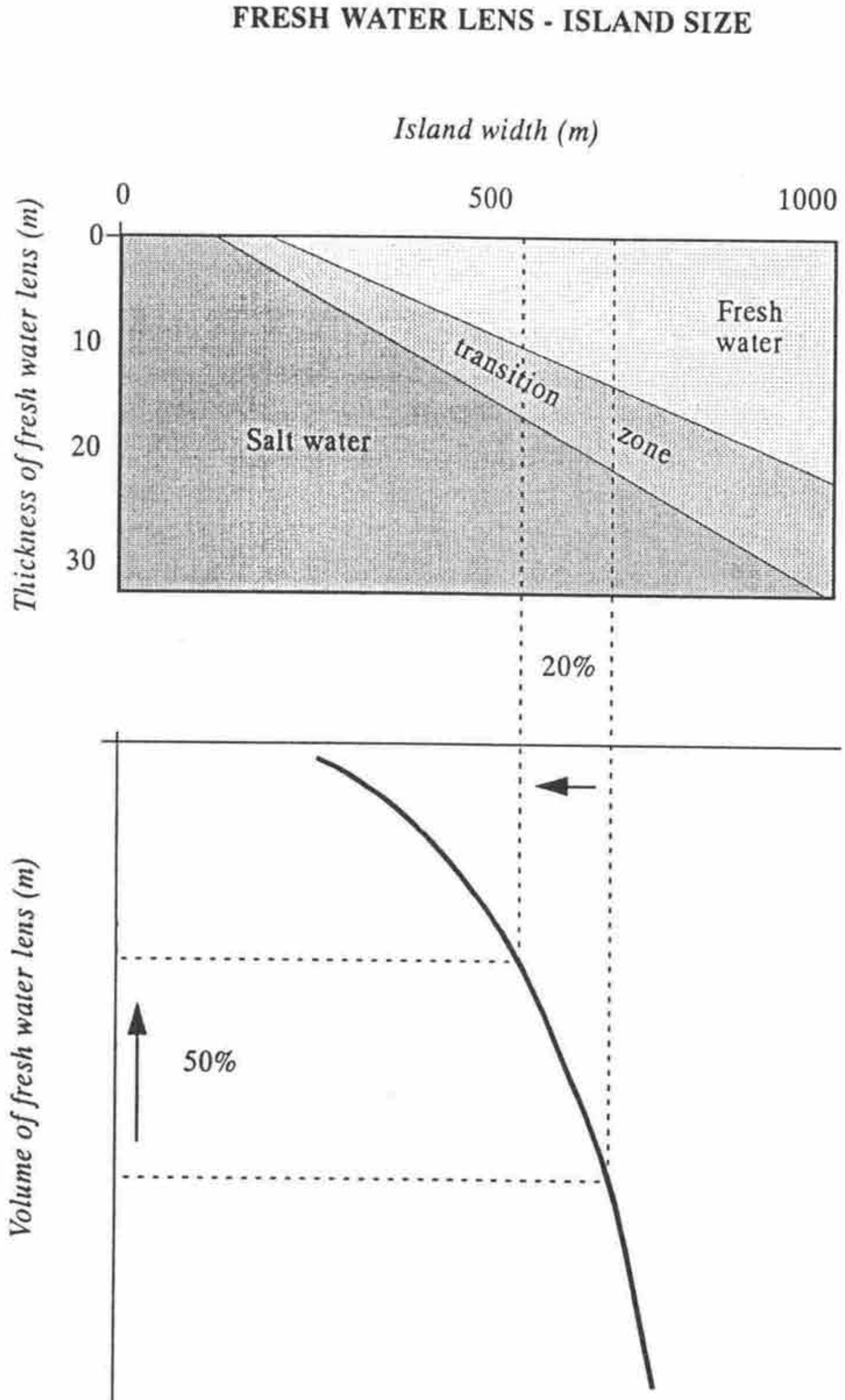

Figure 6: Water-Level and Chloride Contours at Laura, April 1973

(Source: Hamlin and Anthony 1987: 7)

his study of Arno atoll in the Marshall Islands, and is illustrated in the case of Laura (Figure 5). The shape of the freshwater lens is determined principally by hydraulic characteristics of the aquifer and size and shape of the island. The freshwater nucleus of the lens is in the unconsolidated sediments of relatively low permeability. The thickest part of the freshwater nucleus above sea level also coincides with the deepest accumulation of unconsolidated sediments, as in Laura (Figure 6). The lower surface of the freshwater nucleus roughly follows the slope of the lower limestone unit. The highly permeable lower limestone is like a sponge that facilitates the intrusion of seawater, acts as a drain for the overlying freshwater, and promotes mixing of the two water types.

During droughts, water table levels fall and the ground water may become brackish. Environmental stress is manifested by trees loosing leaves, not fruiting and even dying. On small islands especially, groundwater reserves are particularly vulnerable to the vagaries of rainfall and storms. Droughts and cyclone disruption of groundwater supplies may force bathing in saltwater or even migration. However, the most severe threat to permanent water supplies is not from climatic factors directly, but rather from marine processes that cause coastal erosion and increase the frequency of storm overwash. Figure seven shows, in generalised form, the relationship between the dimensions of the ground water lens and island size, expressed in terms of width, and illustrates the general effect that a 20 per cent reduction in island width would have in reducing the volume of freshwater. Thus any decline in island area has a very dramatic influence on the availability of freshwater supplies. Clearly, for a given rise in sea level, the amount of erosion will depend on the composition and height of a particular island, its exposure to wave attack and current erosion and the frequency and intensity of storms. Conceivably, in the next 50 years or so, greenhouse - induced shoreline erosion rates of the order of 1-2 metres per year could reduce the dimensions of some presently inhabited islands to the point where their ground water supplies would no longer support viable ecosystems or permanent human habitation.

The types of change that might accompany a greenhouse induced rise in sea level are illustrated in Figure Three. As erosion reduces island size, ground water lenses shrink beneath larger islands and virtually disappear under small ones causing all except the most hardy vegetation to perish. Sea levels rising at the rates contemplated under future greenhouse conditions could outstrip the ability of islands to grow upwards thus leading to a reduction in island




PR6510mp HS=600 24/6/92A

Figure 7: Freshwater Lens and Island Size

The maximum thickness of the Ghyben-Herzberg lens of freshwater beneath atoll islands increases in direct proportion to island width but the volume of freshwater increases semi-exponentially. Thus changes in island width due to erosion or accretion have a disproportionately large impact on freshwater reserves. (Source: Roy and Connell 1991: 1066)

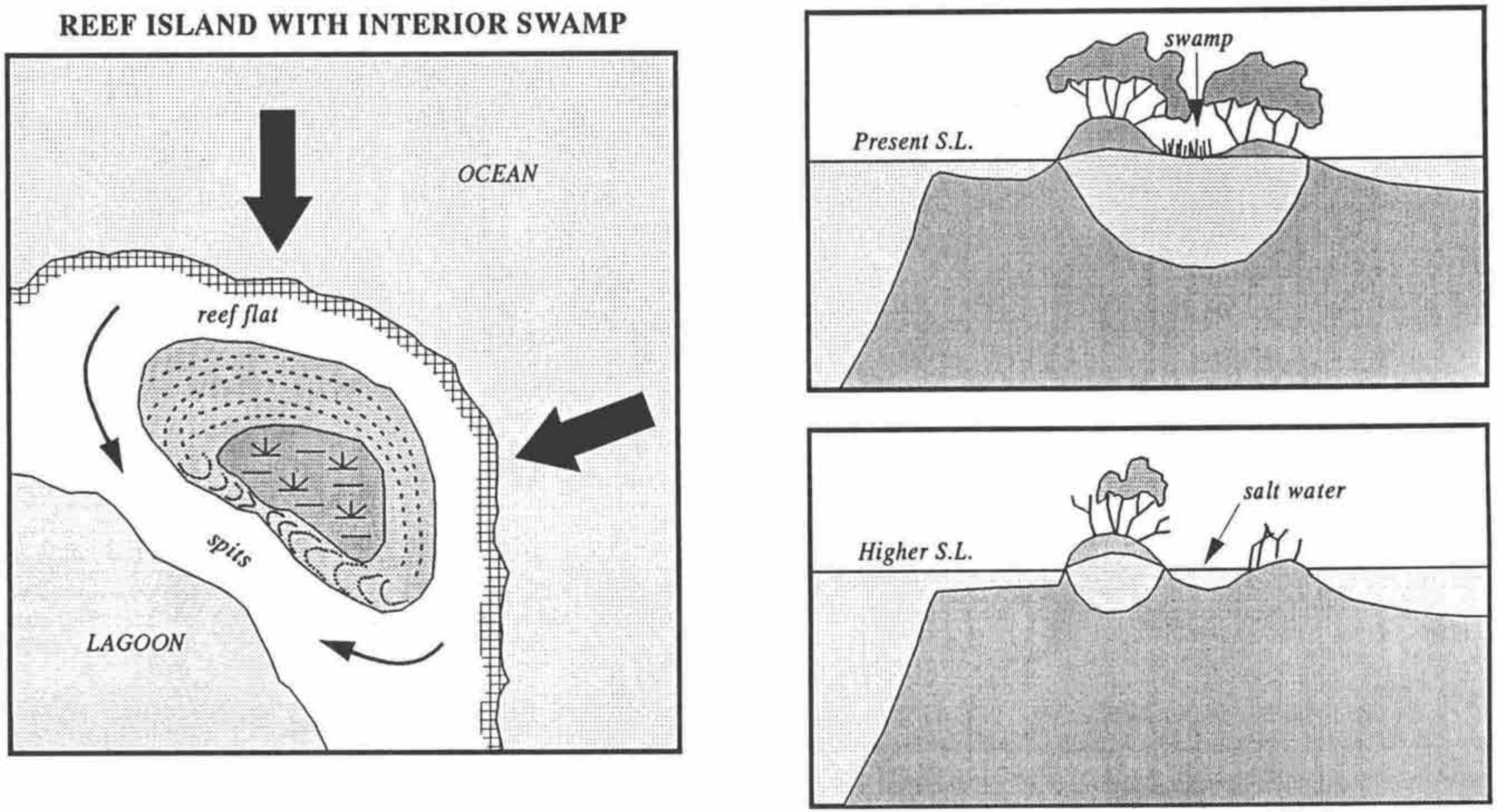



Figure 8: Reef Island Formation on Atolls

Wide islands with relatively large groundwater lenses form where converging waves (big arrows) build gravel ridges and recurved spits (small arrows) at bends in the reef crest. Lower areas in their interiors are highly productive but, if sea level rises, inundation and salt intrusion could destroy their productivity and the island's ground water reserves. PR6509mp HS=600 24/6/92A

(Source: Roy and Connell 1991: 1067)

'freeboard' (height above mean sea level). Storm overwash would therefore become an increasingly frequent occurrence, causing damage to buildings and vegetation and salination of the ground water lens. This is exactly what occurred in D-U-D, Majuro in 1979. Probably the most severe situation is likely to occur on what are today the widest and most productive islands. These triangular islands typically occur at bends in the reef crest where waves approach from two or more directions and series of recurved spits have formed around a central low area (Figure 8). Low areas are swampy and historically have been used for taro patches; many islands of this type support relatively high population densities. The effect of a marine incursion on this type of island is illustrated in Figure eight. Not only are productive food areas in the interior of the island destroyed by salt water, but the groundwater lens is greatly reduced as is the productivity of coconut and breadfruit crops. The construction of expensive sea walls to protect low-lying areas from saltwater intrusion would only be effective in the early stages. As sea level continued to rise, so would the ground water table until, eventually, the central parts of the island would become a shallow, and relatively unproductive lake of fresh water becoming increasingly brackish as storms overwashed the island surface.

Tides in the Marshall Islands are of the semi-diurnal type with generally two uneven high tides and two uneven low tides during a daily cycle. The average tidal range is about three feet (one metre) during a cycle. During monthly neap tide conditions, tidal ranges can be less than 1-2 feet while during spring tides, they can exceed 4-5 feet. Maximum annual tidal range is between 6-7 feet (2 metres). Most shallow reef flats lie at about mean lower low water, barely uncovered at most low tides. However on many windward reefs, the outer reef flats include a coralline algal ridge feature near the surf zone projecting 2 or more feet above mean lower low water, rendering boat passage through the surf and over the reef extremely hazardous, especially at low tide.

Two major currents flow through the Marshall Islands. The North Pacific Equatorial Current is a broad current system moving westward near the northern atolls between latitudes of 10-15$^{o}$ N. The narrow but strong Pacific Equatorial Counter-current flows eastward through the Southern Marshalls between latitudes of 5-6$^{o}$ N. Large pelagic and migratory fish populations are associated with these current systems, but the currents have less influence on the nearshore environments of atolls in the Marshall Islands compared to tidal, wind and wave driven currents.

The prevailing tradewinds generate moderate to large swells in open seas which steepen and break along the upper ocean slopes of reefs facing north to east in the Marshall Islands. This wave action piles up water on the outer ridge of the reef flats and drives water over the reef ridge where it runs "downhill" across the reef into the lagoon or passes. These wave driven currents are particularly strong at high tide, can achieve speeds of 2-4 knots, and are generally unidirectional towards the lagoon on windward reefs, no matter what is the state of the tide. These currents are a major source of ocean water exchanging with lagoon water and help to keep lagoons relatively well mixed. Where wave driven water currents push over reefs and against island shorelines (wave set up), water levels can be elevated one metre or more above ambient sea level. As water seeks the path of least resistance in running downhill into the lagoon, very strong currents can be generated especially through restricted openings between adjacent islands on the reef flat. These are major factors influencing the design of causeways on windward ocean reef flats to link individual islands.

Tidal currents are also significant along the lagoon, pass, and ocean faces of reefs in the Marshall Islands. Tidal currents are especially strong within deeper passes of atolls with large lagoons and few openings through the reef, achieving speeds of up to 8 knots or more in narrow channels through the reef of some "closed" atolls. During a flooding (rising) tide, sea level on the ocean side eventually becomes higher than lagoon sea level, causing waters to run "downhill" rapidly through the passes into the lagoon. During an ebbing (falling) tide, ocean sea level eventually drops below that of the lagoon causing currents to slacken and then reverse and flow quickly "downhill" out of the lagoon. Lagoon circulation and water quality is greatly influenced by tidal exchange and the cross sectional size and position of passes through the atoll reef. Navigation through narrow meandering passes with swift currents can be hazardous.

Circulation in lagoons varies from atoll to atoll and depends upon width, depth, and number of passes through the reef, depth and number of reef pinnacles in the lagoon, and the proportion of perimeter atoll reef covered with islands. Passes promote exchange of water between the ocean and lagoon while islands block movement of water over shallower reefs. Atolls with well mixed lagoons have proportionately fewer islands and proportionately larger passes (e.g.

Enewetak, Bikini). Lagoon circulation is most sluggish or restricted on "closed" atolls lacking deep passes or having proportionately greater island distribution (e.g. Ebon, Namorik, Majuro). The construction of causeways as proposed on Bikini and Kwajalein, and as accomplished on Majuro and other atolls outside the Marshalls (Tarawa, Canton, Palmyra), usually restricts lagoon circulation and degrades water quality. The average residence time of water in such lagoons is lengthened, increasing the duration and concentrations of pollutants discharged into the lagoon.

Most prevailing wave energy is directed towards the north and east sides of reefs and islands and is generated by tradewind swells. However, infrequent tropical storms and high latitude polar storms generate large swells and breaking waves which significantly affect the Marshall Islands. Tropical storms (including typhoons) can originate from any direction and generate wave action in all directions, but the storms generally approach from the southwest to southeast. Large waves generated by storms in the Aleutian Islands/Bering Sea approach the atolls from the north especially during the northern winter while Antarctic storms generate large waves approaching the Marshalls from the south, especially during the northern summer. The prevailing nature of the trade-wind waves and the catastrophic nature of infrequent but large storm waves greatly influence the configuration and morphology of islands and reefs in the Marshall Islands. Tradewind breaking waves approach heights of 5-15 feet (2 to 5 metres) while storm waves are often greater. The presence of the coralline algal ridge on the outer edge of windward reefs offers additional protection to nearby islands from wave attack. The structure of windward reef slopes is also more resistant to wave damage and is better configured to dissipate wave energy. Open atolls with wide or numerous passes through the reef can allow large waves to enter the lagoon, as at Bikini in 1986, and break on lagoon shorelines.

Coral islands, with land areas less than 3 metres above sea level are vulnerable to storm surge inundation and wave attack during typhoons. Although infrequent, severe storms can have long lasting effects on coral atolls including disruption of the groundwater lenses, destruction of housing, vegetation and crops intolerant to salinity, and shoreline and island erosion. After typhoon Ophelia struck the southern Marshall Islands in 1958, temporary evacuation of whole villages and replanting of coconut groves were necessary. Islands closest to the outer edge of exposed ocean reefs are most vulnerable. Over the centuries and millennia, Marshall Islanders have tended to establish villages on the most protected (lagoon) shorelines of the larger islands, perhaps in response to previous catastrophic storm events.

Between the atoll and island reefs of the Marshall Islands are wide expanses of open seas with well mixed waters. Centrally located in the northwest Pacific, the waters of the Marshall Islands are not protected from large nearby land masses and continents. The Pacific Ocean is deep near the reefs and its waters are pollution free and extremely transparent.

### 3.3 Soils, Fauna and Flora

Atoll soils are underdeveloped, other than in the depressions that have been cultivated as taro patches. There, following long periods of cultivation (associated with mulching and other intensive techniques) they are often rich peaty loams but of very limited extent. Otherwise atoll soils usually support a relatively limited vegetation. Only one detailed soil survey has been undertaken in the Marshall Islands, though this examined soils on Taroa (Tarawa) and Airik on Maloelap, Majuro and the main islands on Arno and Mili (Laird 1989); Fosberg (1990) has provided an overview of soils in the Marshall Islands. The climate, parent material, topography, vegetation and age of the soils were all fairly uniform throughout the survey area. As a result, the number of different soils was limited. Only seven map units were delineated. The variables used to separate them in mapping were the content of coarse fragments on and below the surface, the content of organic matter in the surface layer, and depth to the water table.

Subtle differences among the soil-forming factors account for the differences among the soils on the islands. For example, the Ngedebus soils that have a dark surface layer have more organic matter in the surface layer than other Ngedebus soils. The higher content of organic matter results from a protected position in the interior of the islands. The soils in these protected areas receive less newly deposited sand than other soils on the islands and thus are older. They are also less affected by salt spray and thus support denser and more varied vegetation, which is the origin of the organic matter. The content and size of coarse fragments in the soils are related to the position on the landscape. Nearly all of the areas of cobbly and rubble land are along the oceanside of the islands, and sands and loamy sands are generally along the lagoon side (although this is not true of some areas of southern Majuro, influenced by the 1905 storm). These slight distinctions are typical of atoll soils (Stone 1953) and, although the soil survey was only undertaken in the relatively wet southern Marshall Islands, the basic differences are almost certainly typical of those elsewhere.

The general impression of the terrestrial flora (and fauna) of atolls is of rather limited species diversity, especially in comparison with high islands, with only a few plant types predominating. This limited diversity is a result of the necessity to tolerate salinity, recent colonisation, isolation and the low nutrient status of soils (Fosberg 1990: 19-20). Species numbers vary considerably between islands and there seems to be a direct relationship between diversity and island size and rainfall (Wiens 1962). Williamson and Sabath (1982) have extended these relationships into a human context. Some islands are reported to have more than one hundred plant species (including many that were introduced by Europeans) but only a few are commonly used for food. Recent studies of atoll vegetation (e.g. Manner and Mallon 1989) have demonstrated that earlier studies tended to underestimate the number of valuable plant species on atolls, though some of these are recent introductions. The main food crops are usually coconuts, breadfruit, taro and pandanus. In wetter conditions crops such as bananas are also cultivated.

Because of the relatively small size and the low elevation of atoll islands, virtually all plants have some tolerance to salt spray and brackish groundwater conditions. Species such as the coconut and pandanus can withstand quite high levels of salt and even occasional inundation by storm waves. They survive (albeit unproductively) on downward percolating rainwater in relatively exposed sites and quickly colonise even small rubble mounds that rise above high tide level. In contrast, swamp taro and Cyrtosperma taro are much more sensitive to salinity changes and grow in low areas, usually manually excavated (taro patches) in the central parts of islands; on occasion, notably after storms, salinity causes a substantial reduction in taro productivity.

The extensive alteration and manipulation of plant communities by indigenous agriculturalists on Pacific atolls is well known. The indigenous vascular flora is limited with, for example, 44 species recorded on Arno (Hatheway 1953) although there are now thought to be more than 120 indigenous species, and almost the same number again that have been introduced and naturalized (Fosberg 1990: 21-39). Plant introductions by Micronesians significantly increased the vascular flora of most islands; on Arno 24 species had been introduced by the 1940s (Hatheway 1953) though other indigenous species have been lost in the process of these vegetational changes. Only the driest atolls have escaped major vegetation changes (Fosberg et al 1956). The situation in Arno may have been typical of other southern atolls. Prior to human occupation, the islands were bordered with a shrub and tree layer of Scaevola taccada, Tournefortia argentea, Pandanus tectorius, Terminalia samoensis L. and Guettarda speciosa. Island interiors were forested with Barringtonia asiatica, Hernandia sonora, Ochrosia oppositifolia, Intsia bijuga, Pandamus tectorius, Guettarda speciosa, Pisonia grandis and Cordia subcordata. On sandy interior soils trees such as Allophylus timorensis, Pipturus argenteus and Premna obtusifolia occurred. Pemphis acidula occupied the saline flats.

The early Marshallese established the horticultural subsistence agriculture that persists on many atolls. Cocos nucifera, Artocarpus altilis, Morinda citrifolia, Calophyllum inophyllum and numerous cultivars of Pandanus were introduced to the interior forests. The areas covered by these aboriginally introduced species were relatively minor until the Marshallese came under the increasing influence of missionaries and traders. Coconut and breadfruit groves were significantly expanded in the late nineteenth century. In response to the copra trade, coconuts were planted over large areas to become the dominant atoll tree. For example, in 1952, some 69 per cent of Arno Atoll was planted in coconuts (Hatheway 1953). This is almost certainly true of other southern islands.

With the arrival of missionaries and traders in the mid-nineteenth century 1800s a new series of plant introductions began which brought Erythrina, Carica, Citrus, Musa, Pemphis and Plumeria. Recent introductions have been dominated by ornamental trees and shrubs. On Arno 20 of the total 48 trees and shrubs were recent introductions (Hatheway 1953) with 15 ornamental species. On Majuro, 11 of 14 recently introduced trees and shrubs were ornamentals (Sabath 1977) and urbanization has altered indigenous and aboriginally introduced plant communities primarily by replacing forested areas with open yards. The urban vegetation is characterised by scattered trees resulting in open canopy, a high percentage of ornamental shrubs, and dominance of yards containing grasses, herbs and hedges. Most of the ornamental trees and shrubs had been recorded in Laura village on Majuro prior to major development (St. John 1951). The recently introduced species were to be found around the isolated family dwellings in the Cocos and Artocarpus groves on Long Island (Rairok) and Majuro. On the northern atolls, change in the vegetation cover is less obvious; a general account of this cover is given elsewhere (Thomas 1989: 12-16).

There are relatively few discussions of the fauna, land or marine, of the Marshall Islands, hence the following discussion is largely dependent on the State of the Environment Report (Crawford 1992). Only one land mammal, the Polynesian rat (Rattus exulans) is indigenous to the Marshall Islands, and this probably arrived with the earliest human settlers. Marine mammals, including whales, dolphins and porpoises occur; there are a number of different species of each of these, but no study appears to have been undertaken of their extent and significance. Several species of lizards and reptiles exist; on some islands, there are monitor lizards, introduced by the Japanese as a food source. Insects, spiders and land crabs are common, and coconut crabs exist throughout the Marshall Islands but may be becoming a threatened species on some islands. Chickens, dogs, cats and pigs are the main introduced species. A wide variety of birds are present in the Marshall Islands; some seventy-nine species have been listed for the Marshall Islands, of which 37 are seabirds (Fosberg 1990:40). The unpopulated northern atolls provide nesting sites for many birds, including boobies, frigate birds and terns (Amerson 1969). Fifty-four species of birds are known for Kwajalein atoll alone, one of the longest faunal lists of any oceanic atoll in the Central Pacific. Native bird populations on Kwajalein have probably been much reduced as a result of habitat modification, but this change has allowed a substantial increase in wintering shorebird populations (Clapp 1990). Three native birds are either rare or extinct, the Crimson-Crowned fruit dove (Ptilinopus porphyraceus) and the Wake rail (Rallus wakensis) are believed to be extinct, and the Ratak Micronesian pigeon (Ducula oceania ratakensis), mainly found on Wotje and Arno, is classified as an endangered species. A detailed discussion of endangered species is given elsewhere (Thomas 1989: 81-89; Crawford 1992).

Marine flora and fauna are much more diverse than terrestrial flora and fauna. A recent study of all published records of marine algae from the Marshall Islands yielded a total of 238 species (Tsuda 1987); more recent unpublished studies have identified new species hence this total is likely to be far from complete. Assessments of the abundance and significance of algae have not been undertaken. Sea grasses are relatively rare in the Marshall Islands.

Coral reef species are both diverse and abundant. On Arno, where the most detailed analysis has beeo undertaken, some 180 species from 60 different genera have been recorded. Similar numbers are likely to be present on other atolls in the group, though coral fauna are significantly fewer on northern atolls such as Bikar (Thomas 1989: 33). There is also a wide range of marine invertebrate fauna associated with the coral reefs; sponges, clams, oysters, mussels, whelks, gastropods, worms, crabs, shrimps, sea cucumbers and starfish exist in abundance though in some areas, notably Majuro, clams have been significantly depleted. Most of these species are useful foods. Some, like giant clams, trochus and pearl shells, are being produced in aquaculture projects. All five of the world's marine turtle species occur in the Marshall Islands and both the green turtle and the hawksbill turtle nest there. The hawksbill turtle and the leatherback turtle are both regarded as endangered species (Crawford 1992).

More than 800 species of fish are known in the Marshall Islands, and most of these are edible. There have apparently been no detailed studies of reef fish in recent years; it is probable that more varieties exist (Hiatt and Strasburg 1965) though a recent checklist is unusually comprehensive (Randall and Randall 1987). There are a large number of pelagic species, dominated by several varieties of tuna, which are the objects of commercial fishing enterprises. Game fish, including marlin, are also abundant in local waters. There is some indication that the number of fish species is smaller in the northern atolls (Thomas 1989). A number of fish in the lagoons and ocean are of particular significance because of their abundance and their nutritional value. Mullet (Crenimugil crenilabis and Neomyxus chaptalii) are herbivorous and detrital lagoon feeders that ingest considerable quantities of bottom sediment along with food. Convict surgeonfish (Acanthurus triostegus) are herbivorous browsers feeding on small algal fronds and filamentous algae that grow on reef rock or on the base of dead coral. The unicorn fish (Naso lituratus), also a herbivore, browses on larger seaweeds growing on sandy and rocky areas. Rabbitfish (Siganus rostratus) are herbivorous browsers but will occasionally feed on fleshy items found in garbage dump areas. Rudder fish (Kyphosus cinerascens) are strictly herbivorous browsers. All of the above fish belong to the second trophic level. Parrot fish (Scarus sordidus) are common reef-dwelling, grazing omnivorous feeding on live coral heads and occasional algae. Parrotfish are in the fourth trophic level.

Larger benthic, midwater, and surface carnivores are less frequently taken from the lagoons. Groupers (Epinephelus sp.) are benthic carnivores of the third trophic level that feed on small fish and invertebrates. Jacks (Caranx melamphygus) and rainbow runners (Elegatis bipinnulatus) are fast-swimming carnivores that feed on small fish and squid. Rainbow runners may occasionally eat swimming crustacea. Jacks are in the fourth trophic level. Snappers (Aprion virescens (grey snapper) and Lutjanus bohar (red snapper)) are hovering midwater-to-surface carnivores. Another snapper (Letherinus kallopterus - pigfish) is a bottom dweller feeding primarily on benthonic crustacea. Tuna (Thunnus albacares, Gymnosarda nuda, Euthynnus affinis (bonito)) and mackerel (Grammatorcynus billineatus) are large, rapid swimming carnivores feeding on small fish and any other prey of appropriate size. They represent species of the fifth trophic level.

## 3.4 Current Environmental Problems

The most critical environmental problem in the RMI is the limited supply of freshwater, for domestic consumption, washing and other uses. Other serious problems include the pollution of land, lens and lagoon in Majuro through waste disposal, coastal erosion in some areas and damage to coral reefs. These are not necessarily new problems. The special issue of the nuclear contamination of the northern atolls of Bikini, Enewetak, Utirik and Rongelap is not discussed here. This, and all the environmental problems that currently concern the Marshall Islands, are examined in more detail elsewhere (Crawford 1992), and the following sections largely summarise the issues raised in that report.

Water Supply. Increasing the availability of clean potable water is an important need especially in light of the rapidly expanding populations of Ebeye and Majuro, and proposals for further development of industry and commerce. Water supply and quality is also a problem in some outer islands. Majuro almost constantly experiences a severe water shortage, which is more pronounced in dry seasons, when water supply is rationed to a few hours a day, if at all. Currently almost all the water used in urban Majuro comes from the airport runway catchment. The Majuro system is about to be expanded by tapping into the Laura freshwater lens, though, even with the two systems in operation together, it will not be possible to provide a 24 hour water supply for Majuro.

The airport runway was constructed at a level 2 metres below the intended level, consequently water quality is intermittently affected by salt-water spray and by garbage from high water levels in the lagoon. The passage of Typhoon Axel through Majuro in January 1992 demonstrated the fragility of this water supply as high waves washed chunks of coral and sand into the airport catchment, clogging pipes and putting half the system out of commission. Any sea-level rise would therefore both reduce the utility of the airport runway catchment area and reduce the size of the Laura lens, thus threatening both water sources There is ample evidence that residents prefer to use rainwater, especially from the airport runway (Detay et al 1989: 68), rather than wells, though roof water catchments are limited in extent and under-utilised (Stephenson and Kurashina, 1987); there is therefore scope for the extension of these catchments though, because of contamination, only about 30 per cent of those that now exist provide potable water. A significant number of the wells in the D-U-D area are polluted. Only one is in regular use but others are used during droughts, supposedly only for bathing and washing. It is intended that over the next plan period (1991-1996) rainwater catchment systems be constructed on a number of public buildings, and that new building codes will be enforced that would require freshwater collection and storage facilities being incorporated into all new construction projects.

Ebeye does not experience the same kind of fresh water shortage problems since it has a desalination plant, but water supplies are restricted to 45 minutes in the morning and 45 minutes in the afternoon. Desalination is expensive, must be linked to available power supplies and storage capacity, and cannot provide a realistic solution for urban Majuro.

Contamination of water supply on the outer atolls may also be a problem. As population levels increase, groundwater and cistern water may be more susceptible to bacterial and viral contamination. Over 60 per cent of rural households have no toilet facilities. Domestic water supply may be inadequate on some outer atolls. Buckets can introduce contamination into wells which are sometimes left uncovered. Shallow groundwater is highly subject to microbiological, physical and chemical contamination (Detay et al 1989).

Waste. Solid waste disposal is a major problem in the urban areas, since waste management systems are strained, space for disposal is limited and the volume of non-biodegradable material has increased. Garbage often piles up in urban areas, providing breeding areas for rats, flies and mosquitoes, and also providing playgrounds for small children. Garbage collected in Majuro is taken to a public landfill on Long Island; gabions contain the waste (Plate Four), but there is seepage from the dump into the ocean and coastal waters close to the dump are polluted. Disposal on Ebeye, and increasingly in the outer island islands, also poses environmental problems. On Jaluit at least, some wells have been contaminated by solid waste disposal. There are few areas appropriate to waste disposal (especially the disposal of hazardous waste, which is not discussed here) in atoll situations. Environmental management is limited by the land tenure system which gives landowners absolute control over land use and access and thus reduces the utility of regulations concerning waste disposal, sewage disposal, toilet construction and so on. There is no public land in the Marshall Islands; all government buildings are on leased land. This has meant that there are no public parks in the country and virtually no recreational areas, other than basketball and tennis courts. All of these factors have significantly reduced the quality of life in Majuro, and have also discouraged the development of tourism.

Reef and Lagoon Pollution. There is some evidence of pollution of coral reefs, particularly those near urban areas, and eutrophication of lagoon waters. In Majuro and Ebeye sewage disposal into the ocean has reduced this problem but on Majuro lagoon waters have consistently been found to be polluted in two sites: close to Rita (where toilet facilities are inadequate) and at Laura. The use of the inter-tidal beach zone as a toilet in these two areas has also contributed to the spread of fly and shellfish-borne diseases. This has been exacerbated by the construction of a series of causeways on Majuro, preventing the natural flushing of the lagoon water. The proposed Ebeye-Gugeegue causeway may contribute to a similar situation on Kwajalein. Causeways also prevent the natural dispersion of water from storm surges, which may lead to flooding being more sustained and erosion being more significant. These changes have resulted in the status of fish and shellfish (especially Tridacna spp.) populations throughout the Marshalls varying greatly. The giant clam (Tridacna gigas) is scarce almost everywhere. Generally, populations of reef and lagoon fish near inhabited atolls and the main urban centres of Majuro and Kwajalein are depleted in comparison to those of the more remote uninhabited or lightly inhabited atolls. These do not suffer from over-fishing or the effects of habitat damage from pollution, dredging, channel blasting, boat anchoring, mining and shoreline infilling. In the past decade one beach on Delap (Majuro) disappeared in the course of a few years after sand dredging operations had been conducted up-current. In turn the removal of sand increases the probability of erosion in these areas.

In some areas therefore the coral reefs have been severely damaged. Yet the coral reefs are critical areas, because of their potential for food production, their role in contributing to tourism and recreation and their barrier effect against some hazards. Around Majuro, and especially the urban areas, reefs are largely exhausted, due to population pressures and the lack of conservation measures; this is evident from fish catches, subjective observations and changes in the species composition of reefs (Marshall Islands 1991: 9). There is however little indication of the extent to which there has been species depletion or declining numbers in any parts of the Marshall Islands, other than evidence that populations of the giant clam, and of small clam species, are declining, especially in areas close to human settlement (SPREP 1989). Aquarium fish have also been depleted in some reef and lagoon areas.

It is crucial to protect important lagoon and reef resources and limited land resources on the atolls and islands of the Republic. The reefs provide much of the food, shore protection, recreational enjoyment, habitat for rare species, cultural tradition, and future economic potential to Marshall Islanders, particularly on the outer atolls. In addition, reefs facilitate land expansion, construction of protective structures, and production of materials (quarry stone, tiles, concrete, landfill) for the urban centres. Reef and lagoon resources are finite and can be damaged or destroyed by construction, landfilling, dredging, causeway construction (blocking circulation), sewage pollution, and dumping of solid and toxic wastes. The incidence of ciguatera (fish poisoning) may also be related to disturbances to the reef ecosystem.

Planning. Environmental planning and management has never had a high priority in the past, and many environmental problems in the RMI are a result of quite new trends. The establishment of the RMIEPA in 1986 began the process of incorporating environmental issues into development and this has continued to occur. Adequate environmental planning and management is nonetheless hindered by the difficulties set out above and by problems of coordination and communication between government departments, limited local skilled and professional human resources, difficulties of enforcing existing environmental management regulations (notably that on prior environmental impact assessment), lack of some environmental protection regulations and lack of awareness of environmental issues amongst the public, in part because of the absence of environmental education in school curricula. There is some indication that this last problem will soon be remedied.

Many of these planning and management problems have been exacerbated by a rapidly increasing population, rural-urban migration and changing patterns of consumption, including house-building (which has contributed to an increased demand for sand). Legal and illegal removal of sand, especially in urban Majuro, has hastened coastal erosion and made land areas more vulnerable to storm waves and further erosion. Causeways, increasingly perceived as necessary in an era of land transport, have further emphasized erosion, lagoon pollution and eutrophication. The urban islands are now more vulnerable to hazard than they have ever been. These issues are currently being addressed through an Action Strategy for Managing the Natural and Cultural Environment of the Republic of the Marshall Islands and the National State of the Environment Report (Crawford 1992).

## 4. GLOBAL CLIMATIC CHANGE

The build-up of industrial gases in the earth's atmosphere over the past 30 to 40 years is now well documented. The resulting 'Greenhouse effect' is expected to raise temperatures over much of the earth's surface and lead to a rise in the levels of the world's oceans. A great deal has now been written on the projected changes in climate which are likely to develop from greenhouse-induced global warming (see e.g. Hoffman 1984, Barth and Titus 1984). In the South Pacific it is reasonable to conclude that for around a hundred years there have been increases in land and sea temperatures comparable to those calculated for the whole globe (Nunn 1990). McGregor (1988) has summarised the likely climatic changes for the South Pacific, based on world-wide general circulation models, and has discussed various scenarios of likely climate change. Such scenarios project a likely pattern of global warming over the next 30 years which ranges from 17$^{o}$C in sub-Arctic regions to about 2$^{o}$C near the equator (Pearman 1988). Consequent upon this warming will be a rise in world ocean levels, brought about by both thermal expansion of the surface layer of the oceans and some melting of glacial ice (Thom 1989). Initially sea level rise will follow the expansion of surface waters in the oceans and melting of mountain glaciers; not until much later will melting of the polar ice sheets significantly augment the ocean volumes. Tide gauge records from around the world, analysed by a number of researchers (Gornitz et al 1982; Barnett 1984; Aubrey and Emery 1983; Emery and Aubrey 1986; Bryant 1988) show a small rise in relative sea level (1.0-1.5 mm per year) over the past few decades. The current measured world-wide sea-level rise is about 1.4 mm per year, and this may be expected to increase slightly in the future. However, the results are variously interpreted. Factors that remain to be assessed include (i) the extent to which the distribution of the recording stations can be divorced from regional tectonic trends and local earth movements; (ii) whether the apparent sea level changes are due to the global greenhouse phenomenon or to local climatic variability (Bryant 1988) and (iii) in contexts other than the Marshall Islands, whether possible changes in river discharges to the oceans over the past century are due to the building of dams, irrigation schemes and land clearing for agriculture.

Because of uncertainty concerning the pattern and extent of future heating of the earth's surface and the rate at which heat will be absorbed by the oceans (Pittock 1988; Tucker 1988), rates of expansion of the oceans cannot be determined with any accuracy. Extreme scenarios for the next 50 years range from virtually no change in mean sea level to an elevation many metres higher (Hoffman 1984; de Robin 1986). There has been no assessment of evidence from the Marshall Islands that might relate to sea level rise in this area. There are currently two tidal gauges in the RMI, one on Majuro, which has been in place for about ten years as part of the University of Hawaii's Tropical Ocean Global Atmosphere (TOGA) Project (Wyrtki 1990) and one on Kwajalein, maintained by the US Military Forces. No data from these sites are locally available to provide any indication of contemporary fluctuations. A third tidal gauge funded by AIDAB, also on Majuro, will be set up early in 1992. Any indication of sea-level changes in the RMI must therefore be deduced from information available elsewhere; necessarily this provides an imprecise measure of the local situation.

In the case of nearby Kiribati, McLean used Hoffman's (1984) middle-range projection of likely rates of sea level rise, and assumed that the average overall rise by the year 2020 would be of the order of 40 cm. He also demonstrated, from a preliminary evaluation of *Porites* micro-atoll sections, that at times in the recent past local sea level in Kiribati has stood up to 40 cm higher than it does at present, and that the Kiribati islands will therefore survive such a sea level rise. However there is no reason to believe that similar conclusions are valid for the Marshall Islands, and there are no studies in place, other than the TOGA project, which will provide comparable results that are of national use.

Associated with climatic warming will be changes in the general atmospheric circulation patterns. For the equatorial tropics this is likely to result in a weakening of pressure differences and a subsequent weakening of the trade wind patterns which prevail in the near-equatorial zones. Weakening in the El Nino pattern, which could accompany global warming would result in lower rainfalls throughout RMI. At present the interactions between ocean and atmospheric circulation patterns are not well understood, but future research should enable better predictions of the likely changes in atmospheric circulation patterns. While there is also expected to be an increase in the intensity, and possibly the frequency of tropical cyclones or hurricanes as sea surface temperatures rise, it will remain improbable that cyclones will occur within $5^{o}$ of the equator. The effect of increased cyclonic activity at slightly higher latitudes may affect RMI through increased storm surges or climatic instability, phenomena which are not unknown in the Marshall Islands.

The potential impacts of any future changes in sea-levels, temperatures and other climatic phenomena are impossible to determine with any accuracy, since the rates of change cannot be known and the relationships between variables are extremely complex. Even a simplified representation of the physical environmental parameters and their interactions in the coastal zone (Figure 9) demonstrates the large number of variables that are involved, each of which may act independently or collectively in an indirect or direct manner on components of the biological system and the society concerned (Pernetta and Elder 1992). While the details can never be known, and the future is certain to contain surprises, some broad guidelines can be identified and are considered here.

### 4.1 <u>The Impact of Climatic Change in the Marshall Islands</u>

The basic effect of a greenhouse-induced rise in sea level would be for low lying lands to be inundated and for coasts to erode. Erosion, as opposed to inundation, will be most severe on shorelines composed of unconsolidated

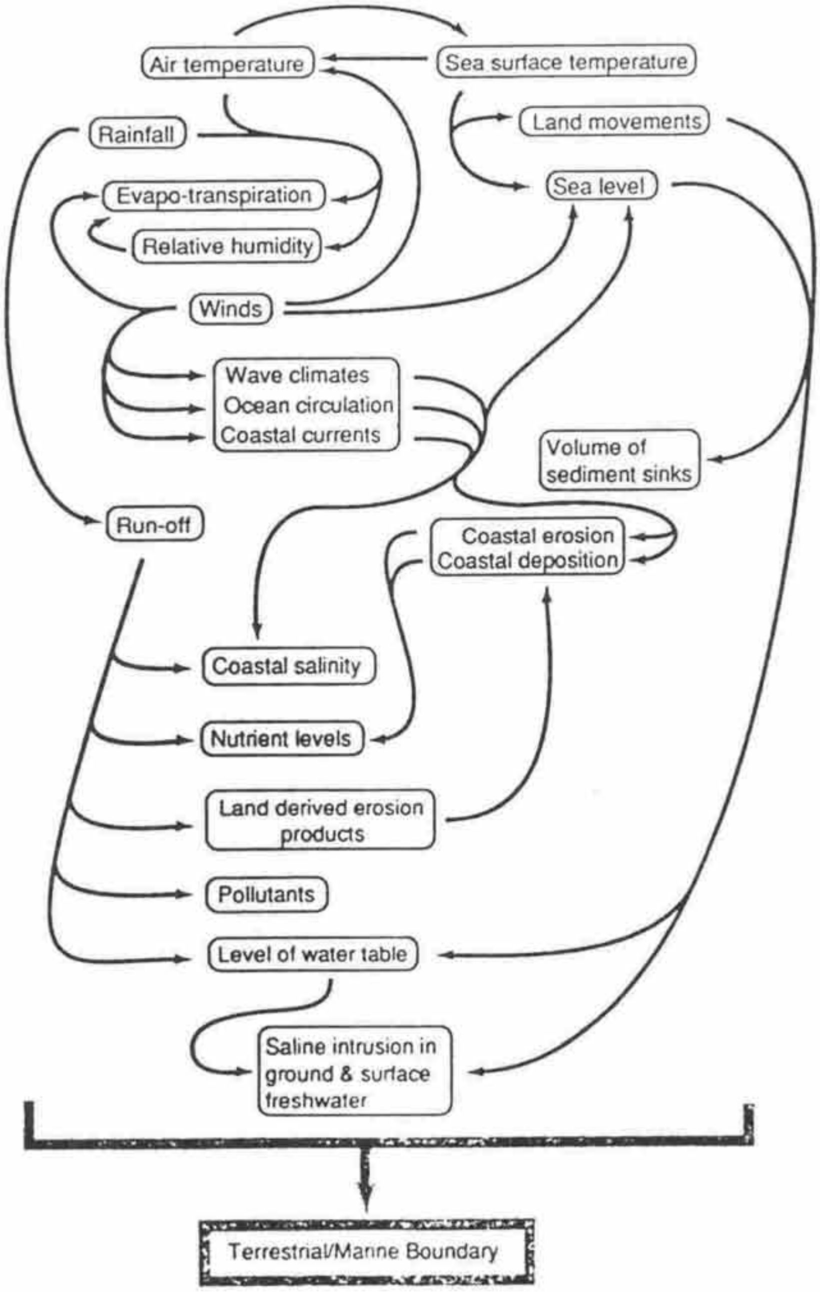



Figure 9: Physical Environmental Parameters and Their Interactions in the Coastal Zone

(Source: Pernetta and Elder 1982: 135)

sediment exposed to storm wave attack on high-energy coasts. Here, a gradual rise of mean sea level will progressively lift the zone of flooding, storm wave set-up and surge effects to new levels, thus eroding areas hitherto considered safe. Human responses will vary depending on the values of the coastal land under attack and the resources available to provide protective measures. In Pacific atoll states, where resources are very limited and populations widely scattered, the provision of expensive engineering works will not be a feasible option. The direct changes in climate in the Marshall Islands are likely to be slight in the foreseeable future. Temperatures in the islands are already uniformly hot and show very little seasonal variation. That pattern would not be expected to change with global warming. Some indirect changes are however likely. These have been identified for Kiribati (Sullivan and Gibson 1991) and are likely to be also true in the Marshall Islands:

1. In his regional prediction of direct greenhouse induced climatic changes, McGregor (1990) projected that by the year 2060 for all equatorial and sub-equatorial locations in the Pacific there will be year-round conditions of severe discomfort and thermal stress.

2. Such decreases in thermal comfort, with the associated increase in heat stress while working outdoors, especially during the middle part of the day, will mean that the patterns of work, especially for outdoor workers will need to change, so that people can avoid being outdoors during the hottest three hours around mid-day. These changes have economic implications unless plans are made to gradually modify outdoor working hours. Since subsistence activities are currently of limited significance in the Marshall Islands such effects are unlikely to be substantial.

3. Another direct implication of increasing thermal discomfort is the associated increasing need for atmospheric management in urban areas. McGregor (1990) noted that some changes could be made in commercial or office building design to encourage air circulation and avoid the need for expensive and energy-consuming air-conditioning. This requires advanced planning, and is of some importance already in the Marshall Islands, where energy costs are high and many buildings are air-conditioned.

4. An increase in storm surges and higher energy wave action generated by intensified cyclonic activity in higher latitude areas to the north of the Marshall Islands.

5. A change in the pattern of temporary high sea level stands as the ENSO pattern changes. Reduction in El Nino events would decrease temporary higher sea level stands around the Marshall Islands and partially offset the impacts of world-wide rise in sea level.

6. A direct change in local ocean water temperatures of 1 to $2^{o}$, which may cause coral die-back. Bleaching and death of coral colonies was noted for instance in the Maldives, during a period in which the local sea surface temperature was 1 to $1.5^{o}$C higher than average, and in Hawaii and Indonesia with similar temperature rises (Sullivan and Gibson 1990: 20). This suggests that coral communities are currently living near their upper levels of thermal tolerance. Such coral dieback has other implications, notably a resultant increase in the energy of coastal wave action, and hence a greater propensity for erosion and flooding to occur.

7. A change in the agricultural potential for many food crops, and a consequent change in crop varieties which may able to be grown, given a $2^{o}$C average rise in ambient air temperature. However, unless rainfall patterns also change, this is unlikely to be of significance in the Marshall Islands where existing food crops are likely to be able to withstand higher temperatures.

The potential impacts of sea-level rise on the Marshall Islands are far more dramatic than the direct climatic changes alone. These impacts have been summarised by Sullivan and Gibson (1990) for Kiribati, and again there are acute parallels between the situation in Kiribati and the Marshall Islands, hence their conclusions can be examined further here.

Several scenarios have been advanced to project the likely rate of rise in sea level; current trends suggest that sea level will rise at a rate of about 1.5 mm annually, or slightly faster, for the next 50 years or so. It should be stressed however that unless global greenhouse gas emissions are considerably reduced, the trend to an increasing rate of sea level rise will persist, and by a little more than 100 years from now sea level could well stand as much as two metres above its present level. In view of this it would be advisable for the RMI to take into account in all future physical planning decisions, the likelihood that sea level will be about 40 cm higher than its present level in about 30 years time. Longer term policy planning can be based on better global data than are now available, and on assessments of the results of local monitoring of the immediate Marshall Islands environment, but may need to take into account the possibility of continuing rises in sea level.

A number of direct consequences follow from these assumptions of short term (30 years) and possible longer term sea level rise:

#### 4.1.1 Impact on Coral Reefs

The general impacts of sea level rise on reef bases and atolls have been outlined by Sullivan and Pernetta (1990). Much has also been written on rates of growth of individual coral colonies and of overall coral reef growth. Many reefs in the Pacific grew upward to their present level following the rapid postglacial rise in sea level in late Pleistocene and early Holocene times, between about 15,000 and 6,000 years ago; they are 'catch up reefs' as described by Buddemeier and Smith (1988).

#### Growth Rates of Coral Atolls and Other Reefs

McLean (1989) presented evidence to show that reef growth in Kiribati and in other parts of the Pacific is about 5 to 8 mm annually. This is comparable with rates of coral reef growth summarised from a variety of locations (Sullivan and Pernetta 1990: 50) and is most likely to be also true of the Marshall Islands. Coral reef growth is primarily a response to light availability and is highest just below the surface water layers. Marshall and Jacobsen (1985) noted that coral growth kept pace with sea level rise during the most rapid rises in the early Holocene when rates of accretion were measured at 5-8 metres/1,000 years. Should sea level rise at a rate faster than 8mm per year, then that rate slow down, or should sea level stabilise as it did about 6,000 years ago, it could be expected that reef growth would initially lag behind the rising sea level then 'catch up'. Present projections of sea level rise over the next century do not exceed the upward growth potential of healthy reefs (Buddemeier 1991), though there has been a global decline in the extent of such healthy reefs.

Plate 5: Laura Lagoon: Beach Rock and 1905 Storm Ridge

There have been a variety of estimates of average and maximum rates of both coral growth and vertical reef accretion, and the question of maximum rate of accretion is vital to any projection of coastal processes and morphological changes which occur in response to rising sea levels. Wiens (1962: 90) noted that on average individual coral colonies grow upwards and outwards at about 1 metre/40 years or 2.5 metres/100 years. Reefs grow more slowly due to the compounded effects of storm damage and recovery, the interaction between the growth of coral and algal mantles and the rate of clastic sediment production to fill interstices of the reef platform. He noted normal rates of reef growth of 0.5 to 2 metres/100 years consistent with those later recorded by Marshall and Jacobsen (1985), but quoted extreme growth rates (1962: 91) of 30 metres/100 years. None of this relates directly to the situation in the Marshall Islands; reef growth rates are likely to vary within the country and to be related to the species composition of reefs.

Buddemeier and Hopley pointed out that predictions of reef growth rates must take into account the structure of the reef community, and the likely occurrence of local events such as cyclones or predator attacks, which would temporarily inhibit reef growth. Although rising sea levels generally favour reef growth, this growth may not keep up with predicted sea level rises due to global warming (1988: 4). Sea level rises of around 15 mm annually over the next century would be several times greater than the modal rates of vertical accretion on reef flats (about 1 metre/100 years), and 50% greater than currently measured maximum rates, although Holocene data indicate that vertical reef growth rates of 14 metres/100 years are possible in favourable circumstances (Buddemeier and Smith 1988). Such predictions are based on an assumption that coral growth will not keep pace with sea level rise. It is however likely, depending on a number of biological factors, that coral growth will be able to keep pace with even rapidly rising sea levels, perhaps with changed reef composition and form, if such rises occur no more rapidly than 3 metres per 100 years. Unfortunately there is inadequate information to determine if this is so, and if such an optimal situation might occur in the Marshall Islands.

4.1.2 Impact on Low Islands

Clearly the impact of sea level rise on motu is closely related to the impact on their reef bases. Wiens (1962: 134) expressed early concern about the fate of atolls, and low islands developed on atolls, should sea levels continue to rise at the rate then recognised. He described a likely sequence of landform changes which could be expected to occur on small atolls, and which still remains valid in the light of more recent observations. Continually rising sea levels would produce gradually rising beach ridges when sediments on the seaward side of atolls piled up, as they were pushed inwards towards the lagoon. This would result in a slope from the top of the beach ridge towards the central lagoonal depression, down which sediment could move, gradually filling the central depression, and forming new islands with swampy interiors. This effect would be exacerbated on occupied atolls by the digging of taro pits in the swampy depressions.

Based on the present state of knowledge of the formation of, and subsequent changes in, atolls and low islands, Sullivan and Pernetta (1989) presented two simple models of changes which are likely to occur on Pacific atoll motu should sea level continuously rise, or rise as much as two metres, then stabilise. These models are based on the alternative assumptions that coral reef growth either will or will not keep up rising sea level. This and the problem of reef dieback in water which exceeds the maximum temperature for coral growth require careful monitoring to make the models useful for planning purposes. The negative effects on coral growth of increasing surface water temperature may be sufficient, in either 'keep up' or 'catch up' reefs to maintain reef platform growth somewhat below the average tidal level. Slightly below the ocean surface, water temperatures should remain near the optimum range for coral growth, but hotter surface layers may inhibit such growth. This would ensure that reef surfaces would remain submerged below mean low water level, which would in turn mean that sediments would no longer be deposited on the reef surfaces, and island building could not continue (Sullivan and Gibson 1991).

*Model 1. Assuming coral growth keeps pace with sea level rise*

(i) Low island sediments will be swept either into atoll lagoons, where the sediment will be stored in the central depression, or off the leeward margins of platform reefs. In the case of platform reefs on a shallow shelf zone, this sediment will be stored on the leeward side of the reefs, but in deeper water conditions it will be lost to the ocean sediment sink.

(ii) Coral growth will be re-established on newly submerged reef flats, and there will be an upward and outward growth, resulting in the extension of atoll rings, and possibly the enlargement of knoll, patch and ribbon reef flats.

(iii) These reef flats may bear ephemeral low islands, but such islands are unlikely to establish stable vegetation communities or to maintain a lens of fresh groundwater.

(iv) If the sea level rise slows or stabilises, there will be a re-establishment of motu on atolls, possibly including the establishment of motu on the leeward side of lagoons due to the supply of stored sediment.

(v) There will be island growth on the leeward side of platform and ribbon reefs and a possible rapid development of motu on the windward side of such reefs if they occur downwind of reefs currently bearing motu.

(vi) The end result will be of a gain in low island land area, but in other than the current locations of low islands, and with the subsequent slow development of freshwater lenses. Biological communities, which may take 20-30 years to re-establish, will regain stability only when the rate of sea level rise falls below the rate of sediment production.

*Model 2. Assuming coral growth does not keep pace with sea level rise*

(i) Low islands will (a) become saline swampy islands, then (b) undergo submergence. Their sediments will be swept into atoll lagoons or to the leeward side of platform reefs.

(ii) There will be a lagging upward and outward growth of atolls and platform reefs, but at a rate insufficient to support motu development.

(iii) Island coastlines which are presently protected from storm waves by offshore atolls and motu or by wide reef flats will become subject to storm wave erosion as the protective barriers are removed.

(iv) The overall effect of this will be a significant loss of land.

For either model, should sea level continue to rise, reefs would probably 'keep up' or 'catch up', but the sandy islands on their surface would be severely disturbed and displaced. In situations described by such models the removal of surface sediments may be followed by the upward growth of coral, the development of submerged atoll structures, and the re-establishment of new islands. Temporary removal or displacement of the low island land is inevitable, even if a later result is the formation of a new island land mass. The social implications of this for populations resident on the motu are considerable.

McLean (1989: 21, 73) has proposed the development and implementation of a vulnerability index to determine the relative risk factor for small atoll islands. It is essential that further work be carried out to refine such an index, particularly for the physical attributes of the islands, to allow rational planning which might incorporate resettling populations from small highly vulnerable islands.

### 4.1.3 Impact on Coastlines

Increased wave height and increased storminess are both likely to cause erosion of unstable coastlines. On some islands in the Marshall Islands coastline stability is greater than on other atoll islands because of the extensive fringe of sandy or conglomeratic beachrock, and the existence of natural beachrock accumulations; such islands appear to be fewer than in Kiribati (McLean 1989: 31, 74). These deposits will offer temporary resistance to the erosion likely to be caused by rising sea level, but in time will themselves succumb to this erosion. Few atolls, even in the southern Marshall Islands, have mangroves (Bruguiera) but where mangrove groves exist erosion will be less significant.

4.1.4 Impact on Watertables

The complex interaction between the groundwater lens of an atoll, recharged by rainwater and tidal mixing in the layers below the freshwater cap of that lens has been described by Oberdorfer and Buddemeier (1989) and Buddemeier and Oberdorfer (1986, 1988).

In the northernmost Marshall Islands the groundwater lens commonly becomes saline following drought periods. In the southern islands, including Majuro and Kwajalein, adequate rainfall prevents this from occurring, except on the small atoll islands.

At present, as noted by McGregor (1989: 32) and McLean (1989: 49), warmer periods in the tropical Pacific are associated with positive Southern Oscillation Index values or anti-El Nino movements, and drier climatic conditions. Should this association of lower rainfall with higher temperatures persist with global warming, the groundwater resources of these atolls would decrease, with less rain-fed recharge, increased evaporation and increased water demand.

Should sea level rise however, the freshwater lens which floats above a mixed and saltwater base will be elevated, and its slope and head increased. This is likely to result in increased lateral saline mixing, increased evaporation through taro pits and wells, increased loss of freshwater by coastal leakage, saline water being brought within the reach of coconut and other tree crop roots or well and pump intakes, and generally a loss of the freshwater resource. If sea level rise is accompanied by increased storm surges, which will favour island building, such wash processes will render groundwater saline until a state of stability returns. Such stability is possible only if sea level rise ceases.

Atoll island growth however involves the deposition of coral rubble onto the existing base through storm wave activity. Should such islands grow it is likely therefore that saline storm waves will deposit sediments onto the islands, and in doing so will exacerbate salt water intrusion into the aquifers from above. Should such island building reach a level of stability then cease, the layered groundwater lens would be expected to resume its normal form. However in the intervening period, or while sea levels continue to rise, it is likely that groundwater lenses will be rendered saline.

Plate 6: Lagoon Walls: Darrit (above and Airport (below)

### 4.1.5 Impact on Land Use

Agriculture, including the subsistence production of taro, coconuts, breadfruit, pawpaw (papaya) and the commercial production of copra are highly dependent on fresh groundwater supplies. Similarly, a significant proportion of water used for domestic purposes is taken from groundwater aquifers. Any change in groundwater resources would have a significant impact on land use in the RMI. Since subsistence agriculture has a more limited role in the Marshall Islands than in most other atoll states, the result would not be as severe as elsewhere. Nevertheless although atoll plant species are generally resistant to some salt intrusions there are unlikely to be any species that would benefit from a greater level of salinity.

Most of the settlements in the Marshall Islands are necessarily located near the coast. Increased coastal location would threaten some of these settlements and make relocation necessary. This would be virtually impossible in Ebeye and Majuro (D-U-D) where the urban areas are almost completely built-up and private land tenure prevents some kinds of relocation. Elsewhere central depressions, and mosquitoes, discourage residence at a greater distance from coasts. Only in a few areas, such as Laura, is relocation possible.

### 4.1.6 Impact on Infrastructure

Sea walls, wharves, slipways and causeways are all threatened by rising sea level, as are associated port facilities, roads and other infrastructure (including some tourist facilities). Again, in most cases, relocation is not feasible.

In addition possible changes in current patterns, which may occur with ocean surface warming, could weaken or even reverse present nearshore circulation. These changes could have the effect of re-circulating sewage from ocean outfalls back towards the coastline, or changing the patterns of sediment movement. Such potential impacts also require monitoring.

#### 4.1.7 Impact on Fishing Zones

Very little has been done to model the complex current systems which occur at ocean-wide and local scales in the Pacific. Fishing areas are closely tied to ocean circulation, zones of upwelling and tidal change areas. Future oceanographic changes would obviously affect this situation.

#### 4.1.8 Impact on Archaeological Sites

Most archaeological sites and cultural sites of significance in the Marshall Islands are either two-dimensional sites (house platforms) that are similar to contemporary sites or are relatively recent buildings and other infrastructure, much of which dates from the war time era (Rynkiewich 1981). Many of these sites would be affected by sea-level rise and erosion, as are many wartime sites. These are also of significance because they can be used to calibrate the rate of coastal erosion.

## 5. ENVIRONMENTAL PLANNING IN THE MARSHALL ISLANDS

The Republic of the Marshall Islands (RMI) is composed of atolls and islands with very simple and vulnerable ecosystems, hence environmental management is of unusual importance. The tasks of environmental planning have been addressed in several reports, notably the UNCED Country Report (RMI 1991) and those of Crawford (1992) and the RMI Task Force (1992). The following sections again largely summarise some of the data, conclusions and interpretations produced in these reports. The Environmental Protection Authority (RMIEPA) was established as a statutory authority in 1984 by the Nitijela to preserve and improve the quality of the environment. Although the RMIEPA has been very active, the small staff, limited funds, lack of adequate training and community ignorance of the significance of environmental protection have frustrated efforts to achieve many goals. Nevertheless much has been achieved since 1984. Routine management and conservation of the environment has also been undertaken by the Marshall Islands Marine Resources Authority (MIMRA).

The objectives and functions of the RMIEPA are broad and include: (1) the study of the impact of human activities on the natural resources; (2) the prevention of the degradation or impairment of the environment, (3) the regulation of individual and collective activity in such a manner as to ensure the people safe, healthy, aesthetically and culturally pleasing surroundings; and (4) the preservation of important historical, cultural, and natural aspects of the nation's heritage, maintaining at the same time an environment which supports multiplicity and variety of individual choice. The EPA was given broad powers to promulgate and enforce regulations to fulfill these objectives. The National Environment Protection Act (NEPA), under which the EPA was established, also requires the preparation of environmental impacts for every governmental action significantly affecting the human environment. The NEPA has also retained Trust Territory environmental regulations until they are revoked or modified as appropriate for the Marshall Islands (Marshall Islands 1991).

RMIEPA programs include: water quality, monitoring of public water supplies, pesticides, solid and hazardous waste management, toilet facility regulation, village environmental health, inspections of sewage disposal, earthmoving, and public education. Regulations specific to some program areas have been promulgated, including Earthmoving, Solid Waste Regulations, Toilet Facilities and Sewage Disposal, and Pesticide use regulations, and are now in effect. Water Quality Regulations have been drafted and approved by the RMIEPA Board. The water quality regulations include provisions for the discharge of wastes into marine waters. Draft Air Quality Regulations have also been proposed. A permitting system has been established for each of the regulations. The RMI has placed a special emphasis on the area of solid and hazardous waste management and earthmoving activities. Earthmoving activities in coastal areas are of particular concern. It is regarded as imperative that the earthmoving programme at RMIEPA be strengthened by a sound Environmental Impact Assessment procedure, so that reef health is protected, coastal erosion minimised and the longevity of coastal construction maximised. Legally an EIA is required for all major government projects. The RMIEPA has two environmental specialists on staff but they are not fully trained for this purpose. This is also necessary for evaluating and upgrading the point-source discharge permitting and monitoring programme at the RMIEPA. The RMI currently has no contingency plan in case of an oil spill emergency and no point-source monitoring programme.

The Toilet Facilities Permitting Program, although legally established, is not operational. Occasionally toilet facility permits are requested and are processed by the solid waste management specialist (Crawford 1992). There is no enforcement unit which specifically regulates toilet facilities. With water and power now available in Laura a population increase can be expected along with an increase in both the domestic sewage and agricultural waste disposal pollution potential of this important drinking water source. The RMIEPA environmental specialists will therefore need training in evaluating and establishing appropriate sewage disposal systems.

The RMIEPA's effectiveness may come into conflict with the traditional land tenure system which resists government control of land through environmental regulations. Public understanding of the environmental consequences of unplanned development and uncontrolled increases in population and infrastructure is limited. Consequently, public education is an important, high profile activity of the RMIEPA. However the present public education program of the RMIEPA is constrained by the geography of the Marshall Islands. The atolls are isolated from one another, and each requires a separate public education effort. This presents a unique challenge to public education initiatives as a whole. The RMIEPA public education program is otherwise active and would significantly benefit from short-term technical assistance.

The Nitijela passed the Coast Conservation Act (CCA) in late 1988. The act provides for: (1) a survey of the coastal zone; (2) preparation of a Coastal Zone Management Plan that regulates and controls development activities within the coastal zone (within 3 years of the enactment of the act); and (3) formulation and execution of schemes to enable specific forms of coastal conservation. The CCA provides for a Director who may also establish a permit and environmental impact system consistent with the Coastal Zone Management Plan. At the present time, the RMIEPA General Manager is the designated Director. The Act is three years old and yet to be implemented.

The RMIEPA will continue to develop regulations pursuant to NEPA and CCA in the coming years. Trust Territory regulations, that are now in force under NEPA and still to be revised and adapted specifically for the Marshall Islands are the Public Water Supply Systems Regulations and Freshwater and Groundwater Regulations. New regulations for environmental impact assessment, categories of development within coastal zones, and foreshore use control and restrictions will be developed pursuant to the CCA.

MIMRA was established by the Marshall Islands Resources Authority Act in 1988 to provide for the exploration, regulation and management of marine resources. MIMRA has the power and duty to: (1) conserve, manage and control marine resources, (2) establish an exclusive economic zone management program, (3) issue fishing licences and issue licences for the exploitation of the seabed and subsoil of fishery waters, and (4) negotiate foreign fishing agreements with the approval of cabinet (Marshall Islands 1991). Implementation of major development projects has been assigned to the Marshall Islands Development Authority (MIDA) which has the responsibility of overseeing and coordinating economic and infrastructure development. Infrastructure development activities include the capital improvement projects (CIP), water and sewerage, and electrical generation. The Kwajalein Atoll Development Authority (KADA) is specifically assigned to manage development on Kwajalein Atoll through U.S. lease payments.

Other RMI legislation related to management and conservation of the environment includes: (1) The Marine Resources Act which is based in the Trust Territory Code of the 1960s and 1970s; (2) The Marine Resources (Trochus) Act of 1983; and (3) the adopted Trust Territory Endangered Species Act of 1975. The Marine Resources Act provides for the control of destructive fishing methods, prohibits killing of marine turtles on land or the taking of their eggs, and sets seasonal and size limits on their capture at sea. It also limits the harvesting of cultivated sponges and sets size and seasonal limitations on the taking of black-lipped mother-of-pearl oysters. The Endangered Species Act prohibits, with certain exceptions, the taking of, engaging in commercial activities with, possession of, or exporting of any endangered or threatened species. The Trust Territory list of endangered species was adopted by regulation in 1976. These Acts have limited effectiveness due to their source in the Trust Territory Code, in terms of legal status and enforcement.

The Marshall Islands Historic Preservation Act was passed in 1991. This Act provides for a Historical Preservation Council which will have the authority to establish regulations for activities affecting historical and cultural preservation and a Historical Preservation Office to enforce those regulations. The Office is administratively connected to the Ministry of Interior and Outer Island Affairs.

Museum staff are currently developing appropriate procedures and regulations for the Office, which became functional at the end of 1991.

The RMIEPA has a number of special projects in various phases of development. The areas covered include: solid waste management, hazardous waste management, water quality, nature conservation, coastal erosion, public education, and staff development. Water quality projects underway include development of the water monitoring program and a Rainwater Catchment Workshop, funded by the U.S. Department of Interior. A "Rainwater Catchment Planning, Construction, and Maintenance" pamphlet project has been funded by SPREP. These projects provide both technical assistance, public education, and staff development. SPREP has also funded a project request for environmental education readers. The RMIEPA encourages aluminium can recycling in the community and schools.

Underlying these institutional developments is the RMI government's recognition of the fragility of the nation's island environment and the importance of its environment and natural resources to its people and culture. It has also recognized the importance of its natural resources and environmental quality to continued economic development. Several policies address natural resource and environmental issues. The First Five Year Development Plan(1986-1991) expressed the government's intention to make preservation of the environment and the natural beauty of the islands a major national objective. The development plan identified five categories of development strategies: economic development, manpower and employment, population and social development, regional development and preservation of cultural and environmental heritage. The Second Five Year Development Plan emphasises the goals of ensuring an increase in the real incomes of the Marshallese people through promoting self-sustaining growth of the economy, increasing employment opportunities for the rapidly growing labour force, improving the quality of life, promoting balanced development between urban and rural areas and promoting national identity and unity through the preservation and promotion of a common cultural heritage. It does not stress environmental issues though these are implicit in some of the specific recommendations.

To encourage economic development, and as an attempt to improve efficiency of certain government operations, the RMI created state-owned enterprises in a number of public utility areas. These include: the water and sewer operations

(Majuro Water and Sewer); power production (Majuro Energy Corporation), Capital Improvement Project Management, and telecommunications. The utility companies, though still heavily subsidized, are improving services at a lesser cost to the government.

The RMI is also a member country of regional and international organizations committed to addressing environmental protection and resource management issues. The RMI is a member of the South Pacific Regional Environmental Program, the World Heath Organisation, and the Alliance of Small Island States (an organisation formed to address climatic change issues). It is a signatory to the SPREP Convention and SPREP Dumping Protocol, a member of the South Pacific Commission, the Asian Development Bank, the Forum Secretariat and the United Nations.

The RMIEPA is the principal agency concerned with all facets of environmental management and planning; it is the sole agency that is concerned with issues related to long-term environmental change, including potential greenhouse-induced sea-level rise. The RMIEPA is therefore the appropriate agency to coordinate all future environmental planning and management. It will need to be strengthened in order to do this effectively.

## 6. RECOMMENDATIONS

From the above it is apparent, firstly, that the RMI experiences a number of contemporary environmental management problems, including waste disposal, coastal erosion and lagoon pollution, secondly, that there are a number of significant social and economic development problems, some of which relate to the decline in Compact funding, including rapid population growth, malnutrition and a negative and worsening balance of trade. In these circumstances the necessity to consider responses to future greenhouse-induced sea-level rise and associated environmental changes may easily be perceived as of less than immediate priority. It is nonetheless crucial to consider the potential implications of such changes as part of contemporary environmental management plannings. Such activity should be centred in the RMIEPA which has already demonstrated its willingness and ability to be involved in such activities. The EPA is the key environmental agency in the Marshall Islands. As such it must be equipped with the appropriate skills and infrastructure to enable it to adequately fulfil its functions. It must play a key liaison and coordinating role both between the various agencies in the Marshall Islands but also on behalf of the Marshall Islands in international and regional environmental forums. The EPA must also be adequately represented on all relevant planning and development bodies, such as the National Planning Coordination Committee.

Despite the present role of the RMIEPA, the magnitude of the environmental problems facing the Marshall Islands necessitates a cross-sectoral approach, involving the range of authorities involved in environmental management. Various approaches to improved environmental management have been examined by the RMI Task Force (1992) and this and the following two paragraphs emphasize some of their conclusions and those of the UNCED Report (Marshall Islands 1991). Environmental management responsibility does not rest with the EPA alone; there are a number of other agencies that have important environmental responsibilities and must be closely involved in the implementation of the National Environmental Management Strategy. Relevant agencies need to recognise their environmental responsibilities and the important role they can play in this area. Relevant agencies should thus nominate officers to represent departmental interests in the environmental area. Effective environmental action also requires close liaison and cooperation between relevant agencies involved in this area. This should occur at both Permanent Secretary level, as represented through the National Taskforce on Environmental Management and Sustainable Development, and also at officer level.

A number of agencies are involved in environmental management in the Pacific. The major relevant regional organisation is the South Pacific Regional Environment Programme (SPREP), which offers considerable expertise in the area of environmental management. It can also provide a regional perspective on many of the issues that may affect the Marshall Islands. In many instances the problems faced in the Marshall Islands are not unique - they are often faced by other countries in the Pacific and, in many cases, there may be approaches tried elsewhere that may be applicable in the Marshall Islands. This represents a source of expertise that should be drawn on to assist in the implementation of environmental programmes in the Marshall Islands. A number of major programs will be implemented through SPREP in the next five years, including the Biodiversity Programme and the Climate Change

Programme. These represent important initiatives with which the Marshall Islands must be closely involved. A number of bilateral and multilateral donor agencies, such as the Asian Development Bank (ADB) and the Australian International Development Assistance Bureau (AIDAB), also offer assistance in the development of environmental programmes. Such agencies should be closely involved in the development and implementation of environmental programmes in the Marshall Islands, wherever appropriate and possible.

There is an increasing awareness throughout the Pacific of the important role of Environmental Impact Assessment (EIA) in the implementation of environmental and development projects. EIA offers an opportunity for the environmental impacts of development proposals to be considered at an early stage of project development and for environmental factors to be incorporated into project implementation. As such EIA has been recognised as a significant factor in ensuring that sustainable development occurs in Pacific countries. The requirement for Environmental Impact Assessment is also mandatory for a number of donor agencies, such as the Asian Development Bank. The need for EIA is clear in the Marshall Islands. However, EIA policies and procedures are poorly developed at present. It is thus recommended that formal procedures be developed by the government of the Marshall Islands to incorporate EIA procedures into decision making procedures. The development of EIA must also be accompanied by appropriate training which is practically oriented and addresses major environmental issues.

A series of recommendations for strengthening the activities of the RMIEPA has been made earlier (Hamnett et al. 1990; RMI Task Force 1992) and these are emphasized and developed here.

1. **The ability to conduct Environmental Impact Assessment within the RMIEPA needs to be strengthened.** An EIA is required for all major government projects hence it is necessary for the RMIEPA to have personnel qualified to audit or undertake such assessments. This can be combined with evaluating and upgrading the point-source discharge permitting and monitoring programme at RMIEPA. This will involve creating and implementing a marine pollution and oil spill management plan for the RMI, and training at least one environmental specialists in point-source pollution detection and management. They would assist the RMIEPA legal counsel during the revision of Trust Territory Marine and Fresh Water Quality Standards Regulations, and Trust Territory Air

Pollution Control Standards and Regulations. Presently, there is a significant level of point-source pollution in the RMI. Many ships call at the Majuro and Ebeye harbours, and some small industries discharge waste materials into the lagoon and ocean. To date, the RMI has no contingency plan in case of an oil spill emergency, and no point-source monitoring program. As the RMI continues rapid development, it will become necessary to perform these tasks. Additionally, the RMIEPA has assumed responsibility for drafting regulations, pursuant to the Coast Conservation Act (1988), concerning Environmental Impact Assessment, and prescribed categories of development activities within coastal zones and the foreshore. Adequate environmental input into the drafting of these regulations is essential.

2. **The ability to evaluate and upgrade the hazardous waste management and disposal programme at RMIEPA also needs to be strengthened.** This will involve creating and implementing a hazardous waste management plan for the RMI, and training for two environmental specialists in the safe management of hazardous waste emergencies, and the selecting and purchasing of equipment for the safe handling and containment of hazardous materials from Majuro and Ebeye. As development proceeds in the RMI, hazardous materials are accumulating, mainly on Majuro and Ebeye. Since the atolls have no significant land mass, and since they are frequently covered with salt spray, they are unsuitable for the storage of hazardous materials. No disposal facilities exist in the RMI. Hazardous wastes presently accumulating on Majuro and Ebeye include PCB's, cyclogens, hospital waste, school laboratory waste, and used petroleum products. The need for a comprehensive hazardous waste management and disposal plan for the Marshall Islands is therefore considerable.

3. **There is a necessity for a marine biologist and a coastal geomorphologist to be employed to work within the RMIEPA.** Coastal management and pollution problems are substantial in the RMI. Yet very little is known about the changing status of coral reefs and coastal flats on Majuro or on other atolls in the country. Damage to coral in the vicinity of the principal sewage discharge on Majuro has occurred, yet there is no monitoring of this, nor of other sites under some form of threat. There are a number of projects on which a marine biologist and a coastal geomorphologist might work. These include:

- assessment of the possible effects of eutrophication on reef flats adjacent to the sewerage outfalls on Majuro and Ebeye.

- determine the effectiveness of sewerage processing in the RMI, and make recommendations concerning sewerage treatment feasibility and value.

- design and implement a sewerage outfall monitoring program for Majuro and Ebeye, incorporating the use of the Majuro and Ebeye water monitoring laboratories.

- train existing water quality monitoring personnel how to evaluate sewage treatment processes on Ebeye and Majuro, how to evaluate the health of reef flats surrounding the outfall area, and how to monitor the marine waters surrounding the outfalls for suitability of recreational activities (see Crawford 1992).

- monitor the change in the extent of mangroves. This could be done using air photos to establish recent changes.

- carry out analyses of past air photographs and maps (many of which exist for the war years) to map coastline changes since 1945 and the extent and location of coastal erosion. This would lead on to work to plan protection strategies for the most vulnerable coastal locations. Such protection strategies are likely to involve reforestation. This is particularly necessary because of the impact that causeways have had on coastal changes, existing proposals for further causeway construction in Ebeye and the possibility that bridges may be more appropriate.

- liaise with curriculum advisers on the design of an 'environmental change' module which could be introduced in schools' environmental studies courses. Much relevant resource material is available through SPREP/UNEP.

- monitor sea level changes in a sample of Marshall Islands, using Porites micro-atolls, the methodology for which has been described elsewhere (Woodroffe and McLean 1990; cf. Sullivan and Gibson 1991: 30).

- examine the structure of growth in coral reef communities of different compositions.

- liaise with universities, and particularly with the USP Atolls Research and Development Unit in Kiribati, on the secondment of research workers from such institutions to conduct studies and workshops/public education seminars on environmental matters and provide some training for local environmental staff. There are many research workers outside the Marshall Islands who would be willing to undertake such studies and provide relevant training.

- work with the U.S. Corps of Engineers programme in developing the atlas series on 'high priority' atolls. This extremely valuable series has enabled a range of planning and management actions relating to the protection and preservation of particular sites and 'at-risk' areas.

4. **Funding and staffing of the RMIEPA need to be expanded and stabili{ed.** Until an adequate and stable annual budget is allocated to the Authority, little additional effort at improving environmental management can be expected. The RMIEPA is currently unable to monitor accurately important development projects such as sewage disposal or toilet construction or have an adequate basis for carrying out EIA procedures. These are crucial issues in a country where substantial development projects are regularly coming on line, where the population is growing rapidly and where coastal management poses special problems.

5. **RMIEPA needs to develop a process to establish environmental and programmatic priorities.** RMIEPA has clearly made decisions about what regulations to promulgate, to develop a public education and media programme, and to offer certain kinds of services. As environmental problems become more severe and the demands on RMI increase as a result of population growth and infrastructure and industrial development, RMIEPA will require a mechanism to review the following questions on a periodic basis:

* What environmental problems are most important and require the greatest attention; what problems will simply have to be ignored because there are not adequate resources to address them?

* How much of RMIEPA's effort should be allocated to public education, how much to regulation and enforcement, how much to participatory planning, how much to water quality testing, how

much to inspecting of drinking and eating establishments, and how much to the processing and administration of permits?

6. **RMIEPA should strongly consider delegating appropriate permitting, inspection, enforcement and other environmental management responsibilities to local governments.** RMIEPA could maintain responsibility for establishing standards and promulgating appropriate regulations. However, the delegation of certain management responsibilities to local governments could reduce the pressure on the limited resources of the Authority. Given the desires expressed by local governments to become involved in and to take responsibility for environmental management, it may be an opportune time to begin negotiating memoranda of understanding with local governments to pass on some of RMIEPA's current workload to local governments.

7. **RMIEPA should concentrate more efforts on increasing public awareness about environmental problems and solutions and on stimulating the involvement of individuals and groups outside government to solve current environmental problems.** There is an interest in greater community participation in environmental management, and it appears that many individuals and groups acknowledge many of the environmental problems facing the Marshall Islands. They are also aware of solutions to many of those problems that are available to them as individuals and to RMIEPA. Creating incentives, using the media, particularly video, and resources of educational institutions and community organisations and providing some leadership in environmental management may result in individuals and groups outside government taking an active role in environmental management with relatively limited continuous involvement by RMIEPA.

8. **RMIEPA should involve a wider range of individuals and groups in planning implementing activities and programmes.** Involvement in programme planning, the development of standards, the promulgation of regulations, and enforcement of standards and regulations would provide RMIEPA with a broader base of support in the community. Individuals and groups would have more opportunities to learn about the complexities of environmental protection and EPA's resource base would expand as a result of the personal involvement of more individuals. Expanding membership in the authority would also provide opportunities for more individuals to become involved. Whilst such as expansion could cause procedural problems such as achieving a quorum for meetings, it

could greatly advance the mission of the Authority. Participatory planning workshops for alabs, students, community groups, and government agencies appear to be an effective method for increasing awareness. They may also prove useful in getting individuals and groups to take a more active role in environmental management.

9. **RMIEPA should make more use of external resources to help solve environmental problems facing the Marshall Islands.** Even externally funded projects and technical assistance can significantly tax existing RMIEPA staff resources. Furthermore conferences and reports invariably stress the need for further studies and planning efforts that could be financed and conducted with external resources, some of which were discussed above. Such studies and planning efforts will require at least some external technical assistance and/or research.

10. **The RMIEPA must take the lead in developing policies relating to greenhouse-induced environmental change.** Global warming may lead to a rise in the average level of the sea. The atoll nations of the Pacific have expressed particular concern for their very survival due to possible rises in sea-level. Uncertainty abounds as to the amount and rate of such a rise, but the cautious approach of the International Panel on Climate Change projects a sea-level rise of 20 cm by the year 2030 and 30-100 cm by the end of the 21st century. The President of the Republic of the Marshall Islands, Amata Kabua, in addressing the United Nations in September 1991, stated that global warming is the most formidable problem facing the Republic, but there is little that can be done by the country to alleviate the problem other than continue to raise the issue with the international community. There are however a number of other activities which should be pursued, at a national level and through the RMIEPA.

- RMI should adopt a high profile in support of the efforts of the Alliance of Small Island States and of other regional and international forums in voicing concern for the possible consequences of global warming in raising the level of the sea.

- RMIEPA should prepare a series of contingency plans for the Marshall Islands which cover the spectrum of possibilities, from preparing people by education and other means to cope best with an enforced evacuation of the atolls, to taking all local measures which may serve to alleviate the effect of sea-level rise on the land and the people. The development of contingency plans should focus on such issues as (a) construction of sea-walls around the main population centres (perhaps incorporating the use in sea-wall construction of compressed car bodies and other metal waste); (b) increasing the country's ability to rely on rainwater catchments for water supply because of the loss of freshwater lenses as sea-level rises; (c) affordable house designs which can withstand increased storm effects; and (d) increased attention to vocational and professional education training which will equip Marshallese better for paid employment overseas.

11. **The public education efforts of the RMIEPA also need to be strengthened.** The public education program of RMIEPA is very important. It seeks to teach the public about environmental concerns, to impart a sense of public control of environmental quality, and to inform the public of the roles of the RMIEPA. As rapid development burgeons in the Marshall Islands, it will become increasingly important to have public participation in maintaining environmental quality. The expertise to improve the RMIEPA public education program is not presently available. As the public education efforts of the RMIEPA have become more sophisticated, utilizing more media, staff training needs in the areas of desk-top publishing, camera-ready layout, video editing and dubbing, underwater photography, and public speaking have become urgent (see Crawford 1992).

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**PROGRAMME OF THE VISIT TO KIRIBATI**

*Wednesday, 11 December 1991*
Arrived in Majuro at 6.30pm, after a delay caused by a burst tyre at Tarawa.

*Thursday, 12 December 1991*
Discussions with Ms Martha Crawford (EPA) and Mr Abraham Hickiog (Acting General Manager, EPA). Brief visit to Office of Planning and Statistics.

*Friday, 13 December 1991*
Discussions with Dr Dirk Spennemann (Alele Museum, Ministry of Interior and Outer Islands Affairs) and Mr Jewon Lemari (Chief Planner, OPS).

*Saturday, 14 December 1991*
Visit to Laura, Majuro (Mr M. Maata).

*Sunday, 15 December 1991*
Visit to Mili atoll with Dr D. Spennemann to examine coastal changes and cultural sites.

*Monday, 16 December 1991*
Discussions with Ms Barbara Barber (EPA) and Ms Elisabeth Harding (EPA).

*Tuesday, 17 December 1991*
Discussions with Dr Neal Palafox (Ministry of Health), Mr Paul Peter (US Weather Bureau) and Ms Kathy Relang (Ministry of Education). Visit to tidal monitoring station.

*Wednesday, 18 December 1991*
Discussions with Ms Carmen Bigler (Ministry of Interior and Outer island Affairs), Dr H.M. Gunasekesa (UNDTCD, Chief Technical Adviser, OPS) and brief meeting with Mr Jiba Kabua (Secretary for Foreign Affairs and Chairman, EPA).

*Thursday, 19 December 1991*
Discussion with Ms A. Pollpeter (College of Marshall Islands). Preparation of Draft Report. Visit to Laura with Dr D. Spennemann to examine various coastal sites.

*Friday, 20 December 1991*
Final meeting with Mr Abraham Hicking (EPA). Depart from Majuro for Tarawa and Nadi.

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