7.2. Recommendations

1) Although the potential consequences of sea-level rise remain uncertain, water level reconstructions for Kiribati from tide stations and from intertidal corals suggest that the present situation is not one of immediate crisis, but that there is time to undertake monitoring and research to establish the rates of sea-level rise actually in, and relative to, Kiribati, and the response of reef islands to water level changes.

2) There is a need to gather more basic environmental data, on vegetation, sediments, soils, water quality and land use. This might form part of a Natural Resources Survey of the entire country. The aerial photographic coverage already available in Tarawa would provide a good starting point, and mapping would require a minimum of technical expertise. Fieldwork, however, would also be essential.

3) Systematic cross-island surveying is needed (along the lines of the profiles presented in the case studies in this report). These surveys are important because they indicate elevations of features, and hence susceptibility both to inundation under present sea-level conditions (i.e. during storm surges), and in the face of accelerated sea-level rise. These surveys need to be undertaken by an environmental scientist, because they are essentially environmental surveys, not geodetic or cadastral surveys.

4) A program of research needs to be undertaken into sediment production, transport and deposition. Techniques should involve investigation of the geological and geomorphological history of several islands, and regular monitoring of beach/shoreline profiles (along the lines of the twice-yearly surveys of Betio and Bairiki, but including areas remote from human disturbance and causeways) to gauge natural processes of accretion and erosion.

5) Vulnerability analysis needs to be combined with coastal zone mapping. In view of the inevitable shortage of resources in the Environment Section of the Ministry of Environment and Natural Resources Development, coastal zone mapping should probably be undertaken as a part of the broader land resources study suggested above. Coastal types should be determined in a manner somewhat similar to that attempted for Buota in the case study below (see Figure 20). This should then allow determination of a vulnerability index as has been attempted for Buota (see Figure 21). This vulnerability indexing of the coast is intended as a planning and management tool for the present coast, to regulate building setback distances from the high watermark, or to demarcate certain beaches from which no sediment should be collected, or to protect a stretch of coastal vegetation. This would also then serve to indicate vulnerability to ASLR.

6) The collection of reef rock from areas of the reef flat is to be strongly discouraged, and in areas close to settlements it should be prohibited. Similarly collection of sand and shingle from beaches should be prevented, particularly from beaches whose protective role is especially needed.

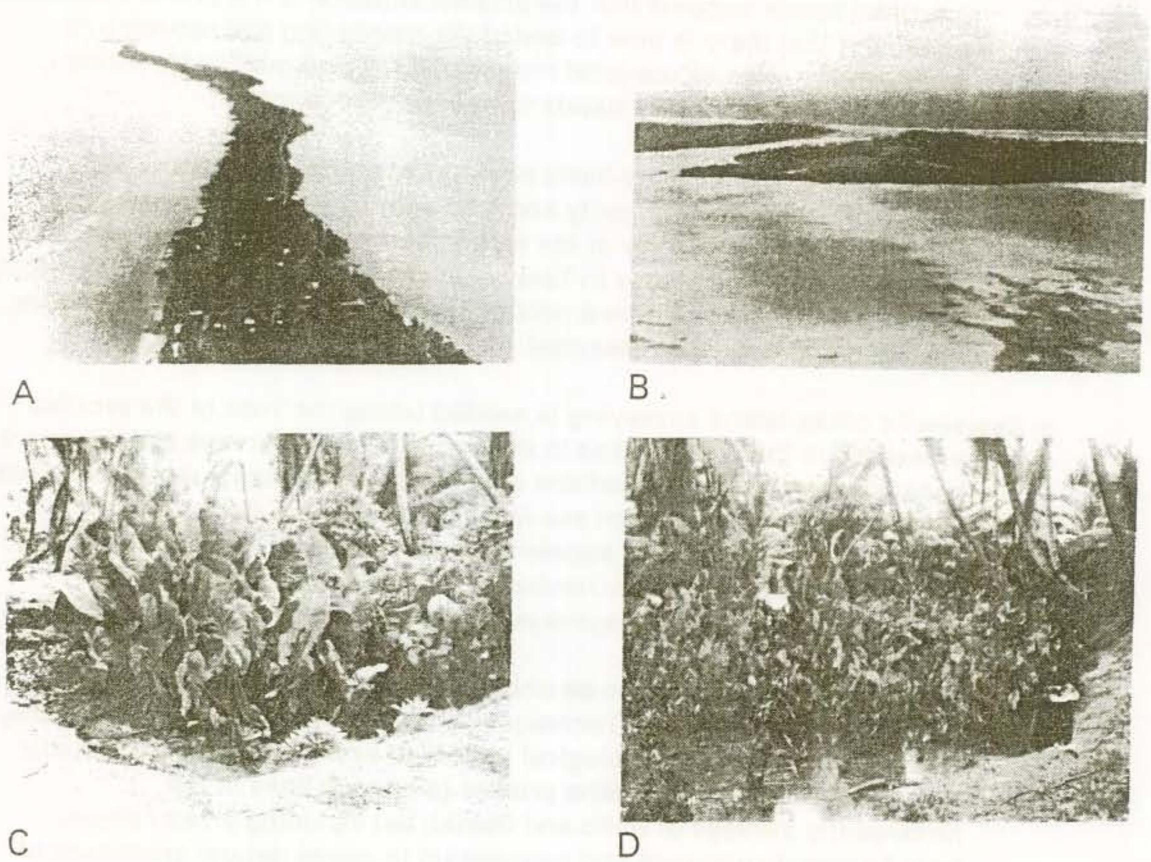

Plate 1 Aerial Views of reef islands, Tarawa, and babai pits on Maiana.

A) Long, linear reef island, Tarawa. Clearly the cost of protection of both shores will be high compared to the total area protected. B) Buota, the lagoonward shore is fringed by a dense stand of mangroves. C) Babai pit in village, Maiana. D) Babai pit excavated to the water table, Maiana.

1. Boundary Condition Delineation

The initial step in the Common Methodology involves the delineation of case study and specification of accelerated sea-level rise (ASLR) boundary conditions.

1.1 Study area

It is important that any study of vulnerability of Kiribati to ASLR involves the entire nation, because no part of the nation can be regarded as being of sufficient elevation, or bein enough from the influence of the sea to be immune from impact should the sea rise at the mc extreme rates that have been projected.

In order to develop the methodology a number of case study areas will be identified studied in greater detail. These include:

a) The island of Betio, South Tarawa, a densely populated, urbanised island
b) The island of Buota, South Tarawa, an island undergoing a rapid population incre
c) The island of Buariki, North Tarawa
d) The out-lying atoll of Maiana
e) The reef-top island (table reef) of Kuria
f) Kiritimati in the Line Islands

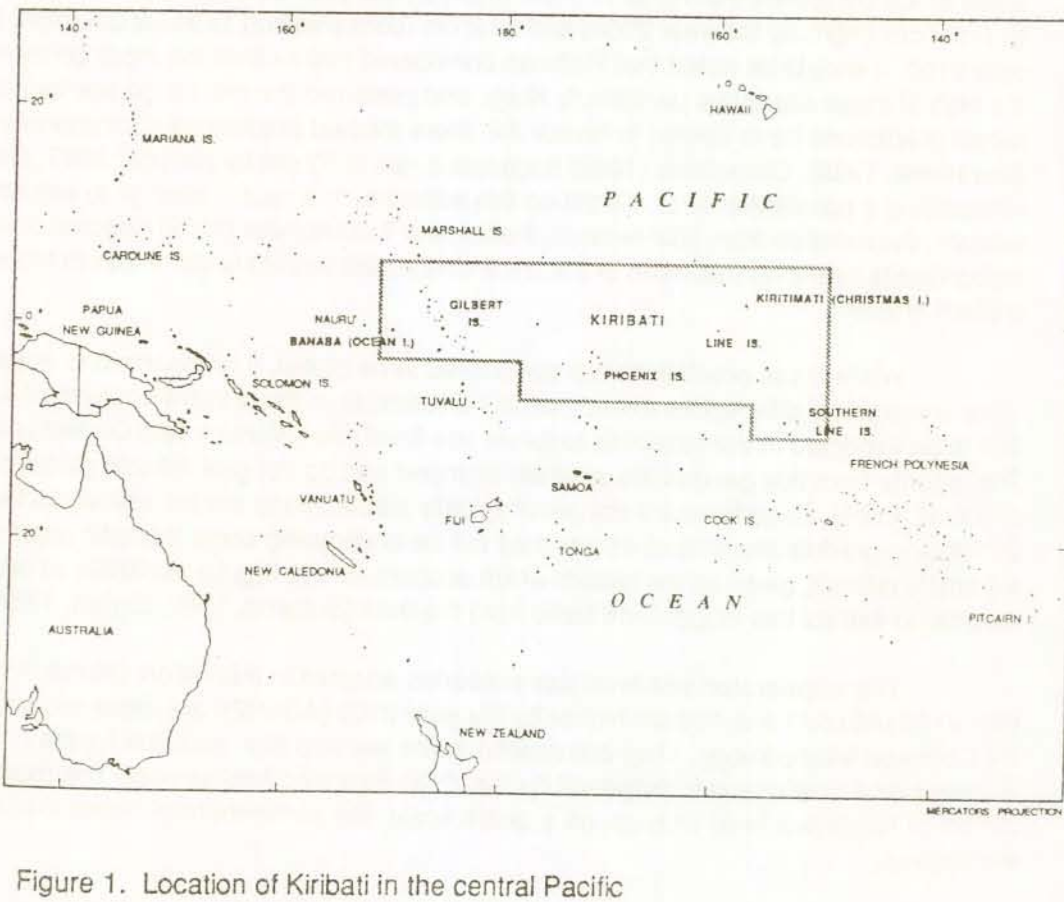

Figure 1. Location of Kiribati in the central Pacific

It is important, however, to stress that the characteristics of many of the more remote of the islands in Kiribati are poorly known, and detailed coastal zone mapping, preferably as a part of a major natural resources study, is required. The preliminary data available indicate considerable differences between islands, even neighbouring islands which might appear similar can be dominated by different processes of sediment production and transport, and hence respon differently to the same forces.

Vulnerability assessment of each of the islands of Kiribati will be necessary to adequately assess the overall vulnerability profile of the country.

1.2. Sea-level rise

There have been a series of predictions which indicate that global warming (the greenhouse effect) will result in sea-level rise, and that this will accelerate with the accumulation of greenhouse gases (principally carbon dioxide, but also methane, nitrous oxide and chlorofluorocarbons) in the atmosphere. Analysis of tide gauge records suggests current global rates of sea-level rise in the order of 1.0-1.5 mm/yr (Gornitz et al., 1982; Barnett, 1983, 1984; Warwick and Oerlemans, 1990). The principle reasons for sea-level rise appear to be thermal expansion of the oceans, combined with melting of grounded ice, principally from glaciers (Warwick and Oerlemans, 1990). Ice-melt from the major Antarctic ice-cap appears unlikely to occur until a considerable time has elapsed but could result in sea level many metres higher than present in some hundreds of years time.

The first widely used predictions of sea-level rise were those made by Hoffman (Barth and Titus, 1984). These contain a number of different scenarios (conservative, mid-low, mid-high and high) and suggest that the rate of sea-level rise will accelerate. Hoffman projected a rise of 4.8 cm (conservative) to 17.1 cm (high) by the year 2000; 23.8 cm (conservative) to 116.7 cm (high) by the year 2050; and 56.2 cm (conservative) to 345.0 cm (high) by the year 2100. It should be noted that Hoffman considered that neither the more conservative nor the high of these scenarios particularly likely, and preferred the mid-range scenarios. More recent predictions have tended to favour the more modest predictions (Commonwealth Secretariat, 1989). Oerlemans (1989) suggests a rise of 33 cm by the year 2050, although recognising a substantial error margin on this estimate. In a recent attempt to extract ongoing isostatic deformation from tidal records, Peltier and Tushingham (1989) suggest that there is a recognisable sea-level rise trend of 2.4 ± 0.9 mm/yr, this implies a sea 9-20 cm higher than present in 2050.

While these predictions are considered to be global, it is important to emphasise that there are regional differences already clearly discernible in the present analysis of tide gauges, and to be expected in the response to future sea-level rise (Warwick and Oerlemans, 1990). The records from tide gauges are spatially clumped and do not give reliable global coverage (Pirrazoli, 1986). Coastlines are not geophysically stable, many are tectonically active and undergoing gradual movement, others may still be undergoing some isostatic adjustment. It is extremely difficult, given all the factors which account for the regular variability of tide records, to extract this longer-term trend from the data (Belperio, 1989; Bryant, 1988).

The accelerated sea-level rise scenarios adopted in this report (30 cm higher by the year 2100 (ASLR1) and 100 cm higher by the year 2100 (ASLR2)) are those recommended fc the Common Methodology. They correspond to the low and high estimate for the Business-as-Usual scenario proposed by the IPCC Scientific Assessment. The most probable pattern of future sea-level change, on a global scale, lies somewhere between these two alternatives.

1.2.1 Sea-level rise in Kiribati

There have been several studies of the impact of sea-level rise in Kiribati (Lewis, 1988; Nunn, 1988; McLean, 1989; Sullivan and Gibson, 1991). The study by McLean (1989) is the most detailed. It was undertaken for the Commonwealth Secretariat, and was intendec

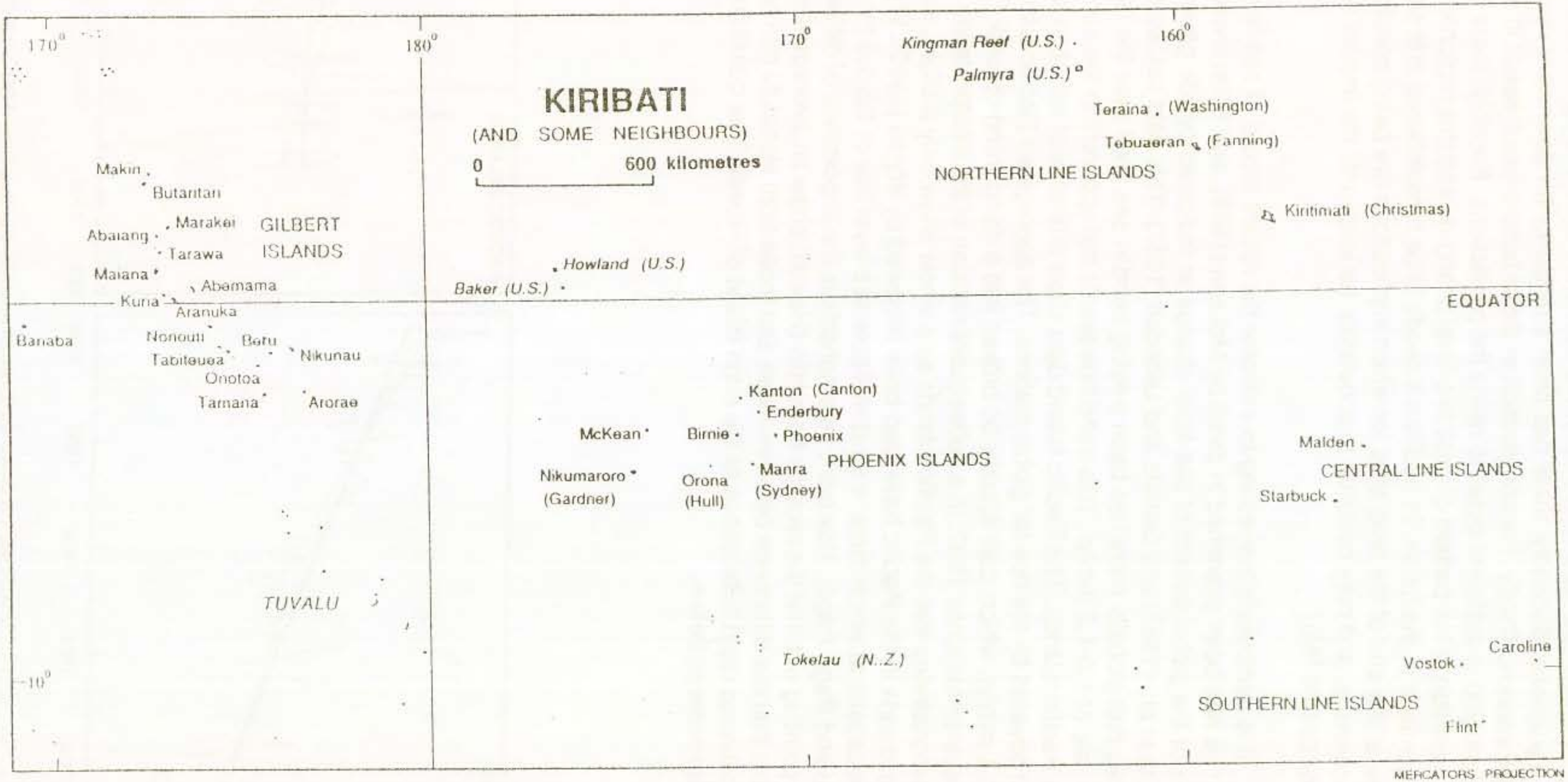

Figure 2. Location of islands and island groups in Kiribati

look at the effect of sea-level rises of 50 cm and 150 cm by the year 2030. It should be noted that these scenarios are much faster than generally predicted and considerably greater than the scenario favoured by the Commonwealth Secretariat in their own report (1989).

McLean (1989) has highlighted several important reservations on the adoption of any scenario for future sea-level rise. Firstly, the scenarios are merely possible outcomes and not reliable predictions. Secondly, there has been a tendency for downward revision of the more extreme scenarios. Thirdly, the contribution of those factors which result in sea-level rise has not been studied in sufficient detail to refine the predictions. Fourthly, there has been much regional variation in the pattern of past sea-level changes, and this regional variability is likely to continue in the future. In addition it needs to be remembered that sea-level change will not cease at the end of the time-slice for which implications are being considered, but that it is likely to continue, and may continue to accelerate (at least until the impact of efforts to reduce emissions can be felt).

It is particularly interesting to examine the recent record of sea-level change from the Pacific. This has been examined in detail by McLean (1989), and is reviewed here. The synthesis of the global pattern of sea-level change as indicated by tide gauges has been examined by Gornitz et al., (1982) and Gornitz and Lebedeff (1987). This data set, summarised in Figure 3 indicates that globally there has been a rising trend in sea level over the last century at an average rate of 1.0-1.2 mm/yr. This trend however is not apparent in the summary of data from the Pacific Islands. The Pacific Island data show interannual variation over a range greater than that covered by the rise for global stations. The aggregated Pacific Island data indicate a rise of only 0.1 mm/yr, which can actually be broken into a rising trend up until 1931, and a gradual overall fall since 1932. In a subsequent revision of the interpretation Gornitz (1990) again demonstrates that the Pacific islands as a whole show only a slight, or no, sea-level rise. Sea-level trends in the Pacific have also been reviewed by Wyrtki (1990). Wyrtki identifies several locations at which there is an identifiable sea-level rise of 1.5-1.6 mm/yr (i.e. Honolulu and Pago Pago). However, he emphasises the importance of differential subsidence of islands, pointing out that the records from Hilo (Hawaii) show an average sea-level rise of 3.8 mm/yr, but that the difference between these and those from Honolulu can be directly attributed to the continued rapid subsidence of the main island of Hawaii. The question of subsidence in Kiribati is reviewed below.

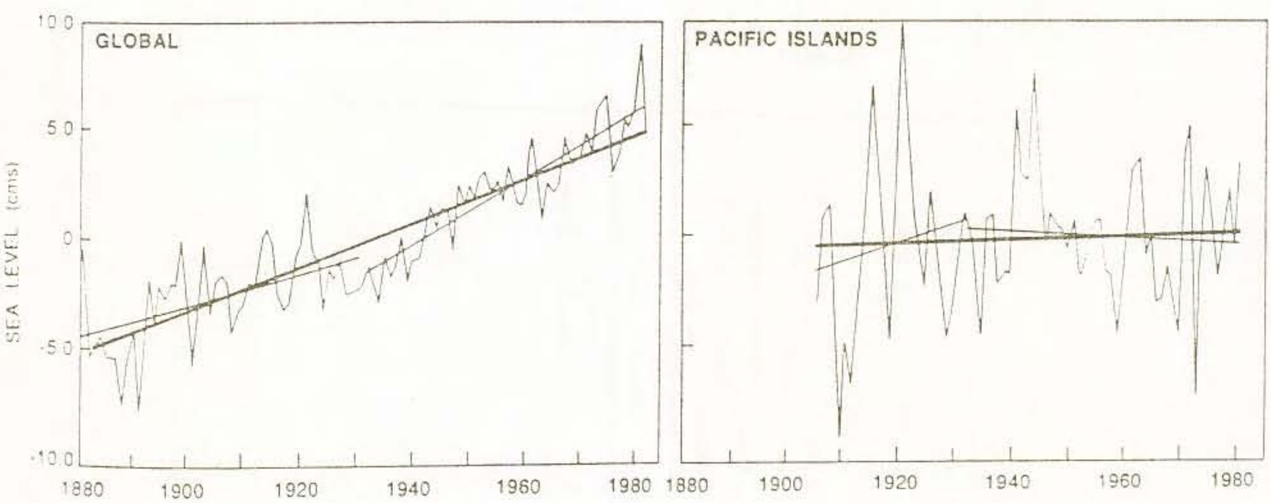

Figure 3. Global and Pacific Islands sea-level curves for the last 100 years. Heavy lines best fit for entire record, light lines for intervals 1880-1931 and 1932-1980. The global curve is based on over 200 stations; the Pacific Islands curve is based on 6 stations (after Gornitz and Lebedeff, 1987).

Table 1. **Boundary conditions related to accelerated sea-level rise (ASLR) scenarios**

Boundary conditions Accelerated sea-level rise	ASLR1	ASLR2
sea-level increase by 2100	300 mm	1000 mm
average rate of change 1990-2030	3.3 mm/yr	5.8 mm/yr
average rate of change 2030-2070	3.3 mm/yr	10.5 mm/yr
average rate of change 2070-2100	3.5 mm/yr	13.0 mm/yr
maximum rate of change	3.5 mm/yr	15.0 mm/yr
estimated rate of subsidence	0.1-0.2 mm/yr	0.1-0.2 mm/yr
relative sea-level increase by 2100	290 mm	990 mm
subsidence-corrected maximum rate of change	3.3 mm/yr	14.8 mm/yr

Four tide gauges are presently being operated in Kiribati by the University of Hawaii: Tarawa, Kanton, Fanning and Kiritimati; that at Kanton goes back to 1949, while that at Kiritimati goes back to 1956 (Wyrtki, 1990). Figure 4 shows data on mean sea level for the last 15 years (after McLean, 1989). It is immediately apparent that there are extremely large fluctuations in mean sea level from year to year, and even from season to season. It is difficult to distinguish any overall trend or greenhouse-related change in the record.

All tide stations in Kiribati show a strong seasonal cycle in water level of the order of 10-20 cm related to the location and strength of the trade wind system (Wrytki, 1974; McLean, 1989). There is also a strong cyclic fluctuation in water level related to the El Niño Southern Oscillation phenomenon, with the movement of a large volume of surface water from one side of the Pacific Ocean to the other. The factors which give rise to this El Niño effect are summarised by McLean (1989). This effect is particularly pronounced and it can be seen from Figure 4 that the monthly mean sea level was up to 28 cm above the long term mean in late 1982, but up to 21 cm below the long term mean in late 1983. These means represent the level around which monthly tides fluctuate, and indicate that the islands of Kiribati are naturally subject to short phases of uncharacteristically high and low mean water levels.

Tide gauges are expensive to run, and also require a length of record of 15-20 years before they can be reliably used to determine trends in mean sea level. On the other hand the level of the sea represents a critical constraint upon the development of many aspects of the reefs and reef islands. It limits, for instance , the height to which corals can grow. Individual corals cannot grow above a level at which they are exposed too frequently, a limit to coral growth which lies close to low spring tide level. Several intertidal massive corals (particularly of the genus Porites) adopt a flat-topped form, living only around the periphery when they reach this level. These are termed microatolls; they commence growth as hemispherical corals but when they reach the limit to coral growth they die on their upper surface and continue to grow laterally. Their upper surface thus contains a record of past water level fluctuations. Analysis of the record from microatolls from several atolls in the Pacific and Indian Oceans indicates that those atolls have undergone negligible overall change in water level for the last 20-30 years, and that most have in fact seen fluctuations often incorporating a slight fall of sea level of several centimetres over the last decade (Woodroffe, 1989a; McLean, 1989; Woodroffe

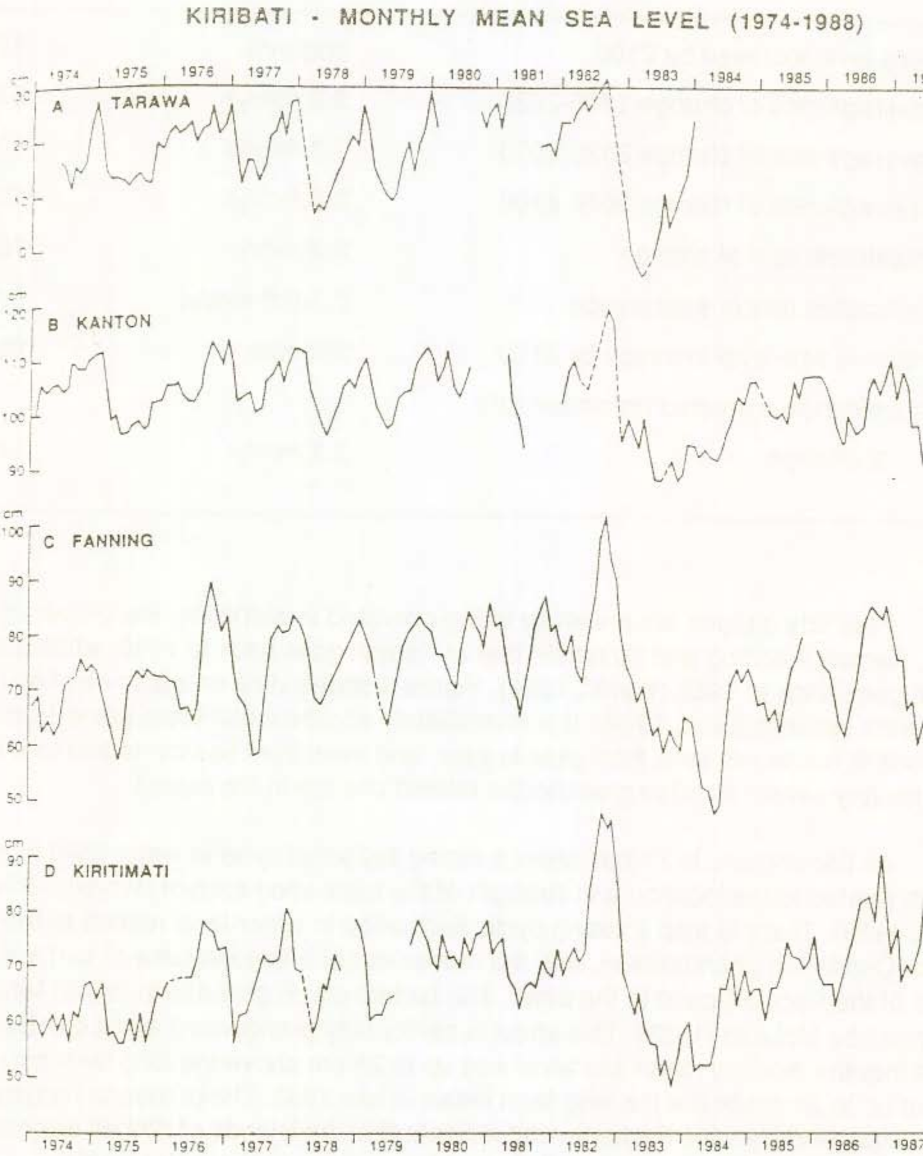

Figure 4. Monthly mean sea-level at four tidal stations in Kiribati, 1974-19
supplied by Dr. Klaus Wyrtki, Department of Oceanography, Univers
Vertical scales are not related to a datum (after McLean, 1989).

and McLean, 1990). Corals from several islands in Kiribati have now been collected as a part of our program of research, and although these have yet to be analysed in detail and do show fluctuations in the water level which limits coral growth, they do not show evidence of a rapidly rising sea-level trend.

There seems to be reasonable evidence that sea level is not, at this stage, rising at the rate of 1.0-2.0 mm/yr (i.e. the global average rate) with respect to some of the principal islands of Kiribati. There must, therefore, be some doubt about the rate at which the sea will rise in the future.

1.3. Subsidence

The geological evolution of coral atolls, with particular reference to those of Kiribati, has been reviewed by McLean (1989) and is summarised below. It is generally accepted that atolls, especially those in linear chains of islands such as the Gilbert Islands, have formed upon gradually subsiding volcanic basements.

There is no information on the age of the linear chain of Gilbert atolls to confirm this general model of geological development. However, shallow bores for water do indicate the near-surface stratigraphy of limestones beneath Tarawa atoll (Marshall and Jacobson, 1985). A solutional unconformity was found at a depth of between 11-17 m below ground level. This surface is interpreted, on the basis of radiometric dating, as the surface of the atoll during the last interglacial (c 120,000 years ago), that is the last time that the sea was at a level close to present prior to the last glacial. There is some dispute as to the maximum height of the sea at theat time, but it is generally considered to be 0-6 m above present. The depth of the discontinuity on Tarawa is broadly similar to that on other atolls (i.e. Eniwetok, Szabo et al., 1985; Cocos (Keeling) Islands, Woodroffe et al., 1991), and if this is explained primarily by subsidence rather than by solution, then it suggests a subsidence rate of 0.1-0.2 mm/yr. This rate can probably be extrapolated to the majority of islands in Kiribati, although our preliminary observations on Kiritimati suggest that this may be subsiding more slowly if at all.

The rate of subsidence is imperceptibly slow. Nevertheless it is interesting to note that the estimated rate of subsidence is of almost exactly the same order of magnitude as the observable trends in sea-level rise indicated by tidal records or corals from Kiribati.

1.4. Other climatic change under greenhouse conditions

There is little information as to what other changes might be expected as a result of the greenhouse effect. It seems probable that air and sea-surface temperatures would increase. On the other hand, the temperatures are already close to 30° C for much of the time, and Wyrtki (1990) suggests that disproportionate increases in evaporation, cloudiness and precipitation at these temperatures are likely to partially offset any tendency for the temperature to increase.

Increased sea-surface temperatures could have two consequences. Firstly, water temperatures of around 3-4° C above ambient for prolonged periods can lead to coral 'bleaching' and mortality (Jokiel and Coles, 1990; Williams and Bunkley-Williams, 1990). Healthy coral reefs are vitally important for the ecological well-being of atoll communities, for the protection that reefs afford, and for the production of sediment. It is beyond the scope of this study to examine the likelihood and consequences of increased coral bleaching.

Secondly, increased sea-surface temperatures have been generally supposed to lead to increased frequency and intensity of tropical cyclones (hurricanes). Cyclones are presently extremely rare in Kiribati, because within 5° latitude of the equator there is lack of cyclonic vorticity or background rotation necessary for cyclone formation. McLean has reviewed the factors which control cyclone formation in the Pacific and suggests that it is improbable that cyclone formation will increase in Kiribati under greenhouse conditions (McLean, 1989). Given the large degree of uncertainty, it seems inappropriate at this stage to incorporate any further factors related to climate change into the vulnerability assessment for Kiribati.

Table 2. Land, reef and lagoon areas, Gilbert Islands (after McLean, 1989).

Island	Land	Reef	Land & Reef	Lagoon	Total Area	Land area as % of land and reef area	Land Area as % of total reef top	Land & Reef area as % of total reef top	Lagoon Area as % of total reef top
Makin	7.89	5.97	13.86	0.34	14.20	57	56	98	2
Butaritari	13.49	87.61	101.11	295.77	396.87	13	40	25	75
Marakei	14.13	13.31	27.44	17.85	45.29	51	31	61	39
Abaiang	17.48	74.20	91.68	182.15	273.83	19	6	33	67
Tarawa	31.02	129.03	160.05	329.65	489.70	19	6	33	67
Maiana	16.72	84.72	101.44	73.95	175.39	16	10	58	42
Abemama	27.37	67.86	115.25	152.49	247.72	24	11	47	53
Kuria	15.48	13.02	28.50	-	28.50	54	54	100	-
Aranuka	11.61	22.25	33.86	35.86	69.72	34	17	49	51
Nonouti	19.85	118.14	137.99	351.69	489.68	14	4	28	72
Tabiteuea	37.63	172.53	210.16	359.20	569.36	18	7	37	63
Beru	17.65	33.98	51.63	2.88	54.51	34	32	95	5
Nikunau	19.08	7.08	26.16	-	26.16	73	73	100	-
Onotoa	15.62	21.56	37.18	75.38	112.56	42	14	33	67
Tamana	4.73	1.68	6.41	-	6.41	74	74	100	-
Arorae	9.48	0.98	10.46	-	10.46	91	91	1001	-
Total	279.23	843.92	1133.15	1877.21	3010.36				

2. Inventory of study area characterisitcs

2.1. Physical characteristics

The extent to which data is available on the physical characteristics of islands differs from island to island. For none of the islands of Kiribati is the data inventorised in a form which is adequate for detailed vulnerability analysis. The best account of environmental factors is that contained within the forthcoming report to UNCED (National Task Force, 1992). This report, however, does not report upon areas, or lengths, of particular coastal types or communities.

The broad details of land area, reef area and lagoonal area for the Gilbert Islands are outlined in Table 2. The principal sources for determination of the susceptibility of coastal areas are the existing maps and aerial photographs. Detailed topographic maps prepared by the Directorate of Overseas Survey in the 1970s, based on photogrammetric interpretation of aerial photography undertaken in 1945 by the U.S. Navy and in 1969 by the Department of Lands, Mines and Surveys, Fiji, are a valuable source of information and are listed in Table 3. Outlines of the Gilbert Islands compiled from those maps are shown in Figure 5. The maps have been used to compile data on area, perimeter, maximum length and maximum width of individual reef islands (see Appendix).

A still more valuable source of information are the aerial photographs. The Department of Lands holds aerial photography from 1945, 1969, and photography taken of the Gilbert Islands and some of the Line and Phoenix Islands in 1984. The aerial photography could form the basis of either a detailed Coastal Zone Mapping Program, or a Natural Resources Survey of the country, similar to the Land Resources Survey recently completed for Tuvalu (McLean and Hosking, 1991a). The availability of aerial photography taken at different times over the last 40-50 years makes it feasible to map shoreline changes.

In addition it would be possible to acquire SPOT satellite imagery, as the satellite can be programmed to record imagery on a particular overpass. While such imagery would undoubtedly be useful as part of a full Natural Resources Survey, the spatial resolution of pixels on the ground (c 30 m with SPOT) is not sufficient to adequtely assist with coastal zone mapping.

Elevation data are crucial in assessing vulnerability to ASLR. This is generally scarce. Benchmarks for South Tarawa (and some on Kiritimati) have been reduced to mean sea level, but survey marks on other islands are generally not well controlled for elevation.

2.1.1. Geological development of reef islands on coral atolls

Mid-oceanic coral atolls have evolved as a result of a delicate balance between the constructional and destructional forces of the sea, being composed of skeletal sands derived from corals, algae, molluscs and other organisms, and isolated in the middle of vast oceans subject to occasional extremely rough seas. Recent geological research has generally substantiated the subsidence theory of coral atoll evolution proposed by Charles Darwin (Braithwaite, 1982). Darwin (1842) recognised three types of coral reefs, fringing reefs, barrier reefs, and coral atolls, and he suggested that these evolved through a sequence in which the driving force was gradual subsidence of the volcanic basement on which the reefs were founded. As the volcanic island subsided, the reef grew vertically by the accumulation of coral (and associated carbonates). The Darwinian sequence of coral atoll development has been incorporated into plate tectonic theory, and much of the subsidence can be explained in association with the aging and contraction of the ocean floor with tangential movement of the plate (Scott and Rotondo, 1983). Atolls in the Pacific are often found in linear chains, several of which (i.e. the Hawaiian Islands) demonstrate stages in the Darwinian sequence along their length (Figure 6). Reef growth, however, has not been continuous, but has been interrupted by fluctuations of sea level during the Quaternary (the Ice Ages); atolls being exposed above the sea and eroded during glaciations, with reef growth re-establishing over the surface during interglacials.

When sea level was high an atoll perhaps somewhat similar to that presently found, would have existed where there are atolls today. When sea level was low, that atoll was exposed up to 100m above the sea as an emergent limestone island, and it underwent solution giving rise to a highly eroded karst surface (Figure 7). During the 100,000 years or so that it has taken for the sea to return to its present level, the atoll has gradually subsided so that the former (last interglacial) surface is about 10-20m below present sea level beneath the present atoll. The upper 10-15 m of limestone has formed as a result of reef growth over the last few thousands of years.

There is still some doubt over the exact timing of ice melt , particularly from Antarctica, but most post-glacial melting is thought to have finished by 6000 years ago (Nakada and Lambeck, 1988). Coastlines have, however, adjusted since that time, both to regional ice and water loads (as well as undergoing tectonic movements where tectonically active). Consequently the apparent sea-level history at any point depends upon those lithospheric adjustments as well as global (eustatic) sea-level history (Clark et al., 1978; Nakada and Lambeck, 1988).

There is considerable evidence that the sea stood 1-2 m above its present level with respect to many of the coral atolls of the Pacific and Indian Oceans about 4000-3000 years ago and that in the last few thousand years it has fallen relative to those islands. Cemented coral conglomerates on the reef flats and islands of atolls and above the present limit to coral growth have been radiometrically dated on many islands (Newell and Bloom, 1970; Tracey and Ladd, 1974 ; Buddemeier et al., 1975; Pirrazoli and Montaggioni, 1986, 1988; Woodroffe et al., 1990a), including Kiribati and Tuvalu (Schofield, 1977a, 1977b).

There is a good radiometrically dated record of the pattern of reef growth for Tarawa, which is summarised by McLean (1989). Subsurface dating of reef growth can be projected to demonstrate that the sea must have been at its present level after the postglacial rise at least 4500 years B.P. (before present). Schofield (1977a, 1977b) has radiocarbon-dated reef-top corals, giant clams (Tridacna) and onshore sediments to indicate that the sea was about 2 m above its present level around 4000 years B.P.. Such an interpretation was not widely accepted when first proposed, and the elevation by which the sea exceeded that of the present is now usually regarded as less than 2 m, but there is now widespread evidence from throughout Kiribati to substantiate that many of the reef-surface deposits were formed at a time when the sea was higher than present.

Our own observations, and unpublished dating results, from Kiritimati support a sea level 0.5-1.0 m above present about 3000 years ago (see Plates 2d, 3a and 3b). Evidence for emergent reefs has been reported from Kiritimati (Valencia, 1977), Kanton (Guinther, 1978), and radiocarbon dates of 2150-2650 years B.P. have been reported from Enderbury, up to 2800 years B.P. from Jarvis, and 3500-3950 years B.P. from Malden and Starbuck (Tracey, 1972).

Based on these data a three stage model (Figure 8) can be proposed for the evolution of all islands (except Banaba) in Kiribati (McLean, 1989); a similar three stage model for atoll reef and reef island evolution has been proposed for Indian Ocean atolls (Woodroffe et al., 1990b). The first phase from about 8000 to 6000 years B.P. was a phase of rapid vertical reef growth as the reefs strived to 'catch-up' with a rapidly rising sea level. The second phase from about 6000 to 3500 years B.P. was a phase of reef flat formation as reefs caught up with sea level and consolidated. The third phase, perhaps starting around 3500 years ago and continuing to the present was a phase of reef island formation.

What is clearly shown is that the islands are geologically very young in age, and that although the processes of island erosion and accretion are continuing to this day, the basic form of the islands has been preserved partly as a result of a net fall in sea level in the last 2000 years (Schofield, 1977b). It is also likely that different reef platforms might be at different

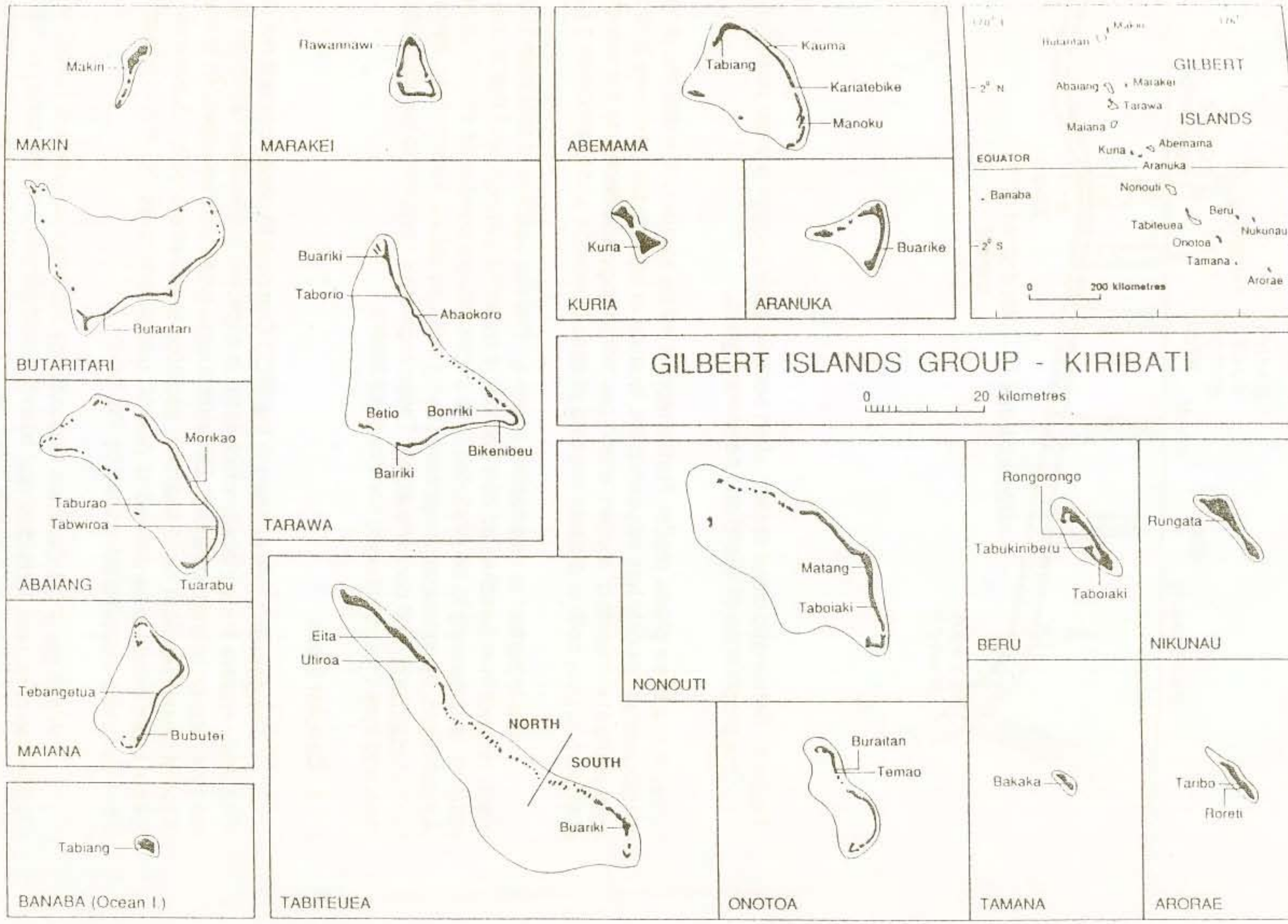

Figure 5. Reef and island outlines, Gil

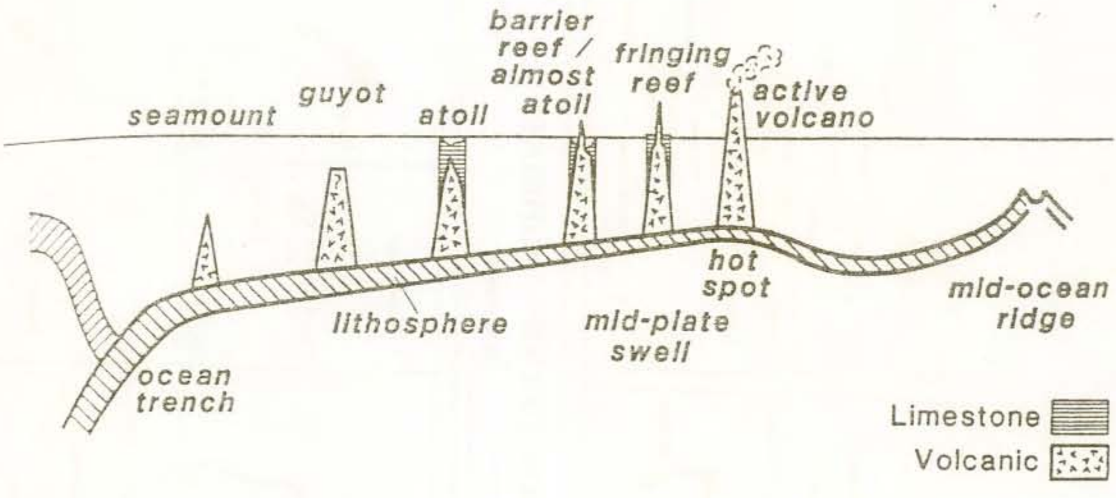

Figure 6. Schematic cross section of an oceanic plate through a linear island chain, showing the progression of island and seamount types.

stages in this three phase model. Furthermore it will be shown below that the disposition of conglomerates not only has influenced the location of islands, but continues to form one of the more resilient elements of modern island geomorphology and decrease the vulnerability of par of modern islands both to present ongoing phases of erosion and to anticipated sea-level rise.

It is important to emphasise, however, that the beaches of reef islands differ in one critical respect from beaches on non-carbonate terrestrial settings, and that is that the sediment is continuing to be produced. The sediments are composed entirely of biogenic grai skeletal origin, the principal components being coral, molluscs, foraminifera, calcareous algae such as Halimeda, and coralline algae. These organisms continue to be abundant throughout atolls and they thus continue to contribute sediment.

2.1.2. Coastal types

The coastal types outlined in the IPCC Common Methodology are not detailed eno adequately resolve the variability which is to be expected in shoreline response to accelerate sea-level rise on islands in Kiribati. Different coastal types may be expected to show a wide range of responses from rapid sediment accretion to extreme erosion. A more detailed suite coastal types needs to be defined as part of coastal zone mapping, and is one of the objecti the vulnerability mapping advocated by this study.

Within the IPCC Common Methodology the entire coastline of Kiribati would be identified as coral reef. Individual reef islands would contain only flat sandy or flat muddy (mangrove) shorelines. In practise there are a range of shoreline types differing particularly in degree of lithification and hence vulnerability.

There are a number of features which need to be taken into account in describing mapping individual islands in Kiribati because the precise impact will not be dependent sim upon island size, but on several other factors too. The most important are listed below:

a) type of island (atoll/ reef-top island (table reef), etc.
b) island shape and size

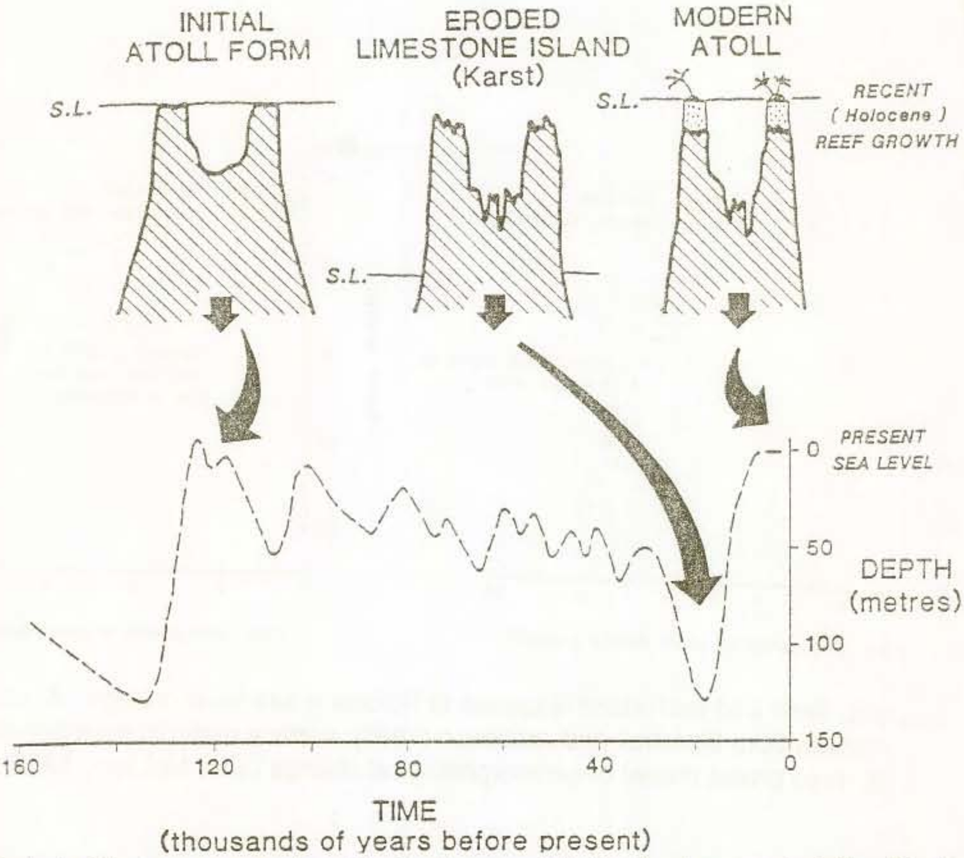

Figure 7. Late Quaternary sea-level fluctuations and their effect on coral atolls. The lower diagram shows actual reconstruction of sea-level and ocean volume variations for the last 140,000 years (after Chappell and Shackleton, 1986). The atoll is gradually subsiding.

c) island perimeter
d) reef width, shape and orientation
e) island elevation
f) island sediment
g) sediment lithification
h) beach slope and beach ridge crest height
i) coastal vegetation
j) shoreline dynamics
k) land use
l) natural coastal protection (conglomerate outcrops, mangroves etc.)
m) artificial coastal protection

A example of an appproach that could be adopted is given for the individual case study of the island of Buota (Figure 20 and 21).

Three coastal types which are especially important are conglomerate platforms, conglomerate ramps, and beachrock. Conglomerates composed of cemented coral boulders are a feature of many atolls. Their origin has been the subject of some controversy; in some cases they appear to have been deposited at a sea level above present, whereas in others they are considered to be formed from storm deposits. Our preliminary research into the form and distribution of these conglomerate platforms indicates the they vary from atoll to atoll. They tend to be most conspicuous and and most lithified on the oceanward shore of islands, only in a few cases extending through to the lagoon shore.

Beachrock is a rapidly cemented deposit which stabilises the lower beach. It can form rapidly as is shown by the inclusion of relicts from World War II in beachrock on Tarawa. Beachrock increases the stability of the beach, though the conditions necessary for its formation are still the subject of debate. Initially it was interpreted as the result of mixing of fresh water and marine waters at the island margin where outflow of water from the lens would be expected (Russell, 1962). More recently this has been questioned because outflow does not appear

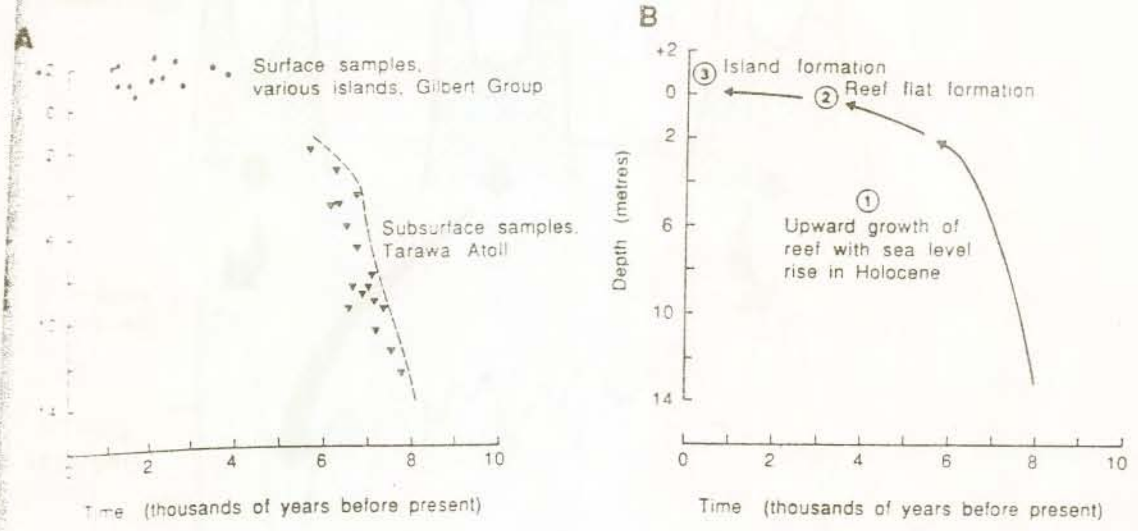

Figure 8. Reef and reef island response to Holocene sea-level change. A: subsurface data for Tarawa from Marshall and Jacobson (1985); surface material from Schofield (1977a). B: three phase model of geomorphological change (after McLean, 1989).

necessary, and chemical changes within the water table, especially carbon dioxide degassing are believed to be involved (Hanor, 1978).

2.1.3. Tidal levels, climate and freshwater resources of islands

Tidal levels are reported relative to chart datum. Mean sea level is 0.95 m above chart datum. Average tidal range is 1.2 m. The maximum recorded levels (by 1976) were -0.3 m and +2.45 m. Mean low water spring (MLWS) is 0.1 m, MLWN 0.7 m, MHWN 1.2 m, MHWS 1.8 m (Hydraulics Research Station).

Kiribati lies on a steep climatic gradient in the Pacific (Burgess, 1987). Mean annual rainfall (Figure 9) decreases from an average of 3167 mm at Butaritari to 882 mm on Kiritimati. In addition to this pronounced geographical gradient, there are marked fluctuations from year to year (Figure 10). This is particularly shown for Kiritimati which received 240 mm in 1985 and 3730 mm in 1987, a fifteen-fold difference!

On small islands the freshwater lens is an important resource, both as a source of potable water and water for irrigation and it is directly dependent upon precipitation. Water quality can be impaired either by intrusion of salt water into the aquifer or by contamination of the lens from sewage, storm runoff, fertilisers, pesticides, industrial effluents and other contaminants.

Small islands composed of limestone or unconsolidated calcareous sediments represent a porous medium through which groundwater permeates. The first approximation of the freshwater lens of a small island is provided by the Ghyben-Herzberg principle (Ayers and Vacher, 1986). This relationship is based on density differences between rainwater and seawater; the lower density freshwater (specific gravity 1) floats on the underlying salt water (specific gravity 1.025).

The elevation, or doming, of the freshwater lens above mean sea level is a fortieth of the depth of the lens beneath mean sea level according to the Ghyben-Herzberg principle, which assumes a homogeneous substrate, uniformly recharged, and without variations of the sea surface to mix waters. However, on small islands where outflow is not likely to be large, the

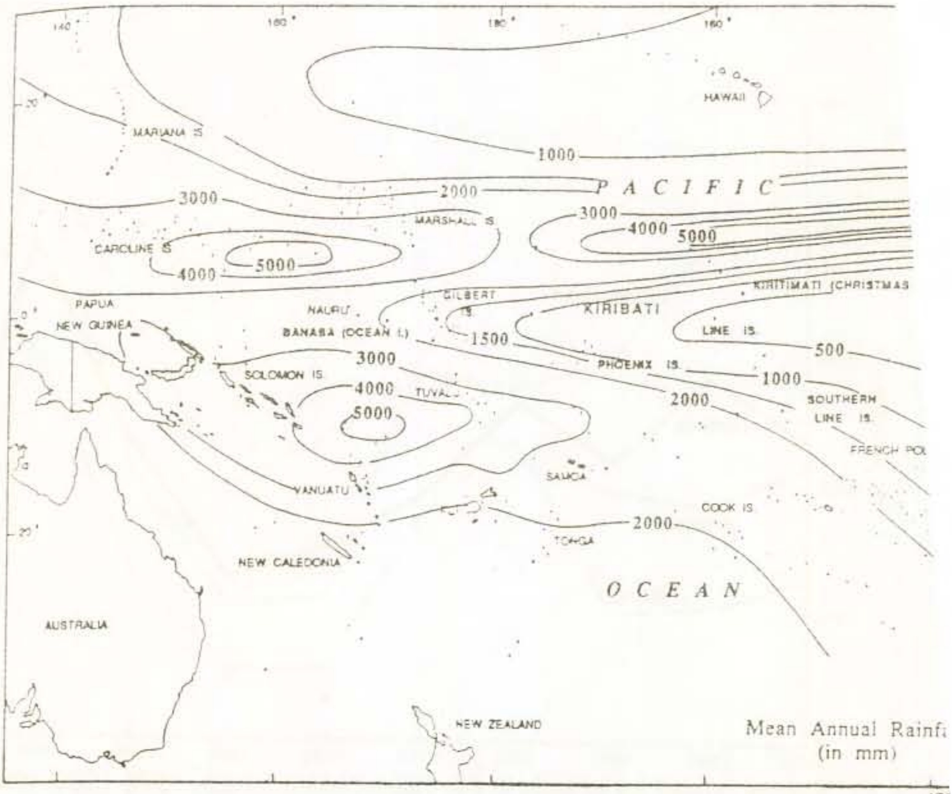

Figure 9. Mean annual rainfall (in mm) over the central Pacific Ocean (after McLeai

Table 3. Details of individual islands (Department of Lands)

	Orthophoto Maps		Dyeline Maps	
	Scale	No. of sheets	Scale	N
Makin	1:25,000	1	1:50,000	1
Butaritari	1:25,000	3	1:50,000	1
Marakei	1:12,500	1	1:25,000	1
Abaiang	1:25,000	3	1:50,000	1
Tarawa	1:25,000	3	1:74,000	1
	1:50,000	1	--	
South Tarawa	--	--	1:2,500	18
Maiana	1:25,000	1	1:25,000	1
Abemama	1:25,000	2	1:500,000	1
Kuria	1:25,000	1	1:10,000	1
Aranuka	1:25,000	1	1:10,000	2
Nonouti	1:25,000	2	1:500,000	1
Tabiteuea	1:25,000	4	1:500,000	2
Beru	1:25,000	1	1:400,000	1
Nikunau	1:25,000	1	1:100,000	1
Onotoa	1:25,000	1	1:500,000	1
Tamana	1:25,000	1	1:5,000	1
Arorae	1:25,000	1	1:5,000	1
Kiritimati	1:50,000	1	1:50,000	1
Kanton	--	--	1:25,000	1
Fanning	--	--	1:48,690	1
			1:20,000	1
Banaba	--	--	1:25,000	1

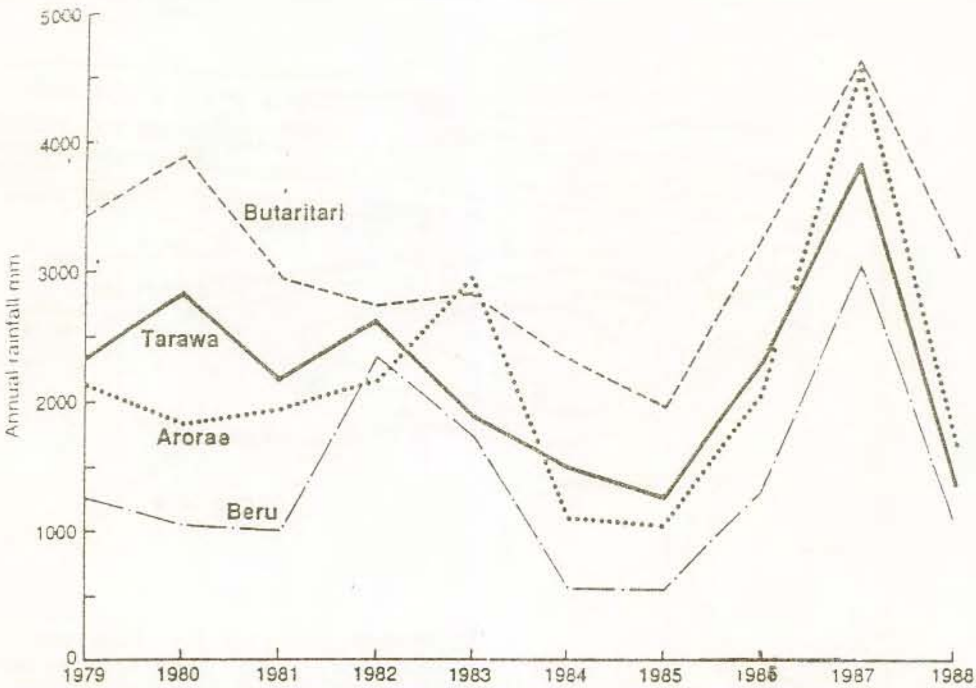

Figure 10. Annual rainfall for islands in the Gilbert Island chain, 1979-1988, showing the marked interannual variability (after Ward and Monsell-Davis, 1990).

ideal Ghyben-Herzberg lens is not found and there is a thick brackish transition zone (Falkland and Brunel, 1989). Several studies, including those on Kiribati, have suggested that the 1:40 ratio of fresh water above to that below mean sea level does not apply in practice, but that the ratio is nearer to 1:20 - 1:25 (Lloyd et al., 1980).

Recently the assumptions of horizontal flow, and horizontal tidal propagation have been questioned and it has been suggested that the freshwater lens is actually vertically coupled with a more permeable aquifer at depth rather than horizontally linked to open water (Buddemeier and Holladay, 1977; Oberdorfer and Buddemeier, 1988). The older limestone (formed during the last interglacial) found at 10-15 m depth on Tarawa is considerably more porous than the overlying younger limestones, and gives rise to this suggestion of a dual aquifer (see Figure 11).

Figure 12 shows the form of freshwater lens which can be as deep as 29m on Tarawa (Marshall and Jacobson, 1985).The principle factors which effect the size of the freshwater lens are island width, rate of freshwater recharge, and porosity/permeability of the aquifer (Mather, 1975). Tidal range can be important in that it influences the thickness of the transition zone. The amount and type of vegetation on the island, as well as man-made modifications to the surface of the island, influence the proportion of rainfall reaching the lens as recharge.

Freshwater lenses only develop on islands that are large enough. Initial observations suggested that the threshold size was 1.4 ha, or a width of 200m (Wiens, 1962). However lenses are not found beneath all islands of that width and in some places 300-400m may be a more realistic minimum width for a lens to develop (i.e. in Kiribati, Cloud, 1952; Marshall and Jacobson, 1985).

In Kiribati, the water resources of Tarawa and Kiritimati are the best known having been examined in detail in recent surveys (Jacobson and Taylor, 1981; Falkland, 1983). The size of the lens in both of these cases varies considerably from year to year as a function of rainfall (see also Guinther, 1974). This is especially influenced by the El Niño.

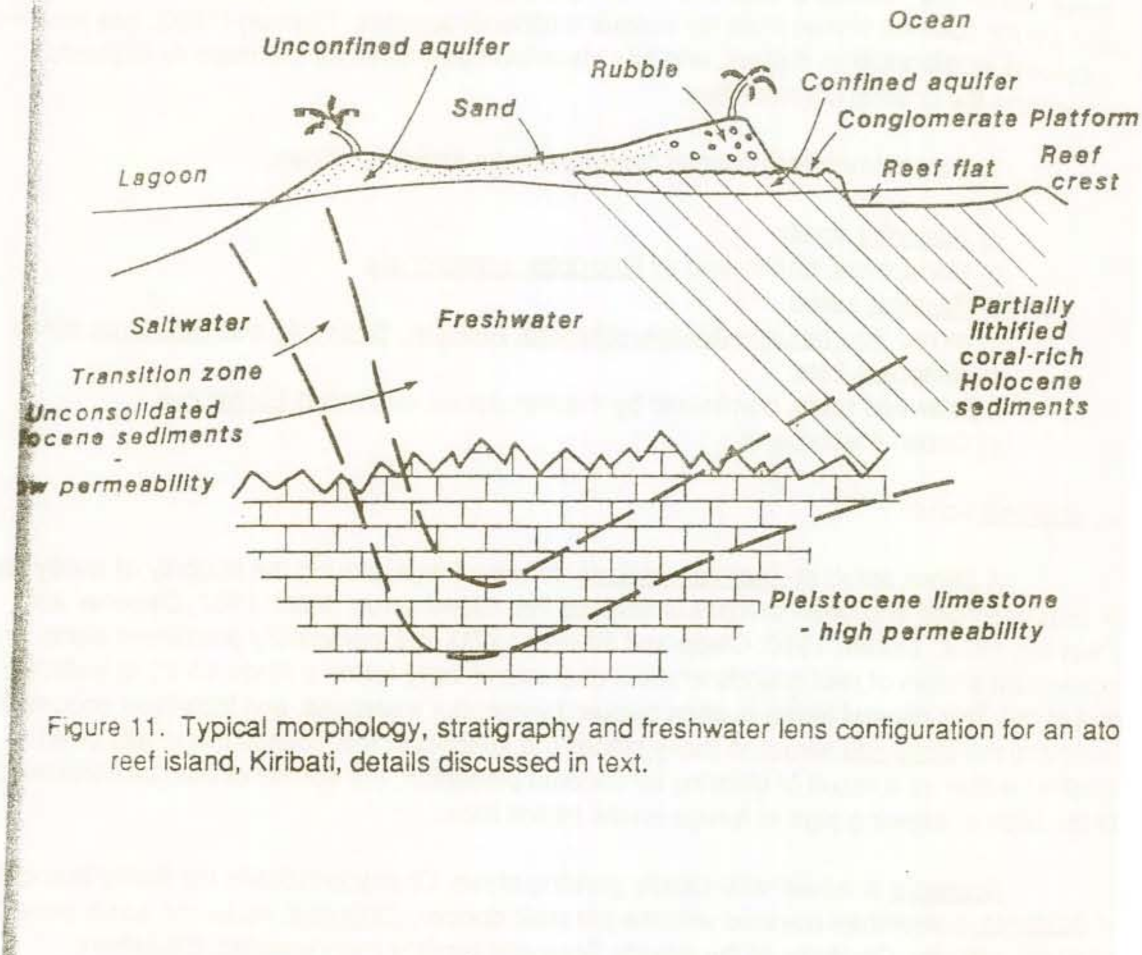

Figure 11. Typical morphology, stratigraphy and freshwater lens configuration for an ato reef island, Kiribati, details discussed in text.

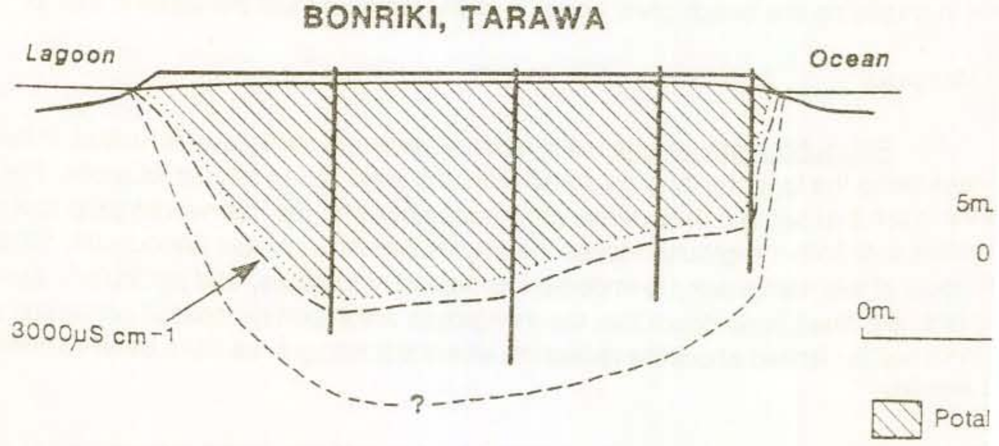

Figure 12. Freshwater lens beneath Bonriki, Tarawa (after Marshall and Jacobs

2.2. Habitats and species

The most authorative overview of the floral and faunal composition of communities in Kiribati is that compiled by the National Task Force (1992) for presentation at the UNCED meeting. The vegetation types which play an important role in coastal protection do not contain any endemic species. The majority of the area of most of the islands has been planted to coconu (except on Kiritimati, Wester, 1985), and there is very little of the natural forest vegetation preserved on the islands (Moul, 1957). Nevertheless, important tree species are still found, and are the sources of materials for various traditional activites. Thaman (1990) has reviewed traditional agroforestry in Kiribati, and has identified many uses for the majority of plants comprising the coastal communities.

The most important coastal habitats can be listed as follows:

a) Scaevola scrub
b) Mangroves, dominated by Rhizophora mucronata
c) Pemphis scrub
d) mixed Tournefortia (Messerschmidia, Argusia), Scaevola and Guettarda scrub
e) Seagrass flats
f) Seaweed beds, dominated by the introduced, cultivated Eucheuma
g) Coconut woodland

a) Scaevola scrub

A dense scrub of Scaevola sericea forms a fringe around the majority of sandy reef islands of Kiribati and often merges landwards into inland scrub (Moul, 1957; Degener and Degener, 1959; Doran, 1960; Clapp and Sibley, 1971). It is particularly prominent along oceanward shores of reef islands where it characteristically forms a fringe 15-20 m wide, up to 4 m tall. This coastal fringe is often backed by coconut woodland, and individual coconuts overhang the Scaevola scrub. In many places the integrity of this coastal fringe has been modified either as a result of clearing for coconut plantation, the spread of coastal settlements, or the habit of allowing pigs to forage on the beach face.

Scaevola is a relatively rapidly growing shrub. Characteristically the fleshy branches of Scaevola, sometimes covered with the parasitic dodder, Cassytha, make the scrub penetrable only with difficulty. On many of the islands Scaevola scrub is monospecific. Elsewhere Tournefortia, Pandanus and Guettarda emerge above the canopy. This scrub plays an important role in stabilising the beach crest and preventing wind and salt penetration inland.

b) Mangrove

Rhizophora mucronata is the most widespread mangrove in Kiribati. It forms extensive fringes along the lagoonal shores, particularly the west-facing shores, of atolls. The trees rarely reach 6 m tall, but their dense growth together with the interwoven prop root system reaching 2 m from the ground makes the vegetation impenetrable (Woodroffe, 1988). The dense stilt roots of this mangrove are important as sediment trappers, and particularly as sediment binders, and there is no doubt that the mangroves are important coastal protection and that there is evidence for limited shoreline recession where the mangroves have been removed (see Plates 6c and 6d).

Better developed stands of mangrove occur in the wetter, northernmost atolls (especially Butaritari), where mangroves (Sonneratia) are found on the seaward as well as lagoonward shores. Bruguiera is also reported from the northern Gilbert Islands. Lumnitzera littorea is found throughout the Gilbert chain, but is not as important as Rhizophora, and its frequent associate, Pemphis, as a coastal protection.

The proportion of the shoreline occupied by mangroves has been calculated for the outer Gilbert Islands and is given in the Appendix.