Integrated Coastal Zone Management Programme for Western Samoa and Fiji Islands

Assessment of Coastal Vulnerability and Resilience to Sea-Level Rise and Climate Change

Case Study: Yasawa Islands, Fiji

Phase II: Development of Methodology

March 1994

South Pacific Regional Environment Programme (SPREP)
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SOUTH PACIFIC REGIONAL ENVIRONMENT PROGRAMME

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Case Study: Yasawa Islands, Fiji

Phase 2: Development of Methodology

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Foreword

Small islands in South Pacific region are giving special attention and challenges to environmental planning and sustainable development. Small islands have numerous environmental problems including the various pressures like economics and population concentrated on the coastal zone or in limited land area.

In addition, extreme climate events, for example, high tides, typhoons, cyclones and storm surges threatens island existence. The islands are ecologically and economically fragile and vulnerable to the effects of climate change and have identified as the priority action area for developing adaptive response strategies for future sea level rise.

The object of this study is to contribute to the integrated coastal zone management at national (Fiji), regional (South Pacific) and international levels. The study consists two phase projects to achieve this object.

This is the Phase 2 report which refers to the supplemental investigation for Phase 1 and the further development of the methodology for assessing the impacts of predicted sea-level rise which was tested initially in Phase 1.

This study was sponsored by the Environment Agency of the Japanese Government and was carried out by the Overseas Environmental Cooperation Center (OECC) in collaboration with South Pacific Regional Environment Programme (SPREP).

We are very grateful to the Government of Fiji providing this study with useful data and information.

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Chapter 1. Executive summary

Introduction

This is Phase 2 of a project which contributes to integrated coastal-zone management, integrated coastal-hazard management and sea-level rise impact mitigation at the national (Fiji), regional (Pacific) and international levels. Fiji is the country of study. It further develops the methodology for assessing the impacts of predicted sea-level rise which was tested initially in Phase 1 of the study. Rather than refine the methodology based on testing in the `core' of Fiji, the periphery was sampled in this study.

The five specific aims of the Phase 2 study are as follows.

(a) To determine the present tectonic condition of the islands and to consider this in association with what is known of recent sea-level changes in order to establish a clear baseline for the consideration of predicted future sea-level rise.

(b) To further develop the methodology for assessing the impact of future sea-level rise on the islands' coasts by trying to make it more objective (less subjective) so that it can be applied uniformly by different human operators in the future.

(c) To test the revised methodology at two places in the outer islands of Fiji (Yasawa group), which were not considered in Phase 1, which will also serve to characterize the periphery rather than the core of development activity.

(d) To use GIS technology to generate maps of Fiji's coasts, particularly Suva and Lautoka Ports, to show their vulnerability and resilience to sea-level rise. These maps will be the basis for a national vulnerability profile.

Development of a baseline for coastal change

The recent and current tectonic condition of each of the main geotectonic regions within the diverse archipelago of Fiji was considered, together with recent sea-level behaviour. It was possible to cross-check results by demonstrating that recent sea-level rise was less in areas which are stable or rising, and more in areas which are subsiding. Most areas of Fiji's coastline appear to have experienced and to be experiencing relative sea-level rise.

In order to determine the future background trend of sea-level behaviour, an analogy with the Little Climatic Optimum was used. During this period, which ended about AD 1300, temperatures and sea level rose gradually - at a similar rate to that which temperatures have been rising for the past 100 years. Assuming that the present period of warming - ignoring the effects of the enhanced greenhouse effect - is analogous to the Little Climatic Optimum, then temperature would continue rising for the next 100 years - the rise being a total of around 0.2°C. This figure represents a lessening of the rate of temperature rise over the last 200 years.

Using the same analogy, sea level is predicted to continue rising for the next 100 years - again ignoring the effects of the enhanced greenhouse effect - by another 20 cm before AD 2100.

Using these predictions, and the revised 1992 IPCC emissions scenarios, best-guess modelling gives a 1990-2100 sea-level rise of 46 cm for Fiji.

There is clearly great potential for using information from the past to fine-tune predictions for the future. For example, by knowing how particular coastlines responded to a sea-level rise of a certain magnitude over the last few decades, it is possible to predict how that same coastline will change in the future in response to a sea-level rise of a certain magnitude.

Development of the methodology

Several problems were identified with the methodology developed and used in Phase 1 of the Fiji project.

Principal among these problems was the lack of objectivity of the scoring system. This led to a re-ordering of the coastal systems, to improve the logical application of the methodology, and their elaboration.

- natural
- human
- infrastructural
- institutional
- economic
- cultural

The addition of the human coastal system was in recognition of the low priority given to population and population density issues in the Phase 1 scheme.

It was decided that the best way to optimize objectivity in the scoring was to define much more fully than had been the case in Phase 1 exactly what was meant by particular scores. This produced a much lengthier set of information which operators would have to absorb before they could apply the methodology but it was felt that this was appropriate, particularly if operator training could be arranged.

Other minor changes were made to the methodology. In several cases, vulnerability was used as a surrogate for estimating the comparative value of a particular subsystem element or its magnitude.

Problems remaining with the methodology include the observation that sea-level rise is not a problem or stress, potential or otherwise, which can be treated in isolation. To separate it from other environmental stresses creates problems of assessing future environmental impacts, particularly those associated with climate-sea level change interactions. The frequency of catastrophic events is also of concern. Increasing populations, increasing urbanization, poverty, inequality and other social ills in the Pacific islands are another important source of stress on the environment, which cannot be conveniently divorced from sea-level associated stress in the future.

Testing of the methodology

For Phase 2, the priority in the selection of study sites was to represent the periphery rather than the core. The people inhabiting the periphery have a different relationship with the coastline compared to many living in or close to the core. Dependence on the natural environment for subsistence is generally far more profound because there are few opportunities nearby for cash employment. Infrastructural development and communications in most parts of the periphery are less developed and/or efficient than close to the core.

The Yasawa islands are typical of Fiji's periphery. They are a chain of volcanic islands occupied largely by subsistence agriculturists. There is some tourism. These islands lie in the dry part of Fiji; water has often to be shipped there during the dry season. They also receive a disproportionate number of tropical cyclones on account of facing the northwest, from which most approach Fiji. Two island study sites were selected within the Yasawas; Viwa, a low limestone island, and Nacula, a high volcanic island.

Nacula can sustain its present population without undue difficulty, although problems arise after a `direct-hit' cyclone. With increasing environmental stress from temperature rise, and sea-level rise inundating some low-lying areas and rendering others unusable for agriculture owing to saltwater intrusion, it will become more difficult to sustain the population. However, the strength of indigenous culture with its communal support mechanisms, will assist in finding solutions. Much of the higher ground, now currently covered with a grassland-savanna assemblage and relatively unused, may have to be rehabilitated for future agricultural use.

Viwa is more isolated and more resource poor. Being low, it is affected more by storm surges associated with tropical cyclones. The problem of fresh water is acute. It is far less capable of sustaining existing population levels both now and in the future than Nacula. However, the limestone is elevated and will not be affected significantly by predicted sea-level rise over the next century.

Impacts on ports

Although Suva Port is ideally positioned to take advantage of its natural surroundings, many of the foreshore structures are inadequately constructed and of insufficient height to repel the 50-year storm surge, let alone those which may affect the area if the sea level rises as predicted. Similar comments apply to Lautoka Port although here there are fewer natural advantages of the site.

Towards an integrated coastal-zone management plan

A coastal-zone management plan is the best way of planning rationally and consistently for an accelerated rise of sea level in the future. It is a way of minimizing deleterious impacts of sea-level rise on Fiji's people, resources and infrastructure.

The physical fabric of Fiji has been regarded as comparatively immune from deleterious effects of accelerated sea-level rise in the future. This view is fallacious, although it is true that the effects will be neither so rapid nor so disruptive in a national sense in Fiji as for the narrow low-lying islands in the world's oceans. There is a very real danger that acceptance of the superficial view by those unconcerned with Fiji's long-term future will result in considerably more disruption than is necessary.

Despite the fact that Fiji is made up largely of high islands, their higher areas are currently of minimal importance compared to their low-lying coastal fringes. There are few settlements in the interior of any except the largest islands and the percentage of people occupying such areas is less than 5% of the nation's whole population. Most people live on the coast, most of those people on coastal plains which rise no more than a few metres above the high-tide level. Most economic activity - industrial, manufacturing, commercial - is concentrated in these areas. Most parts of the coastal plains which are not otherwise used are used intensively for agriculture, ranging from vast areas of commercial crops to coconut plantations on outer islands.

Sea-level rise alone will clearly have a negative effect on agricultural productivity in Fiji. This will be extremely significant since agriculture is the single largest sector of the Fiji economy, accounting for about 20% of the Gross Domestic Product and 80% of employment. Much of the most fertile land is in low-lying alluvial areas in river valleys and deltas which will be subject to inundation and increased flooding should sea levels rise. Increasing salinity of the groundwater and salt spray will also have negative impacts.

Subsistence agriculture is very important in Fiji where about 60% of the population lives in rural areas. Most Fijians practice classical slash-and-burn agriculture but with declining fallow periods owing to increasing populations in the villages. Root crops, tree staples, fruits and vegetables are the main foods harvested. Fiji Indian farmers also tend to grow most of the foods they consume. Where possible, most of this farming is done on higher land but the main river deltas are places where no elevated land may be available to a village for agriculture. This is especially true of the large population of the Rewa Delta (on Viti Levu island) whose subsistence agriculture could be seriously threatened should sea levels rise as predicted.

Most available land in Fiji is already under cultivation. In the last decade, there has been increasing movement of both commercial and subsistence agriculture onto steep slopes. In general, agricultural productivity per hectare is low so that one partial solution to the loss of land resulting from sea-level rise would be to increase yield per hectare by more efficient agricultural practices. Some improvements in this area are possible but the long-term sustainability of high-input agriculture with improved cultivars has been called into question, especially in fragile island ecosystems. Certainly though, the development of more salt-resistant cultivars of tropical food crops should be a high priority area of research.

A Nationwide Vulnerability Assessment (NWVA) is required before an appropriate Integrated Coastal Zone Management Plan, considering sea-level rise and climate change, can be developed for each nation. Preliminary maps and tabled output show the potential of GIS technology for developing a NWVA.

Recommendations in brief

1. Results should be used to develop an integrated coastal-zone management plan.
2. Studies of recent coastal change should be made.
3. The methodology must be further developed, in more areas, and using pilot groups of operators.
4. A study of the impacts and changed frequency of catastrophic events in Fiji should be made.
5. GIS should be used to extend the embryonic Nationwide Vulnerability Assessment.
6. This work should be integrated with similar efforts to take a whole-environment impact approach.

Chapter 2. Background and aims

2.1. Introduction

This report summarizes the results of Phase 2 of a two-phase project with the broad aims of contributing to integrated coastal-zone management, integrated coastal-hazard management and sea-level rise impact mitigation at the national (Fiji), regional (Pacific) and international levels. In Phase 1 of the project for Fiji, two goals were achieved, summarized as follows.

(a) An appropriate methodology was developed for assessing internal and external stresses on coastal systems.

(b) The utility of this methodology for assessing the vulnerability and resilience of the coastline to predicted sea-level rise and climate change was demonstrated by three case studies, all on Viti Levu; namely, the Suva-Walu Bay section of the capital's coastline, the Korovou (a rural centre) area, the Verata coastline including the small offshore island of Viwa (a different Viwa from that in the Yasawas studied in Phase 2), and the tourist developments along the Serua-Veivatuloa coastline.

In addition, a comprehensive report (Nunn et al., 1993) was prepared which included considerable background information necessary for the understanding of the probable impacts of future sea-level rise and climate change on Fiji. This background information included brief accounts of human and physical factors affecting the coastline, with more detailed accounts of these for the study areas. The potential of Geographic Information System (GIS) technology for helping to mitigate impacts of future sea-level rise on the coastline of Viti Levu were also explored in Phase 1 of this study.

The Phase 2 study in Fiji both extends the Phase 1 treatment of various elements and introduces new factors which are considered relevant to the issue of future sea-level rise impacts on the islands' coastlines. In summary, the aims of the Phase 2 project for Fiji are as follows.

(a) To determine the present tectonic condition of the islands and to consider this in association with what is known of recent sea-level changes in order to establish a clear baseline for the consideration of predicted future sea-level rise.

(b) To further develop the methodology for assessing the impact of future sea-level rise on the islands' coasts by trying to make it more objective (less subjective) so that it can be applied uniformly by different human operators in the future.

(c) To test the revised methodology at two places in the outer islands of Fiji (Yasawa group), which were not considered in Phase 1, which will also serve to characterize the periphery rather than the core of development activity.

(d) To use GIS technology to generate maps of Fiji's coasts, particularly Suva and Lautoka Ports, to show their vulnerability and resilience to sea-level rise. These maps will be the basis for a national vulnerability profile.

(e) To outline the basis for an integrated coastal-zone management plan for Fiji with special emphasis on accommodating future changes in sea level and climate.

Each of these aims is elaborated in the following sections.

2.2. Establishment of a baseline for coastal change

In order to make accurate predictions of what is likely to happen to any particular part of the Fiji coastline in future, it is no longer satisfactory to assume that external variables affecting the coastline have not changed in the past. Principal among these external variables are sea level and land level.

Land-level (or tectonic) movements affect many islands in the South Pacific. The net rate of some of these movements is so fast that it has offset the effects of sea-level rise over the last few decades causing coastline extension rather than recession. Such rates are not thought to be approached throughout Fiji although they may occur in certain areas.

There have been secular sea-level changes recorded over the last hundred years or so at tide gauges in Honolulu (Hawaii) and Wellington (New Zealand) which cannot be ascribed to tectonic changes. These changes are manifested as a Pacific-wide sea-level rise at a rate of 1-1.5 mm/year for the past 100 years or so. There is no reason to suppose that Fiji has been immune from such changes, which would have been exacerbated locally by subsidence and reduced by uplift.

Coastal changes as the result of future sea-level rise will not therefore act on an unchanging system; an environment which has been unaffected by external variables over the past few decades. It is consequently of great importance to establish the nature and rate of these changes as accurately as possible prior to making recommendations concerning the mitigation of undesirable future coastal changes.

A survey of the available literature will be made. In addition there are other data, both published and unpublished, which have some information about rates of recent coastal change in Fiji. In the present study, there will also be some first-hand data analysis of recent coastal changes using available aerial photographs and maps over as long a time span as possible.

2.3. Methodological development

The stress-impact assessment framework established in Phase 1 was one especially adapted to the Fijian situation. Internal and external stresses were viewed as impacting on 6 interacting Coastal Systems: namely, human, natural, infrastructural, cultural, economic and institutional.

The assessment framework considers the vulnerability (0 to -3) and resilience (0 to 3) of each coastal system for each study area, values being decided subjectively. Values were first given for the present, taking present internal and external sources of stress into account. The values were given for the future, assuming that sea-level rise (and climate change) would occur. Future values were given for both a `no-management scenario' and an `optimal management scenario'. The long-term viability of particular coastal systems in particular places was measured by adding vulnerability and resilience scores for particular scenarios and expressing the result as the `sustainable capacity' of each coastal system.

One weakness of this system is that different values would undoubtedly be subjectively assigned to the same situation by different human observers. In Phase 2 we are seeking a way to minimize subjective judgments. One way to try and assign particular values to particular numbers for vulnerability and resilience, but we recognize that is not a total solution. Another way, which will be tested in Phase 2, is to increase the complexity of the vulnerability-resilience scoring framework to take not only the 6 major coastal systems into account but also a number of sub-systems and their constituent elements.

In addition, Phase 2 will address the fundamental difficulty in applying the IPCC Common Methodology to coastlines where everything cannot be meaningfully assigned a monetary value. Unless a surrogate way of valuing coastal elements can be found, direct comparisons with places where the Common Methodology has been applied successfully will be practically impossible.

2.4. Study sites in the Yasawas

In Phase 1 of this project, the three study areas where the methodology was tested were on Viti Levu, the island which is generally the most developed in terms of infrastructure and economy. Viti Levu can be portrayed as containing the core: the outer islands, including the Yasawas, as being the periphery (Bayliss-Smith et al., 1988).

In order to obtain a true picture of the likely impacts of future sea-level rise on the nation as a whole, it is deemed necessary to select case studies for Phase 2 from outer islands. Two areas in the Yasawas are selected. The first is the high volcanic island of Nacula (pronounced Nathula), an island with a low population density and four villages whose inhabitants follow a largely subsistence lifestyle. The second is the isolated, low limestone island of Viwa (not to be confused with Viwa off the Viti Levu coast which was part of a case study in Phase 1) where the inhabitants live in two villages and follow a subsistence lifestyle constrained by the generally resource-poor nature of the terrain compared to Nacula.

2.5. National vulnerability profile

One of the most efficient ways of assessing the vulnerability of the whole coastline of Fiji to external stresses such as sea-level rise is to establish a national vulnerability profile. This is best done using GIS to map coastlines and plot various variables and combinations of variables to characterize vulnerability.

In Phase 2 of this study, maps of the Fiji coastline and related features (such as reefs and mangrove swamps) will be digitized. Various data relating to climatic parameters (rainfall, temperature etc.), aspect, wave regime, coastal sediment supply and mobility, land use, settlement and population distribution will be input and various vulnerability indices computed and displayed graphically.

Users of the database will be able to interrogate it, update and use it for many other purposes.

Essential data will be sought in Phase 2. These data include up-to-date population distribution, land-use, and climatic statistics, particularly rainfall which varies considerably around the main islands depending largely on a place's position with respect to the southeast tradewinds.

In-depth studies will be made of Suva and Lautoka Ports with a view to recommending appropriate strategies for coping with predicted future sea-level rise.

2.6. Integrated coastal-zone management plan

By virtue of signing the Framework Convention on Climate Change, Fiji is called upon to produce its own integrated coastal-zone management plan. It is an important aim of this project that its results should be used in and indeed form the basis for a national integrated coastal-zone management plan. A particular concern of the signatories to the Framework Convention on Climate Change was that likely future sea-level rise and climate change should be incorporated into such plans.

The kinds of optimal management strategies identified for each of the case studies in both Phase 1 and Phase 2 will characterize virtually all of Fiji's coasts. A major problem which will be addressed in Phase 2 is how to make the strategies realistic, given the limited funds available.

It has not been possible to draw up the basis for an integrated coastal-zone management plan in the time available for this study. It remains one of the most important outstanding areas for future work.

Chapter 3. Establishment of a baseline for coastal change

One of the major deficiencies of many studies of Fiji's coasts is that the prediction of future changes is based on observations of the present (rather than the present and the past). Such a "snapshot" of coastal dynamics is highly unsatisfactory for the purpose of predicting future changes.

Some historical studies of coastal change in Fiji have been made. But as the islands are so diverse in nature, tectonic regime, coastal morphology and wave characteristics, generalization is fraught with difficulty. It is necessary to acknowledge the tectonic diversity of Fiji and to understand the reasons for the diversity in island character. Equally it is necessary to understand how sea level is likely to have changed in the archipelago in the past and what the implications are for the future. Finally, it is necessary to know how Fiji's various coasts have responded to recent tectonic and sea-level changes.

These issues are considered in the following sections.

3.1. Tectonic changes in Fiji

Fiji lies astride the complex boundary between two major lithospheric plates - the Pacific Plate and the Indo-Australian Plate. In the Fiji region, the Pacific Plate is moving in a direction a little north of west, and the Indo-Australian Plate is moving approximately northeast. The convergence of the two plates is therefore oblique and the present tectonic diversity of the Fiji islands can be ascribed to the accommodation of this oblique convergence.

Present plate boundaries in the Fiji region are shown in Figure 3.1. The major boundary between the Pacific Plate and the Indo-Australian Plate runs from the South Vanuatu Trench northwards through the North Fiji Basin as a divergent (sea-floor spreading) boundary, thence northeastwards as a transverse plate boundary known as the Fiji Fracture Zone. The Fiji Fracture Zone runs across the northern end of Fiji offshore the Vanua Levu platform and is the location of most seismic activity in Fiji. The junction between the eastern terminus of the Fiji Fracture Zone and the hook at the northern end of the Tonga (-Kermadec) Trench is not well understood. The latter is a convergent (subduction) plate boundary along which the Pacific Plate is being thrust beneath the plate to the west.

It is clear that there are several small (micro-) plates in the Fiji region. There is one on which the islands of Tonga are situated because, to the west running down the centre of the Lau(-Havre) Basin, is an active divergent (sea-floor spreading) boundary. To its west lie the Lau group of eastern Fiji, an abandoned island arc once joined to the Tonga arc. From a point about 100 km west of the main Lau Ridge, an ocean trench is found which extends from this point southwestwards south of the island of Kadavu, a young volcanic conglomeration. This trench, variously known as the Kadavu Trench or the Hunter Fracture Zone, is believed to be a convergent plate boundary which was accommodating plate convergence during the late Quaternary (last few hundred thousand years). It may still be accommodating plate convergence.

Details of the plate-tectonic character of the Fiji region are from Malahoff et al. (1982), Hamburger (1986) and Nunn (1988, 1991b).

What all this means for the Fiji islands is that there are different sets of stresses acting on different groups. The main seismotectonic divisions of Fiji are shown in Figure 3.2 and discussed individually below. Seismotectonic zoning of Fiji was

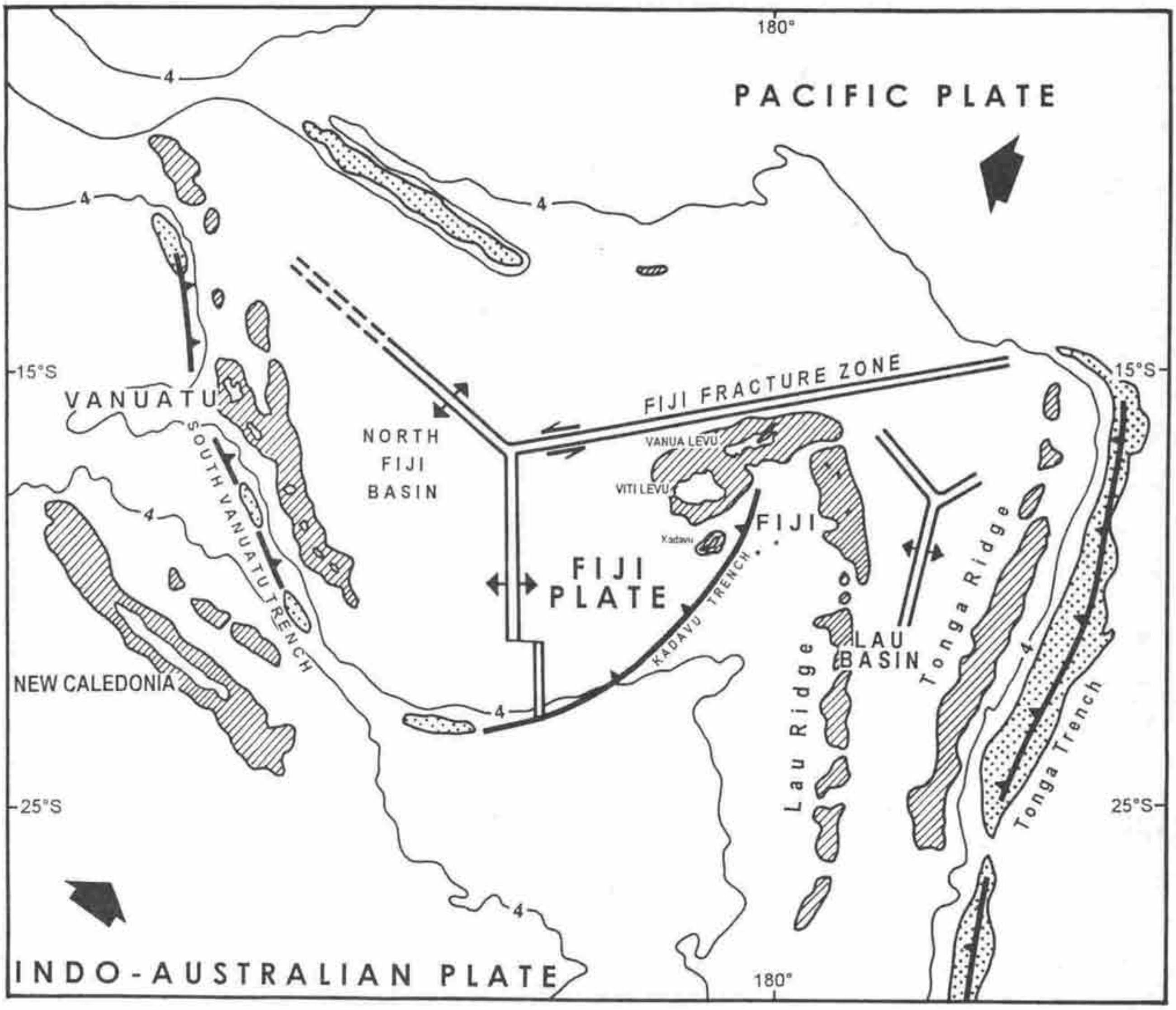


Figure 3.1. Major plate boundaries in the Fiji region (after Nunn, 1991b). The main island(s) of Fiji is on a small plate (the Fiji Plate), the tectonic history of which has been determined largely by the oblique convergence of the Indo-Australian and Pacific Plates. Sea-floor spreading centres (divergent plate boundaries) are shown in the North Fiji Basin and Lau Basin, subduction is (or has been recently) occurring along convergent plate boundaries in the Tonga Trench, South Vanuatu Trench and Kadavu Trench. The Fiji Fracture Zone is a transverse plate boundary. Line shading defines that area less than 2 km deep, dot shading indicates areas more than 6 km deep. The 4 km isobath is also shown.

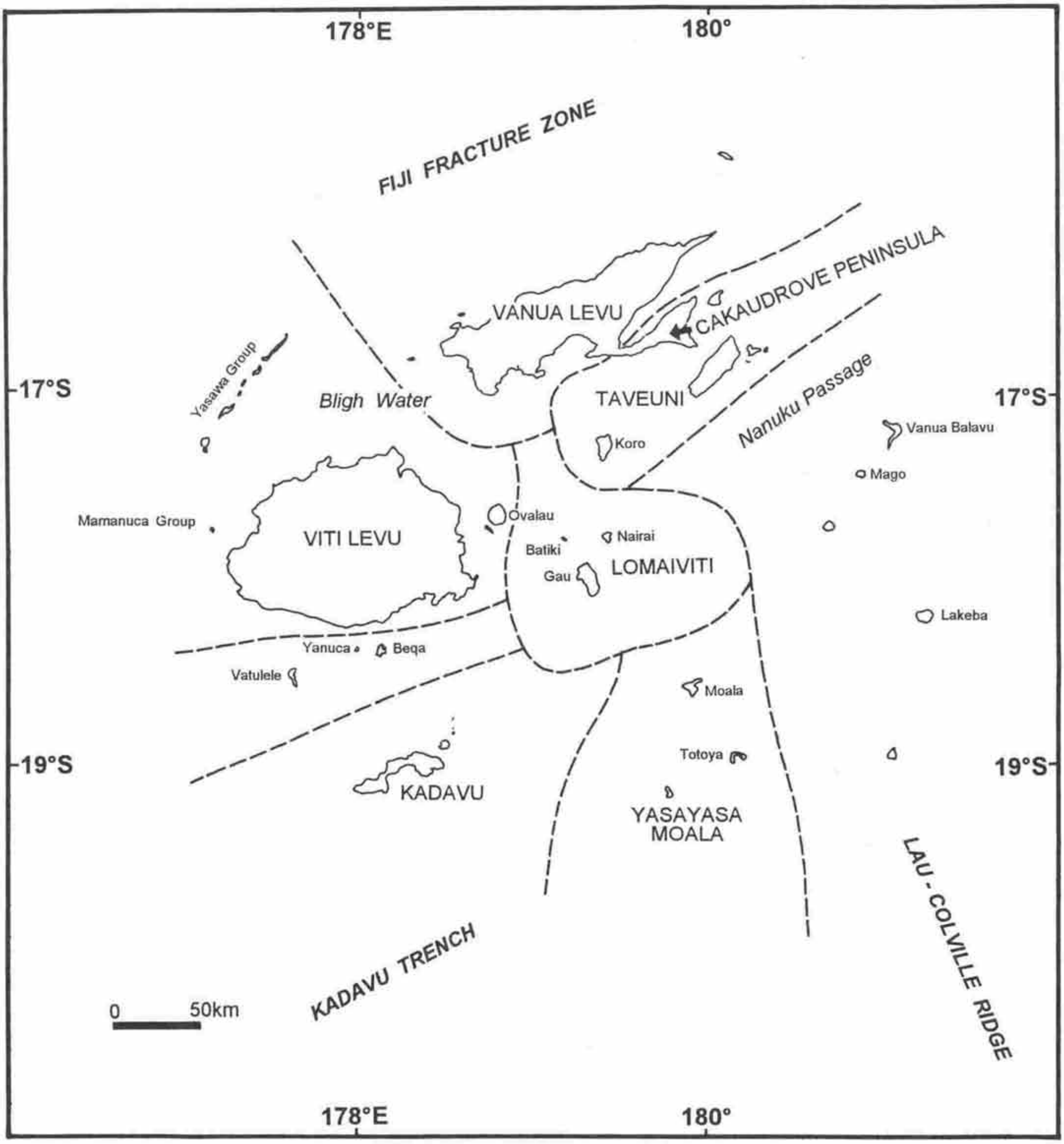


Figure 3.2. Tectonic environments of Fiji, slightly revised from Nunn et al. (1993) The tectonic character of each division is described separately in the text.

pioneered by Berryman (1979), and followed by Hamburger and Everingham (1986) and Nunn (1990a, 1991b).

The Kadavu islands are a young, possibly active forearc with signs of trenchwards tilting. The south coasts of the main island are conspicuously more submerged than the north coasts. This is the only place in Fiji where it is probably that differential movements within the same island have taken place.

The Vatulele-Beqa Ridge was the forearc about 4 (Ma) million years ago, since which time it has been affected by several coseismic uplift events, some probably during the Holocene. The occurrence of these events suggests that plate convergence has been accommodated during the Holocene along the Kadavu Trench.

There are signs of recent and continuing uplift on the large island of Viti Levu, best marked in its centre. The evidence is consistent with the updoming of the island for most of the Quaternary (last 2 million years). The Yasawa and Mamanuca island groups are included in the Viti Levu division largely out of ignorance of their Quaternary tectonic behaviour.

Together these three divisions are believed to lie on a single (Fiji) microplate which is being updomed and uplifted as the result of convergence along the Kadavu Trench. The western boundary of this microplate is the divergent boundary in the North Fiji Basin but the eastern boundary is less well marked. Some have considered that it runs through Bligh Water, others that it follows the trend of the trench and continues northeastward through Nanuku Passage. It is by no means clear.

The tectonics of the Vanua Levu division (excluding the Cakaudrove Peninsula) are strongly influenced by the proximity of the Fiji Fracture Zone. Much of the main island's north-facing coast has been uplifted recently although many of its river valleys appear largely submergent. Such movements could have been caused by compression of the island northwards against the rigid Fiji Fracture Zone in the same way as Viti Levu. It is probably correct to suppose that they are on the same microplate.

The Taveuni-Koro-Cakaudrove area is one of young volcanism and recent uplift perhaps associated with the propagation eastwards of a tear fault. Evidence for coseismic uplift is apparent along the south-facing coast of Cakaudrove and possibly on Taveuni. A large earthquake in 1932 just off Koro Island caused uplift of part of the fringing reef by about 50-70 cm.

The central islands of Fiji (Lomaiviti) exhibit evidence of variable tectonics, probably none of it within the late Quaternary.

The Yasayasa Moala (Moala group) to the southeast are four oceanic central volcanoes whose levels have been affected by lithospheric flexure during the Quaternary yet show no signs of significant movement during the Holocene.

The islands of Lau in eastern Fiji are not well known and while many authorities have assumed them to be stable, there are reports of isolated earthquakes and an abundance of evidence for coseismic uplift (Nunn, 1994). This is most conspicuous on the limestone-fringed islands like Cicia, Nayau, Lakeba and Namuka-i-Lau. It has been tentatively concluded that most of these uplift events occurred during the middle Holocene and that there have been few in its later part.

In summary, there are several areas of Fiji which are subject to uplift, mostly through coseismic uplift, at present. These include the Vatulele-Beqa line, the Cakaudrove peninsula of Vanua Levu and possibly the north coast of Vanua Levu and parts of Lau. Areas which are subsiding include northern Viti Levu, southern Kadavu and most of the islands in Lomaiviti and the Yasayasa Moala.

Typical coseismic uplift magnitudes are around 1.0-1.5 m, frequencies of such events in places where they still occur is probably between 300 and 2000 years. Typical (aseismic) uplift rates are probably less than 1 mm/year. Typical subsidence rates are probably less than 0.5 mm/year.

Information about localities in Fiji is from Nunn (1988, 1990a, 1991b, 1994, submitted) and sources quoted therein.

3.2. Sea-level changes in Fiji and the Pacific

From work largely in Australasia, Vanuatu and Japan, it is known that sea level at the height of the last Glacial (ice age) was around 120-150 m below what it is today in the southwest Pacific. It reached its present level around 6000 years ago and then, in most parts of the region (including Fiji), it rose above its present level by as much as 2 m and then fell.

The chronology of late Holocene sea-level behaviour in Fiji has become quite well known in recent years (Miyata et al., 1990; Nunn, 1990a, 1991a). From evidence throughout the group, it seems that sea level reached around 1.5 m above its modern level between 2500 and 3500 years BP (BP is years Before 1950 AD). From the evidence of late Holocene reef growth and shoreline erosion, it seems likely that the sea level has been at its present level for around 1000 years although minor fluctuations have occurred during this time. It is probable that sea level rose slightly as the result of slightly high temperatures in the period leading up to 1300 AD then fell abruptly as temperatures fell in the Little Ice Age. Since the end of this period, around 1800 AD, sea level and temperatures have probably been rising slowly. This series of events was discussed in section 3.4.2 of the Phase 1 report (Nunn et al., 1993).

The recent rise of both temperature and sea level have been measured in Fiji and many other Pacific islands, either directly or indirectly. Temperature data are shown in Nunn (1993b)

The data from the Honolulu tide gauge on the stable Hawaiian island of Oahu are shown in Figure 3.7 of the Phase 1 report (Nunn et al., 1993). Sea level appears to have been rising in the Fiji region by about 1.5 mm/year since 1900 and it was probably rising for the previous hundred years to 1900.

In Fiji there are no long-term tide-gauge records similar to that for Honolulu. As discussed in section 3.5 of the Phase 1 report (Nunn et al., 1993), several surveys of coastal changes at long established settlements in Fiji have been carried out. It was argued therein that the average rate of coastal inundation in Fiji of 15 cm/year for the last 80 years or so is most probably a manifestation of sea-level rise. This sea-level rise has been crudely measured at Nataleira village in eastern Viti Levu as being between 10-30 cm in the last 80 years - an average rate of between 1.25-3.75 mm/year.

A summary of the various timescales for sea-level change in Fiji is shown in Figure 3.3. It is important to appreciate that, although sea level has probably been rising for the last 200 years or so, the long-term trend is probably still one of sea- level fall from the Holocene Climatic Optimum about 5000 years ago.

3.3. Historical studies on coastal change

There have been few precise studies carried out on coastal changes in Fiji. Most such studies have been based not on quantitative data but on qualitative data - the recollections of elderly inhabitants of long-established coastal settlements about how the shoreline has changed since the earliest time they can remember. The results of this work were reported in Phase 1.

More precise studies could be carried out using old maps and series of aerial photographs of particular areas. Only one study is known - that of the sand cay of Makaluva in Laucala Bay near Suva (Figure 3.4). Unfortunately sand cays are inherently mobile so their movements are difficult to reconcile with sea-level or other extraneous changes.

Similar studies to that on Makaluva could be made over much longer time periods. Several areas are thought worth studying.

(a) The Bua Bay area of Vanua Levu which was the original target of the earliest sandalwood traders in Fiji. Maps of these areas may exist from the early nineteenth century and, when combined with the aerial photograph record, could yield one of the largest records of precisely recorded coastal change in Fiji.

(b) The area around Tubou on Lakeba island in Lau (eastern Fiji) was one of the first places in Fiji visited by missionaries. A mission station was established there in the 1840s.

(c) The area around Galoa island in the Kadavu group was used as a watering station by the earliest trans-Pacific steamships.

(d) The Levuka area of the island of Ovalau was Fiji's original capital until this was transferred to Suva in the 1880s.

(e) The Suva area, established as Fiji's capital in the last century, and precisely surveyed by the colonial government at the time must have a precise record of coastal change.

Figure 3.3. The timescales of sea-level change in Fiji over the past few thousand years.

A. The first-order trend is that which follows global temperature changes and associated land-ice melting and formation. Sea level rose to a maximum in Fiji just after the warmest time during the Holocene (last 10,000 years), perhaps as late as 2000 years ago (after Nunn, 1990a).

B. The second-order trend is one which probably occurs in response largely to thermal expansion of ocean-surface water resulting from comparatively minor temperature changes. The difference between the higher sea levels of the Little Climatic Optimum and the lower sea levels of the Little Ice Age are clear here. This curve is based largely on dates from Samoa and New Zealand (after Nunn, 1994).

C. The third-order trend (with the second-order trend shown as a broken line) as monitored at the Honolulu tide gauge in Hawaii (after Nunn, 1992).

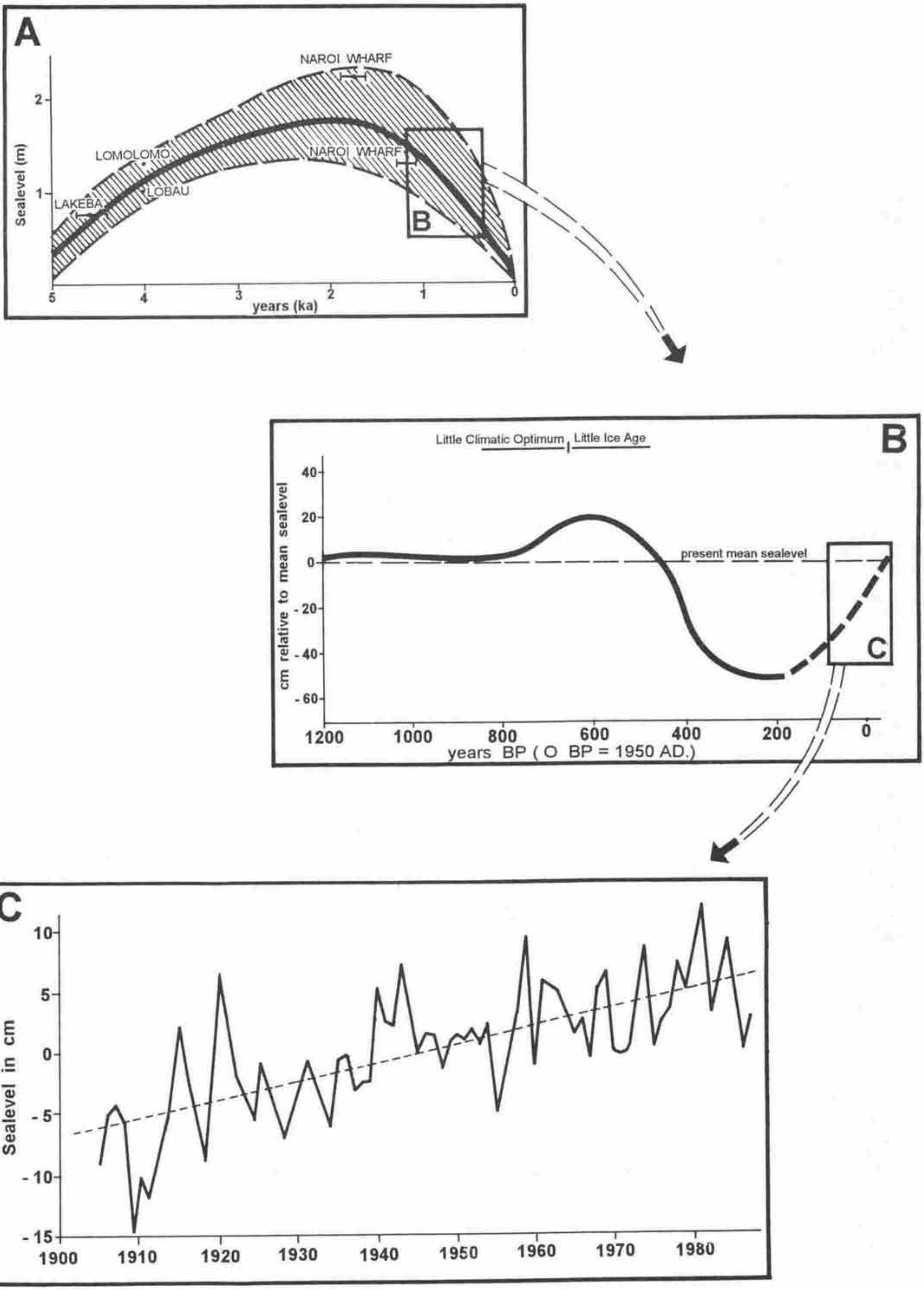


Figure 3.3. The timescales of sea-level change in Fiji over the past few thousand years (A. B. C.)

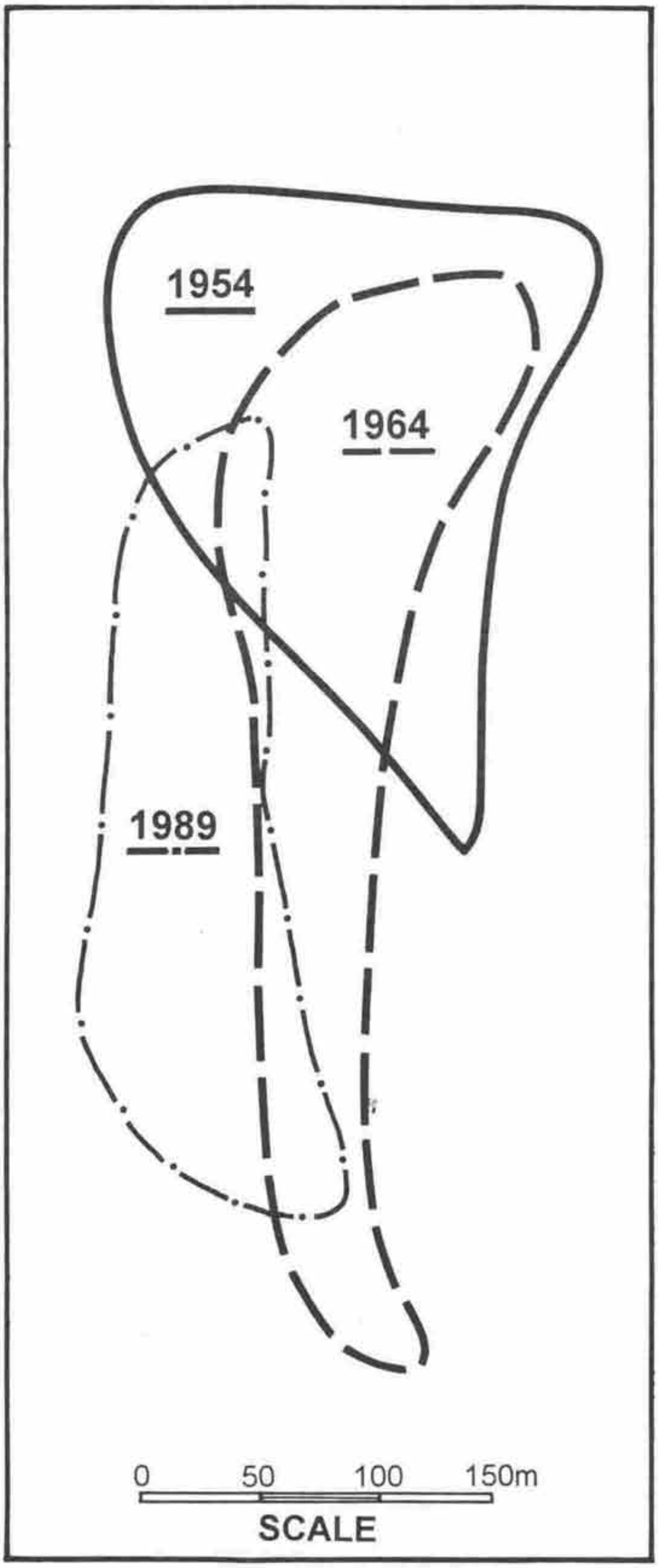


Figure 3.4. Changes in the from of Makaluva island, a sand cay on the barrier reef off the Suva Peninsula, between 1954-1989 as determined from comparison of aerial photographs (after Watling and Chape, 1992)

3.4. A baseline for future coastal changes in Fiji

It is clearly important to be able to predict as clearly as possible the way in which particular coasts in Fiji will behave in the future. The importance to this of knowing about past coastal changes is twofold.

First, whatever is predicted for the future as the result of warming caused by the enhancement of the greenhouse effect will be superimposed on the past. It is not enough to plan on the basis that the past was unchanging or that the causes of past sea-level change will suddenly cease once the enhanced greenhouse effect begins to cause sea-level change. Thus the rate of future sea-level change will most likely be, in the initial decades at least, what is predicted by the IPCC (see section 5.2) plus what has been happening in the recent past.

Secondly, it is of paramount interest to know how particular coastlines will change in response to future sea-level changes. In one way we are fortunate in the Pacific because here we have abundant analogues pertaining to the past. If we want to know how sandy coastlines or delta coastline will change, we have analogies from the past.

These two issues are discussed separately in the following sections.

3.4.1. Future rates of sea-level change

Let it be assumed (since we have no clear evidence to the contrary) that, were it not for the warming and sea-level rise associated with human enhancement of the greenhouse effect, the recent (200 year) temperature rise would be the same in both magnitude and duration as that which took place around a millennium earlier - the so-called Little Climatic Optimum.

We know much less about the Little Climatic Optimum in the Pacific than we do about the Little Ice Age which succeeded it. Nevertheless the Little Climatic Optimum has been recorded elsewhere in the world (Lamb, 1977) and from most parts of the Pacific Rim. The Little Climatic Optimum was not a period of consistently high temperature (compared to the present), although it is often portrayed as such, but a period in which temperature rose then fell abruptly (Nunn, 1992). The generally accepted dates for the Little Climatic Optimum in the Pacific are 1000-700 years BP (950-1250 AD), a period of 300 years. Temperatures reached about 1°C above their present level. Shortly after 700 BP, sea level reached 18-20 cm above its level at the beginning of the Little Climatic Optimum.

In contrast, the present temperature rise has been continuing, albeit discontinuously, for about 200 years and temperatures have risen perhaps 0.8°C. Sea level in the last 200 years has risen perhaps 15 cm. This has also been discontinuous yet the overall trend is clear.

Given these observations, it is likely that, without the intervention of temperature and sea-level rise caused by the enhanced greenhouse effect, temperature would continue rising for the next 100 years - the rise being a total of around 0.2°C. This figure represents a lessening of the rate of temperature rise over the last 200 years. This scenario assumes that the enhanced greenhouse effect has not yet started to be a contributory cause of temperature rise, a view some scientists reject; it is, however, the simplest way of calculating future background temperature changes and any error is likely to be small. Using the same assumption, sea level would also continue rising for the next 100 years, perhaps rising another 5 cm in the period. As with temperature, this figure represents a lessening in the rate of sea-level rise of the past 200 years.

These scenarios are shown graphically in Figure 3.5. The `background sea-level change' is that which has been observed in the Fiji region between 1800-1990 and that which is predicted to occur here assuming that there is no accelerated sea-level rise as the result of the enhancement of the greenhouse effect and attendant global warming. This assumption is invalid but the trend is reconstructed because it is likely that accelerated sea-level rise will be superimposed on it. The reconstruction of the background trend is based on analogy with what happened during the Little Climatic Optimum. During this period, a comparatively rapid rise in the early part was succeeded by a levelling off in the later part: in Figure 3.5, this is shown, the total sea-level rise being around 20 cm. If the analogy is valid, one might expect the background trend to decrease after 2100 as it did at the end of the Little Climatic Optimum.

The three scenarios shown for accelerated sea-level rise are those based on the 1992 IPCC revised emissions scenarios (Wigley and Raper, 1992; Warrick et al., 1993), all of which assumed no decline in emissions over the period (`business as usual'). For the central emissions scenario (IS92a), best-guess modelling gives a 1990-2100 sea-level rise of 46 cm, a figure lower than the 1990 IPCC best-guess estimate (66 cm). Added to the additional 5 cm of rise expected from the background trend, this gives a figure of 51 cm for sea-level rise between 1990-2100. High and low IS92a scenarios are calculated similarly and illustrated in Figure 3.5.

3.4.2. Effects of future sea-level changes

We know very little about how Pacific island coasts responded to the change in sea level associated with the Little Climatic Optimum 950-1250 AD. What we do know is that certain rivers became graded to that level in New Zealand and that reefs responded by growing a few centimetres higher in American Samoa (Nunn, 1994). On account of the slow pace of the background changes between 1800-2100 AD, we can reasonably assume that such adjustments have been widespread in the Pacific and would continue were it not for the probability of accelerated sea-level rise in the near future (see Figure 3.5).

There are many more examples of how Pacific island coastlines have changed over the past few decades. Some of these have been compiled by Nunn (1990b, 1993a), others await publication. Such case studies could be used to predict what will happen in the future in particular situations.

In conclusion, there is clearly great potential for using information from the past to fine-tune predictions for the future. For example, by knowing how particular coastlines responded to a sea-level rise of a certain magnitude over the last few decades, it is possible to predict how that same coastline will change in the future in response to a sea-level rise of a certain magnitude.

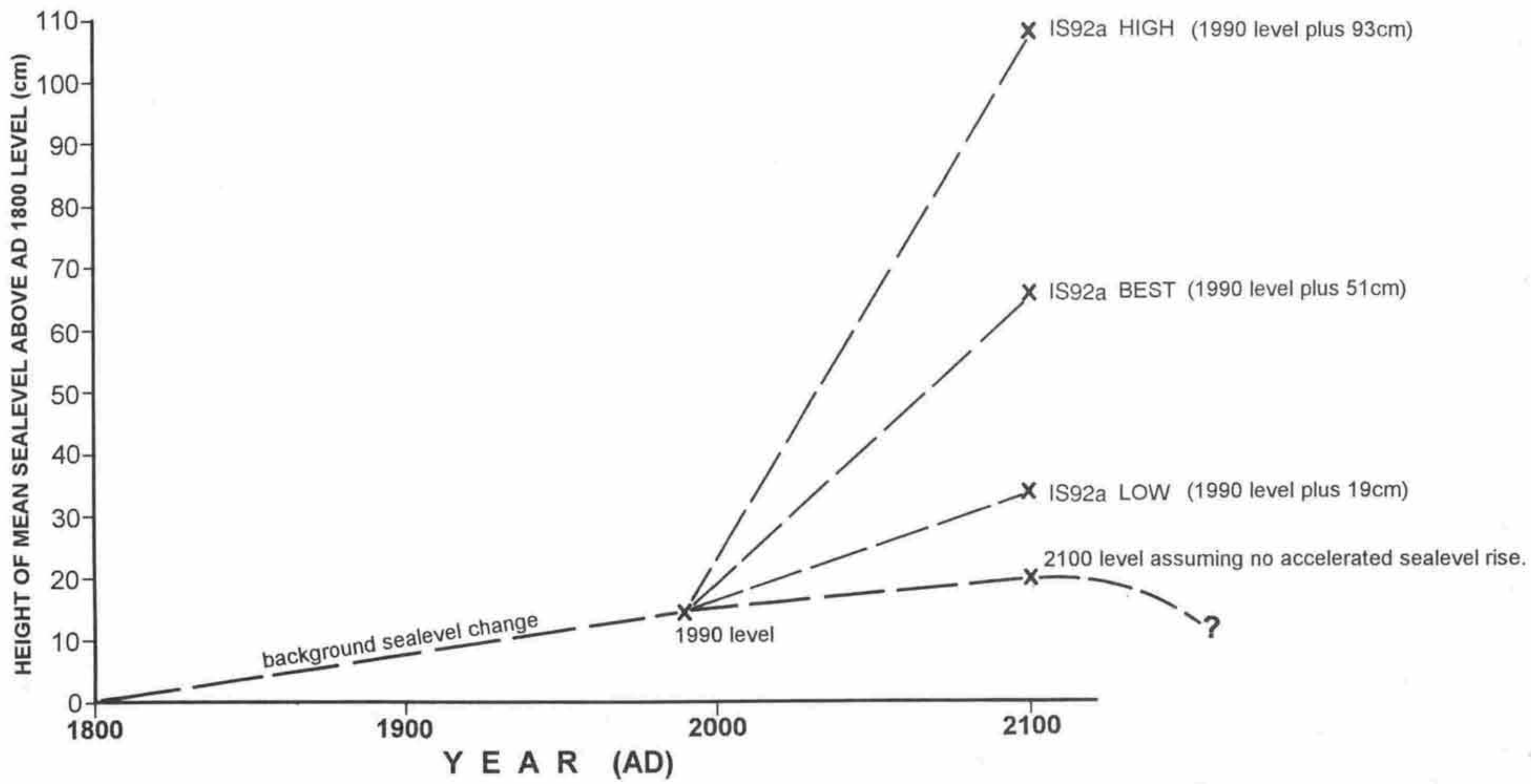


Figure 3.5. Scenarios for future sea-level and temperature rise in Fiji derived from measurements of these variables in the recent past and an analogy between this period and that of the Little Climatic Optimum

Chapter 4. Development of the methodology

4.1. History of methodological development

One of the principal purposes of this study of Fiji is to adapt the "Common Methodology for Assessing Vulnerability to Sea-Level Rise" developed by the Coastal Zone Management Sub-Group of the Intergovernmental Panel on Climate Change (see Chapter 4 in Nunn et al., 1993). Another major purpose of the studies of Fiji and Western Samoa is to test the adaptations in realistic situations and modify them accordingly.

The major outcome of the Phase 1 studies in Fiji and Western Samoa (Kay et al, 1993; Nunn et al., 1993) was to realize that Pacific island coasts cannot be satisfactorily valued using monetary values. This approach is essentially suited only to highly monetized economies and not to nations, like most of those in the island Pacific, which are largely subsistence-based.

To take this argument further, it is not possible to assess the preferred response option for the mitigation of future coastal impacts using cost-benefit analysis. One of the major conclusions of the Phase 1 reports was that, unless Pacific island coasts can be valued both objectively and in quantitative terms (although not necessarily monetary terms), the optimum response options for particular situations will have to be based on qualitative (value) judgments. While these are not necessarily undesirable, they are unlikely to be consistently correct. Furthermore, they may vary from observer to observer depending on an individual's particular set of values and how much value, per se, he/she assigns to particular elements of the coastline.

The approach taken with the Phase 1 studies in both Fiji and Western Samoa was a flexible conceptual approach which assessed coastal systems by vulnerability, resilience and sensitivity to external environmental stresses, principally sea-level rise. The approach emphasized socio-cultural factors in Fiji as much as the physical characteristics of the islands. This highlights a major difference between subsistence economies, such as Fiji, and those of the wealthier nations. In Fiji, much of the response to mitigating the effects of future sea-level rise will have to come from individuals and individual communities rather than from central or local government. The methodology developed in Phase 1 particularly recognized the importance of the following issues for sea-level rise assessment and mitigation in Fiji.

- high dependence on a subsistence economy in most areas (both land and offshore);

- close ties of indigenous Fijians to land through customary land tenure and leasing to others;

- cultural bond between indigenous Fijians and their land;

- importance of extended family structures and communal activities;

- comparative ineffectiveness of much land-use planning or building codes;

- importance of the proximity to roads in rural areas;

- strength of religious beliefs;

- often ineffective linkages between national (parliamentary) and village (customary) decision making resulting in rural people making unilateral decisions about their environment;

- human, financial, technical and data resource limitations;

Details of the philosophical underpinning of the approach adopted here is contained in Kay et al. (1993) to which the interested reader is referred. It is believed that such a flexible approach will be appropriate for other south Pacific nations, and other countries of the world with similar physical, economic and cultural conditions.

The basic methodology used in Phase 1 of the Fiji project (Nunn et al., 1993) used an impact assessment technique which had a qualitative basis. Five "Coastal Systems" were used to characterize the coast of Fiji, as follows.

- natural
- cultural
- institutional
- infrastructural
- economic

Each of these coastal systems was made up of a number of subsystems, shown in Figure 4.1 in the Phase 1 report (Nunn et al., 1993).

Assessment deliberately forced the separation of vulnerability and resilience. By assessing their relationship to both modern and future coastal environments, scores were assigned to the vulnerable and resilient components of each coastal system. This was achieved through an analysis of those elements contributing to system vulnerability and resilience. Scores were assigned through a process of consensus by study team members. Vulnerability scores ran from 0 to -3, with -3 being the most vulnerable, while resilience scores ran from 0 to +3, with +3 being most resilient.

The vulnerability and resilience scores were added together to obtain a Sustainable Capacity Index (SCI) for each coastal system. The SCI was envisaged as an estimate of the ability or capacity of each coastal system to cope with external environmental stresses, notably sea-level rise.

This system-scoring exercise was applied first to the present situation and then to the future. Two scenarios were pictured for the future; the first was one with no management taking place in response to future sea-level rise (and directly-associated environmental changes), the second was one with an optimal management response being made to mitigate the impacts of future sea-level rise (and directly-associated environmental changes). Sustainable Capacity Indices were calculated for both scenarios.

4.2. The revised methodology

Several problems were identified with the methodology developed and used in Phase 1 of the Fiji project.

Principal among these problems was the lack of objectivity of the scoring system. Even insisting on consensus among the scoring team does not ensure that another team would come up with the same answer. Yet, given that the ultimate aim of the methodology is to accurately assess the comparative efficacy of various possible responses to sea-level rise, it became clear that a greater degree of objectivity was necessary.

This led to a re-ordering of the coastal systems, to improve the logical application of the methodology, and their elaboration.

- natural

- human

- infrastructural

- institutional

- economic

- cultural

The addition of the human coastal system was in recognition of the low priority given to population and population density issues in the Phase 1 scheme.

It was debated whether or not to increase the number of subsystems significantly so that for each location one was assigning scores not to eleven subsystems (as in Phase 1) but to, say, fifty subsystems. This was not done because it was felt that it would have made the methodology unwieldy and cumbersome, and not very user-friendly. It would also have inevitably brought about confusion over what belonged within which subsystem and whether or not overlaps would be permitted. It might have increased objectivity but it was felt that the undesirable attributes of increasing the number of subsystems far outweighed any possible benefit.

It was decided that the best way to optimize objectivity in the scoring was to define much more fully than had been the case in Phase 1 exactly what was meant by particular scores. This produced a much lengthier set of information which operators would have to absorb before they could apply the methodology but it was felt that this was appropriate, particularly if operator training could be arranged. The definitions of particular subsystem scores are given in the following section.

Other minor changes were made to the methodology. In several cases, vulnerability was used as a surrogate for estimating the comparative value of a particular subsystem element or its magnitude.

For example, vulnerability of the biological subsystem is used partly to measure the degree of biodiversity at a particular site. The reasoning is that, in general, the greater the biodiversity, the greater the potential impact of external stresses on a large number of species. Vulnerability is also partly measured by the number of important species occurring at a particular site, a number which is assumed to have a linear relationship with the degree of biodiversity. The reasoning here is that the greater the number of important species, the greater the likelihood that a given proportion of those species will be affected adversely by sea-level rise (and directly-associated effects). Hence it contributes to the vulnerability.

Simpler examples are provided by population and individual infrastructure. Assuming that every person has the same intrinsic value, the number of people in a particular area is a measure of the vulnerability of the population of the area (relative to the whole country). Similarly, assuming that each individual's house has roughly equal value, which it does in many rural settings in Fiji, the number of houses (relative to the total area of the site) is a good indication of the comparative vulnerability of individual infrastructure.

These points are elaborated further under the descriptions of the various scores for particular subsystem elements in the following sections.

A final point to be made refers to what is meant by the no-management and optimal-management scenarios for the future which are used throughout the following descriptions. Both these scenarios are intended to be realistic not interpreted literally.

In its literal sense, `no management' is unlikely because coastal people will respond to coastal changes, even if it means moving away. They will not attempt to rebuild on land which has been removed by erosion, so no-management in this context means what is perceived as the minimal response to coastal change.

In a similar way, optimal management is defined as the best possible response given the human, physical and financial resources available for making that response. Most Pacific islanders cannot afford to build a 25-m high wall around their island so that cannot be considered as an optimal response, however much it may appear to be one in the view of persons unfamiliar with the region. An optimal response in this situation might be the construction of appropriately-designed seawalls at key locations along the coast using locally available materials and local labour.

4.3. Scoring of subsystems

4.3.1. Natural subsystem - physical

System :Natural
Subsystem :Physical

Vulnerability refers to coastal morphology and coastal lowlands.

A score of -3 implies that most of the hinterland is 1.5 m or less (considered to be the most vulnerable height range to sea-level rise of around 0.5 m and associated increase in maximum-wave amplitude) above mean sea level and that the majority of the coast is made of erodible materials and is poorly protected against erosion.

A score of -2 implies that around 50% of the hinterland is 1.5 m or less above mean sea level. A score of -2 also means that no more than approximately 50% of the coast is made of erodible materials and is poorly protected against erosion, the remainder being made of more resistant material and/or better protected either by artificial structures and/or appropriate vegetation from marine erosion.

A score of -1 implies that at least 25% of the hinterland is at least 1.5 m above mean sea level. A score of -1 also means that only a few parts of the coast are made from erodible materials and poorly protected from erosion, the remainder being more resistant and/or better protected as for -2.

A score of 0 implies that there is no significant part of the hinterland below 1.5 m above mean sea level and that the shoreline is not made of easily erodible material and is not highly vulnerable to marine erosion.

Resilience refers to coastal morphology and to the physical effect which fringing reefs and mangrove forests, for instance, have in reducing external stresses from the ocean on the shoreline.

A score of +3 implies that the shoreline is well protected from erosion, both internally and externally. External protection along the entire stretch of coast is afforded by a healthy fringing coral reef and/or by mangroves which are not being actively cleared.

A score of +2 implies that overall the shoreline is moderately well protected internally. External protection from offshore reefs and mangroves is present but is either discontinuous and/or in a state of moderate stress as the result of physical damage and human overexploitation for instance.

A score of +1 implies that the shoreline itself is only slightly protected throughout or well protected in places yet with conspicuous parts of it poorly protected. External protection from offshore reefs and/or mangroves is slight. Reefs may be either discontinuous and/or under stress, mangroves may be sparse and likewise under stress.

A score of 0 implies that the shoreline has no internal protection from marine erosion, and that reefs and mangroves are absent or severely debilitated.

4.3.2. Natural subsystem - biological

System :Natural
Subsystem :Biological

Vulnerability refers to species diversity, biomass and valued species along the shoreline and the areas immediately adjacent to it.

A score of -3 implies that the biota of the site are extremely diverse (there is a comparatively large number of species, and/or extremely productive in biomass terms, and/or that highly valued species occur here. Plants used in daily faunal (including human) subsistence living may occur in abundance.

A score of -2 implies that there is moderate species diversity, moderate production of biomass, and that there is a moderate number of valued species occurring here. Some plants needed for daily faunal (including human) subsistence living may be found.

A score of -1 implies that species diversity is low, as are production of biomass and the numbers of valued species in the area. Only a few plants needed occasionally for faunal (including human) subsistence may be found.

A score of 0 implies that there are only a few species (3-5) growing on the study site, which are not productive in terms of biomass. There are no species of any notable value growing.

Resilience refers to the tolerance of plants in the study area to external stresses such as erosion, storm surge damage, wind damage, groundwater salinization and human impacts.

A score of +3 implies that the tolerance of all species within the study site is very high. There is little that could disturb the ecosystem, perhaps because it is well protected from physical damage, such as wave attack, and/or because it is diverse and well developed.

A score of +2 implies that the tolerance of most species is high. There may be minor weaknesses in the ecosystem which could be exploited by certain types of external stress and/or the ecosystem may not be adequately protected from the sea and/or it may be slightly under stress because of existing disturbances.

A score of +1 implies that the tolerance of most species is moderate. The ecosystem has been subject to change recently but has not been completely transformed and is demonstrating some internal resilience. The ecosystem may be subject to severe destabilization if external stresses continue to affect it.

A score of 0 implies that there is little tolerance of plants in the area to stress. Evidence of imminent ecosystem collapse may be manifest.

4.3.3. Human subsystem - population

System :Human
Subsystem :Population

Vulnerability refers to the number of people in the area compared to the perceived average densities of the nation as a whole.

A score of -3 implies that the area has a very large population, perhaps crowded together (a much higher population density than for the country as a whole) and growing. It implies that at present humans are the principal source of stress on the physical fabric of the area. It implies that there is an imbalance between human demands on the area and its short-term capacity to meet those demands.

A score of -2 implies that the area has a large population and that there are some signs of stress within it as the result of its size. It implies that humans are an important source of stress to the area's physical fabric.

A score of -1 implies that the area has some people living in it but that they are not crowded together and do not pose a significant threat to its natural elements. The relationship between people and the environment within the area is clearly sustainable.

A score of 0 implies that the area has very few (or no) people living in it. There is little perceptible effect of human habitation on the environment.

Resilience is a measurement of the numbers of people living in the area who are protected from and well able to withstand stresses, both internal and external.

A score of +3 implies that (almost) all of the people living in the area are adequately protected from stress associated with each other, as the result of overcrowding, for instance. They are also well protected from external stresses such as those originating from the ocean and from inland areas.

A score of +2 implies that at least 60% of the people living in the area are adequately protected from both internal and external stresses as elaborated for +3.

A score of +1 implies that less than 30% of the people living in the area are adequately protected from both internal and external stresses. There may be some overcrowding, localized problems of effluent disposal, some pollution, inadequate sea defenses locally or suchlike.

A score of 0 implies that (almost) all the people in the area are unprotected from the principal sources of either internal or external stresses.

4.3.4. Infrastructural subsystem - individual

System :Infrastructural

Subsystem :Individual

Vulnerability refers to the concentration of individually (rather than communally or nationally) owned and managed infrastructure, such as houses, kitchens, shops and workshops. The degree of concentration is measured relative to the rest of the nation.

A score of -3 implies that individually owned and managed infrastructure is highly concentrated in more than 50% of the study area. There may be an industrial or residential subdivision in (part of) the area or a parade of shops to which people from other areas depend on for regular needs. Most of the area is urban or suburban; it may be close to the sea and/or only slightly above mean sea level.

A score of -2 implies that individual infrastructure exists within the area but is interspersed with other elements such as communal infrastructure and/or agricultural land. The area is not urban but may be a rural settlement with a few shops and other commercial infrastructure; it may be near the sea and/or less than 3 m above mean sea level.

A score of -1 implies that there are some houses and other individually-owned infrastructure within the area but that these occupy a smaller area (<30%) than other elements such as communal infrastructure and/or agricultural land. Most individual infrastructure is well above 3 m above mean sea level.

A score of 0 implies that there are few houses in the area but that there is no other individually-owned infrastructure and that other elements such as communal infrastructure and/or agricultural land occupy around 90% of the area. Most individual infrastructure is well above 3 m above mean sea level.

Resilience refers to the degree of protection from various sources of stress possessed by individual infrastructural elements.

A score of +3 implies that most of the individually-owned infrastructure is well protected from stress. Most (>90%) of the buildings will be made of strong, durable materials and located in least vulnerable locations and/or will be easily relocated/rebuilt.

A score of +2 implies that more than 60% of the individual infrastructure is well protected by virtue of its construction and/or its location.

A score of +1 implies that less than 40% of the individual infrastructure is well protected by virtue of its construction and/or its location.

A score of 0 implies that there are only a few or none (<5%) elements of individual infrastructure which have any protection against external stresses.

4.3.5. Infrastructural subsystem - communal

System :Infrastructural
Subsystem :Communal

Vulnerability refers to the concentration of communally-owned infrastructure in the area such as churches, meeting houses, cooperative society buildings, and certain seawalls and jetties. It may also include communally-developed water supply and waste disposal systems, and any electricity generators which operate for the community's benefit.

A score of -3 implies that there is an unusually high concentration of communal infrastructure in the area compared to the national average. This may be because the area is a well-developed and comparatively prosperous settlement. Communal shoreline infrastructure may be concentrated here because the community also depends on large-boat access (hence has built jetties/wharves) or because seawalls have also been communally built.

A score of -2 implies that there is a concentration of communal infrastructure but that this is close to the national norm. This might be what is expected of a typical rural settlement with perhaps some communally constructed seawalls and jetties.

A score of -1 implies that there is a comparatively low amount of communal infrastructure in the area, less than the national norm. This may be because the settlement is not prosperous or well-developed and because the resources are not available communally to improve infrastructure.

A score of 0 implies that there is an insignificant amount of communal infrastructure in the area.

Resilience refers to both to the degree of protection afforded communal infrastructure and to the ease with which it could be shifted, rebuilt or relocated to a more protected site if necessary.

A score of +3 implies that all communal infrastructure is well protected from external stresses and that, should it become necessary, there are many sites to which it could be relocated. It also implies that the physical shift involved in relocation of particular communal infrastructure would be comparatively easy.

A score of +2 implies much communal infrastructure is well protected from stress. There are a few places to which it could be shifted if necessary. The process of relocation would be problematic but not beyond the means of the community.

A score of +1 implies that only some of the communal infrastructure in the area is protected from stress, the rest is not. There is an inadequate number of places to which such infrastructure could be shifted and/or the infrastructure would be extremely difficult to relocate/rebuild.

A score of 0 implies that none or a very small proportion of the communal infrastructure is protected from stress. There is nowhere suitable for any of this infrastructure to shift and/or it would be impossible to replace this infrastructure.

4.3.6. Infrastructural subsystem - national

System :Infrastructural
Subsystem :National

Vulnerability refers to the concentration of national infrastructure such as roads, railways, national port facilities, shoreline protection structures constructed with national funds, and utilities such as water supply, waste disposal and electricity generation.

A score of -3 implies that there is a significant concentration of national infrastructure in the area, perhaps a major port facility or airport serving a number of dispersed settlements or a major storage or processing centre for an industry of national importance.

A score of -2 implies that there is some national infrastructure of importance in the area, perhaps reflecting its importance to a number of other settlements.

A score of -1 implies that there is no national infrastructure in the area of significance outside the area. Yet the area is still well endowed with communications (such as road, rail and rivers) which are maintained by national authorities.

A score of 0 implies that there is no national infrastructure of significance within the area. There may be a few roads and other elements but these may not be well maintained.

Resilience focuses on the degree to which national infrastructure is protected from stress within the area. In the case of coastal roads, for example, it is a measure of the adequacy of its protection from marine erosion. It is also a measure of the ease of relocation of national infrastructure and the availability of alternative, better-protected sites (whether another route exists for the coastal road, for example).

A score of +3 implies that most (>80%) of the national infrastructure in the area is adequately protected. It may also mean that, were it necessary to move that infrastructure, there are many alternative sites in better-protected locations, and that the process of relocation would be comparatively straightforward.

A score of +2 implies that some of the national infrastructure is adequately protected but that some (<40%) is not. It may also mean that, although there are ample sites available where these elements of national infrastructure could be relocated, the process of relocation would be largely problematic.

A score of +1 implies that a little (<30%) of the national infrastructure in the area is adequately protected, the rest is not. There are some sites available for relocation but these are insufficient to accommodate all elements of national infrastructure in the area.

A score of 0 implies that only a small amount (<5%), if any, of the national infrastructure, is protected from stress. There are no suitable places for relocation.

4.3.7. Institutional subsystem - settlement

System :Institutional
Subsystem :Settlement

Vulnerability refers to the degree to which the people living in or dependent on the area are organized. It refers to whether or not settlements are established as cities, towns or villages with all the functional implications of such categories. It also refers to land tenure, particularly whether land is communally-owned or whether it is leased; this is a measure of the attachment of the people living in an area to the land they work and thus the responsibility they feel for it.

A score of -3 implies that no formal settlements are established in the area and that people are not organized in a community although they may have cultural and/or familial links. Land may be alienated.

A score of -2 implies that settlements (at any level) are established but that their operation is problematical. Perhaps people are strongly divided, unable to cooperate. Perhaps the organization is if an insufficient degree to assure the settlement functions satisfactorily.

A score of -1 implies that settlements are established and are operating reasonably well despite conspicuous problems.

A score of 0 implies that settlements are established and are operating efficiently.

Resilience refers to the flexibility of the organization of settlements, particularly with reference to their response to external stresses. For instance, is the community sufficiently well organized to fund and/or build seawalls? Is the land tenure system flexible in the face of receding coasts, or could some sections of the community become landless?

A score of +3 implies that the settlement is operated in a flexible manner. External stresses are coped with efficiently and communally.

A score of +2 implies that there is some flexibility in the management of the settlement but that conspicuous aspects of this (such as land tenure) are highly inflexible.

A score of +1 implies that there is little flexibility in settlement management, perhaps because things have been done in a certain way for so long that this is regarded as the only way.

A score of 0 implies extreme rigidity in settlement management and operations. Its attitude to external stresses is potentially calamitous.

4.3.8. Institutional subsystem - national

System :Institutional
Subsystem :National

Vulnerability refers to the degree to which national initiatives affect the area. Such initiatives include the establishment and operation of a national land-use plan, a nature reserve or marine park, conservation of particular endangered biota and suchlike. They also include projects organized under the auspices of the principal religious bodies in a country.

A score of -3 implies that no national initiatives affect the area to a significant degree.

A score of -2 implies that the effect of national initiatives on the area is noticeable but that these are not well established and are not accorded the value which national authorities might desire for them.

A score of -1 implies that national initiatives do affect the area and are moderately well managed although some major deficiencies remain.

A score of 0 implies that well-managed national initiatives affect the area and largely control daily existence within it.

Resilience refers specifically to the flexibility of national initiatives in a particular area. They measure the degree to which stresses can be accommodated within such initiatives.

A score of +3 implies that there is a high degree of flexibility. National management strategies may even have been designed with the view to accommodating specific stresses. Well-briefed persons may be involved in such initiatives locally.

A score of +2 implies that there is moderate flexibility of national initiatives within the area but that there are conspicuous shortcomings, perhaps the lack of trained persons locally, which may adversely affect the accommodation of stress.

A score of +1 implies that there is only a little flexibility in national initiatives in the area. Many aspects appear inflexible. Trained persons may be absent.

A score of 0 implies that there is no flexibility in national initiatives and that they are unlikely to prove sustainable in the face of stresses. No-one is available locally to adapt these initiatives to changing conditions.

4.3.9. Economic subsystem - cash

System :Economic
Subsystem :Cash

Vulnerability refers to the importance of the cash economy to the area.

A score of -3 implies that there is considerable cash-generating economic activity. The area may be industrial and/or commercial or, if it is rural, may have a large income from forestry, cash cropping, fisheries and/or tourism.

A score of -2 implies that there is some cash-generating economic activity, certainly enough to satisfy the needs of the people in the area but perhaps insufficient to improve their collective situation significantly.

A score of -1 implies that there is a little cash-generating economic activity but that this is neither assured nor does it continue regularly. It could be seasonal, it could be carried out just when funds are needed for a particular purpose.

A score of 0 implies that there is no significant cash-generating economic activity in the area.

Resilience refers to the flexibility of the cash economy in the area. It measures the degree to which present levels of cash income could be maintained were the principal sources of that income adversely affected by stress. In other words, it measures whether there are alternative source of cash income for people in the particular area.

A score of +3 implies that the present cash economy is founded on a diverse base and is not dependent on a single type of activity. Were certain elements of the economy to cease to be viable, there are many other options for cash generation in the area.

A score of +2 implies a lesser diversity of cash-generating enterprises and a moderate possibility of successful conversion to other types of activity should any of the present ones fail.

A score of +1 implies that the present cash-generating activities are few and that other potential cash-generating activities are possibly viable.

A score of 0 implies that the present cash economy has an unhealthy-narrow base yet that there are no alternatives for cash generation available in the area.

4.3.10. Economic subsystem - subsistence

System :Economic

Subsystem :Subsistence

Vulnerability refers to the dependence of the people in the area on a subsistence livelihood and the vulnerability of that livelihood to the effects of future sea-level rise. It measures the degree to which people feed and clothe themselves rather than depending on their own cash-generating activities for such purposes and the vulnerability of the supply of raw materials to sea-level rise.

A score of -3 implies that people are wholly dependent on their own resources and that there is little cash exchange in the community. Crops are grown largely for home consumption, fish and other animals are caught and killed for the same purpose. Most crops are grown in places less than 3 m above sea level and are not generally tolerant of saline conditions. Most sea food is from the reef or lagoon rather than the open sea. Most land animals are grazed and/or kept in places which are less than 3 m above mean sea level.

A score of -2 implies that, although people depend heavily on a subsistence lifestyle, they do occasionally earn cash which they need for certain purposes. Cash might be earned by fishing, selling surplus crops or by handicraft manufacture. Of the subsistence crops grown, some are grown in places which are less than 3 m above mean sea level but others are not. Some crops may be well adapted to saline groundwater conditions.

A score of -1 implies that, although people do grow/catch some food for their own consumption, most of them depend on cash earned to supply their daily needs.

A score of 0 implies that the people of the area are not in any way dependent on a subsistence lifestyle.

Resilience refers to the flexibility of the existing subsistence economy, the degree to which its elements could be replaced by others if it came under stress. Of particular note is the diversity of the major elements (staples, vegetables, protein) of the subsistence economy. The less diverse, the more inflexible is a particular system.

A score of +3 implies that the subsistence economy is diverse and that, were one or two elements of that economy prove more difficult to cultivate and/or obtain in the future, this shortcoming would be easily remedied by a greater reliance on other elements. It may also mean that there is potential for new elements to be added to the existing subsistence base: new crops which could grow well, new initiatives for correcting dietary inadequacies, for example. There are sites where subsistence crops could be grown and animals grazed which are higher than those at which they are grown/grazed at present.

A score of +2 implies that the subsistence economy is diverse yet there are few alternatives to a few of its constituent elements. There may be some higher sites where subsistence crops could be grown and animals grazed.

A score of +1 implies that the subsistence economy is not very diverse but that there are some elements which could be added to supplement or replace existing elements. There are few alternative sites on higher ground available for growing subsistence crops or grazing animals.

A score of 0 implies a very limited subsistence economy with few(or no) alternatives possible for particular elements. Most of the crops are grown and animals grazed within 3 m of sea level and there are effectively no alternative sites for these activities.

4.3.11. Cultural subsystem - communal

System :Cultural
Subsystem :Communal

Vulnerability refers to the degree to which the community shares a common culture or cultures and the degree to which this affects their everyday life. It also measures the importance of the site in a cultural sense to the people living there; high values may be because it is a long-established settlement, low values because the people are transient and feel no particular affinity to the site.

A score of -3 implies that cultural ties within the community and to the site are very strong.

A score of -2 implies that cultural ties within the community are strong but perhaps showing signs of minor disruption. The people feel a strong bond with the site but it is perhaps not their most valued site.

A score of -1 implies that cultural ties within the community are diverse and not particularly strong. No particular tie is felt with the site although people may still talk of it as part of their land.

A score of 0 implies that there is no significant cultural consensus within the community. No bond with the site is apparent.

Resilience refers to the ability of the culture to withstand change, the ability of the communities bonded by a shared culture to withstand disruption to their traditional site.

A score of +3 implies that the culture(s) is very strong, and is likely to remain so whatever happens to the community and the site they are now occupying.

A score of +2 implies that the culture is not able to cope entirely satisfactory with external stresses and perhaps a few people are breaking away from the community and its traditional site.

A score of +1 implies that the culture is becoming diffused and is threatened by various stresses. Perhaps a large number of the community have rejected (the majority of) its traditional ways and abandoned its traditional site.

A score of 0 implies that the culture(s) is under stress and/or only superficial compared to the way it once was. The community is dispersed, no longer operating as a cultural entity. Perhaps the proximity of a nearby urban centre and/or rural depopulation have contributed to this situation.

4.3.12. Cultural subsystem - national

System :Cultural
Subsystem :National

Vulnerability refers to the importance of the site, its people and their collective behaviour in the national context. If the site is of great archaeological or historical significance, if its people are custodians of a special tradition, then high values will be scored.

A score of -3 implies that there is immense importance attached to the site and/or its occupants at a national level.

A score of -2 implies that the site and/or its people have some importance at a national level but that there are several comparable sites within the area.

A score of -1 implies that the site and/or its people have little importance at the national level. There is nothing here that is not found in a large number of other places.

A score of 0 implies that there is nothing of national interest in the site and/or its occupants.

Resilience refers to the likely degree of preservation of the national heritage at the site in the face of stress. Implicitly it refers to the support given to the preservation by national government and associated agencies.

A score of +3 implies that there is optimal support from national bodies for the preservation of the site. Were it to come under undue stress, it is clear that steps would be taken to preserve the site.

A score of +2 implies that there is some support from national bodies but that this support is inadequate to completely guarantee the site's preservation in the face of stress.

A score of +1 implies that there are serious deficiencies in the support for the preservation of this site by national government.

A score of 0 implies that national government no longer supports the preservation of this culturally-significant site.

4.4. Remaining methodological difficulties

A worldwide difficulty with using the Common Methodology to assess the impacts of sea-level rise and the optimal response options for its mitigation is that sea-level rise is not a problem or stress, potential or otherwise, which can be treated in isolation. It may be theoretically convenient to pretend that it can be. In some highly-industrialized societies, such as Japan where most other stresses have been annulled, it may be practically possible to treat it as such. Yet in countries with disproportionately large coastlines and comparatively little wealth available to provide for their protection, the issue of sea-level rise cannot be neatly separated from other issues.

In Fiji, if sea level rises, then offshore reefs may be overtopped resulting in profound changes to lagoon and coastal processes and sediment mobility. Erosion under future conditions is likely to prove a more effective agent of shoreline erosion, a process probably to be exacerbated by the Bruun effect - the replacement of the old equilibrium shoreline profile with another - on most soft-rock coasts. Beaches will be subject to increased scour, lagoon-floor sediment will become increasingly mobile, leading perhaps to smothering of reefs and seagrass beds with concomitant effects on littoral and offshore ecosystems. Such effects would be particularly severe in places like the Pacific islands where the dependence of people on these ecosystems for subsistence is generally very high (David, 1994).

If sea level rises in the future, it will probably be as a result of temperature rise of the uppermost layers of the ocean. Ocean-surface warming brings its own set of problems, not least of which in Fiji is the effect of increased stress on marine ecosystems, particularly those close to the shore. Principal among these is the reef ecosystem, which reacts to temperatures rising above a critical point by ejecting their symbiotic algae and dying - the phenomenon of `coral bleaching'. Incidences of bleaching have been reported during unusually hot periods in French Polynesia and elsewhere in the coral seas.

Future climate changes will interact with sea-level rise to pose problems which would not necessarily be considered in wealthier countries. Much agriculture in the Pacific islands is currently marginal in the sense that it is carried out on lands which are steep or have nutrient-deficient soils. Further, much agriculture in the Pacific islands is wasteful of both soil and water resources and is not sustainable in the long term irrespective of climate changes (Eyles, 1987; Aalbersberg, 1993). Finally, there is evidence to show that recent climate changes, while much less severe in magnitude than those predicted for the future, have had noticeable effects on the landscape, most notably in terms of soil erosion (Nunn, 1990c).

In the future, some areas of the Pacific islands will become wetter - such places may be faced with even greater amounts of soil loss than in the past unless conservation measures are implemented and enforced soon (Watling and Chape, 1992). Other parts of the Pacific islands may become drier - irrigation may be needed to grow subsistence crops where none is needed now. Certain crops may no longer be viable owing to changing precipitation conditions.

Throughout the Pacific islands, if global predictions can be regarded as applicable, temperatures will rise. This will cause a rise in evapotranspiration which may render various types of agriculture currently being practiced in various places to become impossible without water conservation measures. Temperature rise will also mean that some crops and other semi-subsistence plant specie may no longer be able to grow (so well) and that dependence on these will have to be changed. By way of illustration, the northernmost islands of Tonga (Niuatoputapu group) are tropical and the southernmost islands (Tongatapu-'Eua group) are subtropical. Certain crops grown in the south cannot thrive in the north because of their intolerance of high temperatures. In the future, if the southern islands become tropical, their inhabitants may have to change their subsistence and export agricultural base to something similar to that which exists in the northern islands at present.

The frequency of catastrophic events is also of concern. Most predictions regard the frequency of tropical cyclones as likely to remain at its present high level in Fiji if the recent temperature rise is maintained (Nunn et al., 1993) or even increase (Holland et al., 1988) and increase in intensity (Emanuel, 1987; Pittock, 1993). The effects of sustained high levels (8-15 per decade in Fiji) of tropical cyclones on all aspects of human existence in Fiji will be profound. Its combination with other sources of stress such as sea-level rise will only exacerbate matters.

Increasing populations, increasing urbanization, poverty, inequality and other social ills in the Pacific islands are another important source of stress on the environment (Bryant, 1993). Some commentators regard rising population as likely to have a far more profound effect on human existence in the Pacific islands than sea-level rise (Wyrtki, 1990). Problems of water supply and waste disposal for Pacific islands are also of relevance (Bryant, 1994).

The point of all this is that it is manifestly unsatisfactory for sea-level rise to be treated as a problem in isolation in the Pacific Islands. In order to measure the likely impacts of future sea-level rise on a large, diverse archipelago such as Fiji, it is necessary to consider it as part of a much larger set of concerns encompassing all environmental problems and their likely impacts on the Fiji of the future. A holistic or `whole- environment' approach is needed and response options developed on that basis rather than for a single element of environmental change. Fiji has gone some way towards this by having a National State of the Environment report prepared (Watling and Chape, 1992) which has been followed up by a National Environment Management Strategy. This document has been endorsed by Cabinet but the critical issue which remains is one of implementation. If this strategy can be effectively implemented, then it will reduce stress throughout the environment. This in turn means that new stresses, such as accelerated sea-level rise, will be accommodated more successfully in the future.

The methodology developed in this chapter is not limited to sea-level rise - that is one of its strengths - but at the same time it is not perfectly holistic. For coastal-zone management, limits have to be drawn if the methodology is to be effective. The solution lies in users of the methodology being sufficiently well aware of those issues which it does not encompass to be able to realize when one or more of these will impact seriously on the conclusions being drawn.

4.5. Future methodological developments

The revised methodology described in section 4.2 above has been tested in only two areas of Fiji and two areas of Western Samoa. In all it has performed satisfactorily but there are still additional developments which might prove beneficial before it is considered as a widespread means of assessing various competing strategies for mitigating the impacts of future sea-level rise in particular places.

Further testing of the revised methodology might well pinpoint discrepancies which require resolution before it is made widely available. The re-revised methodology described in section 4.2 has been tested in only four places, all from the periphery rather than the core of development activity in Fiji and Western Samoa. This was to correct the imbalances of site selection in the Phase 1 studies but it is regarded as important to test the revised methodology in parts of the core as well as other diverse environments within Fiji and Western Samoa.

We are still a comparatively long way away from being able to use these assessments to make an objective assessment of all possible response options for a given area using objective criteria analogous with cost-benefit analysis. The way forward is to begin comparing the vulnerability and resilience of particular places with a view to deciding which of them merit particular kinds of protection. More-valued places will receive greater and more effective protection than less-valued places.

The present Sustainable Capacity Index is calculated by a straightforward addition of vulnerability and resilience scores. While it is a useful measure of `sustainable capacity', it is not suitable as a surrogate for value. A new type of index, based on vulnerability and resilience scores, needs to be developed by which surrogate values can be calculated. These `values' could then be assessed for different places using conventional cost- benefit analysis techniques.

Chapter 5. Case studies

5.1. Selection of study sites

Owing to time and financial constraints in Phase 1 of this study (Nunn et al., 1993), all four study sites selected were close to Suva, where the team was based.

The first study area in Phase 1 was the most developed part of Suva city. It is least representative of Fiji's coastline but was included since it is the most important stretch of coast in Fiji in economic terms. This study area is comparable to other highly important urban coastlines in the country, including that at Lautoka and, less so, those at Labasa and Savusavu on Vanua Levu and Levuka on Ovalau.

The second study area in Phase 1 comprised Korovou town and the surrounding lowland area, particularly to the east. This lowland is a merged alluvial flood plain and delta and used intensively for agriculture, particularly dairying and the growing of market crops. It is similar to many other lowland coasts in Fiji, particularly around the mouths of the large rivers on Viti Levu and Vanua Levu. Korovou is a market town of medium size, typical of many in rural Fiji such as Tavua and Vaileka (Rakiraki) on Viti Levu.

The third study area in Phase 1 was the Verata (properly the Verata-Tailevu-Bau) coastline of eastern Viti Levu. It is a typical rural coastline, comprised of mangroves and a complex offshore reef system, and traditional villages occupied by indigenous Fijians. The island of Viwa was included in this area. Although only 1 km offshore of the main island, Viwa is typical of many small islands elsewhere in Fiji. Viwa has one village occupied largely by traditional agriculturists. Note that this Viwa island is not the same as the Viwa island in the Yasawa group visited in Phase 2 of the study (see Figure 5.1).

The fourth study area selected for Phase 1 was the Serua-Veivatuloa coastline of southern Viti Levu. It is similar to the Verata coastline in many ways; it has both mangrove and coral and villages of indigenous Fijians. It is similar to the Korovou area in other ways; it has an important rural centre (Navua) surrounded by an intensively farmed lowland area at the mouth of the Navua river. All these characteristics are played down when considering the impacts of predicted sea-level rise on this study area in favour of its importance to tourism. Although this is not one of the main tourist areas on Viti Levu, it contains a large resort complex (Pacific Harbour) and several smaller resorts. The tourism here is important not only nationally but also locally.

All four study sites selected for Phase 1 are more densely populated than most parts of Fiji and have consequently had a much longer and more intense history of human disturbance of natural ecosystems. All sites selected are covered with vegetation which has been subject to clearing by humans several times since initial colonization of the islands. Many coastal plains are covered with coconut palms, others have even more deliberately planted vegetation.

All the coasts are reef and mangrove fringed but to varying extents. The Suva study site faces the harbour; the reef is 1-2 km distant; most mangroves have been cleared. The Serua-Veivatuloa area has only a narrow discontinuous offshore reef and only a few mangroves in embayments. The Korovou and Verata coasts both have an almost continuous mangrove fringe, more than 1.5 km wide in places, and face a broad lagoon with considerable patch reef development which makes navigation hazardous.

All study sites selected in Phase 1 show the interplay between customary land ownership, leasing and freehold land. This provides a range of management problems and constraints.

For Phase 2, the priority in the selection of study sites was to represent the periphery rather than the core. In terms of economic and infrastructural development, amongst other attributes, Suva is the core of Fiji. Minor cores occur at other major urban centres including Lautoka, Sigatoka and Ba on Viti Levu and Labasa on Vanua Levu island. These areas are not typical of most of Fiji's coastline, largely because there is more money and more incentive in such places to protect the coastline should it become profoundly threatened by external stresses such as sea-level rise.

Most areas of coastline in Fiji are distinctly less `well-developed'. The people inhabiting these areas (the `periphery') have a different relationship with the coastline compared to many living in or close to the core. Dependence on the natural environment for subsistence is generally far more profound because there are no (or comparatively few) opportunities nearby for cash employment. As might be expected from a government with a limited budget, infrastructural development and communications in most parts of the periphery is less developed and/or efficient than it is close to the core. In Fiji, the government's efforts at rural development are far in advance of many parts of the `developing' world yet certain types of infrastructural development, such as roads, are low priority developments owing to the lack of demand, itself a product of the comparative lack of involvement of the periphery in the cash economy.

Many parts of Fiji's periphery have been studied in recent years. Two notable books are those edited by Overton (1988) and Bayliss- Smith et al. (1988). The former has a selection of studies from Viti Levu, Vanua Levu and Kadavu; the latter concentrates on the Lau islands of eastern Fiji, together with Taveuni and parts of Lomaiviti. One area of the periphery about which little has been written is the Yasawa group of western Fiji. All locations mentioned above are shown in Figure 5.1.

The Yasawa islands are a group of high, elongate, narrow volcanic islands lying to the west and northwest of the largest Fiji island of Viti Levu (Figure 5.2). They are the remains of a chain of volcanoes which erupted 6-8 million years ago in the main. They rise from part of the huge Yasawa-Mamanuca lagoon which is bordered on the east by Viti Levu and on the west by a barrier reef, 10-30 km west of all the Yasawa islands except Viwa. Viwa is anomalous within the Yasawa group, not just on account of its location (Figure 5.2), but also because it is a low limestone island rather than a high volcanic island. It is an uplifted part of the great barrier reef which fringes the western end of the Yasawa-Mamanuca lagoon. Most Yasawa islands have fringing reefs up to 1 km wide surrounding them.

In socio-economic terms, the Yasawas have long been part of the periphery within Fiji. The nearest urban centre is Lautoka[1] , the second largest city in Fiji, on Viti Levu, which is typically 8-10 hours from Viwa by fishing boat (a distance of 75 km); Viwa is also several hours by fishing boat from the nearest island in the Yasawa chain. There are no roads in the Yasawas. Most transport is by boat (punt).

All settlements in the Yasawas are on the coast, typically at the heads of broad bays containing wide fringing reefs. This observation emphasizes the dependency of the islands' inhabitants on nearshore marine resources, both today and in the past. With the exception of the small islands of Tavewa and Nanuya Lailai (Nanuya Sewa), all land in the Yasawas is native-owned.

The Yasawas lie in the dry part of Fiji. Although too distant from Viti Levu to be represented as lying within its rain shadow, the cause of the Yasawas aridity is certainly linked to the presence of Viti Levu. Most of the precipitation received in Fiji is

[1] Ba is actually closer to some Yasawa islands but much less easier to reach than Lautoka, where better facilities exist.

associated with the southeast tradewinds. Since the Yasawas lie to the northwest of the large island of Viti Levu, the only tradewinds they receive are those which have crossed Viti Levu where they have left behind most of their moisture as orographic precipitation. The tradewinds which affect the Yasawas are mostly hot and dry; even northwest Viti Levu and the Mamanuca islands to the south of the Yasawas receive more rain than they do. The Yasawas receive significant rain only when it is of cyclonic origin. Most cyclones (including tropical cyclones) occur between November and March. When the study team visited the Yasawas in November 1993, they had had no significant rain for six months. By the end of December 1993, several cyclones (not tropical cyclones) had affected Fiji and relieved the drought in the Yasawas.

Most tropical cyclones (hurricanes) affecting Fiji come from the northwest and move either southeast or south-southeast upon encountering land. The first land which most tropical cyclones affecting Fiji encounter is the Yasawa group of islands. Not only do the Yasawas therefore experience more tropical cyclones than any other part of Fiji but they also generally experience more intense tropical cyclones. This is because tropical cyclones typically intensify while moving across the ocean yet decelerate and lose strength after encountering land, owing to increased friction and loss of heat and water-vapour input from below.

The Yasawas can thus be pictured as that part of Fiji's periphery which is most susceptible to climatic disasters. These are not confined to droughts and strong winds but also to the storm surges which are usually associated with tropical cyclones. The passage of the storm surge associated with Tropical Cyclone Nigel in 1985 on Viwa is shown in Figure 5.5.

The vegetation of the Yasawa islands is mostly grassland, a response to the prolonged droughts which occur most years, with forest occurring only in valleys where there are concentrations of water and soil, the latter washed off higher ground during storms. The origin of this grassland, assumed for decades to be anthropogenic, now appears more likely to have been in the dry postglacial period, about 9000 years or more ago, long before people are believed to have arrived in Fiji (Nunn, 1992). There is no doubt that many such grasslands are maintained by regular burning, evidence for which we saw on several occasions in the Yasawas. Pine plantations have been planted on some islands in the Yasawa group but pine trees are susceptible to burning by sea-spray. Mangrove forests occur at the heads of uninhabited bays in particular.

From information collected on Viwa and several other islands during November 1993, it appears that many of the large trees which were found dotted about in grassland-savanna areas have been toppled during the last decade during cyclones. This may be a manifestation of the undoubtedly increased tropical-cyclone frequency (and perhaps intensity) on vegetation (Nunn, 1992).

Most agriculture in the Yasawas is practiced close to the villages. Few of the upland areas on any islands are used for agriculture, partly because there is no demand and partly because the soils are poor and thin in such areas and more susceptible to drought. Most of the uninhabited coastal lowlands in the Yasawas are covered with coconut palms, a legacy of the time when copra was an important cash crop encouraged by the colonial government in particular.

In the last twenty years, several tourist resorts have been established in the Yasawa and Mamanuca island groups. Owing to their small-island appeal and unspoilt appearance, most of these resorts have been moderately profitable and are now responsible for a large proportion of visitor arrivals in Fiji. Most resorts try to become integrated within the environment and the society. They employ local people, depend on local supplies of seafood, and manifest an interest in the well-being of Yasawa islanders. Except on alienated islands, Yasawa people also receive the benefits of lease money from these resorts.

Two study sites were selected in the Yasawas for Phase 2 of this study: the islands of Nacula and Viwa. In addition, the study team landed on and investigated several other islands in the vicinity including Tavewa, Nanuya Levu and Matacawalevu.

Nacula was selected as a study site because it is a high volcanic island, typical of most in the Yasawas. It has four villages of largely subsistence agriculturists, although some islanders have paid employment at Turtle Island Resort on Nanuya Levu.

Viwa was chosen principally because, unlike any of the case studies in Phase 1, the shoreline is limestone. It is also extremely remote, even within the Yasawa group. It has two main villages, one at either end of the island. The only cash which most families living on Viwa earn directly is from the sale of fish, cooled on ice, and taken to Lautoka.

5.2. Summary of boundary conditions

Boundary conditions for case studies in Fiji were discussed in section 5.3. of the Phase 1 report (Nunn et al., 1993). In this volume, we revise future boundary conditions based on the revised emissions scenarios presented by Wigley and Raper (1992) and by Warrick et al. (1993).

They predict that sea level will rise relative to its 1990 level by a global average of 46 cm by 2100 (IS92a BEST scenario) which means 51 cm for Fiji (see section 3.4.1. and Figure 3.5).

This means that the future rate of sea-level rise will probably increase to around 4.64 mm/year. Given that the rate of sea-level rise in the Pacific for the past century or so has been about 1.5 mm/year, this means that sea level is likely to rise at least three times faster in the foreseeable future.

When assessing the figures for temperature and sea-level rise in the future, it should be borne in mind that the IPCC predictions are all associated with large error margins, 21-93 cm for the 51 cm rise quoted above (see Figure 3.5).

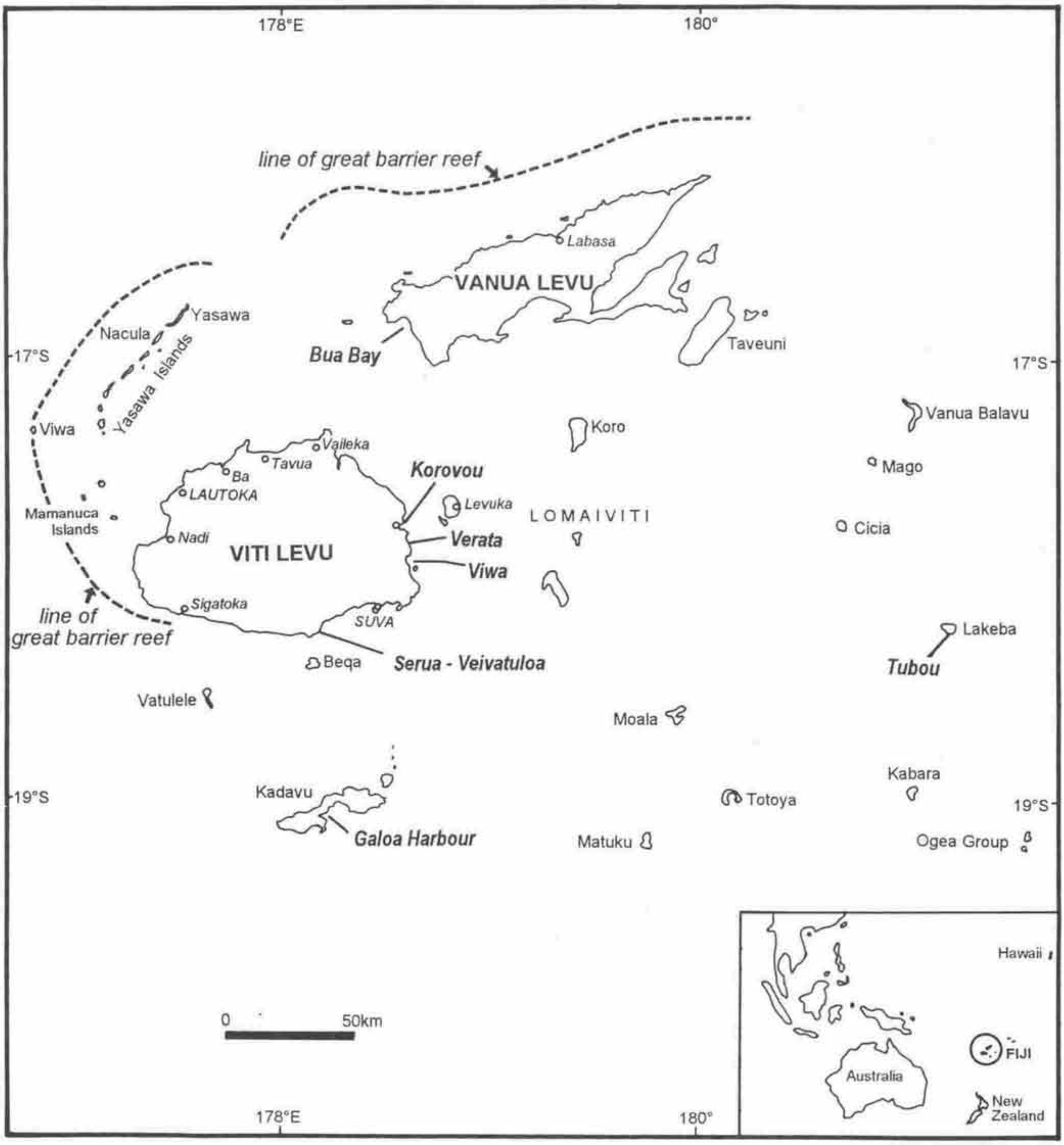


Figure 5.1. Locations of study sites for Phase 1 and Phase 2 along with comparable sites mentioned in the text

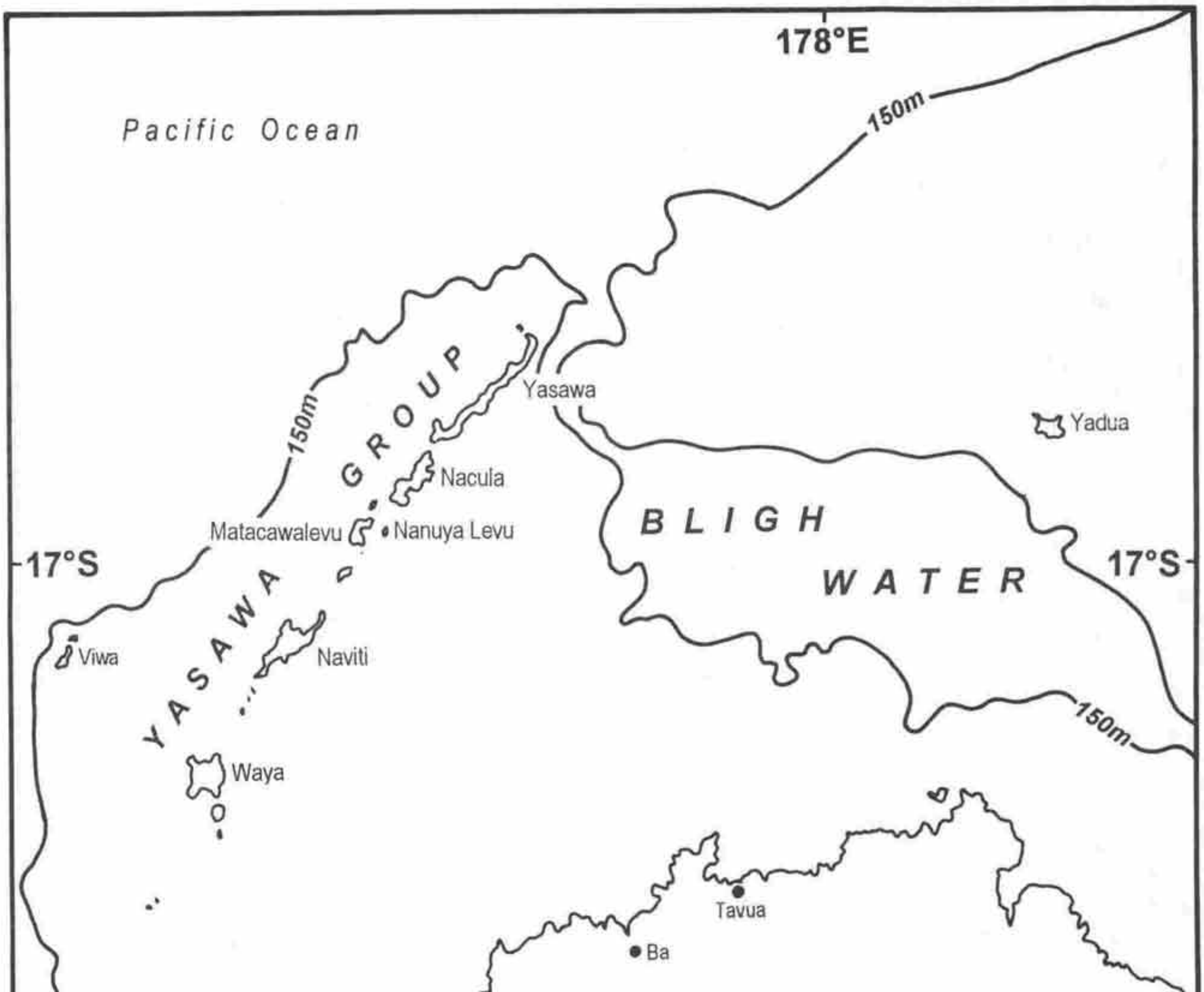


Figure 5.2. The Yasawa group of islands showing their position relative to Viti Levu (after Nunn and Nagasima, 1993). Only the 150 m isobath marking the edge of the insular shelf is shown. Ocean depths to the west exceed 3 km in places. Most of the Yasawa islands are surrounded by seas which are less than 30 m deep.

5.3. Nacula study site

5.3.1. Introduction

Nacula island is located in the central part of the Yasawa group. This comprises mainly hilly volcanic islands with many small bays. Flat sandy areas of elevation less than 2 m and of varying dimensions border these bays. The four villages on the island occupy these sandy coastal plains. Two villages are located close to each other in the centre of the western side while the other two are located at the extremes of the eastern side (Figure 5.3).

These villages are large by the standards of rural Fiji, each containing about 300 residents. Additional members of the villages live and work on Viti Levu but may have a house in the village. The present village sites have moved from the hills as tribal warfare ceased in the last century and more recently (in at least one case) in response to increasing populations.

Hurricanes and droughts have a major impact on the island. The Yasawa group is on a common hurricane track and these islands are the first land fall so often bear the full fury of the storms. Direct hits come every 10-20 years with sideswiping hurricanes occurring more numerously in between.

Being affected by the rain shadow of Viti Levu and not being large enough to generate their own orographic rainfall, annual precipitation is close to the lowest in Fiji (~1500 mm). In the period May to December there are few rainfall events, especially during El Niño years. This leads to water shortages that affect water availability for human use and agriculture.

People are fairly isolated from "modern" life on Nacula. Most have a radio. Other contact is by a radiotelephone system that operates occasionally. Trips to the mainland by open punt or fishing boat take 4-6 hours and are usually undertaken only for commercial and/or traditional reasons. Life in the island consists mainly of subsistence activities, especially fishing, agriculture and mat-making, together with traditional ceremonial activities.

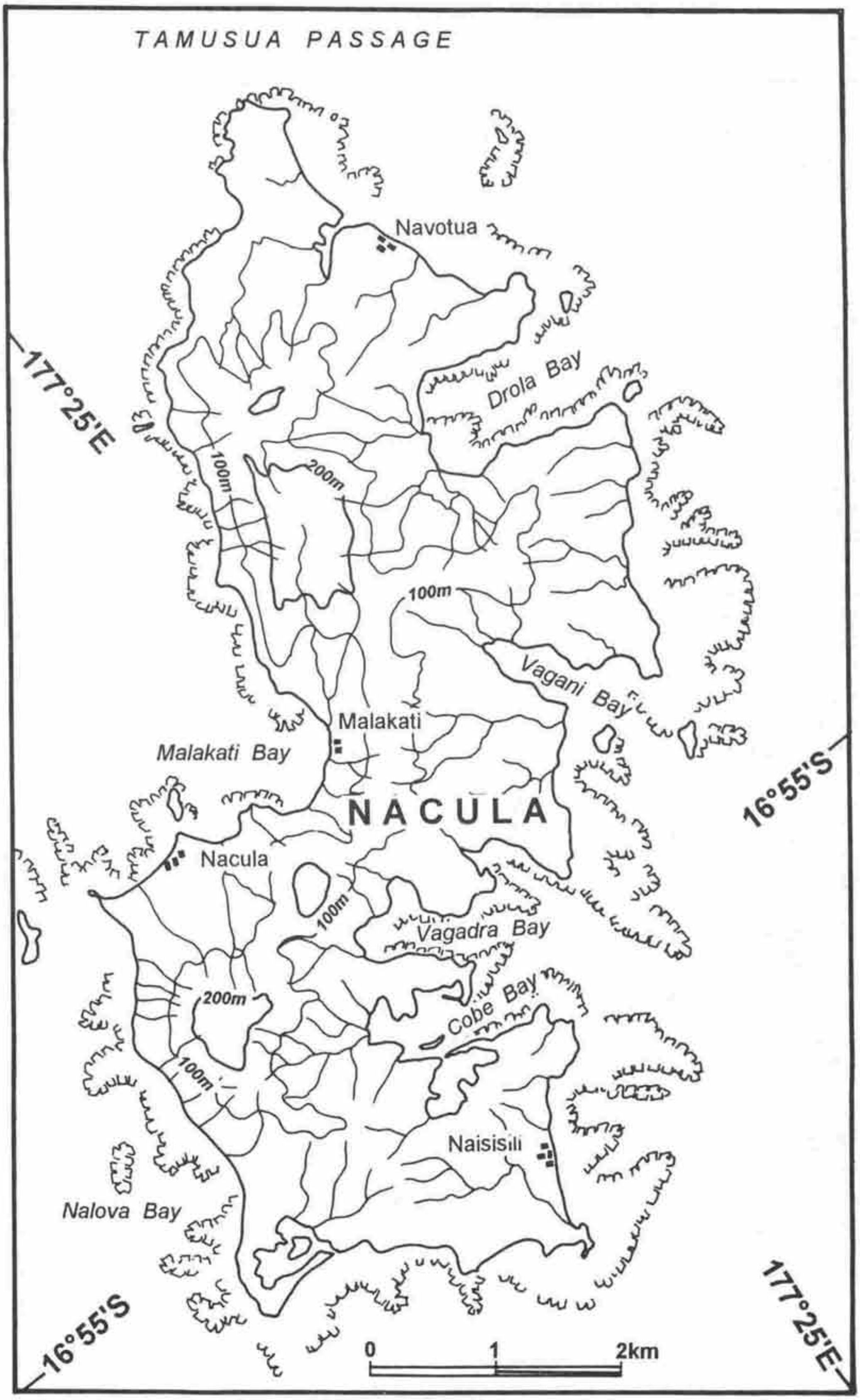


Figure 5.3. The island of Nacula showing the outlines of the physiography and the major settlements

5.3.2. Physical elements

Nacula is a volcanic island, high for a small island (reaching 250 m above sea level in two places), and well dissected (Figure 5.3). It is divisible into three parts, separated by geological faults along Drola and Vagadra Bays on the southeast coast. The northernmost division is made up largely of rocks erupted underwater, similar to those on adjoining Yasawa island. The southernmost division is made up largely of rocks erupted above the sea surface. The central division is made up of hydroclastic rocks, rocks formed by the interaction of molten lavas erupting close to shorelines. Limestone occurs locally (Rodda, 1990).

Most of the higher parts of Nacula are covered by grassland or, where there is insufficient soil, consist of bare rock. Trees are usually confined to valley bottoms, where there are thicker soils and a concentration of fresh water. Most of the coastal lowlands are covered with coconut palms, people's food gardens tend to be on slightly higher ground. Mangroves fringe many coastal plains and have grown out recently in narrow inlets such as Cobe, Vagadra and Tuka Bays on the southeast coast near Naisisili. In these inlets there has been increased sedimentation recently, as the result of vegetation clearance for various reasons including the construction of a resort, a initiative now aborted.

Nacula is surrounded by a fringing reef which in places extends more than 1 km from the shoreline. This reef has been adversely affected by recent sedimentation in places but overall appears healthy.

Most of the villages on Nacula are located on coastal plains which are among the lowest parts of the island relative to sea level yet still higher than some. Naisisili, for example, moved to its present site within the last two decades and now occupies a large area some 1.5 m above mean sea level separated from the sea by a well-vegetated berm, some 20 m wide, which rises about 2.5-3.0 m above mean sea level in places. This berm is planted with mature coconuts and its surface is covered with a variety of crawling plants. Vegetated berms of this kind afford considerable protection against storm surges.

The composition of most of these coastal plains is of superficial materials - beach sand, colluvium and alluvium - resting on a rock platform, probably about 0.5 m above sea level along the modern shoreline. Were sea level to rise by a similar amount, it would cause increased erosion of the superficial sediment cover, a process whose severity could be significantly offset by maintaining, even increasing, the amount of vegetation separating settlements from the shoreline. Human destruction of vegetation along this coastal strip should be discouraged.

Many people were aware of the effects of sea-level rise. People of Nacula village reported that their shoreline had receded some 10 m in the last 30-40 years, pointing out that large trees used to grow where boats are currently anchored. Naisisili villages report the inland reach of a very gently sloping inlet had increased some 50 m in the last two decades (Figure 5.4).

Afforestation of upland areas should be encouraged as a method of stabilizing existing soils and encouraging soil development and water retention. Landslides and rockfalls on the steeper slopes, which occur mainly on the northwest coasts of Nacula, would be reduced by afforestation of grassland areas. Should the present high frequency of tropical cyclones persist in the future, then the Yasawa group including Nacula are likely to experience continued high levels of soil loss at such times. Since most storm surges approach the island from the northwest, gardening on southeast-facing slopes, which are sheltered from the worst effects of such events, could be encouraged. Resettlement on the windward (southeast-facing) side of Nacula may also become an option to be encouraged.

Certain aspects of Nacula are vulnerable to sea-level rise, notably the lower-lying coastal plains, but on the whole the island is comparatively resilient. If there is no management, then many coastal plains may become badly eroded and unusable for settlement or agriculture. The most vulnerable area is probably around the village of Nacula itself although the coastal plains on which the villages of Naisisili and Malakati lie are also at risk. Old village sites around the heads of windward bays such as Cobe would prove more resilient to sea-level rise than many of the modern sites.

Optimal management strategies for reducing the effects of future sea-level rise on the physical elements of Nacula include raising the level of coastal plains and coastal defenses. This process has been done already by the far-sighted management of Turtle Island Resort on nearby Nanuya Levu island using large boulders. The resort management is also notable for having engaged in considerable reafforestation of the island it occupies and has generally behaved in an environmentally responsible manner.

5.3.3. Biological elements

In undeveloped areas, coastal trees such as *dilo* (Calophyllum inophyllum) and *tavola* (Terminalia catappa) and shrubs such as *vevedu* (Scaevola toccada) line the edge of the beach front. In the inland flats, *vaivai* (Leucaena leucocephala) forests are common. The mangrove ecosystem is found in a few areas. The hills are mostly covered by coarse grass, droughts and repeated burning having denuded them of trees.

Offshore from the island are extensive patch reef systems. There is a fringing reef in some places. Many reefs are extremely healthy owing to minimal fresh water or sediment inputs from the land. Marine resources form a major source of food and income.

Breadfruit trees are common and are a major source of carbohydrate in season. Coconuts are common, especially near Naisisili where the large coastal flat behind the village is utilized as a copra plantation. There are also wild citrus in a number of areas. The main cultivated crop is cassava although yams and bananas are also planted. Wild yams grow in the hills and are harvested during food emergencies. Most planting is in lower flat areas since plants in these areas have easy access to the water table that is often less then a metre underground.

The present biological vulnerability is -1, a reflection of the limited range of land biota (Table 5.1). The reef biota is of course much more complex. The resilience is +2. Most plants are tolerant of the dry, salty conditions in this area.

In the future, increased intrusion of salt water will affect the coastal land biota and rising sea levels and temperature may affect the reefs. Increased intensity and frequency of cyclones will affect both. This raises the vulnerability score to -2. There is little that can be done at a local level to offset these problems. However, afforestation, better soil management and restrictions on burning could improve the biological resources of the hilly areas so that the optimal management score is -1. The resilience under both regimes is +1.

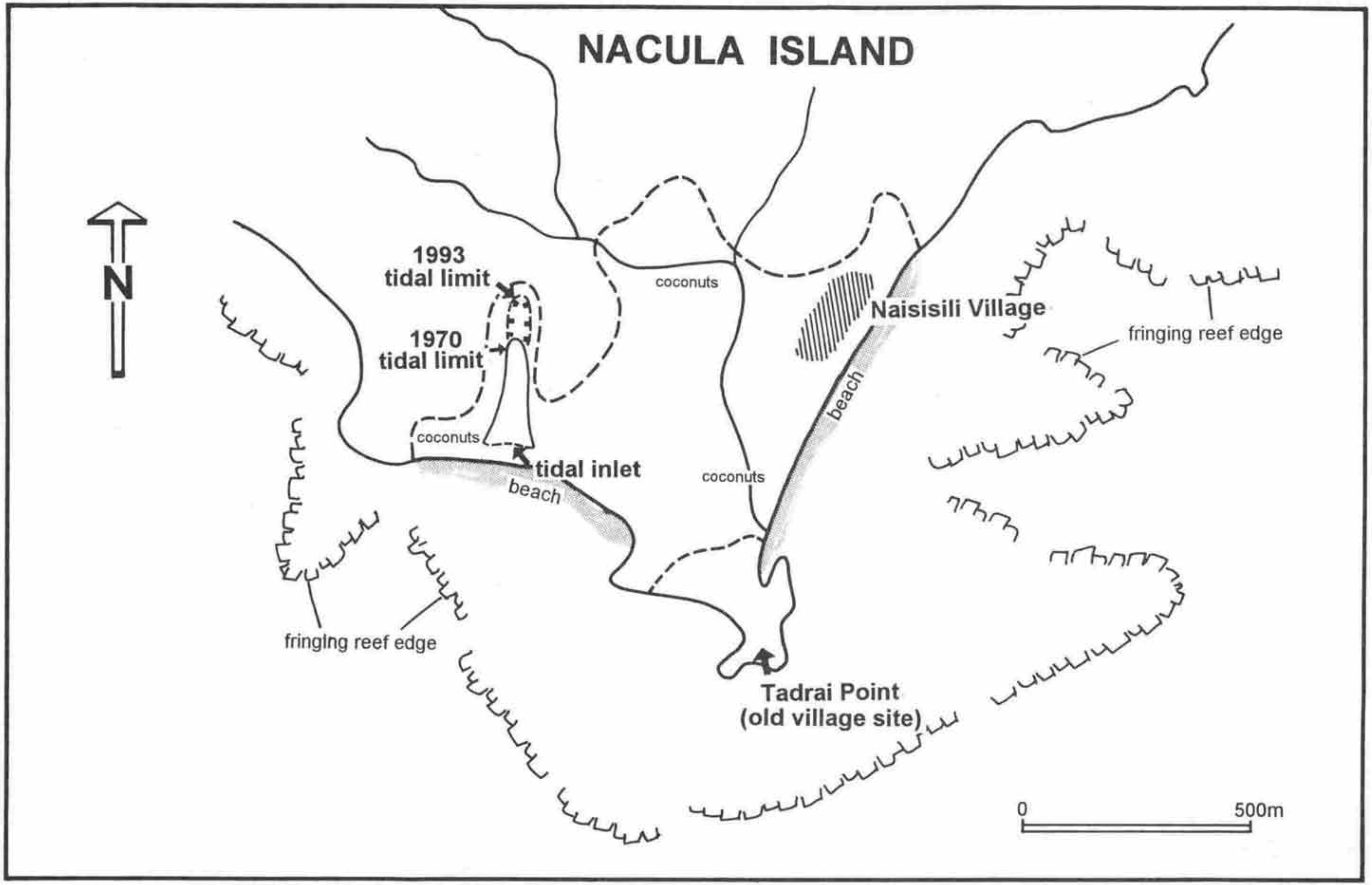


Figure 5.4. Evidence of recent inundation from the area around Naisisili on Nacula island

5.3.4. Human elements

The population density on Nacula is low with a total permanent resident population of about 1000 people. About half again as many Nacula islanders are not permanently resident owing to employment or study. Some of these people are permanently alienated as even on retirement they will stay in the urban centres, others will retire to Nacula. All will however continue to visit the island and contribute to its welfare.

Improved living conditions and health care have led to significant increases in the rural Fijian population. This has also occurred on Nacula. The main reason for the relocation of Naisisili village was the lack of space at the old village site. Other villages are expanding onto land at the edge of the village that would otherwise be used for agriculture. There is still much land available as long as this coastal land is not inundated.

Elevated land is available for settlement but in some parts of the island the classical plan of a rectangular array of houses surrounding a village green (*rara*) would not be possible if sea-level rise necessitated a move to the hills. However, this "traditional" village structure is a post-European contact one so there is no reason to believe that other village configurations would be unacceptable. The main feature would have to be sufficiently close proximity to share everyday life.

The human population vulnerability is -1 and resilience is +2. With optimal management the vulnerability would remain -1 but with none it could rise to -2. Resilience could fall to +1 with no management but rise to +3 with optimal management.

5.3.5. Infrastructural elements

As would be expected in a rural area, infrastructural elements are few beyond individual houses. Each village contains two large churches (one Catholic, one Methodist). These are usually located at the landward side of the village. A primary school and medical post are located near Nacula village. Both are situated inland at the edge of the hills on higher ground.

The only other infrastructure is the piped water supply system that serves the villages. Each village has a piped water system linking them to large tanks filled from water sources in the hills. These tanks sometimes empty during droughts. The national government is working to improve the supply by drilling and filling these tanks by pumping. These systems would not be affected by sea-level rise.

Individual houses are constructed either of concrete blocks with corrugated iron roofs or of traditional materials (wood and grass). Concrete houses predominate because they last longer and are easier to maintain. There seemed to be a tendency among people interviewed to return to building more traditional houses as these are cooler and easier to repair if damaged in hurricanes. The presence of more traditional houses increases resilience as it would be easier to move and replace them.

All individual and communal structures are currently located near the coast on sandy substructures at elevations of not more than 2 m. Thus a significant rise in sea level and/or storm surges could cause these structures to be abandoned or moved. Some protection is offered by the fact that houses are set back somewhat from the sea front which is planted to some measure with trees whose roots will slow erosion. In most villages an elevated sand bank occurs at the sea front. Rocks are available to build seawalls in front of villages to slow erosion but the effort to build an effective one would be quite great. Whether this effort would be warranted is not clear.

Vulnerabilities and resiliences for these infrastructure elements are given in Table 5.1.

5.3.6. Institutional elements

The institutional framework at the village level is akin to the cultural aspects described below. The organization is well established at a traditional level that has been validated by the legal system. Resource management occurs through discussion at the village level with the final decision being that of the chief.

An example on Nacula is the banning of burning. This decision has been reached by consensus and is known to everyone. Violation results in a fine imposed by the village.

Such a system has low vulnerability (0) and high resilience (+3). It is unlikely that this will change in the future given the strength of the traditional system in the outer islands (the periphery) of Fiji.

At the national level, the situation is somewhat different. Although especially for a developing country, the national government is well run and understands the importance of rural development, the realities of working on outer islands with few resources limit the effectiveness of government efforts.

A case in point is the drilling for water that was taking place when we visited Nacula. The drilling team had been preceded by a geologist who suggested where drilling should take place. In one village where water was not found, the driller reckoned a different drilling site had a greater chance of success but the geologist was not available to discuss this. In the meanwhile a piece of equipment had broken and the workers had been idle for some time waiting for a replacement part.

As this area of Fiji tends to be under-represented in government, less pressure is put on government to develop it. An additional factor is that at present throughout Fiji the management of the coastal zone is fragmented among several government departments. The score would be -2 for vulnerability and +2 for resilience.

With optimal management the vulnerability could go to 0 and resilience to +2. With no management vulnerability could be -3 and resilience +1.

5.3.7. Economic elements

The monetary economy has only recently become important for Fijians living in the Yasawa islands. Food, housing and clothing needs were traditionally obtained from the immediate environment or by ceremonial interchange. The need to pay educational expenses and a desire for western goods has changed this.

Marine life such as fish and lobsters abounds around the Yasawa islands and these can be sold, generally in Lautoka. Access to this market requires a lengthy and sometimes quite dangerous boat trip. Ice storage boxes have helped this enterprise to expand. People will generally engage in such activity if they have a specific urgent need for money.

In the last decade or so, tourism has become important in the Yasawa chain. Tourists are drawn by the white beaches, colourful water and reefs and friendliness of the people. This enterprise started as cruise ships touring the island chain. Villages benefited mainly by landing fees and being paid for entertaining guests and selling handicrafts.

More recently, two very exclusive resorts have opened as well as a few which cater mainly to the lower end of the tourist scale. These resorts are all small but do provide employment and a nearer market for fish and other traditional items such as supplying thatch for the hotel buildings.

Another major source of funds for these islanders is mainland employment either directly or via remittances from relatives.

No hotels exist on Nacula island but the nearby Turtle Island Resort on Nanuya Levu provides some employment and markets. The Blue Lagoon cruises use Nacula island anchorages. Some international cruise ships are also being drawn by the unique beauty of the Yasawa Islands.

Another major economic activity that occupies much of the islanders' time is agriculture. Some coconut trees are grown for copra but its low price has lessened the return from this activity. The vast majority of agricultural activity is at the subsistence level. Although this does not generate income, the cost of replacing these mainly carbohydrate items in the diet could be thousands of dollars per year in an average household. Most protein in the diet is provided by reef fish.

When we visited the islands, there was considerable consumption of rice and flour. This was due to the twin blows of a devastating hurricane associated with Tropical Cyclone Kina in early 1993 which destroyed large quantities of standing crops followed by a severe drought between August and November which withered many of the crops that had been planted after the hurricane and has delayed the seasonal fruiting of the breadfruit tree.

The 1993 situation exemplifies the agricultural difficulties. Low-lying land around the villages seems to be better for agriculture owing to a better natural supply of water and perhaps richer soil. This land is being lost though as villages expand. Hillside planting is especially susceptible to drought and hurricanes. More land could be made available for subsistence farming by converting coconut plantations.

Owing to this wide range of economic activities it is difficult to determine single scores. Agriculture, especially on the low-lying area might benefit initially as the water table rises but would definitely deteriorate once salt-water intrusion occurred. If enough water was made available by the drilling scheme (which should in theory be possible), irrigation could solve the problems of droughts (this has been successful on Turtle Island). Tree planting and refraining from burning could help make the hill areas more productive.

The availability of fish and other sea resources are unlikely to be affected in the foreseeable future. Tourism, however, is more problematical. Evidence from our inspections indicated that sand eroded from one cove was generally deposited in another so there is no net loss of sand from most island shorelines. It is possible that accelerated sea-level rise could change this. Sandy beaches and multi-hued waters are likely to keep the cruise ships coming.

Land-based resorts are generally built in areas similar to those occupied by villages and are thus susceptible to rises in sea level. The richer resorts will probably have resources available to build seawalls that will protect their investment in infrastructure.

The study area has limited cash economic activity and is therefore given a vulnerability of -1. Subsistence is more important and rates a -2. The chance of changing to different economic activities is limited but more so in the commercial sense than the subsistence one. Resiliences are therefore given as +2 and +1 respectively. Effective management practices in terms of agriculture and coastal management for hotels could greatly improve the ability of these economic activities to survive sea-level rise and these are reflected in the scores given in Table 5.1, especially the differences in the sustainable capacity index for the no management and optimal management options.

5.3.8. Cultural elements

The four villages on Nacula are populated by indigenous Fijians. The traditional system is very strong. This system emphasizes communal activity under the direction of the chief. In such a system there is strong cohesion within the village in which decisions are reached by extensive discussion of problems facing the village until a consensus is achieved. For further details, see sections 2.2.3 and 6.4.4 in the Phase 1 report (Nunn et al. 1993).

One feature unusual to the Nacula island villages is the presence of a large religious minority of Catholics (as opposed to the predominant Methodists). This is due to the fact that the first missionaries to reach this area of the Yasawas were Catholics. Since the church is such an important focus of village life this does create a division within the village. At present, though, this does not seem to have a major effect on village unity when it comes to secular and traditional matters.

The strong community-oriented Fijian culture is ideal for dealing with outside threats. Since this system is so important, its vulnerability is rated as -2 and resilience at +3. This is unlikely to change significantly in the future, in fact unity is likely to increase in countering increased problems. These villages have had to relocate in the past and have done so successfully.

A possible problem is that communal land is considered to be held by sub-units in the village called mataqali. If land is lost as the result of sea-level rise it would likely differentially affect the different mataqali. This might result in land being needed by a mataqali. This problem is likely to be solved in the traditional manner as land arguments tend to occur only when financial returns are involved and not land being used for subsistence living, as is the case with all the land on Nacula.

Even with no management it is expected that vulnerability and resilience would change only slightly to -1 and +2 respectively, whereas with optimal management they would remain at 0 and +3.

In terms of national cultural importance, the status of Nacula as an outlier means that there is little national importance to this area. Vulnerability is -1 and resilience is +1. These values would not change significantly regardless of the management approach.

5.3.9. Response options

It is unlikely that the magnitude of sea-level rise predicted by the IPCC for the year 2050 will have any serious effects on the important aspects of life on Nacula island. Some areas may suffer salt-water intrusion but there is sufficient land available that such land could merely be abandoned. Certainly some decisions such as not building on the lowest-lying land or near the sea would make sense. Planting the shoreline areas of villages with vines and trees that might build up the coastal embankment and help prevent erosion would also be wise.

With the likely acceleration of sea-level rise beyond 2050, the land occupied by the villages on Nacula at some point will become inundated. Both village and agriculture would need to move to higher ground. The time when this happens could be postponed by building shoreline-protection structures but this would only be a stop-gap measure, especially given the permeability of the sandy soils. For some villages, suitable land in the hills is already available. For others, flat sites would probably have to be created. The availability of water to support domestic uses and agriculture on the hills would have to have been developed by this point. Practices that help retain water and soil fertility would certainly need to be followed. With sustainable agriculture being practiced and a continued supply of marine resources [the viability of reefs should not be seriously affected (at least not by sea-level rise alone) in the foreseeable future], life as is currently practiced on Nacula should be able to continue.

It is not clear, however, what the carrying capacity of this island would be, especially under a scenario of inundation of coastal land. Populations are likely to continue to rise in villages. The trend of greater migration to urban centres is likely to accelerate to offset this increase.

The example of the development of Turtle Island Resort on Nanuya Levu island provides testimony that with appropriate machinery, planning and expertise, the quite stark environment of a small Yasawa island can be greatly enhanced. This is reassuring evidence that the potential is available for the people of the Yasawa islands to respond effectively to the threat of sea-level rise and associated external stresses.

Table 5.1. Nacula present day and future coastal system vulnerability and resilience components and sustainable capacity indices

Coastal systems	Coastal sub-systems	Vulnerability component	Resilience component	Sustainable capacity index	Vulnerability component		Resilience component		Sustainable capacity index	
Present day					Future					
		present management regime	present management regime	present management regime	No management	Optimal management	No management	Optimal management	No management	Optimal management
Natural	physical	-1	+2	+1	-3	-1	+1	+2	-2	+1
	biological	-1	+2	+1	-2	-1	+1	+1	-1	0
Cultural	communal	0	+3	+3	-1	0	+2	+3	+1	+3
	national	-1	+1	0	-1	-1	+1	+1	0	0
Institutional	village	0	+3	+3	0	0	+3	+3	+3	+3
	national	-2	+2	0	-3	0	+1	+2	-2	+2
Infrastructural	individual	-2	+2	0	-2	-1	+1	+3	-1	+2
	communal	-1	+1	0	-2	0	+1	+2	-1	+2
	national	0	+2	+2	-1	0	+1	+3	0	+3
Economic	subsistence	-2	+2	0	-2	0	+1	+3	-1	+3
	cash	-1	+1	0	-2	0	+1	+2	-1	+2
Human	populations	-1	+2	+1	-2	-1	+1	+3	-1	+2
Average Sustainable Capacity Index										

5.4. Viwa study site

5.4.1. Introduction

Viwa is an uplifted limestone island in the Yasawa group of western Fiji (Figure 5.5; Plate 5.1). It is situated some 30 km west of the main Yasawa chain of islands and it is the westernmost island of the Fiji group. It is 0.81 km^2 in area and has a total population of about 400 people. Administratively and culturally, Viwa island is a part of the Yasawa tikina, and comes under the province of Ba.

The two main villages on Viwa are Natia and Naibalebale. Both villages are close to the coast. The third is the two household settlement of Yakani, where the Yavusa Namakatoka's first ancestral house-foundation or yavu was established. It is a little inland from the sea. The people of Viwa depend largely on fish and other marine products for protein food and cash. For starch and energy food, the island is capable of growing bananas, plantains or vudi, yam, sweet potato and cassava on the very thin soil developed on the coral limestone rocks. Bele (Hibiscus manihot), tomatoes and water melon can also be grown in small patches on the island. Fruit trees are few and they include, coconut, breadfruit, dawa (Pometia pinnata), and damudamu (Plates 5.2 and 5.3). Damudamu is a tree which bears berries which the people sometimes eat after a severe hurricane when all other crops have been destroyed. Shop food such as rice, flour, biscuits, tea and sugar supplements local foodstuffs.

For transportation to other islands of the Yasawa group and to the main island of Viti Levu, the people of Viwa generally use 40 horse-power outboard engine driven punts. A journey to the main market and shopping centres of the western coast of Viti Levu takes at least six hours each way. The island's communication link with the rest of Fiji is through a radio-telephone station at Naibalebale village which operates for only a few hours in the morning and in the late afternoon.

The island of Viwa has no flowing source of water such as a stream. It depends entirely on rain water collected in tanks. Brackish water from a few wells is sometimes used. During droughts, fresh water has to be carted from the main island of Viti Levu by Public Works Department barges. Provision of fresh water is a major problem for the people of Viwa.

Apart from subsistence gardening and fishing, there are hardly any other economic activities on the island.

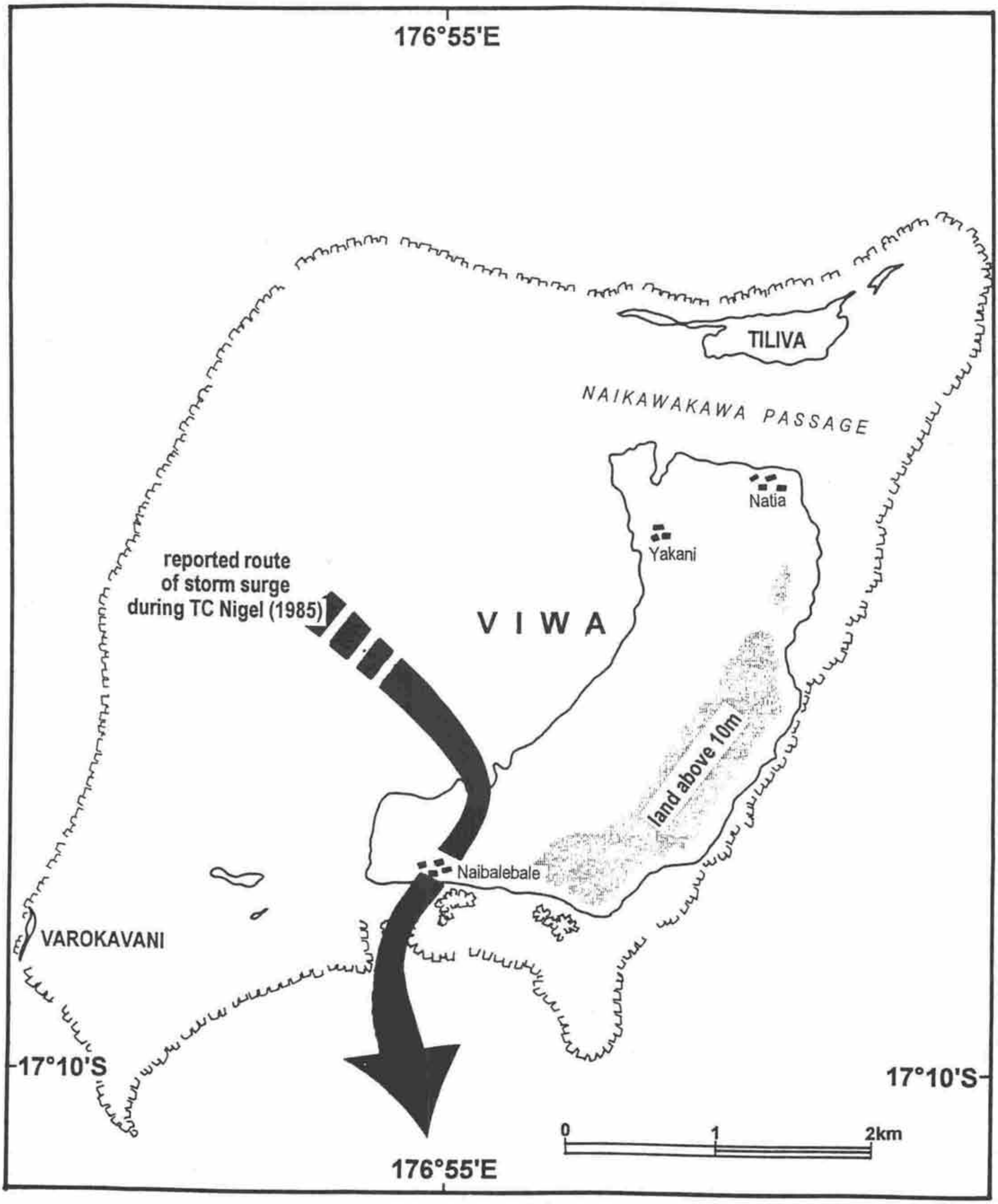


Figure 5.5. The island of Viwa (Yasawas) showing the outlines of the physiography and the major settlements

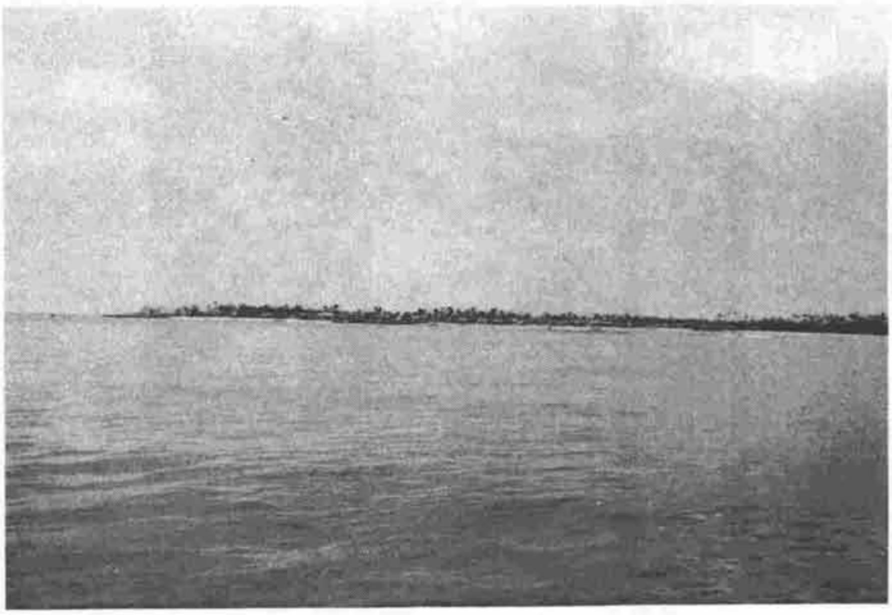


Plate 5.1. The approach to Naibalebale village on Viwa island in the Yasawas

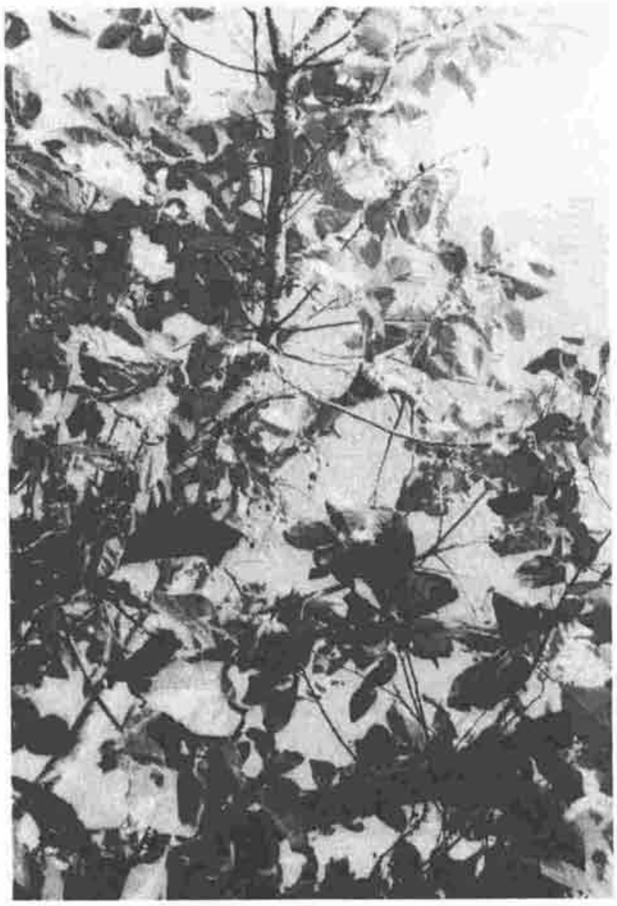


Plate 5.2. Damudamu tree - an emergency food for eating after cyclones have damaged crops on Viwa

Plate 5.3. The fruits of damudamu

5.4.2. Physical elements

Viwa is an emerged limestone island situated on the barrier reef which rises from the western edge of the Yasawa-Viti Levu island platform. It is similar to other inhabited islands of this type in the area like Vatulele in southwest Fiji and Vatoa in southern Lau. It is also similar to most of the major inhabited islands in Tonga (Nunn and Waddell, 1992).

Viwa is anomalous because it is a limestone island in a group of mostly volcanic islands. It is an emerged section of the barrier reef, dating from the Last Interglacial at a time when the sea level is widely believed to have been around 6 m higher than today. Two separate emerged reefs have been identified on Viwa, separated by an angular unconformity visible in the 15-20 m cliffs along the island's east coast. Corals from the upper (younger) reef have been dated to 125,000 - 135,000 years ago (Taylor, 1978). There has probably been negligible land-level movements here since this time.

Viwa is flat, its surface sloping gently from east to west. Most of the vegetation is bush with only a few tall trees remaining after the impact of an unusually high number of tropical cyclones over the last 20 years. The higher ground in the east is mostly unutilized, most food gardens and coconut plantations are close to the villages. A fringing reef lies close to the island's cliffed east coast, a barrier reef lies some 3 km offshore the island's low sandy west coast (Figure 5.5).

Were sea level to rise as predicted in the next 50-100 years, there are few coastal sites which would be directly affected. Much of the area covered by the two largest settlements, Naibalebale and Natia, is 4 m or more above sea level. The only school on the island at Naibalebale is located on a surface about 6 m high, surrounded by cliffs cut in bedrock limestone. The lower ground between the edge of Natia and the sea is planted with coconuts and other vegetation which protect the village infrastructure during storm surges and reduce shoreline erosion.

The reefs off the island's west coast are reportedly affected by a large number of crown of thorns starfish (Acanthaster sp.) which may cause serious destruction to the reef if not removed soon. A debilitated reef is a less effective barrier to storm surges than a healthy one.

The effects of tropical cyclones on Viwa are commonly severe. Several islanders attributed the absences of large trees on the island to storm damage, particularly associated with Bebe in 1972 and Nigel in 1985. These storms commonly approach Fiji from the northwest, so that Viwa (and the rest of the Yasawa group) usually bear the brunt of their attack. High winds on flat islands like Viwa may cause much greater damage than on more irregular islands. Storm surges are capable of sweeping across the island. The route of the surge associated with Tropical Cyclone Nigel in 1985 is shown in Figure 5.5.

The only lasting effect of cyclones seems to be the loss of large trees. Food gardens can be replaced; the soil of Viwa is surprisingly fertile. Houses can be repaired.

The major effects of future sea-level rise would be felt along the island's west coast where unconsolidated sand covers bedrock for a considerable distance inland. Much deforestation has occurred recently along this coast, particularly involving the use of nokonoko trees for houseposts. Although the area is not greatly utilized, the danger is that the combination of sea-level rise and deforestation could cause a large amount of unconsolidated sand and finer sediments to be released into the lagoon where it might smother reefs, contribute to algal blooms, and adversely affect marine fauna used for subsistence.

With that exception, the island appears quite resilient to the problem of future sea-level rise. A greater problem will be if the climate of the future becomes more arid than it is already.

The biggest problem on the island is a lack of fresh water. Most years, water is shipped from Lautoka on the Viti Levu mainland to replenish the communal water tanks in Naibalebale. Most households have roof catchment systems but droughts are common.

Boreholes and other sub-surface tests for water have been carried out over the years; the most recent report is that of Rodda and Gale (1987). Unfortunately, all the tests were carried out close to Naibalebale and encountered (largely) saline water. Boreholes in the centre of the island are much more likely to encounter a freshwater lens.

The present vulnerability of the physical elements is considered to be low, although the score of -1 reflects the drinking water problem. The resilience is comparatively high, the rocks of the island are resistant to erosion yet its inhabitants are affected by periodic droughts.

For the future, if there is no management, then vulnerability of the island's physical fabric, particularly along its west coast, will increase; resilience will likewise decrease. Optimal management will involve replanting and conserving coastal vegetation, and perhaps encouraging mangroves to grow across the mouths of bays like Yawalevu Bay, through which cyclone storm surges often pass. The health of the Viwa reefs could also be improved.

5.4.3. Biological elements

Apart from planted and settled areas, Viwa is covered by a light bush with few large trees but an often impenetrable undergrowth. Nokonoko (Casuarina equisetifolia) trees planted along the island's west-facing coast appear to have been planted deliberately. These are commonly used for stabilizing coastal areas made of unconsolidated materials. Coconut groves occur within the bush, commonly along footpaths.

The main crops, which are used exclusively for subsistence, have been described in section 5.4.1. The soils of Viwa are surprisingly productive compared to many similar limestone islands and it may be that Viwa's soils are less intensively used or founded on limestones which may be uncommonly retentive of water.

Viwa's coast supports a few mangroves in inlets and patches along the west coast. The island is surrounded by a broad reef which hugs the east coast yet extends up to 3 km off the west coast. The reefs appear largely healthy yet had a considerable number of Acanthaster (Crown of Thorns starfish) at the time of our visit in November 1993. Mangrove clearance appears largely insignificant.

The biodiversity of Viwa is not great but it is not clear whether the island could support a greater diversity of species. The score of -1 for present vulnerability reflects this and also the subsistence value of the naturally growing plants. Viwa is a harsh environment - nowhere is immune from the effects of sea spray. Further, tropical cyclones affect the island more often than most other parts of Fiji and islanders claim that the absence of large trees on Viwa is a consequence of an increased number of such storms having affected the island in recent years. A score of +1 is appropriate for present resilience.

Vulnerability is likely to increase in the future if there is no management including the replanting of nokonoko and the removal of Acanthaster from the island's reefs. Such steps should be part of an optimal management strategy which might also include the deliberate spread of mangroves along the vulnerable coasts including those along the fronts of villages.

Resilience is likely to be reduced if reefs and mangrove areas are inundated. Optimal management would involve reducing existing stress levels on these ecosystems.

5.4.4. Human elements

The 400-strong population of Viwa is no threat to the sustainable use of the island's resources. Indeed, there are many overgrown food gardens and abandoned house sites which testify to a reduction in population over the last two decades or so as a consequence of out-migration.

Present vulnerability is -1; the relationship between people and the environment is clearly sustainable. Present resilience is +2. Most of the people have their houses on ground which is 2 m or more above mean sea level; only a few parts of Natia and Naibalebale are lower lying.

In the future, it is likely that population reduction will continue as young people seek greener pastures on the main islands of Fiji. Thus, in spite of increasing stresses, the relationship between people and the environment will likely remain sustainable, whatever management options are tried. Resilience will not vary either since there are plenty of protected places for people to live if sea-level rise inundates even part of the existing settlements.

5.4.5. Infrastructural elements

Individual infrastructure on Viwa comprises the most important infrastructural element and includes houses, kitchens and toilets. Communal infrastructure includes water tanks and churches in each of the main villages, community halls and the school, nursing station and radiotelephone in Naibalebale. National infrastructure is absent, the only road linking the two main villages is for foot traffic alone.

Most infrastructure is well constructed. In the two villages, there are a few traditionally-constructed bures but the number of these has declined in recent years and been replaced by concrete houses. These are hotter and are affected more by flooding than *bures* but still are able to withstand strong winds better. There is a certain element of family and communal pride in the construction of infrastructure which ensures the permanence of these dwellings.

5.4.6. Institutional elements

In both of the main villages on Viwa, the various family or kinship groups generally garden on their land. It is also normal practice for others in the village who do not have any rights to land close to the village in which they reside to request the use of other people's land. Although the land on the island of Viwa has been registered under the ownership of the various social units such as the <u>yavusa</u> and the <u>mataqali</u>, generally the Fijian traditional concept of land use known as <u>kana veicurumaki</u>, whereby others can use other people's land for their sustenance, is still generally practiced for the sake of maintaining the <u>vanua</u> (people and their customary practices and expectations).

Communal or village togetherness is often expressed in the principle of "share and care" where the concern for others are emphasized. The possibility of using other people's land for family sustenance and the share and care principles are today somewhat affected negatively by population pressure and monetary economy.

Landowners at times are not so willing to let other people use their land if they perceive the economic advantages the other users are likely to gain from such usage. Nevertheless a family could continue to use such land without much difficulty if it is using it only for subsistence.

There is also the problem of population pressure on the use of land. Some groups have a very inadequate area of good gardening land for their members. Not enough land is available to everyone in the village to garden upon. This somewhat limits access to the use of other people's land and also restricts the time period a piece of land is let out to other non-land owners to use.

The utilization of marine resources including deep sea fishing is still generally open to all members of the two villages. This is, however, also suffering from exploitation through the use of new fishing technologies such as large nylon nets and dynamite which exploit the resource faster than it can be replaced by the normal or natural regeneration process. Unless proper management is taken, the regular and frequent marketing of marine resources can also lead to the depletion of the supply. This major food source will be more vulnerable in the not too distant future.

No national initiatives affect this area.

5.4.7. Economic elements

Apart from trying to continue with a subsistence mode of living from their inadequate land and sea resources, the people of Viwa also participate in the market economy, subsidizing and supplementing their somewhat erratic means of subsistence living. Increasingly the major sources of subsistence such as fish and food crops such as plantain and cassava are being sold for cash. Cash is generally required for the satisfaction of new wants and aspirations in life. Although such developments in some ways lessen the dependency of the people on the few food crops which they can grow on the island and which are often susceptible to physical disasters such as hurricanes and high storm surges and droughts, it also increases the dependence of the Viwa people on outside sources over which they have little control.

This would definitely increase their vulnerability in the future, in particular when the market economy fails to perform to their advantages and expectations. Because they have little control over it, they will become more helpless and dependent on outside resources and assistance.

Increase in cash demands for the satisfaction of their new lifestyle and eating habits has forced a good number of young men and women of Viwa to look for wage employment on the mainland of Viti Levu and some of the island resorts within the Yasawa and Mamanuca groups of islands.

The limitation of natural resources on Viwa island, and its lack of fresh water, limit the possibility of making any effort at developing and diversifying the economic base of the inhabitants. Even the rather scarce subsistence sources for livelihood have also been sold at the mainland markets for cash. This is then expended on manufactured foodstuffs such as flour, biscuits, rice and sugar, for instance. Such manufactured food can be kept longer than root crops which are usually susceptible to droughts, hurricanes, and storm wave surges.

Coconut, breadfruit, and dawa (Pometia pinnata) tree crops are as yet to fully revive from the damages of the last hurricane 11 months ago. There were hardly any fruits on these tree crops at the time of the study (November 1993).

Viwa, in general, has limited economic activity, and its inhabitants will increasingly depend more on outside sources and assistance.

5.4.8. Cultural elements

The people of Viwa are structured into kin groups known as yavusa and its small sub-unit known as mataqali. Each yavusa has its own land, and such land is subdivided into allotments for the mataqali unit. Land is thus communally owned by the yavusa with its mataqali becoming the land-owning unit. Each household or family has its own gardening sites upon which the members grow their food crops such as vudi (plantain) and cassava. The members of the yavusa and the mataqali are distributed in the two main villages of Naibalebale and Natia; a few members of the yavusa Namatoka are still residing at Yakani.

Each yavusa is headed by a chief, and each mataqali by a sub- chief. Each household is normally under the control of the most senior male member of the family, usually the father. The society continues to be male-dominant although women have increasingly participated in decision-making processes such as the village council.

The wide network of kinship relations is an important element influencing how decisions are made in relation to social, economic, religious and political activities. Individualism is still very much suppressed and consensus by the majority is normally the ideal way of initiating village or communal activities. Individual rights per se have to be curtailed for the sake of maintaining communal rights and togetherness. It is the existence of this very important cultural principle, and of course others, that will make this culture less vulnerable than many other cultures to changes caused by sea-level rise and other physical disasters.

5.4.9. Response options

There is little that could be done entirely within the island of Viwa to satisfactorily preserve its present lifestyle and so to protect it from being badly affected by future physical disasters in terms of sea-level rise and high storm wave surges. Given the limitation of land area together with its almost flat nature, very thin soil covering and lack of fresh water, the only other option for the people is to depend increasingly on outside resources, relief and other forms of assistance.

Migration to and resettlement on other larger islands in the Fiji group cannot be ruled out as an option. Migration to the urban centres of the mainland of Viti Levu has already been the trend. During one of the worst hurricanes of the early 1930s, a number of people from Viwa were removed and settled in Nadroga on the south-western coast of Viti Levu. Today, Viwa people are to be seen working and living in Lautoka, Nadi and Suva. Migration to the urban centres both for wage employment and seeking better opportunities in improving one's life is not unique to Viwa but also to other small islands in Fiji. Viwa, however, would be more affected by such outward migration than other islands in the Fiji group owing to its lack of adequate natural resources to sustain its increasing population.

One of the difficulties of taking the option of migrating and resettling in other islands is that of acquiring land from other indigenous landowners. The inflexible land-tenure system introduced for the Fijians provides little resilience to accommodate outsiders who do not have any rights to land in the locality where they have to be resettled. This has forced the people to stay where they are and where their rights to land are secured.

The other option of moving into urban areas allows for some opportunities for the migrants to acquire land and residences through purchase, lease, or rent, or just by squatting on crown or city council land. It also provides the new settlers with the opportunity to find wage employment. The option of moving into the urban centres is thus more attractive than settling down on other people's land.

Table 5.2. Viwa present day and future coastal system vulnerability and resilience components and sustainable capacity indices

Coastal systems	Coastal sub-systems	Vulnerability component	Resilience component	Sustainable capacity index	Vulnerability component		Resilience component		Sustainable capacity index	
Present day		present management regime	present management regime	present management regime	**Future** No management	Optimal management	No management	Optimal management	No management	Optimal management
Natural	physical	-1	+2	+1	-1	-2	+1	+2	0	0
	biological	-1	+1	0	-2	-1	0	+1	-2	0
Cultural	communal	-2	+2	0	-2	-2	+2	+2	0	0
	national	-1	0	-1	-1	-1	0	0	-1	-1
Institutional	village	-1	+2	+1	-2	-1	+2	+3	0	+2
	national	-3	+1	-2	-3	-3	+1	+1	-2	-2
Infrastructural	individual	-1	+2	+1	-1	-1	+3	+2	+2	+1
	communal	-2	+2	0	-2	-2	+2	+2	0	0
	national	0	+3	+3	0	0	+3	+3	+3	+3
Economic	subsistence	-3	+2	-1	-3	-2	+2	+2	-1	0
	cash	-1	0	-1	-1	-1	0	0	-1	-1
Human	populations	-1	+1	0	-1	-1	+2	+2	+1	+1
Average Sustainable Capacity Index										

Chapter 6. Impact Assessment of Sea-Level Rise on Port Facilities in Fiji

The port facilities in Fiji have important roles not only for international but also domestic transportation. Fiji lies at the heart of the South Pacific, and serves as the international crossroads for shipping services among Western and Southern Hemisphere countries. In recent years, tremendous developments have taken place in Fiji's ports as the nation has grown economically. It has made the role of Fiji's ports more important. From the domestic point of view, as Fiji is made up of 332 islands of varied sizes, marine transportation systems play extremely important roles for people's lives and in economic activities.

The IPCC predict that, as a result of global warming, sea level will rise relative to its 1990 level by an average of 46 cm by 2100 (IS92a BEST scenario) which means 51 cm for Fiji (see section 3.4.1. and Figure 3.5). Global warming will also cause climate changes, such as changes of precipitation, tidal wave and the power of cyclones. Such sea-level rise and climate change are anticipated to have adverse impacts on coastal zone, where a lot of natural and human activities are taking place.

Port facilities are one of the important types of infrastructure which may be affected by sea-level rise. In particular, the impacts on the port facilities in Fiji may be very serious for the above-mentioned reasons.

In this section, Suva and Lautoka ports are selected as case study sites since they are the most important international and domestic ports. First of all, the present conditions of those two port facilities are examined. After that, the future impacts of sea-level rise on them are investigated through qualitative and quantitative analysis.

6.1. Impact of sea-level rise on Suva Harbour, Fiji

6.1.1. Introduction

Suva, housing Fiji's largest port, is situated on the southeast coast of Viti Levu. The city is the centre of government and commerce with a population of approximately 160,000 in 1988, around 20% of the entire population of Fiji.

The port of Suva and other commercial vessel facilities were developed in Suva Harbour because of the favourable natural environmental conditions, primarily the sheltered harbour, well protected from prevailing southeast to east winds, natural deep water access with plenty of room for maneuvering, and protection from deep-water and/or large amplitude waves by the barrier reef. Wave conditions in the harbour are extremely mild, and there are no strong currents. This is an ideal anchorage. While conditions for vessel berthing and mooring are good, the geotechnical aspects of many waterfront structures are poor. For most of Suva's history, development was piecemeal and it is only in recent decades that specific zones have been allocated for medium and/or heavy industrial use.

The active area of the Port of Suva extends from Nabukalau Creek adjacent to the Suva Market to the Royal Suva Yacht Club, near the northern boundary of the city. The full length of this foreshore is occupied by marine-oriented activity, shipping and small craft, and associated facilities.

Suva Port handled about 618,000 tonnes of cargo in 1990 compared to about 576,000 tonnes in 1989 (figures exclude petroleum products and other liquids). Cruise vessel visits were 23 in 1990 and 34 in 1989.

The specific study sites in this part extend from the new reclamation site next to the Bowling Club to the Royal Suva Yacht Club and the Rokobili Container Depot and associated reclamation scheme.

6.1.2. Bathymetric conditions

Marine and bathymetric charts are shown in Figures 6.1 and 6.2.

6.1.3. Existing facilities

Sections of existing facilities at Suva Harbour are shown in Figure 6.3.1, 6.3.2.

6.1.4. Impact of sea-level rise on port facilities and protection facilities

Generally speaking, sea-level rise may cause physical changes one after another on the coastal zone which might have serious impacts on port facilities and port-protection facilities. An impact propagation diagram (Mimura et al., 1990) is shown in Figure 6.4. This diagram shows how the impacts which begin at sea level change the physical phenomenon in the coastal zones, and spread to harbours, rivers and structures on the coasts.

6.1.5. Wave study

In order to evaluate the impact of sea-level rise at the locations shown on Figure 6.5 inside Suva harbour, firstly the deepwater wave condition and the design water level have to be set. Secondly, considering wave propagation, wave heights (equivalent deepwater wave height Ho' and significant wave height H1/3) have to be calculated. In the following sub-sections, estimation of the deep wave condition as well as the design water level for a return interval (RI) of fifty years is presented, followed by wave height estimation.

a. Deep water-Wave Condition (Ho, To)

Deepwater wave height (Ho) and wave period (To) were given by Carter (1990) as follows.

Ho = 7.8 m, To = 10.7 sec

These values will be adopted here. Equivalent deepwater wave height in front of Reef H'OR is needed to estimate the wave height over the reef and then the transmitted wave inside Suva harbour. It is calculated by multiplying the deepwater wave height Ho by refraction coefficient Kr. The refraction coefficient Kr is assumed to be 0.9, the same as given by Carter (1990), then

H'OR = Kr Ho = 7.0 m

b. Design Water Level (D.W.L)

The Design Water Level (D.W.L) at Suva harbour is estimated as follows.

Design Water Level (D.W.L) =

C.D+Astronomical Tide+ η Storm Surge+ η Wave + Setup on Reef

I Chart Datum (C.D) = $\pm$ 0.0

II Astronomical Tide
Mean High Water Springs (M.H.W.S) = + 1.6 m

III Storm Surge (ηs)

ηs = water level rise due to barometric pressure drop($\Delta\eta_B$)+ wind setup($\Delta\eta_w$)

III-1 $\Delta\eta_B \approx 0.6$m

III-2 $\Delta\eta_w \approx 0.2$m

IV Wave Setup on Reef(η_R)

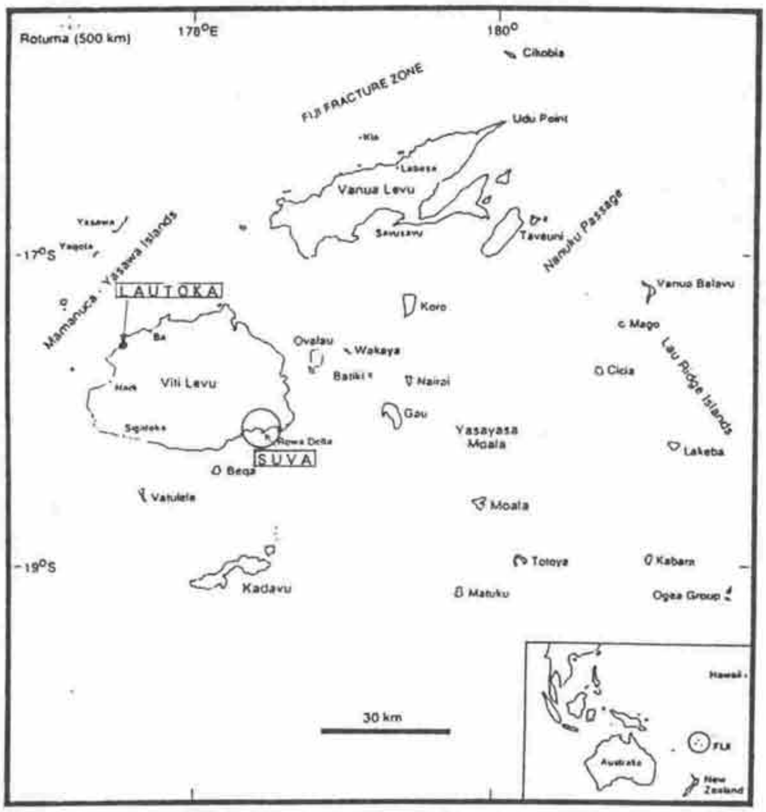
With the equivalent wave height in front of reef H'_{OR} = 7.0 m and wave period To = 10.7 sec. and using the following graph (Figure 6.6 - after Goda, 1975) for i=1/10.

$\therefore$ η_R = 1.20 m

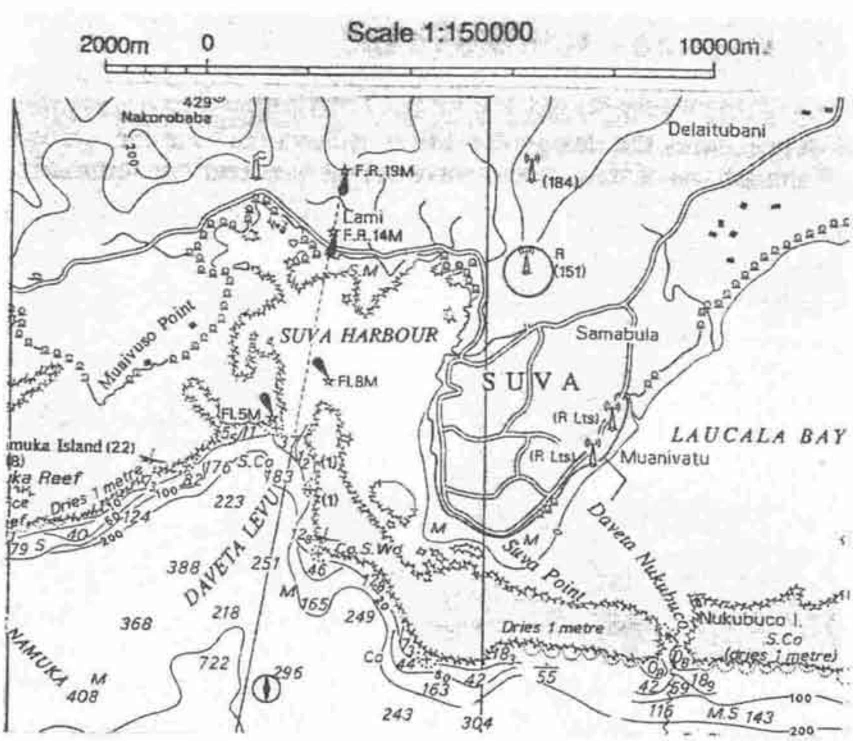
This value and due to return flow will be reduced by about 50% inside Suva harbour to be 0.6 m. Thus

D.W.L = 1.6 + 0.8 + 0.6 = 3.0 m above C.D.

Table 6.1 summarizes the design condition at Suva harbour for a return period of fifty years. Calculations of transmitted wave height over reef are summarized in Table 6.2.



Location map



Marine chart

Figure 6.1. a. Location map
b. Marine chart

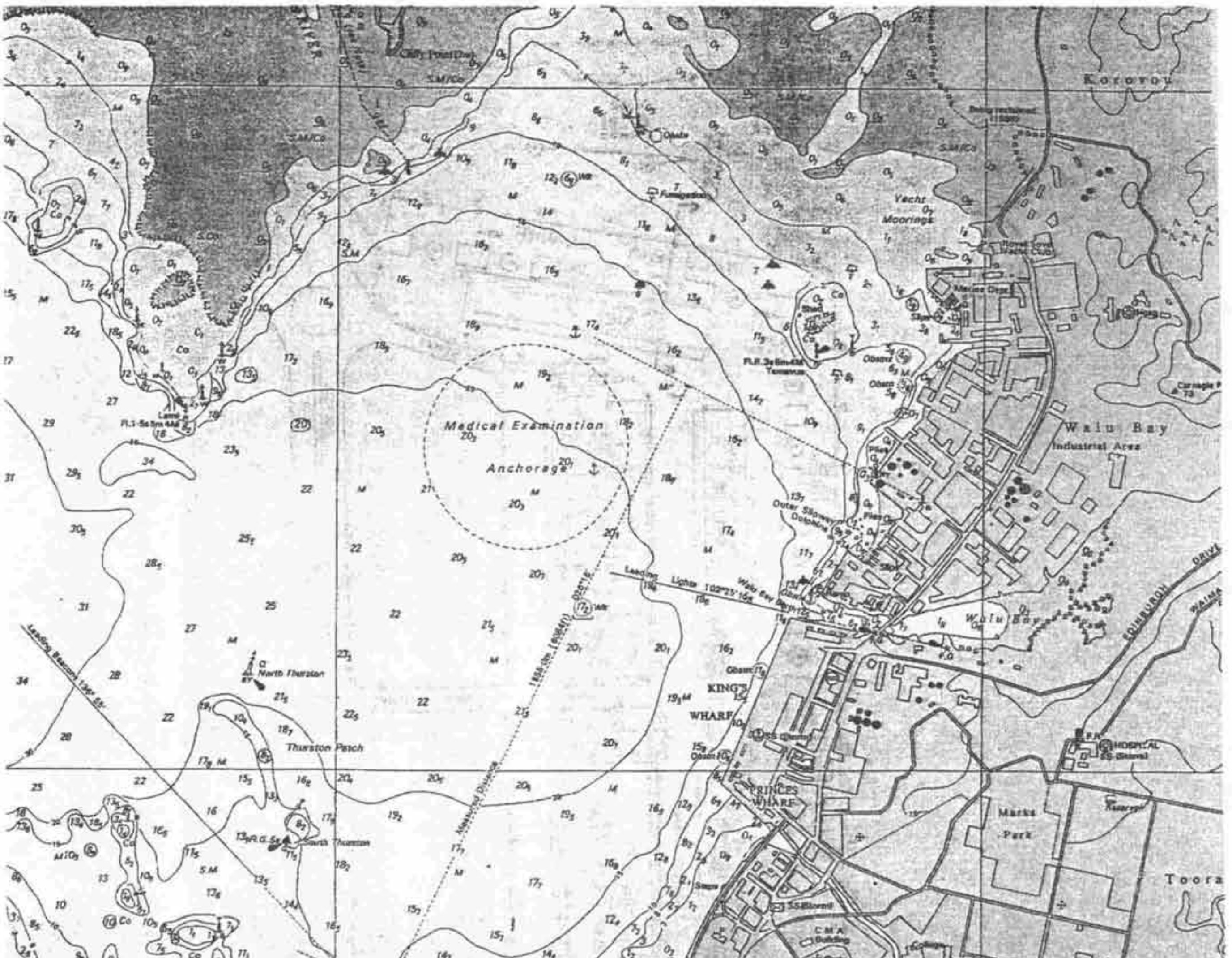


Figure 6.2. Bathymetric conditions

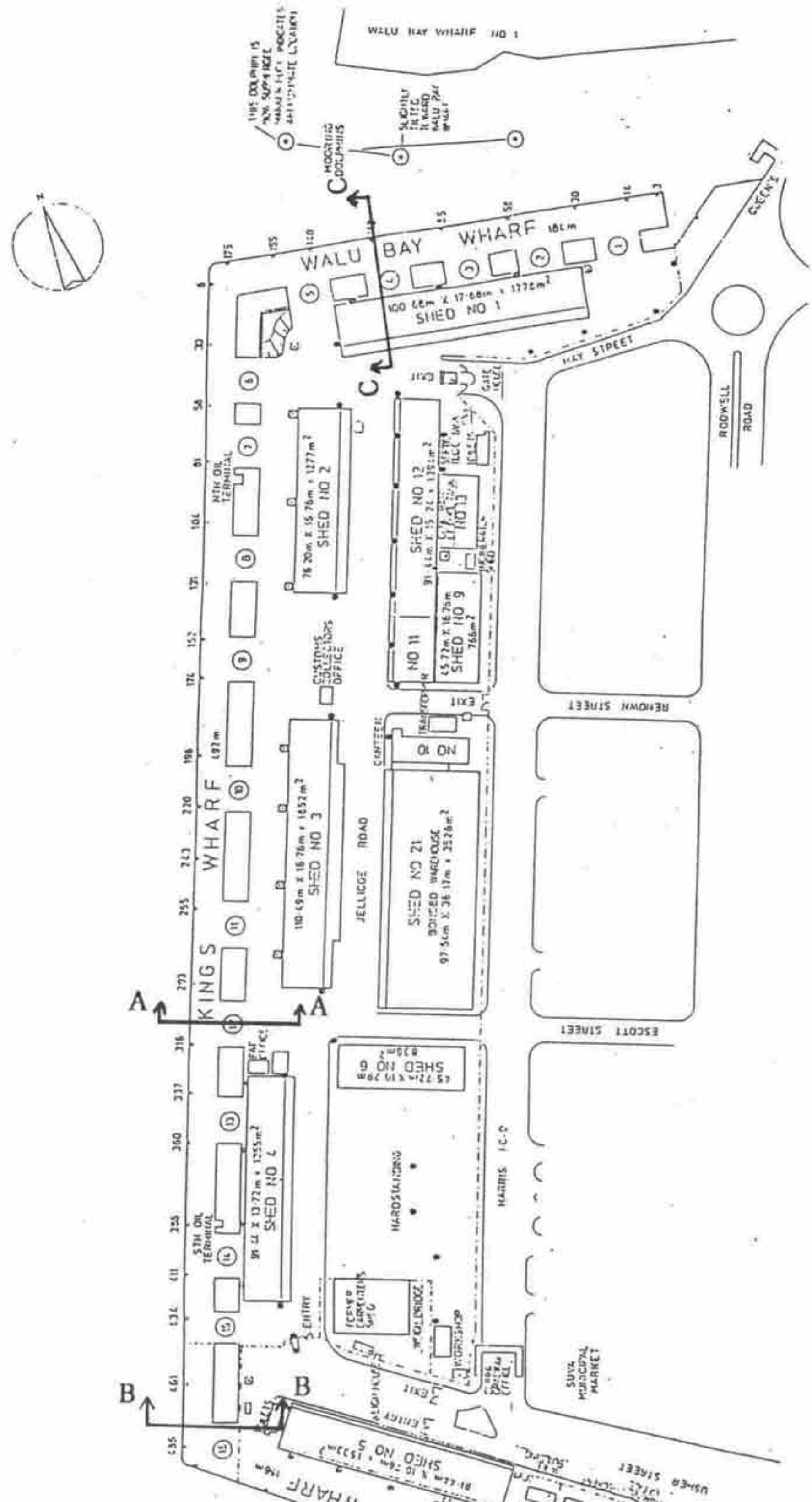
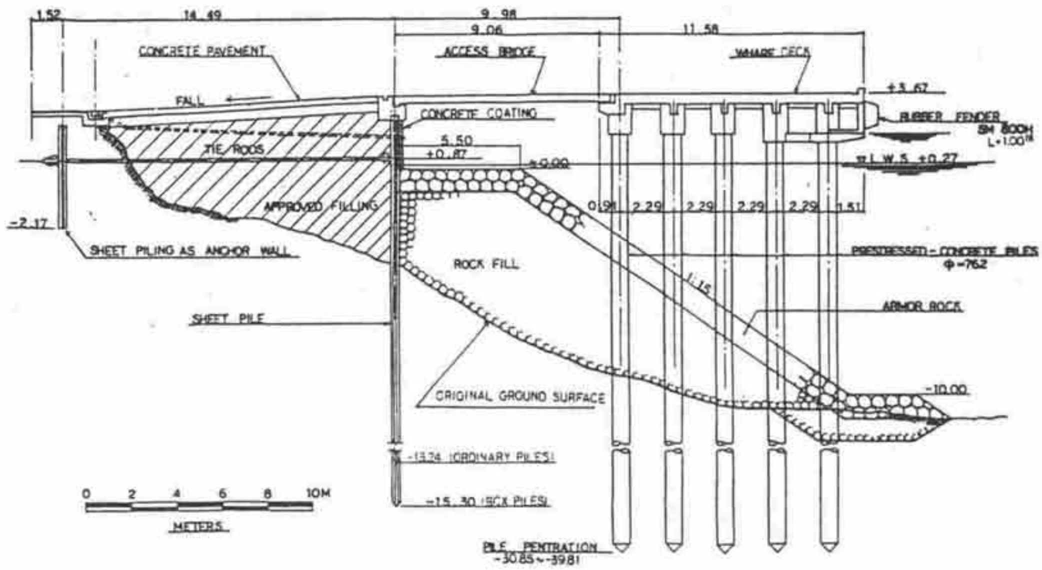
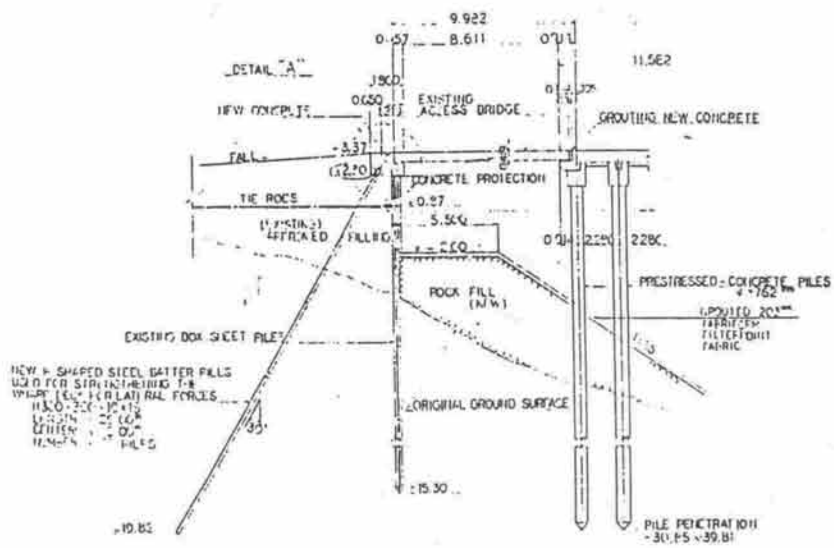


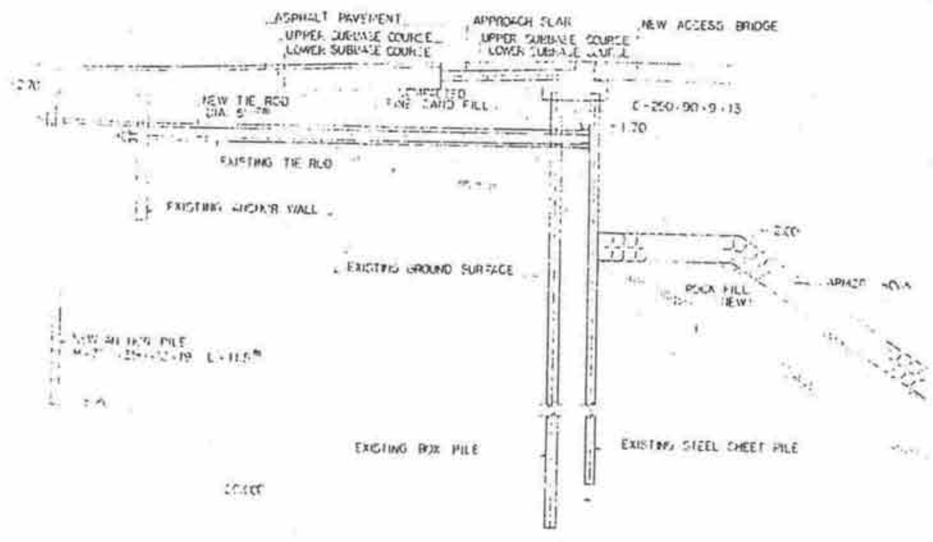
Figure 6.3.1. Existing facilities at Suva Port (1)



Section A − A

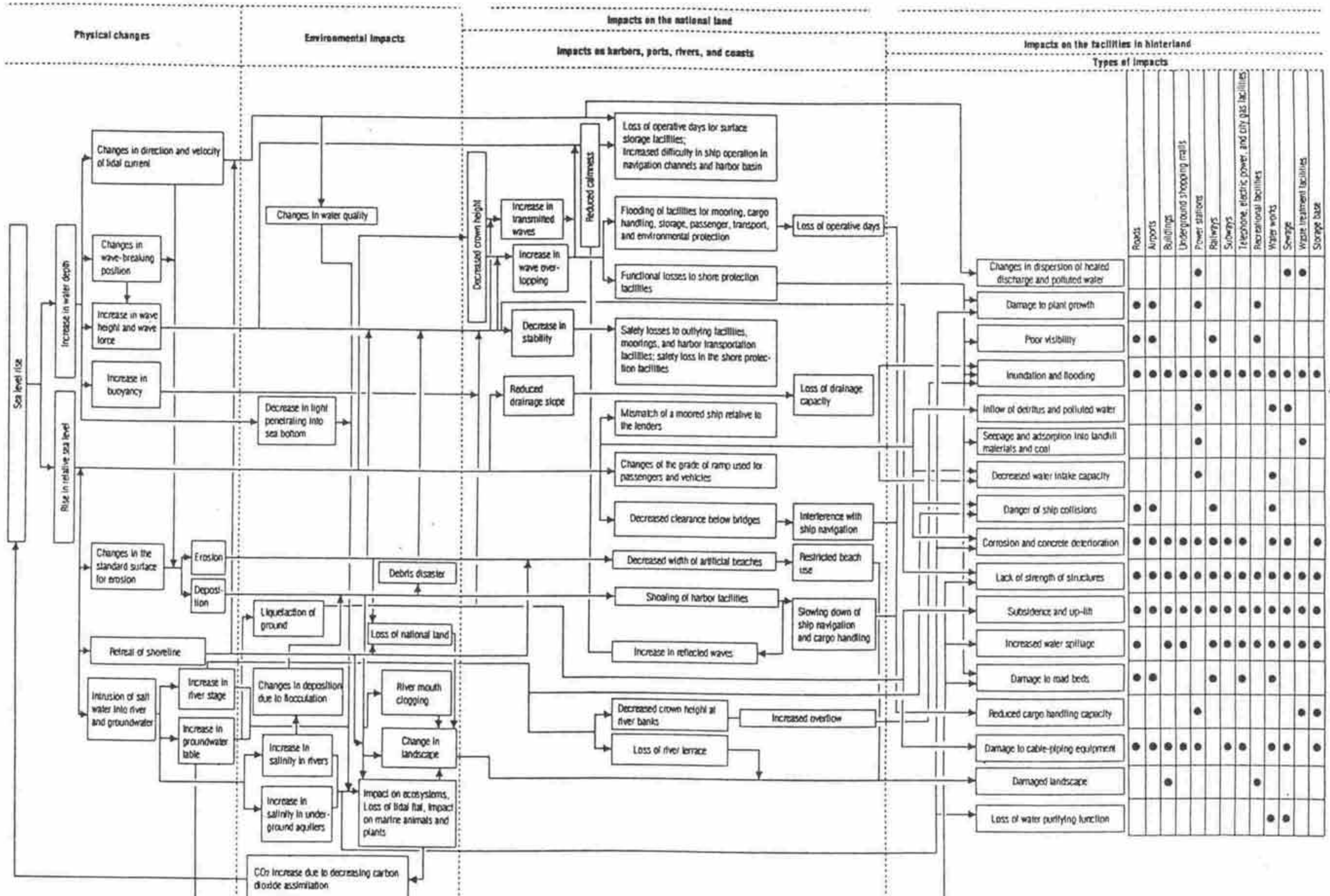


Section B − B



Section C − C

Figure 6.3.2. Existing facilities at Suva Port (2)



Note: This figure was made based on the Ports and Harbors Bureau, the Ministry of Transport (1991)

Figure 6.4. Propagation of impacts induced by sea level rise

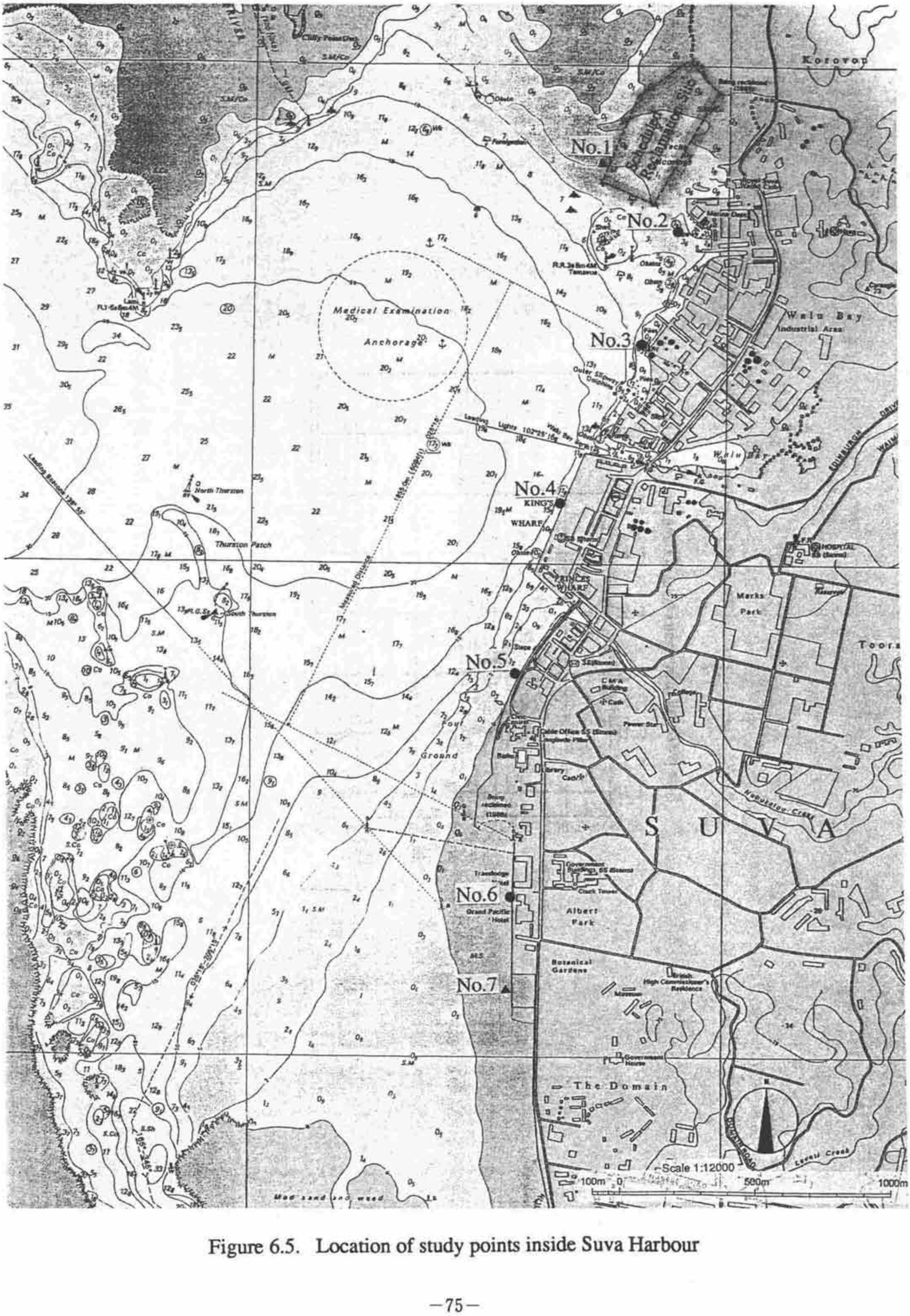


Figure 6.5. Location of study points inside Suva Harbour

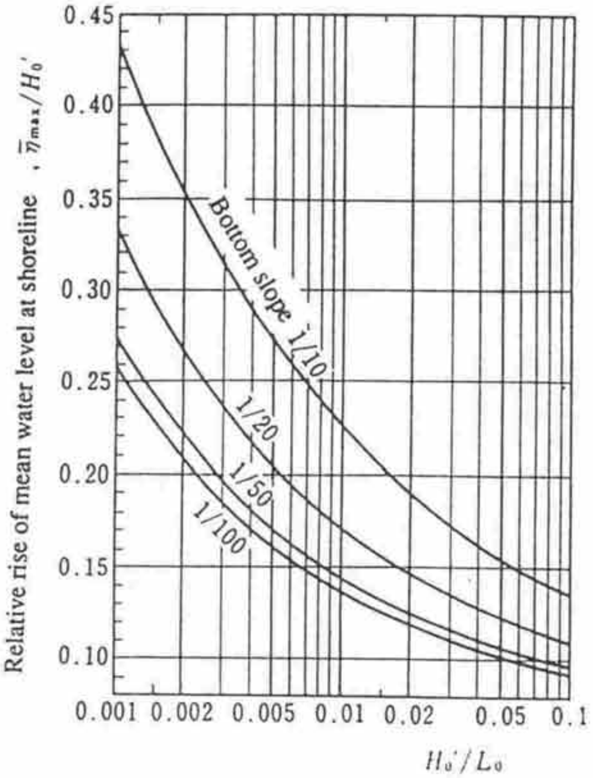


Figure 6.6. Relative rise of mean water level at shoreline

Table 6.1. Suva Port design conditions

Return Period RI	RI = 50 years	
Astronomical Tide	M.H.W.S. +1.6m M.L.W.S +0.3m C.D ±0.0m	Fiji Nautical Almonac (1994)
Storm Surge	Barometric Tide $\Delta\eta_B = 0.6m^{*1}$ Wind Set – up $\Delta\eta_w = 0.2m^{*2}$ total $\Delta\eta_S = 0.8m$	*1: Given by Carter (1990) *2: Carter (1990) gave 0.08～0.18m ↓ we set 0.2m
Wave Set-up on Reef	$\Delta\eta_R = 0.6m$	*: Calculate from Equivalent deep water wave Ho'R, To by Goda (1975)'s Diagram and ×50% Ho'R/Lo = 0.039 $\overline{\eta}_{R\,max}$ / Ho' R = 0.16 (using bottom slope = 1/10) $\overline{\eta}_{R\,max} = 0.16 \times 7.0$ $= 1.12$ m ↓ ×50% $\Delta\eta_W = 0.56$ m ≒0.6m
Design Water Level D.W.L	M.H.W.S + $\Delta\eta_S + \Delta\eta_R$ C.D + 3.0m	
Design Wave	Offshore wave $Ho = 7.8m^{*1}$ $To = 10.7 sec$ Equivalent deep water wave height Ho' in front of Reef $Ho'_R = Kr \cdot Ho$ $= 0.9 \times 7.8^{*2}$ $= 7.0m$	*1: Given by Carter (1990) *2: Refraction Coefficient Kr=0.9: given by Carter (1990)

Table 6.2. Calculation of transmitted wave height across the reef (Ht)

Formula for wave deformation on Reef given by Egashira et al. (1985)

$$\frac{Hx}{Ho'} = B\exp\left\{-A\left(\frac{x}{Ho'}\right)\right\} + \alpha\frac{(ho+\overline{\eta}_\infty)}{Ho'}$$

$$\alpha = \begin{cases} 0.202 & \text{for } 4m > Ho' \geqq 2m \\ 0.332 & \text{for } Ho' \geqq 4m \end{cases}$$

$$A = 0.089\,(Ho'/h_2) + 0.015$$

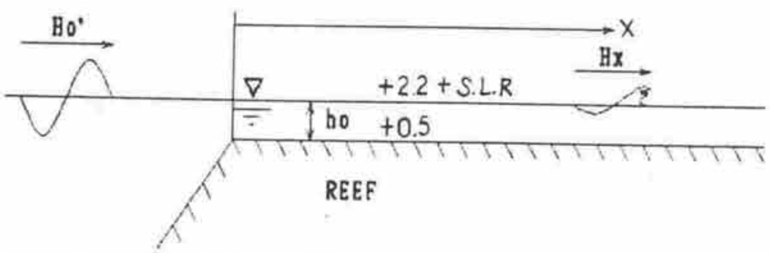
$$h_2 = ho + \overline{\eta}_\infty$$

$$B = \min(B_1, B_2)$$

$$B_1 = 0.639\,(h_2/Ho') + 0.147$$

$$B_2 = -0.200\,(h_2/Ho') + 1.248$$

Hx : Wave height distance xm from reef edge.
Ho' : Equivalent deep water wave height
ho : Still water depth on reef
$\overline{\eta}_\infty$: Wave set-up at x = ∞ (estimated by Goda (1985)'s diagram)



Calculation Condition

○ Incident wave : Ho'_R = 7.0 m, T = 10.7 sec

○ Reef : Width : x = 500 m (width = 500~1500m →take minimum value 500m)
Level of top of Reef : C.D + 0.5 m (assumed)

○ Still water level : M.H.W.S + Barometric tide + Sea level rise η_{SLR}

$$= 1.6m + 0.6m + \eta_{SLR}$$

$$= C.D + 2.2m + \eta_{SLR}$$

○ Still water level : M.H.W.S + Barometric tide + Sea level rise η_{SLR}

○ $\overline{\eta}_\infty = 1.12m$: $Ho'_R/Lo = 0.39 \rightarrow \overline{\eta}_\infty = 1.12m$ (by Goda (1975)'s diagram)

Calculation of Ht

Sea level rise η_{SLR} (m)	Ho'_R (m)	ho (m)	$\overline{\eta}_\infty$ (m)	h_2 (m)	α	Width of reef X (m)	Transmitted wave height Ht (m)
0.0	7.0	1.7	1.12	2.82	0.332	500	0.9
0.5	7.0	2.2	1.12	3.32	0.332	500	1.1
1.0	7.0	2.7	1.12	3.82	0.332	500	1.3

c. Wave Heights Estimation

Once the equivalent deepwater wave condition in front of Reef H'OR and the design water level have been set, transmitted wave height (Ht) as well as the transmitted wave period (Tt), are estimated for different values of the sea-level rise. Wind waves generated inside Suva harbour are assumed to be as given by Carter (1990). Equivalent deepwater wave height Ho' at the study points will result from the combination of both transmitted waves Ht and wind waves Hw. Table 6.3 summarizes the equivalent deepwater wave height Ho' calculations inside Suva harbour.

Significant wave heights H1/3 are estimated for different values of the sea-level rise (S.L.R.). Significant wave heights will be used to check the impact of sea-level rise on the stability of various coastal structures. Meanwhile, equivalent deepwater wave heights will be used to estimate its impact on wave run-up at different locations inside Suva harbour. Figure 6.7 illustrates the wave propagation procedure used in this study.

The change of significant wave height H1/3 at different locations owing to sea-level rise is given in Figure 6.8. Figure 6.9 presents the increase ratio in H1/3 owing to sea-level rise.

Results of wave calculations at the specified points inside Suva harbour are summarized in Table 6.4.

6.1.6. Study on revetment crown height

The impact of sea level rising by 0.5m and 1.0m on the present crown height is reviewed here. Crown height of the existing revetments was obtained by site survey.

Study points along Suva Port area are selected depending on the land use of the hinterland, and they are shown on Figure 6.5.

Summary of crown heights of existing revetments, water level at HWL, storm surge, sea-level rise and incident waves at the study points is shown in Table 6.5.

Even disregarding future sea-level rise, current crown height of revetments is insufficient. For example, the following calculations were made on wave run up without considering effects of sea-level rise:

1) Ho = 1.70 m, Lo = 1.56 To^2 =1.56 x $(5.0)^2$ = 39.0m
   Ho/Lo = 0.044
   h/Lo = 0.064
   Bottom Slope = 1:2
   R/Ho = 2.05
   R = 2.05 x 1.70 = 3.49 m
   Run-up Height = DL + 3.00 + 3.49 m = 6.49m
   (Near Travelodge, Reclamation Area)

2) Ho = 2.50 m, Lo = 1.56 To^2 =1.56 x $(5.6)^2$ = 48.9m
   Ho/Lo = 0.051
   h/Lo = 0.102
   Bottom Slope = 1/20
   R/Ho = 1.60
   R = 1.60 x 2.50 = 4.00 m
   Run-up Height = DL + 3.00 + 4.00 m = 7.00 m
   (Near Scheduled Reclamation Area)

The equivalent numbers after sea-level rise are shown below:

1) Sea Level Rise by 0.50 m
   Ho = 1.90 m, Lo = 1.56 To^2 =1.56 x $(5.3)^2$ = 43.8 m
   Ho/Lo = 1.90/43.8 = 0.043
   h/Lo = 0.068
   R/Ho = 1.90
   R = 1.90 x 1.90 = 3.61 m
   Run-up Height = DL + 3.50 + 3.61 m = 7.11 m

2) Sea Level Rise by 1.0m
   Ho = 2.0 m, Lo = 1.56 To^2 =1.56 x $(5.6)^2$ = 48.9m
   Ho/Lo = 2.00/48.9 = 0.041
   h/Lo = 0.072
   R/Ho = 1.90
   R = 1.90 x 2.0 = 3.80 m
   Run-up Height = DL + 4.00 + 3.80 m = 7.80 m
   (Near Travelodge, Reclamation Area)

From the above results, the change in run-up height (R) due to sea-level rise is about 10% at least in these two locations.

Table 6.3. Calculation of design wave at Suva Port

Point		Sea level rise	Wind wave in harbor		Reef's transmission wave		Composed Wave	
		η_{SLR} (m)	Hw (m)	Tw (sec)	Ht (m)	Tt (sec)	Ho' (m)	T (sec)
1	Reclamation Site A	0.0	2.3	5.3	0.9	7.5	2.5	5.6
		0.5			1.1	7.5	2.5	5.7
		1.0			1.3	7.5	2.6	5.8
2	Yacht Club	0.0	2.3	5.3	0.9	7.5	2.5	5.6
		0.5			1.1	7.5	2.5	5.7
		1.0			1.3	7.5	2.6	5.8
3	Shell Oil	0.0	2.1	4.9	0.9	7.5	2.3	5.3
		0.5			1.1	7.5	2.4	5.5
		1.0			1.3	7.5	2.5	5.6
4	Kings Wharf	0.0	1.9	4.6	0.9	7.5	2.1	5.1
		0.5			1.1	7.5	2.2	5.3
		1.0			1.3	7.5	2.3	5.5
5	YWCA	0.0	1.7	4.2	0.9	7.5	1.9	4.9
		0.5			1.1	7.5	2.0	5.2
		1.0			1.3	7.5	2.1	5.4
6	Travellodge Hotel	0.0	1.5	4.1	0.9	7.5	1.7	5.0
		0.5			1.1	7.5	1.9	5.3
		1.0			1.3	7.5	2.0	5.6
7	Reclamation Site B	0.0	1.5	4.1	0.9	7.5	1.7	5.0
		0.5			1.1	7.5	1.9	5.3
		1.0			1.3	7.5	2.0	5.6
Remark			*Point No.2, 5, 6 are given by Carter (1990), others are estimated by interporation		Table 2-2		$H'o = \sqrt{Hw^2+Ht^2}$ $T = \frac{Hw^2Tw+Ht^2Tt}{Hw^2+Ht^2}$	

Table 6.4. Calculation of $H_{1/3}$ at Suva Harbour

· Design water level : C.D + 3.0 m

	Point	Bottom level (C.D m)	Bottom slope tan β	Ho' (m)	Ho'/Lo	Sea level rise $\overline{\eta}_{SLR}$ (m)	depth h (m)	h/Ho'	h/Lo	$H_{1/3}$/Ho'[*1]	$H_{1/3}$ (m)
1	Reclamation Site A	-2.0	1/50	2.5	0.051	0.00	5.00	2.00	0.102	0.90	2.25
				2.5	0.049	0.50	5.50	2.20	0.109	0.91	2.28
				2.6	0.050	1.00	6.00	2.31	0.114	0.91	2.37
2	Yacht Club	-2.0	1/50	2.5	0.051	0.00	5.00	2.00	0.102	0.90	2.25
				2.5	0.049	0.50	5.50	2.20	0.109	0.91	2.28
				2.6	0.050	1.00	6.00	2.31	0.114	0.91	2.37
3	Shell Oil	±0.0	1/10	2.3	0.052	0.00	3.00	1.30	0.068	0.98	2.25
				2.4	0.051	0.50	3.50	1.46	0.074	1.00	2.40
				2.5	0.051	1.00	4.00	1.60	0.082	1.00	2.50
4	Kings Wharf	-12.0	1/10	2.1	0.052	0.00	15.00	7.14	0.370	0.97[*2]	2.04
				2.2	0.050	0.50	15.50	7.05	0.354	0.97[*2]	2.13
				2.3	0.049	1.00	16.00	6.96	0.339	0.96[*2]	2.21
5	YWCA	-1.0	1/50	1.9	0.051	0.00	4.00	2.11	0.107	0.90	1.71
				2.0	0.047	0.50	4.50	2.25	0.107	0.92	1.84
				2.1	0.046	1.00	5.00	2.38	0.110	0.92	1.93
6	Travellodge Hotel	+0.5	1/100	1.7	0.044	0.00	2.50	1.47	0.064	0.81	1.38
				1.9	0.043	0.50	3.00	1.58	0.068	0.84	1.60
				2.0	0.041	1.00	3.50	1.75	0.072	0.88	1.76
7	Reclamation Site B	+0.5	1/100	1.7	0.044	0.00	2.50	1.47	0.064	0.81	1.38
				1.9	0.043	0.50	3.00	1.58	0.068	0.84	1.60
				2.0	0.041	1.00	3.50	1.75	0.072	0.88	1.76

Remarks *1 : estimate by Goda (1975)

*2 : Shoaling coefficient.

Table 6.5. **Summary of crown heights of existing revetments, water level at HWL, storm surge, sea-level rise and incident waves in Suva Port**

Point	Tide				Water Level	Wave		Crown Height
	Astronomical Tide	Storm Surge	Wave Set-up	Sea Water Level Rise		Height ($H_{1/3}$)	Period	
1	MHWS =+1.60	0.80	0.60	0.0 0.5 1.0	+3.0 +3.5 +4.0	2.25 2.28 2.37	5.6 5.7 5.8	+3.20
2				0.0 0.5 1.0	+3.0 +3.5 +4.0	2.25 2.28 2.37	5.6 5.7 5.8	+2.79
3				0.0 0.5 1.0	+3.0 +3.5 +4.0	2.25 2.40 2.50	5.3 5.5 5.6	+2.81
4				0.0 0.5 1.0	+3.0 +3.5 +4.0	2.04 2.13 2.21	5.1 5.3 5.5	+2.48
5				0.0 0.5 1.0	+3.0 +3.5 +4.0	1.71 1.84 1.93	4.9 5.2 5.4	+3.22
6				0.0 0.5 1.0	+3.0 +3.5 +4.0	1.38 1.60 1.76	5.0 5.3 5.6	+2.44
7				0.0 0.5 1.0	+3.0 +3.5 +4.0	1.38 1.60 1.76	5.0 5.3 5.6	+2.55

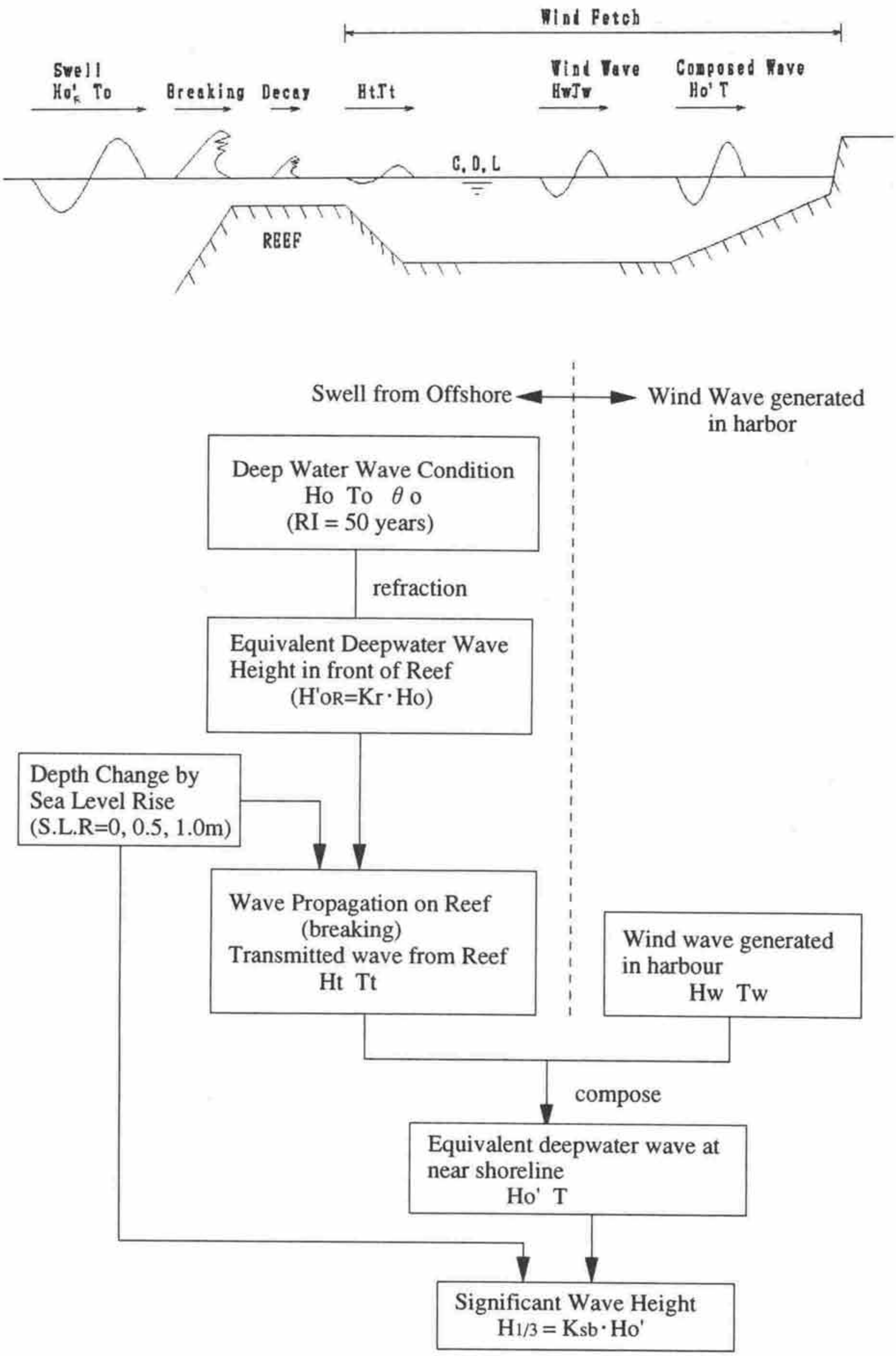


Figure 6.7. Flow chart of wave calculation procedure

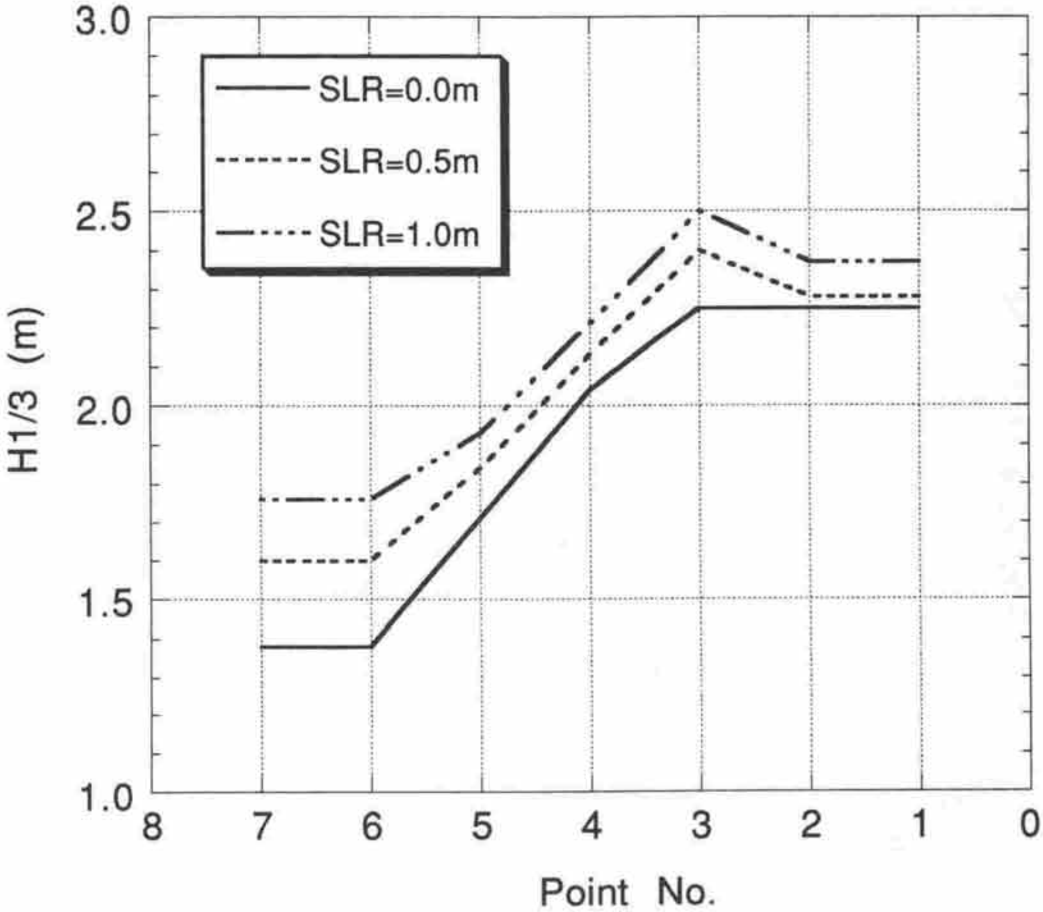


Figure 6.8. Change of $H_{1/3}$ due to sea level rise

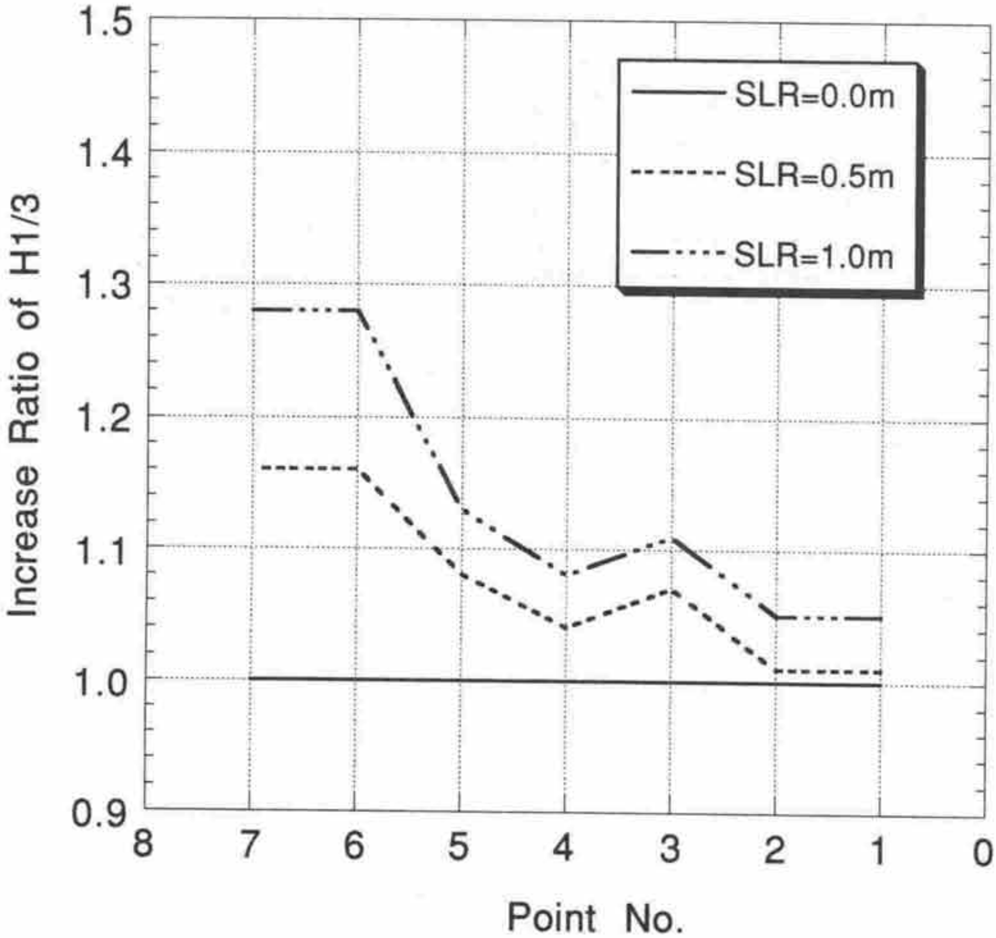


Figure 6.9. Increase Ratio of $H_{1/3}$ due to sea level rise

6.1.7. Study on revetment stability

An increase of water depth caused by sea-level rise leads to an increase of wave height. Thus there will be a problem of increasing structural instability as a result of increasing wave force in the future.

The revetments of reclamation areas in Suva Harbour are made of stone masonry. It is important for these structures to be armoured with heavyweight rocks in order to withstand increased wave height. In this study, therefore, a comparison was made using Hudson's formula in order to know how much weight of armour rock would be necessary, when sea level rises 0.5 m and 1 m, for stone masonry revetments.

a. Revetment of stone masonry type

(1) Study points

The existing reclamation area has not yet been covered with armour rock. Therefore, in order to study the stability of revetments, two reclamation areas were selected along the Suva foreshore. Locations of study points 1 and 7 are shown in Figure 6.5.

(2) Condition of revetment

The following assumptions will be made:

Ground level of the revetment	: C.D + 0.0m
Slope of revetment	: 1: 2.5

(3) Condition of external forces

The present magnitude of external forces is calculated with water level (MHWS+ storm surge) and design wave height for a 50-years return period. Parameters are recalculated on the assumption that sea level will rise by 0.5m and 1.0m. Significant wave height for both cases has already been obtained by a wave study in section 6.1.5. The values are:

Design Water Level	: C.D+3.0m+sea-level rise
Design deep wave	: Ho=7.8m, T=10.7sec
Sea-level rise	: 0.5m, 1.0m

(4) Required stone weight

The required stone weight was computed by Hudson's Formula as follows:

$$W = \frac{W_r H^3}{K_D (S_r - 1)^3 \cot\theta}$$

where,

- W :Weight of armour unit in the primary cover layer
- Wr :Unit weight of armour unit (t/m^3)
- Sr :Specific gravity of armour unit = Wr/Ww
- Ww :Unit weight of water
- H :Design wave height at the structure site (m)
- θ :Angle of structure slope measured from horizontal in degrees
- KD :Stability coefficient that varies primarily with the shape of the armour units, roughness of the armour unit surface, sharpness of edges

Here, in order to minimize the probable damage of facilities, $K_D = 3.2$ has been used.

Probable Damage Rate	K_D
0 - 1%	3.2
1 - 5	5.1
5 - 15	7.2
10 - 20	9.5
15 - 40	12.8
30 - 60	15.9

Calculations for the required weight were made before and after the sea-level rise, and results were compared.

(5) Calculation results

Table 6.6 shows the calculated results in case of the present condition, and then after sea level rises by 0.5m and 1.0m. It also includes required stone weight at each study point.

Table 6.6. Computation of armour rock weight

	No.1 Scheduled Reclamation Area		No.7 Existing Reclamation Area	
	$H_{1/3}$ (m)	W (t)	$H_{1/3}$ (m)	W.(t)
Present Condition	2.25	0.98	1.38	0.23
After 0.5m Sea level rise	2.28	1.02	1.60	0.35
After 1.0m Sea level rise	2.37	1.14	1.76	0.47

6.1.8. Other points to be noted

The main facilities of Suva Port consist of Kings Wharf, Princes Wharf and Walu Bay Wharf. The crown height of all wharves has been set for +3.37 m. A comparison chart showing the relation between existing wharf structure, and still-water level, astronomical tide, storm surge, wave set up and sea-level rise is given in Figure 6.10.

As shown, wharves have a clearance of 1.3 - 0.8 m above M.H.W.S plus sea-level rise. Crown height of wharves will be overtopped only when sea level rises by 1.0m and Suva harbour is attacked by a 50-year return interval cyclone. There is a danger of flooding of the hinterland even without taking sea-level rise into account.

Wave-height increase following water-level rise will also affect the main wharves. Sea-level rise will bring about a decrease in the clearance between water level and the wharf superstructure, and increase the uplift force, which may lead to critical stress on existing facilities.

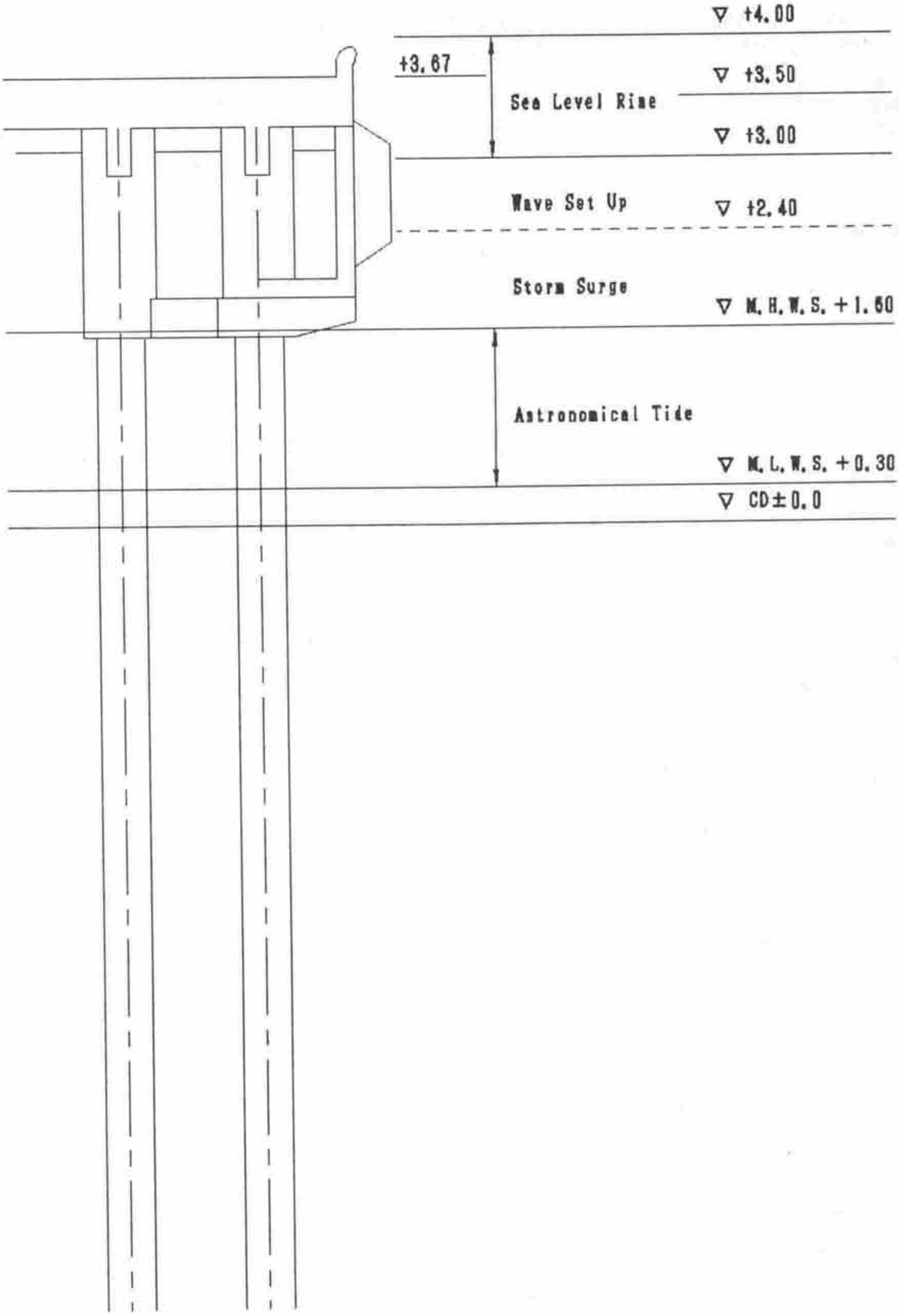


Figure 6.10. Relation between still water level and existing structure

Table 6.7. Lautoka Port design conditions

Return Period RI	RI = 50 years	
Astronomical Tide	M.H.W.S. +1.9m M.L.W.S +0.4m C.D ±0.0m	Fiji Nautical Almonac (1994)
Storm Surge	Barometric Tide $\Delta\eta_B = 0.6m^{*1}$ Wind Set – up $\Delta\eta_w = 0.3m^{*2}$ total $\Delta\eta_S = 0.9m$	*1: assume as same as Suva Port *2: Calculate from wind speed U, and Fetch and mean depth $\Delta\eta_w = K\frac{F}{h}U^2$ $k = 4.8 \times 10^{-2}$ $F = 11km$ $U = 44m/s$ $h = 30m$ $\Delta\eta_w = 34cm \fallingdotseq 0.3m$
Design Water Level D.W.L	$M.H.W.S + \Delta\eta_S$ $C.D + 2.8m$	
Design Wave	Offshore wave $Ho = 3.4m^{*1}$ $To = 5.4sec$ Wave direction WSW*2	*1: estimate from wind speed and effective Fetch by S.M.B method. F = 11km (JICA:1986) U = 44 m/s (using the diagram given by Carter (1990) for maximum wind speed in Fiji's 5 degree area.) *2: given by JICA (1986)

6.2. Impact of sea-level rise on Lautoka Harbour, Fiji

6.2.1. Introduction

Lautoka is the second largest port of entry in the country and handles the bulk of Fiji's sugar and timber exports. The port services the shipping needs of western Viti Levu and is an important base for local cruise vessels which ferry passengers to and from the many holiday resorts on offshore islands.

In addition to the wharf owned by the Ports Authority of Fiji (PAF), other port facilities include a number of privately owned terminals for the handling of petroleum, gas, bulk sugar, molasses and woodchips. PAF-owned facilities for handling of other cargoes and passengers remain unchanged since the construction of the main wharf in 1959-1961. Prior to this, all general cargo was handled through the Colonial Sugar Refining Co. Ltd. pier, which now belongs to the Fiji Sugar Corporation Ltd.

The new woodchip loader owned by Tropik Wood Industries Ltd. began operations in July 1987 and indications are that this new facility will boost port activities in the West.

In addition, the new Fishing Port completed in mid-1988, aided by Japanese Government, services the requirements of local fishermen.

Plans are now being considered for the upgrading and rehabilitation of cargo and passenger facilities at the port.

6.2.2. Bathymetric conditions

Marine and bathymetric charts are shown in Figures 6.11 and 6.12.

6.2.3. Existing facilities

Sections of existing facilities at Lautoka Fishing Port are shown in Figure 6.13.1.,6.13.2.

6.2.4. Wave study

In order to evaluate the impact of sea-level rise at the locations shown in Figure 6.14 at Lautoka port, firstly the deepwater wave condition and the design water level have to be set. Secondly, wave heights (equivalent deepwater wave height Ho' and significant wave height H1/3) are calculated. In the following sub-sections, estimation of the deep wave condition as well as the design water level for a return interval (RI) equal to fifty years are presented, followed by wave height estimation.

a. Deep water-Wave Condition

Deepwater wave height Ho and wave period To are calculated for a wind speed U with a return period RI = 50 years using the SMB method. Wind speed U for RI = 50 years was estimated using the diagram given by Carter (1990), which gives the return interval RI for given maximum wind speed in Fiji's 5 degree area. It was equal to 44 m/s. Wave direction and effective fetch F are set to be WSW and 11 km respectively (JICA, 1986).

b. Design Water Level (D.W.L)

The Design Water Level (D.W.L) at Lautoka is estimated as follows.

Design Water Level (D.W.L) =
C.D+Astronomical Tide+ η Storm Surge+ η Wave Setup on Reef

I Chart Datum (C.D) = ± 0.0

II Astronomical Tide
Mean High Water Springs (M.H.W.S) = + 1.9 m

III Storm Surge (η_s)

η_s = water level rise due to barometric pressure drop ($\Delta\eta_B$) + wind setup($\Delta\eta_w$)

III-1 $\Delta\eta_B \approx 0.6$m

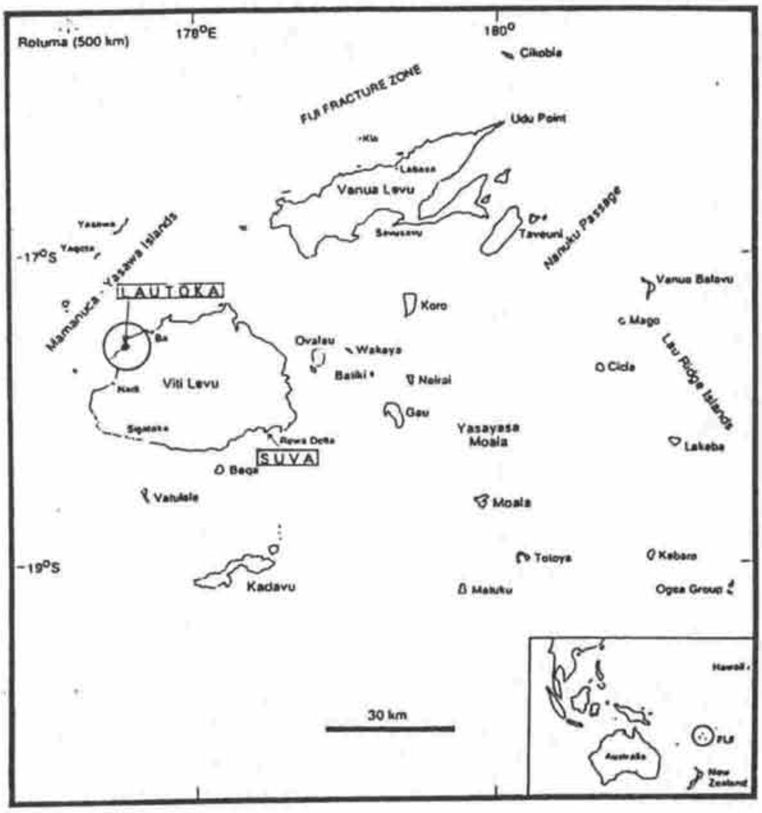
III-2 $\Delta\eta_w \approx 0.2$m

$\therefore \eta_s = 0.6 + 0.3 = 0.9$m

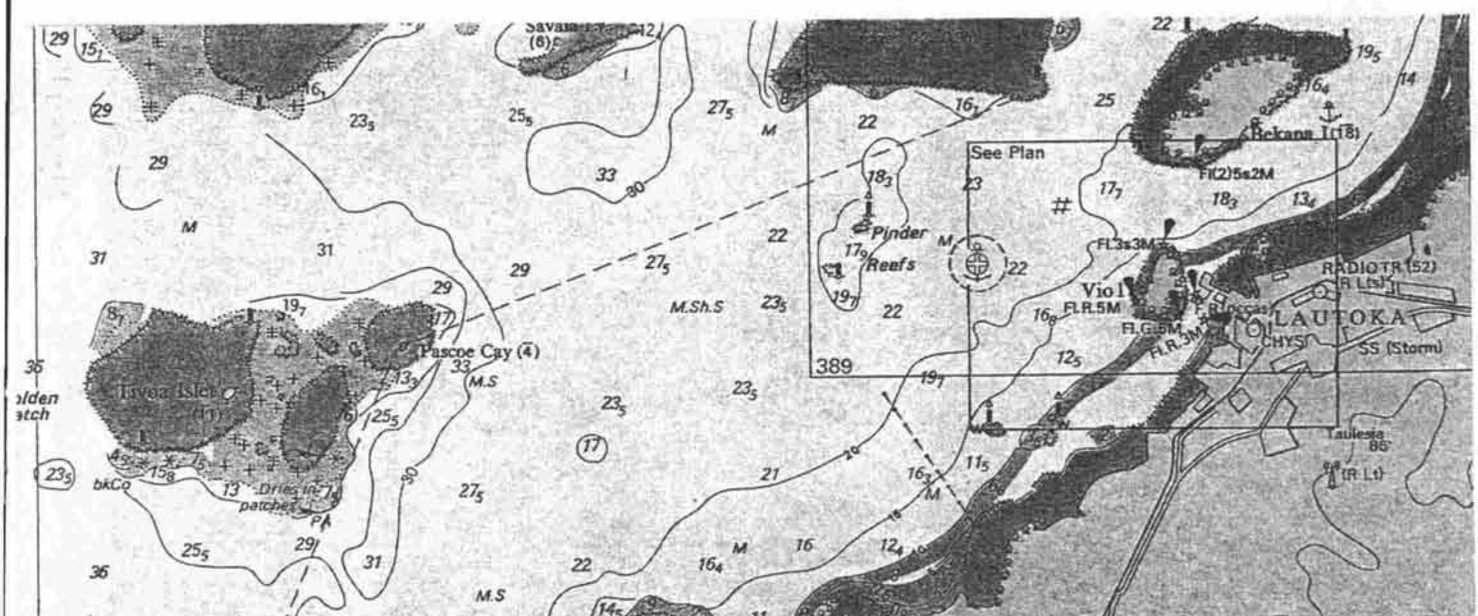
Table 6.7 summarizes the design condition at Lautoka port for a return period of fifty years.

c. Wave height estimation

The deepwater wave height Ho is calculated considering diffraction effects only. Diffraction coefficients are estimated using the angular spread method (Goda, 1985) as shown in Figure 6.15. Significant wave heights H1/3 are estimated for different values of assumed future sea-level rise (S.L.R.). Table 6.8 summarizes wave calculations at Lautoka port.



Location map



Marine chart

Figure 6.11. a. Location map
b. Marine chart

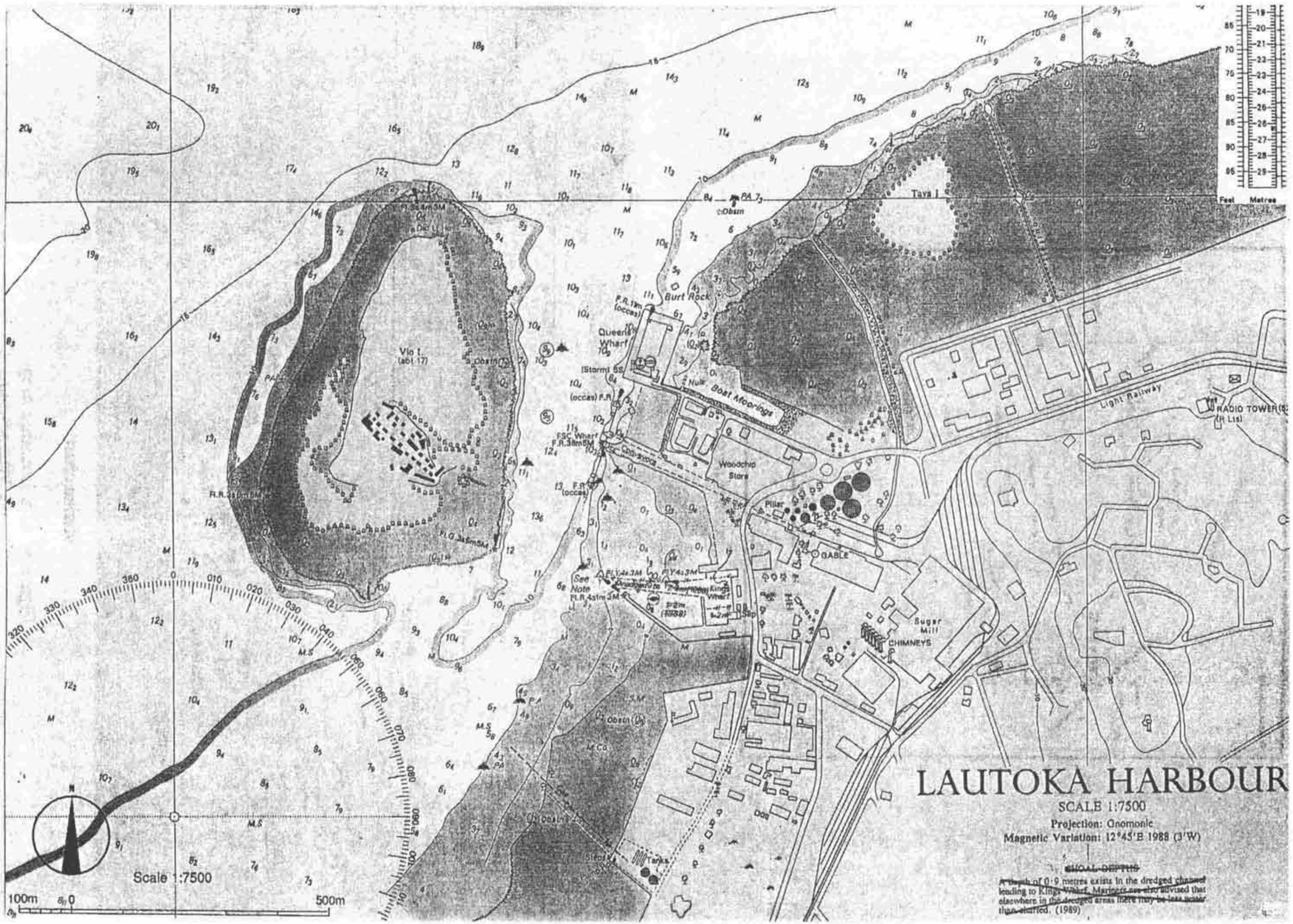
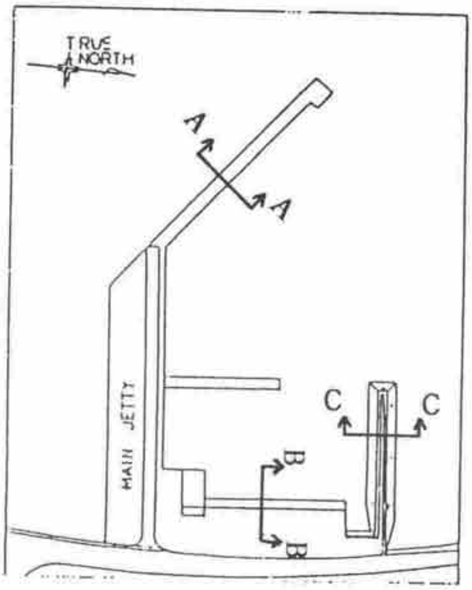
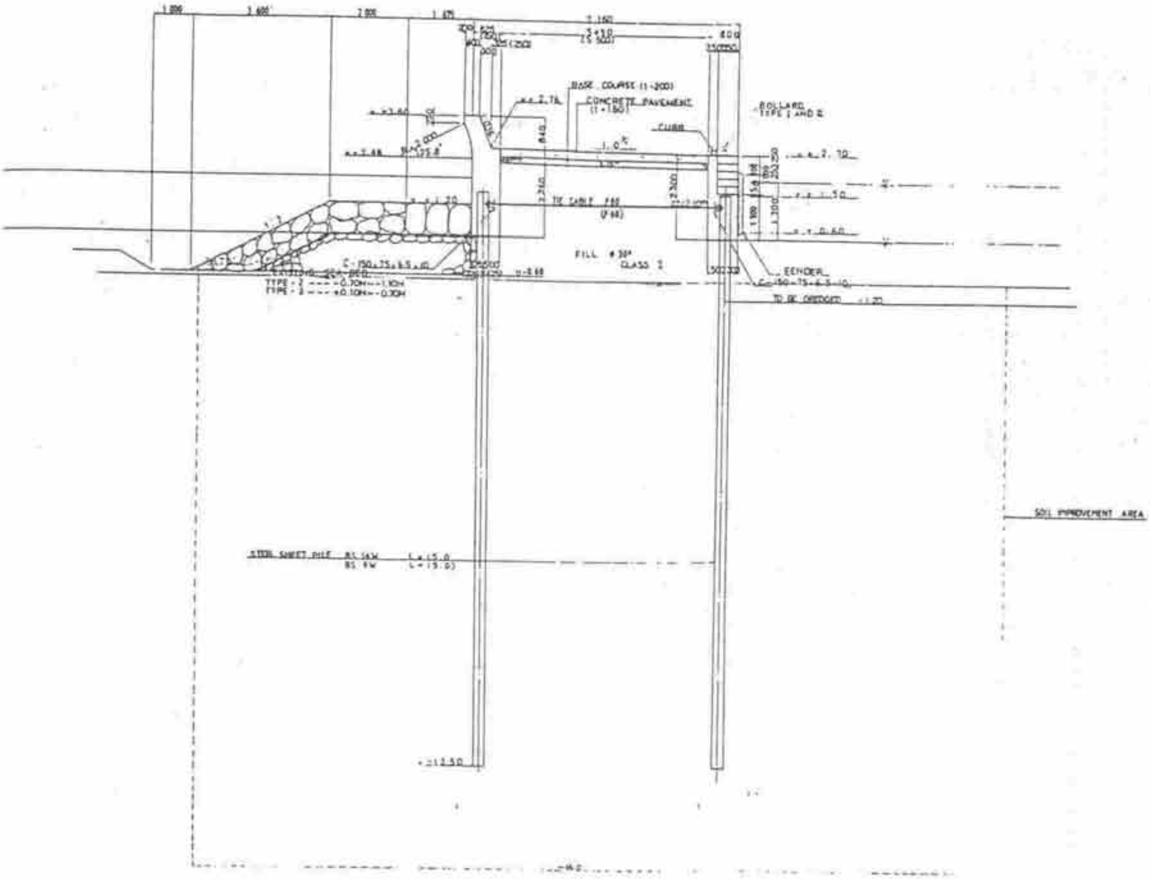


Figure 6.12. Bathymetric conditions



Plan of Lautoka Fishing Port



Section A − A

Figure 6.13.1. Existing facilities at Lautoka Port (1)

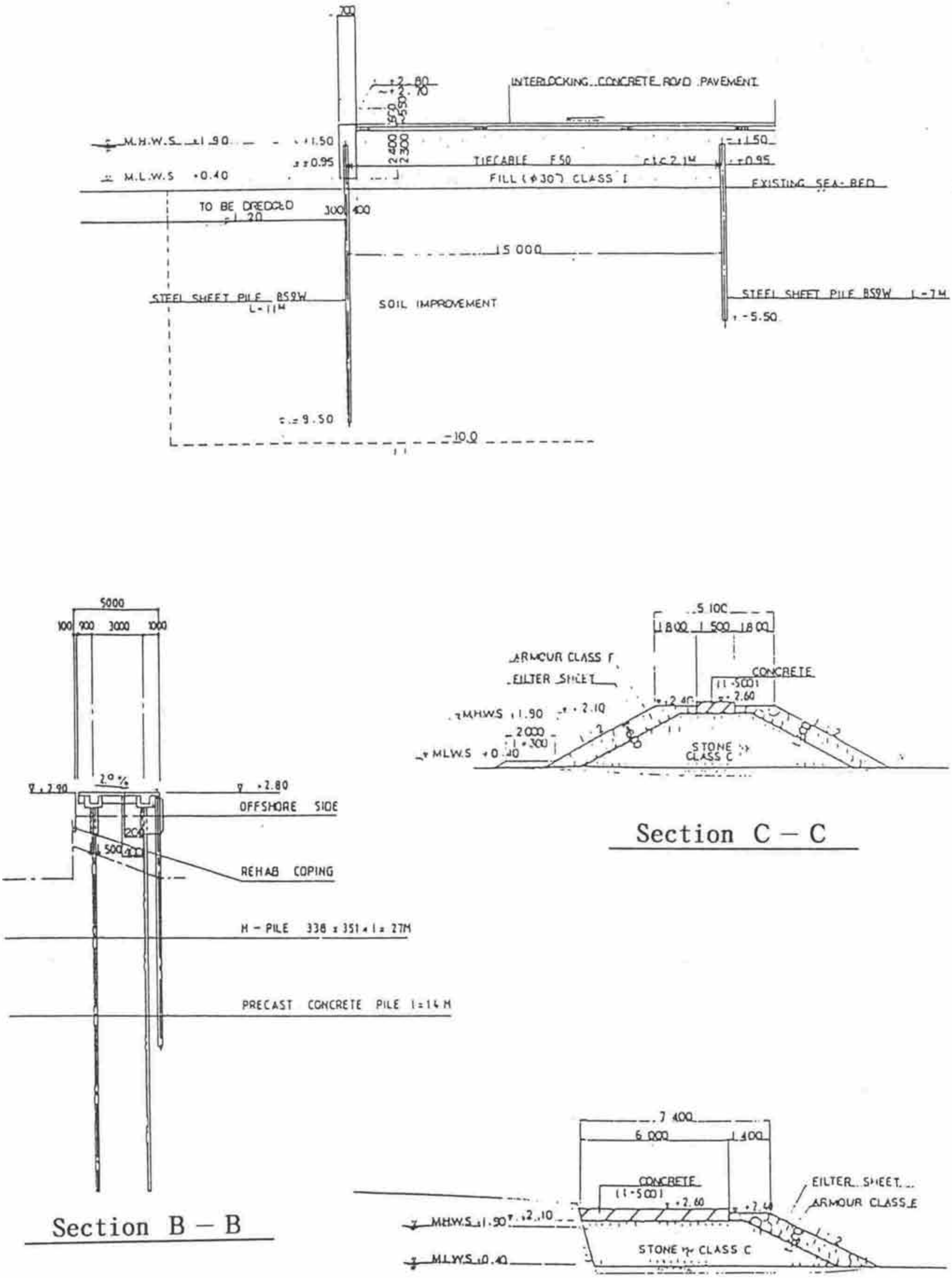


Figure 6.13.2. Existing facilities at Lautoka Port (2)

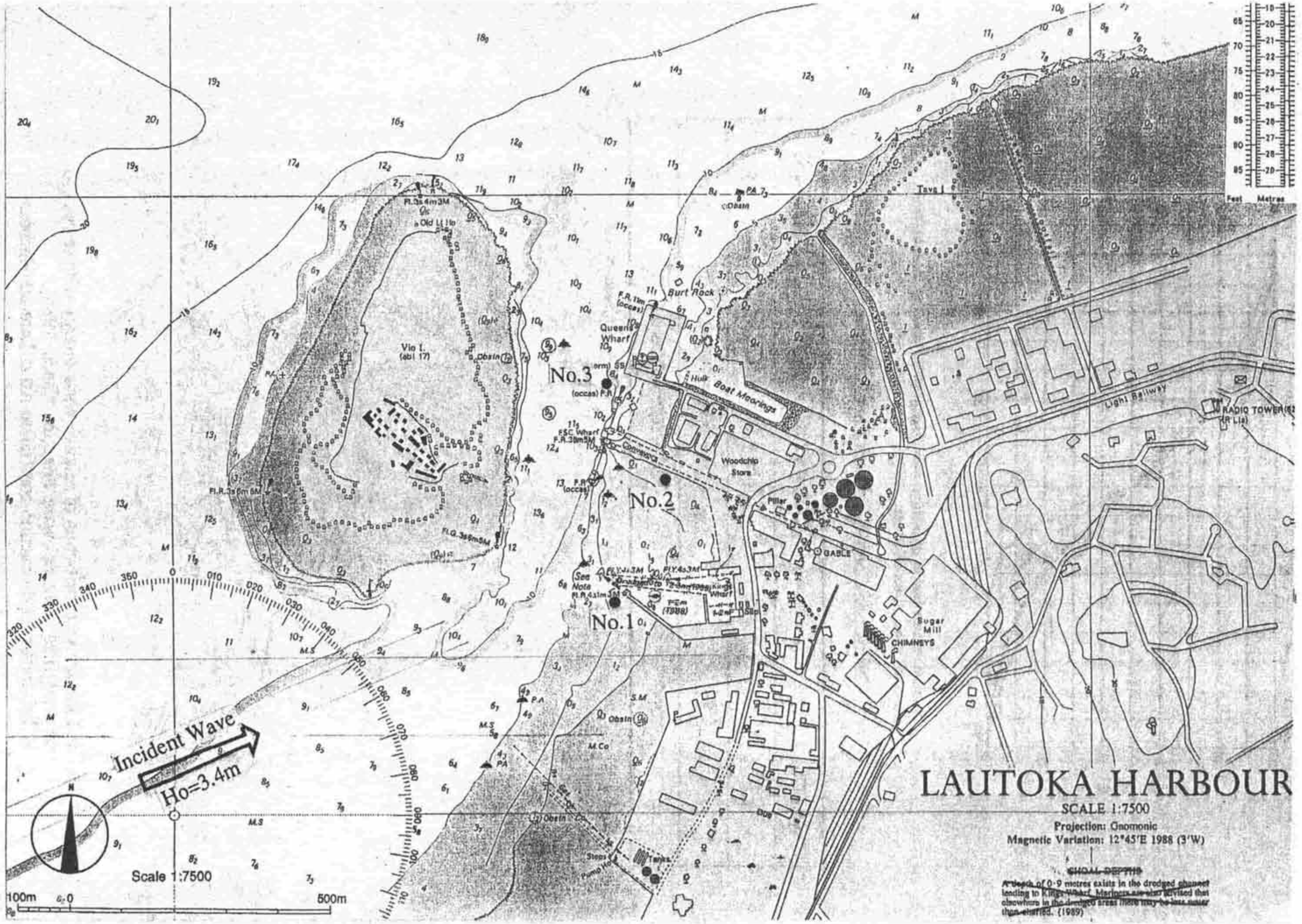
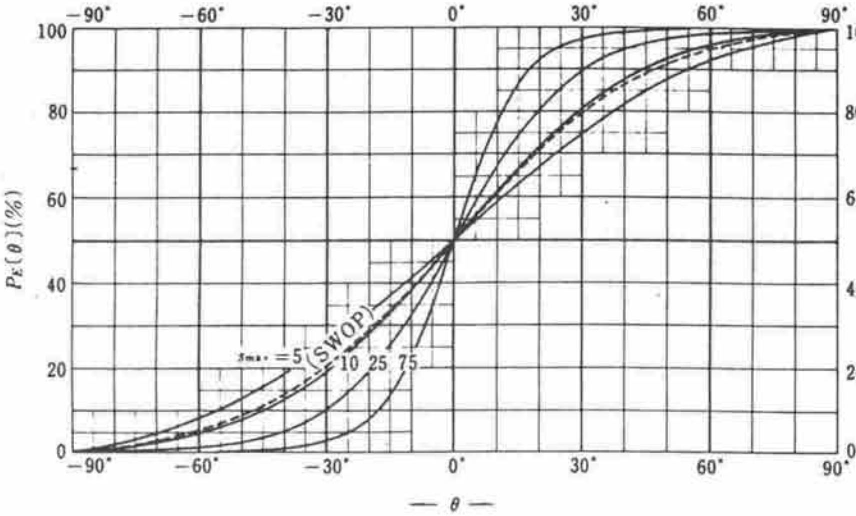


Figure 6.14. Location of study points inside Lautoka Port



Cumulative distribution of relative wave energy with respect to azimuth from principal wave direction (Goda, 1985)

Diffraction Coefficient Kd at Lautoka Harbor

Point No.	θ_1	θ_2	$\Delta E = P_E(\theta_1) - P_E(\theta_2)$	$Kd = \sqrt{\Delta E}$
1	36°	-39°	0.85 – 0.13 = 0.72	0.85
2	12°	-50°	0.63 – 0.08 = 0.55	0.74
3	-15°	-61°	0.33 – 0.05 = 0.28	0.53

(Smax = 10)

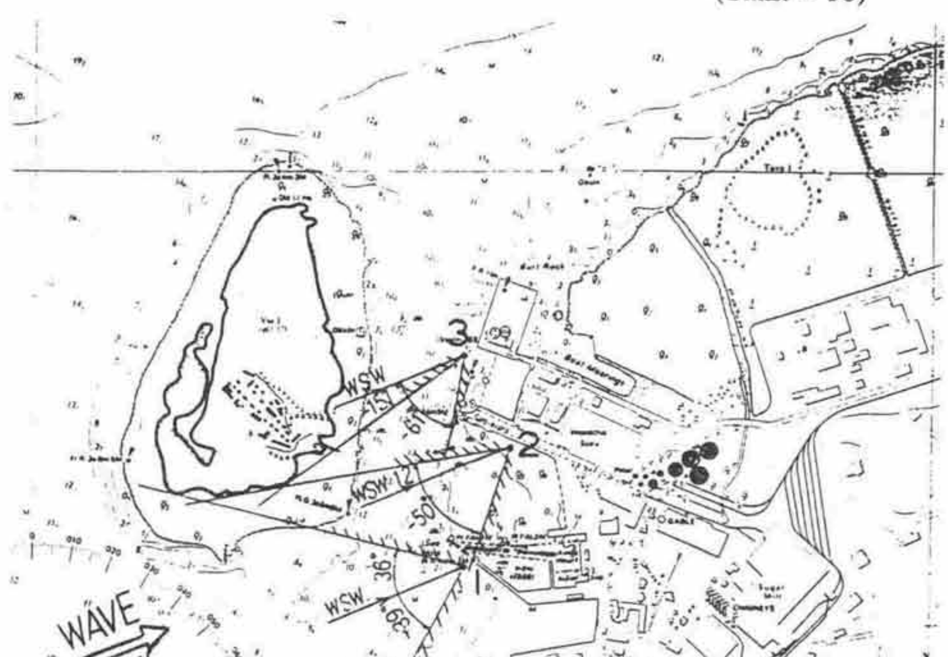


Figure 6.15. a. Cumulative distribution of relative wave energy with respect to azimuth from principal wave direction (Goda, 1985)
b. Estimation of diffraction coefficient Kd at Lautoka Harbour

Table 6.8. Calculation of $H_{1/3}$ for Lautoka Port

· Offshore wave : Ho = 3.4 m, To = 5.4 sec (Lo = 45.5 m), WSW

· Design water level : C.D + 2.8 m

	Point (DEPTH LEVEL)	Diffraction*1 coefficient K_D	$Ho' = K_D Ho$ (m)	Ho'/Lo	η_{SLR} (m)	h (m)	h/Ho'	h/Lo	$H_{1/3}/Ho'$*2	$H_{1/3}$ (m)
1	Fishery Port (C.D -1.5m)	0.85	2.9	0.064	0.0	4.3	1.48	—	0.82	2.38
					0.5	4.8	1.66	—	0.84	2.44
					1.0	5.3	1.83	—	0.87	2.52
2	Conveyer site (C.D ±0m)	0.74	2.5	0.055	0.0	2.8	1.12	—	0.72	1.80
					0.5	3.3	1.32	—	0.80	2.00
					1.0	3.8	1.52	—	0.86	2.15
3	Queen's Wharf (C.D -10m)	0.53	1.8	0.040	0.0	12.8	7.11	0.281	0.94*3	1.69
					0.5	13.3	7.39	0.281	0.95*3	1.71
					1.0	13.8	7.67	0.281	0.95*3	1.71

Remarks *1 : estimate by Directional Spread Method (Goda, 1985).

*2 : estimate by Goda (1975)

*3 : Shoaling coefficient by linear wave theory.

6.2.5. Study on revetment crown height

Shapes and crown heights of the existing stone masonry revetments and Queen's Wharf were obtained by a site survey of Lautoka Harbour. The impact of sea-level rise of 0.5m and 1.0m on the present crown conditions is discussed below.

The places at which measurements were made are shown in Figure 6.14. The crown heights of existing revetments, sea level at MHWS, storm surge, sea-level rise and incident waves at the study points are shown in Table 6.9.

The present crown levels of the port structures are higher than D.W.L (C.D + MHWS + storm surge) by about 1.0 m. Therefore, if the sea level rises 1.0 m, then the port structures and the sea surface will almost have the same level. Following the same study approach as for Suva port, crown levels of stone masonry revetments should therefore be checked for the effects of possible wave run-up.

1) The present condition
   Ho = 2.50 m, Lo = 1.56 To^2 =1.56 x $(5.4)^2$ = 45.5m
   Ho/Lo = 0.55, h/Lo = 2.8/45.5 = 0.062
   Side Slope of Revetment = 1:2
   Sea Bottom Slope = 1/30
   R/Ho = 1.8
   R = 1.8 x 2.5 = 4.5 m
   Run up Height = DL + 2.80 + 4.5 m = D.L + 7.30

2) After 0.5m sea-level rise
   h/Lo = 3.3/45.5 = 0.073
   R/Ho = 1.9
   R = 1.9 x 2.50 m = 4.75 m
   Run up Height
   = D.L + 2.80 + 4.75 m
   = D.L + 7.55 m

3) After 1.0m sea-level rise
   h/Lo = 3.8/45.5 = 0.084
   R/Ho = 1.95
   R = 1.95 x 2.50 m = 4.88 m
   Run up Height
   = D.L + 2.80 + 4.88 m
   = D.L + 7.68 m

6.2.6. Armour weight of stone masonry revetment

The weight of armour rock is determined using Hudson's Formula (refer to section 6.1.7. for Hudson's Formula).

(Conditions)

Cot θ = 2.5 K_D = 3.2 Wr = 2.65 t/m^3
Ws = 1.03 t/m^3
Sr = 2.65/1.03 = 2.57

	Wave Height	*Required Weight*
Present Condition	1.80 m	499 kg
Sea Level Rise 0.5m	2.00 m	685 kg
Sea Level Rise 1.0m	2.15 m	851 kg

Table 6.9. Summary of crown heights of existing revetments, water level at HWL, storm surge, sea-level rise and incident waves in Lautoka Port

Point	Tide				Water Level	Wave		Crown Height
	Astronomical Tide	Storm Surge	Wave Set-up	Sea Water Level Rise		Height	Period	
1	MHWS =+1.90	0.90	0.0	0.0	+2.80	2.38	5.40	+3.70
				0.5	+3.30	2.44		
				1.0	+3.80	2.52		
2				0.0	+2.80	1.80		+3.70
				0.5	+3.30	2.00		
				1.0	+3.80	2.15		
3				0.0	+2.80	1.69		+5.19
				0.5	+3.30	1.71		
				1.0	+3.80	1.71		

6.2.7. Other points to be noted

Relations between the port structures (including Queen's Wharf), the Lautoka Fishing Port breakwater, the still-water level, tidal fluctuations, and sea-level rise are shown in Fig. 6.13.

The present Queen's Wharf level is higher than the D.W.L. and there is no possibility of sinking. Therefore, it is presumed that the stability of port facilities is assured even after sea- level rise since the attacking wave height is predicted to be fairly low. However, as the increase of horizontal wave force and uplift becomes inevitable, a review based on more detailed data should be carried out.

The crown height of the breakwater of Lautoka Fishing Port is above the D.W.L. and there is no chance that it will become unusable, even if sea level rises as predicted. However, there is the possibility of a considerable increase in waves which overtop the breakwater which might cause its efficient use to diminish. The basic structure of the breakwater is a Double Wall Structure type, therefore the increase of the subsiding area might affect the stability of other port facilities. However, compared to other gravity type structures, its stability is able to be sustained under such conditions.

As for the armour stones set up at the foundation of the belt conveyor at the private factory location, it is predicted that the stability will not be affected by increased wave heights associated with a sea-level rise of 50 cm.

6.2.8. Countermeasures in maintenance

a. Port operation and management

Many of the existing facilities should be raised in anticipation of sea-level rise. The height to which facilities should be raised should be determined on the basis of the height of predicted sea-level rise as well as associated wave-height rise.

Two methods of raising the heights of existing facilities should be considered:

(1) Raising only at the waterfront line.
(2) Raising of whole hinterland.

An appropriate method should be selected in accordance with type of management at the project site.

b. Stability of facilities

Increased weight sometimes becomes disadvantageous to the stability of facilities. For gravity-type structures, it is necessary not only to raise height but also to expand width. For sheet-pile structures, the increase of surcharge load due to raising heights brings an increase of both stresses on sheet piles, and soil pressure, which can reduce stability of facilities. For pile-supported structures, increased weight of the superstructure made by raising structures heights affects the stability of supporting piles.

The above-mentioned points should be considered when a comprehensive countermeasures to sea-level rise impacts are to be selected.

Chapter 7. Towards an integrated coastal-zone management plan for Fiji

7.1. Introduction

It is worthwhile briefly reiterating the ultimate aim of this project and the way in which it was decided to attain this aim.

Under the terms of the Framework Convention on Climate Change, to which Fiji is signatory, Fiji is called upon to develop a national coastal-zone management plan with the specific purpose of accommodating the effects of future sea-level rise with as little disruption as possible. The Intergovernmental Panel on Climate Change developed a Common Methodology for Assessing Vulnerability to Sea-Level Rise, which was intended to be at the core of such national management plans. Yet, although deemed to be applicable worldwide, the Common Methodology, largely because of its insistence on assigning everything a monetary value, is not adequately applicable to Pacific Islands.

In Phase 1 of the Fiji study, the Common Methodology was radically altered to apply to the Fiji situation. As the result of testing this methodology at four sites in Phase 1, further modifications were made in Phase 2 (this study). These have been tested at two sites and the results indicate considerable improvement in objectivity, thus making this methodology more comparable to the original Common Methodology.

It is necessary for the methodology to allow objective comparison because it will be used to make decisions about the various response options available to mitigate the effects of future sea- level rise. If the methodology remains largely qualitative, then it has little value as a decision-making aid. The methodology developed in Phase 2 is a major step towards the goal of realizing an effective decision-making tool but, as explained in section 4.16, there are still improvements which could be made.

Development of a methodology in isolation is useless. Recognizing this for Fiji in Phase 1, a major effort has been started in Phase 2 to develop a national vulnerability profile. This profile is a database for the whole of Fiji into which various variables have been input and can be mapped at will using GIS technology. It is eventually intended that this database will be used in conjunction with the methodology to draw up an integrated coastal-zone management plan for Fiji.

This coastal-zone management plan is the best way of planning rationally and consistently for an accelerated rise of sea level in the future. It is a way of minimizing deleterious impacts of sea-level rise on Fiji's people, resources and infrastructure.

In the following sections, the three principal aspects of Fiji's coastline are examined and summary statements made about their future in the face of rising sea level given.

7.2. The physical fabric and its changeability

Superficially, since Fiji is comprised largely of high islands, it has been regarded as comparatively immune from deleterious effects of accelerated sea-level rise in the future. This view is fallacious, although it is true that the effects will be neither so rapid nor so disruptive in a national sense in Fiji as for the narrow low-lying islands in the world's oceans. There is a very real danger that acceptance of the superficial view by those unconcerned with Fiji's long-term future will result in considerably more disruption than is necessary.

Despite the fact that Fiji is made up largely of high islands, their higher areas are currently of minimal importance compared to their low-lying coastal fringes. There are few settlements in the interior of any except the largest islands and the percentage of people occupying such areas is less than 5% of the nation's whole population. Most people live on the coast, most of those people on coastal plains which rise no more than a few metres above the high-tide level. Most economic activity - industrial, manufacturing, commercial - is concentrated in these areas. Most parts of the coastal plains which are not otherwise used are used intensively for agriculture, ranging from vast areas of commercial crops to coconut plantations on outer islands.

Although the geology of the Fiji islands is surprisingly diverse for what most outsiders perceive as a small-island nation, the coastal plains are reasonably uniform in composition. The evolution of a typical coastal plain in Fiji is shown in Figure 3.5 of the Phase 1 report (Nunn et al., 1993). Most coastal plains are made of sediment overlying a bedrock platform. On narrow coastal plains, these platforms are usually close to mean sea level, on larger coastal plains drained by large rivers, the bedrock floor may be much lower. Either way, the sediment cover of these coastal plains is liable to erosion under both present (1993) and future (predicted) sea-level regimes. The presence of groundwater bodies in these coastal plains, on which plants growing thereon depend, are liable to salinization, usually in the form of a saltwater wedge moving inland. The effects of saltwater on the foundations of buildings is also a factor of potential concern.

If coastal plains are areas of most concern, it follows that many adjoining coastal areas are less threatened by sea-level rise. Many cliffed and semi-cliffed areas of Fiji's coastline are composed of hard rocks, typically of igneous origin, which are comparatively resistant to erosion and, on account of their morphology, can easily accommodate a rise in sea level of 1 m or more. But most of these areas are uninhabited and comparatively unimportant to both the local and the national economy.

Limestone coasts are a special case, less important than igneous coasts nationwide, yet dominant in the Lau group of eastern Fiji and present elsewhere. Most limestone has a comparatively low resistance to erosion by the sea but some limestone, including that comprising Viwa island in the Yasawas (see section 5.4.2), are case-hardened and extremely resistant to erosion. The effect of sea-level rise on freshwater lenses within limestone islands is likely to be minimal on most since the water table will simply rise as sea level does. This could result in freshwater flooding on low limestone islands but there are few of these in Fiji.

Of great concern too are the offshore areas of most parts of Fiji's coasts, which are occupied by fringing (and barrier) reefs and associated marine ecosystems. It is doubtful whether most reefs in Fiji could respond so effectively to predicted sea-level rise that their present role in protecting Fiji's coasts and supplying their inhabitants with a variety of seafood could be sustained. Not only is the species composition of Fiji's reefs mostly inappropriate to respond to sea-level rise by growing upwards, but sea-level rise will be only one of numerous stresses (including temperature rise) likely to adversely affect them in the next 50 years or so.

Finally, as explained in section 4.15, it is in some ways an artificial exercise to separate sea-level rise impacts from those associated with future climate change and other stresses on the islands' physical fabric in the future. For example, the combination of increasing population pressure and a changed climate could cause serious problems to many lowland areas in Fiji long before sea-level rise has a significant effect.

7.3. Threats to agriculture and possible response options

Sea-level rise alone will clearly have a negative effect on agricultural productivity in Fiji. This will be extremely significant since agriculture is the single largest sector of the Fiji economy, accounting for about 20% of the Gross Domestic Product and 80% of employment. Much of the most fertile land is in low-lying alluvial areas in river valleys and deltas which will be subject to inundation and increased flooding should sea levels rise. Increasing salinity of the groundwater and salt spray will also have negative impacts.

Sugar-cane exports dominate the agricultural exports of Fiji, amounting to F$300 million each year. Other agricultural exports such as copra, ginger, root crops, fruits and vegetables all amount to less than F$10 million annually. Extensive pine plantations have been developed in the last two decades and products derived from these trees are rising annually to an expected annual level of F$150 million.

Extensive work has been undertaken in reclaiming coastal swamplands for rice production to meet local demand. A majority of such production would be threatened by a rise in sea level.

Subsistence agriculture is very important in Fiji where about 60% of the population lives in rural areas. Most Fijians practice classical slash-and-burn agriculture but with declining fallow periods owing to increasing populations in the villages. Root crops, tree staples, fruits and vegetables are the main foods harvested. Fiji Indian farmers also tend to grow most of the foods they consume. Where possible, most of this farming is done on higher land but the main river deltas are places where no elevated land may be available to a village for agriculture. This is especially true of the large population of the Rewa Delta (on Viti Levu island) whose subsistence agriculture could be seriously threatened should sea levels rise as predicted.

Most available land in Fiji is already under cultivation. In the last decade, there has been increasing movement of both commercial and subsistence agriculture onto steep slopes. In general, agricultural productivity per hectare is low so that one partial solution to the loss of land resulting from sea-level rise would be to increase yield per hectare by more efficient agricultural practices. Some improvements in this area are possible but the long-term sustainability of high-input agriculture with improved cultivars has been called into question, especially in fragile island ecosystems. Certainly though, the development of more salt-resistant cultivars of tropical food crops should be a high priority area of research.

Sea-level rise will, of course, be accompanied by important climate changes that will also affect agriculture. The positive "fertilization effect" of higher carbon dioxide levels in the atmosphere will most likely be negated by more heat stress, a greater incidence of weeds and pests, and more damage caused by more severe and frequent droughts, tropical cyclones and floods. It is likely that Fiji agriculturists will need to make substantial changes in their agricultural practices in the next century to maintain productivity in the face of sea-level rise and climate change.

7.4. Human occupation of the coast and possible response options

Most Pacific islanders, including the Fijians, like to live by the coast because of accessibility to marine food sources and sea transportation. Coastal flats also provide much better gardening land than the high hills and mountains which are difficult of access and usually used only for hunting and gathering activities.

Existing infrastructure and other facilities have been long established along the coast and near ports and other transport facilities such as wharves, jetties and road transport. All were established by the coast for easy access and less manual effort in carrying out one's life's activities and communal efforts. Permanent and expensive church buildings are built close to the coast.

Fijians like many other Pacific islanders have a strong attachment to their land and in particular to original ancestral house sites where some of their ancestors and close relatives have been buried. There is also a tendency for most of them to also live close to their centre of worship.

People would only move away from the coast if they are threatened by or suffer from catastrophic events such as high storm surges and flooding. Even threats alone would not make some to leave the coast unless they suffered heavily and their lives are endangered.

The attraction of migrating to other greener pastures overseas where there are more opportunities for improving one's socio- economic position provides another response option.

The establishment of certain infrastructure such as roads, shops, hospitals and other service facilities inland (rather than along the coast) can encourage people to move away from the coast.

7.5. Island-wide Vulnerability Analysis (VA)

A Nationwide Vulnerability Assessment (NWVA) is required before an appropriate Integrated Coastal Zone Management Plan, considering sea-level rise and climate change, can be developed for each nation. The principal aims of NWVA are to understand the condition of the whole coastal area and to precisely study a number of areas simultaneously. However, it is impossible to intensively assess the vulnerability throughout the coastal area in an archipelagic nation such as Fiji.

The first step of the NWVA is to acquire a general understanding about the whole coastal area in Fiji, including information on geography, landuse, and population. Complete information is not available. In this section, a preliminary study of island-wide VA using Geographic Information Systems is described. Viti Levu island was selected to be the study island because of its importance in Fiji.

Geographic Information System (GIS) technology is a powerful analytical tool enabling the rapid processing of large sets of data stored in a geographic form. GIS is often used for computer mapping, by simply storing mapped information in a computer. GIS is useful to quantify the impact of particular phenomena on such attributes as the area of lowland, population, infrastructure, rather than to characterize qualitative values such as social and cultural parameters.

The GIS software used was ARC/INFO housed on a computer operating under UNIX. Topographic maps at a scale of 1:50,000 and a scale of 1:250,000, and landuse map of at a scale of 1:250,000 were digitized to form the data set. Populations in each village, tikina were also input from the Report on the 1986 Population Census. Twenty five "layers" of geographic and population data for Viti Levu were input from these maps and the report. Each layer is a separate data set (Table 7.1). The GIS can overlay these data to produce composite digital maps. The maps in digital form allow the GIS to rapidly undertake a range of analyses.

The 100-feet contour line was the first contour above the mean sea-level contour. This zero-feet contour was used to define the coastline. Thus the land between 0-100 feet is regarded as coastal lowland, although this is obviously too crude a basis for the measurement of future sea-level rise.

Topographic maps at a scale of 1:50,000 and a landuse map at a scale of 1:250,000 were drafted in 1960-72. Though topography in Viti Levu has not changed dramatically since then, the landuse, in particular the agricultural area, must have changed. For this reason, data in Tables 7.2 and 7.3 should be revised when a new landuse map is prepared.

Table 7.1. Data input into the GIS

Layer	Description	Element
1	coastline	-
2	100-feet contour	-
3	road	-
4	water course	-
5	coral	-
6	boundary	village
7		tikina
8		province
9		division
10	population	village
11		tikina
12		province
13		division
14	landuse	forest
15		light forest
16		scrub
17		grass/ferns/reeds
18		sugar cane
19		sugar cane/rice
20		rice
21		coconuts
22		maize/other crops
23		rice/maize/other crops
24		pasture (improved)
25		urban

The results are shown in Table 7.2. While only about 12% of the land area of Viti Levu is between 0-100 feet, about 60% of the agricultural area is within the coastal area. In particular, more than 70% of sugar cane, rice and coconut areas are within the coastal area. However, as mentioned above, the landuse map made in 1964 is inadequate for assessing the present landuse in Viti Levu.

77% of the urban area and 36% of the road system are within the coastal area. In particular, most of the main roads, such as the Queen's Road and King's Road, are along the coastline for most of their length.

Table 7.2. Summary of results for whole island and 0-100 feet area obtained from GIS analysis.

Layer	Whole Island	0-100 ft	% 0-100 ft
Area (km^2)	10,830	1,280	11.8
Road (km^2)	2,360	840	35.6
Land Use (km^2)			
Forest	4,590	106	2.3
Light forest	1,070	114	10.7
Scrub	658	116	17.6
Grass/reeds/fern	3,480	281	8.1
Sugar cane	439	326	74.3
Sugar cane/rice	292	135	46.2
Rice	35	31	88.6
Coconuts	4.2	3.0	71.4
Maize/other crops	29	9	31.0
Rice/Maize/other	89	33	37.1
Pasture (improved)	155	77	49.7
Urban	61	47	77.0

Urban population between 0-100 feet was estimated from the GIS analysis. Supposing that most people are concentrated in the urban area on the landuse map, the population between 0-100 feet in Suva, Lautoka and Nadi was estimated. These urban areas are the main cities in Fiji. The results of population analysis in these areas are shown in Table 7.3.

More than 70% of the population in these urban areas are within the coastal area. In particular, the population in Nadi (99.5%) and Lautoka (79.6%) are concentrated in coastal lowland areas.

As mentioned above, although the land between 0-100 feet may be too broad a category within which to assess the impact of future sea-level rise, these results give a general indication of urban population within the coastal lowland zone.

Table 7.3. Population in urban areas and that between 0-100 feet obtained from GIS analysis.

Urban area	Whole urban	0-100 feet	% 0-100 feet
Suva	77,760	54,430	70.0
Lautoka	28,860	22,960	79.6
Nadi	13,820	13,750	99.5

Topographic maps with closely spaced contour lines (of 1 m spaced contours between 0 and 5 m), an up-to-date landuse map, precise and large scale maps (1:20,000) with infrastructure, residential area, etc. are required for future work. Sample graphic output is shown in Figures 7.1, 7.2 and 7.3.

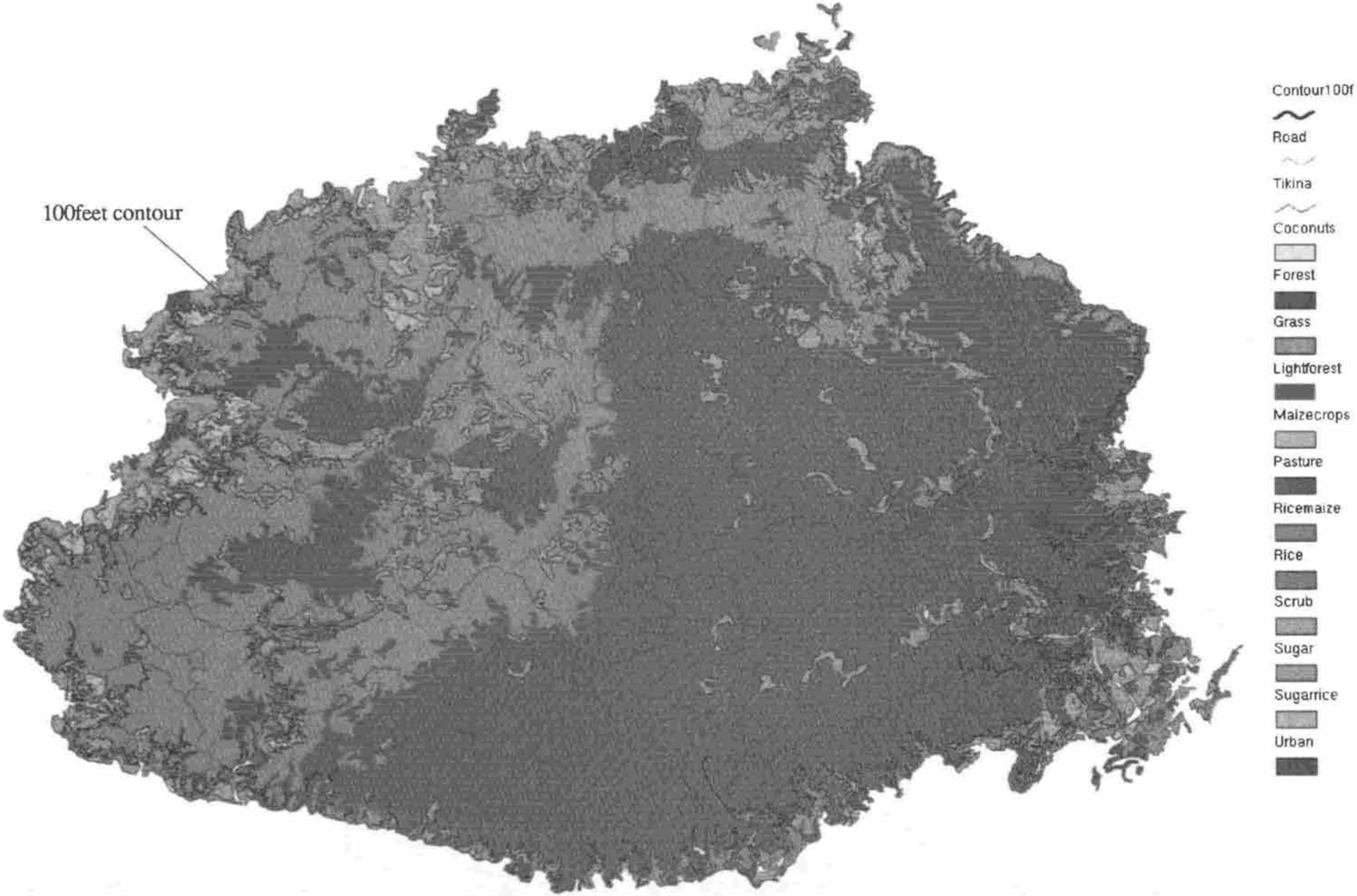


Figure 7.1. Land use of Viti Levu made using GIS

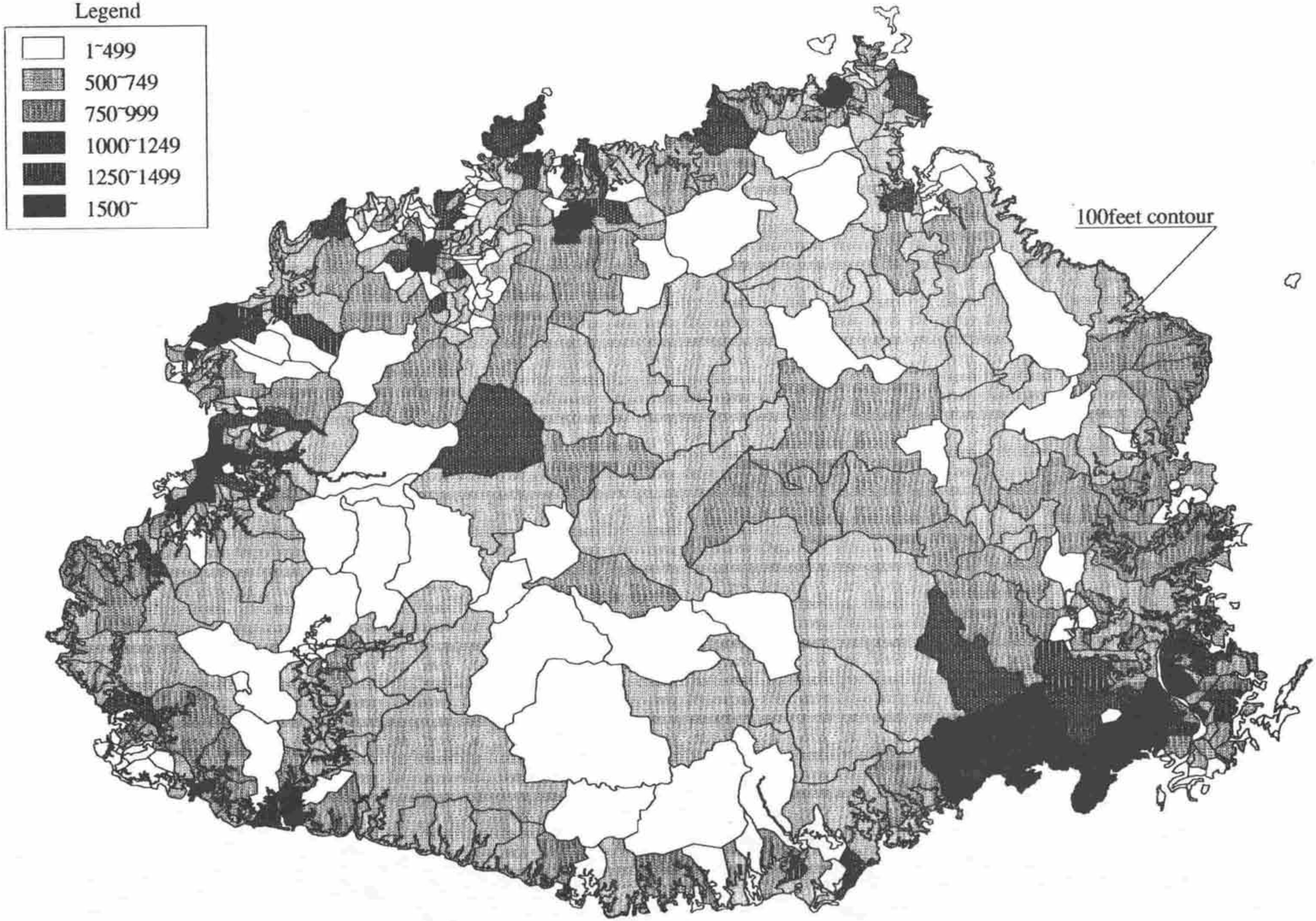


Figure 7.2. Population distribution on Viti Levu made using GIS

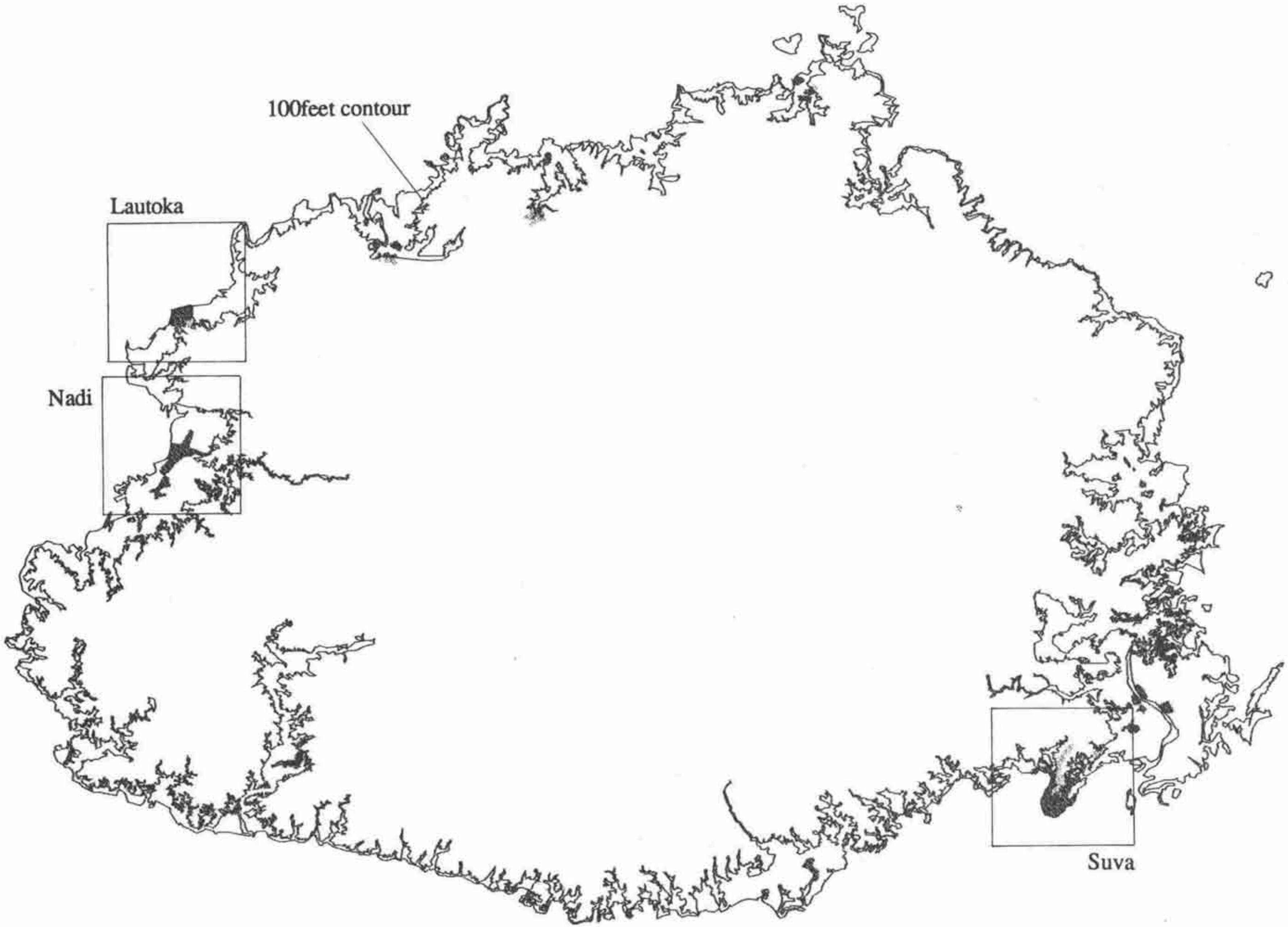


Figure 7.3. Urban area on of Viti Levu made using GIS

Chapter 8. Conclusions and recommendations for future work

This project set out to modify the Common Methodology for assessing impacts of future sea-level rise with a view to demonstrating its practical application in the Pacific Islands. In this it has succeeded, but there is clearly more work to be done. Key recommendations follow.

1. It has not been possible to develop the basis for an integrated coastal-zone management plan as intended originally in Phase 2 of this study, largely owing to time constraints. However, most available data have been assembled to allow this objective to be fulfilled. It is therefore *recommended* that the basis for an integrated coastal-zone management plan for Fiji is drawn up, perhaps in a Phase 3, and thereafter developed in coordination with the Fiji Government's Environment Unit along international guidelines.

2. We are still ignorant about the typical rates of coastal change in Fiji, and therefore *recommend* that a series of precise studies on recent coastal changes be carried out. Such studies will allow rates of coastal change for various coastal environments under particular conditions of external change to be quantified. This will provide a secure basis for future planning.

3. The methodology is still not adequately developed or tested. It must be applied in a greater range of coastal/insular situations, particularly in a diverse archipelago like Fiji, in order that all problems can be anticipated in the final version. It is also important to begin testing the methodology on pilot groups of operators to look at problems of consensus, operator perceptions etc. in order to make the methodology as objective as possible. It is *recommended* that the methodology be tested and modified accordingly.

4. It is *recommended* that a study of the changed frequency and effects of tropical cyclones should be made in order that likely future frequencies and effects can be precisely predicted. A study of other catastrophic events, such as storm surges, tsunamis, and droughts associated with ENSO should also be carried out.

5. The Nationwide Vulnerability Assessment should be extended by gathering more data and inputting more base maps to enable graphic output to be extended outside Viti Levu. It is *recommended* that more appropriate data be collected and the NWVA extended. It is envisaged that the NWVA will eventually be placed in the hands of the Fiji government so increased cooperation with them is desirable in the future.

6. Efforts should be made to extend/integrate this study with other initiatives aimed at assessing future environmental changes. It is *recommended* that a whole-environment approach be taken in order to improve insights into the issue rather than focus on a single source of external stress.

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