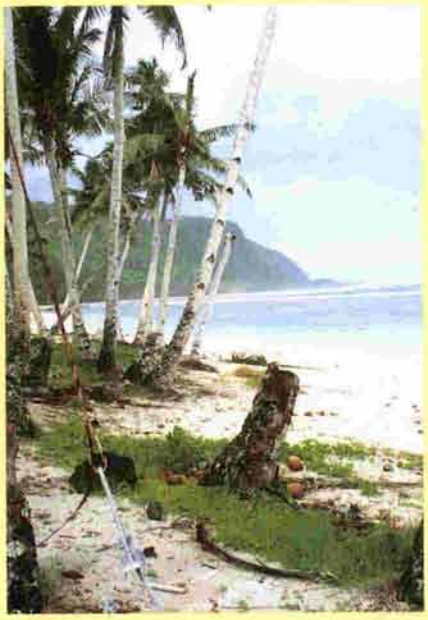
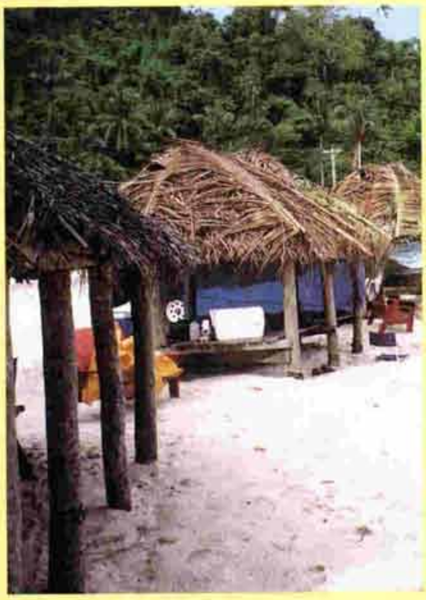
Integrated Coastal Zone Management Programme for Western Samoa and Fiji Islands





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

Case Study: Savai'i Island, Western Samoa

Phase II: Development of Methodology

March 1994

South Pacific Regional Environment Programme (SPREP)
Environment Agency, Government of Japan (EAJ)
Overseas Environmental Cooperation Center, Japan (OECC)

SOUTH PACIFIC REGIONAL ENVIRONMENT PROGRAMME

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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 (Western Samoa), 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 Western Samoa 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 (Western Samoa), regional (Pacific) and international levels. Western Samoa 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 Western Samoa, the periphery was sampled in this study.

The four 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 on Savai'i, the other main island of Western Samoa which was 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 Western Samoa's coasts 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 Western Samoa was considered, together with recent sea-level behaviour. It was found that there is no acceptable evidence for subsidence of the islands recently but in fact plentiful evidence for their emergence.

The clearest evidence for emergence in Western Samoa is all low- level (< 10 m). Emerged shoreline indicators greater than about 2 m all tend to be congregated in small areas which suggests that the cause of their emergence was local rather than regional.

The 7-m emergence in Upolu is confined to the offshore tuff island of Nu'utele. This may lie on the (north/northeast) upthrown side of the well-marked south-coast fault between Saleapaga and Tuiolemu on the main island of Upolu. Recent movement along this fault may account for the comparatively high- level indicators of emergence on Nu'utele.

On Savai'i, the 4-m emergence of the Ga'utavai area has been attributed to localized thermal uplift (Nunn, 1994).

Lower-level emergence can all be explained by late Holocene sea- level fall. Contrary to the opinion of many earlier writers, we believe that there is no sound evidence of significant late Holocene submergence of Samoa.

The present tectonic condition of the Samoa group is difficult to discern in many places. There are areas, such as south-central Savai'i which may be slowly rising as the result of lithospheric upbending and/or heating. There are probably areas, like that around the Ferry Berth site in Upolu and that along the easternmost part of Upolu's south coast, which have experienced rapid subsidence during the Holocene. Yet the preservation of indications of recent emergence, particularly the Little Climatic Optimum high sea level at Poloa on Tutuila (in American Samoa), suggest that subsidence is not the dominant process affecting the islands at present. If it is, then it must be extremely slow. There is no unequivocal evidence of a uniform emergence of the islands in the last millennium so their general condition is most accurately described as stable for that period.

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 Western Samoa.

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 Western Samoa 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.

Savai'i island is unmistakably the periphery. Most people living there are largely dependent on subsistence harvesting, both from the land and the sea, for sustenance although cash received from relatives working elsewhere (on Upolu or overseas) is important. The terrain of Savai'i is not conducive to high levels of agricultural productivity. In contrast to most parts of Upolu, many parts of Savai'i are composed of such young volcanic rocks that these have not yet had time to break down and form soil. Cultivation is therefore carried out in pockets of `soil' formed in places between unweathered rock. On many of the older lavas, forest grows but this is being increasingly cleared causing problems of soil erosion and flooding in lower areas.

In parts of Savai'i, particularly along the south coast, reefs are absent and the offshore area plunges steeply into deep water. This situation exacerbates the difficulties of subsistence living on Savai'i. The point about this is that the way of life in the periphery on Savai'i appears marginal at present because of stresses which are not associated with sea-level rise. Mercifully, many parts of the Savai'i coast are well protected from the physical effects of sea-level rise in the future but others are not. Among these is the lowland area in the east and southeast of the island which includes Puapua.

The two main types of coast on Savai'i are the `ironbound' coasts, common in the areas of young lava flows in the south, north and northeast, and the low-lying coasts made largely of superficial materials. One site was chosen for this study on each; Ga'utavai-Gataivai and Puapua.

Ga'utavai village on the south-central coast of Savai'i island is one of many coastal villages of Western Samoa. Its shoreline is generally rock-bound consisting of hardened volcanic lava rock several thousand years old rising about 3-4 m above sea level. Yet adjoining Gataivai is low-lying, at the mouth of a river, and has suffered inundation during storm surges and high rainfall events frequently in the past twenty years.

Response options to sea-level rise are generally few in the Ga'utavai-Gataivai area because of the very high vulnerability and limited flexibility of the various coastal elements. The only options readily available are outward migration for cash employment and increasing dependence on international aid. The increasing involvement of the villagers in the cash economy to cater for their changing lifestyle and eating habits, and the limited availability of natural resources to cater for their subsistence and cash needs has made and will certainly increase outward migration for the inhabitants not only of the study site but for the Savai'i population as a whole.

Puapua village, the second study site, is on the eastern side of Savai'i. It is situated in a sandy embayment which displays the effects of strong winds and storm surges during the two recent hurricanes mentioned above. The Puapua site shoreline is much more exposed to storm surges and coastal erosion and thus it is much more vulnerable to natural disasters than Ga'utavai.

Response options for Puapua mostly involve protection of the physical site by, for example, ensuring a healthy reef offshore, and planting salt-tolerant, deep-rooting trees along the shoreline. It is also possible that Puapua could be relocated further inland; a government-funded road exists to encourage landward migration here.

Impacts on Apia harbour

Most of the shoreline structures around Apia Harbour are designed for present conditions, not those which will prevail if predictions of future sea-level rise prove correct. In addition, many facilities are inadequate to cope with low-recurrence storm surges. 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.

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 Western Samoa's people, resources and infrastructure.

The physical fabric of Western Samoa 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 Western Samoa 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 Western Samoa's long-term future will result in considerably more disruption than is necessary.

Despite the fact that Western Samoa 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. Much 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 Western Samoa. This will be extremely significant since agriculture is the single largest sector of the Western Samoa economy.

Subsistence agriculture is very important in Western Samoa where about 60% of the population lives in rural areas. Most Western Samoans 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.

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 Western Samoa 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 (Western Samoa), regional (Pacific) and international levels.

In Phase 1 of the project for Western Samoa, 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 Upolu; namely, the rural coastline at Safata Bay and from Saleapaga to Lalomanu, the Apia urban/commercial coastline, and the Faleolo International Airport and Mulifanua Wharf.

In addition, a comprehensive report (Kay 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 Western Samoa. 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 Upolu were also explored in Phase 1 of this study.

The Phase 2 study in Western Samoa 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 Western Samoa 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 on Savai'i, the other main island of Western Samoa which was 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 Western Samoa's coasts to show their vulnerability and resilience to sea- level rise. These maps will be the basis for a national vulnerability profile.

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 Western Samoan 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 in Western Samoa; most commentators have regarded the islands as stable or slowly subsiding.

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 Western Samoa 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. Additionally, there are other data, both published and unpublished, which have some information about rates of recent coastal change in Western Samoa. 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 Western Samoan 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 is to 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 on Savai'i

In Phase 1 of this project, the three study areas where the methodology was tested were on Upolu, the island which is generally the most developed in terms of infrastructure and economy. Upolu can be portrayed as containing the core, Savai'i (the other main island) as being the periphery.

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 Savai'i. Two areas will be selected, one from an `ironbound' coast, such as that around Gataivai in the south-central part of the island, the other from a low-lying sandy coast, such as that around Puapua in east-central Savai'i.

2.5. National vulnerability profile

One of the most efficient ways of assessing the vulnerability of the whole coastline of Western Samoa 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 Western Samoan 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 aspect.

2.6. Integrated coastal-zone management plan

By virtue of signing the Framework Convention on Climate Change, Western Samoa 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 Western Samoa's coasts. A major problem which will be addressed in Phase 2 is how to make the strategies realistic, given the limited funds available.

Chapter 3. Establishment of a baseline for coastal change

One of the major deficiencies of many studies of Western Samoa'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 Western Samoa 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 Western Samoa - 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 Western Samoa'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 Western Samoa

3.1.1. The geological context

Like many other islands in the Pacific, those of American and Western Samoa are arranged in a linear chain believed to extend west along a line of seamounts and islands (Figure 3.1). Most island chains in the Pacific are volcanically active at only one end, from which point the age of the islands increases uniformly along the chain. These observations may be explained by the movement of a lithospheric plate across a fixed mantle hotspot, magma from which builds a volcanic island on the ocean floor above. This island eventually becomes volcanically inactive, cools and subsides as it is moved away from the hotspot on the moving plate.

As with all the other islands in the Samoan chain, those of Western Samoa are composed almost wholly of the products of subaerial volcanic activity, mostly lava of either blocky structure (aa) or having a ropy appearance (pahoehoe) or pyroclastics. The most detailed account of the geology of Western Samoa is that of Kear and Wood (1959): other accounts of note are Jensen (1907), Friedländer (1910), Thomson (1921), Stearns (1944) and Nunn (submitted) from which most of the following details come.

The oldest extrusive rocks are found on both Upolu and Savai'i and were believed by Kear and Wood (1959) to be contemporaneous. Yet Natland and Turner (1985) argued that those on Savai'i were older and petrologically distinct from those on Upolu. While those on Upolu were named Fagaloa Volcanics by Kear and Wood (1959), the name Vanu Volcanic Series was proposed by Natland and Turner (1985) for those rocks formerly mapped as Fagaloa Volcanics on Savai'i. The Fagaloa/Vanu volcanics were formed in Pliocene-Pleistocene times, between 2.69 and 1.54 Ma (Kear and Wood, 1959; Natland and Turner, 1985). Based on their palaeomagnetic character, Keating (1992) regarded the Vanu Volcanics as erupted more than 2.5 Ma, during the Gauss Normal Chron. All volcanic rocks younger than the Fagaloa/Vanu series correspond to the Brunhes Normal Chron and are therefore less than 700,000 years old (Keating, 1985).

The Salani Volcanics were erupted in both main islands following a period of quiescence after the end of Fagaloa/Vanu volcanism. The degree of weathering of the lavas suggested to Kear and Wood (1959) a probable age for this activity of Last Interglacial (~125,000 BP). Most of the smaller islands in Western Samoa (Apolima, Fanuatapu, Namu'a, Nu'ulua and Nu'utele) are built from Vini Tuff, the pyroclastic product of eruptions which are believed to have occurred within the early period of Salani volcanism.

The Mulifanua Volcanics are similar to the Salani Volcanics except in the lesser degree of weathering exhibited by the former. They are found on both main islands and the offshore island of Manono and date from the Last Glaciation (70,000-10,000 BP) according to Kear and Wood (1959).

The Lefaga Volcanics are of early to middle Holocene age and were mapped by Kear and Wood (1959) only in Upolu although "it now seems likely that the Falealupo peninsula [in Savai'i] could also be formed of lava flows of that age rather than Mulifanua [Volcanics]" (Kear et al., 1979: 21).

The Puapua [Pu'apu'a] Volcanics are middle to late Holocene in age; radiocarbon dates of between 1850-750 BP have been obtained (Kear et al., 1979). Puapua eruptions occurred on both main islands.

The products of historical volcanism are classified as Aopo Volcanics. Major eruptions occurred only in Savai'i in the years AD 1760, 1902 and 1905-1911. Eruptions were located along a large collapse fault.

3.1.2. Recent tectonic history - various theories

The Samoan islands are located in a poorly understood area of the southwest Pacific close to the northern terminus of the Tonga-Kermadec Trench within which the Pacific Plate is being subducted under the Indo-Australian Plate (Figure 3.1). It is possible that the whole Samoan island chain is being tilted towards this trench resulting in emergence of the islands' north coasts and submergence of their south coasts. This interpretation is somewhat simplistic since it assumes an improbable degree of rigidity for the Pacific Plate in the Samoa region. It seems more likely that the plate here is being flexed or bent along the islands' volcanic axis. This view is suggested by the conclusion of Natland and Turner (1985) that recent eruptions in Samoa were the result of bending and dilation of the Pacific Plate in the area.

Such a suggestion is complicated by the observation of volcanic activity in the islands within the last hundred years. This implies that there is a some residual heat below the surface and associated thermal expansion could have caused recent uplift of the islands, at least locally (Nunn, 1994).

A third view is that volcanic activity has been declining in intensity and frequency in recent millennia. This points to a cooling of the Earth's crust in the area, resulting, as elsewhere, in subsidence of the islands. This view is favoured by Bloom (1980), Hopley (1987) and Richmond (1992), who believe that the loading effect of recent volcanism also contributed to subsidence.

The lack of agreement about the recent tectonic history of the Samoan islands is manifested by the three possible, yet mutually exclusive, theories summarized above. The solution to the puzzle lies partly in an understanding of recent tectonics and it is surprising that so little has been done on this topic. Part of the reason for this may be the emphasis placed by Kear and Wood (1959) and Kear (1967) on a eustatic (sea-level change) rather than a eustatic-tectonic explanation of emerged shoreline indicators, a view they justified by the apparent uniformity in age-height relationships throughout Western Samoa.

A good starting point for a reassessment of the islands' tectonic history is thus an account of the evidence for low-level, implicitly Holocene, emergence preserved along their coasts.

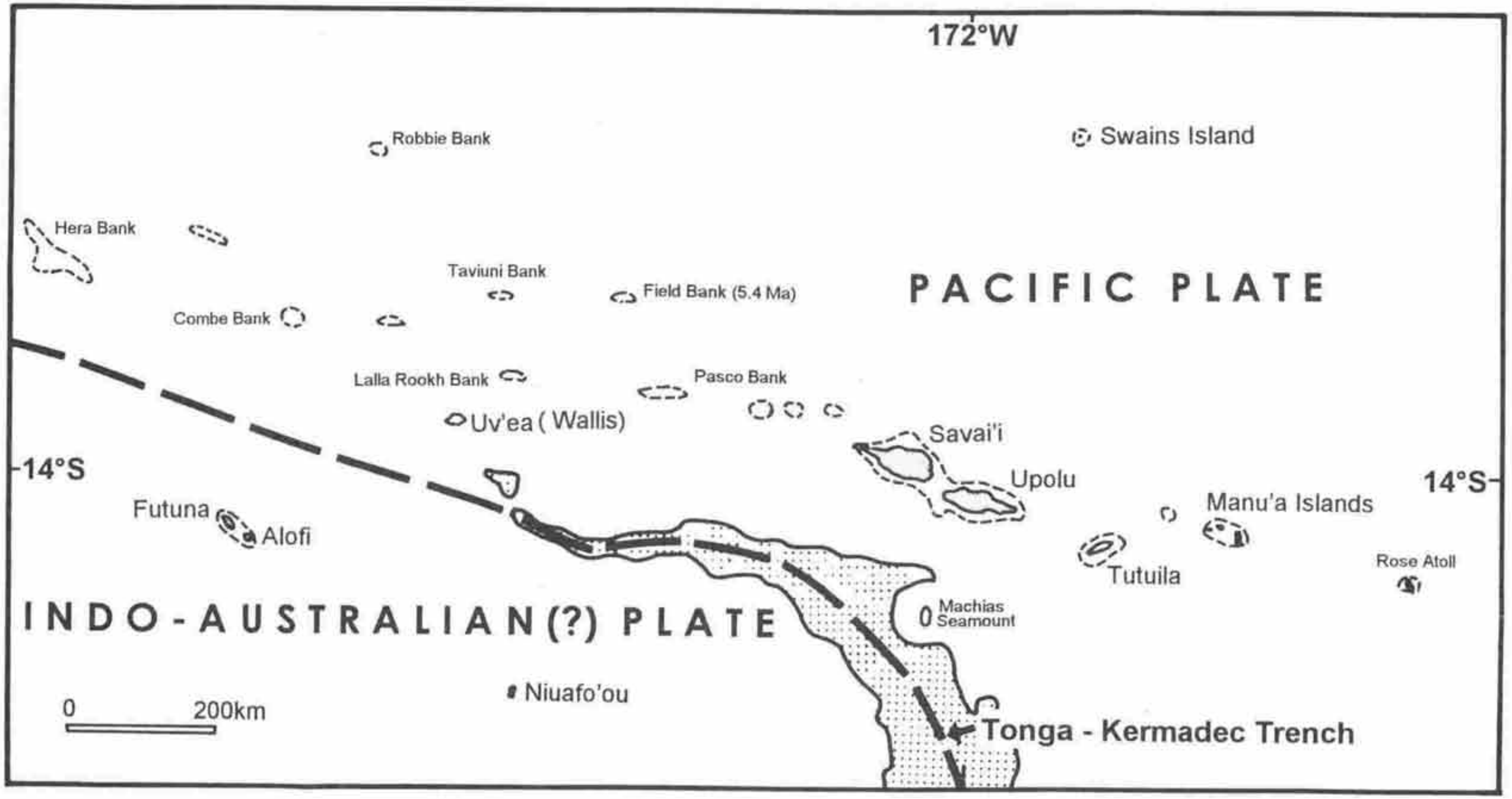


Figure 3.1. The islands of Western Samoa and the rest of the Samoa island-seamount chain (after Nunn, submitted) Major plate boundaries are also shown.

3.1.3. Recent land/sea-level changes on Upolu in Western Samoa[1]

One of the earliest observations relating to land/sea-level changes on Upolu was that of Jensen who, despite finding "no marked indication of raised beaches" (1907: 646), clearly believed they (had) existed and emphasized the absence of evidence for submergence which Dana (1849) speculated may have affected the western end of the island.

Friedländer (1910) thought that the estuaries of Upolu were drowned, indicating recent submergence. The likelihood of recent fault movement as an explanation for the `drowned' bays of Upolu was highlighted by Thomson (1921) especially for Fagaloa Bay. Coastal plains covered by coral sand in Aleipata and Salufata may have been uplifted. But this could not have been uniform or widespread, Thomson argued, since no parts of the old reef were exposed. Yet emerged reef was observed by Stearns (1944) on the modern reef flat at Fagali'i Bay and corresponded, he believed, to the 1.5 m emergence he thought to have affected American Samoa. Stearns also reported emerged cliffs and (intertidal) flats raised 1.8-2.4 m above sea level on Upolu.

A contrary view was taken by Mayor (1924) who reported that Upolu did not show the emerged shore platform, so widespread in American Samoa, and speculated that this was the result of a slight submergence of Upolu.

In their 1959 account of the geology of Western Samoa, Kear and Wood found sedimentary evidence of emergence at 1.5-2.4 m (Tafagamanu Sand), 4.6 m (Nu'utele Sand) and 9 m (Vini Tuff). The latter two levels are found almost exclusively on the smaller islands in Western Samoa. Kear and Wood also reported erosional shorelines at higher levels on Upolu, particularly southeast of Falelatai and around the sides of Fagaloa Bay where "a single bench, imperfectly measured as 130-200 ft [39.7-61 m] above sea level, was noted" (1959: 59). Schofield (nd) noted probable wave-cut platforms 5.5 m above low-tide level at Lalomanu and Le'auva'a.

On the offshore islands of Upolu, a 9 m emergence was tentatively recognized by Kear and Wood (1959) in the Vini Tuff. They believed it marked a Last Interglacial (~125,000 BP) sea level. On all islands composed of Vini Tuff, the presence of finely-bedded molluscs and coral sand is found to a maximum height of 9 m. The apparent uniformity of this emergence was clearly one important reason why Kear and Wood (1959) regarded it as a eustatic rather than a tectonic level.

Also found only on the smaller islands in Western Samoa is the Nu'utele Sand which represents a 4.6 m emergence believed to be of Holocene age (Kear and Wood, 1959). This deposit rests mostly on weathered Vini Tuff and comprises rounded gravel with coral fragments. Kear and Wood (1959) thought it was contemporary with the emerged shore platform at the same level at Gataivai on Savai'i.

As indicators of recent tectonics, low-level indicators of shoreline displacement are more important because they are both clearer and more numerous. The 1.5 m emergence, recognized by Kear and Wood (1959) on the basis of the Tafagamanu Sand, accounts both for the flats on which many coastal villages are built on Upolu and also for the sand spits such as the Mulinu'u Peninsula in Apia and that at Vaie'e on the island's south coast. Kear and Wood (1959) regarded shore platforms 1.8-2.4 m above sea level on the coast east of Apia as coeval with the Tafagamanu Sand level, which they regarded as being formed at a higher sea level, dated at the type site to 1180±55 BP (Grant-Taylor and Rafter, 1962).

[1] This account is largely from that of Nunn (submitted) with other references included therein.

Principally because of the accordance in height between remnants of low-level shorelines, Kear and Wood (1959) regarded them as having emerged as the result of a sea-level fall rather than uplift (eustatic rather than tectonic), the character of which would more likely be uniform than differential in such situations. This is not wholly satisfactory reasoning and it is significant that subsequent investigations brought the role of tectonics much more to the fore than it has been previously.

The next phase of research on Upolu was carried out by archaeologists trying to calibrate late Holocene settlement history on Pacific islands.

Work at Lotofaga on the south coast uncovered an ancient settlement on the Tafagamanu Sand which came to be regarded by the investigators as a "largely cultural" rather than a natural deposit (Davidson, 1969: 232). Yet it was also regarded as the product of emergence for

> "at the edge of the present beach, exposed at low tide, is an old coral reef. The area between this reef and the base of the cliff, which is now occupied by the cultural deposits under consideration, must at one time have been part of a lagoon. It seems that change in the land/sea-level caused this reef to become "raised" and sand to accumulate behind it, forming the surface on which the cultural deposits later accumulated" (Davidson, 1969: 232).

A minimum age for this emergence is provided by the date obtained from the cultural deposit of 735±85 BP (Davidson, 1969). In her summary of the prehistory of Western Samoa, Davidson (1979) favoured the idea that a uniform inundation of the Upolu coast had occurred.

Contrary to the interpretation of Kear and Wood (1959), the conclusion of archaeologists who had excavated sites in the Tafagamanu Sand was that "varying degrees of uplift of the land" (Green and Davidson, 1974: 223) had been responsible for associated emergence. Like Kear and Wood's (1959) ideas, this seems to be an inference based on prevailing wisdom rather than a deduction based on field evidence. It was an inference that was rapidly called into question with the discovery of the Ferry Berth site, widely cited as evidence of recent subsidence of Upolu.

The deepening of a turning basin for inter-island ferries at Mulifanua on the northwest coast of Upolu led to the discovery of a Lapita pottery deposit beneath a cemented coral/shell crust, the surface of which was about 1.8 m below sea level. The deposit paralleled the modern beach about 114 m offshore and comprised pottery in an organic `soil' matrix. The pottery included Lapita ware making it the oldest known settlement in Samoa. The zone of sherd concentration is approximately 2.7 m below mean sea level.

The first archaeologist to examine the site favoured "sudden local subsidence" as the explanation for the site being underwater (Jennings, 1974: 177). The pottery sherds exhibited no signs of comminution from wave attack which, argued Jennings, militated against the site having been submerged slowly. Sudden local subsidence of the type Jennings envisaged could be coseismic (coincident with large earthquakes) or related to landslides, as is common on the flanks of large mid-ocean volcanoes like Upolu.

Minimum dates of 2170±70 BP and 2890±80 BP for the settlement assumed to be associated with the pottery were obtained by Green and Richards (1975) from the overlying coral/shell crust. These authors favoured the interpretation of the site as indicating a stillstand of sea level 2.7 m <u>below</u> its present level around 3000 years ago during the postglacial sea-level rise. The reasons for this conclusion are not clear although the influence of the `Micronesia Curve' of Holocene sea-level changes, derived from the work of the CARMARSEL expedition in the late 1960s, was perhaps an influential factor. The CARMARSEL results indicated that sea level in part of the northwest Pacific had been rising up until present and, although the extension of this scenario to other parts of the Pacific has been questioned, it was an idea which was gaining popularity in the mid-1970s and undoubtedly influenced contemporary interpretations of submerged sea-level indicators such as that at Ferry Berth.

The view that the Ferry Berth site was the result of a lower- than-present sea level around 3000 years ago apparently convinced Jennings who subsequently favoured subsidence of the whole island of Upolu to explain it. Jennings (1976) cited unpublished work of Bloom (see below) in support of this view and also noted that Hawkins and Natland (1975) "have concluded that Upolu is subsiding at the rate of 1.5 mm per annum, a figure interestingly congruent with Bloom's estimates, and equally compatible with the 3 meters submergence of the Ferry Berth site since 3000 B.P." (Jennings, 1976: 7). This statement is based on a misreading of Hawkins and Natland who made no statement about the recent tectonic history of Upolu but noted that a date from a phonolite dredged from the surface of Machias Seamount, on the edge of the Tonga Trench about 180 km south of Savai'i, indicates "a subsidence rate of about 1.5 mm/yr" (1975: 431). The tectonic setting of Machias Seamount is entirely different from that of Upolu (Coulbourn et al., 1989).

Despite a lack of compelling evidence, the idea that Upolu had subsided about 3 m in the last 3000 years or so persisted and is still widely quoted. An alternative explanation for the Ferry Berth site has presented itself following the discovery of postholes at Lapita sites in Papua New Guinea (Kirch, 1988). The implication is that Lapita people may have lived in stilt-houses and thus the pottery level at the Ferry Berth site (and elsewhere) may bear no relation whatsoever to the contemporary shoreline level. Leach and Green (1989) tentatively inclined to this view.

Bloom reported several dates from peaty muds from Upolu's south coast which he interpreted as demonstrating "tectonic subsidence of Western Samoa in the Holocene, probably related to active effusive basalt volcanism" (1980: 508), a conclusion he supported by citing the Ferry Berth site. Bloom (1980) did not give the locations of his dated samples which is unfortunate since some parts of Upolu's south coast are unmistakably downfaulted. Neither did he explain whether allowance had been made for compaction of the peats, a factor which often causes them to be erroneously interpreted as indicating subsidence (Gill and Lang, 1977).

The work of the HIPAC (Hydro-Isostasy in the Pacific) team in Upolu specifically addressed questions of Holocene shoreline displacement. Sugimura et al. (1988) found emerged beachrock reaching 0.95 m above sea level at Safa'atoa and Matautu on the coast of Lefaga Bay in southern Upolu.

Recent unpublished work by Nunn in Upolu involved recording emerged shoreline indicators around the whole coast of the island, but especially along its southern coast. The highest- level indicator is the ~7 m notch found only on Nu'utele island. A ~1.5 m shoreline is more widespread. This comprises emerged notches, raised beaches and, at Fagali'i Bay, an emerged reef.

3.1.4. Recent land/sea-level changes on Savai'i in Western Samoa[2]

The observations of Jensen (1907) in the low, coral-sand covered Fasaleaga area of eastern Savai'i led him to believe that it had probably once been an area of sea floor, uplifted subsequently 1.8-2.4 m. He noted similar areas, including that at Safune, but was more doubtful about their origin. The idea of uplift to explain coastal plains in Savai'i was also favoured by Thomson (1921), particularly for those at Salealua (Matautu) and Fa'asalele'aga.

[2] This account is largely from that of Nunn (submitted) with other references included therein.

On Savai'i, the Tafagamanu Sand is commonly covered with Puapua Volcanics but can still be interpreted as a raised beach correlatable with a sea level 1.5 m higher than present (Kear and Wood, 1959). A date of 1850±80 BP was obtained from coral within the Tafagamanu Sand 0.92 m above sea level at Puapua (Grant-Taylor and Rafter, 1962).

At Ga'utavai-Gataivai on the south coast of Savai'i, Kear and Wood (1959) described an emerged notch and raised beach 4.6 m above sea level which emerged a minimum of 760±50 BP: another minimum age of 715±50 BP was obtained for the same site (Grant-Taylor and Rafter, 1962). This emerged shoreline was regarded by Kear and Wood (1959) and Keating (1992) as contemporary with the Nu'utele Sand found only on offshore islands.

Unpublished work by Schofield (nd) concerning coring of sea-floor sediments in Asau Harbour concluded that subsidence compatible with the 3 m since ~3000 BP which may have affected the Ferry Berth site on Upolu may also have occurred here. It is equally possible that rapid subsidence associated with earthquakes and/or submarine landslides has affected this site in the same way as the Ferry Berth site on Upolu has probably been affected.

Investigations by the HIPAC team in Savai'i concentrated on the western extremity of the island. An emerged notch at the back of the beach at Fagalele represents an emergence of possibly 2.3 m (Sugimura et al., 1988). At Cape Mulinu'u, the island's westernmost point, corals were found in emerged beachrock to around 1.05 m above present mean sea level (Sugimura et al., 1988). Beachrock, possibly above high-tide level and therefore likely to indicate emergence, is also visible east of Utuloa and near the Asau airstrip (Rodda, 1988). A caution was also expressed by Rodda:

> "many beaches and notches can be seen along the basalt cliffs of northern Savai'i, but most benches are flow tops, and most notches have probably not been cut at sea level - their elevations are almost certainly governed by the occurrence of breccia or tuff that is much softer than the flow basalt" (1988: 88).

The most interesting area observed by the present writer during recent fieldwork was on the south coast around Ga'utavai (near Gataivai) where the emerged reef flat and shore platform described by Kear and Wood (1959) was thoroughly examined. The landform has been interpreted as the product of localized thermal uplift, perhaps associated with the presence of a magma body close to the surface of south central Savai'i (Nunn, 1994).

3.1.5. Recent tectonic history - synthesis

The clearest evidence for emergence in Western Samoa is all low-level (< 10 m). Emerged shoreline indicators greater than about 2 m all tend to be congregated in small areas which suggests that the cause of their emergence was local rather than regional.

The 7-m emergence in Upolu is confined to the offshore tuff island of Nu'utele. This may lie on the (north/northeast) upthrown side of the well-marked south-coast fault between Saleapaga and Tuiolemu on the main island of Upolu. Recent movement along this fault may account for the comparatively high- level indicators of emergence on Nu'utele.

On Savai'i, the 4-m emergence of the Ga'utavai area has been attributed to localized thermal uplift (Nunn, 1994).

Lower-level emergence can all be explained by late Holocene sea- level fall. Contrary to the opinion of many earlier writers, we believe that there is no sound evidence of significant late Holocene submergence of Samoa.

The present tectonic condition of the Samoa group is difficult to discern in many places. There are areas, such as south-central Savai'i which may be slowly rising as the result of lithospheric upbending and/or heating. There are probably areas, like that around the Ferry Berth site in Upolu and that along the easternmost part of Upolu's south coast, which have experienced rapid subsidence during the Holocene. Yet the preservation of indications of recent emergence, particularly the Little Climatic Optimum high sea level at Poloa on Tutuila (in American Samoa), suggest that subsidence is not the dominant process affecting the islands at present. If it is, then it must be extremely slow. There is no unequivocal evidence of a uniform emergence of the islands in the last millennium so their general condition is most accurately described as stable for that period.

3.2. Sea-level changes in Western Samoa 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 (Hopley, 1987). It reached its present level around 6000 years ago and then, in most parts of the region (including Western Samoa), it rose above its present level by as much as 2 m and then fell.

The chronology of late Holocene sea-level behaviour in Western Samoa has become quite well known in recent years (Nunn, 1991). From evidence throughout the group, it seems that sea level reached around 1.5 m above its modern level between 2000 and 3000 years BP (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 for Fiji (Nunn et al., 1993).

The recent rise of both temperature and sea level have been measured in the Western Samoa region. Temperature and sea-level data are shown in Nunn (1992, 1993b). Temperature data for two stations on Upolu island in Western Samoa are shown in Figure 3.2. An unmistakable rise in temperature since the late 1970s at both stations is shown. By analogy with longer records (Nunn, 1992, 1993b), the Apia data may well be part of a more prolonged rise of temperature, comparable to global trends.

The data from the Honolulu tide gauge on the stable Hawaiian island of Oahu are shown in Figure 3.3. This record is probably valid for much of the Pacific Basin including Samoa (Wyrtki, 1990; Nunn, 1992). Sea level thus appears to have been rising in the Western Samoa region by about 1.5 mm/year since 1900. If one accepts the association of this sea-level rise with temperature rise since the end of the Little Ice Age (about AD 1800), then it was probably rising for the previous hundred years.

In Western Samoa there are no long-term tide-gauge records similar to that for Honolulu. In order to counter this difficulty for the south Pacific, several surveys of coastal changes at long-established settlements in the region have been carried out. These surveys involve the interviewing of elderly inhabitants of long-established coastal settlements about how the coastline of these has changed since the time that they can remember (Nunn, 1990b). The results from the four settlements studied in Western Samoa are given in Table 3.1.

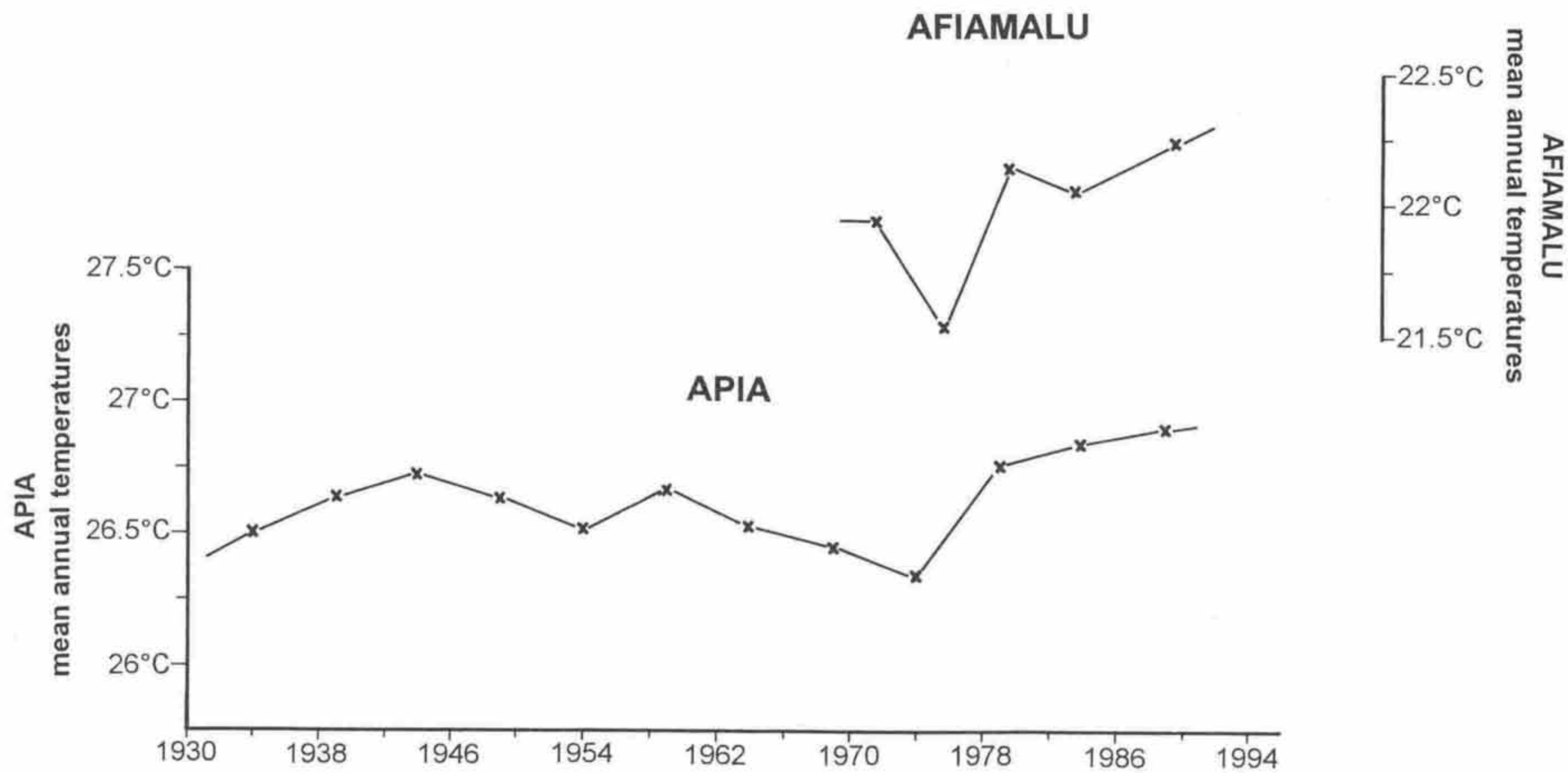


Figure 3.2. Variations of mean annual temperature in Western Samoa: at sea level at Apia and at Afiamalu on the crest of Upolu. Apia data are 5-year running means from 1932-1991, Afiamalu data are 4-year running means from 1970-1991 (1986 and 1987 not recorded). Data collected from Apia Observatory, Western Samoa, courtesy of the Government of Western Samoa.

Figure 3.3. The timescales of sea-level change in Western Samoa 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 Western Samoa 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).

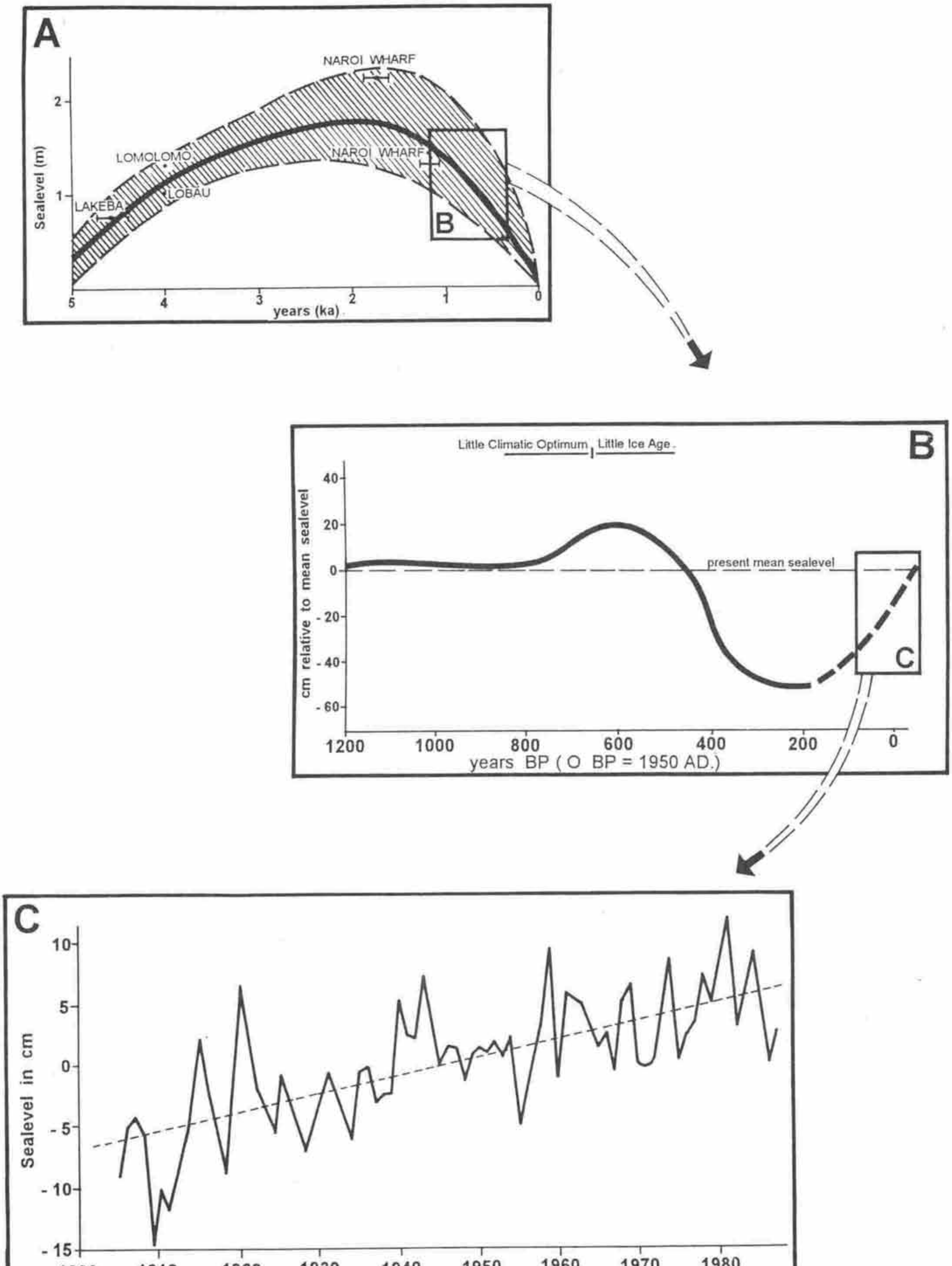


Figure 3.3. The timescales of sea-level change in Western Samoa over the past few thousand years (A. B. C.)

Table 3.1. Data relating to recent coastline changes in Western Samoa (from Nunn, 1990b)

Island	Site	a	b	c	d	e	f
Savai'i	Avao	59	+	?	?	1.9	32.2
Savai'i	Faga	59	+	1	1.41	1.15	16.2
Savai'i	Iva	71	+	?	?	0.8	13.56
Upolu	Satalo	69	+	70	101.5	3	43.48

Key to columns

a. Time span over which sea-level behaviour was observed, that is the average age of the village informants.

b. Direction of sea-level change over time span, that is rising (+) or falling (-).

c. Maximum shoreline inundation or emergence (m) in a lateral (earth-surface parallel) sense at average high-tide level.

d. Maximum rate of lateral inundation (cm/yr) calculated from a and c. Rates of shoreline emergence are indicated by negative figures.

e. Maximum vertical rise or fall of sea level (m) at high-tide level.

f. Maximum rate of sea-level rise (mm/yr) at high-tide level calculated from a and e. Rates of sea-level fall are indicated by negative.

From Table 3.1, it can be seen that the average rate of coastal inundation in Western Samoa has been 15 cm/year for the last 80 years or so. This is most probably a manifestation of sea-level rise. This sea-level rise has been crudely measured at Nataleira village in eastern Viti Levu in Fiji as being between 10-30 cm in the last 80 years - an average rate of between 1.25-3.75 mm/year (Nunn, 1990a).

A summary of the various timescales for coastal change in Western Samoa 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 Western Samoa. 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 are shown in Table 3.1.

More precise studies could be carried out using old maps and series of aerial photographs of particular areas. Several areas are thought worth studying.

(a) The area around the capital, Apia, Upolu. This has been the capital of Western Samoa (as it is now) since the earliest maps of the island of Upolu were made.

(b) Lealatele, Savai'i. This was the site of the first Catholic mission (established in 1845). Records of the Catholic Church in Samoa are available for consultation.

(c) The 'Iva-Tuasivi coast of Savai'i: a low-lying coast with a barrier reef and small islands in a shallow lagoon offshore facing the direction of dominant winds. This coastline is one of the most changeable in Savai'i as the frequent relocations of the coastal road demonstrate. Map exists at 1:20,000.

(d) The Aleipata coast of Upolu: a low-lying coast with a barrier reef and small islands in a shallow lagoon offshore facing the direction of dominant winds. This coastline is one of the most changeable in Upolu as the frequent relocations of the coastal road demonstrate. Map exists at 1:20,000.

3.4. A baseline for future coastal changes in Western Samoa

It is important to be able to predict as clearly as possible the way in which particular coasts in Western Samoa will behave in the future. There are two reasons why knowing about past coastline changes is important.

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 <u>or</u> 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 <u>plus</u> a continuation of processes and changes that have prevailed in the recent past.

Secondly, it is of paramount interest to know <u>how</u> 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 3.4. The `background sea-level change' is that which has been observed in the Western Samoa 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 3.4, 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).

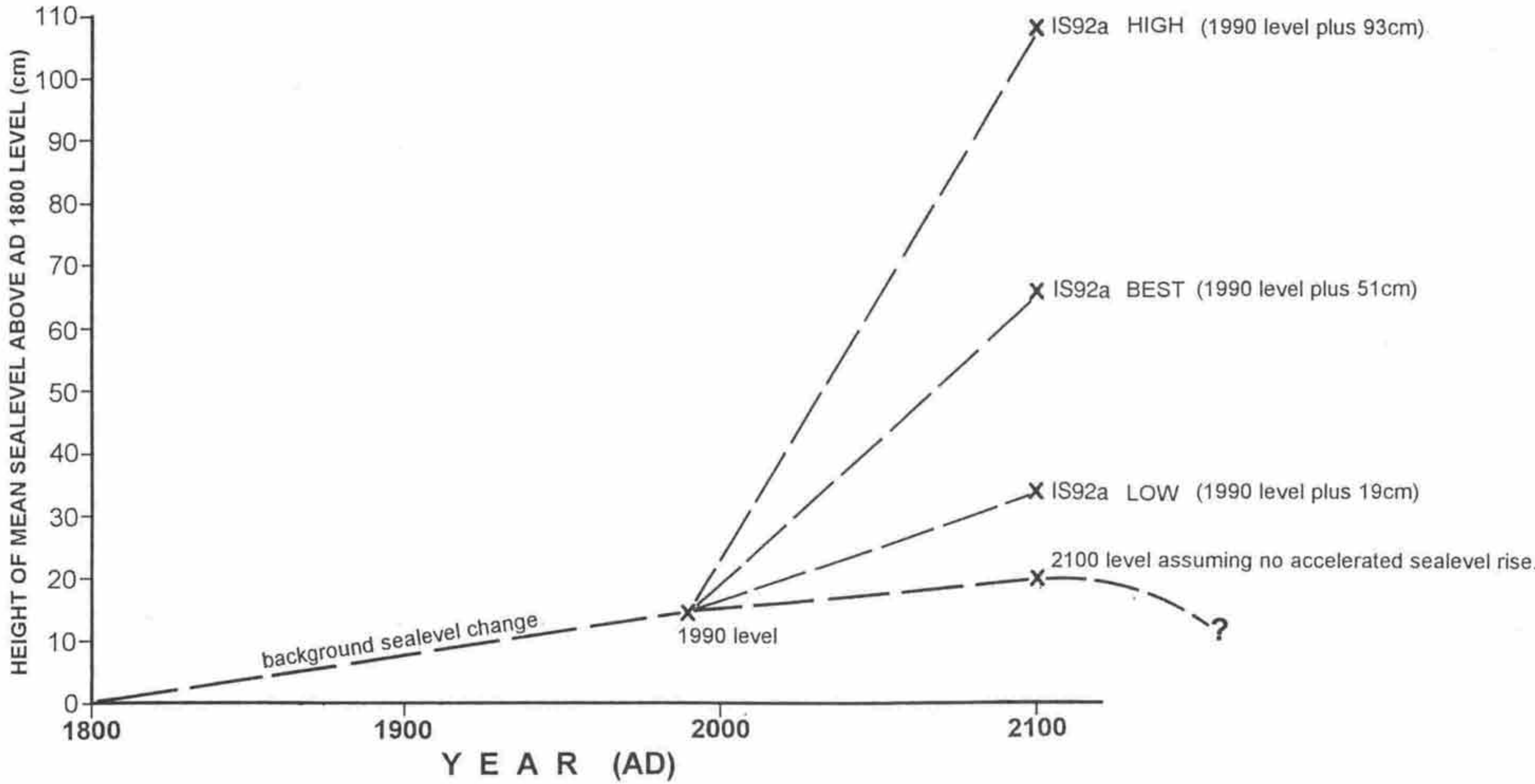


Figure 3.4. Scenarios for future sea-level and temperature rise in Western Samoa derived from measurements of these variables in the recent past and an analogy between this period and that of the Little Climatic Optimum

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 3.4.

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 3.4).

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 (see Table 3.1).

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.

Chapter 4. Development of the methodology

4.1. History of methodological development

One of the principal purposes of this study of Western Samoa 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 Kay et al., 1993). Another major purpose of the studies of Western Samoa and Fiji is to test the adaptations in realistic situations and modify them accordingly.

The major outcome of the Phase 1 studies in Western Samoa and Fiji (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 magnetized 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 therefore 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 Western Samoa and Fiji 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 Western Samoa as much as the physical characteristics of the islands. This highlights a major difference between subsistence economies, such as Western Samoa, and those of the wealthier nations. In Western Samoa, 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 Western Samoa.

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

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

- cultural bond between indigenous Western Samoans and their land;

- importance of extended family structures and communal activities;

- gift-giving and remittances as a mechanism for extended family economic resilience;

- 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;

- the day-to-day decision-making powers of village committees (*Fono*);

- 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 Western Samoa project (Kay et al., 1993) used an impact assessment technique which had a qualitative basis. Six "Coastal Systems" were used to characterize the coast of Western Samoa, as follows.

- natural

- cultural

- institutional

- infrastructural

- economic

- human

Each of these coastal systems was made up of a number of subsystems, shown in Figure 4.1 in the Phase 1 report (Kay 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 Western Samoa 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

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 decided against largely on the ground that it would have made the methodology somewhat 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 this possibility.

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 is the case in many rural settings in Western Samoa, 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.

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 3m 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 Western Samoa, if sea level rises, then offshore reefs (where they exist) 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 Western Samoa 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 and vegetation damage (Nunn, 1990b).

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. 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 species 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. For many years, the islands of Western Samoa were considered to lie outside the area which experienced tropical cyclones (hurricanes). The effect of Tropical Cyclone Ofa in February 1990 provided a dramatic reminder that such an area does not have fixed boundaries. The number of cyclones which have affected Western Samoa since Ofa suggests that it is now well within the `cyclone belt' and that a regular incidence of such storms should be considered in future development plans. The combination of an increased frequency of tropical cyclones 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 mid-ocean islands such as those in Western Samoa, 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 Western Samoa of the future. A `whole-environment' approach is needed and response options developed on that basis rather than for a single element of environmental change. Western Samoa has gone some way towards this by having prepared a National Environment Management Strategy (NEMS Task Team, 1993). 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 Western Samoa and two areas of Fiji. 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 Western Samoa and Fiji. 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 Western Samoa and Fiji.

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, the sites selected for testing the revised methodology in Phase 1 were all on the island of Upolu. It was a priority in Phase 2 that we select study sites from the periphery in order that the range of all possible sites in Western Samoa was realistically sampled.

In Phase 1 of this project (Kay et al., 1993), three sites were selected for the testing of the revised methodology. These were are follows.

(a) The rural coastline of Upolu as illustrated by

- (i) the coastlines of Safata Bay, and
- (ii) the Saleapaga to Lalomanu coastline.

The selection of two areas of rural Upolu reflected the wish to sample the 80% of Western Samoa's resident population who occupy the 362 villages, mostly along the coast. In such areas the traditional way of life is preserved. Safata Bay was selected largely because of its unique offshore reef-lagoon complex (including mangroves and depositional landforms). The Saleapaga-Lalomanu area is more representative of Western Samoa's rural coastline.

(b) The urban/commercial coastline of Apia, the capital city of Western Samoa, is obviously unrepresentative but was included as a case study in Phase 1 because of its manifest importance to the whole nation, not only as the commercial-industrial centre but as the cultural and administrative centre of the nation.

(c) Faleolo International Airport and Mulifanua Wharf were selected as the third case study because of their importance as national coastal infrastructure. Faleolo is the only international airport in the country. The wharf at Mulifanua is the departure point for the Upolu-Savai'i ferry, which is a vital facility for Western Samoa's population.

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, Apia is the core of Western Samoa. Minor cores occur at other major urban centres including that around the wharf on Savai'i and that between Vaisala and Asau in northwest Savai'i. Upolu's population is better dispersed and less clustered than that on Savai'i so minor cores are less readily identifiable.

Core areas are not typical of most of Western Samoa's coastline, largely because there is more money, commonly manifested as more investment in infrastructure, and thus 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 Western Samoa 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 major 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 Western Samoa, the government's efforts at rural development are far in advance of many parts of the `developing' world.

Although the larger of the two main islands in Western Samoa, Savai'i is unmistakably the periphery. Most people living there are largely dependent on subsistence harvesting, both from the land and the sea, for sustenance although cash received from relatives working elsewhere (on Upolu or overseas) is important. The terrain of Savai'i is not conducive to high levels of agricultural productivity. In contrast to most parts of Upolu, many parts of Savai'i are composed of such young volcanic rocks that these have not yet had time to break down and form soil. Cultivation is therefore carried out in pockets of `soil' formed in places between unweathered rock. On many of the older lavas, forest grows but this is being increasingly cleared causing problems of soil erosion and flooding in lower areas.

The coast of Savai'i was described in general terms in section 3.2 of the Phase 1 report (Kay et al., 1993). In parts of Savai'i, particularly along the south coast, reefs are absent and the offshore area plunges steeply into deep water. This situation exacerbates the difficulties of subsistence living on Savai'i. The point about this is that the way of life in the periphery on Savai'i appears marginal at present because of stresses which are not associated with sea-level rise. Mercifully, many parts of the Savai'i coast are well protected from the physical effects of sea-level rise in the future but others are not. Among these is the lowland area in the east and southeast of the island which includes Puapua (see section 5.4).

The two main types of coast on Savai'i are the `ironbound' coasts, common in the areas of young lava flows in the south, north and northeast, and the low-lying coasts made largely of superficial materials. One site was chosen for this study on each.

5.2. Summary of boundary conditions

The boundary conditions relevant to the methodological implementation of this study are a range of climatic and oceanographic parameters typical of a wider region in addition to the more specific features characteristic of Western Samoa.

5.2.1. Present boundary conditions

Present boundary conditions in the southwest Pacific are controlled by the close coupling of atmospheric and oceanic circulation patterns which involve transfers of heat, moisture and momentum. Present weather and climatic characteristics are dominated by several large-scale meteorological systems - the Inter-Tropical Convergence Zone and the South Pacific Convergence Zone. Both are low pressure regions of moist rising air which form at the convergence of tradewind systems in the north and south Pacific and also easterlies blowing along the Equator.

Associated with the convergence zones are large-scale circulation cells (Hadley and Walker) which operate along the Pacific equatorial zone. Interannually the Walker circulation between the Indonesian and South Pacific regions fluctuates in strength. This process represents the most significant meteorological feature in the Pacific, the El Niño - Southern Oscillation or ENSO. The location of convergence zones and wind patterns in the Pacific undergoes major shifts during ENSO (positive) and anti- ENSO (negative) events. The result is abnormal rainfall patterns, temporary changes in mean sea level and latitudinal shifts in tropical cyclone incidence.

In Western Samoa, seasonal rainfall decreases significantly during ENSO events while countries on the equator like Kiribati experience above average rainfall at such times. Droughts affect such countries during anti-ENSO events.

The characteristics of the Western Samoa climate were summarized in section 3.1 of the Phase 1 report (Kay et al., 1993). Recent changes in the Western Samoa climate, notably the rise in temperature and tropical-cyclone frequency are discussed in the same place and also in section 3.2 of the present report.

5.2.2. Future boundary conditions

Future boundary conditions in the Pacific are expected to be influenced significantly by continued climate and sea-level changes. The most authoritative global predictions for the future are those of the Intergovernmental Panel on Climate Change (IPCC) comprehensively reported in Houghton et al. (1990) and IPCC (1992). Sea-level figures based on revised emissions scenarios have been presented by Wigley and Raper (1992) and by Warrick et al. (1993).

Assuming that carbon dioxide proportions in the earth's atmosphere will double by the year 2050, which seems quite likely at present emission rates, earth-surface temperatures will increase relative to 1990 temperatures by an average of 1°C by the year 2025 and 3°C by the year 2100. By comparing this to the rate of temperature rise over the past century in the region (approximately 0.5°C in 100 years - Nunn, 1990e), this means that the rate of future temperature rise may be five times greater.

The effects of this temperature rise on sea level, through the medium of thermal expansion of the ocean surface and the melting of land-grounded ice bodies, were also modelled by the IPCC (Wigley and Raper, 1992; Warrick et al., 1993). They predict that sea level will rise relative to its 1990 level by an average of 46 cm by 2100 (IS92a BEST scenario) which means, in the absence of any region-specific predictions, 51 cm for Western Samoa (see section 3.4.1. and Figure 3.5).

This means that the future rate of sea-level rise will probably increase to around 4.5 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, 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). In addition, they are global averages and most experts believe that temperature rise in the tropics will not be as great as that in mid or high latitudes (Warrick et al., 1993).

Other boundary conditions which may change in the future relate to extreme events, primarily the El Niño - Southern Oscillation (ENSO) and tropical cyclones (hurricanes). It is unclear how ENSO periodicity will alter in a warming world. Studies are presently being carried out, including one at the University of the South Pacific, to examine ENSO periodicity at various times in the past millennium when temperatures were either slightly higher or slightly lower. Tropical cyclone frequency in the central Pacific is closely linked to sea-surface temperatures and is predicted to increase as the region enclosed by the 27°C isotherm increases in size (Holland et al., 1988; Nicholls, 1990; Nunn, 1993b).

Future boundary conditions in Western Samoa will be determined by localized interactions between various climatic and oceanographic parameters. No specific information is available for Western Samoa (or the other South Pacific island nations) from global climate models since their resolution is still too crude to permit islands as large as those in New Zealand to be modelled. The best predictions we have are little more than the products of reasoned conjecture (Aalbersberg et al., 1993).

A general increase in temperature throughout Western Samoa will bring about changes which will be most noticeable in summer (November to March). The most noticeable change will perhaps be in human comfort. Rising temperatures may impose constraints on the successful cultivation of particular crops.

It must not be forgotten that these climate changes will be associated with sea-level rise so plans must be made for simultaneous impacts. For example, lowland crops may be affected both by increasing salinization associated with sea-level rise and with stress associated both with rising temperature and a change in annual temperature regime. The third major factor to consider is human impact. If human-induced stress on ecosystems rises as the same time as does climatic stress, then the overall impact will be proportionately greater. Conversely, if human- induced stress on ecosystems can be reduced then these will be affected much less and may even prove resilient beyond expectations.

In the case studies which follow, estimates of future vulnerability and resilience of particular coastal situations is made using the above predictions.

5.3. Ga'utavai study site

5.3.1. Introduction

Ga'utavai village on the south-central coast of Savai'i island is one of many coastal villages of Western Samoa (Figure 5.1). Its shoreline is generally rock-bound consisting of hardened volcanic lava rock several thousand years old rising about 3-4 m above sea level. The island of Savai'i on which Ga'utavai is situated is still considered volcanically active with its most recent eruptions producing lava flows between 1905 and 1911 (Kerr and Wood 1959). Thus the placement of Ga'utavai near the coast may not only be interpreted as a means of close access to marine food resources and sea transportation but also as a way of avoiding any catastrophic event if the still active volcanic mountains of the inland erupt again.

Nevertheless, there is a trend at present for some coastal villagers to move inland where they have established garden plots and have built family homes. Such a move is partly due to increasing population pressure within some coastal villages but is also a response to adverse experiences in the two worst hurricanes of the last 169 years, Ofa and Val, which struck Western Samoa in 1990 and 1991 respectively. Although Ga'utavai is situated a few metres inland from the volcanic rock protected coastline, the effects of strong storm surges and winds are evident from the presence of defoliated plants and damaged houses.

In both Ga'utavai-Gataivai and Puapua, the second case study (section 5.4), evidence of outward migration of the population looking for wage employment in the urban centre of Apia on Upolu island and elsewhere in the Pacific is seen from the presence of Western-type buildings in the two villages as well as in other villages. The daily ferry services which run between Savai'i and Upolu are usually full to capacity conveying workers (not migrants), shoppers and visitors to and from Savai'i.

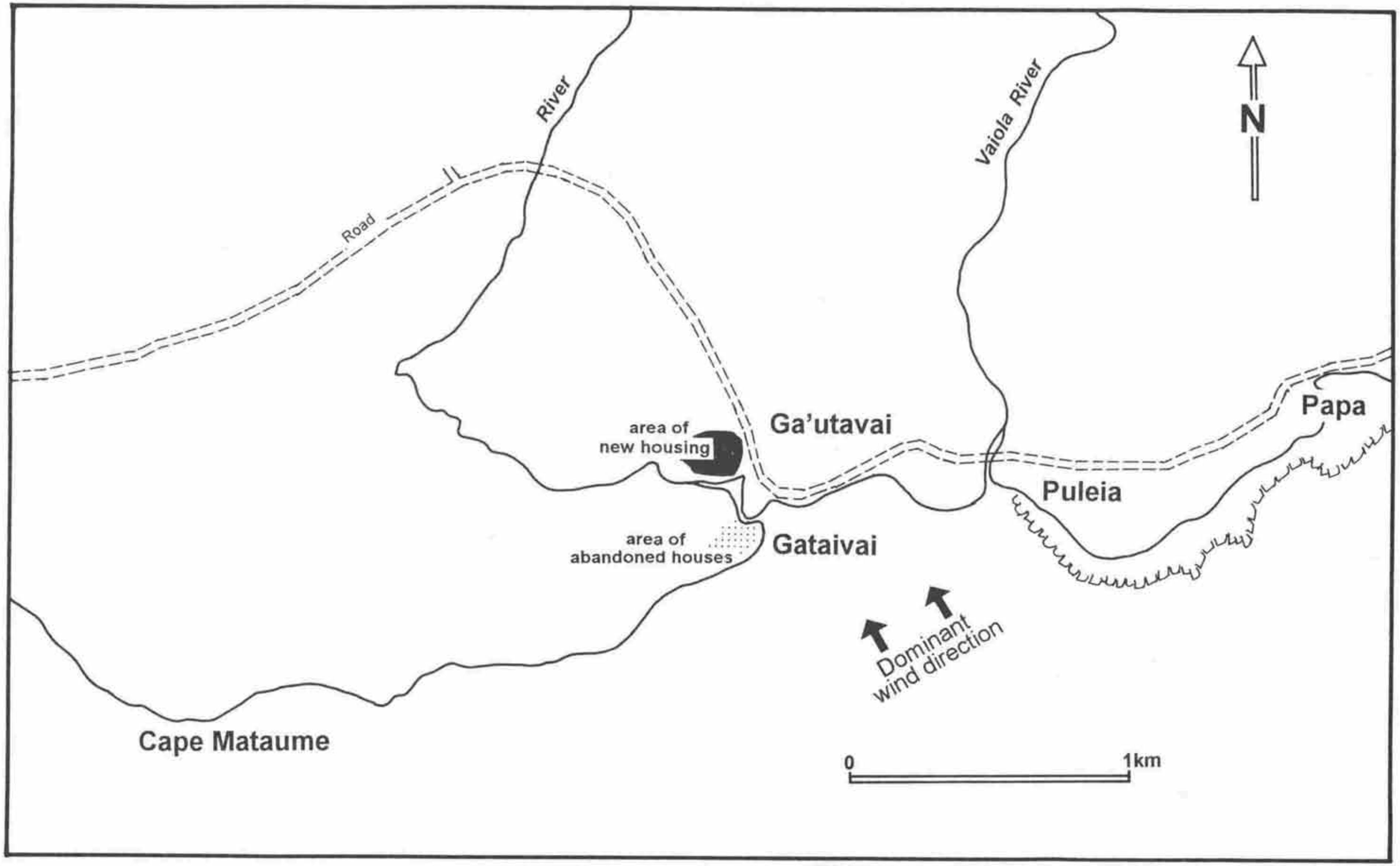


Figure 5.1. Location of the Ga'utavai-Gataivai site on the south coast of Savai'i

5.3.2. Physical elements

The south-central coast of Savai'i around Ga'utavai is composed of basaltic Puapua lavas, erupted probably only a few thousand years ago from two major inland centres. There is no evidence for younger (Aopo) volcanic activity in the immediate area. Where Puapua lavas meet the coast, they have been cut back to form a bench 4.6 m (15') above mean sea level.

Kear and Wood (1959) thought that the surface of this bench was cut when sea level had been higher than at present. Sharing this conclusion, Nunn (1994) noted that it was highly unlikely that sea level had exceeded 2 m in this area during the last 10,000 years and therefore concluded that the site had also been uplifted during the last few thousand years, possibly as a consequence of underground heating associated with a magma body.

Corals in growth position are found across the surface of the platform in the Ga'utavai area testifying to it having once been occupied by the sea. Corals from here or possibly a site close by were dated by Grant-Taylor and Rafter (1962) to 715 and 760 years BP.

Across the mouth of the Lata River, west from Ga'utavai, lies Gataivai which is founded not on lavas but from the products of explosive eruptions, best described as pyroclastics. In contrast to Ga'utavai, the Gataivai area is low-lying and there is no sign of the 4.6 m platform.

The Puapua rocks in the Ga'utavai-Gataivai area are only a little weathered, soils are thin and discontinuous. Where pyroclastics dominate over lavas, the ground surface is noticeably uneven. Volcanic terraces occur at the edges of younger lava flows, where these did not extend as far as the older flows underlying them.

There are no offshore reefs along Puapua lava coasts which demonstrates that erupted material was sufficiently voluminous to have covered pre-existing reefs a few thousand years ago. The existence of the emerged corals at Ga'utavai and ephemeral living `reefs' elsewhere in the vicinity (at Nu'u, for example) show that the potential for coral growth has certainly existed for around 800 years at least.

The physical vulnerability of the modern coastline in the area is highly variable. At Ga'utavai, where the coast is fronted by a 2-3 m wall of lava, it is hardly vulnerable to coastal erosion regardless of the lack of offshore reefs. Across the bay at Gataivai, the absence of offshore reefs is highly significant as the coast is low-lying and gently sloping, possibly the worst possible geometry for such a coast. These contrasts between the two sites is manifested by the human responses to recent storm surges. At Ga'utavai, although the houses are not close to the shore, there are no signs to recent disruptions to human activities as the result of storm surges. In contrast, the foreshore at Gataivai is dotted with the remains of fales and other structures abandoned and/or destroyed during recent storms. None of the area is particularly well vegetated.

Present physical vulnerability of the site is scored as -2, reflecting both the high vulnerability of Gataivai and the low vulnerability of Ga'utavai. In the future, should sea level rise as predicted, the vulnerability of the Ga'utavai part of the site will hardly change, although the spray zone may extend marginally further inland. The vulnerability of the Gataivai site will increase. Optimal management for the protection of this site would involve construction of seawalls but, owing to the large low hinterland, preservation of the coastal strip here is unlikely to become a priority.

Present physical resilience is as variable as vulnerability across the study area. Resilience will decrease throughout in the future but more substantially at Gataivai than at Ga'utavai.

5.3.3. Biological elements

In biodiversity terms, the present Ga'utavai study site is very poor. On the bare lava rocks of the shore area between the main coastal road and the cliffs, no vegetation of any significance is present, only some grass at the roadside. On the landward side of the road, there is some vegetative biodiversity and biomass in between and behind the irregularly-spaced village houses.

On the coast at the river mouth separating Ga'utavai from Gataivai, the bare lava is gradually replaced by sand and some coconut trees are growing. East of Ga'utavai, a mature coconut plantation is growing on the flat lava outcrop there. The areas around the village houses have a somewhat bare, stony appearance.

There is no lagoon in front of the village, since the reef that once existed was covered several thousand years ago by lava. Open sea and deep water is found immediately seaward of the low (± 2.5 m) lava cliffs. The marine ecosystem is therefore far less complex and sensitive than if there was a lagoon. The marine fauna associated with reefs and lagoons are absent.

Owing to the sparse vegetation, both the present biological vulnerability and resilience are low (Table 5.1). Most certainly at least one recent major cyclone has adversely affected Ga'utavai's vegetative biodiversity and biomass.

Under no-management conditions the future biological vulnerability and resilience would likely remain unchanged, both remaining low.

Under optimal-management conditions the future biological vulnerability and resilience could increase from low to moderate. Unlike the Puapua study site (section 5.4) where a low-lying coast vulnerable to erosion and flooding might prompt the villagers to try and increase coastal vegetative biodiversity and biomass by actively planting salt-tolerant species, the Ga'utavai study site is a lot less dependent on protection involving biodiversity; most of this site's natural protection is provided by its `ironbound' shoreline.

Owing to the natural protection provided by the lava-armoured coast against external stresses such as sea-level rise impact and climate change, there will be little or less incentive and therefore less contributing activity in promoting protective biodiversity than in Puapua.

Yet it would be still wise to do so, not only for protecting the road, but also to provide protection for the village infrastructure and crops from wind and salt-spray damage. The effectiveness of this will depend on the species chosen and their spacing.

The real major or tangible benefit from the villagers' point of view will be the increased sustainability of the natural resources for subsistence harvesting, such as for the harvest of timber (*fale* posts, woodcarving, canoe making) and some firewood.

By enhancing biodiversity under optimal-management conditions, the future biological resilience through increased vegetative biodiversity will increase as will biomass. The future biological vulnerability will increase too as a consequence.

5.3.4. Human elements

The Ga'utavai-Gataivai centre is an important one in southern Savai'i, occupying one of the few low areas in the south-central and south-west parts of the island's coast which is also supplied with fresh water. The absence of a broad fringing reef is a disadvantage for subsistence agriculturists but is one shared by many coastal communities on Savai'i.

Compared to the rest of the island, population density in Ga'utavai-Gataivai is high. Much of the population now lives well back from the shoreline. This is true of both urban centres but especially for Gataivai where the spread of the settlement is much greater inland than on the 1964 topographic maps. Many abandoned *fales* are visible on the shoreline at Gataivai.

Population vulnerability is presently quite high (-1) but has clearly been lessened by population movement inland in recent years. Resilience refers to the numbers of protected population, which is higher in Ga'utavai than in Gataivai, where most houses are liable to be affected by storm surges which are funneled into the river estuary here. Present resilience is scored at +1.

In the future, if no management is undertaken, then the situation will deteriorate, particularly for Gataivai. Optimal management solutions might involve building seawalls along the shoreline around the river mouth but shifting the settlement further inland might prove less expensive.

5.3.5. Infrastructural elements

Ga'utavai and Gataivai villages are located in an irregular manner along the southern coastal main road. Most houses and shops are some 30 m from the lava-armoured coast, with the coastal road in between the nearest buildings and the shore. No communal buildings are close to the shore.

The coastal main road is a wide tarsealed road in good condition and is the only infrastructural element of national importance in the area. At Ga'utavai, the road follows the lava-armoured coast line and turns inland (going westward) avoiding the creek, across which Gataivai is actually located.

The coastal area of Ga'utavai is elevated above present sea-level by approximately 2.5 metres. Parts of Gataivai reach 6-8 m above mean sea level, most of the settlement is on the 3 m platform.

With only one infrastructural element of national importance, the present national infrastructural vulnerability is low. The elevated lava-armoured coast offers some protection against external stresses, therefore the present national infrastructural resilience is moderate.

Owing to some houses relatively near the road the present infrastructural vulnerability is moderate, while the present communal vulnerability is low. The present individual and communal infrastructural resilience is low as none the buildings are protected against external stresses.

Under no-management conditions, the future individual infrastructural vulnerability would increase from moderate to high, by expecting more individual buildings in the same area being built to accommodate the likely increase in population. Similarly the future communal infrastructural vulnerability would increase from low to moderate, expecting more communal buildings in response to the likely increase in individual infrastructural development.

Under no-management conditions, the scores would remain unchanged for the national infrastructural vulnerability and resilience, respectively low and moderate.

Optimal management would maintain the future individual infrastructural vulnerability as moderate, and both the future communal and national infrastructural vulnerability as low.

New individual and communal buildings would likely be built further inland and would be protected against increasing external stresses, improving their future infrastructural resilience from low to moderate.

Future national infrastructural resilience would remain moderate, with still only the one coastal road of national importance. This could be relocated without disturbing the (present) village too much.

5.3.6. Institutional elements

The authority over all the land belonging to the 'aiga is in the hands of the matai. He has power to grant rights of use to 'aiga members. He, however, cannot alienate 'aiga land without the consensus of the members of his 'aiga. Usufruct rights are heritable with the approval of the matai of one's 'aiga. 'Aiga land normally includes village house lots, gardens, plantation lots, and family reserve sections - particularly in taro gardens and swiddens. Family reserve sections usually run in strips from the coast into the mountains. There are also village lands. This category includes firewood and herbal medicine gathering areas, beach-fronts, reefs and lagoons, playgrounds and unused lands which may be claimed by the 'aiga through use and occupation which in turn comes under the matai's control. There are also lands belonging to traditional Samoan district councils consisting of the highest-ranking matai of the district villages. This consists of high mountain lands used primarily for hunting and gathering.

Although 'aiga land is controlled by its matai at the village level, the state traditionally acted as trustee in perpetuity over all Samoan lands. This, however, has been changed since independence in 1962, whereby all land has been classified into customary, freehold, and public lands. Customary land is no longer held in trust by the state. The government, however, does not allow the alienation of customary land but it authorizes and regulates the granting of licenses and leases of customary lands; and it could also take it for public (national interest) uses. In addition, all land below the high-water mark has been declared public land. The Land and Titles Court has been retained, and it continues to settle disagreements over succession to matai titles and authority over land. Decisions made by the Court are not subject to appeal. Recommendations of the village fono heavily influence decisions made by the Court.

Matai leadership and control have survived for more than five hundred years and changed very little. Even the 'aiga and village identities are little affected. Land allocation and usages are still very much managed by the 'aiga and village fono through its matai and are thus less vulnerable to external forces and demands.

The flexibility and resilience of traditional institutions to accommodate change can be observed only from the few changes that have occurred. These have come about as a result of new economic demands where the market economy and cash benefits have become important elements in the lives of the Samoans. For instance, there is an effort to encourage individual land tenure within the framework of 'aiga and public land controlling authorities through occupation rights and leases. In another example, an Alienation of Customary Land Act was passed by Parliament (1965) allowing the matai to lease customary land for economic development purposes but still with the approval of the Ministry of Lands. An act was also passed in 1977, allowing the Western Samoan Trust Estates Corporation (WESTEC), a public corporation, to sell some of its lands as free holdings for development.

At the village level the vulnerability of such institutional elements is rated at -1 and resilience is +1. At the national level, vulnerability is nil (0) and resilience is also nil (0).

5.3.7. Economic elements

Ga'utavai villagers are to a great extent living a subsistence mode of life whereby they still depend a great deal on what they can produce from their biophysical environment. Taro (Colocasia esculenta), yam and bananas are the main food crops grown, and these are complemented by manufactured foodstuffs from the shops. Marine products supplement such food crops, and both are sold for cash. Since there is not much that can be grown from the thin soil covering of the weathered lava rocks, the varieties and amounts of root and tree crops that can be produced for subsistence and cash are very limited. Apart from taro (which is at present badly affected by a leaf blight - section 5.4.7), yam, and a few tree crops such as banana, breadfruit, coconut, and pineapple, marine and forest resources - particularly timber and fish - are sold for cash. Handicrafts such as mats are also sold for cash. Although coconut is the main tree crop grown on the island of Savai'i, this (during the study visit), still bears the scars of the last hurricane which struck the islands. Not many nuts could be gathered from them for another six months or more. Breadfruit has yet to revive fully.

Increasingly, the villagers of Ga'utavai have to depend on wage employment and cash remittances from relatives working in Apia and overseas to subsidize their subsistence and cash needs.

On the whole, the study site is economically vulnerable and inflexible and rated at -1 and nil (0) respectively for cash, and -3 and nil (0) for subsistence flexibility.

5.3.8. Cultural elements

Ga'utavai villagers, like many other Samoan villagers are organized in family groupings known as 'aiga. Each village is administered by a fono (council) consisting of matai heads or chiefs from each 'aiga. Although a Samoan villager can claim relationships with several matai in his or her village and others, in reality he or she is most closely related to the matai of the 'aiga in which he or she resides. To become a matai, a Samoan must show a strong commitment to the welfare of the 'aiga, by providing services and satisfying 'aiga obligations and demands.

Decisions made within the village fono are generally achieved through consensus strongly influenced by deference to the titular head or ali'i (high chief), who is supported by the tulafale (talking chief). The latter oversees the implementation of such decisions among the members of his 'aiga.

It is observed from the above that the traditional social and cultural system is still very much highly communal and well established both at village and national level, as evidenced by the government's recognition of the traditional system and its incorporation into most aspects of national decision making. Matai control within the village is still very strong. Although universal adult suffrage is now practiced, only the matai continue to be members of the village fono and the national parliament. The traditional Samoan way of life still very much dominates people's activities both at village and national level.

The traditional culture of Western Samoa is still strong locally, as evinced by paramountcy of the village-level decision making process, discussed in section 5.3.6 above and also in section 5.1.2 of the Phase 1 report (Kay et al., 1993). It is, however, a culture in transition, one which is being permeated by changes introduced from outside.

This area has a traditional culture which is vulnerable to change (-2) yet which has demonstrated a degree of resilience (+2) which some may find surprising. In the future, this situation is unlikely to change substantially if sea level rises as predicted although it may lead to an increase in migration and thus an increase in cultural interchange and breakdown.

In a national sense, the particular culture of the Ga'utavai-Gataivai area is unimportant, a status which is unlikely to change in future.

5.3.9. Response options

Response options are generally few in the Ga'utavai-Gataivai area because of the very high vulnerability and limited flexibility of the various elements discussed above. The only options readily available are outward migration for cash employment and increasing dependence on international aid. The increasing involvement of the villagers in the cash economy to cater for their changing lifestyle and eating habits, and the limited availability of natural resources to cater for their subsistence and cash needs has made and will certainly increase outward migration for the inhabitants not only of the study site but for the Savai'i population as a whole.

Table 5.1. Ga'utavai 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	-2	+2	0	-3	-2	+1	+2	-2	0
	biological	0	0	0	0	0	0	+1	0	+1
Cultural	communal	-2	+2	0	-3	-2	+2	+2	-1	0
	national	-1	+1	0	-1	-1	+1	+1	0	0
Institutional	village	-1	+1	0	-1	-1	+1	+1	0	0
	national	-1	+2	+1	-1	-1	+2	+2	+1	+1
Infrastructural	individual	-1	0	-1	-2	-1	0	+1	-2	0
	communal	0	0	0	-1	0	0	+1	-1	+1
	national	0	+1	+1	0	0	+1	+1	+1	+1
Economic	subsistence	-3	0	-3	-3	-2	0	+1	-3	-1
	cash	-1	0	-1	-1	-1	0	0	-1	-1
Human	populations	-1	+1	0	-2	-1	0	+1	-2	0
Average Sustainable Capacity Index										

5.4. Puapua study site

5.4.1. Introduction

A priority in the Phase 2 study is to look at Savai'i, the larger, generally less developed in terms of infrastructure and economy, island in Western Samoa.

Puapua is the second of two selected case study sites on Savai'i for assessing coastal vulnerability and resilience to sea-level rise and climate change.

Puapua village, the second study site, is on the eastern side of Savai'i (Figure 5.2). It is situated in a sandy embayment which displays the effects of strong winds and storm surges during the two recent hurricanes mentioned above. The Puapua site shoreline is much more exposed to storm surges and coastal erosion and thus it is much more vulnerable to natural disasters than Ga'utavai (section 5.3).

Puapua is a typical Samoan rural coastal village of above average size, still very dependent on its subsistence economy. It is spread out along the coastal main road in close vicinity to the beach, and is facing a shallow lagoon with a wide fringing reef. It is located on Mulifanua volcanic rocks rather than on its namesake volcanics slightly to the north. Its coastal zone is only slightly elevated (< 2 m) above the present sea level. Consequently the integrated coastal system is uncommonly vulnerable to the impact of sea-level rise and climate change. Its biological diversity is rather limited and has a low resilience.

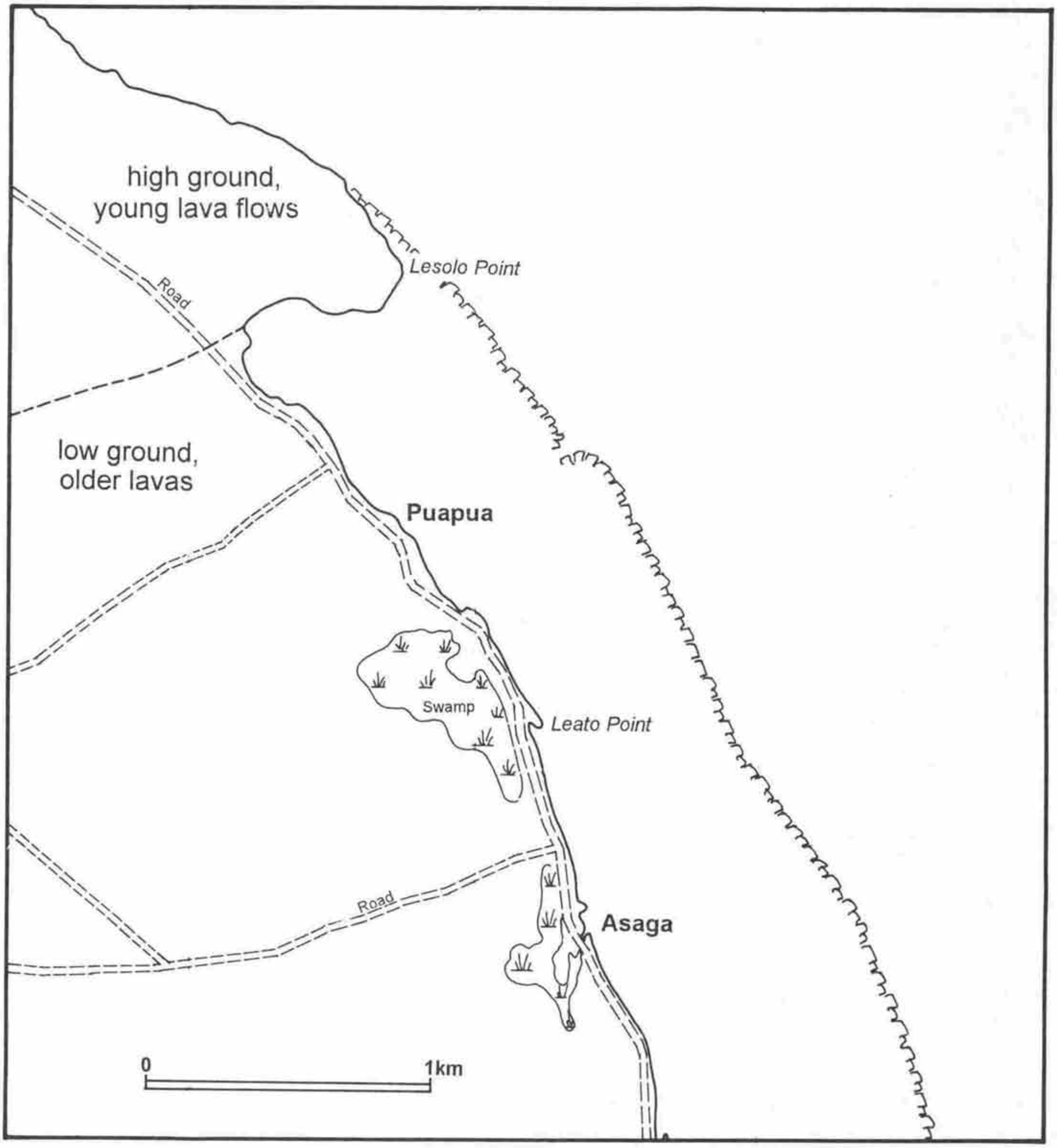


Figure 5.2. Location of the Puapua site on the east coast of Savai'i

5.4.2. Physical elements

The settlement of Puapua (Pu'apu'a) is built largely on rocks different from those to which its name has been given. The Puapua basalt lavas occupy a large area north of the settlement and were formed a few thousand years ago. Puapua itself lies on the older Mulifanua volcanic rocks, eruptions of which in eastern Savai'i were confined to the Fa'asaleleaga coastal plain at the northern extremity of which lies Puapua. Kear and Wood (1959) suggested that, on account of their distribution in eastern Savai'i, Mulifanua lavas flooded over an old coral reef. It seems possible that Mulifanua eruptive centres in the area were parasitic on the flanks of earlier Salani volcanic rocks.

The Mulifanua Volcanics are assumed to have been erupted late during the Last Interglacial, about 120,000 years ago. Although these rocks are conspicuously unweathered compared to many older volcanic formations, they form a much more subdued landscape and support thicker soils than the Puapua Volcanics to the north and elsewhere (see section 5.3.2).

Locally, the coastal rocks in Western Samoa are covered by the Tafagamanu Sand, a sand-gravel mixture formed from beach sand, colluvium and alluvial deposits. In many places, Kear and Wood (1959) and Nunn (1991) regard the Tafagamanu Sand as indicating a higher-than-present sea level within the last few thousand years. Dates from shells and corals within the Tafagamanu Sand range from 735-1180 (Davidson, 1974; Grant-Taylor and Rafter, 1962).

Most of the settlement of Puapua is founded on Tafagamanu Sand, which has evidently filled an embayment in the Mulifanua bedrock cut when sea level was slightly higher, a few thousand years ago. At the northern end of Puapua, just where the road rises onto the younger Puapua lavas, there is an small cliff on the landward side of the road in which beach sand of probable Tafagamanu Sand age is buried by Puapua lavas. This indicates that the high sea level at which this beach formed predated the eruption of these Puapua lavas.

Like the other Mulifanua-Tafagamanu coasts in eastern Savai'i, that around Puapua is exposed and comparatively vulnerable to damage both by storm surges and by normal processes of coastal erosion. Unlike those coasts where sediment is accumulating as a result of upland soil erosion, this coastline shows every sign of recession in recent decades. The beach front is generally steep, collapses are plentiful, there is little vegetation at the back of the beach. Houses built on land reclaimed at the front of the beach show signs of collapse and in many cases have been abandoned already.

The area was badly affected during Tropical Cyclones Ofa (February 1990) and Val (December 1991), the road being largely washed away and the superficial covering of many beaches being blown inland. The degree of recovery of many beaches, including that at Puapua is good; sand now covers the areas where beachrock was exposed after the cyclones. Elsewhere along this coast, presumably in locations where sediment supply from offshore reefs to shorelines is less and less dependable, such as in the Vaimaga-Fatausi area, beachrock remains exposed.

In response to damage during Ofa and Val, settlements like Puapua have moved further inland and some attempt has been made to plant the areas between the houses and the sea in order to stabilize them. This process is not well advanced at Puapua.

Physical vulnerability of the Puapua site is high, resilience is low. The whole site appears to be in disequilibrium, not yet recovered from the impact of the two cyclones. Should another cyclone affect the site in the near future, it is likely that the damage will be similar to that associated with Ofa and Val. The offshore coral reef at Puapua is probably under a degree of stress from human activity, a problem compounded for

Western Samoa by the poor health of its reefs compared to those in neighbouring countries (Chase and Veitayaki, 1992).

Should sea level rise as predicted, it is likely that Puapua and every site like it along the low eastern coasts of Savai'i will experience increased vulnerability and lowered resilience. Offshore reefs are unlikely to be able to respond effectively to sea-level rise resulting in larger waves crossing the reef than do at present. The coastline is already exposed; increased wave energy and sea-level rise along the shoreline will increase this exposure.

Under conditions of no management, it is unlikely that human occupation of this site could be sustained in the future. Optimal management would involve artificial structures but, given the length of the coastline and the consequent high cost of such solutions, it is more likely that the settlement will simply move inland.

5.4.3. Biological elements

In biological terms, the Puapua study site is comparatively impoverished. The biodiversity is very low and its biomass is also low.

It is obvious that cyclones Ofa and Val have taken their toll. A few mature trees, mainly coconut trees, did survive. The planting of seedling coconut trees in the wake of Val is an attempt to replace lost ones and to try to combat further coastal erosion.

Only a few mature coconut trees are found between the high water mark and the coastal road. They are the only `major' producer of biomass. Three species of native coastal tree grow close to some of the mature coconut trees. Where coastal erosion has been most severe, on the narrow sandy stretch between the high water mark and the coastal road, two to three rows of seedling coconut trees have been planted. Some coastal vine (*Fue moa* - Ipomoea spp.) is present too. Between the road and the village is a grassy expanse. In between and behind the village houses are the common garden household trees and plantation crops.

There is no information on the marine/aquatic fauna situation in the lagoon. There seems to be no obvious pollution and/or sedimentation affecting the lagoon, but the degree of stress on the reef is unknown. At present the subsistence harvesting pressure might be sustainable, though the potential of over exploitation is very real, as fish stocks have been declining all over Upolu (and perhaps therefore Savai'i) during the last ten years (Zann, 1991).

Present biological vulnerability of the Puapua site is low. Basically what could be damaged has been damaged by Ofa and Val. There is very little left to be damaged by further external stresses. Likewise present biological resilience is low too as the tolerance of the species left is low.

Future vulnerability of the Puapua site and similar sites along the low-lying eastern coasts of Savai'i is likely to remain low under no-management conditions. The biodiversity situation will probably worsen but the vulnerability remains the same. Future resilience will remain low too under no-management conditions.

Optimal management would involve active and committed planting of salt-tolerant species, both at the beach and between the road and the village. This would mitigate coastal erosion caused by the predicted sea-level rise and the possible increased frequency and intensity of tropical storms.

The roots of such salt-tolerant species help to hold the sand together and the upper structure, branches and foliage, will function as a front-line windbreak and a possible salt-damage reducer. There are many useful suitable native littoral forest and shrub land species which could be used. One selection criterion to keep in mind is the root-system, as such species should not be able to be uprooted easily. Many species are also important in traditional ways such as providing timber (*fale* posts, woodcarving, canoe making) and some firewood.

Increasing the coastal biodiversity by maybe interspacing coconut trees with purposely planted herbaceous littoral species, as a way to mitigate coastal erosion, wind and salt-spray damage, requires a radical change in attitude at both national (governmental) and village (*fono*) level as this is alien to the *fa'a samoa*.

Village-based projects which are part of the integrated coastal zone protection management programmes as run by the Department of Environment and Conservation (DEC) are able to do this. The process is gradual but nonetheless resulting in a positive change in local attitude towards a greater ecological awareness and understanding.

Depending on the speed of sea-level rise and the nature of climate change, a committed increase in biodiversity might provide a low-cost and sustainable coastal-zone protection management system. There is another important aspect to this. By using salt-tolerant native species, all the mutual interests of the government (in developing low-cost sustainable coastal-zone protection systems), of conservation and environmental organizations like DEC and O le Siosiomaga, of the villagers themselves (for sustainable natural resource exploitation) and of those involved in (eco-) tourism, can be combined and served simultaneously.

Under conditions of optimal management, an increase in both future vulnerability (less) and future resilience (more) can be expected for Puapua and other similar sites. It is likely that optimal management will result in a high future resilience and a moderate future vulnerability.

5.4.4. Human elements

The settlement at Puapua is larger than that at Ga'utavai- Gataivai (see section 5.3.4) and, typical of those settlements along the low east coast of Savai'i, is spread out along the coastal flat. People have been attracted to this area because it is generally better watered and more easily cultivable than much of this island's coast.

This settlement is intrinsically more vulnerable than that at Ga'utavai-Gataivai owing to both its larger size and attractiveness among all possible sites for settlement on Savai'i. In terms of the proportion of protected population, resilience is less; all of Puapua's people live in comparatively unprotected areas because there are no others close to the sea.

In the future, if there is no management, then the situation will deteriorate. Optimal management would involve moving people to higher ground to the north and the west (inland) where roads already exist.

5.4.5. Infrastructural elements

Puapua village conforms to the traditional lay-out of a Samoan village. It is located on the low-lying coastal area in a spread-out fashion parallel to the main coastal road with the village green area in between.

Houses are typically 20-30 m from the high water mark. Only some churches or communal buildings are right on the beach. The coastal road runs parallel to the village very close (2-10 m) to the shore.

The road is a wide tar-sealed road in excellent condition (re- made after Cyclone Val). Some protection to the road against damage by unusually high waves and spring tides is offered by a narrow embankment of rocks and boulders deposited at the beach side. In a further attempt to protect the relatively narrow sandy strip between the high water mark and the rock embankment of the road, two to three parallel rows of seedling coconut trees have been planted.

Although the road is extremely vulnerable to damage by external stresses, the road is the only infrastructural element of national importance. Therefore the present national infrastructural vulnerability is considered low. The present individual infrastructural vulnerability is low too, while the present communal vulnerability is high.

Very few individual and communal buildings are protected. The present individual, communal and national infrastructural resilience are all low.

Under no-management conditions the future individual infrastructural vulnerability would increase from low to moderate. Because of likely population increase more houses might become concentrated in the area. The future individual, communal and national infrastructural resilience will remain low. Future vulnerability will be high for communal and low for national infrastructure.

Optimal management would keep the future individual, communal and national infrastructural vulnerabilities low.

By having more and better protected individual, communal and national infrastructures their resilience scores would improve. But the consequent high costs will most likely prohibit most of this. However the customary land tenure system provides the ability to adapt to coastal impacts. If threatened, at least the individual and communal infrastructure can be relocated further inland on other areas of communally owned land. By relocating the infra- structure plus providing some essential additional protection, the future individual, communal and national infrastructural resilience could increase to moderate.

5.4.6. Institutional elements

The authority over all the land belonging to the 'aiga is in the hands of the matai. He has power to grant rights of use to 'aiga members. He, however, cannot alienate 'aiga land without the consensus of the members of his 'aiga. Usufruct rights are heritable with the approval of the matai of one's 'aiga. 'Aiga land normally includes village house lots, gardens, plantation lots, and family reserve sections - particularly in taro gardens and swiddens. Family reserve sections usually run in strips from the coast into the mountains. There are also village lands. This category includes firewood and herbal medicine gathering areas, beach-fronts, reefs and lagoons, playgrounds and unused lands which may be claimed by the 'aiga through use and occupation which in turn comes under the matai's control. There are also lands belonging to traditional Samoan district councils consisting of the highest-ranking matai of the district villages. This consists of high mountain lands used primarily for hunting and gathering.

Although 'aiga land is controlled by its matai at the village level, the state traditionally acted as trustee in perpetuity over all Samoan lands. This, however, has been changed since independence in 1962, whereby all land has been classified into customary, freehold, and public lands. Customary land is no longer held in trust by the state. The government, however, does not allow the alienation of customary land but it authorizes and regulates the granting of licenses and leases of customary lands; and it could also take it for public (national interest) uses. In addition, all land below the high-water mark has been declared public land. The Land and Titles Court has been retained, and it continues to settle disagreements over succession to matai titles and authority over land. Decisions made by the Court are not subject to appeal. Recommendations of the village fono heavily influence decisions made by the Court.

Matai leadership and control have survived for more than five hundred years and changed very little. Even the 'aiga and village identities are little affected. Land allocation and usages are still very much managed by the 'aiga and village fono through its matai and are thus less vulnerable to external forces and demands.

The flexibility and resilience of traditional institutions to accommodate change can be observed only from the few changes that have occurred. These have come about as a result of new economic demands where the market economy and cash benefits have become important elements in the lives of the Samoans. For instance, there is an effort to encourage individual land tenure within the framework of 'aiga and public land controlling authorities through occupation rights and leases. In another example, an Alienation of Customary Land Act was passed by Parliament (1965) allowing the matai to lease customary land for economic development purposes but still with the approval of the Ministry of Lands. An act was also passed in 1977, allowing the Western Samoan Trust Estates Corporation (WESTEC), a public corporation, to sell some of its lands as free holdings for development.

At the village level the vulnerability of such institutional elements is rated at -1 and resilience is +1. At the national level, vulnerability is nil (0) and resilience is also nil (0).

5.4.7. Economic elements

The village economies of rural Upolu and Savai'i are dominated by the primary production of agricultural and marine resources. Puapua is no exception to that. The majority of resources harvested becomes part of the village's subsistence economy and is shared between either members of an extended family or the entire family. Primary economic resources in a rural village generally include fish and shellfish caught in lagoon and reef areas; coconuts, taro, banana and breadfruit from plantations; domestic animals, pigs, chickens and some beef cattle; and the produce from household gardens (Kay et al., 1993).

From the point of view of vulnerability of the cash economy, Puapua has very little in terms of activities, labour and productivity in agriculture, fishery and forestry. The flow of remittances into the village is unknown yet suspected to provide a sizable proportion of its cash income. There might be a certain potential for (eco) tourism; a typical rural coastal village, located behind a wide but short white sand beach with some coconut trees with, from a tourist point of view, an attractive looking shallow lagoon stretched out in front of it.

The present economic vulnerability for the cash component is considered moderate and the cash resilience low.

The subsistence component is rated as extremely vulnerable for the present. External stresses such as tropical storms or sudden production-limiting crop diseases like the current (November 1993) "taro blight", caused by Phytophthora colocasiae, can disrupt easily its monetary contribution. The economic resilience is considered moderate rather than low because of a potential for (eco) tourism.

It is unlikely that the village economy is going to change dramatically in the future. The future of the remittances and tourism for the cash economy is unknown.

Under no-management conditions, the future cash vulnerability will be low and the future subsistence vulnerability will remain extreme. Both future cash and subsistence resilience will remain low.

Optimal management would involve efforts to attract and promote tourism like renting beach fales similar to the scheme in Aleipata, Upolu. In this case, the future cash vulnerability would remain moderate and the future cash resilience could improve from low to moderate.

Under optimal management conditions, the future subsistence vulnerability would lessen somewhat and become high. The future subsistence resilience would probably remain moderate.

5.4.8. Cultural elements

Puapua villagers, like many other Samoan villagers are organized in family groupings known as 'aiga. Each village is administered by a fono (council) consisting of matai heads or chiefs from each 'aiga. Although a Samoan villager can claim relationships with several matai in his or her village and others, in reality he is most closely related to the matai of the 'aiga in which he reside. To become a matai, a Samoan must show a strong commitment to the welfare of the 'aiga, by providing services and satisfying 'aiga obligations and demands.

Decisions made within the village fono are generally achieved through consensus strongly influenced by deference to the titular head or ali'i (high chief), who is supported by the tulafale (talking chief), who oversees the implementation of such decisions among the members of his 'aiga.

It is observed from the above that the traditional social and cultural system is still very much highly communal and well established both at village and national level. Matai control within the village is still very strong. Although universal adult suffrage is now practiced, only the matai continue to be members of the village fono and the national parliament. The traditional Samoan way of life still very much dominates people's activities both at village and national level.

The traditional culture of Western Samoa is still strong locally, as evinced by paramountcy of the village-level decision making process, discussed in section 5.3.6 above and also in section 5.1.2 of the Phase 1 report (Kay et al., 1993). It is, however, a culture in transition, one which is being permeated by changes introduced from outside.

This area has a traditional culture which is vulnerable to change (-2) yet which has demonstrated a degree of resilience (+2) which some have not expected. In the future, this situation is unlikely to change substantially if sea level rises as predicted although it may lead to an increase in migration and thus an increase in cultural interchange and breakdown.

In a national sense, the particular culture of the Puapua area is unimportant, a status which is unlikely to change in future.

5.4.9. Response options

The SCI scores show that the average vulnerability of the natural system is moderate for the present and moderate to high for the future no-management scenario. Under optimal-management conditions, this can be improved to a low to moderate resilience.

The infrastructural system can be improved similarly under optimal-management conditions from moderate vulnerability (no- management) to a moderate resilience.

The economic system remains weak even under optimal management with only a low to neutral vulnerability.

It is clear that under no-management conditions the present average vulnerability either increases or remains the same at best.

The future outlook for this coastal system is then one of moderate to high vulnerability.

So sea-level rise and climate change will have a substantial impact on the integrated coastal zone systems of such low-lying coastal systems in Western Samoa and elsewhere in the island Pacific.

In considering possible response options involving some degree of management, several factors should be considered. Care should be taken that the provided response options for any crucial area (system, subsystem, subsystem-elements) are not isolated segments but are integrated purposely into the overall optimal-management strategy.

For example, the economic system is intimately linked with the natural system owing to its predominantly subsistence nature. By addressing enhancing the resilience of the natural system, the economic system will benefit because of the shared or integrated effect of the natural system's resilience-vulnerability status.

The following response options for the optimal-management strategy are suggested:

(1) To improve the natural system by improving the physical resilience, a high cost option would involve artificial structures for protection against coastal erosion and maintaining these structures. The less expensive and arguably more sustainable option would involve relocating the village and the road further inland.

(2) A low cost, sustainable, option for improving the biological resilience would involve increasing the biodiversity by actively planting selected strongly rooting, salt-tolerant native tree species as described in 5.4.3.

(3) The physical and biological resilience can be mutually supported by a healthy marine ecosystem (reef, lagoon). A healthy marine ecosystem might eventually adapt successfully to accelerated sea-level rise and assist in protecting the coast from increased erosion.

(4) Overexploitation of the marine resources and harmful fishing practices (dynamiting, poisoning) and lagoon pollution (sewage, chemicals) should be avoided altogether if present maximum resilience is to be achieved now.

(5) Village-based campaigns aimed at increasing ecological awareness and understanding as organized by the Department of Environment and Conservation, like for the Sa'anapu-Satao integrated coastal protection zone project (mangroves, coastal rain forest) in Upolu, are recommended.

Table 5.2. Puapua 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	-3	+1	-2	-3	-2	0	+2	-3	0
	biological	0	0	0	0	-1	0	+2	0	+1
Cultural	communal	-2	+2	0	-3	-2	+2	+2	-1	0
	national	-1	+1	0	-1	-1	+1	+1	0	0
Institutional	village	-1	+1	0	-1	-1	+1	+1	0	0
	national	-1	+2	+1	-1	-1	+2	+2	+1	+1
Infrastructural	individual	0	0	0	-1	0	0	+1	-1	+1
	communal	-2	0	-2	-2	0	0	+1	-2	+1
	national	0	0	0	0	0	0	+1	0	+1
Economic	subsistence	-3	+1	-2	-3	-2	0	+1	-3	-1
	cash	-1	0	-1	0	-1	0	+1	0	0
Human	populations	-2	0	-2	-3	-1	0	+1	-3	0
Average Sustainable Capacity Index										

Chapter 6. Impact of sea-level rise on Apia Harbour, Western Samoa

6.1. Introduction

Western Samoa is a maritime country which presently depends on trade with foreign nations for most household commodities. Thus, ports play a key role in the daily lives of the Western Samoans. The foreign trade ports are Apia and Asau, but most foreign trade cargoes are handled at Apia on Upolu Island (Figure 6.1).

Apia Port is located on reclaimed land at the northeast edge of a reef-protected natural harbour. The port has a main wharf with a length of 185 m and a depth of -10 m, three mooring buoys for tankers, ferry facilities to Pago Pago (American Samoa) with a depth of -3.4 m, four transit sheds and two coconut oil tanks.

6.2. Bathymetric conditions

The marine and bathymetric charts are shown in Figure 6.2.2.

6.3. Existing facilities

Sections of existing facilities at Apia Harbour (taken from 1987 JICA Report) are shown below (Table 6.1., Figure 6.3.1.~6.3.3.).

6.4. Impact of sea-Level rise on port facilities and protection facilities

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

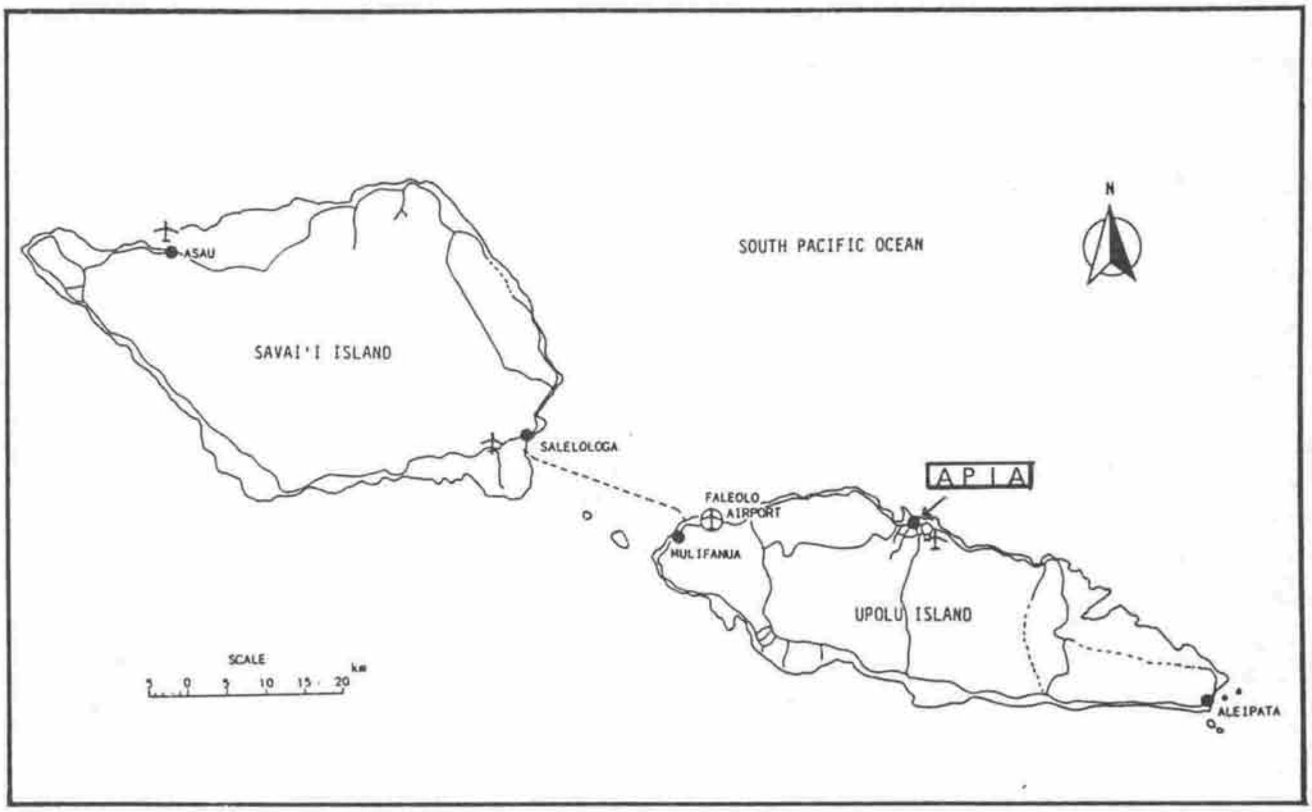


Figure 6.1. Location map

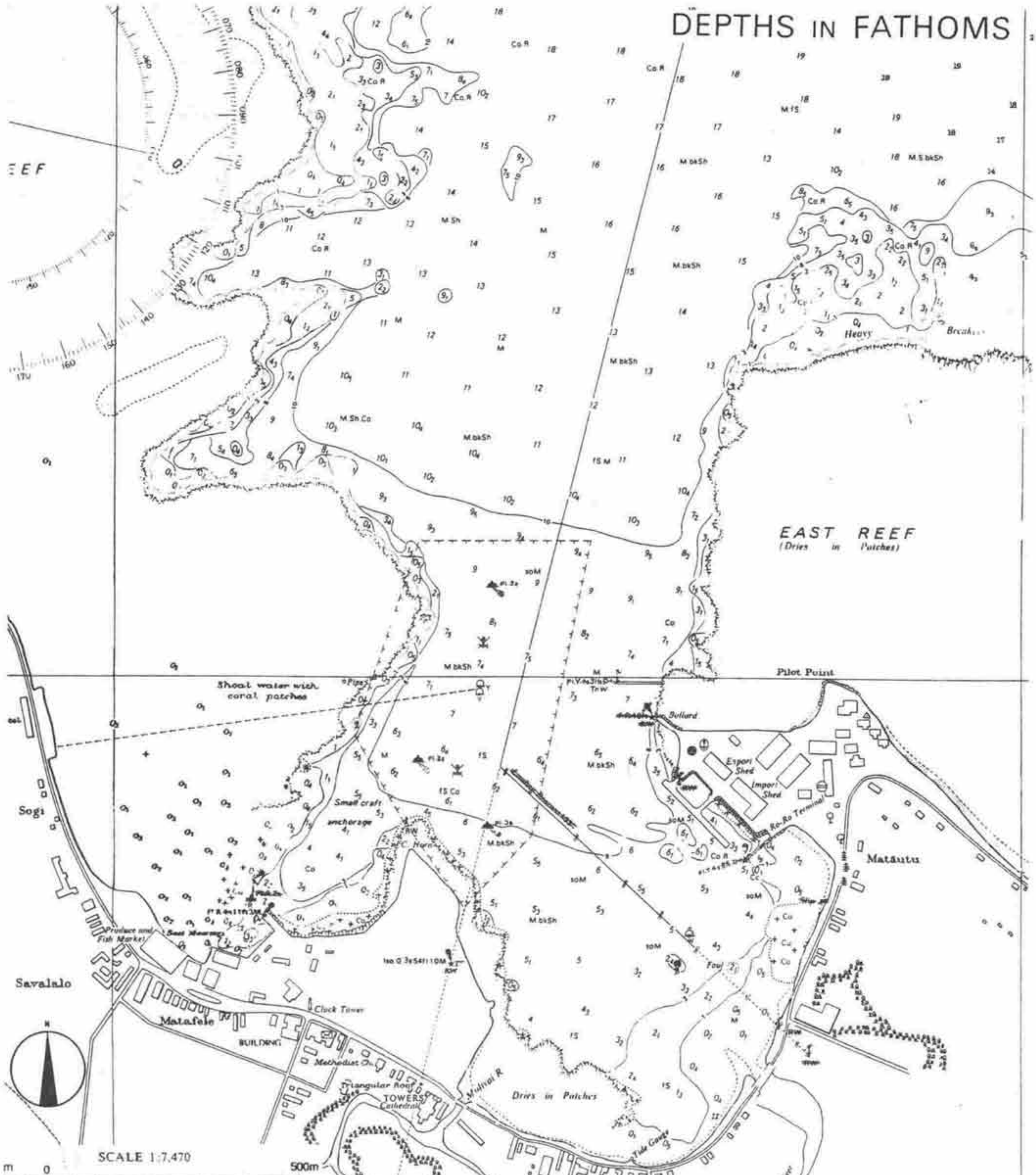


Figure 6.2.1. Marine chart

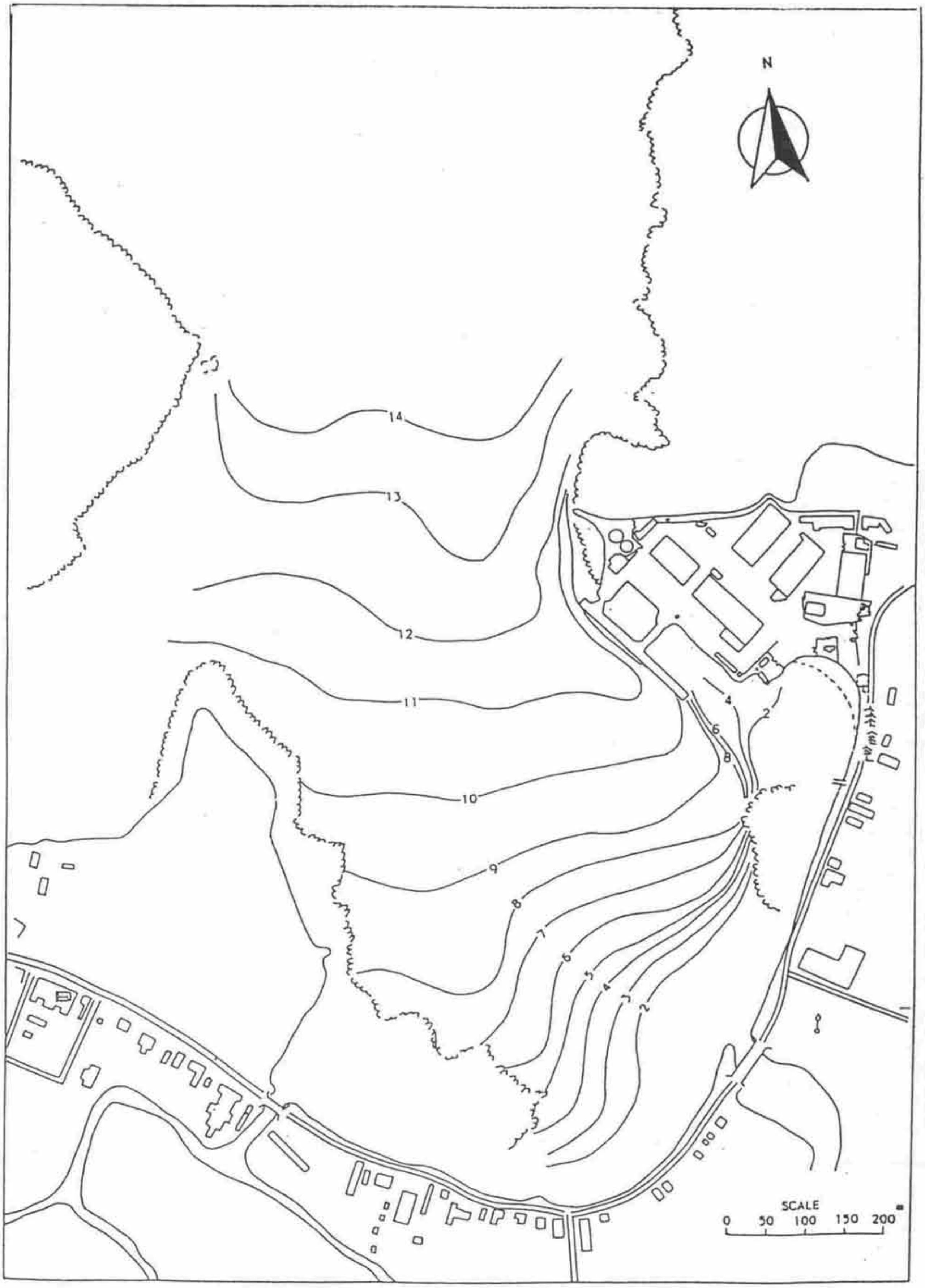
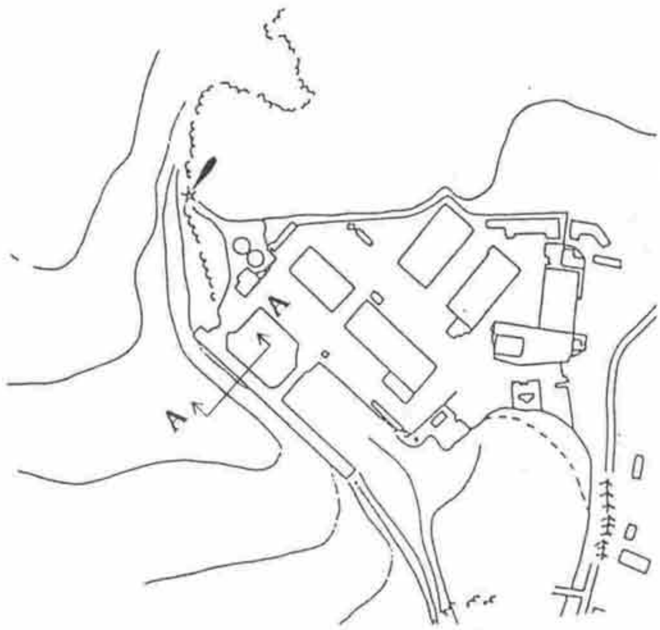


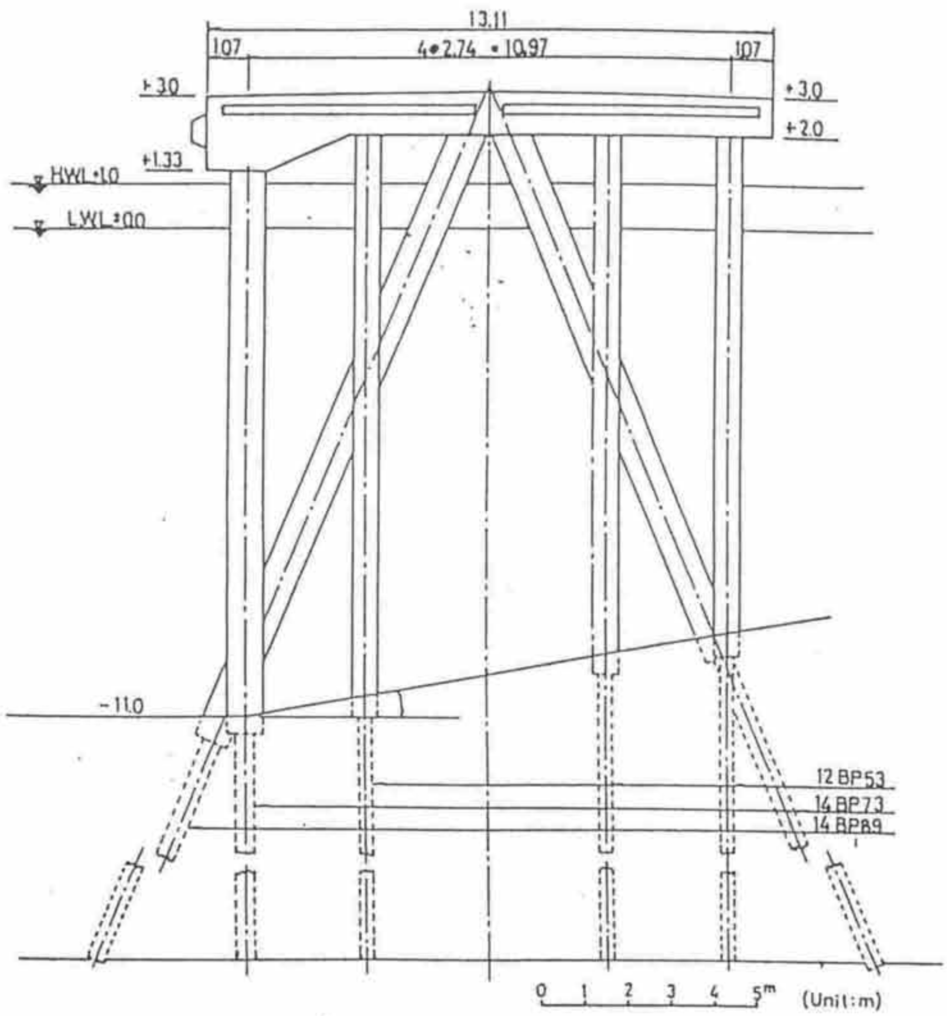
Figure 6.2.2. Bathymetric chart

Table 6.1. Existing port facilities and equipment (Apia)

Facility/Equipment	Number/Capacity	Construction Year	Owner
Whalf	- main berth (length 184.7m) (width 13.1m) (depth -10.0m) -small ship berth (length 80.0m)	1966	M.O.T.
Mooring Buoy	3 buoys	1960's	Private
Turning Basin	depth -11.0m	1967	M.O.T.
Ferry berth	depth -3.4m		M.O.T.
Shed No.1	3,645m^2		M.O.T.
Shed No.2	1,792m^2		M.O.T.
Shed No.3	2,541m^2		M.O.T. (damaged by fire)
Shed No.4	2,486m^2		M.O.T.
Coconut tanks	1,500 x 2 (one is under construction)		Copra Board
Storage Shed (Copra Meal)	1,500t (about 300m^2)		Samoa Coconut Products
Chemical Shed	about 100m^2		Samoa Coconut Products
Cool Storage	about 800m^2		Agriculture Department
Leading Light			Produce Marketing Dept.
Beacon			M.O.T.
Tugboats	"Pualele" 425bhp "Savaii" 175bhp	1972 1964	M.O.T.
Pilot-boat	120bhp	1960's	M.O.T.

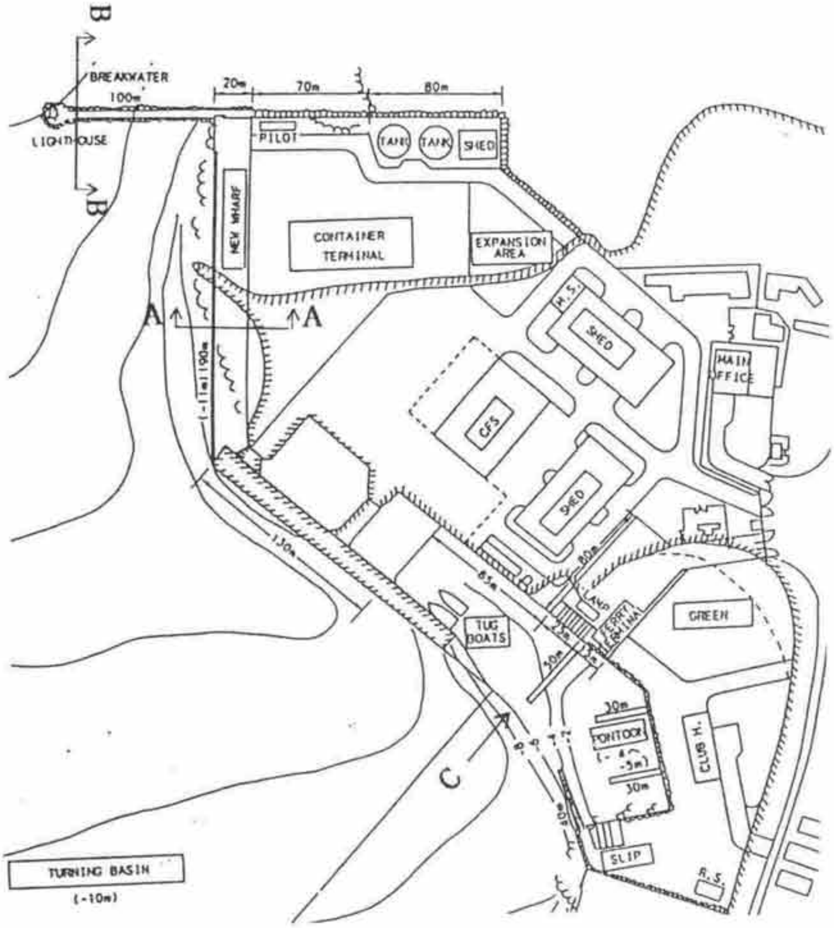


Plan of Apia Port

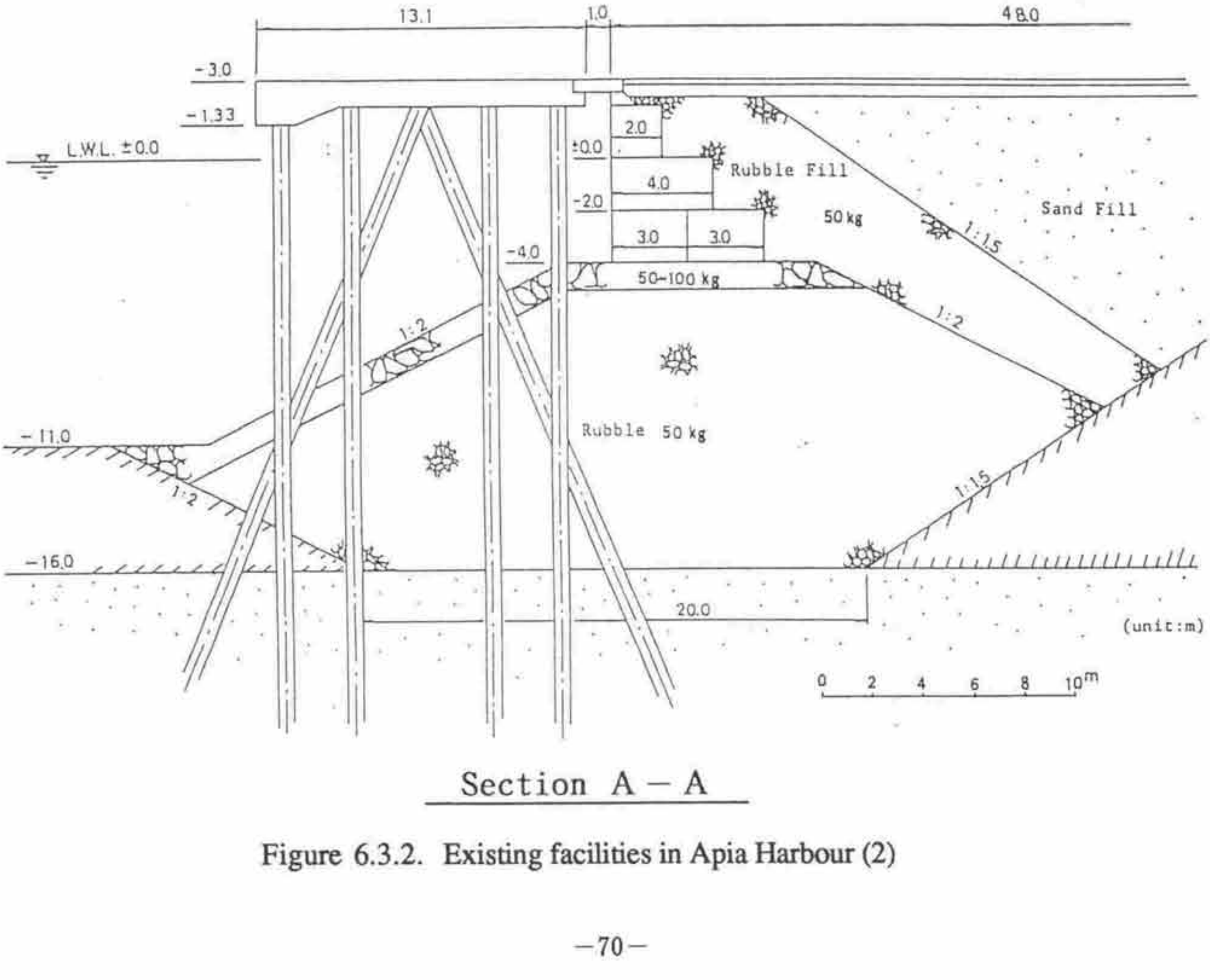


Section A − A

Figure 6.3.1. Existing facilities in Apia Harbour (1)

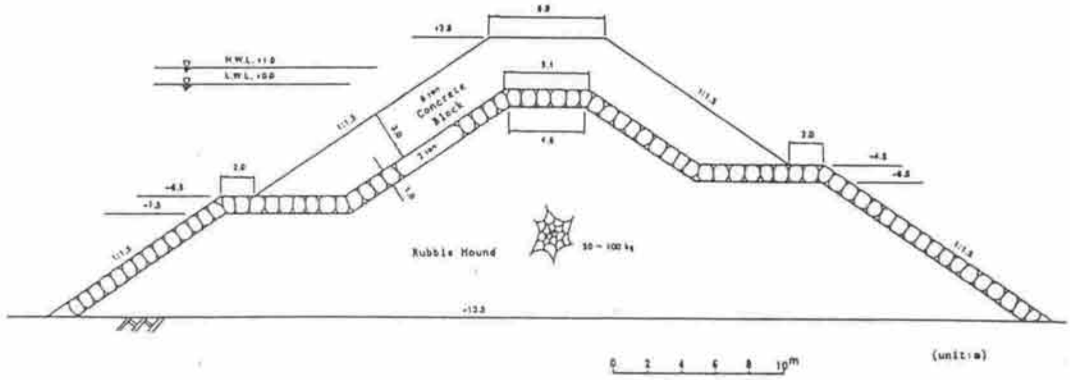


by JICA study (1987)

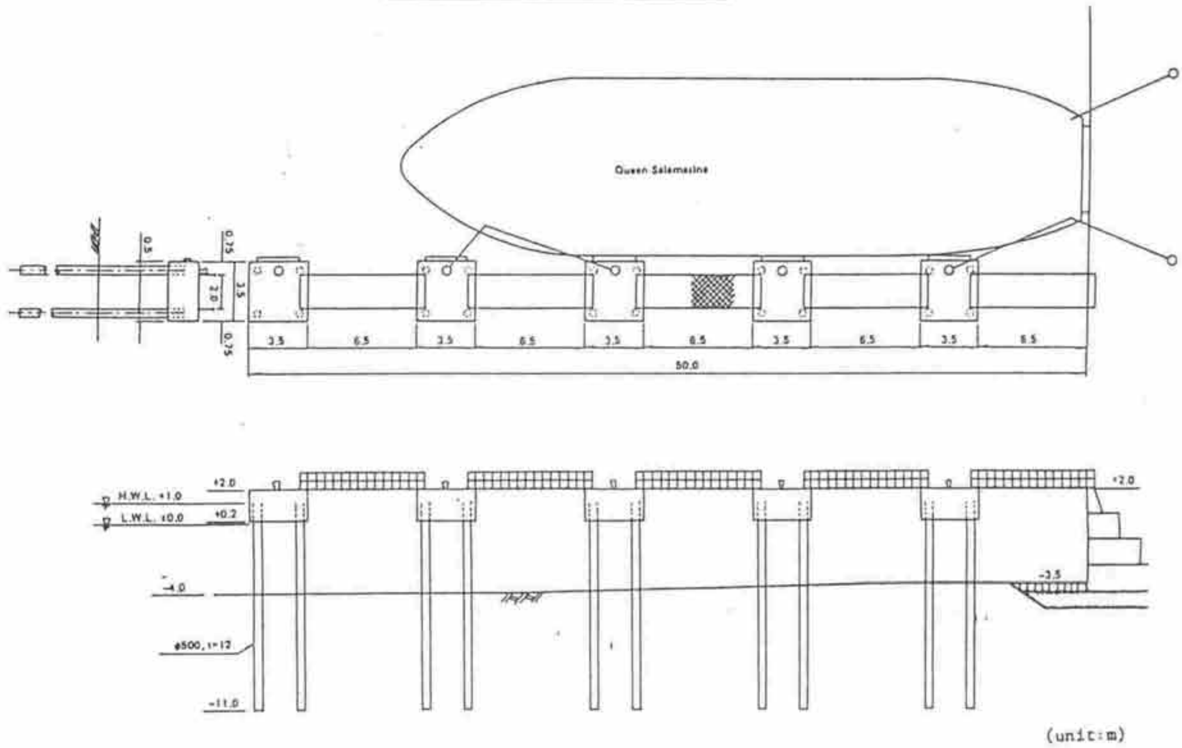


Section A – A

Figure 6.3.2. Existing facilities in Apia Harbour (2)



Section B – B



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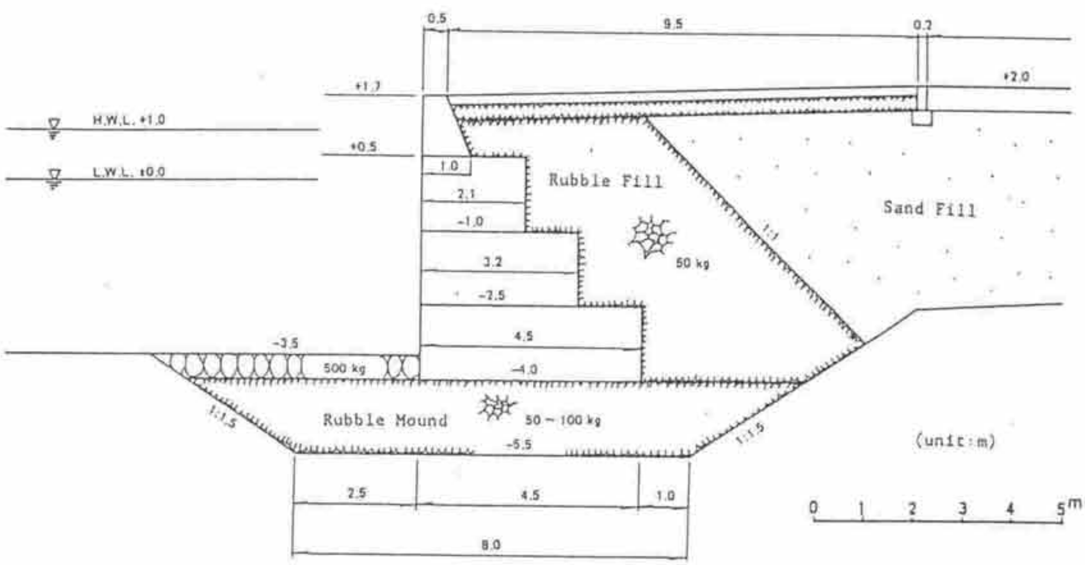
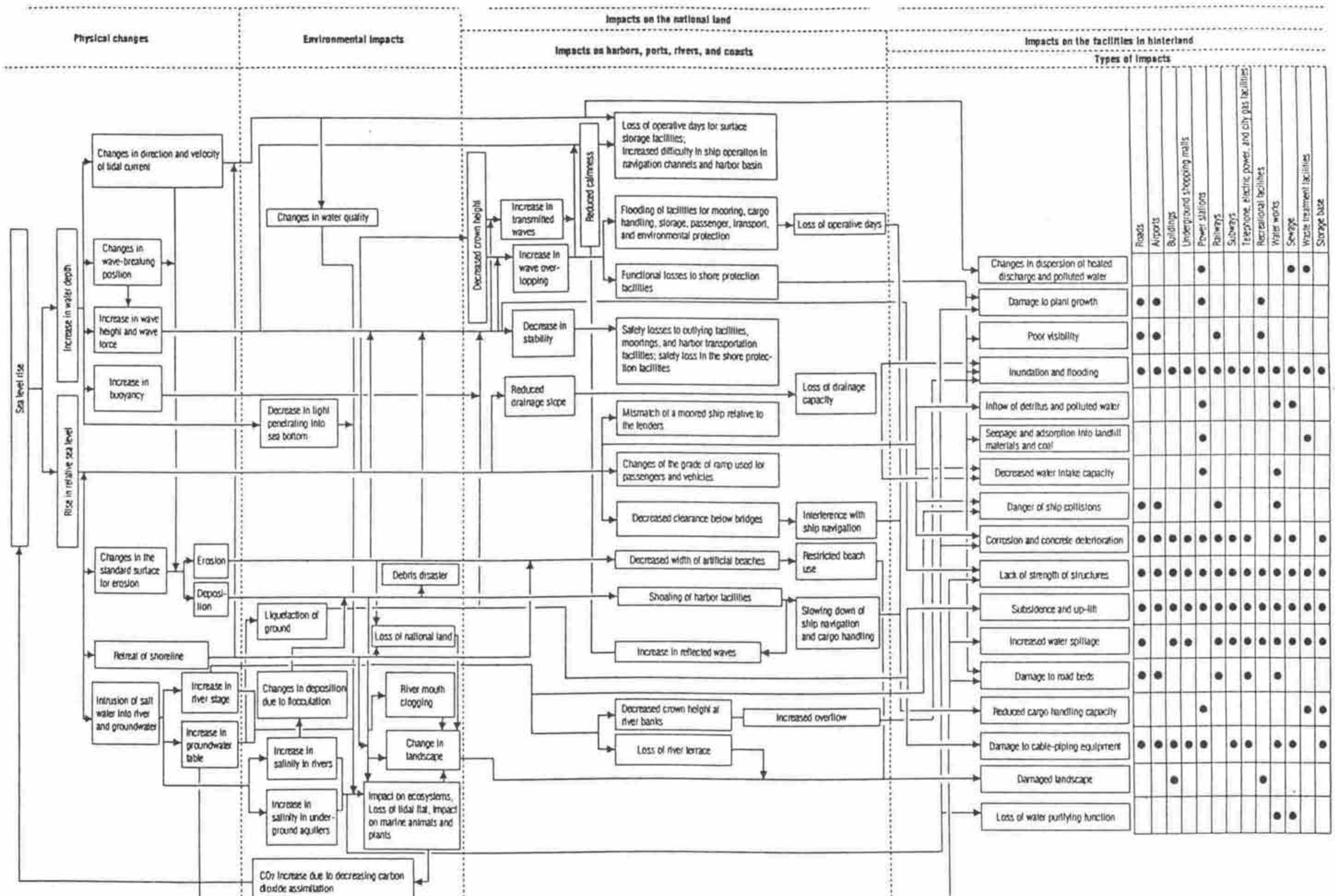


Figure 6.3.3. Existing facilities in Apia Harbour (3)



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

6.5. Wave study

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

6.5.1. Deep water-Wave Condition (Ho, To & θo)

Using the six highest sustained wind speeds observed in the 40 years of Apia wind data, Carter (1990) presented the following expression:

$Ho^{1.4} = 73.658 \times \log(RI) - 21.986$

where Ho is the deepwater wave height in ft, RI the return interval in years.

This relationship can be used to estimate the return interval RI for the deepwater wave height Ho generated over a fetch of 36 nautical miles. With a return interval RI equal to fifty years, Ho will be equal to 8.4 m. With reference to Carter (1990), the wave period To is assumed to be 10 sec. The deepwater wave direction is set to be N10E.

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

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

Design Water Level (D.W.L) =

C.D+Astronomical Tide+ηStorm Surge+ ηWave Setup on Reef

1) Chart Datum (C.D) = ± 0.0

2) Astronomical Tide
Mean High Water Springs (M.H.W.S) = + 1.0 m

3) Storm Surge (η_S)

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

3)-1 $\Delta\eta_B \approx 0.7$ m

3)-2 $\Delta\eta_w = K \frac{F}{h} U^2$

F : effective fetch (in km); h : water depth (in m);
U : design wind speed (m/s); K : constant = 4.8×10^{-2}

Carter (1990), using wind data recorded at Apia Observatory, developed the following relation to calculate the return interval for a given maximum sustained wind speed:

$U^{1.4} = 304.904 \times \log(RI) - 50.865$

where U is the wind speed in knots, RI is the return interval in years.

Values estimated using this relation should be increased by 10% to estimate wind speed over water, since these data were recorded at the shoreline (Carter, 1990). Upon using the above mentioned relationship with a return interval of 50 years, U is equal to 45 m/s. With F = 1.5 km and an average water depth at Apia harbour h = 15 m, then

$\Delta\eta_W = 10\ \text{cm} = 0.1\text{m}$

$\therefore\ \eta_s = 0.7 + 0.1 = 0.8\text{m}$

4) Wave setup on reef (η_R)

With the deep wave height Ho = 8.4 m and wave period To = 10 seconds, and using the graph (Figure 6.6), for i=1/10

$\therefore\ \eta_{Rmax} = 1.26\text{m}$

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

D.W.L = 1.0 + 0.8 + 0.6 = 2.4 m above C.D.

Table 6.2. summarizes the design condition at Apia harbour for a return period of fifty years.

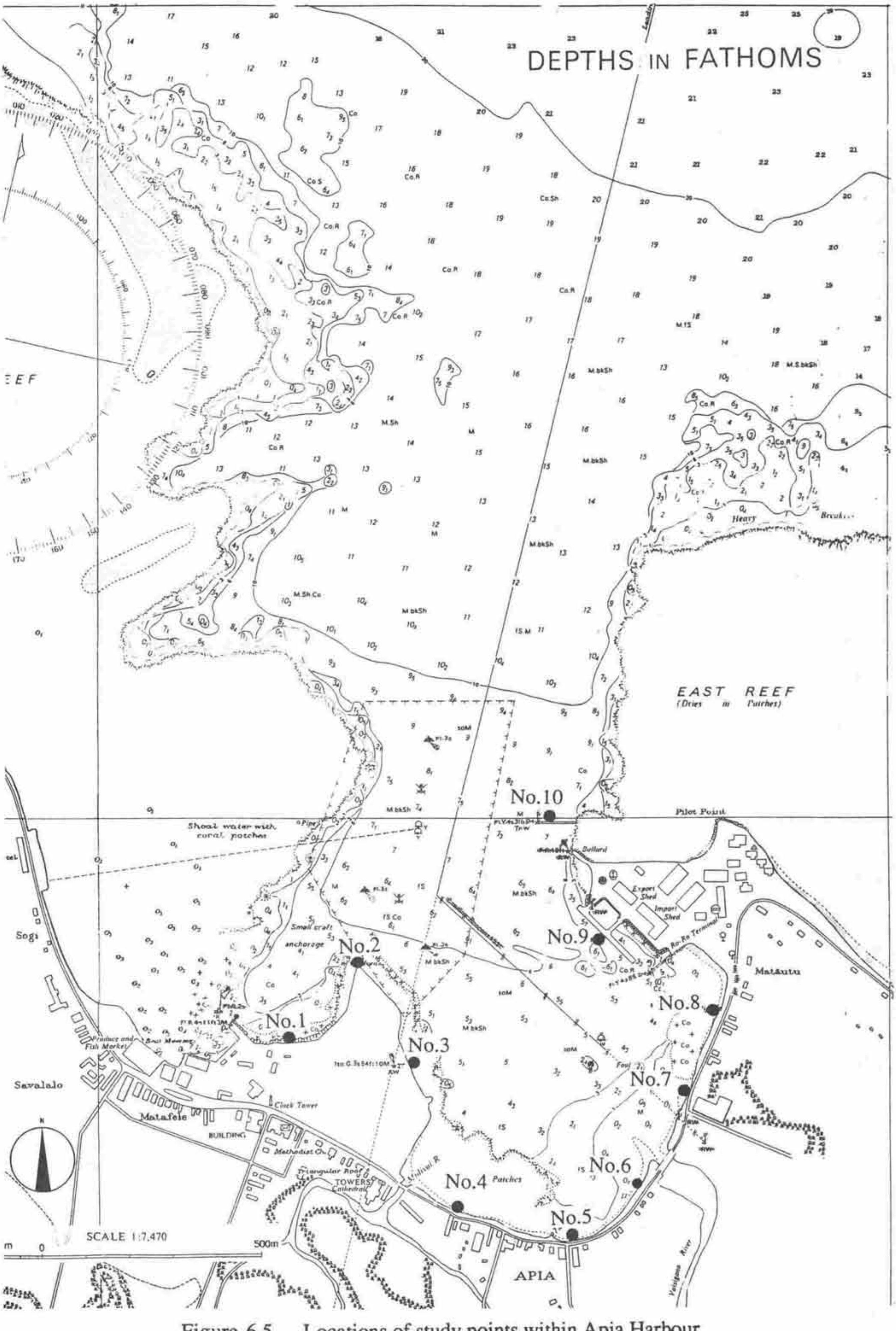


Figure 6.5. Locations of study points within Apia Harbour

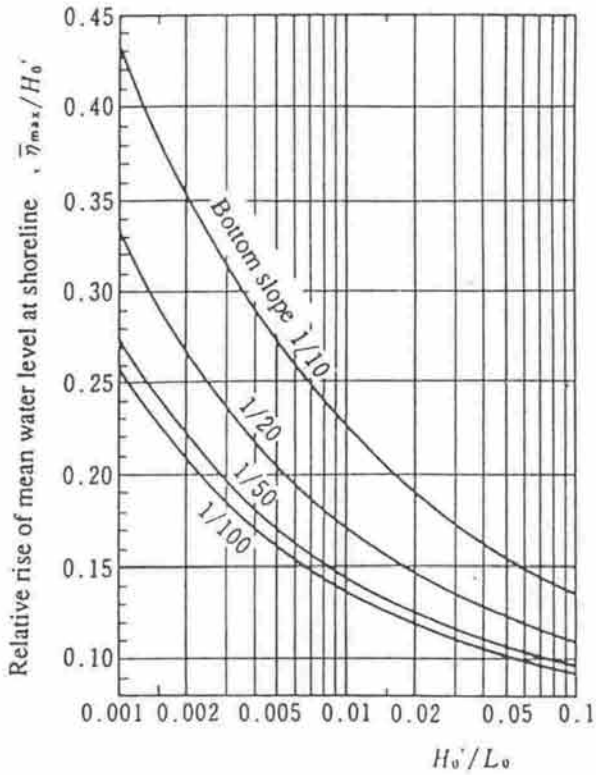


Figure 6.6. Relative rise of mean water level at shoreline (after Goda, 1975)

Table 6.2. Apia Port design conditions

Return Period RI	RI = 50 years	
Astronomical Tide	M.H.W.S. +1.0m M.S.L +0.5m M.L.W.S ±0.0m C.D ±0.0m	given by JICA (1987)
Storm Surge	Barometric Tide $\Delta\eta_B$ 0.7m*1 Wind Set – up $\Delta\eta_w$ 0.1m*2 total 0.8m	*1: given by Carter (1990) 0.68m≒0.7m *2: Calculate from wind speed U and Fetch and mean depth of Apia harbour by next formula. $\Delta\eta_w = K\frac{F}{h}U^2$ $k = 4.8 \times 10^{-2}$ $U = 45m/s$ (given by Carter (1990)'s Diagram for RI of 50 years) $F = 1.5km$ $h = 15m$
Wave Set-up on Reef	$\Delta\eta_R = 0.6m$	*: Calculate from Offshore wave Ho, To by Goda (1975)'s Diagram and ×50% Ho/Lo = 0.054 $\overline{\eta}_{R\,max} / Ho = 0.054$ (using bottom slope = 1/10) $\overline{\eta}_{R\,max} = 0.15 \times 8.4$ $= 1.26$ m ↓ ×50% $\Delta\eta_W = 0.63$ m ≒0.6m
Design Water Level D.W.L	$M.H.W.S + \Delta\eta_S + \Delta\eta_R$ C.D + 2.4m	
Design Wave	offshore wave Ho = 8.4m*1 To = 10sec Wave direction N10°E*2	*1: estimate by Carter (1990)'s formula for RI = 50 years $Ho^{1.4} = 73.568 \times \log RI - 21.986$ RI = 50 years ↓ Ho = 27.4ft = 8.4m *2: given by JICA (1987)

6.5.3. Wave height estimation

Once the deepwater wave condition and the design water level have been set, equivalent deepwater wave height Ho' as well as the significant wave height H1/3 at the locations shown in Figure 6.5., can be estimated. Significant wave heights H1/3 are estimated for different values of the sea-level rise (S.L.R.).

Significant wave heights are used to check the impact of sea-level rise on the stability of various coastal structures. Meanwhile, equivalent deepwater wave heights are used to estimate its impact on wave run-up at different locations inside Apia harbour. Figure 6.7 illustrates the wave propagation procedure used in this study. Results of wave direction and equivalent deepwater height Ho' contours are presented in Figures 6.8 and 6.9 respectively. On the other hand, the change of significant wave height H1/3 at different locations, due to sea-level rise is given in Figure 6.10. Figure 6.11 presents the increase ratio in H1/3 due to sea-level rise.

Results of wave calculations at the specified points inside Apia harbour are summarized in Table 6.3.

6.6. Study of revetment stability

The increase of water depth caused by sea-level rise leads to the increase of wave height. There will thus be a problem that the stability of structures will decrease as a result of the increasing wave force.

Many of the revetments in Apia Harbour are of the stone masonry structure type; the concrete-block armour structure type is used for offshore breakwaters. It is important for these structures to secure the weight of armour rock to be supportive of 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 the revetments of the stone masonry type.

(1) Study points

Details of the existing stone masonry revetments are still largely unknown. Therefore, in order to understand the question of revetment stability, eight study points were selected along Apia Harbour. Location of study points are shown in Figure 6.5.

(2) Condition of revetments

Although an example of stone masonry revetment in Apia Harbour is seen in Plate 6.1, details of structural conditions are not known. Therefore, the following assumptions will be made:

Ground level of the revetment : C.D+0.0m
Slope of revetment : 1:2

(3) Condition of external forces

The present condition of external force is calculated with water level (MHWS + storm surge) and design wave for 50 years return period. A further study is made assuming sea level rises by 0.5 m and 1.0 m. Significant wave height for both cases has been already obtained by a wave study in Section 5 and they are:

Design Water Level :C.D+2.4m+sea-level rise

Design deep wave	:Ho=8.4m, T=10.0sec
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
- K_D : 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 probable damage of facilities, $K_D = 3.2$ has been used.

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 was made before and after the sea-level rise, and results were compared.

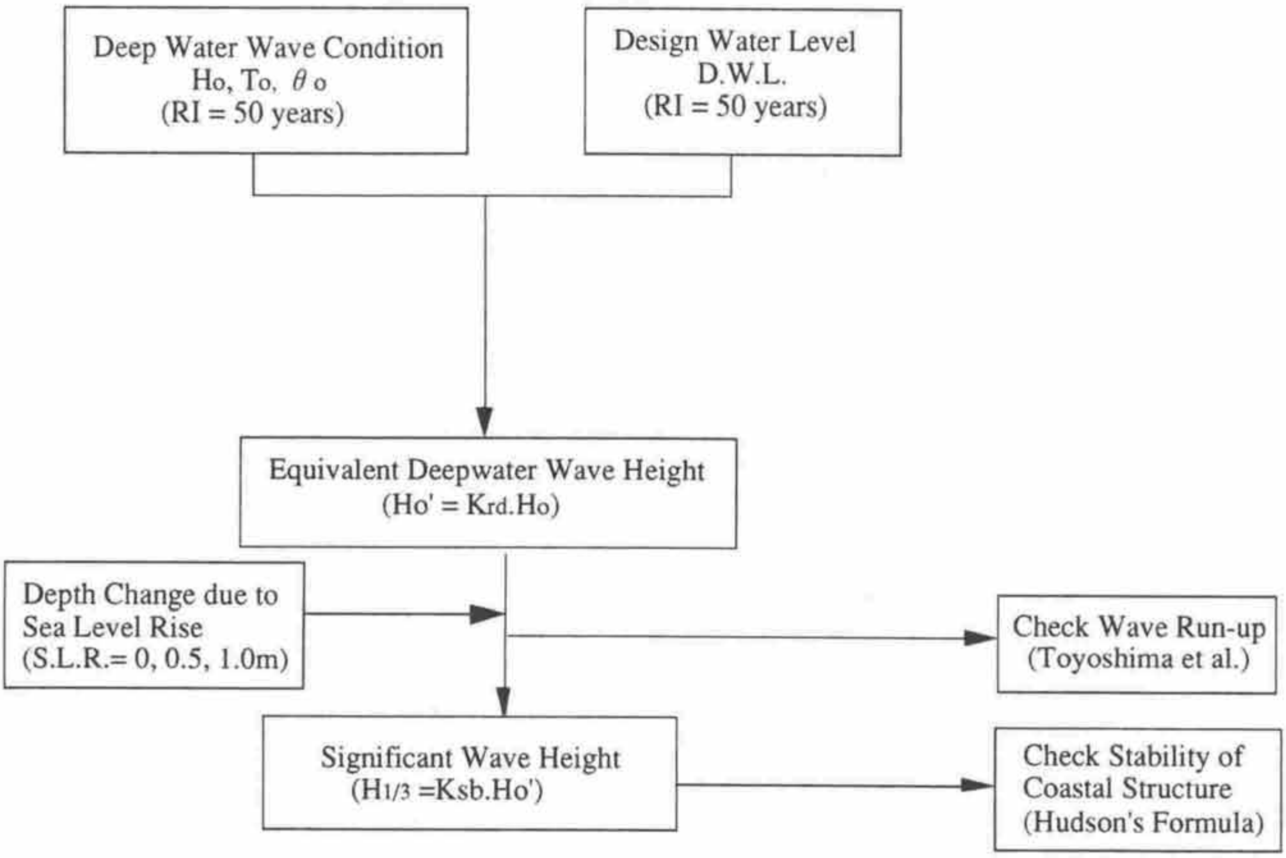


Figure 6.7. Flow chart of wave propagation calculation

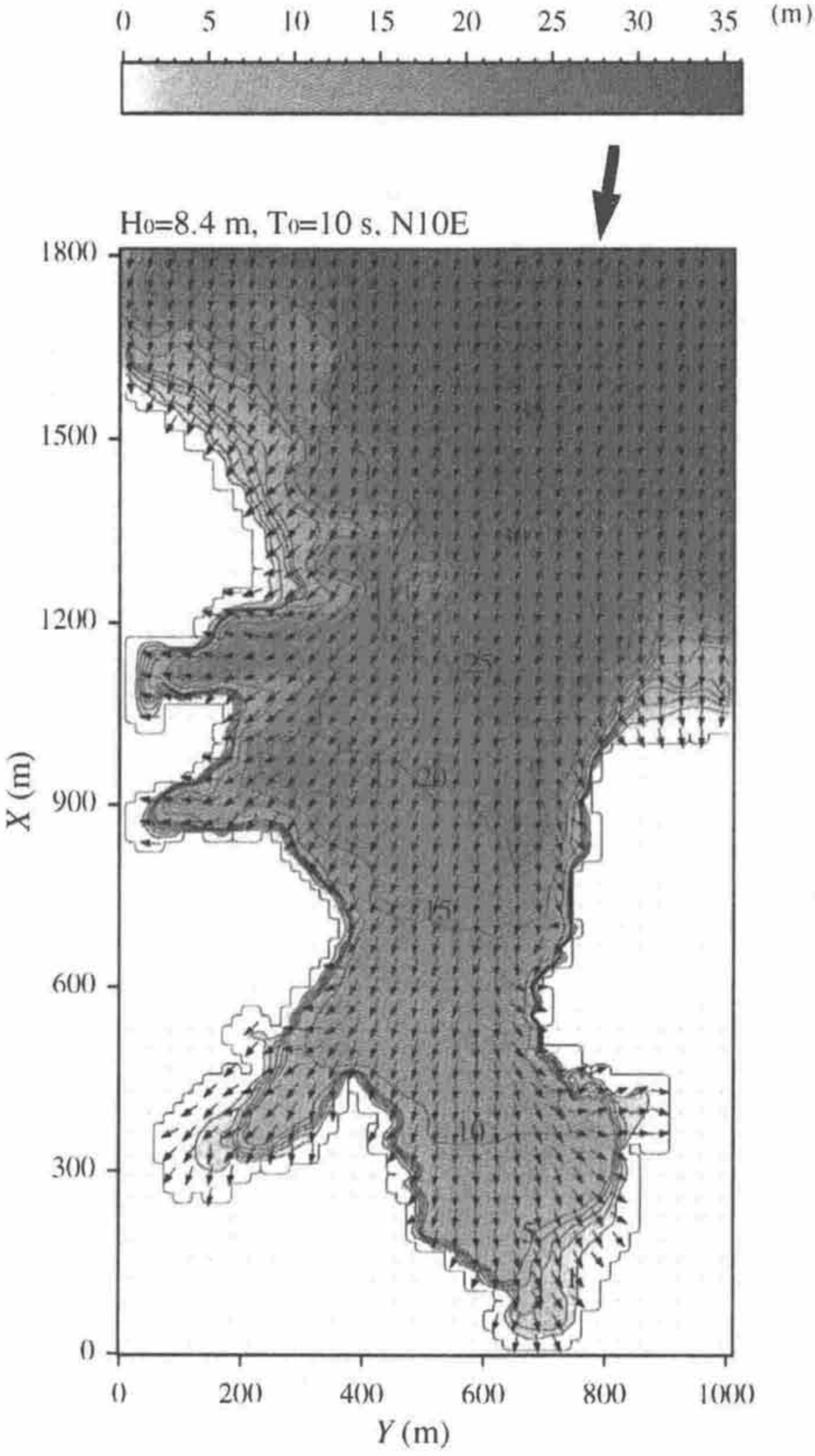


Figure 6.8. Wave direction contours in Apia Harbour

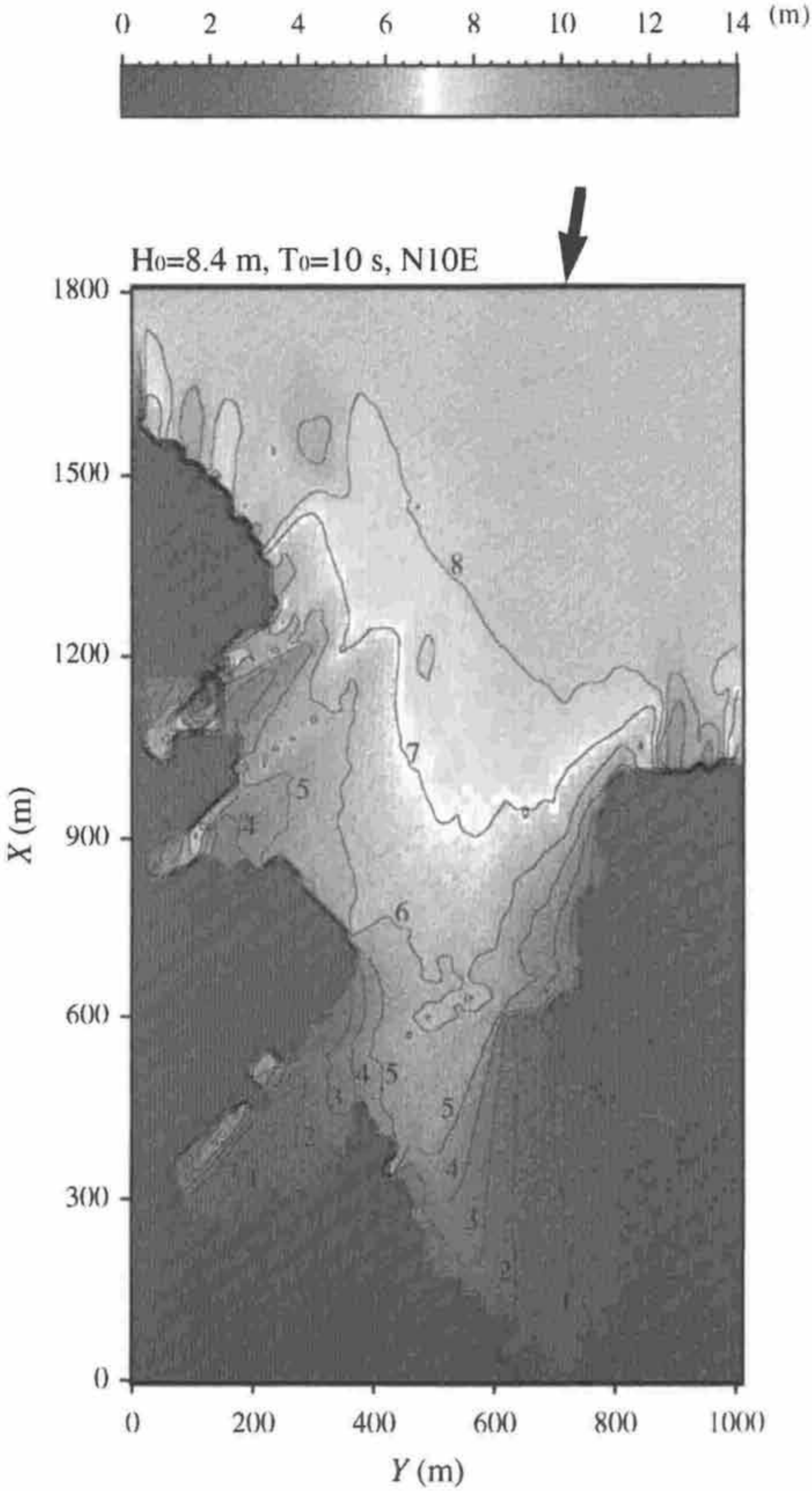


Figure 6.9. Equivalent deep water wave height (Ho') contours

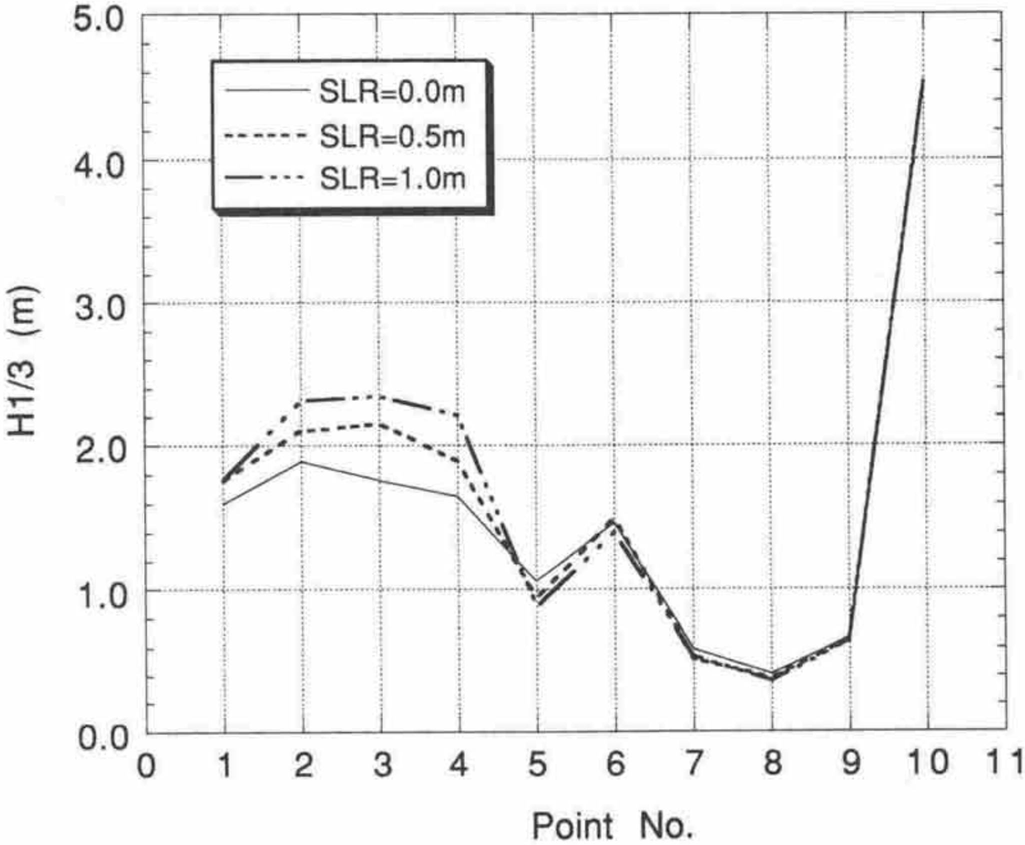


Figure 6.10. Change of significant wave height H1/3 due to sea- level rise

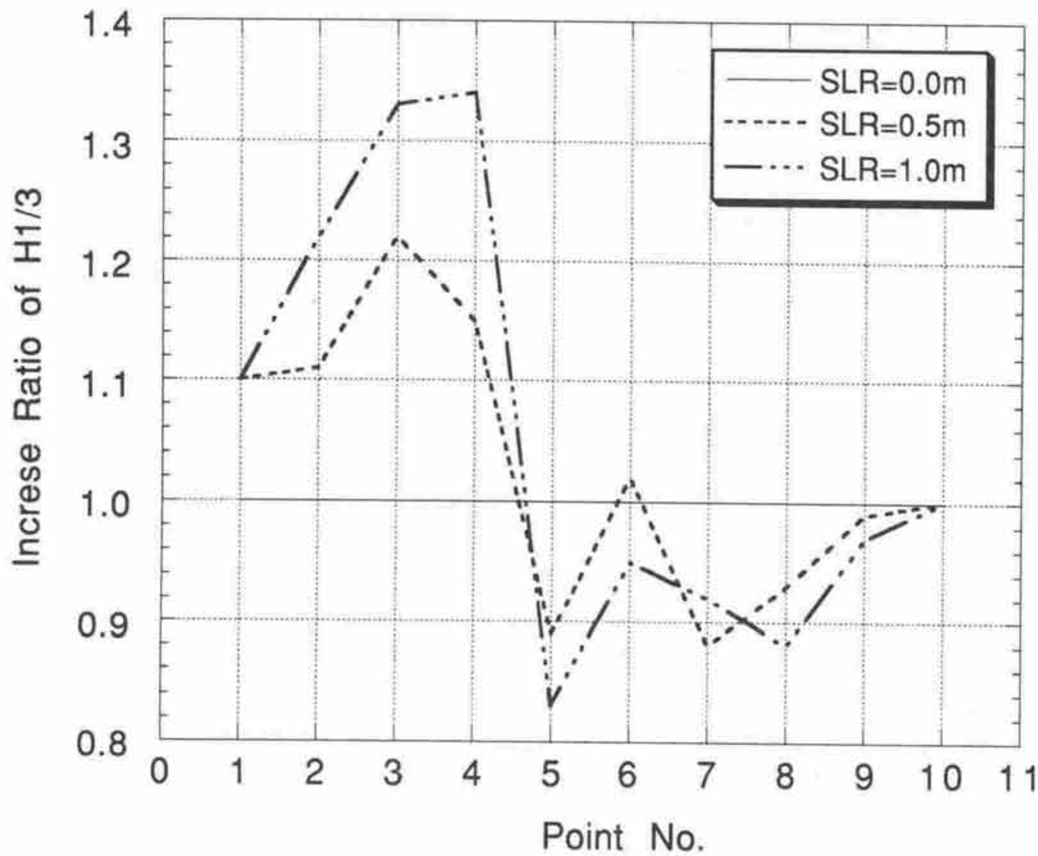


Figure 6.11. Increase ratio of H1/3 due to sea-level rise

Table 6.3. Calculation of H1/3 at Apia Harbour

- Offshore wave : Ho = 8.4 m, To = 10.0 sec (Lo = 156 m), N10° E
- Design water level : C.D + 2.4 m

Point	Bottom level (C.D m)	Bottom slope tan β	Refraction & Diffraction[*1] coefficient Krd	Ho'=Krd Ho (m)	Ho'/Lo	Sea level rise $\overline{\eta}_{SLR}$ (m)	depth h (m)	h/Ho'	h/Lo	$H_{1/3}/Ho'$[*2]	$H_{1/3}$ (m)
1	±0.0	1/50	0.16	1.3	0.008	0.0	2.40	1.85	0.015	1.23	1.60
						0.5	2.90	2.23	0.019	1.35	1.76
						1.0	3.40	2.62	0.022	1.35	1.76
2	±0.0	1/100	0.50	4.2	0.027	0.0	2.40	0.57	0.015	0.45	1.89
						0.5	2.90	0.69	0.019	0.50	2.10
						1.0	3.40	0.81	0.022	0.55	2.31
3	±0.0	1/100	0.47	3.9	0.025	0.0	2.40	0.62	0.015	0.45[*3]	1.76
						0.5	2.90	0.74	0.019	0.55[*3]	2.15
						1.0	3.40	0.87	0.022	0.60[*3]	2.34
4	±0.0	1/100	0.32	2.7	0.017	0.0	2.40	0.89	0.015	0.61	1.65
						0.5	2.90	1.07	0.019	0.70	1.89
						1.0	3.40	1.26	0.022	0.82	2.21
5	±0.0	1/50	0.08	0.7	0.004	0.0	2.40	3.43	0.015	1.52	1.06
						0.5	2.90	4.14	0.019	1.34	0.94
						1.0	3.40	4.86	0.022	1.25	0.88
6	±0.0	1/50	0.12	1.0	0.006	0.0	2.40	2.40	0.015	1.47	1.47
						0.5	2.90	2.90	0.019	1.50	1.50
						1.0	3.40	3.40	0.022	1.40	1.40
7	±0.0	1/50	0.05	0.4	0.003	0.0	2.40	6.00	0.015	1.48[*3]	0.59
						0.5	2.90	7.25	0.019	1.30[*3]	0.52
						1.0	3.40	8.50	0.022	1.36[*3]	0.54
8	±0.0	1/50	0.03	0.3	0.002	0.0	2.40	8.00	0.015	1.36[*3]	0.41
						0.5	2.90	9.67	0.019	1.25[*3]	0.38
						1.0	3.40	11.33	0.022	1.20[*3]	0.36
9	-11.0	1/50	0.08	0.7	0.004	0.0	13.40	19.14	0.086	0.95[*3]	0.67
						0.5	13.90	19.86	0.089	0.94[*3]	0.66
						1.0	14.40	20.57	0.092	0.93[*3]	0.65
10	-13.5	1/50	0.58	4.9	0.031	0.0	15.90	3.24	0.102	0.93[*3]	4.53
						0.5	16.40	3.35	0.105	0.93[*3]	4.53
						1.0	16.90	3.45	0.108	0.93[*3]	4.53

Remarks
*1 : estimate by Parabolic equation (Isobe, 1986).
*2 : estimate by Goda (1975)
*3 : Shoaling coefficient.

Plate 6.1. Example of revetment in Apia Harbour

(5) Calculation results

Table 6.4 shows the results in case of the present condition, and after sea level rises by 0.5 m and 1.0 m. It also includes required stone weight at each study point as well as increase ratio of required weight. Figures 6.12 and 6.13 show those results visually.

At points 1-4 stone weights are required to be increased by about 150% and 200% due to sea-level rise by 0.5 and 1.0m respectively.

On the other hand, at points 5-8 where wave height is comparatively small, the stone weight is not required to be increased since waves do not initially break here. Furthermore, even after sea-level rise wave height is still small.

Table 6.4. Calculation of stone weight of revetment W at Apia Harbour

· Offshore wave : Ho = 8.4 m, To = 10.0 sec (Lo = 156 m), N10° E

· Design water level : C.D + 2.4 m

· Calculate condition for Hudson formula

$K_D = 3.2$, $W_s = 2.65\ t/m^3$, $W_w = 1.03\ t/m^3$, $S_r = 2.57$, $\cot\theta = 2$

Point	Bottom level (C.D m)	Equivalent wave height (m)	Ho'/Lo	Sea level rise $\overline{\eta}_{SLR}$ (m)	depth h (m)	$H_{1/3}$ (m)	Stone's Weight	
							W (kg)	Increase Ratio
1	±0.0	1.3	0.008	0.0	2.40	1.60	438	1.00
				0.5	2.90	1.76	583	1.33
				1.0	3.40	1.76	583	1.33
2	±0.0	4.2	0.027	0.0	2.40	1.89	722	1.00
				0.5	2.90	2.10	991	1.37
				1.0	3.40	2.31	1319	1.83
3	±0.0	3.9	0.025	0.0	2.40	1.76	583	1.00
				0.5	2.90	2.15	1063	1.82
				1.0	3.40	2.34	1371	2.35
4	±0.0	2.7	0.017	0.0	2.40	1.65	481	1.00
				0.5	2.90	1.89	722	1.50
				1.0	3.40	2.21	1155	2.40
5	±0.0	0.7	0.004	0.0	2.40	1.06	127	1.00
				0.5	2.90	0.94	89	0.70
				1.0	3.40	0.88	73	0.57
6	±0.0	1.0	0.006	0.0	2.40	1.47	340	1.00
				0.5	2.90	1.50	361	1.06
				1.0	3.40	1.40	294	0.86
7	±0.0	0.4	0.003	0.0	2.40	0.59	22	1.00
				0.5	2.90	0.52	15	0.68
				1.0	3.40	0.54	17	0.77
8	±0.0	0.3	0.002	0.0	2.40	0.41	7	1.00
				0.5	2.90	0.38	6	0.86
				1.0	3.40	0.36	5	0.71

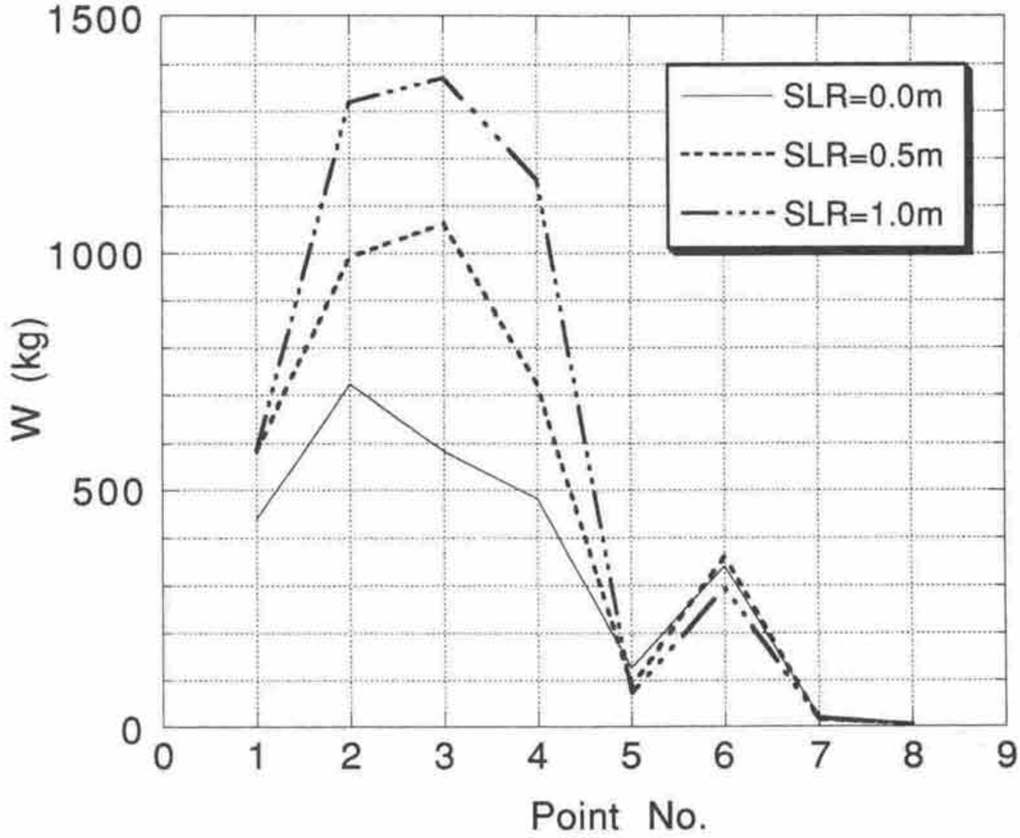


Figure 6.12. Change of weight of armour unit `W' due to sea-level rise

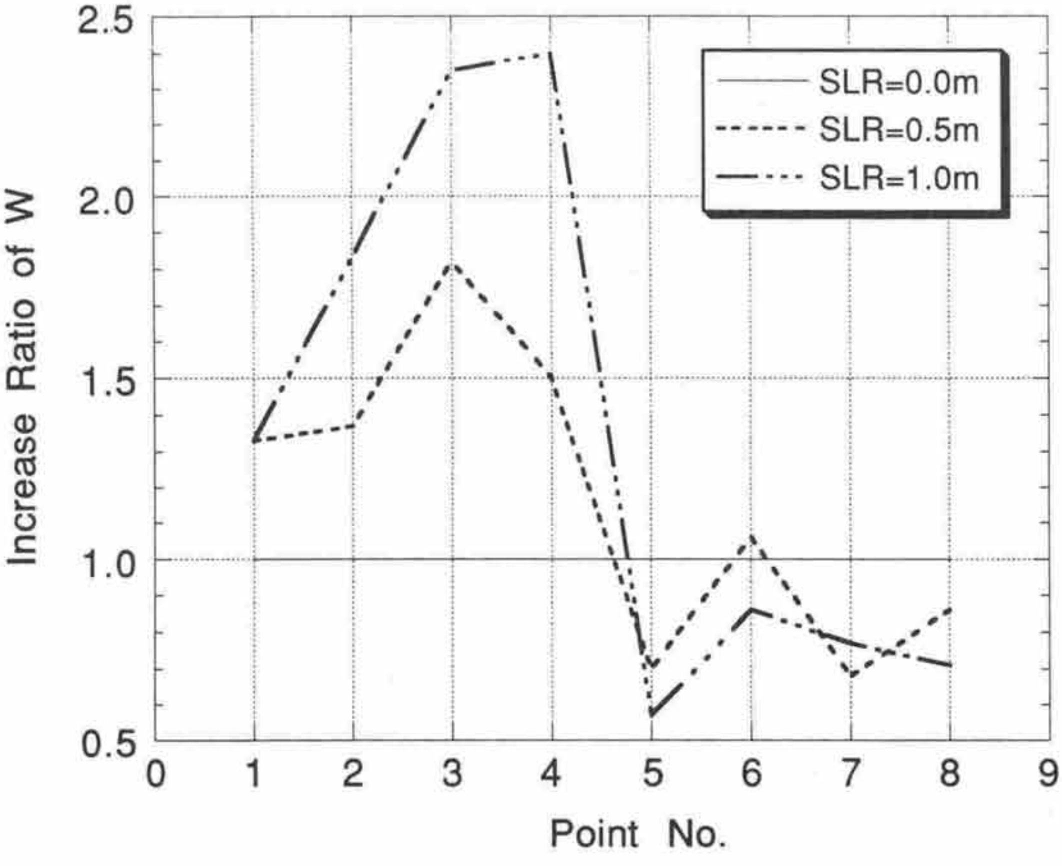


Figure 6.13. Increase ratio of `W' due to sea-level rise

6.7. Other points to be noted

The existing port facilities have been built using a piled pier structure. A comparison chart showing the relation between port structures, still water level, astronomical tide, storm surge, wave set-up and sea-level rise is shown in Figure 6.14.

It can be seen that the surface elevation of the pier is less by 1.0-1.5 above M.H.W.S after sea-level rise. Therefore, the pier may sink only when sea level rises by 1.0 m and Apia harbour is attacked by a cyclone with a return interval of 50 years.

As for the hinterland, if the crown level of the present structures is below CD + 2.40, then there is a possibility of flooding by a cyclone that has a 50-year return period, even without considering sea-level rise.

There is no extreme change in wave height in accordance with water-level rise in the port basin. However, due to sea-water rise, the water level rise changes, the clearance between the structure and sea level (at MHWS) is about 0-0.5 m, and thus helps to increase uplift force. The increase of wave pressure should be reviewed in connection with the stability of the foundation piles.

6.8. 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.

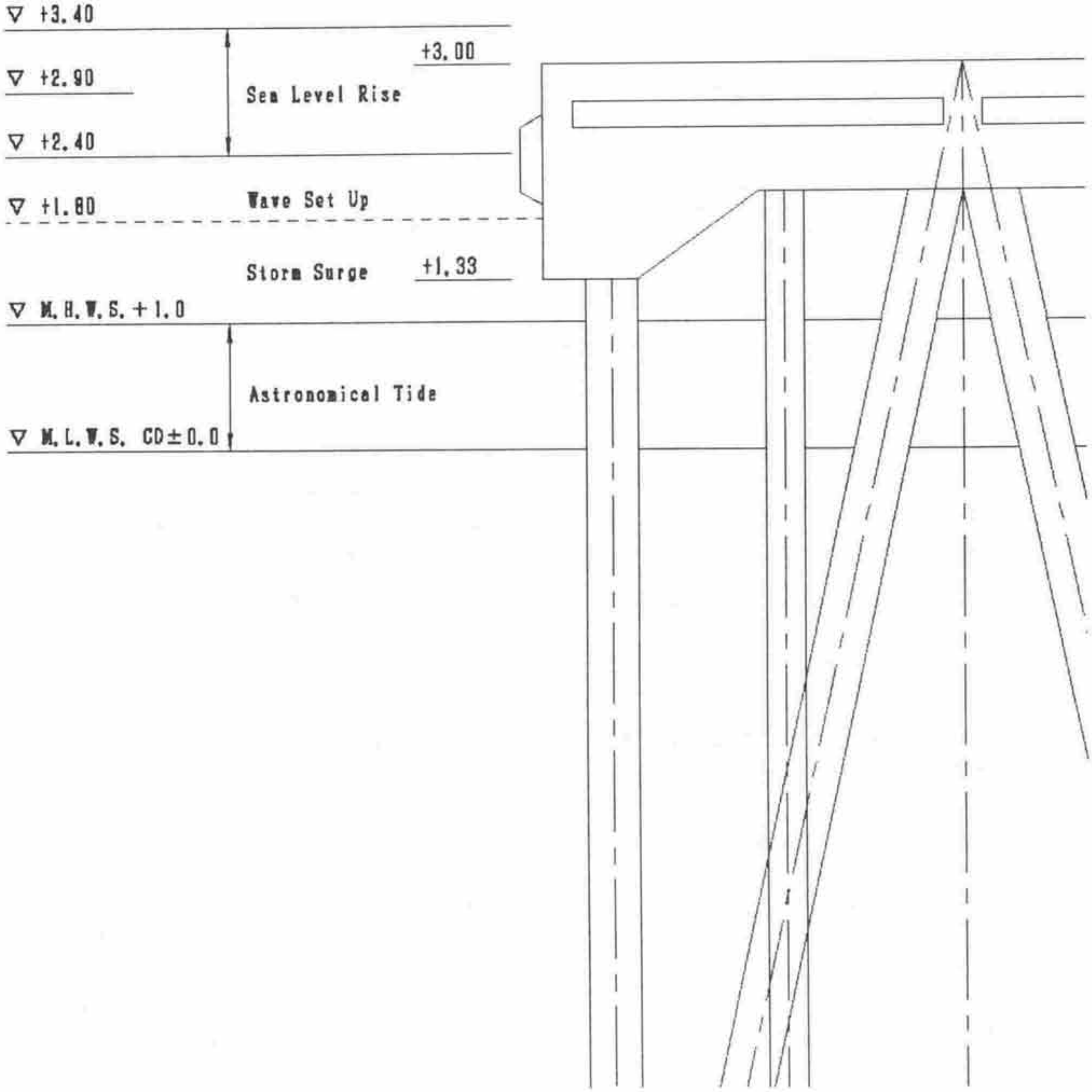


Figure 6.14. Relation between still water level and existing structures in Apia Harbour

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

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 Western Samoa is signatory, Western Samoa 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 Western Samoa study, the Common Methodology was radically altered to apply to the Western Samoa 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. In short, the method of recognizing individual components of the coastal system and assigning them numbers based on a standardized measure of their value, both quantitative and qualitative, allows one to treat Pacific island coasts in a similar way to those on which the Common Methodology was tested and refined.

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 Western Samoa 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 Western Samoa 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 Western Samoa.

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 Western Samoa's people, resources and infrastructure.

In the following sections, the three principal aspects of Western Samoa's coastline are examined and summary statements made about their future in the face of rising sea level given. There follows a section on the vulnerability profile of Western Samoa.

7.2. The physical fabric and its changeability

Superficially, since Western Samoa 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 Western Samoa 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 Western Samoa's long-term future will result in considerably more disruption than is necessary.

Despite the fact that Western Samoa 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 Western Samoa 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 Western Samoa 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 both from salt-water intrusion and sea spray, 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 Western Samoa'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.

Of great concern too are the offshore areas of most parts of Western Samoa's coasts, which are occupied by fringing (and barrier) reefs and associated marine ecosystems. It is doubtful whether most reefs in Western Samoa could respond so effectively to predicted sea-level rise that their present role in protecting Western Samoa's coasts and supplying their inhabitants with a variety of seafood could be sustained. Not only is the species composition of Western Samoa'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 Western Samoa long before sea-level rise has a significant effect.

7.3. Possible threats to agriculture and subsistence farming and possible response options

7.3.1. General relationship of agriculture and coastal lowland

Most human activities are focused in the coastal and adjacent lowland areas of Upolu and Savai'i.

Of the agricultural crops, only coconut trees are grown immediately at the coast. The existing pattern of agriculture, generally either subsistence or plantation cropping, is confined mainly to the lowland and foothill areas up to about 230 metres (Pak-Poy and Kneebone, 1981). On both Upolu and Savai'i, most land used intensively for agriculture is located on coastal lowland below 75 m above sea level (Asghar, 1986). Cattle (beef) can be found grazing on coconut plantations, on partly-cleared or disturbed forest areas, and in designated pastures.

Landuse and land capacity are not necessarily connected as nearly 25% of agriculture and forestry is practiced in unsuitable areas, on class 3 and 4 soils (Chase and Veitayaki, 1992). Yet the classification as to what are actually unsuitable soils is still debated because of different evaluations of the same soils made by different soil scientists (Paulson, 1992b). Wright (1963) emphasized the natural soil fertility and its sustainability, while ANZDEC (1990) assumed that the need to use fertilizer presents only a moderate constraint to agriculture (Paulson, 1992b).

Land-use patterns have changed in important but subtle ways. Old-established coconut plantations continue to dominate the coastal zone. Taro plantations, planted on freshly cleared land continue to be planted further inland and at higher elevations (Paulson, 1992a). The mixed-crop zone of cocoa and banana changed to old cocoa intercropped with coconut, and banana, once a major export crop, is now grown mainly in many small plantations or subsistence patches (Paulson, 1992a).

If there is a positive side to the currently devastating taro blight (Phytophthora colocasiae) affecting Western Samoa, it might be that the trend of clearing indigenous forest for taro may have halted and even be reversed as farmers abandon such plots.

7.3.2. Possible threats to agriculture

7.3.2.a. Sea-level rise influence

One would expect that the obvious threat to agriculture as the result of sea-level rise would be the loss of coastal lowland area owing to flooding or inundation of land above the present high-tide mark. It is presently unknown what the actual range of the predicted sea-level rise will be. Assumed sea-levels of 1, 1.5 and 2 metres have been used by Chase and Veitayaki (1992) to determine the effect of such sea levels on the future coastline of Apia.

Knowing how much coastal lowland used for agriculture is going to be affected, will give an indication of the possible increase in land pressure on the remaining lowland area for agriculture. This will influence in its turn the rate at which native forest might be cleared, and therefore threaten Samoa's biodiversity, to compensate for lost agriculture area.

Most agricultural lands in Western Samoa are found at elevations of 10 metres and higher above sea level (IPCC, 1990). Thus it seems unlikely that the predicted sea-level rise is going to have any direct impact on agriculture in terms of causing any constraints on land area availability.

Unknown is what effect relocating coastal infrastructures might have on land close to the coast already used for agriculture. With rising sea level, villages and the coastal main road will have to be relocated further inland if they become susceptible to flooding or inundation. Still, if an average-sized village would have to move into an original plantation area, it might not limit the area of land available for agriculture significantly.

7.3.2.b. Climate change influence

More likely is that climate change will have an impact on agriculture. The associated increase in rainfall, soil moisture and temperature could mean a change in farming practices and the growing of better adapted types of crops (IPCC, 1990).

If climate change also means an increased frequency and strength of storms such as tropical cyclones, the impact will be substantial. This would include wind damage to crops resulting in blown over or snapped trees (including bananas and other shallow-rooting trees) and foliage severely bruised (such as taro) or completely stripped (such as breadfruit, cocoa, fruit trees) as well as salt-spray damage to crops and inland forest.

During tropical cyclone Val on Savai'i, 90% of all indigenous and plantation trees were defoliated, 40% of indigenous and 47% of plantation trees were snapped in half or uprooted (Chase and Veitayaki, 1992).

The last three cyclones have already caused a complete lack of confidence in perennial cash crops such as cocoa and coffee. This does not mean that these crops are not grown any more. Small holders will continue to grow them for their own uses. Banana is another crop vulnerable to cyclones. Regular cyclones (one every one or two years) might mean a change from more or less continuous to a more seasonal availability of bananas since production of bananas in the cyclone season would be effectively inhibited.

It is uncertain what the impact on the future national food crop production might be. A comparable situation is highlighted by the severe drop in taro production owing to the constraint of `only' one single serious crop disease. Effects on (beef) cattle might be increased by environment-induced stress causing loss in production and physical harm caused by flying debris or panic.

7.3.3. Possible threats to subsistence farming

7.3.3.a. Subsistence farming versus subsistence agriculture

Agriculture in Samoa consists predominantly of subsistence or mixed-subsistence agriculture; commercialized farming systems represent less than 10% of the farm holdings of Western Samoa (Opio-Ekongocka, 1992).

Subsistence agriculture can be seen as part of a wider range of food-growing and gathering activities which fall under the heading of subsistence or traditional farming. In the case of subsistence farming, most of the production (crops, animals) is consumed within the household, the rest used for social obligations. Over 60% of the farm households operating on communal land are of this category (Opio-Ekongocka, 1992). Most importantly, these subsistence farmers also rely in varying degrees on their immediate natural resources, the inshore resources (lagoon, reef) and the remaining indigenous forests for daily supplementation of their diet (mainly from the marine fauna) or the provision of some extra income (fish, timber). Although pigeons and flying foxes are still hunted in the forests and their future presence is seriously threatened (Park and Hay, 1992), they do not represent an essential part of the diet and neither are the forests, except for the periphery, used much for gathering (Paulson, 1992b).

7.3.3.b. Possible threats to subsistence farming

The biodiversity of the marine and native forest ecosystems is quite sensitive, both to human influences, as the modern fa'a samoa is placing unsustainable demands on the natural resources (Park and Hay, 1992), and to changing natural influences, as exemplified by the recent series of violent cyclones.

The forests will be most likely affected more by climate change rather than by sea-level rise. The effects on forests by cyclones have already been mentioned in 7.3.2.b. Further, the sustainability of the forests as a natural resource for subsistence farming is highly questionable (Park and Hay, 1992).

The inshore marine environment is likely to be affected by accelerated sea-level rise and increased wave energy.

The possible repeated flushing of lagoon areas owing to sea-level rise could have both beneficial and damaging effects (IPCC, 1990). It could lead to a reduction in eutrophication and pollutants, which would benefit sensitive marine fauna. Yet increased sediment mobility could cause the smothering of sensitive lagoon and reef ecosystems.

Most important is whether mangrove systems would benefit or suffer. The mangrove wetlands are important ecosystems, both for humans and the rest of nature. Apart from protecting the shore from coastal erosion, mangroves function as marine life habitats and nurseries for certain fish and crustaceans (Zann, 1991).

Essential to this is whether the fringing reefs can keep up with the sea-level rise. If not, because of bigger waves and increased wave energies, the coast will become more vulnerable to flooding and erosion, and the mangrove ecosystems might suffer badly.

7.3.4. Possible response options

Agriculture is probably an area requiring only minimal response. By its very nature, agriculture is adapting continuously to accommodate for the changes in market, environment and labour.

Even if global warming were to result in a sea-level rise of about 1 m and produce a change in rainfall quantity and tropical storm patterns, farming practices would change to accommodate these changes.

Some suggestions are noted below.

-By looking at other Pacific nations that have a history of frequent cyclones, and observing how they have adapted their agricultural practices or farming systems, this will increase understanding of how Samoa might be affected and might have to adjust in future.

- Research in agriculture, forestry, fisheries should take into consideration the possible effects of sea-level rise and climate change on their long-term plans right now.

- Fundamental changes in attitude towards the environment are needed to secure maximum resilience of the land and marine ecosystems now, as a buffer to adverse future impacts on the environment.

- Village-based projects as conducted by the Department of Environment and Conservation should be encouraged as they provide the best means for increasing environmental awareness and understanding.

- Improving the vegetative biodiversity and biomass along low-lying coasts where villages might be at risk from sea-level rise.

Some specific agriculture related items are as follows.

- Research is needed into which sort of crop diversification is feasible and acceptable, incorporating wind damage resilience and local (staple food) preferences.

- Optimal use of windbreaks/shelter belts around plots of crops susceptible to wind damage should be made.

- There should be an increase in crops that can be harvested within the cyclone-free period.

7.4. Human occupation of the coast and possible response options

Most Pacific islanders, including the Samoans, prefer 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 roads. 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.

Western Samoans 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. Such strong attachment to one's own traditional land and original village sites can be well demonstrated by the return from Upolu back to Savai'i of some of the occupants of the two villages destroyed by lava flow in 1905 and 1911. In 1911, some coastal villagers of Savai'i had to abandon their village and migrate to Upolu for safety, when hot lava flowing from nearby mountain volcanoes destroyed their villages and gardening land, and covered the fringing reefs upon which they fished and gathered other marine food sources. These people have been observed to live on their customary land irrespective of its bareness; it consists mostly of young consolidated lava rocks incompletely covered with a very thin layer of soil.

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. Fears of disasters alone will not make people leave the coast. Only if they had suffered severely and their lives had been endangered, would they leave to resettle inland. For example, it was only after hurricanes Ofa and Val that some people moved inland to avoid being again inundated by the high storm surges that usually accompany such strong winds.

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. A substantial amount of cash is remitted back to Western Samoa's people by their relatives living abroad every year. This sends a clear message to potential migrants that more money is to be made overseas and leads to many more migrating. Such a response option is not necessarily to be encouraged since lucrative wage employment overseas is not guaranteed and likewise the desire to remit funds back to Western Samoa may diminish over the years, particularly as more and more people of Samoan ancestry are born in other countries.

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. In eastern Savai'i inland from Puapua and other coastal villages, there is a road along which some people have already settled and to which more seem likely to be attracted if the coastline becomes less easy to inhabit. On Upolu, in the northeast quadrant of the island, an inland road is now well used and becoming an increasingly popular focus for habitations as the coastal zone becomes more crowded and thus less desirable. Such initiatives should be encouraged.

7.5. Nation-wide vulnerability analysis (VA)

In the Phase 1 of this study, the use of a Geographical Information System (GIS) approach to understanding the likely effects of future sea-level rise was described. Upolu island was selected to be the study site because of its importance in Western Samoa. The results showed the strong coast-dependence of the infrastructure and services on Upolu.

A Nationwide Vulnerability Assessment (NWVA) is required to establish an appropriate Integrated Coastal Zone Management Plan, considering sea-level rise and climate change in each Pacific island nation. A successful NWVA is one that understands the condition of the whole coastal area and allows one to precisely study several areas simultaneously.

As the first step of the NWVA, a general understanding about the whole coastal area in Western Samoa is important. Yet all required data such as geography, landuse, and infrastructure are not available. In this chapter, a preliminary study for the nationwide VA was implemented using Geographic Information System (GIS) techniques.

Geographic Information System (GIS) techniques provide powerful analytical tools 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 quantitatively assess the impact of particular stresses such as sea-level rise on such elements as the area of lowland, population, infrastructure, rather than qualitative values such as social and cultural items.

The GIS software used was ARC/INFO housed on a computer operating under UNIX. Topographic maps of the whole of Upolu and Savai'i Islands at a scale of 1:20,000 were digitized to form the data set. Fifteen "layers" of geographic data for both islands were digitized from these maps. The 10 meter contour line in Upolu Island was digitized from the maps of Coastal Morphology of Western Samoa at a scale of 1:25,000 established by SOPAC. Each layer is separate data set (Table 7.1). The GIS can overlay these data to produce composite digital maps. The GIS allows a range of analyses to be undertaken.

The 10 meter contour line in Upolu and the 50 feet contour line in Savai'i are the first contours above mean sea level or the zero meter (feet) contour. The zero contour used to define the coastline. Thus the land between 0-10 meters and 0-50 feet is regarded as coastal lowland.

Table 7.1. Layers digitized from topographic maps into the Geographic Information System (GIS)

	Description
A	coastline
B	10 m / 50 ft contour
C	coastal types (natural, artificial)
D	sealed roads
E	unsealed roads
F	coral and rocks
G	mangroves
H	swamps
I	schools
J	churches
K	springs
L	wells
M	streams
N	water courses
O	airports

The results are shown in Tables 7.2 and 7.3 and examples illustrated graphically in Figures 7.1 and 7.2. In Upolu, while only about 6% of the land area is between 0-10 meters, about 70% of the churches are within the coastal lowland area. In Savai'i, while only about 7% of the land area is between 0-50 feet, about 73% of the churches are within the coastal lowland area.

Churchgoers generally live within walking distance of church in Western Samoa. Families with school children also generally live close to schools. Therefore, the concentration of schools and churches between 0-10 meters or 0-50 feet in Western Samoa gives a general indication of the overall density of household infrastructure within the coastal zone. This proportion of household infrastructure within the coastal lowland area may be between 60-70%. However, the definition of coastal lowland as the area between 0-10 meters (0-50 feet) cannot be correlated directly with the exposure to external or internal stresses, including future sea-level rise and climate change.

GIS analysis can be used to assist disaster management by evaluating the extent of the area at risk from direct inundation from the sea. This approach can be extended to include potential direct inundation risk areas due to future sea-level rise. Maximum future sea-level rise projections are approximately 1 m by the year 2100. Hence, studies using contour lines with close 1.0 m spacing mapped between 0 and 5 m give an indication of the potential areas at risk from direct inundation from a combination of cyclone-surges and sea-level rise, assuming that the present coastline does not evolve in response to sea-level rise.

Table 7.2. Summary of results for the whole of Upolu Island and 0-10 meters area obtained from GIS analysis.

Layer	Whole	0-10m	%0-10 m
Area(km^2)	1,132	72	6.4
Roads(km)	706	158	22.4
Churches(number)	302	211	69.9
Schools(number)	126	77	61.1
Mangrove(km^2)	1.6	1.6	100
Swamp(km^2)	6.6	3.2	100

Table 7.3. Summary of results for the whole of Savai'i Island and 0-50 feet area obtained from GIS analysis.

Layer	Whole	0-50 ft	%0-50 ft
Area(km^2)	1,704	124	7.3
Roads(km)	890	147	16.5
Churches(number)	144	105	72.9
Schools(number)	52	31	59.6
Mangrove(km^2)	0.2	0.2	100
Swamp(km^2)	1	1	100

Western Samoa is one of the biggest countries in the South Pacific from the point of view of land area, population, and economic activity. It is said that Western Samoa has less to fear from future sea-level rise because of relatively high mountains and volcanic islands than have low coral islands. It is, however, believed that Western Samoa is equally vulnerable to the impact of future sea-level rise as well as island countries with low altitudes because of the observation that the limited coastal lowland is densely populated.

In establishing an Integrated Coastal Zone Management Plan in Western Samoa, landuse management in the coastal lowland area with dense population is one of the important themes. In addition to the GIS study, indigenous social and cultural systems, and the land tenure system in Western Samoa are also required to be investigated in depth.

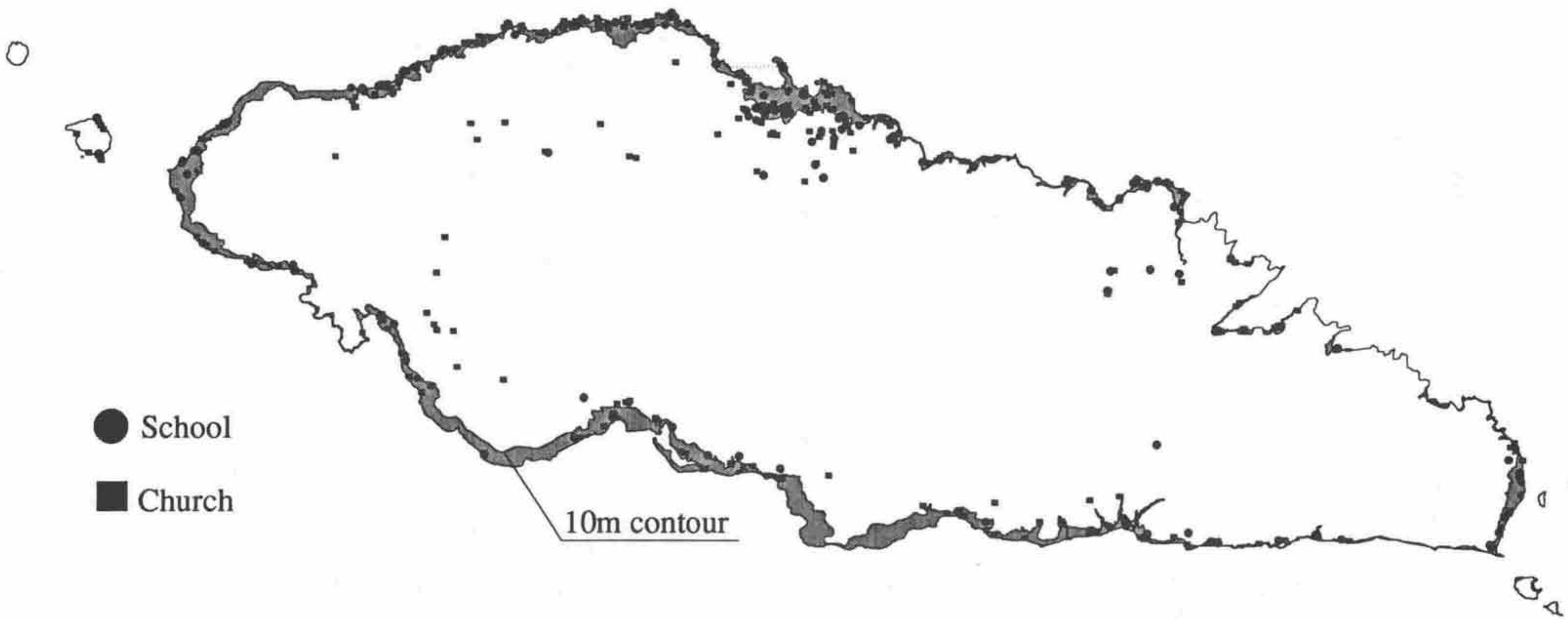


Figure 7.1. Location of schools and churches in Upolu, made using GIS

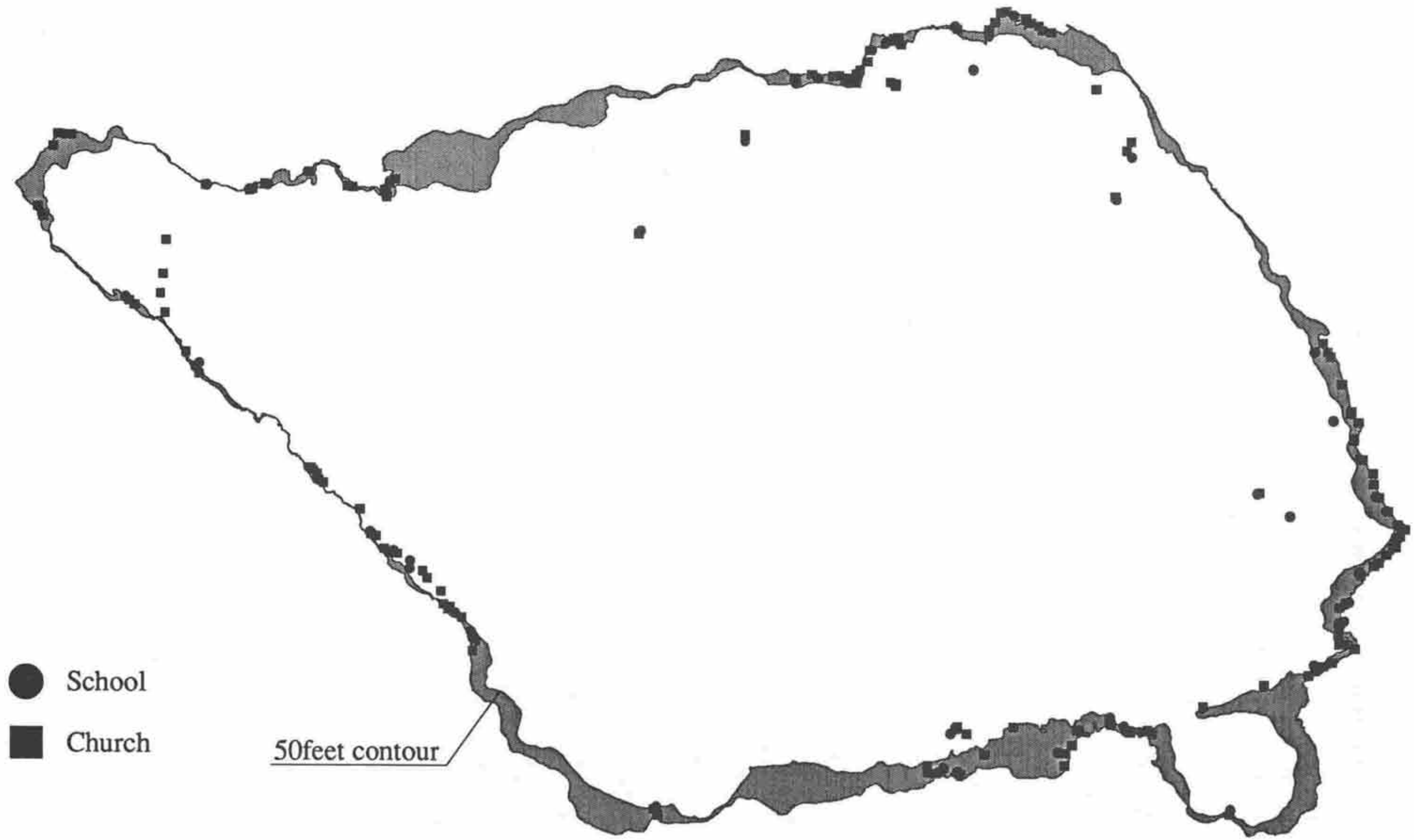


Figure 7.2. Location of schools and churches in Savai'i, made using GIS

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 Western Samoa is drawn up, perhaps in a Phase 3, and thereafter developed in coordination with the Western Samoa Government's Environment Department along international guidelines.

2. We are still ignorant about the typical rates of coastal change in Western Samoa, 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 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. 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 Western Samoa 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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