South Pacific Regional Environment Programme

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

Case Study: 'Upolu Island, Western Samoa

Phase I : Concepts and Approach

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FOREWORD

Small islands in South Pasific 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 Pasific) and international levels. The study consists two phase projects to achieve this object.

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 Prigramme(SPREP).

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

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Finally, the project team would like to thank the many people of Western Samoa who provided input and assistance during field studies.

Contents of Report

Appendices

1. Executive Summary

This report summarises Phase I of a two-phase project which analyses the potential future impact of climate change and sea-level rise on the coast of Western Samoa.

Phase I focussed on the development of a broad new stress-impact assessment framework for the assessment of vulnerability to climate change and sea-level rise. Upolu Island, the most populated, and second largest island of Western Samoa was used as a case study. The conclusions and recommendations of Phase I will form the basis of the workplan for Phase II.

The development of a new stress-impact assessment framework was required because of the inapplicability of economic (cash) cost-benefit vulnerability assessment techniques to the subsistence economies and customary land tenure systems of Western Samoa. The feasibility of the new stress-impact assessment framework was tested by use of a series of preliminary case studies.

The development of the new stress-impact assessment framework was carried out without consideration of specific climate change and sea-level rise scenarios. Consequently, no specific assessments of the potential future impacts of climate change and sea-level rise are undertaken in this report.

Phase II aims to contribute to a national action plan which will assist in reducing the impact of coastal hazards, including future sea-level rise, within Western Samoa. Coastal management policies and plans are required of Western Samoa under the Framework Convention on Climate Change (FCCC) and encouraged by Agenda 21. Moreover, Phase II aims to contribute to regional and international work programmes, particularly those of the South Pacific Regional Environment Programme (SPREP). It was also intended that the methods used in this study would contribute to the development, by the IPCC Coastal Zone Management Sub-Group (CZMS), of an appropriate vulnerability and resilience assessment methodology for the specific characteristics of small island states with largely subsistence economies.

The Western Samoan study has been carried out in parallel with a study of the impact of external and internal stresses on the island of Viti Levu, Fiji. Both studies form part of an ongoing programme of sea-level rise and climate change impact assessment studies coordinated by the South Pacific Regional Environment Programme.

Central to this study was the strong coastal-dependence of the people of Western Samoa. The vast majority of its population, services, infrastructure, cultural centres, social facilities and conservation areas are located within coastal areas, and are therefore vulnerable to stress. The people and government of Western Samoa are already well aware of coastal and climatic hazards. Powerful cyclones struck in Samoa in 1989, 1990 and 1991 and the country was still recovering from their impacts at the time of this study.

The Coastal System vulnerability and resilience analysis undertaken in this report has highlighted the wide range of critical issues requiring the intervention of coastal managers. Critical coastal management issues occur in Western Samoa because of the impact of external and internal stresses on complex and strongly interacting Coastal Systems.

Important external stresses to the Coastal Systems of Western Samoa include: cyclones, tourists, fluctuations in global markets, aid donor requirements and remittances. Two additional external stresses, future sea-level rise and climate change, are likely to add to the already extensive array of external stresses. When external stresses are imposed on Coastal Systems already stressed by considerable internal stresses, critical coastal management problems result. Important internal stresses in Western Samoa include: pollution; the social pressures of unemployment/underemployment, migration and poverty; cultural change; land reclamation; modernisation; and natural resource exploitation.

Critical coastal management problems that result from the interaction of internal and external stresses include: coastal erosion; flooding; and degradation of reefs, mangroves and coastal plains. In many cases coastal management problems result from the impact of more than one stress. Further, internal and external stresses often interact. Consequently the resultant coastal impacts do not have clear cause and effect. As a result, formulating and implementing appropriate management responses was extremely difficult. For example, coastal erosion in rural 'Upolu was probably due to the combined impacts of many stresses. Some stresses which exacerbate coastal erosion include: cyclones, beach and lagoon sand mining; reduction in reef productivity due to overfishing and sediment runoff from poorly managed watersheds; and the construction of poorly designed seawalls by villagers.

However, despite multiple and interacting stresses there are significant opportunities for the effective and integrated management of the Coastal Systems of Western Samoa. This opportunity stems from both recent national government initiatives and the continued strength of involvement in the day-to-day use and management of coastal resources at the village level.

At the national level, the most recent Development Plan 1992-1994 strongly advocates sustainable resource management. There was also a comprehensive array of environmental management legislation which may be enacted to achieve the goal of sustainable coastal resource management. In addition, a range of environmental and disaster management issues are being addressed through national government initiatives, including the National Environmental Management Strategy (NEMS) and those of the National Disaster Council. All of the twelve Target Environmental Components which NEMS has identified as being of high priority for national consideration have direct significance to the coastal areas of Western Samoa.

The Optimal Management Response for the reduction of the impact of stresses to Coastal Systems will require the integration of such environmental management, disaster management and development planning policies and initiatives. Effective implementation of national policies and strategies in urban Apia will require the creation of the proposed Apia Municipal Authority.

The customary ownership of much of 'Upolu's coastal land, and the traditional ties of coastal villagers with coastal land and water, also provide a significant coastal management opportunity. Western Samoans retain strong links to coastal resources through subsistence economic exploitation. In addition, the decision-making powers of village councils remain strong. Consequently, there was scope for villagers to develop, implement and enforce coastal resource management strategies through village rules and traditional methods of enforcement. If villagers do not feel that they are responsible for the success of a coastal management strategy, it is likely to fail. Therefore, the success of nationally conceived coastal management strategies in Western Samoa was likely to be greatly enhanced through the sharing of coastal management strategy development with village decision-makers.

Unfortunately, notwithstanding the opportunities for effective and integrated coastal zone management in Western Samoa, there are important constraints hindering effective policy development and implementation. There are two critical constraints. The first is the financial and human resource constraints of key central government agencies, such as the Division of Environment and Conservation. Second, poor linkage between the national and village levels of decision-making hinders effective policy development. The poor linkage of national and village level decision-making, will result in sub-optimal policy implementation, assuming national government staff will be provided with enough resources to develop such coastal management strategies. The limited resources in central government mean that the development of an integrated coastal zone management plan in Western Samoa will be a slow and frustrating process. Specific recommendations are made in order to alleviate these constraints.

Development of the new stress-impact assessment approach

The new stress-impact assessment approach to the development of coastal zone management strategies to mitigate the potential future impacts of climate change and sea-level rise considers climate change and sea-level rise as additional stresses within a broad stress-response framework. This broader framework takes into account the stresses imposed on Western Samoa's coastal zone from outside its borders. These "external stresses" include the physical stresses of cyclones, and waves, as well as social and economic stresses including: tourists, remittances, and fluctuations and trends in global economic markets.

In addition, the new stress-response framework considers the impact of stresses generated within Western Samoa. These stresses are generally the result of human actions, but can also be due to natural factors. Internal stresses within Western Samoa's coastal zone include: pollution, social stresses, cultural change, population pressure, land reclamation, developmental stresses and resource exploitation. The magnitude of the internal stresses varies markedly around the island.

Internal and external stresses, including sea-level rise and climate change, are viewed as impacting on separate, yet strongly interacting "Coastal Systems". This "Systems Approach" was a management-oriented view of coastal zones. Coastal Systems are divided into "Hard" and "Soft". This division follows the terminology used in the computer industry for "hardware" and "software" for tangible and intangible components respectively. Thus "Hard Coastal Systems" include all tangible components of the coastal zone, including beaches, cliffs, coastal inhabitants and coastal infrastructure. "Soft Coastal Systems" encompass the intangible components of coastal zones including their socio-cultural and institutional Systems, and the economic benefits gained from the use of hard coastal resources. Soft Coastal Systems can also be thought of as the values and attitudes people have regarding the land and water resources of the coastal environment.

Each Coastal System was made up of a number of "Sub-Systems" which were in turn made up of "Coastal Sub-System Elements". The coastal zone of 'Upolu Island contains six Coastal Systems, twelve Sub-Systems and numerous Coastal Sub-System Elements. The six Coastal Systems are human, natural, infrastructural, cultural, economic and institutional.

The assessment framework considers that each Coastal System contains attributes which contribute to a System's vulnerability, and attributes which contribute to a System's resilience. These vulnerability and resilience attributes are artificially divided and analysed separately. This separation was undertaken in order to clarify the range of management responses available to reduce future climate change and sea-level rise stresses, as well as to reduce the impact of the broader range of internal and external stresses considered.

The "systems approach" developed in this report was a flexible, non-prescriptive method for analysing the diverse coastal zones of the South Pacific region. The three levels - Systems, Sub-Systems, and Sub-System Elements - create flexibility by allowing a hierarchy of commonality between, and within, the coastal zones of the region's nations. Many, and probably most, Coastal Systems will be applicable to the majority of the region's coastal zones. There was less commonality at the Sub-system level. Sub-System Elements will be markedly different between coastal nations, and will also show variations within countries at a case study level.

The term "vulnerability" was used to describe the attributes of a Coastal System which will react adversely to the occurrence of an internal or external stress. Such attributes will tend to produce a negative outcome. The term "resilience" was used in the opposite sense to vulnerability. Resilient attributes of a Coastal System will tend to reduce the impact of internal and external stresses. Resilient System attributes can be inherent characteristics which allow adaptation to stress, or be conscious adjustment decisions and actions taken by people in order to reduce damage.

The net impact on each Coastal System due to internal and external stresses was the net difference between the System's vulnerable and resilient attributes. This net System impact was interpreted to be a measure of the System's ability to cope sustainably with stress, and was termed the "Sustainable Capacity Index (SCI)". The concept of sustainability was introduced in order to highlight the long-term viability of Coastal Systems shown by the difference between vulnerability and resilience scores.

The analysis of coastal system vulnerability and resilience was undertaken through a qualitative scoring process, supported by principles of risk assessment, engineering analysis and resource management. Resilience and vulnerability scores were carried out for present day stresses and System conditions. The scoring process was then repeated for "future conditions". Future conditions include the additional stresses of climate change and sea-level rise, continuing internal and external stresses, as well as assumed changes to Coastal Systems. Thus the assessment framework considers a "real life" evolving and dynamic coastal zone.

Future condition vulnerability and resilience scores are assigned assuming two management intervention scenarios. The "No Management" scenario assumes no attempts will be made by national or village decision makers to reduce the impact of stresses in addition to the present coastal management regime. In contrast, the "Optimal Management Response (OMR)" scenario assumes that a suite of management interventions will be undertaken which will optimise the reduction of stress-induced impacts on Coastal Systems. These may include national coastal management and disaster management policies and plans, and education and training of village level decision-makers. Detailed OMR strategies will be examined in Phase II.

Clearly, the approach requires refinement. At present the assessment framework is a way of approaching the issue of the potential risks to coastal zone Systems from internal and external stresses, including sea-level rise and climate change. In order for this framework to be transformed into a methodology which can be formally applied to support coastal management decisions within countries, and compare the efficiency of management decisions between countries, further development is required. Two major areas for the development of the vulnerability and resilience assessment approach are given below: clarification of vulnerability and resilience scoring; and linking the Coastal System stress assessment framework to Impact Zone and Connected Area Analysis (IZCA).

In its present form the qualitative scoring assessment framework cannot be systematically repeated in other coastal nations, nor can it be repeated in Western Samoa by another study team. This non-repeatability was caused because the vulnerability and resilience scores are assigned by a study team through a consensus process, based on the available information. As a result, the scores have a dependence on the composition, professional backgrounds, experience and value judgements of the study team. In order to develop a repeatable, and hence regionally applicable, vulnerability and resilience assessment framework, further work will need to concentrate on establishing boundaries between scores. Determination of the confidence in assigning scores derived from different amounts of information also justifies further investigation.

Thresholds between scores must be closely examined in future development of the System vulnerability and resilience assessment approach. Clear delineation of the difference between scores will be required if the broad assessment framework was developed further into a methodology which can be readily applied by coastal managers and decision makers.

In addition, a future refinement must relate to identifying the interactions between System attributes that comprise vulnerabilities and resiliences. In this initial framework they are considered independent, and can be added together to give an indication of the overall vulnerability and resilience of the Systems being studied. Future work in Phase II is likely to show that the vulnerability and resilience are highly interactive, and that the vulnerability and resilience scores cannot simply be added together.

Coastal System vulnerability and resilience assessment may be embedded within Impact Zone - Connected Area (IZCA) analysis. IZCA was a recently developed generalised framework for the formulation of stress mitigation strategies, within which Coastal Systems analysis was an integral part. IZCA is a four stage process. The analysis required in each stage is listed below.

Stage 1: Stress-impact zone delineation

Stage 2: Vulnerability and resilience analysis of Coastal System within stress-impact zones (undertaken in this study)

Stage 3: Analysis of links between Coastal Systems within the stress-impact zone and non-stress-impact zone Systems (partially undertaken in this study)

Stage 4: Formulation of management strategies within the stress-impact zone and Connected Areas

Phase I of this project has tested the applicability of the Coastal Systems approach without linkage to the Impact Zone and Connected Area (IZCA) framework. The IZCA framework was not considered due to time constraints, and the desire to undertake thorough initial testing of the appropriateness of the Systems approach. The IZCA approach was recommended for testing and possible implementation in Phase II.

Testing the stress-impact framework

The vulnerability and resilience of separate, yet strongly interacting, Coastal Systems are analysed through loosely structured subject-based analysis. The new assessment framework considers the coastal areas of small islands, such as 'Upolu, as highly interconnected. This approach recognises that stresses occur to a different extent around the island's coast. This concept of "differential stress" was particularly important for the analysis of internal stresses, which are largely due to the intensity of human use.

Discussion of the initial testing of the assessment framework was structured around three main issues, or subject areas. These are:

I The vulnerability of 'Upolu's rural coastline populated by villagers. This section describes traditional Samoan society. Where specific examples are required of Coastal System vulnerability and resilience, these are given from the villages around Safata Bay on the south coast of 'Upolu and the villages along the south-east coast between Saleapaga and Lalomanu;

II The range of stresses and resultant vulnerability and resilience of the Coastal Systems of urban Apia. This section highlights the multiple and intense stresses currently being experienced in Apia; and

III The large coastal infrastructure projects of the International Airport and Mulifanua Wharf. The ferry linking the islands of 'Upolu and Savai'i sails from Mulifanua Wharf.

Finally, the initial testing of a Geographic Information System (GIS) for aiding the implementation of the new vulnerability and resilience assessment framework was described.

The case study of rural 'Upolu concluded that there were significant resiliences within the Coastal Systems to internal and external stresses. These resiliences included reef and lagoon adaptability, the resilience of traditional Samoan culture to external stresses, and the ability of communal infrastructure to migrate inland to other areas of customary land if threatened by coastal erosion and flooding. Remittances and gift giving were concluded to be an important part of the resilience of Samoans to stresses, particulary extreme external stresses such as cyclones.

However, there are also factors which were found to contribute to the vulnerability of rural Coastal Systems. Inland migration of village infastructure is not without social tensions and conflicts. Reef and lagoon fisheries are in many cases resulting in gradual ecosystem degradation. The subsistence economy of villages will suffer if unsustainable fishery practices are allowed to continue.

The rural coast case study concluded that villagers have significant opportunities to reduce the future impacts of future climate change, sea-level rise and other stresses, through adaptation and the maintenance of Coastal System resiliences.

The urban Apia case study found that many of Apia's 35,000 inhabitants and much of its nationally important infrastructure is at extreme risk from multiple and intensive internal and external stresses. The intense land use, lack of sewerage, industrial pollution and poor land use planning are critical internal stresses. The integration of coastal management, disaster management and development planning through an Optimal Management Response was concluded to be an urgent priority to reduce the impacts of these stresses on Apia's Coastal Systems.

The predominance of freehold land, and the intensity of population and infrastructure requires a different management approach in Apia than rural 'Upolu. The proposed Apia Municipal Authority is essential for the control of landuse planning, building codes and standards, social and economic activities and other services in Apia. The implementation of this range of policies and plans is urgently required if the future impacts to Apia of sea-level rise and climate change is to be reduced.

Analysis of the factors which contribute to the vulnerability and resilience of the infrastructure of Faleolo Airport and Mulifanua Wharf revealed an approximate balance between the vulnerabilities and the resiliences. The lagoon and reef systems which protect the Airport and Wharf from ocean waves remain relatively healthy. In addition, the national economic importance of the Airport and Wharf has accorded this infrastructure high priority for protection from external and internal stresses.

The seawalls fronting Faleolo Airport have been efficient in reducing the cyclone and wave damage to the airport's infrastructure. The seawall may need to be upgraded as the airport is expanded, as a precaution against sea-level rise and climate change, and internal stresses such as reef degradation and lagoon pollution. However, reduction in seawall effectiveness is not considered a priority due to the relatively high resiliences of the protective lagoon and reef system.

Mulifanua Wharf may also require upgrading as a result of future sea-level rise and climate change. The direct effects of sea-level rise on the Wharf will be exacerbated by the internal stress caused by its design. The stability of the Wharf is affected by downward force exerted by its submerged weight. Sea-level rise would reduce this submerged weight, and hence reduce its stability. If the upgrading of the Wharf is undertaken in the near future to facilitate the development of Savai'i, it would be wise to build in a factor of safety against possible future sea-level rise and climate change.

The Geographic Information System (GIS) case study made significant progress in assessing the utility of GIS in Western Samoa. Initial GIS analyses highlighted the strong dependence of 'Upolu on the coast. While only 9% of the land area of 'Upolu is between 0-50 ft above sea level, 71% of the schools and 78% of the churches are within this coastal lowland area. The survey of existing data revealed a number of critical data-bases which will be required for further work. Two key areas identified for future GIS research are: the support of environmental management through the linkage with the existing land capability database, and the support of disaster management through the identification of cyclone hazard-risk areas. However, the GIS case study highlighted significant technical, financial, and human resource constraints in Western Samoa. As a result, staff training and education programmes must be part of future GIS development.

Recommendations

The research undertaken in Phase I has revealed a number of issues requiring immediate action. These are:

1. Expedite proposed national environmental management plan amendments to Part VIII of the Lands, Surveys and Environment Act to allow better linkage between national government and village level decision-making.

2. Improve the coordination of, and communication between, government agencies responsible for environmental management, development planning and disaster management.

3. Build awareness of, and support education on issues of reducing vulnerability and enhancing resilience of Coastal Systems.

4. Implement the recommendations made in the report "Implications of climate change and sea- level rise for Western Samoa" by Chase and Veitayaki (1992). These recommendations are:
   - (i) Upgrade the meteorological station.
   - (ii) Improve knowledge of Western Samoa's reefs.
   - (iii) Develop a land- and coastal water-use plan.
   - (iv) Establish a regional information system on the effects of climate change.
   - (v) Undertake a number of desk-studies, including Coastal System sensitivity studies, studies which identify indicators of climate change impacts, improvement of climate models, the study of cyclone frequency and intensity, and analysis of historic meteorological records.

Specific Recommendations resulting from case study analysis

Recommendations 1 - 3 have general applicability in Western Samoa. In addition, the case studies require that a number of specific recommendations are made for each study site.

Apia	Expedite the establishment of the proposed Apia Urban Authority and associated planning legislation.
	Initiate a comprehensive programme of mangrove protection, and the limitation of new reclamation (especially in Vaiusu Bay).
	Approve and initiate the Apia Sewerage Project as soon as possible.
Safata Bay	Support and expedite the South Pacific Biodiversity Conservation Programme project for Sanapu-Safaua/Safata areas
Safata Bay and Saleapaga to Lalomanu	Direct the Western Samoa Visitors Bureau to investigate and include the Safata Bay and Saleapaga to Lalomanu coasts in the proposed ecotourism pilot project.
	Direct the Fisheries Division (in conjunction with the Division of Environment and Conservation) to investigate the potential of aquaculture development.
Faleolo and Mulifanua Wharf	Direct the Public Works Department (in conjunction with Airport the Division of Environment and Conservation) to begin investigations on Optimal Management Strategies, including options for upgrading the Airport's seawalls; upgrading the Wharf; reducing wave energies through reef and lagoon management; and reducing pollution entering the lagoon from the Airport and Wharf.

The Phase I research has clarified the objectives for Phase II research. Phase I has also specifiied the research tasks required to achieve these research obectives. The recommended objectives for Phase II are:

Recommended objectives for Phase II

I That the concepts and principles outlined in this report are to be further developed and implemented.

II That Phase II be undertaken within the ongoing projects of the Government of Western Samoa, specifically the Division of Environment and Conservation.

III Phase II is to support the formulation of vulnerability reduction and resilience enhancement plans and policies appropriate to Western Samoa.

IV Phase II activities are to enhance the internal capacity of Western Samoa to implement and monitor the recommended outcomes of Phases I and II of this project.

V Building awareness and supporting education on issues of reducing Coastal System vulnerability and enhancing resilience within Western Samoa.

Recommended research tasks for Phase II

Five research tasks are recommended for Phase II. All five research tasks support the Phase II objectives listed above. The research tasks are:

I Development and implementation of the vulnerability and resilience assessment approach outlined in this report.

The initial testing of the new approach has proved successful. However, the approach requires further development if it is to be directly applicable to Western Samoa or other countries in the region. Phase II work should include: rigid analysis of the factors contributing to vulnerability and resilience scoring decisions; development of guidelines for making scoring decisions; methods of combining Coastal System scores, including limiting factor techniques. The feasibility of linking the Systems approach to Impact Zone and Connected Area Analysis (IZCA) should also be addressed.

II Stress identification.

A tentative list of external and internal stresses to the Coastal Systems of Western Samoa has been created. Stress identification requires further analysis. Also, the relative strengths of internal and external stresses in different parts of the coast requires additional work.

III Development and implementation of the Optimal Management Response (OMR) concept.

The OMR concept has proved to be a useful device for clarifying the range of management actions required to achieve the maximum reduction of stress-induced impacts on Coastal Systems. Further development of the OMR concept is to be be undertaken.

IV Investigation of Coastal System interconnectedness.

The Coastal Systems of 'Upolu have been shown to be highly interconnected. The strength and spatial extent of Coastal System connection requires additional research.

V Geographic Information System (GIS) analysis of the low-lying land in Western Samoa to support disaster and environmental management.

Initial testing of GIS has shown its value for the support of Coastal System vulnerability reduction and resilience enhancement. Extension of the GIS work by integrating existing GIS data-bases and photographic data is required. The GIS research should be integrated with the development of GIS staff training and education programmes to increase the GIS capacity within Western Samoa.

2. Project Aims

The aim of this project is to contribute to integrated coastal zone management, integrated coastal hazard management and sea-level rise impact mitigation at national (Western Samoa), regional (South Pacific) and international levels. The aim will be achieved through a two phase project. This report relates to Phase I of the project.

Phase I aims to develop an appropriate methodology for the assessment of external and internal stresses on the coastal systems in Western Samoa, and to assess its feasibility through a series of preliminary case studies. This methodological development is carried out without consideration of specific climate change and sea-level rise scenarios. Consequently, no specific assessments of the potential future impacts of climate change and sea-level rise are undertaken in this report.

Phase I focusses on 'Upolu, the most populated, and second largest island of Western Samoa. The conclusions and recommendations of Phase I will form the basis of the workplan for Phase II.

Phase II aims to contribute to a national action plan which will assist in reducing the impact of coastal hazards, including future sea-level rise. Moreover, Phase II aims to contribute to regional and international work programmes, particularly those of the South Pacific Regional Environment Programme (SPREP), and the Intergovernmental Panel on Climate Change (IPCC).

The Western Samoan study has been carried out in parallel with a study of the impact of external and internal stresses on the island of Viti Levu, Fiji. The Fiji study is summarised in Nunn *et al.* (1993).

2.1. National, regional and international project context

National

Central to this study is the strong coastal-dependence of the people of Western Samoa. A vast majority of its population, services, infrastructure, cultural centres, social facilities and conservation areas are located within coastal areas, and are therefore vulnerable to stress. The people and government of Western Samoa are already well aware of coastal and climatic hazards. Powerful cyclones struck in Samoa in 1989, 1990 and 1991 and the country is still recovering from their impacts.

There are also increasing stresses on natural resources, infrastructure and services from increased population, and in particular from urban migration. In response to natural resource depletion issues the government adopted sustainable management principles in its Seventh Development Plan (DP7) for the years 1992 to 1994. In addition, the National Environment and Development Management Strategy (NEMS) (Government of Western Samoa 1993) for Western Samoa attempts to provide a planned and systematic approach to the integration of development and environmental concerns. All of the twelve Target Environmental Components which NEMS has identified for priority for national consideration (listed in Appendix 2) have direct significance to the coastal areas of Western Samoa.

Regional

This study is part of a regional environmental research programme coordinated by South Pacific Regional Environment Programme (SPREP). The 1991-1995 SPREP Work Programme is driven by the requirements of the region's member governments. The Work Programmes are contained in the SPREP Action Plan which provides a regional approach to environmental issues by addressing the unique concerns of South Pacific countries and people (SPREP 1992 a,b). The SPREP Work Programme contains nine programme areas. This study is part of the Climate Change Programme, and has strong links with the complementary Coastal Resource Management and Planning Programme.

The SPREP Climate Change programme has coordinated a number of sea-level rise impact assessments and studies in the region, including the present study. Some investigations have tested the regional applicability of the IPCC's Common Methodology for Assessing Vulnerability to Sea-level Rise (IPCC 1992). Studies using the Common Methodology have focussed on the vulnerability of the atoll nations of Kiribati (Woodroffe and McLean 1992) and the Marshall Islands (Holthus *et al.* 1992) . An initial study of the low island of Tongatapu, Kingdom of Tonga using the Common Methodology has also been undertaken (Fifita *et al.* 1992). The present project extends the work programme onto high volcanic islands through the study of 'Upolu, Western Samoa and the island of Viti Levu, Fiji (Nunn *et al.* 1993).

In addition to studies which used the Common Methodology in the Pacific, a series of SPREP-funded "preparatory missions" were carried out in order to identify the priority areas for in-depth studies of the potential impacts of sea-level rise and climate change. The countries visited by the preparatory missions include the Cook Islands (Sem and Underhill 1992), Tuvalu (Aalbersberg and Hay 1992), Kiribati (Sullivan and Gibson 1991), Tokelau (McLean and d'Aubert - in press), the Marshall Islands (Connell and Maata 1992) and Western Samoa (Chase and Veitayaki 1992).

It has been recognised that these studies support the priority areas of the governments of the region as identified in their National Environment Management Strategy (NEMS) reports.

International

This study also contributes to the development of coastal management policies and plans within the region required under the Framework Convention on Climate Change (FCCC) and encouraged by Agenda 21; both outcomes of the UNCED conference (UN 1992a). Article 4 (Section 1e) of the FCCC requires that nations "... develop and elaborate appropriate and integrated plans for coastal zone management". Other Sections of Article 4 require national programmes to "facilitate adaptation to climate change" and "promote sustainable management ... including coastal and marine ecosystems".

It is also intended that the methods used in this study will contribute to the development of methodologies and guidelines for the assessment of the vulnerability and resilience of coastal systems to external and internal stresses, including the potential impacts of sea-level rise. This study is especially intended to aid the development by the IPCC Coastal Zone Management Sub-Group (CZMS) of an appropriate vulnerability and resilience assessment methodology for the specific characteristics of small island states with largely subsistence economies.

3. An Introduction to Western Samoa, its Coastal Zone and Coastal Zone Management

3.1. An introduction to Western Samoa

Western Samoa comprises two main islands: 'Upolu (1123 km^2) and Savai'i (1708 km^2), and several smaller ones, as part of the Samoan volcanic archipelago in the central south-west Pacific (Figure 3.1). Figure 3.2 presents the main features of the island of 'Upolu and locates the case study sites used in this investigation.

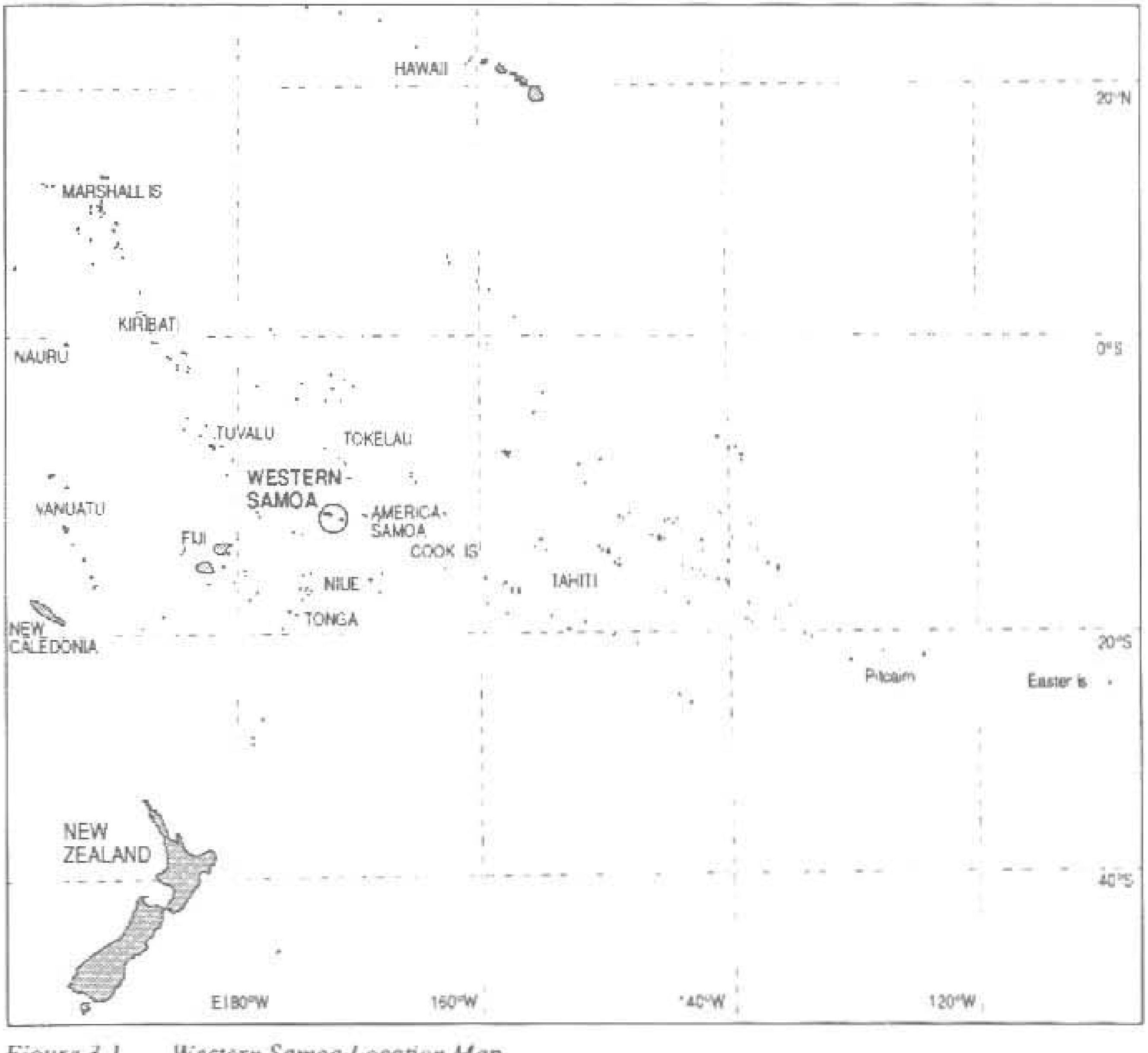

Figure 3.1. Western Samoa Location Map.

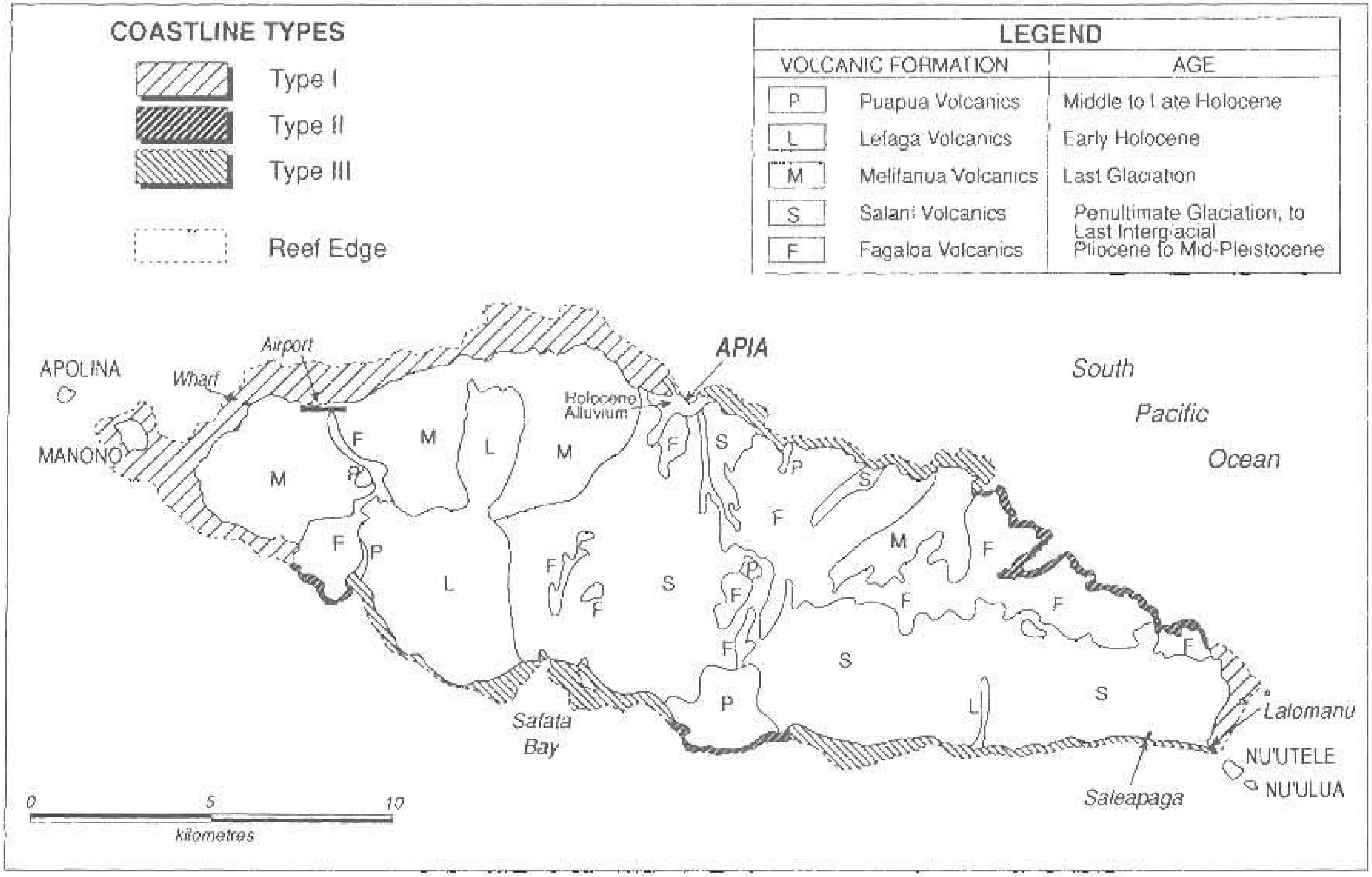

Figure 3.2. Island of 'Upolu, Coastal Types and Case Study Site Location. *Source: Richmond (1991)*

The climate of Western Samoa is influenced by the dominant atmospheric circulation features of the South Pacific, specifically the south-east trade winds and the South Pacific Convergence Zone. Warm and humid climatic conditions prevail throughout the year, with a temperature fluctuation in average monthly temperature of 1-2 °C. The mean annual temperature at sea-level is 26-27 °C. Rainfall occurs throughout the year, although the rainfall patterns delineate a "rainy" (October - March) and "dry" (April - September) season (Burgess 1988). Rainfall tends to be greater on the southern and western flanks of the two main islands, with rainfall totals between 5000 and 7000 mm/yr (Burgess 1988; Chase and Veitayaki 1992).

Three very severe tropical cyclones have hit Western Samoa over the past five years, in 1989, 1990 and 1991, a frequency unknown in the previous 100 years (Carter 1990). The effect of all three cyclones has been dramatic. It is estimated that the loss of production during the 3 weeks following Cyclone Val (1991), was equivalent to 2% of Gross Domestic Product (GDP) for the whole year. The estimated value of homes, crops and infrastructure destroyed by Cyclone Val totalled more than WS$600 million (US$ 228). The latter figure does not include damage due to coastal erosion, loss of biodiversity, damage to catchments and resultant increased soil erosion, loss in conservation areas, damage to reef and lagoon systems, or losses to many other coastal and natural systems.

The population of Western Samoa is approximately 161,300 (Government of Western Samoa 1992f). The population is almost entirely Polynesian, forming the largest single Polynesian population in the world (O'Meara 1990). The capital, Apia has a population of approximately 35,000 people. Population distribution is characterised by four distinct regions: Apia urban area (21%), the north-west coast of 'Upolu (25%), rural 'Upolu (25%), and the island of Savai'i (29%) (Government of Western Samoa 1992e). Approximately 80% of Western Samoans live in the 362 villages. The vast majority of villages are located on the coast.

Agriculture is the backbone of the Western Samoan economy. Along with forestry and fishing, agriculture is a major employer of the population (64%) (Figure 3.3). Despite high employment in this sector, agriculture, forestry and fishing contributed only 21% to the (GDP) in 1989, while subsistence economic activities contributed 26% (Figure 3.3). Western Samoa has experienced a slow rate of GDP growth with agricultural commodities contributing the bulk of exports in 1990 (Figure 3.3). The latter is a result of agricultural production levels remaining constant over the last 30 years, and declining world prices for agricultural commodities. The constant level of agricultural production reflects the constraints of the dominant system of customary land tenure,

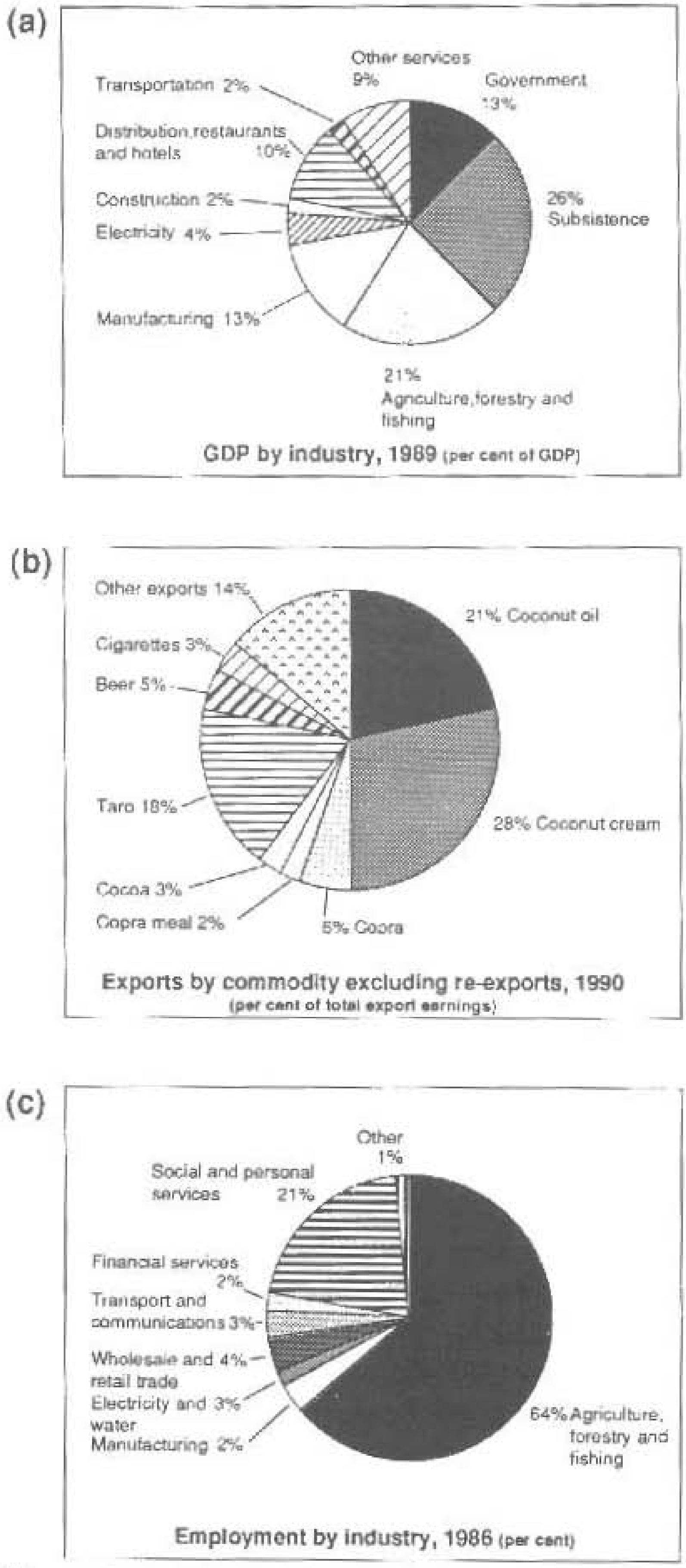

Figure 3.3. Western Samoa Economic Summary. Source: Fairbairn (1991)

and the poor economic returns to village farmers (planters) from agricultural products. The subsistence economic activities which take place in villages, may appear to some as unproductive and uneconomic, but allow villagers to survive economically through communal reciprocal sharing activities.

As Polynesians, Western Samoans have chiefly authority determined by patrilineal descent. The land tenure system in Western Samoa remains dominant today; 80% of all land is under customary title and control of the village chiefs (*matai*), the heads of extended family groups.

3.2. The coastal zone of Western Samoa

The general geological structure of 'Upolu is controlled by five distinct volcanic episodes (Kear and Wood 1959; Keating 1992). Each episode produced extensive lava flows which flowed seaward from high volcanic cones, the remnants of which now form the central highlands of 'Upolu. The lava flows solidified to form olivine rich basalt rocks The oldest volcanic event deposited lava flows during the Pliocene to Mid-Pleistocene period. The most recent lava flows on 'Upolu are mid Holocene in age. In contrast, the latest eruption on Savai'i was in 1911.

The lava flows from each successive volcanic event were deposited onto older lava flows and volcanic deposits. The chemistry and volume of each lava flow determined its progression from the volcanic cone to the coast, where cooling by sea water would slow and eventually halt the lava flow's progression. As a consequence, the lava flows produced by each volcanic episode produced distinctive land-slopes between the volcano and the coast, and distinctive types of coastline. This distinction provides the basis for a division of the coastline of 'Upolu into three "coastal types" (Richmond 1991, 1992). The distribution of the three coastal types is shown in Figure 3.2, while each coastal type is described in detail in Table 3.1.

Reefs almost encircle the entire coast of 'Upolu. Fringing reefs are most common (Type I coast), but barrier (Type III coast) and patch reef types are also present. Reef flats are widespread and typically compose a variety of substrata: coral; algae; cemented reef pavements; marine plants; and carbonate and terrigenous sand and gravel (Richmond, 1991). Reef crests are characterised by either compact coral colonies, encrusted coralline algae, or rubble pavements. High wave energies at reef crests encourage the deposition of coarse sediments between coral formations. Well developed fringing and barrier reefs are usually fronted by submarine terraces. They are separated from the reef crest by very steep reef fronts and are typically covered by wave resistant compact corals. A number of "blue holes" or sinkholes occur in the barrier reefs around 'Upolu.

Coastal Type	Reef characteristics	Depositional Features	Inshore geology
Type I	Wide fringing reef transitional to a shallow barrier reef	Poorly developed mixed carbonate/terrigenous sediments in a narrow fringing reef	Hinterland of gently seaward sloping Mulifanua and Salina Volcanics
Type II	Cliffed coast with little or no reef development	Limited or no depositional features	Puapua Volcanics or older Fagaloa Volcanics
Type III	Either: (a) Fringing reef (b) Wider fringing reef with prominent gaps where freshwater output is high	(a) Narrow coastal strip consisting mostly of storm-derived carbonate sand beach ridges(s) with lesser amounts of terrigenous material (b) Beaches, barriers, spits, and coastal swamps associated with rivers and streams	Predominantly Salani Volcanics but may also include Lefaga and Fagaloa Volcanics

Table 3.1. *'Upolu Coastal Classification.* *Source: Richmond (1991)*

They were developed in the limestone reefs by freshwater during times of lower sea-levels and have unique sedimentation patterns (Richmond, 1991). The shallow lagoons which occur behind barrier reefs average between 2-5m in depth and are up to several kilometres wide. Lagoon bottoms are composed of either smooth-floored sediment, marine floral blanketed substratas, or coral pinnacles interspersed with sediments (Richmond, 1991).

Pocket beaches are the most common beach formation on 'Upolu (Richmond, 1991). The beaches are prone to erosion during storms, and constantly change profile and alignment in response to wave conditions. Beach elevations around the island are indicative of wave energy and runup heights as well as the width of the adjacent reef flat.

Streams and rivers affect the coastline of 'Upolu by delivering large amounts of freshwater and sediments to the coast. Freshwater input and increased turbidity inhibits coral growth around river mouths. The sediment discharge patterns of rivers and streams around 'Upolu are largely uncharacteristic. Incomplete records indicate that floods are the major contributor of sediment to the coast. While some material may be incorporated in depositional features, most is transported directly into deeper water offshore (Richmond, 1991).

Swamp and mangrove communities located in low lying coastal regions are common features in 'Upolu, particularly in drowned valleys and barrier impounded river/stream mouths. The largest mangrove swamps are positioned behind the Mulinu'u peninsula (Apia) and Vaie'e Peninsula (Safata Bay) (Park *et al.* 1992). These two peninsulas are large barrier spits formed from Holocene sands. Smaller swamps also back some beach ridges. Mangroves are believed to have once been more extensive. Mangroves often fronted sand beaches, but were removed for firewood (Richmond, 1991). Mangrove swamplands are currently suffering destruction as a result of land reclamation, especially around Apia.

The coast of Western Samoa appears to be undergoing widespread erosion from a combination of direct wave attack, possible island sinking, shoreline adjustment, sand mining, poorly designed sea walls and revetments, and the destruction of protective vegetation and other natural features. Evidence related to the sea level history for Western Samoa is conflicting, but Richmond (1991) concluded that there is reason to believe that sea levels were not higher than present levels at any time during the past 10,000 years.

Both Morton *et al.* (in press) and Zann (1991), present descriptions of the biological characteristics of the coastal Western Samoa. Specific fauna are located in the different ecosystem habitats of mangroves, fringing and barrier coral reefs, and terrestrial, rock and sand communities.

However, the abundance of marine organisms is dwindling - declining fish catches were recently described as "alarming" (Government of Western Samoa 1992b,). This change is believed to be due to considerably modified coastal ecosystems caused by exploitation, and disruption and alteration of coastal habitats.

Reef ecosystems in Western Samoa have been severely damaged by tropical cyclones as well as outbreaks of Acanthaster planci (crown of thorns starfish) which have destroying large areas of reef in many areas of 'Upolu within the last 20 years (Zann and Bell 1991).

Western Samoa's coastal environment has been modified by a variety of human activities. Despite the limited industry and lack of mineral mining in 'Upolu, there has still been significant modification of the coastal environment (Ko Win 1989). Major areas of industrial and residential development occur in and around Apia. This development has involved extensive clearance of original vegetation, river course alteration, infilling of the lagoon, construction of sea walls and wharves, dredging of harbour sediments, and rubbish dumping. The mangrove, lagoon and reef waters near Apia have industrial wastes and residues, pesticides, municipal rubbish and untreated sewage discharged into them. No studies of the impacts of chemicals on the local fauna have been undertaken, although concern has been expressed regarding their impact (Government of Western Samoa 1992b). However, there has been a number of studies and feasibility plans undertaken to reduce the amount of sewage discharged into the sea (Government of Western Samoa 1992d).

Coastal zone modification is also influenced by events inland, particularly deforestation and erosion. This has led to increased deposition of sediments in lagoons and, in some places, eutrophication (Baisyet 1989). Soil erosion is exacerbated by the large rainfalls in Western Samoa. Inland erosion and eutrophication by fine sediment loads may be exacerbated by quarrying for the extraction of rock for the construction of harbour walls, breakwaters, and roads.

There are 19 conservation sites on 'Upolu, with 13 bordering the coast (Pearsall and Whistler 1991). The O Le Pupu Pu'e National Park in south 'Upolu is adjacent to the coast and extends well into the highlands. The Palolo Deep Marine Reserve near Apia was established in 1979, and is Western Samoa's only declared marine reserve. An area around the Aleipata Islands on the south-eastern tip of 'Upolu was proposed as a Marine Park by Andrews and Holthus (1989), but has not yet been established.

3.3. Coastal management decision-making framework in Western Samoa

Western Samoa was the first Pacific island country to gain independence when, in 1962, it broke colonial ties with New Zealand. Western Samoa possesses two styles of government. A Westminster style parliamentary system of national government is superimposed upon customary village-based decision-making structures (Figure 3.4).

Customary systems of decision-making prevail over the majority of coastal land and nearshore waters. Only in Apia is the customary decision-making system of reduced importance. Customary decision-making is effectively semi-autonomous from national decision-making (Cornforth 1992). Therefore, coastal resource management decisions are expressly made within villages. It is at the village level that any decisions will be made to reduce the impacts of external and internal stresses, including future sea-level rise and climate change.

At the village level, decisions made by the Village Council of Chiefs and Orators (*Fono*) are usually expressed by the formulation of rules (Cornforth 1992). Rules can be either long-standing, forming an integral part of village culture, or short-term in response to immediate village concerns. Rules are enforced and policed through the village Council of Chiefs and Orators and heads of families, and non-compliance results in a punishment that depends on the severity of the offence. Punishment can be through various forms of shaming, and in extreme cases involves banishment from the village. Rule breaking is not usually referred to the police, but is instead settled according to custom.

Recognition of the legality of village council rules by the national government in the Fono Act (1990), effectively gives each village the right to manage its own traditional fishing grounds and coastal areas. However, it is not clear whether this authority extends to the prevention of private individuals, other villages or companies from fishing in a village's waters. Certainly the Act does not bind government to village rules or decisions regarding the villager's fishing and coastal areas. Although all the waters from the high tide mark to the boundary of the 200 mile Exclusive Economic Zone (EEZ) are under the legal control of the national government of Western Samoa, the inshore waters and their fish stocks are under the de facto control of each Village Council. Each village has traditionally fished its nearshore waters, and has effectively laid claim to the waters on an existing use basis. Similarly the foreshore and esplanade reserve, whilst legally controlled by national government, is effectively under de facto control by each village.

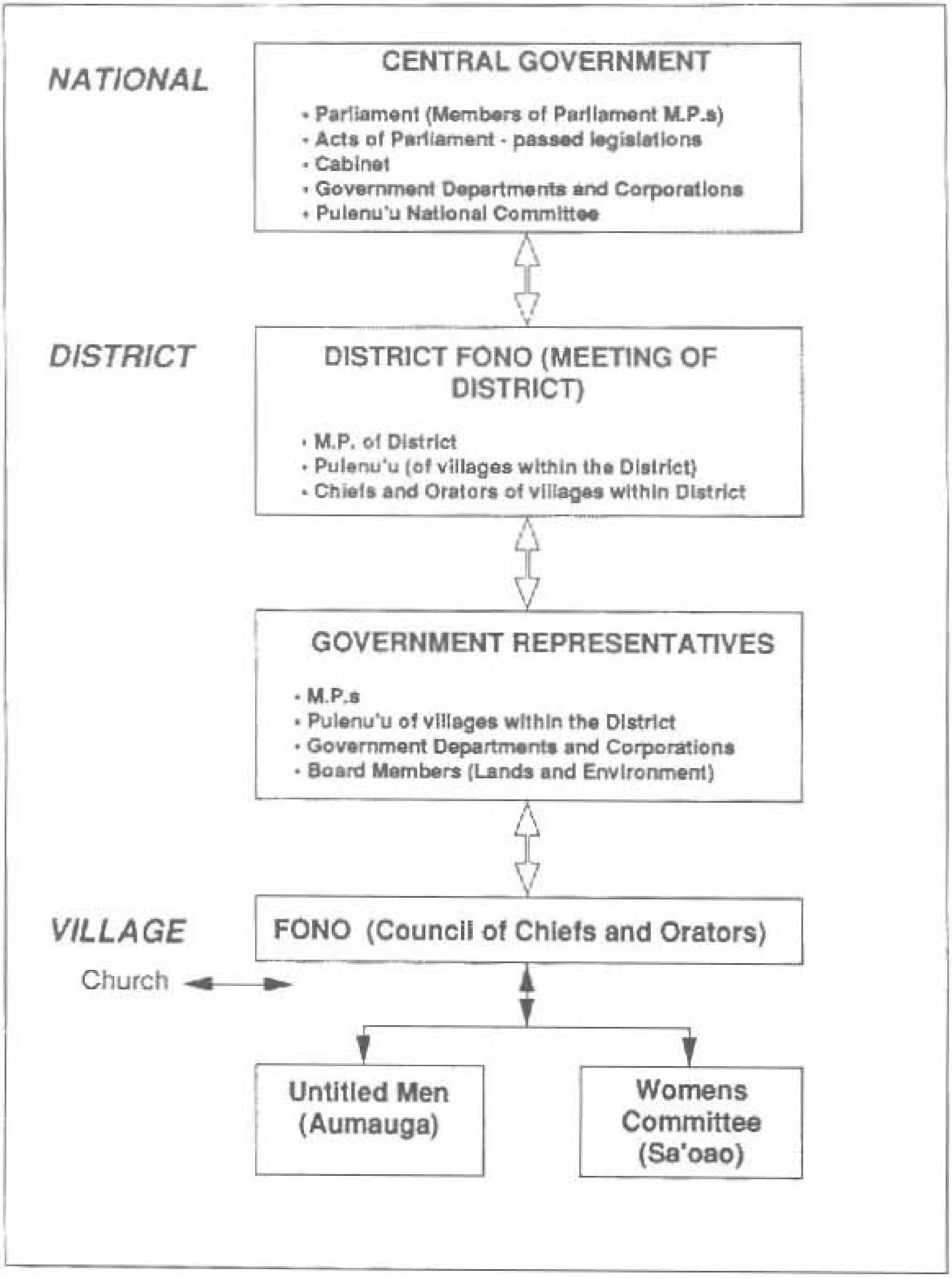

Figure 3.4. Western Samoa Coastal Management Decision-Making Framework.

National level decisions are made by the elected members of parliament. Members of parliament represent electoral districts, usually made up of a group of villages. Acts of parliament are passed by parliament and implemented and enforced by government departments and the police. There are a number of Acts of Parliament of importance for the management of coastal land and water (Appendix 1). In addition, all land below the high water mark is public land controlled by government (Article 104 of the Constitution of the Independent State of Western Samoa).

The government initiative which most strongly reflects the concern and present priority for environmental and coastal area management in Western Samoa was the establishment in 1989 of the Division of Environment and Conservation (DEC) within the Department of Lands, Surveys and Environment. The legislative and procedural mechanisms to address competing pressures and to resolve conflicts between development proposals and environmental protection will form an important part of the future work of the Division. Other DEC functions include the development of environmental impact assessment procedures, increasing public awareness of environmental issues, and monitoring the state of the environment.

The DEC is also responsible for the coordination of the Western Samoa National Environment and Development Management Strategy (NEMS) (Government of Western Samoa 1993). The NEMS is an attempt to provide a planned and systematic approach to the integration of development and environmental concerns. Implementation of NEMS will promote the use of a consistent and sound set of principles and guidelines that will assist sustainable development. Based on the main principles laid out in Agenda 21 (UN 1992a), NEMS places the well-being of people foremost and recognises that people and the environment are interrelated and inseparable. All the twelve critical environmental issues identified in NEMS for priority national consideration (listed in Appendix 2) have direct significance to the sustainable management of the coastal areas of Western Samoa.

A number of national agencies and ad-hoc government committees also control regulations important in the formulation and implementation of a national coastal management policy. These include:

- National Planning Office;
- Cabinet Development Committee;
- Economic Policy Advisory Committee;
- National Disaster Council; and
- Pulenu'u Committee.

Future government programs will place a greater emphasis on integrated natural resource management and sustainable economic growth in comparison to previous practice. The Western

Samoan government in its most recent development plan (DP 7), has acknowledged that reduced emigration opportunities will increase population growth in the country and place increasing pressure on the environment. Proposed development projects will be subjected to more rigorous scrutiny for their environmental impact than in the past. Donors will be invited to focus their attention on human resource development, institutional strengthening and maintenance activities, rather than building new infrastructures. Private sector initiatives backed by government include development of an ecotourism industry around Apia and Western Samoan villages. The ecotourism initiative aims to allow sustainable coastal resource use by tourists and assures that tourism does not conflict with Samoan culture (Government of Western Samoa and Tourism Council of the South Pacific 1992).

The Western Samoan government has also recently refocussed the nation's development goals with respect to institutional structures and arrangements. Past institutional problems are presently being modified through attempts to improve the public administration system through the re-organisation of personnel management, public service incentives, financial planning, and the coordination and distribution of aid. The Government is also adopting a fundamental change in its philosophy by encouraging an economy in which the private sector plays a greater role in the development and growth of Apia, with the intention that the rest of Western Samoa will also benefit.

It is planned to be introduce legislation to establish an Apia Municipal Authority, with powers to control landuse in urban Apia, as well as to improve services to residents and promote the town's economic and social development capacities. Apia is the capital of Western Samoa and is on low-lying coastal land. A new Apia Municipal Authority would tackle unplanned urban expansion in Apia and manage the high rate of migration into its urban and hinterland areas. Proposed planning legislation will promote appropriate town planning in urban Apia.

Western Samoa is party to a number of conventions which implicitly recognise the need for coastal management: the Convention for Conservation of Nature in the South Pacific (Apia Convention), the Convention for Conservation and Protection of Natural Resources and Environment of the South Pacific (SPREP Convention), the South Pacific Nuclear Free Zone Treaty, and the Framework Convention on Climate Change.

However, the implementation of the range of national strategies and legislation described above is fraught with difficulty. Implementation problems arise principally because of the lack of any institutionalised and practiced form of strategic planning and the ongoing problems in commitment and implementation by villages or government. This situation is exacerbated by the lack of an adequate mechanism to integrate national government and village level authority. Draft amendments to the Lands, Surveys and Environment Act (1989) offer some solution to the latter problem (Cornforth 1992). However, the lack of commitment to the formal procedures for land use or development planning are likely to continue to impede effective policy implementation. Again the institutional linkages between national legislation and local administration need to be strengthened and clarified to ensure the successful implementation of any proposed coastal management strategy.

As the previous discussion has shown, there is no lack of national legislation for sustainable management of coastal and marine areas, or lack of implementation capacity by Village Councils. However, a recent analysis of environmental management legislation in Western Samoa found that "very few laws are complied with, and even fewer enforced" (Cornforth 1992). There is a widespread belief amongst resource managers in Western Samoa that harmonising the two systems of national and village level regulation and management is gradually being achieved. Such harmonisation will increasingly lead to improved compliance and more effective enforcement. Therefore, present government policies and legislation do provide a sound basis for successful coastal zone management in the future. Their application to the management of external and internal stresses, including future sea-level rise and climate change, are discussed in Section 7.

4. Development of an Appropriate Framework for the Assessment of Sea-level Rise and Climate Change Impacts in Western Samoa

4.1. The Common Methodology for the assessment of coastal area vulnerability to sea-level rise

In September 1991 the Coastal Zone Management Sub-group (CZMS) of the Intergovernmental Panel on Climate Change (IPCC) released its "Common Methodology for Assessing Vulnerability to Sea-level Rise", hereafter abbreviated to the "Common Methodology" (IPCC 1991). The Common Methodology was developed from an original proposal, made at the 1990 Miami IPCC-CZMS workshop, to send a questionnaire to all coastal nations. The questionnaire attempted to gain a first order estimate of the economic vulnerability of the global coastline to potential sea-level rise due to global warming. The original version of the Common Methodology has been revised slightly as a result of comments received at the April 1992 Margerita Island IPCC-CZMS meeting (IPCC 1992).

The Common Methodology uses monetary valuations as an estimate of a coastal nation's vulnerability to future sea-level rise. A crude cost-benefit test is applied to these results to assess the preferred "response option" to mitigate future coastal impacts. Response options include defending the coast with shoreline protection works, accommodating coastal change, or gradually retreating from the vulnerable coastal area. The Common Methodology has been applied through case studies in over twenty-five countries throughout the world (IPCC 1992).

As the name suggests, the Common Methodology aims to be a method which can be commonly applied to all coastal nations. As such, the Common Methodology should be applicable to Western Samoa and possess the ability to deal with the intricacies of Samoan socio-economic life in as much detail as the geological and biological aspects of its coastal regions. In particular, the Common Methodology should implicitly recognise the importance of the following ten issues for Western Samoa (listed in approximately decreasing order of importance):

I- Subsistence economy;

II- Close ties of Samoans to land through customary land tenure;

III- Importance of extended family structures;

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

V- Lack of urban (Apia) land use planning or building codes;

VI- Importance of the proximity to roads in rural areas;

VII- Ineffective linkages between national (parliamentary) and village (customary) decision making;

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

IX- Strength of religious beliefs; and

X- Human resource, technical and data limitations.

The first two issues listed above render the Common Methodology, and any economic-based assessment technique, fundamentally inappropriate in Western Samoa. Issues III to VII present serious operational problems in carrying out any assessment using the Common Methodology, while issues IX and X could be dealt with through minor adjustments to the Common Methodology. These shortcomings of the Common Methodology, especially the inapplicability of economic-based assessment techniques in countries with important subsistence economies and/or customary land tenure systems, has necessitated the formulation of a new assessment framework appropriate for Western Samoa, described later in this section.

Concerns have been also been raised as to the appropriateness of the Common Methodology by other studies carried out elsewhere in the Asia-Pacific region. These misgivings range from minor operational problems (Holthus *et al.* 1992), to fundamental methodological concerns. The latter concerns centre on four main issues:

I the applicability of economic-based assessment techniques within primarily subsistence economies (Woodroffe and McLean 1992, 1993);

II the utility of the Common Methodology for aiding coastal managers in formulating sea-level rise impact assessment policies (Kay *et al.* 1992);

III the lack of time dependency in the Common Methodology does not allow realistic assessment of potential sea-level rise impacts on highly dynamic coastal systems, including socio-economic and cultural systems (Kay *et al.* 1993); and

IV the narrow geographic conception of the "coastal zone" does not take into account important interactions with the adjoining land and marine systems (Holligan and de Boois 1993; Warrick 1993).

These four fundamental concerns with the Common Methodology add support to the development of a new approach to the assessment of potential future impacts of sea-level rise and climate change in Western Samoa. This approach is introduced in the following section. It is intended that this new approach has the scope be further developed into a methodology which can be applied to allow coastal managers and decision makers to formulate polices to reduce the impact of stresses, including sea-level rise and climate change to Coastal Systems, both in Western Samoa and throughout the South Pacific.

4.2. A new approach to sea-level rise impact assessments within a broader stress analysis framework

A new and innovative approach, which takes note of the concerns regarding the regional applicability of the Common Methodology, is used for the first time in this report. This approach builds on and expands the Common Methodology to provide an assessment and decision-making support framework appropriate for the South Pacific, and generally applicable to the Asia-Pacific region. Further, the approach is not limited to analyses of the effects of sea-level rise and climate change. Instead a flexible conceptual framework is adopted which assesses the vulnerability, resilience and sensitivity of coastal systems to a range of external stresses such as waves, tropical cyclones (typhoons), fluctuations in global economic markets, tourists and sea-level rise and climate change. In addition, internal system stresses, such as population pressure, natural resource depletion, pollution and cultural changes are implicitly considered in the decision support framework. The new approach is similar in concept to the interacting systems approach for the support of decisions to mitigate potential climate change impacts on Caribbean islands, recently explored through computer modelling (Engelen *et al.* 1992).

4.2.1. Coastal zones as interacting systems

The approach adopted here is to view the coastal zone as a set of separate, but interacting, "Coastal Systems" (Figure 4.1). This "systems approach" is a management-oriented view of coastal zones, tailored to the needs of sea-level rise impact assessment, and set within broader and flexible considerations of external and internal stresses to coastal zones. Coastal Systems can be divided into two groups:

I "Hard" Coastal Systems; and

II "Soft" Coastal Systems.

The division between "Hard" and "Soft" follows the division in the computer industry between "hardware" and "software". Tangible computer equipment (computers, printers etc.), is called hardware. The intangible programmes that operate computers, are called software. Thus, "Hard" Coastal Systems include all tangible elements of coastal zones; their natural geomorphological and biological components, such as beaches, reefs and cliffs; coastal zone inhabitants, and coastal zone infrastructure. "Soft" Coastal Systems encompass intangible components of coastal zones; their socio cultural and institutional systems, and the economic benefits gained from the use of "Hard" coastal resources. Soft Coastal Systems can also be thought of as the values and attitudes people have regarding the land, water and resources of the coastal environment. Each Coastal System is made up of a number of "Sub-Systems", which are in turn made up of "Coastal Sub-System Elements".

This "systems approach" is a flexible, non-prescriptive method for analysing the diverse coastal zones of the Asia-Pacific region. The three levels of Coastal Systems, Sub-Systems, and Sub-System Elements create flexibility by allowing a hierarchy of commonality between, and within, the coastal zones of the region's maritime nations. Many, and probably most, Coastal Systems will be applicable to the majority of the region's coastal zones. There is less commonality at the Sub-System level. Sub-System Elements will be markedly different between coastal nations, and will also show variations within countries at a case study level.

4.2.2. Vulnerability and resilience of Coastal Systems

The vulnerabilities and resiliences of Coastal Systems are analysed separately in the decision support system. This is an artificial separation undertaken in order to clarify the range of management responses available to reduce future climate change and sea-level rise impacts. Therefore, impact reduction responses are divided into measures for "vulnerability reduction" and "resilience enhancement".

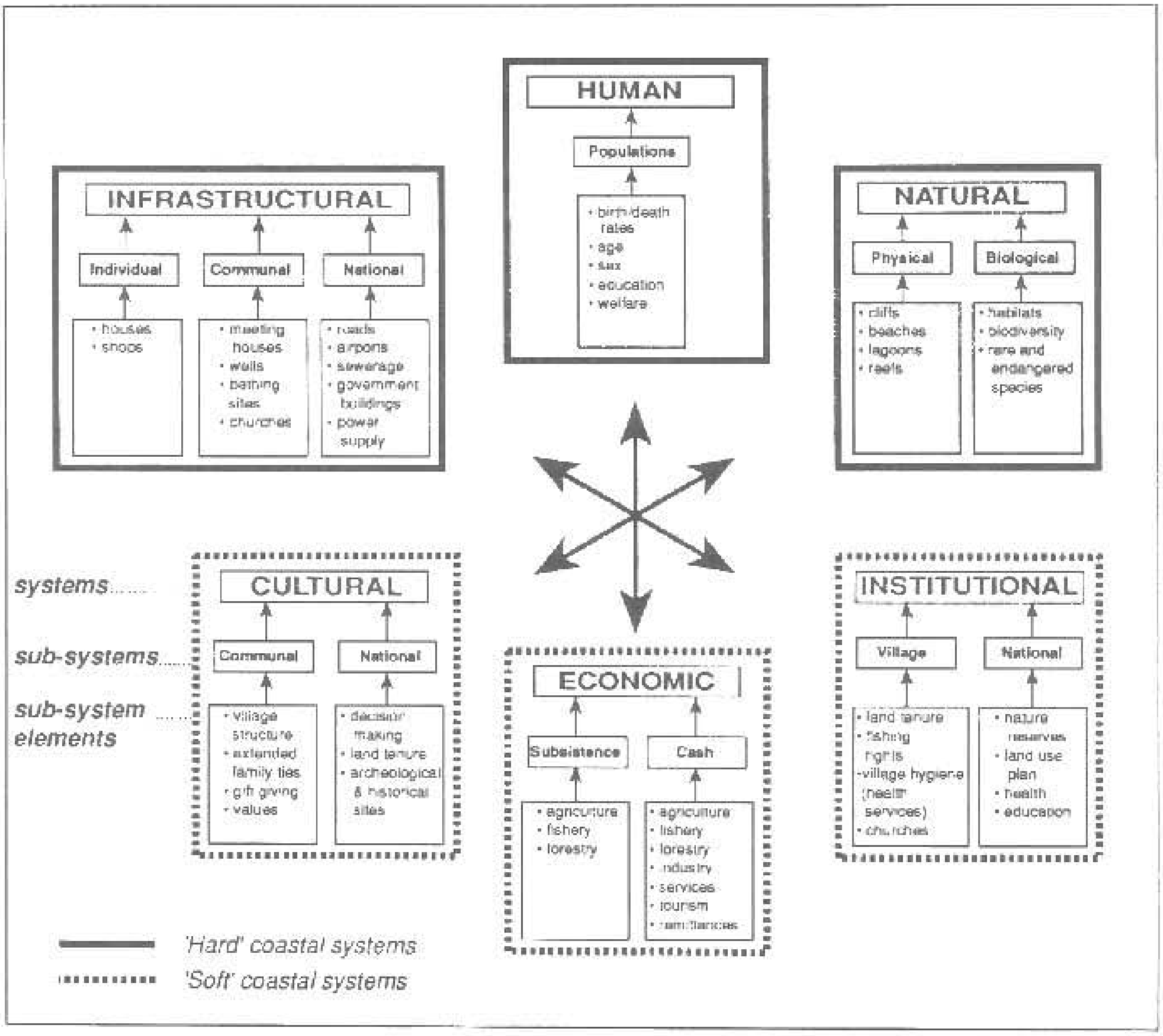

Figure 4.1. *Coastal Systems, Sub-Systems and Sub-System Elements of the Western Samoan Coastal Zone.*

As a general concept, vulnerability is "*the degree to which a system may react adversely to the occurrence of a hazardous event*" (Timmerman 1981). In this sense, vulnerability may be interpreted to describe the potential for damage or the net outcome of a hazardous event on a particular system. However, Timmerman warns that "*vulnerability is a term of such broad use as to be almost useless for careful description at present, except as a rhetorical indicator of areas of greatest concern*". This last point allows a wider interpretation of "vulnerability" to be used for the analysis of the risk to coastal systems from external and internal stresses.

Vulnerability is interpreted here to describe the attributes of a system which will react adversely to the occurrence of a hazardous event. Such attributes will tend to produce a negative outcome, such as poor (vulnerable) building design or location within low-lying (vulnerable) land. The decision support framework introduced in this paper analyses each Coastal System separately in terms of its ability to react adversely to external and internal stresses (Figure 4.2).

Moreover, the decision support framework, assumes that there are also attributes within each system that act to reduce the impact of hazardous events on systems. Such attributes can be inherent characteristics of Coastal Systems which allow adaptation to external and internal stresses. An example is natural reef growth in response to sea-level rise (Buddemeier and Kinzie 1976). There are also conscious decisions and actions, called "adjustments", taken by people in order to reduce damage (White 1945; Burton *et al.* 1978). Adjustment and adaptation mechanisms to external and internal stresses are termed "resiliences" in the decision support framework.

Thus, the net impact to coastal zone systems resulting from external and internal stresses is the difference between the resiliences and vulnerabilities of Coastal Systems. In the decision support system the net impact to Coastal Systems is measured by the Sustainable Capacity Index (SCI), a measure of a system's overall ability to cope sustainably with external and internal stresses.

The analysis of coastal system vulnerability and resilience outlined above is undertaken through a process of qualitative scoring, described in the following section.

4.2.3. Vulnerability and resilience scoring

This decision support technique deliberately forces the separation of the vulnerable and resilient attributes, or "components", of Coastal Systems (Figure 4.1). Qualitative (ordinal) scores are assigned to the vulnerable and resilient components of each Coastal System for present day external and internal stresses.

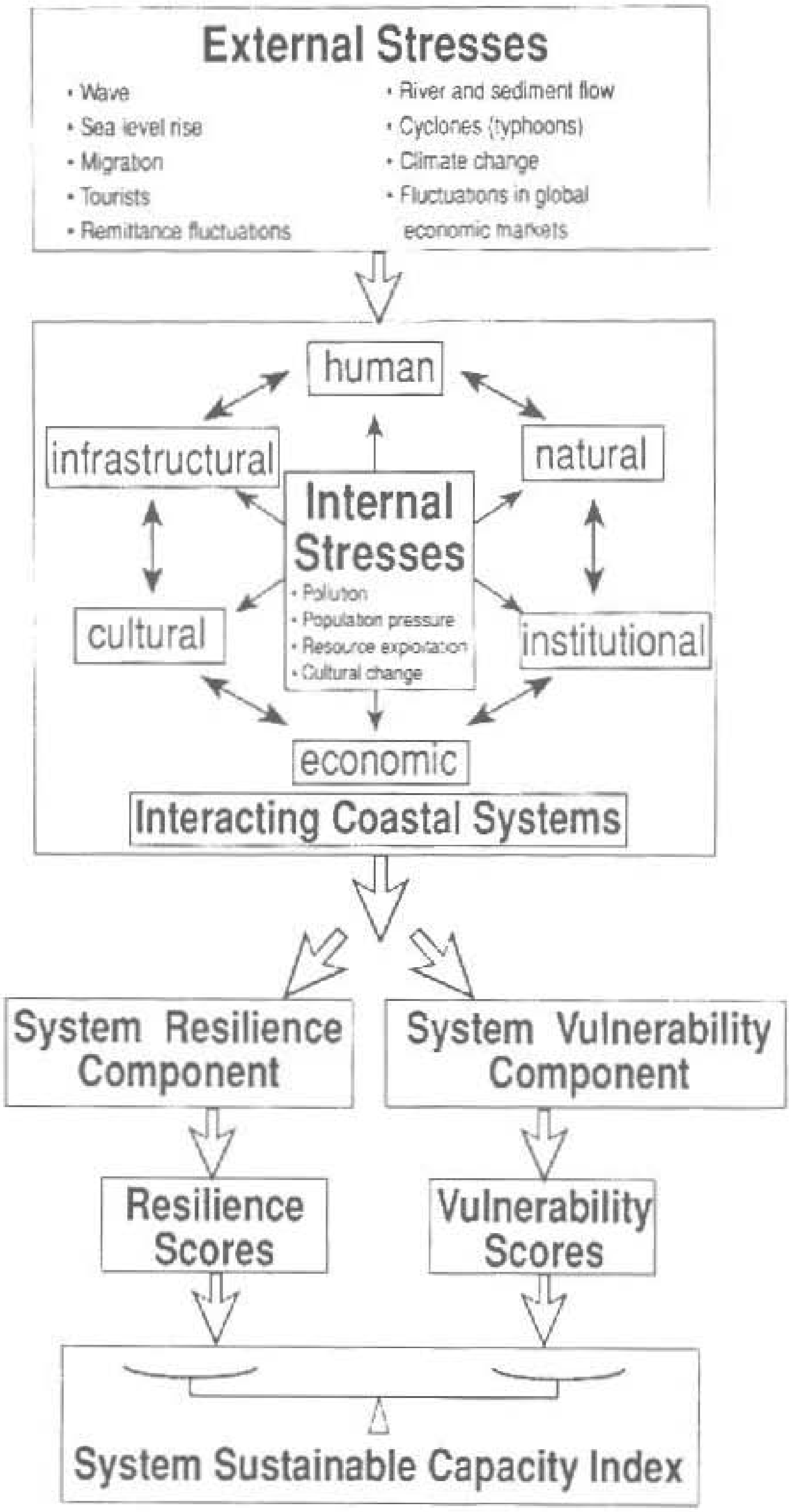

Figure 4.2. Framework for the Assessment of the Vulnerability, Resilience and Sustainable Capacity Index of Coastal Systems to External and Internal Stresses.

The qualitative scores for the vulnerability component of each Coastal System run from 0 to -3, with -3 being the most vulnerable (Table 4.1). Qualitative resilience component scores run from 0 to +3, with +3 being the most resilient. Each resilience and vulnerability component score also has a short descriptor, ranging from extreme vulnerability or resilience, through high, moderate to low (Table 4.1).

The scoring procedure is repeated for "future conditions". "Future conditions" consider changes to external and internal stresses (including sea-level rise and climate change). In addition, the term "future conditions" also takes into account possible future changes produced by internal stresses within each Coastal System. Such internal Coastal System stresses, and the resultant changes, are assumed to occur in isolation from the external stresses of sea-level rise and climate change. Internal stresses may include: population increases, changes in socio-economic conditions and changes to cultural and administrative systems. Thus, the decision support framework considers a "real life" set of evolving Coastal Systems. Each Coastal System has some attributes that will change in the future independently of the changes caused directly by climate change and sea-level rise impacts.

Two qualitative scoring exercises for "future conditions" are undertaken. First, it is assumed that there will be no significant management interventions to reduce vulnerability, or enhance resilience. This is termed the "No Management" scenario. Second, Coastal System vulnerability and resilience component scores are assigned assuming the implementation of a suite of coastal management responses to reduce vulnerability and enhance resilience. Such management responses are assumed to optimise the reduction of vulnerability and the enhancement of resilience, and are called the "Optimal Management Response (OMR)" scenario.

The decision on the rank score of a particular Coastal System's vulnerability or resilience component is achieved through a qualitative analysis of the Sub-System and Sub-System Elements which contribute to a System's vulnerability, and those which contribute to its resilience. The analysis of each Coastal System can be made by a variety of techniques applicable to the range of issues at a particular study site. Appropriate techniques include: risk analysis and assessment, natural hazard analysis, environmental impact assessment, and environmental policy and management analysis frameworks. The choice of techniques will also be driven by the amount and quality of site-specific information. It is important to note that the qualitative scoring technique does not require perfect and/or complete data. As such, the technique has particular applicability in countries where incomplete data sets occur, and where decisions are required under conditions of uncertainty. Such uncertainties and data-gaps occur in the majority of countries in the Asia-Pacific region.

Qualitative Score	Equivalent Descriptor
-3	Extreme vulnerability
-2	High vulnerability
-1	Moderate vulnerability
0	Low vulnerability
0	Low resilience
+1	Moderate resilience
+2	High resilience
+3	Extreme resilience

Table 4.1. Qualitative Coastal System Vulnerability and Resilience Scoring Scale

Probability-consequence curves, adapted from qualitative risk assessment methods (e.g. Royal Society 1983; CSA 1991) are useful as an aid to assigning vulnerability and resilience component scores (Figure 4.3). Frequency-consequence curves are used by risk assessors to display the consequences to systems of a range of probable harmful events. Such curves can be used to consider the range and likely occurrence probability of a range of external and internal stresses. As a result, the vulnerability and resilience component scores assigned with the aid of such curves, are effectively time-integrated summaries of the potential impacts of high probability "normal" events and low probability "extreme" events. Probability-consequence curves are also useful in the delineation of the OMR.

On completion of the qualitative scoring process, the net difference between vulnerability and resilience component scores, the Sustainable Capacity Index (SCI), is calculated. The utility and meaning of SCI is discussed further in the following section.

At present the information and knowledge of Coastal System responses to external and internal stresses does not warrant sophistication beyond the simple addition of the component scores of vulnerability and resilience. However, future development of this decision support framework will need to consider weighting the vulnerability and resilience component scores, and establishing quantified boundaries between scores. Possible future development of the tool is examined in Section 6.

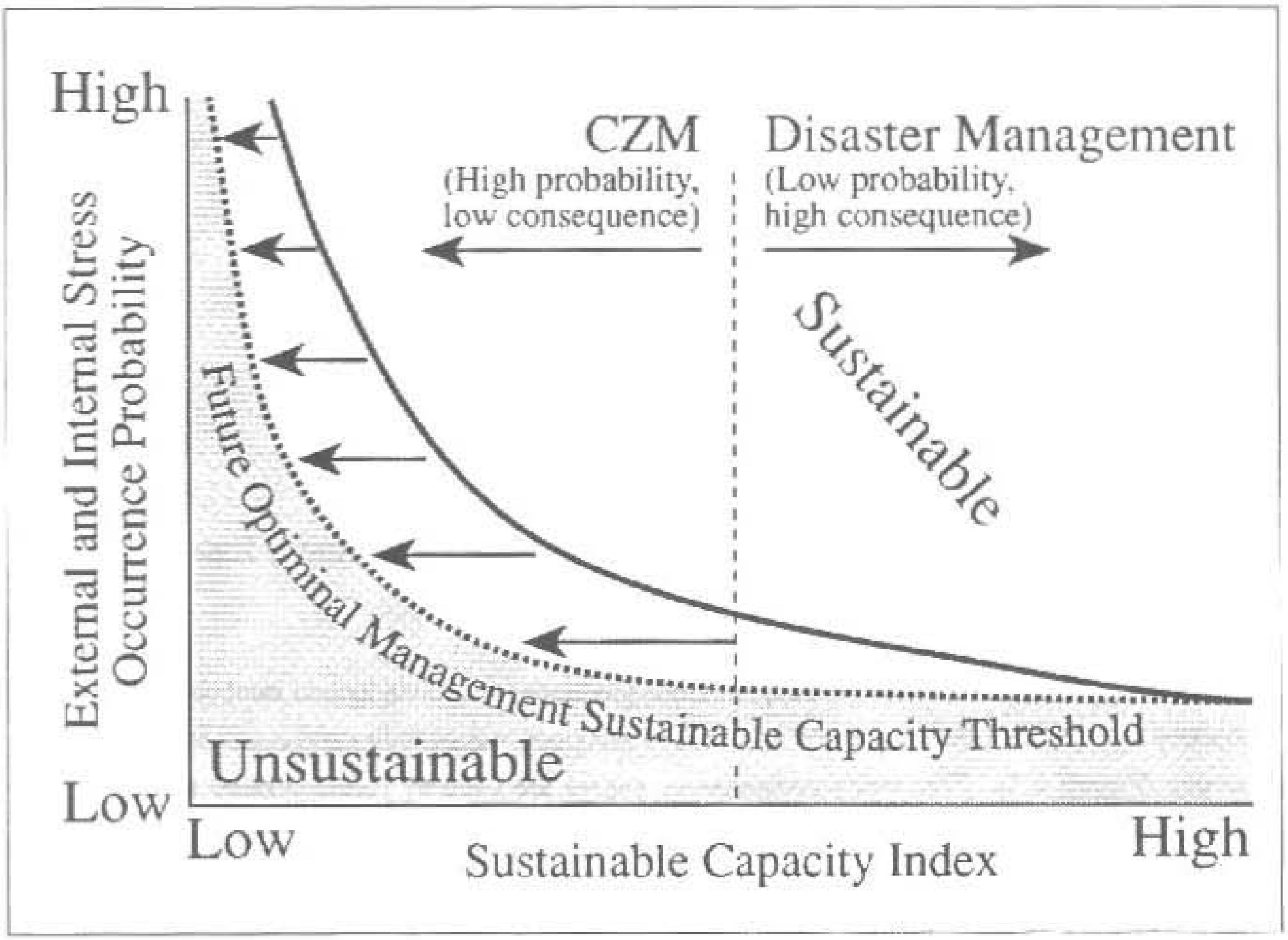

Figure 4.3. Sustainable Capacity Threshold Graph.

4.2.4. Sustainable capacity indices (SCI)

The vulnerability score and resilience score for each Coastal System are added together to derive the "Sustainable Capacity Index (SCI)" for each Coastal System. The result of this addition is a measure of the net impact, or risk, to each Coastal System from external and internal stresses. The SCI can also be taken as a surrogate measure of each System's ability, or capacity, to cope with probable external and internal stresses. The concept of sustainability is introduced in order to highlight the implications for the long-term viability of Coastal Systems shown by the difference between vulnerability and resilience component scores. In this sense, "sustainability" is used in the context of "sustainability thinking" which *"modifies the context to which it is applied"* (Turner 1991).

The average of the Sustainable Capacity Index for all the Coastal Systems gives a rudimentary indication of a study site's ability to cope sustainably with external and internal stresses.

The application of this assessment technique through four case study sites is described in detail in the next section. The case studies show that there is significant scope for the reduction of future sea-level rise impacts in Western Samoa.

4.3. Future development of the assessment framework

Clearly, the approach requires refinement. At present the assessment framework is a way of approaching the issue of the potential risks to coastal zone Systems from internal and external stresses, including sea-level rise and climate change. In order for this framework to be transformed into methodology which can be formally applied to support coastal management decisions within countries, and compare the efficiency of management decisions between countries, further development is required. Two major areas for the development of the vulnerability and resilience assessment approach are given below: clarification of vulnerability and resilience scoring; and Linking the Coastal System stress assessment framework to Impact Zone and Connected Area Analysis.

4.3.1. Clarification of vulnerability and resilience scoring

In its present form the qualitative scoring assessment framework cannot be systematically repeated in other coastal nations, nor can it be repeated in Western Samoa by another study team. This non-repeatability is caused because the vulnerability and resilience scores are assigned by a study team through a consensus process, based on the available information. As a result, the scores have a dependence on the composition, professional backgrounds, experience and value judgements of the study team. In order to develop a repeatable, and hence regionally applicable, vulnerability and resilience assessment framework, further work will need to concentrate on establishing boundaries between scores. Determination of the confidence in assigning scores derived from different amount of information also justifies further investigation.

Thresholds between scores must be closely examined in future development of the System vulnerability and resilience assessment approach. Clear delineation of the difference between a scores will be required if the broad assessment framework is developed further into a methodology which can be readily applied by coastal managers and decision makers.

In addition, a future refinement must relate to identifying the interactions between System attributes that comprise vulnerabilities and resiliences. In this initial framework they are considered independent, and can be added together to give an indication of the overall vulnerability and resilience of the Systems being studied. Future work in Phase II is likely to show that the vulnerability and resilience are highly interactive, and that the vulnerability and resilience scores cannot simply be added together.

A possible future direction for clarifying the interaction between Coastal System vulnerability and resilience is to adapt agricultural crop modelling techniques which consider addatative, multiplicative and limiting factor methods for combining strongly interacting systems (Hackett 1988). The concept of limiting factors may prove to be of particular use in the future development of the assessment framework. The limiting factor concept views that the overall performance of a System is determined by the level of the least favourable factor, and that other favourable factors do not compensate for the limiting factor. Exploring system interactions through limiting factor, and other, concepts is recommended to be undertaken in Phase II.

4.3.2. Linking the Coastal System stress assessment framework to Impact Zone and Connected Area Analysis

The vulnerability and resilience assessment approach described in the previous Sections is a flexible method analysing the potential impact of stresses on Coastal Systems. The approach has been tailored to the needs of sea-level rise and climate change impact assessment. This approach may be applied in its existing form to whole islands or any area in which impacts are assumed to be approximately equal throughout the area being studies. Alternatively, Coastal System vulnerability and resilience assessment may be embedded within Impact Zone - Connected Area (IZCA) analysis. IZCA is a recently developed generalised framework for the formulation of stress mitigation strategies, within which Coastal Systems analysis is an integral part (Kay and Waterman - in press).

IZCA is a four stage process. The analysis required in each stage is listed below.

Stage 1: Stress-impact zone delineation

Delineates and maps zones of potential stress impacts. Impacts can be due to external and/or internal stresses. The impact of one stress can be mapped, or the impact of multiple stresses can be evaluated. For example, areas of storm surge inundation can be mapped within contour lines, and coastal erosion impact assessed by coastal change models. Delineation of areas of stress-impact takes into account physical and biological conditions and any human modification of the shoreline.

Stage 2: Vulnerability and resilience analysis of Coastal System within stress-impact zones

Uses the interacting Coastal Systems approach for the assessment of vulnerability and resilience of Systems within the stress-impact zone(s) delineated in Stage 1. The impact of stresses on the human, cultural, natural, economic, institutional and infrastructural Systems are analysed.

Stage 3: Analysis of links between Coastal Systems within the stress-impact zone and non-stress-impact zone Systems

An analysis of the strength of the linkage between the Coastal Systems within the stress-impact zone(s) and systems outside the stress impact zone(s) is undertaken. Areas outside the stress impact zone which have links with Systems within the stress-impact zone are called "Connected Areas". A gradient of stress-impacts which occur outside the impact zone is established. Delineating the extent of connection is not attempted, hence, Connected Areas have no clearly defined boundaries.

Stage 4: Formulation of management strategies within the stress-impact zone and Connected Areas

The final stage considers that the Impact Zone and Connected Area has two distinct, yet interacting, coastal management and disaster management issues. The stress impact zone(s) could be managed through a suite of hazardous area policies, including reduction in infrastructure intensity through land use planning, building code requirements and disaster preparedness.

Policies formulated to reduce the impact of stresses within Connected Areas would depend on the analysis of the strength of linkage with Impact Zone Systems (Stage 3). For example, in the case of flood impact zones, connected area policies would address issues including the flow of people leaving the flooded area, and assess the economic impact of lost crops and livestock from the flooded area.

Phase I of this project has tested the applicability of the Coastal Systems approach described in Section 4.2, without linkage to the Impact Zone and Connected Area (IZCA) framework. The IZCA framework was not considered due to time constraints, and the desire to undertake thorough initial testing of the appropriateness of the Systems approach. The IZCA approach is recommended for testing and possible implementation during Phase II.

5. Initial Testing in Western Samoa of the Framework for the Assessment of Coastal System Vulnerability and Resilience

The initial testing of the new framework for the assessment of Coastal System response to a range of stresses is described in this section.

The stresses to coastal systems are divided into internal stresses, which arise within Western Samoa, and external stresses which are imposed on Western Samoa from external sources. Sea-level rise and climate change stress are considered as two additional external stresses to an already wide range of external and internal stresses (see Section 4).

The vulnerability and resilience of separate, yet strongly interacting, Coastal Systems are analysed through loosely structured subject-based analysis. The new assessment framework considers the coastal areas of small islands, such as 'Upolu, as highly interconnected. As such, geographically defined site-specific case studies have reduced meaning, and a "whole island" approach to the assessment of Coastal System vulnerability and resilience must be undertaken. However, the whole island approach recognises that stresses occur to a different extent around the island's coast. As such, specific areas of the coast are viewed as being stressed to different degrees, and as a result, show different degrees of impact. But because the Coastal Systems of 'Upolu are so interconnected 'Upolu would suffer "differential but shared' impacts. This concept of "differential stress and differential but shared impact" is particularly important for the analysis of internal stresses, which are largely due to the intensity of human use.

Discussion of the initial testing of the assessment framework is structured around three main issues, or subject areas. These are:

I The vulnerability of 'Upolu's rural coastline populated by villagers. This section describes traditional Samoan society. Where specific examples of coastal system vulnerability and resilienceare required, these are given from the villages around Safata Bay on the south coast of 'Upolu and the villages along the south-east coast between Saleapaga and Lalomanu;

II The range of stresses and resultant vulnerability and resilience of the Coastal Systems of urban Apia. This section highlights the multiple and intense stresses currently being experienced in Apia; and

III The large coastal infrastructure projects of the International Airport and Mulifanua Wharf. The ferry linking the islands of 'Upolu and Savai'i sails from Mulifanua Wharf.

The initial testing of a Geographic Information System (GIS) for aiding the aiding the development and implementation of the new vulnerability and resilience assessment framework is described in Section 6.

The implications for the integrated management of 'Upolu's coastal zone concluded from the case study analysis is summarised in Section 7.

5.1. The rural coastline of 'Upolu with special reference to the coastlines of Safata Bay and Saleapaga to Lalomanu

Approximately 80% of the population live in the 362 villages of Western Samoa, the majority of which are located on coastal lowlands. Samoans are disinclined to live inland, and what sparse inland settlement there is in 'Upolu follows the major cross-island roads. The location of villages is determined by recent volcanic activity, employment opportunities and placement of new coastal round-island roads (Thomas 1986). The size of Samoan villages is variable but the average population in each village is between 200 and 500. Much larger villages are found in the peri-urban area extending along 'Upolu's north-west coast from Apia to Faleolo International Airport, where populations average between 1,000-2,000 per village. The "rural" coastline of 'Upolu described in the following section is the entire coastline of 'Upolu excluding urban Apia and the peri-urban coast between Apia and Feleolo airport.

The resilient and vulnerable components of each Coastal System of 'Upolu's rural coastline are described in the following section. Each Coastal System is described separately, although the linkage between Systems is so strong on the rural coast that this distinction is made only to clarify the major coastal management issues and constraints. A range of external and internal stresses is considered (Table 5.2). Sea-level rise and climate change are considered as two additional external stresses.

Stresses	Source
Internal Stresses	
Pollution	Industrial Sewage/household rubbish Land sediment runoff Agricultural runoff
Social	Unemployment Migration Poverty Alcoholism
Cultural change	Reduction of cultural values
Population pressure	
Resource exploitation	Overfishing Mangrove cutting
Land reclamation	
Developmental	Reliance on imported goods Increased traffic Reduction in cultural values
External Stresses	
Tourists	Resource use Reduction in cultural values
Aid donor requirements	Reduction in cultural values Inappropriate development projects
Cyclones	
Global economic markets	Reduction in value of primary produce
Climate change	Changes in temperature and rainfall
	Possible changes in frequency and magnitude of cyclones
Sea-level rise	Changes in patterns of sedimentation and erosion Changes to extent and frequency of coastal inundation
Remittances	Fluctuations in cash income

Table 5.1. Initial List of Internal and External Stresses on the Coastal Systems of Western Samoa.

5.1.1. Human system

The population of rural coastal villages is gradually increasing. Population growth is slowed by the general out-migration from the rural coast of 'Upolu to urban Apia, and the north-west coastal region (Government of Western Samoa 1986). There is also likely to be international out-migration from rural coastal villages, although this appears to take place after initial migration from rural villages to Apia.

Villagers traditionally eat the staple foods of taro, yam, coconut, banana and breadfruit. Protein is generally supplied through the exploitation of the fish and shellfish resources of the reef and lagoon. Imported foods have become increasingly important in villages, but much less so than in urban Apia. The increased use of imported goods is thought to be heightening the stress to the health of Samoans, with increasing rates of obesity, hypertension and diabetes (Hanna *et al.* 1986).

5.1.2. Cultural System

Western Samoa has maintained the traditional way of life (the *fa'a Samoa*), despite over 200 years of European contact. Probably the most important change to pre-European culture has been the introduction of Christianity. Western Samoans are now amongst the most devout Christians in the world. The traditional way of life is especially strong in the rural villages of Savai'i and 'Upolu.

The influence of the *fa'a Samoa* permeates all aspects of coastal resource use and management in rural 'Upolu. Hence, the discussion in the following sections of natural, infrastructure, economic Coastal Systems will be strongly influenced by cultural considerations. Therefore, future changes to Samoan culture will be crucial for the management of future stresses to the coast, including sea-level rise and climate change. Measures to reduce future coastal impacts will be implemented through the traditional village decision-making framework.

In the *fa'a Samoa*, as in other Polynesian cultures, extended families are ruled by their elected chiefs (*matai*). Typically one member of an extended family holds the *matai* title. Villages are governed by the council of chiefs, or *fono*. Each village also has a women's committee, which is responsible for health, sanitation and other issues.

Traditionally each extended family owns plots of both residential and agricultural land. The members of the extended family own property together, work together and share products of work. In the strictest sense, land is not inherited under the traditional tenure system. Extended families act as corporate groups, owning land in perpetuity. Individual members may come and go but ownership remains in the family and in the name of the family's *matai* title (O'Meara 1990).

The land tenure system has undergone significant changes since colonial intervention. Two new principles, individual ownership and inheritance, now influence land tenure. Today, any individual who is the first to clear and plant the land may become the individual owner, and is able to pass land directly on to his/her children regardless of *matai* status. The change from traditional extended families to new individualism is part of a long and continuing process of land tenure changes resulting in a mosaic of old, new and altered tenures in each village setting (O'Meara 1987, 1990). This change is associated with the efforts of Samoan planters to maintain economic viability and is also an indication of concerns for future generations by clarifying inheritance rights.

Another significant change which has occurred over the last three decades is a dramatic increase in the number of men holding *matai* titles, to the point where most adult men, who control their own economic affairs, are now *matai*. The proliferation of *matai* stems from attempts to attain political status. This process of appointing many *matai* titles is seen by many Samoans as facilitating the ultimate collapse of the *matai* system. Most *matai* today do not hold equal authority and thus the power of the *matai* as a whole is being eroded. This is particularly evident in the way in which traditional conservation practices are not being applied, enforced or adhered to. On the other hand, the growth in *matai* titles, is seen by others as an opportunity to meet the desires of Samoans who are experiencing escalating social, political and economic changes.

The changes to land tenure and *matai* titles are significant in that they show that Samoans are not necessarily inflexible or bound by tradition. They can, and do, adapt to changing economic conditions. O'Meara (1990) believes that in order to take advantage of new opportunities, Samoans have shown their ability and willingness to adapt their culture. As a result, present day cultural resilience to external and internal stress has been rated as extremely high, and its vulnerability rated as low (Table 5.2).

Samoan culture will change in the future, just as it has changed in the past. Future cultural changes may be expected in response to increased stresses imposed by heightened exposure to the cash economy and the availability of a wider range of consumer goods, increased tourist numbers and through changes in migration patterns.

Coastal systems	Coastal sub systems	Vulnerability component: Present management regime	Resilience component: Present management regime	Sustainable capacity index: Present management regime	Future — Vulnerability component: No management	Future — Vulnerability component: Optimal management	Future — Resilience component: No management	Future — Resilience component: Optimal management	Future — Sustainable capacity index: No management	Future — Sustainable capacity index: Optimal management
Present day										
Natural	physical	-2	+3	+1	-3	-2	+2	+3	-1	+1
	biological	-2	+3	+1	-3	-2	+2	+2	-1	0
Cultural	communal	-1	+3	+2	-3	-1	+3	+3	0	+2
	national	-1	+3	+2	-3	-1	+3	+3	0	+2
Institutional	village	-1	+2	+1	-2	-1	+1	+3	-1	+2
	national	-1	+1	0	-2	-1	+1	+2	-1	+1
Infrastructural	individual	-2	+3	+1	-3	-2	+2	+3	-1	+1
	communal	-2	+3	+1	-3	-2	+2	+3	-1	+1
	national	-1	0	-1	-2	-1	0	+1	-2	0
Economic	subsistence	-1	+3	+2	-2	-1	+3	+3	+1	+2
	cash	-1	+1	0	-2	-1	0	+1	-2	0
Human	populations	-1	+1	0	-2	-1	0	+2	-2	+1
Average Sustainable Capacity Index				1.1					-1.0	+1.3

Table 5.2. Rural 'Upolu (with special reference to the coastlines of Safata Bay and Saleapaga to Lalomanu) Present Day and Future Coastal System Vulnerability and Resilience Components and Sustainable Capacity Indices.

However, it is uncertain to what extent cultural dilution will take place, and if such dilution will produce fundamental changes to the *fa'a Samoa*. From the experience of the last two hundred years it seems likely that future social and cultural changes may be reduced, if the continuation of the Samoan culture continues to be the desire of Samoans. The Optimal Management Response (OMR) assumes that cultural strength is maintained, and as a result the resilience of the cultural System to stress remains high, and the vulnerability low (Table 5.2). These future vulnerability and resilience scores assume that the OMR scenario includes plans for the maintenance of cultural strength, possibly including a National Museum and Cultural Centre. In addition, existing traditional family units, churches, women's committees and organisations, youth groups and village councils could be strengthened and developed. The OMR may be more likely to be implemented through these existing systems rather than attempting to create new organisations.

The future No Management scenario assumes that there will be no attempts to maintain cultural integrity. Samoan cultural integrity gradually erodes, becoming increasingly Westernised. These cultural changes are reflected in the resultant increase in vulnerability of thecultural System, and decrease in its resilience (Table 5.2).

5.1.3. Natural System

The natural physical and biological Sub-Systems of 'Upolu were described in Section 3.2. Section 3.2 showed that the rural coastline of 'Upolu could be divided into three coastal types (Figure 3.2; Table 3.1).

Type II coasts are the least common coastal type. Type II coasts have steep plunging cliffs and no, or limited, reefs. These coasts are generally not exposed to human-induced internal stresses, because they are both un-populated and contain limited economic resources.

Type I and type III coasts have gently seaward-sloping volcanic coastal plains, beaches, lagoons and reef complexes. Type I coasts are fronted by fringing reefs, while type III coasts are fronted by extensive barrier reef systems (Figure 3.2; Table 3.1).

The relative vulnerability and resilience of the reef systems of fringing and barrier reef systems is dependent on a range of factors:

I- biological diversity;

II- coral type;

III- the impact of cyclones;

IV- intensity of human use for fisheries;

V- pollution load; and

VI- relative cultural significance.

For example, the reefs in Safata Bay suffered moderate damage during Cyclone Ofa in 1990. About 5-10 % of corals on the upper reef slope were dislodged or overturned. A low tidal cyclone bank was formed. There was severe erosion along sandy beaches of the seaward side of the Vaie'e Peninsula of the older littoral forest which shelters secondary vegetation and the inner lagoon mangroves were seriously damaged. Cyclone Ofa also overturned many older, top-heavy mangrove trees. The mangrove ecosystems on the Vaie'e Peninsula appear to have survived the battering of Cyclone Val in 1991, but the Sataoa-Sa'anapu mangrove forest suffered 30% defoliation (Government of Western Samoa 1992c).

Present day coastal resilience of the physical and biological sub-systems of the natural coast is extremely high and has been rated with a resilience component of +3 in this study (Table 5.2). The main reason for this resilience is the natural processes of deposition from river sources are maintaining a balance with erosion, evidence for which is provided by the barrier spit formed off the coast - Vaie'e Peninsula. The lagoon behind the peninsula has remained colonised by mangroves which not only stabilise the sand of the spit but provide habitats for numerous biota. Further evidence of resilience is provided by the recovery of corals after the Acanthaster outbreak of the 1980s (Zann 1991). The formation of low cyclone sand-coral banks off Fusi indicate natural patterns of alteration in reef and lagoon environments. Extensive harvesting within the lagoon and estuaries of Safata Bay have been maintained at constant levels for some time, which suggests that biological systems in this area are modified, but resilient to exploitation because of the healthy and productive mangrove wetlands.

Present day sustainable capacity of the physical and biological sub-systems of Safata Bay's natural environment is moderate. Like many other coastal locations, Safata Bay undergoes both depositional and erosional processes. However, with its large number of rivers and streams draining the inland region of 'Upolu, depositional landforms and associated ecosystem environments, unique to Western Samoa have formed in this location. The large barrier sand spit, Vaie'e Peninsula, and the mangrove wetlands and estuary are unique natural systems which have high resilience and flexibility to change, but only if natural or human-induced change do not exceed their capacity to adjust. The most serious cause for concern, is damage to the mangrove ecosystems by human removal, infilling or eutrophication. Biological systems are placed in great jeopardy when such activities occur and if unmanaged will reduce their present sustainable capacity. Historically, mangroves were more extensive along the coastal regions of Western Samoa but were removed by people for timber and firewood.

The future vulnerability of the natural physical system in the Safata Bay area is likely to be extremely high, especially if no management strategies are put in place. With respect to sea-level rise, inundation of the wide lowland and erosion of low-lying coastal beaches, sand barriers, mangrove swamps and estuaries is expected to be the greatest vulnerability of this region. Even gradual sea-level rise could significantly affect the morphology of the Vaie'e Peninsula, leading to acceleration of beach erosion which would in turn affect coastal currents and depositional patterns. Despite high biological diversity within the lagoon, estuary and coast the biological ecosystems are expected to be extremely vulnerable to stresses in the future, especially if no management strategies are implemented. Harvesting pressure placed on specific species of aquatic fauna could lead to localised stock collapses, and for those species harvested mainly for sale in Apia there is greater potential for over-exploitation. Biological ecosystems may also suffer depending on the changes to inland runoff and sediment flow into coastal lagoon and estuary waters. Eutrophication may lead to decreased coral abundance and increased algal biomass.

Future coastal resilience of the natural physical system under a No Management response is expected to be high but lower than present day resilience. The coastal region and associated depositional landforms have been subject to fluctuations in deposition and erosion for many years. However, the speed of sea-level rise may determine whether or not the landforms can adapt to a changing ocean environment. The rate of sea-level rise, sources of sediment and rates of sediment supply will also determine the stability of the mangrove ecosystems, which are prolific in this region. Future resilience will depend on the physical nature of the changes which occur; e.g. whether Safata Lagoon remains protected from wave action, and whether extreme events remove mangrove ecosystems. Loss of mangrove wetland areas would greatly alter the stocks of organisms within the lagoon.

The future sustainable capacity of the natural physical and biological system in Safata Bay is expected to be moderately vulnerable if no management strategies are implemented. This is partly due to the fact that the systems are expected to become extremely vulnerable to coastal changes in the future but are also expected to show some natural resilience because such coastal environments have undergone fluxes in deposition and erosion before. However, the natural sustainability of the ecosystems will be significantly threatened by misdirected human activities, particularly with respect to the important role of the mangrove swamps. Local villages must be careful not to dispose of household wastes into the lagoon and mangrove swamps, or undertake indiscriminate infilling or reclamation of the mangrove ecosystems, and must also consider the impacts of causeway construction on the flow of water and sediment in and out of lowland mangrove wetlands. Future sustainability of fish stocks will depend on the health of the mangrove ecosystems as well as the harvesting activities of local people. Careful management of fish stocks will have to be implemented if the livelihood of the bulk of villagers is to be maintained by this resource in the future.

5.1.4. Institutional System

The decision-making institutions of rural 'Upolu consist of village level systems located within the rural coast, and the influence of national policies and plans formulated in Apia (Figure 3.4). A detailed description of local and national coastal management decision-making was given in Section 3.3, where the dominance of village level decision-making in rural areas was discussed.

Village level decision-making is an integral part of the Samoan way of life (the *fa'a Samoa*). Hence, internal and external stresses which influence the vulnerability and resilience of Samoan culture will also have direct effects on the vulnerability and resilience of village based decision-making. Cultural stresses are analysed above in Section 5.1.2. The close ties of village institutions with the Cultural System are reflected in the similarity of their vulnerability and resilience scores (Table 5.2).

The village institutional structures may become increasingly vulnerable in the future as external and internal stresses increase significantly. Such vulnerability could arise if stress-induced impacts require difficult and controversial decisions to be made. Such decisions could result in conflicts within the village and other social stresses, especially if decisions are required which have not previously been within the range of the experience of decision-makers.

The future OMR scenario assumes that enhancing the resilience, and reducing the vulnerability of, village level decision-making institutions is intimately linked to Cultural System OMR strategies. There is also considerable scope for additional measures to support village level decision making through education, training and knowledge sharing. Enhancing the knowledge base of village decision-makers is likely to result in better informed decisions and rules. In the long term, an increased knowledge base could result in sustainable resource management practices being adopted at the village level.

In addition, the OMR assumes that village level decision-making will be co-ordinated by national government. Also the OMR assumes that enhanced village level decision-making ability and/or power will be formally linked with national policies and strategies, made possible by the formalisation in law of village aspirations and rules (Cornforth 1992). National coordination would ensure that a consist approach is taken by villages in different parts of 'Upolu. This would require an increase in resources for a national coordination institution, possibly the Division of Environment and Conservation.

OMR strategies to increase the capability of village level decision-making institutions would have critical flow-on effects on the vulnerability and resilience of the natural, economic, infrastructure and human Coastal Systems. For example, the adoption by villages of sustainable fishing management practices would reduce an important internal stress on lagoon and reef ecosystems. Consequently, the long-term economic vulnerability of the subsistence fishing economy would be reduced. In addition, healthy reefs and lagoons would assist in the reduction of wave attack on shorelines, hence reducing the vulnerability of village infrastructure and people to erosion and flooding.

In contrast, the No Management scenario assumes that there is no future support given to local level decision-making by national government departments, or attempts to maintain cultural integrity. As a result, the ability of village decision-makers to cope with internal and external stresses declines (Table 5.2), with significant negative effects on natural, economic, infrastructure and human Coastal Systems.

5.1.5. Infrastructural System

The Western Samoan village is characterised by a traditional layout-pattern that has persisted despite the juxtaposition of traditional and modern housing styles. Each village has an individual infrastructure of houses and cooking houses. Each village also usually has its own communal infrastructure of church or churches, a primary school, bathing sites and cricket pitch/central communal ground. The structural layout of a typical village is shown in Figure 5.1. Frequently, coastal villages have all houses facing the lagoon, with the village green directly on the coast (Figure 5.1). Behind each village, plots of land belonging to the extended families of the villages, usually stretch from the coastal lowland up to the nearest ridge, upon which plantations are cultivated.

Infrastructure within villages funded wholly or partially by the national government includes reticulated water, gas, electricity supply, telephone lines, roads and district hospitals.

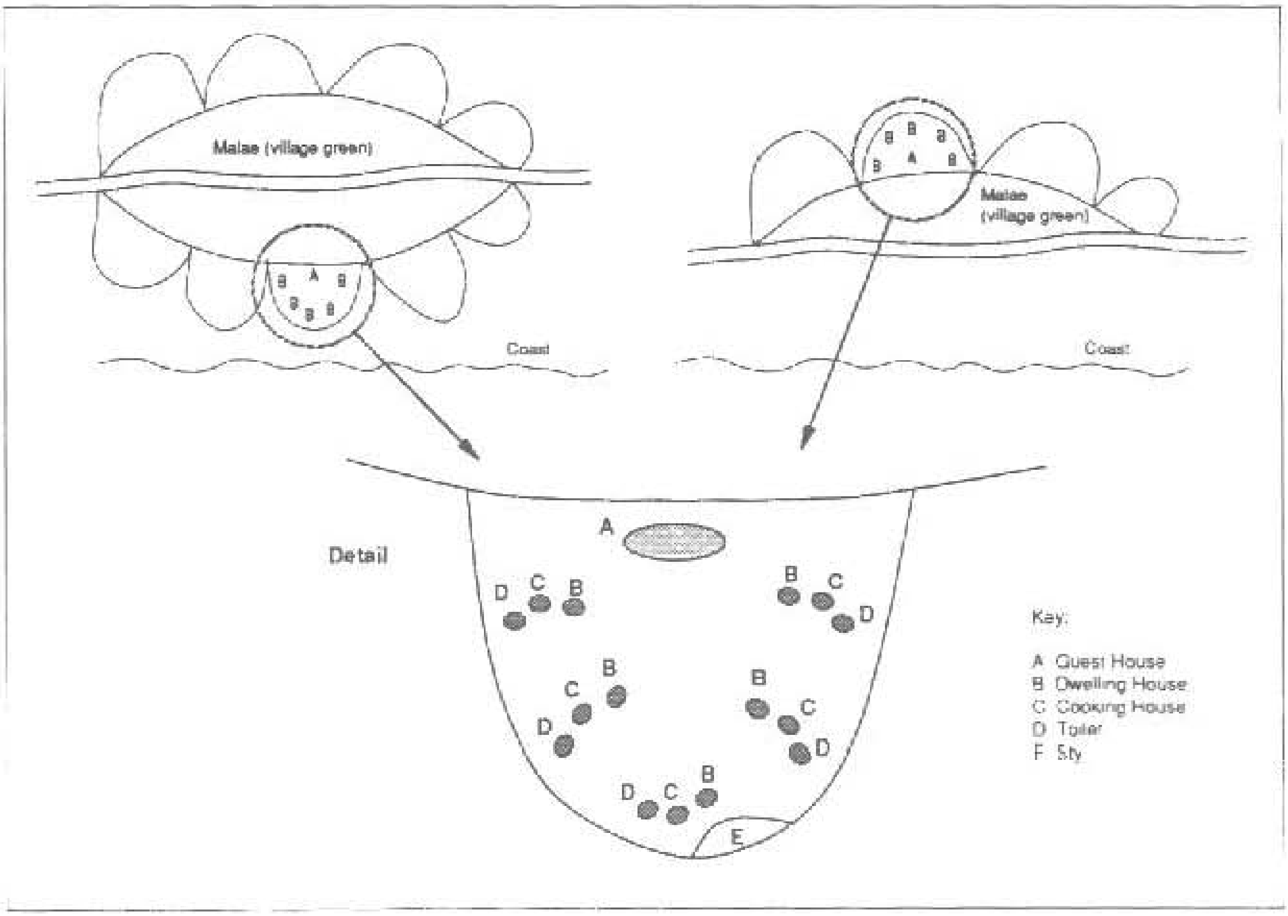

Figure 5.1. *Two idealised Coastal Western Samoan Villages. Source: Adapted From O'Meara (1990)*

Much of the village infrastructure is vulnerable to the external stresses which cause erosion and inundation. Houses, schools and churches are all, to varying degrees, vulnerable. This vulnerability is reflected in the scores assigned to individual and communal vulnerability (Table 5.2). However, there are powerful resilience mechanisms within villages, which offset and in some cases override vulnerable infrastructure location.

Customary land tenure provides the ability to adapt to coastal impacts. If threatened, individual and communal infrastructure can be moved inland to other areas of communally owned land. For example, infrastructure in many villages has been moved inland in recent years as a result of the external stresses of cyclone-induced coastal erosion and flooding (Fauolo 1993). In addition, some rural villagers have moved their houses closer to the new round-island road in order to ease access to Apia and its markets. Villages on the south and south-east coasts show clear evidence of such inland infrastructure migration. As a result, the present day resilience scores of individual and communal infrastructural of rural villages are considered to be extremely high (score of +3) (Table 5.2).

However, the migration of village infrastructure can result in considerable social tension. Tension occurs particularly when moves are forced by external stresses, such as coastal erosion, and less so when moves are deliberate, such as moving closer to a road. Tensions arise due to leaving behind the sites where villagers grew up, their old homes, their past, and burial sites near the coast. Conflicts may arise between old and new generations if some are reluctant to move and this may in turn threaten or weaken the traditional system of authority. Tensions may also be produced due to changing social status associated with migration (Fauolo 1993). However, in some cases the strong ties to previous coastal sites may result in the construction of seawalls to halt erosion and recession of coastlines rather than trigger migration, especially near burial sites.

The OMR assumes that the ability for the inland migration of village infrastructure within customary land will continue in the future, and that villagers will generally decide not to stay adjacent to eroding coasts by building seawalls. Consequently, the resilience of infrastructure would remain extremely high. To allow the possibility of future inland migration, village land must remain in customary ownership, and hence cultural strength must also remain high. The OMR also assumes that vulnerability to village infrastructure will only increase slightly . In order to minimise the increase in vulnerability, OMR strategies must enhance the resilience of fringing reef, lagoon and mangrove systems. Resilience enhancement measures include the implementation of sustainable fishing practices and the maintenance of lagoon and beach sediment volumes.

The OMR scenario also assumes that decisions made on the location of new coastal roads will take into account issues of vulnerability and resilience. Road siting decisions can be made to deliberately facilitate inland migration of individual and communal infrastructure. For example, in early 1993 the decision was made to locate the round-island road on the south-east coast between Lotofaga and Lalomanu inland from the present coastal route. Villagers who were informally interviewed said that they would probably build new houses close to the new road. This action will significantly reduce the amount of infrastructure on the very narrow and potentially hazardous coastal plain, and so reduce the exposure to future stresses.

The future No Management Scenario assumes that the above enhancement measures for natural system resilience will not be adopted. Also, measures for the maintenance of cultural strength will fail to be implemented. As a consequence, the No Management scenario assumes an increase in vulnerability of village infrastructure to extreme, and a reduction of resilience from extreme to high (Table 5.2).

In general, national infrastructural facilities are less vulnerable to present day stresses than individual or communal infrastructure due to the protection of sea-walls. Seawalls front much of the round-island road where it runs adjacent to the coast. However, the protection afforded to the roads by sea-walls, and the taking of customary land required to site the road effectively fixes the road's location. For example, coastal roads were extensively damaged by cyclones in recent years, and have been rebuilt in the same location, often fronted by large sea walls. In this case inland migration of national infrastructure is more difficult than for village infrastructure. As a result, the resilience score for national infrastructure is low (Table 5.2).

5.1.6. Economic System

Primary production

The village economies of rural 'Upolu are dominated by the primary production of agricultural and marine resources. The majority of resources harvested by villagers becomes part of the village's subsistence economy, shared between either members of an extended family or the entire village. For example, in the villages around Safata Bay, subsistence fishery is very important, with a low proportion (17 %) of the catch sold (Zann 1991). Some primary resources are sold in Apia, forming part of the cash economy.

Primary economic resources in rural villages include: fish and shellfish caught in lagoon and reef areas; coconuts, taro and breadfruit from plantations; domestic animals, mainly pigs; and the produce from household gardens. These resources are usually regularly harvested up to several times each week. In addition, occasional cultural events require extra harvesting, possibly the slaughtering of a pig, or the catching of a particular lagoon fish. Such events include visits to the village by dignitaries from neighbouring villages.

The harvesting of primary economic resources for subsistence and cash markets may be thought of as having different degrees of vulnerability and resilience to stresses. Local cash markets are subject to price fluctuations, which are in turn influenced by global market prices. Global prices will have an effect on the volume of locally produced goods exported, versus those placed on the local market because of weak global prices. Thus, the cash component of primary village production is sensitive to both internal and external economic stresses. Subsistence practices within rural villages are extremely adaptable to changing conditions (O'Meara 1987, 1990).

Subsistence fishing activities involve large numbers of people who go fishing at least once a week. Fish catches have declined an estimated 35 % between 1983 and 1991 (Zann *et al.* 1991). The cause of this decline is likely to be from over-fishing through the use of increasingly damaging techniques, including fish fences, underwater torches, dynamiting and poisoning. In addition, lagoons and reefs are being degraded by pollution, principally nutrient loading, sedimentation due to forest clearance and the loss of productive inter-tidal habitat, especially mangrove. The impact of recent tropical cyclones may also be contributing to coastal ecosystem degradation.

Additional stresses to primary village production include pollution and over-exploitation. Pollution may include pesticide pollution of plantations, and runoff pollution of pesticides, sediment and sewage into lagoons. Thus the sustainability of the primary production component of the village economy is closely tied to the sustainable management of the village's physical and biological resources. These resources are currently under threat from the stresses listed above. The future No Management scenario assumes that there will be no management interventions to alleviate the stress, and as a result primary economic production will gradually decline. In contrast the OMR scenario assumes that villagers will be made aware of the dangers to their primary economic resources from non-sustainable use and other human-induced stresses. As a result, it is assumed in this scenario that village and national levels of decision-making will form a partnership to implement sustainable management policies and practices to ensure sustainable economic use.

The cash component of village economies consists of agricultural and fish resources sold in Apia, remittances, some local service businesses and wage earning jobs, such as those in schools and hospitals. Wage-earning jobs are much less common in rural villages than in Apia, as shown in Figure 5.2.

Remittances

Remittances are monetary gifts endowed by extended family members currently living overseas. Remittances play a major role in Samoa's village economies. In 1989, the 76,200 Samoan migrants overseas contributed a total of US$ 38.2 to families in Western Samoa (Ahlburg 1991). New Zealand is the largest source of remittances for Western Samoa (48%), followed by the United States (30%), American Samoa (12%) and Australia (10%).

The flow of remittances into villages is influenced by the economic status of those sending remittances, and the strength of the ties with their extended villages. Thus, the value of remittances sent to rural villages is sensitive to economic fluctuations and trends external to Western Samoa. The value of remittances sent is also sensitive to the needs of those receiving money. For example, remittance is especially noticeable after cyclone disasters. In 1990 remitences peaked at WST$92 million (US$ 35 million) after Cyclone Ofa. Much of this income was spent in Apia to purchase building materials, food, pay bills, school and hospital fees, and finance funerals and community meetings.

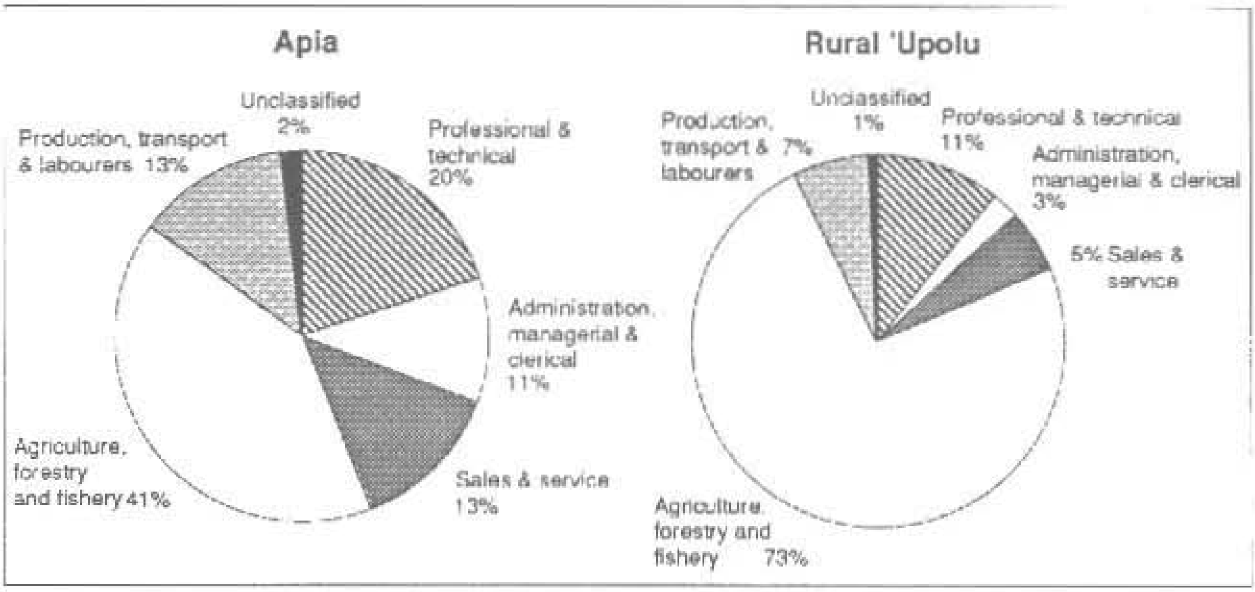

Figure 5.2. *Employment Sectors in Rural 'Upolu and Urban Apia.*
Source: Government of Western Samoa (1992e)

Therefore, remittances can be viewed as a critical mechanism for enhancing the resilience of the village cash economy. The important role of remittances may be expected to continue in the future, influenced by the factors described above. Thus, remittances may play an important role in reducing the economic impact of future sea-level rise and climate change on rural villages. However, this resilience enhancement effect assumes that cultural ties will continue to be strong, that migrants will be economically able to send remittances, and that Western Samoan migrants now overseas themselves do not live in coastal areas impacted by sea-level rise and climate change. In addition, it assumes that banking, postal and international transport facilities in Western Samoa will not be impacted, and continue to allow remittance flow to rural villages. Finally, social and economic changes in Western Samoa and in the countries in which migrants now live may encourage, or even force, migrants to return home to their family's village. The return of large numbers of overseas migrants would both reduce the amount of remittances and place increased stress on the village's natural resources.

The OMR scenario assumes that cultural ties will be encouraged and maintained, and that banking, postal facilities and international transport facilities will be protected. This scenario also assumes that large numbers of migrants will not return home, and will be economically able to send remittances. These latter factors are obviously beyond the control of decision-makers in Western Samoa.

Tourism

Tourism is not well developed on the rural coast of 'Upolu. There are no major hotels outside Apia, and only a handful of small tourist developments. The majority of these developments are on customary owned land. There are no tourist developments on the Safata Bay coast.

There are approximately 15 small beach houses (*fale*) at Aleapata, on the Saleapaga to Lalomanu coast. The *fale* front directly onto the beach, lagoon and fringing reef. The *fale* are built to the traditional Samoan style of wooden floors, open walls and a roof supported by wooden pillars. Each fale costs WST$ 10 per night (US$ 3.8). The fee is paid to extended family members who live behind the *fale*. A number of families rent out *fale* at the site.

This type of tourism development is extremely resilient to external stresses, particularly those which cause beach erosion and coastal flooding. The *fale* can be moved landward to other areas of customary land if threatened by erosion.

There are 6 higher standard *fale* at Vavau beach , just west of the Saleapaga to Lalomanu coast, capable of sleeping 12 people. These *fale* cost US$70 per night, and are built in a mixture of Samoan and western styles. The walls are enclosed, and there is air-conditioning.

Tourist numbers are planned to increase by 10% per year between 1992-2001, from 41,000 visitor arrivals in 1992 to over 100,000 in 2001. Such increases in visitor arrivals are being actively encouraged as one method of reducing Western Samoa's balance of payment deficit. Six of the seven future tourist development areas on 'Upolu are located on the rural coastline (Apia is the seventh) (Government of Western Samoa and Tourist Council of the South Pacific 1992). Small to medium sized, high quality tourist developments on the rural coastline are recommended to be the major focus of future tourist expansion. This tourism development strategy is being persued in order to achieve sustainable growth through the maintenance of the strength of Samoan culture and environmental quality. The government plans to attract "discerning, environmentally and culturally aware visitors", and does not envisage Western Samoa becoming a mass tourist destination (Government of Western Samoa and Tourism Council of the South Pacific 1992).

Tourist growth in rural areas is planned to be owned and run by Samoans, and managed through customary extended family structures. Thus, customary land may be used for tourist developments undertaken in partnership with foreign investors. Tourist resort design will be encouraged to be in keeping with traditional Samoan architecture, and will be subject to environmental impact assessments (EIA) in order to reduce the environmental impact (Government of Western Samoa and Tourist Council of the South Pacific 1992).

This strategy for tourist growth on the rural coastline would significantly increase the resilience of the tourist economy to external and internal stresses. Internal stresses on the cultural system would be significantly reduced though village involvement. In addition, tourist development on customary land would have the capacity to move inland if external stresses, including sea-level rise and climate change, were to erode the coast. This resilience building capacity would be lost by constraining resort development within the boundaries of freehold land.

As a result of the above discussion, the vulnerability, resilience and resultant SCI scores for the economic System of rural villages of 'Upolu are shown in Table 5.2.

5.2. Urban/commercial - Apia

The second case study focuses on Apia, the capital of Western Samoa. Located midway along the northern coast of 'Upolu, Apia is the only town and the political, economic, commercial, urban, industrial and social service centre of Western Samoa. Apia stretches from the village of Letogo in the east, to the village of Vaigaga in the west, incorporating a total shore length of 18.5 km.

Urban Apia contains a wide range of businesses including: supermarkets, hotels, travel agencies, health and emergency services, education and library facilities, diplomatic centres, government departments, communication and transportation facilities, a port and wharf. Most commercial activities in Apia take place along the waterfront on Beach Road. The new multi-storey Central Bank and government buildings are sited on the new Apia coastal reclamation.

Strung out along the Mulinu'u Peninsula and the Beach Road waterfront are numerous historical monuments and colonial buildings. Mulinu'u Peninsula is the site of Western Samoa's Parliament Buildings, the Government Legislative Assembly, the Lands and Titles Court, the Broadcasting Department, the Observatory and Meteorological Station, the Yacht Club and a number of Chiefly tombs.

Located at the eastern end of Apia Harbour, opposite the mouth of Vaisigano River is the port and wharf.

A System by System vulnerability, resilience and sustainable capacity analysis of Apia's human, cultural, natural, institutional, infrastructural and economic Coastal Systems is undertaken in the following Sections.

5.2.1. Human System

Apia has a core population of approximately 35,000, including the suburbs sprawling along the coastal lowland to the east and west and up the gentle hill slopes towards Mount Vaea and Afiamalu. Apia East has a population of some 14,700 people residing in 24 coastal villages with a population density of 1,425 per square kilometre of shoreline. Apia West has a population of 7,400 residing in 9 coastal villages with a population density of 740 per square kilometre of shoreline.

Apia's population has grown dramatically over the past 100 years. The growth in population density in this coastal region is driven by a strong trend in rural-urban migration from Savai'i and rural coastal villages of 'Upolu. However, the overall population of Apia has been relatively stable during the last 10 years due to overseas out-migration from Apia (Government of Western Samoa 1992e). The motivation for the rural population to migrate to Apia is growing dissatisfaction with agricultural prices, and the finite labour absorption capacity of traditional subsistence activities. Also, paid work in Apia and the "freedom" of an urban lifestyle act as a strong magnet for some rural inhabitants.

The number of people living in Apia in the future will continue to reflect the difference between rural-urban migration and international out-migration. The factors that will control the relative strengths of internal and international migration in the future have not been analysed in detail during Phase I of this project.

In the absence of an analysis of potential future trends in migration, the OMR scenario assumes a relatively unchanged future urban population. The No Management scenario assumes future population growth in Apia. However, it must be noted that management strategies to reduce urban population growth, or whether such strategies are required and/or appropriate, have not been analysed. Clearly the analysis of internal and international migration patterns of Western Samoans is recommended as an integral part of Phase II research.

Unemployment rates are low in Western Samoa, being less than 1% in 1986. However, unemployment figures are difficult to interpret. This interpretation problem is summarised in the report of the 1986 census as follows:

"in a subsistence economy such as that of Western Samoa, the concept of unemployment does not always have a clear meaning, because unemployment is transformed by the subsistence economy into underemployment" (Government of Western Samoa 1991e).

Thus, unemployment can be considered to be a minor internal human system stress at present, although this minor stress may be the strongest in Apia where the unemployment absorption-effect of the subsistence economy is weakest (Fairbairn 1991).

It is uncertain how unemployment will evolve in Western Samoa as the economy and society become increasingly modernised, both due to the modifying effects of the subsistence economy and the uncertainties in the development path Western Samoa will take in the future. The Seventh Development Plan (DP7) suggests that, where the subsistence economy and the social control within villages weakens, unemployment may become a major concern. Such future conditions are most likely to occur in Apia, and in turn may lead to "social alienation, crime and abuse of alcohol and drugs (DP7)". Apia's internal human System stress may increase in the future as a result.

Obesity, diabetes and hypertension have become increasingly prevalent in Western Samoa, particularly in urban Apia. These increasing health risks amongst Samoans are closely tied to the process of modernisation, through the heightened use of imported foods, including sugar, flour and canned foods and the more sedentary lifestyle of urban dwellers than villagers (Hanna *et al.* 1986). Thus, modernisation in urban Apia is an internal stress to human health.

Future health problems in urban Apia resulting from increased use of imported goods, and a more sedentary lifestyle, may also heighten internal human-system stress if not managed through health awareness programs (Hanna *et al.* 1986). Such an increase in stress may contribute to the reduced resilience of the inhabitants of urban Apia. The impact of future modernisation on human health may be investigated through the study of Samoan migrants living in Hawaii, mainland America and New Zealand (Hanna *et al.* 1986). Studies of this kind would help to clarify the relative importance of health changes to the residents of Apia in relation to other internal stresses including changes in population, unemployment and cultural conditions.

5.2.2. Cultural System

The rapid growth of Apia has resulted in a variety of social and cultural changes characteristic of many cities in the developing world, but which have a unique Western Samoan flavour.

Coastal systems	Coastal sub systems	Vulnerability component	Resilience component	Sustainable capacity index	Vulnerability component		Resilience component		Sustainable capacity index	
Present day					Future					
		Present management regime	Present management regime	Present management regime	No management	Optimal management	No management	Optimal management	No management	Optimal management
Natural	physical	-2	+1	-1	-3	-2	0	1	-3	-1
	biological	-3	0	-3	3	-1	0	+1	-3	0
Cultural		-2	+1	-1	-3	-2	0	1	-3	-1
Institutional	village	-2	+1	-1	-3	-2	1	2	-2	0
	national	-3	+1	-2	-3	-2	0	1	-3	-1
Infrastructure	individual	-3	0	-3	-3	-2	0	1	-3	-1
	communal	-3	0	-3	-3	-2	0	1	-3	-1
	national	-3	0	-3	-3	-2	0	1	-3	-1
Economic	subsistence	-2	+3	+1	-3	-2	+2	+3	-1	+1
	cash	-3	+1	-2	-3	-2	+1	1	-2	-1
Human		-2	+1	-1	-3	-1	+2	0	-+1	-1
Average Sustainable Capacity Index				-1.7					-2.5	-0.6

Table 5.3. Urban Apia Present Day and Future Coastal System Vulnerability and Resilience Components and Sustainable Capacity Indices.

Traditional Western Samoan culture, which remains strong in rural village communities, has been eroded in Apia through European contact and the process of modernisation. However, the *fa'a Samoa* remains the central social force within Apia where the council of Chiefs and orators *(fono)* supplements the administrative powers of national and town executors, judiciary and parliament. The effect of cultural erosion is an increased dependence on urban infrastructure, utilities, services and imported goods. In addition, the decrease of village authority and control has played a role in the increase in social and cultural problems in Apia, including unemployment, social alienation, crime, and abuse of alcohol and drugs.

Despite cultural changes and problems in urban Apia there are a number of attributes in the traditional Samoan way of life which assist people in times of crises. The most important of these is gift and remittance giving. These cultural resiliences do not completely counterbalance cultural vulnerabilities in Apia, compared to rural Samoa (Table 5.2), as gift giving appears to be sustained for only short periods after disasters.

Section 5.1 detailed possible future changes to traditional Samoan culture. Section 5.1 concluded that cultural integrity may remain strong in the future if this remains the will of Samoans, and is managed effectively by national and local policies. Cultural integrity is at present much weaker in Apia than in rural areas. Thus, any Samoa-wide cultural weakening which may occur in the future is likely to further lower cultural integrity in Apia. However, it is unclear whether a weakening of an already weakened cultural System in Apia will have more overall impact on the resilience and vulnerability, than cultural weakening of a presently strong culture in rural 'Upolu. This issue requires further study in Phase II.

Cultural infrastructure, for example the chiefly tombs on Mulinu'u Peninsula, may be at risk in the future, with a negative effect on traditional culture.

The OMR scenario assumes that cultural strength can be maintained in Apia through management strategies (Table 5.2). However, the development of these strategies may be more difficult in Apia than rural 'Upolu because of the already weakened culture, and the varying cultural and commercial values associated with the mixture of customary landownership and freehold land tenure in Apia. The No Management scenario assumes that cultural strength will gradually decline and become increasingly Westernised.

5.2.3. Natural System

The 18.5 km of coastline fronting urban Apia contains 20.3 km of reef edge, 1,160 hectares of reef and 95 hectares of mangroves. The coastline contains two major inlets at Vaiusu Bay and Apia Harbour separated by the Mulinu'u Peninsula. Apia is on the border between Type I coasts to the east, and Type III coasts to the west (Richmond 1991).

The reef edge in front of Apia Harbour has a prominent 500 m wide gap, a natural result of the freshwater discharged by the Vaisigano River which drains into the harbour. There is also a delta at the mouth of the Vaisigano River formed by the deposition of river-derived sediments (Richmond 1991). In contrast, the reef in front of Vaiusu Bay does not have a gap in the reef, because of the different freshwater drainage characteristics of the river systems of Vaiusu Bay. The Fulusou River and Gasegase Stream mouths in Vaiusu Bay are classed by Richmond (1991) as barrier impounded river/stream mouths. As a result there are well-developed mud flats and mangrove communities, significant portions of which have been in-filled for land reclamation.

The coastal plain is composed of Holocene sedimentary deposits, particularly swamp alluvium, talus and sands (Kear and Wood 1959). The coastal plain grades into the volcanic deposits which rise to the central volcanic peaks of the island.

The vulnerability of the physical system is higher in Apia Harbour than Viasu Bay where the gap in the reef allows storm-generated waves to reach the shore with little wave energy dissipated. The typical response of the physical coastal system is apparent in the formation of a number of extensive coral debris cyclone banks after Cyclone Ofa, which run parallel to Mulinu'u Point (Rearic 1990). The whole of Mulinu'u Peninsula was flooded by the storm surge washing over existing sea walls during cyclones Ofa and Val.

Central Apia is located on a low-lying coastal plain. As such, the physical Sub-System of the natural Coastal System in Apia is highly vulnerable to present day external and internal stresses. For example, recent tropical cyclones have flooded Apia through storm-surge inundation, and through river flooding.

The natural resilience of Apia's natural Coastal Systems has been significantly reduced through human action. Industrial and sewage waste pollution, over-fishing, reef blasting, dredging and siltation have all occurred to varying degrees in this case study site. Zann (1991) noted that since

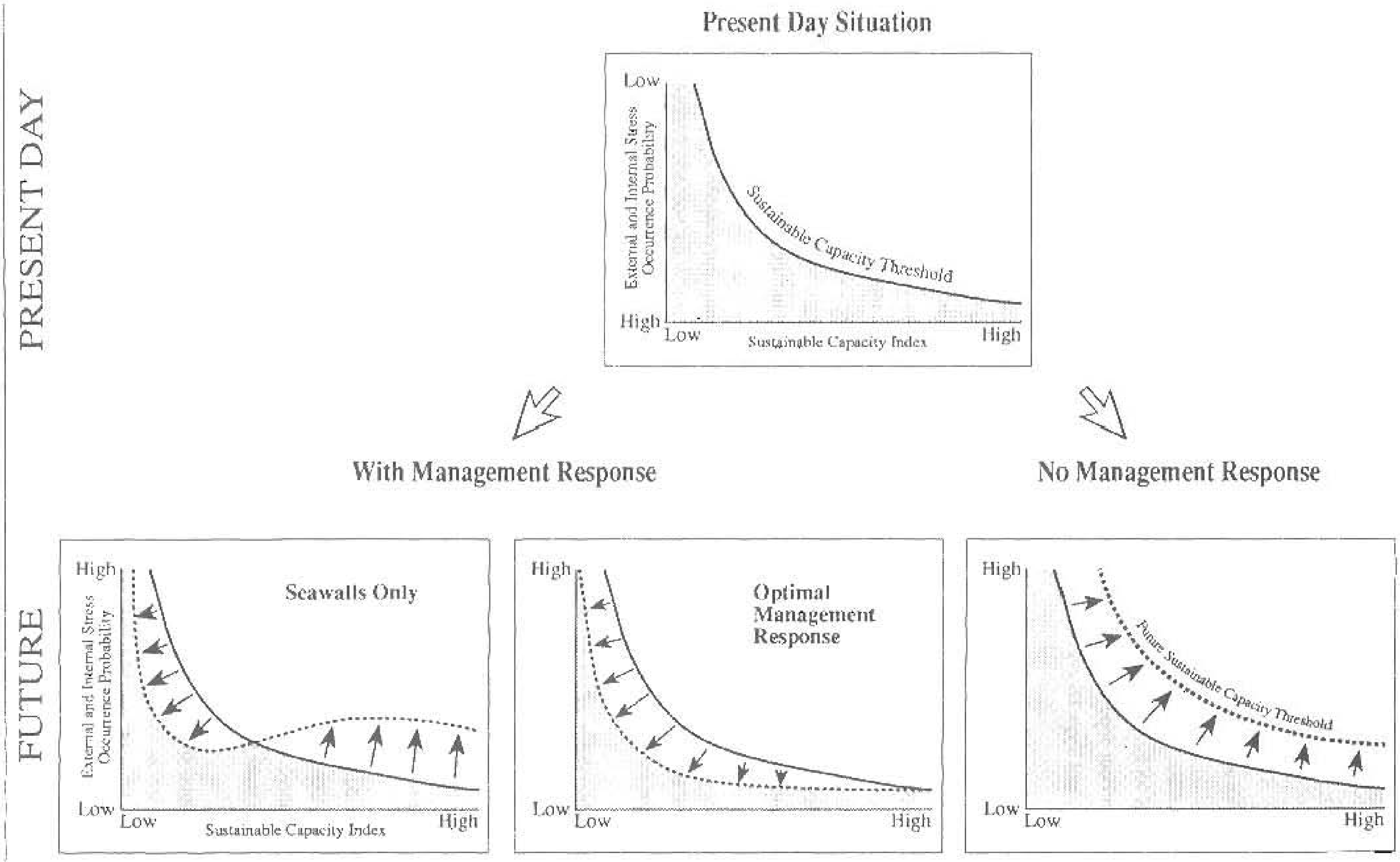

Figure 5.3. Probability Versus Sustainable Capacity Index Graphs for Present Day, Future No Management and Future Optimal Management Scenarios for Urban Apia.

1954 the amount of coral within the lagoon near Apia had decreased significantly and has been replaced by seagrasses, possibly as a result of increased eutrophication. The reefs were also badly damaged by cyclones. Coral debris cyclone banks are still visible in Apia Harbour and Vaisu Bay.

The large mangrove areas within the site are presently being polluted by discharge of untreated sewage and by the dumping of urban and industrial rubbish, especially at the Vaiusu Bay Municipal Rubbish Dump. Mangroves are also being in-filled for land reclamation, at an increasing rate. Significant portions of the mangrove shore between Vaipuna and Moataa have been reclaimed for hotels and housing, and the seaward Moataa mangroves have been entirely reclaimed and the estuary flow diverted through a drain. The Fagalii swamps have also been reclaimed and the seawall constructed along the shore in the front of the East Coast Road did little to protect the villages from storm surge inundation during Cyclone Ofa. All these human influences are reducing the capacity for the whole coastal system to cope with impacts of external and internal stresses.

The physical structure of the coastline is significantly modified from its natural condition by sea walls and revetments. The vulnerability of the coastline to high probability events, such as small stroms and extreme high tides, is reduced by seawalls, but they do not withstand ocean forces during cyclones and may contribute to serious erosion problems further along the coast. Lowland coastal resilience is also being reduced by human disturbance (infilling, pollution) of the mangrove swamps which act as buffer zones during storms and floods.

This range of stresses results in the biological and physical Sub-Systems of Apia being extremely vulnerable, and having a low resilience (Table 5.3).

Under the No Management scenario, Apia's physical and biological Coastal Systems are assumed to continue to be extremely vulnerable to external and internal stresses in the future. This vulnerability is heightened by the influence of human activities in the region. For example, reaction of the fringing coastal coral reef to potential future sea-level rise and climate change is uncertain. But the reef's ability to grow vertically as sea-level rises will be hindered significantly if the biological ecosystem is unhealthy as a result of human-induced damage.

The fringing reefs will also be sensitive to changes to river flows, and thus sediment load. As a result, deposition of sediment in coastal locations may change. However, natural patterns of deposition are likely to be disrupted by human activities along the coast including sand mining and dredging, sea wall construction (which deflects sediment deposition), and destruction of mangrove swamplands.

The reaction of the mangrove biological ecosystem to future stresses is also uncertain, but their ability to remain will be highly dependent upon the influence human activities have on their natural state. In the future, under the No Management scenario, destruction of mangroves by infilling for land reclamation, pollution, and diverted sources of sediment (rivers) may dramatically increase the vulnerability of these coastal environments to future stress.

Under the No Management scenario both physical and biological coastal Sub-systems will have low resilience to future stresses as a result of continued human modification and degradation. The OMR scenario assumes that a range of strategies is adopted to both enhance resilience and reduce vulnerability. Such strategies include the reduction of sewage pollution though the implementation of the proposed Apia sewerage scheme, the reduction in industrial pollution, the development of sustainable reef and mangrove management practices, and closely managed sea-wall maintenance and land use planning. The last strategy could be coordinated by the proposed Apia Urban Authority, which would also coordinate the reduction in the risks to infrastructure.

5.2.4. Institutional System

Apia is the administrative decision-making institutional centre of Western Samoa. The institutional effectiveness with respect to coastal management has been analysed in Section 3.3 (see also Appendix I). This analysis concluded that there is sufficient national legislation to produce effective coastal management strategies. However, lack of human and financial resources and poor linkage with village level decision-making were both obstacles to successful policy implementation. In addition, the control of land use along the coastal hinterland of Apia is minimal. Apia has neither a town council nor land use planning legislation to manage urban development. These factors contribute to institutional vulnerability, and reduce resilience.

Western Samoa has relative political stability, enhancing national institutional resilience through the ability to develop and implement long-term coastal management strategies.

However, future effectiveness of national institutions may be compromised through the physical location of the buildings which house government institutions. The new government building is situated on land recently reclaimed from Apia Harbour. The parliament building is located on the low-lying Mulinu'u Peninsula. These locations effectively create additional internal stress, contributing to national institutional vulnerability.

The OMR scenario assumes strengthening of national institutions would be undertaken, including improving the linkages between national and village levels of decision-making. In addition, the OMR scenario assumes the creation of an Apia Municipal Authority, presently being considered by the Samoan Government. The Apia Municipal Authority, if formed, will be an administrative body with powers to improve land use planning, implement building codes and manage social and economic activities in Apia.

5.2.5. Infrastructural System

Apia is the central point of transportation, communication, administration, education, health and social services of Western Samoa. The majority of central administrative buildings for each service are located along Apia's waterfront and Mulinu'u Peninsula. These coastal locations have been seriously damaged by cyclones in recent years. Most institutions have no backup or support facilities elsewhere in Western Samoa, and disruption of operations as a result of cyclone impacts has hindered recovery and rehabilitation after such disasters (Government of Western Samoa 1992c).

There is extensive service infrastructure in Apia including water supply, electricity, gas, sewerage and waste disposal. However, the location and operation of this infrastructure is not well planned, nor does it work continuously. Household and commercial wastes enter closed and open drains which discharge into mangrove wetlands at Vaiusu Bay. Municipal rubbish disposal and effluent from the Vaitele Industrial Area in east Apia also enters this mangrove wetland. High levels of pollution has resulted. The service infrastructure has little capacity to deal with the demands placed on it by its population and increasing commercial and industrial activities. While the physical service facilities are vulnerable to external stresses, their inefficiency results in a significant internal stress; the adverse impact on the natural Coastal System.

The relative vulnerability of individual, communal and national buildings depends on the design of each building, the materials used and the standard of construction. These factors have not been studied in this Phase. It is recommended that this work be carried out in Phase II, including an analysis of building codes and their implementation in Apia.

There is an extensive seawall building project currently underway in Apia with assistance from the Japanese government. Beach Road, the new Apia reclamation and Mulinu'u Peninsula is being fronted with sloping rubble revetments. This scheme is being undertaken primarily to reduce the vulnerability of urban infrastructure, and its economic production.

Individual, communal and national infrastructure located in Apia has been scored as highly vulnerable, and of low resilience to external and internal stresses (Table 5.3).

In the future, under the No Management scenario, the capacity of infrastructural services in Apia and its hinterland, which are presently unsustainable, are unlikely to have the capacity to keep up with user demands placed on them by a changing urban population and increased industrial use. The demand on infrastructural services may be higher than anticipated under conditions of rural-urban migration trends if traditional overseas destinations reduce their intake of migrants. Infrastructural services will remain vulnerable in the future if present social attitudes towards their use do not change. For example, many Samoans regard water as a gift from God, and expect it to be free as a result. This has led to over-exploitation, waste, and inappropriate use of water resources. The future vulnerability of the water supply will be enhanced, under the No Management scenario, by the accelerated clearance of catchment areas and uncontrolled pollution.

Waste disposal will continue to be a concern for urban Apia and its hinterland villages in the future. With possible future increases in population and the growing use of imported consumer "throw-away" goods the quantity of waste generated is likely to rise dramatically. Existing, and any new coastal disposal sites will be sensitive to future stress changes. Increased leaching of pollutants into the coastal ecosystems may be the result. The disposal of sewage will also pose future problems especially as the present open drain sewerage system may contaminate shallow aquifers. These aquifers are likely to be extremely sensitive to future sea-level rise. In this densely populated site potential water contamination has serious future implications for public health.

The OMR scenario assumes the provision of individual, communal and national services in the future. The provision of service infrastructure is dependent on the future population density in Apia. A large increase in Apia's population may deplete and disrupt the already disturbed coastal ecosystems, and strain beyond present capacity the existing infrastructural services. As a result, optimal coastal management must include integration of policies to attain a sustainable population growth rate.

5.2.6. Economic System

There is an intense concentration of commercial and industrial activities in urban Apia which contributes significantly to the cash economy of Western Samoa. However, economic activities for cash dividends diminish further out into Apia's hinterland because most land within the surrounding villages is under customary ownership and used for subsistence purposes.

The vulnerability of the cash economic system is considered to be higher than for the subsistence economy. This differential vulnerability is a consequence of the reliance on infrastructure located in urban Apia, potentially at risk from external stresses. For example, infrastructure seriously damaged by recent tropical cyclones was disrupted for long periods, causing losses to the cash economy (Government of Western Samoa 1992a, c).

Resilience within the urban economic system in the aftermath of coastal disasters, relies on the capacity of urban residence to share with extended family members who live subsistence economic lifestyles. Despite the economic attractions of Apia, the difficulties intrinsic in a cash-driven economic environment, of which low wages are the most important, inevitably draws people back to some form of subsistence economic lifestyle.

Remittances also play a major role in the economic resilience of the residents of Apia. The role of remittances in the Samoan economy was described in Section 5.1.6.

Western Samoa's tourist industry is centred on Apia. At present 92% of the 489 hotel beds in Western Samoa are within Apia (Government of Western Samoa and Tourism Council of the South Pacific 1992).

The national economic state of Western Samoa in the future will depend significantly on the future vulnerability of subsistence and cash-generating activities to external environmental stresses. The country's GDP has been falling, especially after the last two major cyclones, Ofa and Val. Like many of the small South Pacific island nations, Western Samoa has endeavoured since independence in 1962 to develop a modern economy from traditional village agriculture and primary products. The country has no known minerals and its Exclusive Economic Zone is amongst the smallest in the region. Future exports will remain agriculturally based but will continue to be subjected to external forces (natural and commercial) which are beyond the country's control. The population of Apia is highly dependent on food supplies generated by rural subsistence activities. Therefore, the subsistence and cash economies of rural 'Upolu (described in Section 5.1.6), and the cash economic System of Apia are intimately linked.

Future resilience of the economic Coastal Systems is expected to be moderate to high, mainly because of the inherent resiliences built into the working of subsistence activities. The Seventh Development Plan (DP7) aims to improve the resilience of the cash economy by attaining sustainable economic growth via the creation of skilled employment, development of export oriented and import substitution activities, identification of sources of growth, improvement of land use, achievement of economic efficiency and promotion of local economic development.(Government of Western Samoa 1992a). However, the establishment of proper linkages between national and local levels is essential if these aims are to be achieved.

Apia's key role in the tourist industry is planned to continue through increased hotel numbers and increased visitor facilities in the town centre, especially the harbour-front areas (Government of Western Samoa and the Tourism Council of the South Pacific 1992). Apia is also likely to experience significant economic flow-on effects from increased tourist numbers, including the development of visitor attractions and an increase in retail outlets tailored to tourists' needs.

5.3. Faleolo International Airport and Mulifanua Wharf

Introduction

The third case study focuses nationally important coastal infrastructure. This approach of analysing the net impact on one Coastal Sub-System, departs from the broader analyses undertaken in the previous two sections for Apia and the rural coast. This "System Isolation" approach is initially tested to examine the factors which contribute to the vulnerability and resilience of major infrastructure projects to external and internal stresses. The testing is undertaken in order to assess the potential wider applicability of the technique for Phase II of this project.

There are a number of major infrastructure projects on the coast of 'Upolu, including Faleolo International Airport, Mulifanua Wharf, sections of the round-island road, Apia's port facilities and the new coastal land reclamation in central Apia.

Only Faleolo International Airport and Mulifanua Wharf are analysed in detail in this section. Their vulnerability and resilience components are investigated, and the linkage with other Coastal Systems highlighted. Faleolo Airport is the only international airport in Western Samoa, while Mulifanua Wharf is the berth on 'Upolu for the inter-island ferry, the only public passenger ferry between 'Upolu and Savai'i. The airport and wharf were chosen for initial analysis because both projects were built with the assistance of the Japan International Cooperation Agency and Japanese engineering consultants, and hence detailed design reports were readily available to the study team.

The airport and wharf are located on the north-east coast of 'Upolu (Figure 3.2). Faleolo Airport is 32 km from Apia. The first airport at Faleolo was the airfield built by the United States Marine Corps during the second world war (Government of Western Samoa and Japan International Cooperation Agency 1985). Between 1969 and 1973 the airport was reconstructed with a sealed runway (1,676 m long) built adjacent to the original wartime runway. In addition, terminal facilities were constructed. Between 1973 and 1983 Australian aid projects extended the runway to 2,700 m. Additional airport facilities, such as a power supply system and terminal buildings have been constructed with assistance from New Zealand, Canadian, and Japanese aid projects.

Faleolo Airport suffered an estimated damage of WST$ 2.35 million (US$ 0.89 million) due to cyclone Val (Government of Western Samoa 1992c). Winds caused the greatest damage to the terminal buildings and control tower. Only minor damage was sustained by the runway through wave wash-over.

Cyclone Val also caused an estimated WST$ 1.1 million (US$ 0.42) damage to the terminal building, the access road and the leading beacon on Mulifanua Wharf (Government of Western Samoa 1992). In addition, substantial siltation of the channel leading to the Wharf also occurred. Extensive dredging of the channel was subsequently required.

5.3.1. Coastal System vulnerability and resilience analysis

In this sub-section the vulnerability and resilience components of the natural, cultural, institutional and economic systems are analysed. This analysis is undertaken with specific reference to the contribution of each System's vulnerability and resilience to the overall vulnerability and resilience of the Airport and Wharf's infrastructure. Because the case study focuses on infrastructure only, human Systems are not considered in this case study.

Natural System

The entire western tip of 'Upolu has extensive fringing and barrier reefs between 450 and 1800m wide (Richmond 1991). The lagoon bottom is a patchwork of smooth-floored sediment, marine floral blanketed substrates, and coral pinnacles interspersed with sediments. The lagoon is characterised by the deposition of large volumes of reef-derived sediment. Numerous blue holes have developed within the lagoon and reach depths as great as 14m. The submarine terrace is well-developed and extends up to 800m beyond the reef crest. The coast is fringed by a few scattered areas of mangroves.

The coastal plain is composed mostly of gently-sloping Mulifanua Volcanic rocks. The shoreline is composed of small pockets of Tafaugamanu Sand and alluvial deposits, but no volcanic rock outcrops. No large rivers or streams enter the coastline which has led to sediment being composed mainly of carbonate sand material, with thin and patchy sediment veneers occurring along inner reef flats and beaches. More extensive carbonate sand bodies occur in shallow lagoonal floor. Some mud occurs along protected shorelines, particularly near mangroves.

The reefs fronting the Faleolo Airport and Mulifanua Wharf suffered serious damage during recent cyclones. The cyclones formed major hurricane banks on lagoonal reef flats. Cyclone Ofa created extensive hurricane banks around near Mulifanua and directly opposite Faleolo Airport (Rearic 1990, Zann and Sua 1991).

The inner lagoon floor consists of fine sand and is dominated by a band of seagrasses and macroalgae, and dead eroded Porites microatolls , which indicate a modern disturbance, possibly sedimentation (Richmond 1991). However, such habitats are very vulnerable to erosion by extreme events. Pressure from harvesting is not extreme in this region because of the relatively low levels of population nearby . However, there is a danger of pollution from the Airport and Wharf. The biology of the reef and lagoon is sensitive, especially near Mulifaua Wharf where a channel has been blasted through the reef, disrupting the coral. The channel has remained disturbed and unstable, as demostrated during Cyclone Ofa when the channel was in-filled by sediment and had to be re-dredged. The fringing barrier reef is healthy despite damage suffered during recent cyclones. Persistent erosional processes along this stretch of coast remain strong, but extensive sea walls protect the majority of this coastal area from direct erosion forces.

Present day physical coastal resilience in this study site is high (Table 5.4). The wide lagoon and extensive barrier reef act as a natural buffer between ocean forces and the coast. However, Richmond (1991) describes this coastal region of 'Upolu as having been erosive for many years. The erosion may be partly attributable to the wide and deep lagoon allowing greater wave energy to reach the shore. Higher wave energies have a positive effect on biological resilience. The resulting turbulence in the lagoon reduces the lagoon's susceptibility to eutrophication.

The present resilience of biological ecosystems in the reef, lagoon and along the coastal margins is considered to be higher than the physical System (Table 5.4). This is due to the fact that considerable modification of the areas physical Coastal Systems has already occurred through land reclamation and the construction of seawalls.

Storm water, marine and rainfall flooding of the low-lying airport runway and taxiways creates the potential for toxic chemicals and fuels to be dispersed into the lagoon by runoff. This pollution could have major effects on species which feed on sediments, such as mullet, and could lower the overall resilience of the reef and lagoon System.

Coastal systems	Coastal sub systems	Vulnerability component	Resilience component	Sustainable capacity index	Vulnerability component		Resilience component		Sustainable capacity index	
Present day					Future					
		Present management regime	Present management regime	Present management regime	No management	Optimal management	No management	Optimal management	No management	Optimal management
Natural	physical	-2	+1	-1	-3	-2	0	+1	-3	-1
	biological	-1	+2	+1	-2	-1	+1	+2	-1	+1
Cultural		-1	+2	+1	-2	-1	+1	+3	-1	+2
Institutional	national	-2	+1	-1	-3	-2	0	+1	-3	-1
Economic	cash	-2	+1	-1	-3	-2	0	+0	-3	-2
Resultant infrastructure scores		**-1.3**	**1.2**	**-0.1**	**-2.17**	**-1.33**	**0.3**	**1.2**	**-1.9**	**-0.1**

Table 5.4. Faleolo Internationa Airport and Mulifanua Wharf Infrastructure Projects Present Day and Future Coastal System Vulnerability and Resilience Components and Sustainable Capacity Indices.

Future coastal resilience of the physical environment along the north-west coast of 'Upolu may be expected to be reduced if no coastal management strategies are implemented. If the fringing reef remains healthy and relatively unstressed the resilience of the reef ecosystem to sea-level rise, and other external and internal stresses may remain positive. However, if the reefs are not given sufficient time to repair themselves between cyclone events, the resilience of the reef system may be significantly reduced.

Institutional and Economic Systems

The vulnerability and resilience of the Airport and Wharf's infrastructure is also dependent on the management decisions that are taken to protect the facilities from the impact of internal and external stresses. Local level decision-making is not directly relevant to the two study sites, and is not considered further.

National coastal management decision-making systems were reviewed in Section 3.3, where it was concluded that the present decision-making framework was generally robust, but required changes to increase its capacity to cope with the impact of stresses. The national importance of Faleolo Airport and Mulifanua Wharf to the national economy may be expected to increase the importance given to its protection from internal and external stresses. As a result, high level management decisions are likely to play a major role in increasing the resilience, and reducing the vulnerability of this site to future coastal changes.

Both the Airport and Wharf have considerable importance to the economy of Western Samoa. Several international airline companies operate at Faleolo, including Polynesian Airlines, the national carrier of Western Samoa, Air New Zealand, South Pacific Island Airways, Air Pacific and Air Nauru. There were 81,200 international air passenger arrivals in 1992, of whom approximately half were tourists. There are, 58 international flights a week, on average, including 45 to American Samoa. Air passenger arrivals are projected to increase by approximately 1,400 per year for the next 20 years, mainly due to increased numbers of tourists. In order to cater for the predicted numbers of tourist arrivals, plans have been made to significantly up-grade the Airport (Government of Western Samoa and Tourism Council of the South Pacific 1992). The airport expansion plan involves the lengthening and widening of the runway, and moving and expanding the passenger terminal facilities, at a total cost of WST$600 million (US$ 258 million).

The inter-island ferry run by the Western Samoa Shipping Corporation sails the 11.7 nautical miles between Salelologa Port on Savai'i and Mulifanua Port, 'Upolu. Unlike international travel, the movement of people between 'Upolu and Savai'i largely depends on marine transportation. An estimated 90% of passenger travel between the two Islands is by ship (JICA 1984). The approach channel and turning basin in the lagoon, and the wharf and terminal facilities at Mulifanua were reconstructed during the late 1980s in cooperation with the Japan International Cooperation Agency (JICA) (JICA 1984, Government of Western Samoa and Pacific Consultants 1986, JICA 1987).

Cultural System

Samoan culture places strong emphasis on extended family ties (Section 5.1.2). Some family members often live in other parts of Western Samoa, or may live overseas. As such, Samoan culture can be thought of as contributing to the economic sustainability of transport infrastructure in the country through the encouragement of links between family members, facilitated through travel. The continuation of cultural strength in Western Samoa can be thought of as increasing the resilience, and decreasing the vulnerability, of the Airport and Wharf to stresses.

5.3.2. Resultant impacts on the major infrastructure projects of Faleolo Airport and Mulifanua Wharf

The average of the Coastal System vulnerability and resilience scores, undertaken in the previous section, indicated the balance between vulnerability and resilience of the Airport and Wharf's infrastructure to external and internal stresses (Table 5.3). The natural systems protecting the Airport and Wharf from ocean waves are relatively healthy. In addition, cultural, institutional and economic factors contribute positively to the resilience of the Airport and Wharf's infrastructure. Table 5.3 shows that the present day resultant vulnerability score of the infrastructure is low to moderate (1.3), and the present day resilience score is also low to moderate (+1.2).

The similarity of the average vulnerability (-1.3) and resilience (+1.2) produces a Sustainable Capacity Index (SCI) close to zero (-0.1). This SCI score gives an indication of the potential long-term sustainability of the infrastructure of the Airport and Wharf.

Consideration of future changes to internal and external stresses indicate that the implementation of an OMR strategy could maintain the present balance between vulnerability and resilience, despite potential future sea-level rise and climate change (Table 5.3). Key components of an OMR are strategies to maintain the health of the reef and lagoon ecosystems. The OMR may achieve this objective through a programme of awareness building and public eduction on sustainable fishing practices. In addition, the OMR should attempt to minimise the amount of pollution entering the lagoon.

The sloping rubble revetments which front Faleolo airport have been efficient in contributing to the protection of the airport from cyclone and wave damage (Figure 5.4). Their appears to be little environmental impact of this structure on the adjacent lagoon and reef system.

It may be prudent to consider upgrading the level of protection given to the airport by the sloping seawalls. This upgrading is assumed be part of an OMR strategy. This upgrading may be necessary as a precaution against future sea-level rise and climate change, and as a precaution against the possibility that reef management strategies will fail. Seawall upgrading may be achieved by increasing the size of the rubble blocks. The required minimum weight of the rubble blocks is calculated using the equation in Appendix 3.

Damage to the Airport's revetments may is assumed to occur under the No Management scenario. Damage is assumed to occur from increased wave energy reaching the shoreline due to the decreased resilience of the barrier reef. The possible impacts to the airport under the No Management scenario is shown in Figure 5.4 (b).

The continued balance between the vulnerability and resilience components, and resulting low SCI, under the OMR strategy (Table 5.4) suggests that seawall upgrading at the Airport is not an immediate priority. Instead, the low SCI suggests that seawall upgrading should be carried out as part of any future upgrading of the airport. Airport upgrading has recently been proposed as part the drive for increased tourist arrivals (Government of Western Samoa and Tourism Council of the South Pacific 1992). The importance of protecting Faleolo Airport requires that the issue of upgrading the seawall is investigated further in Phase II.

The Mulifanua Wharf may also require upgrading as a result of future sea-level rise and climate change. It is possible that such upgrading would be ultimately required because of the increased emphasis placed on the development of Savai'i, which is likely to increase the demand for transport between 'Upolu and Savai'i.

However, the direct effects of sea-level rise may require the upgrading of the Wharf sooner than seawall upgrading at Faleolo Airport. The priority for upgrading the Wharf before upgrading the airport may be due to an additional internal stress in the Wharf as a result of its design. The Wharf is built as a gravity type (concrete block) structure. The structure maintains its stability through its own weight (Figure 5.4.c). Stability is achieved through the downward force produced by the Wharf's weight being greater than the lateral forces produced by soil pressure. If lateral forces exceed downward forces, the Wharf would collapse (Figure 5.4.c).

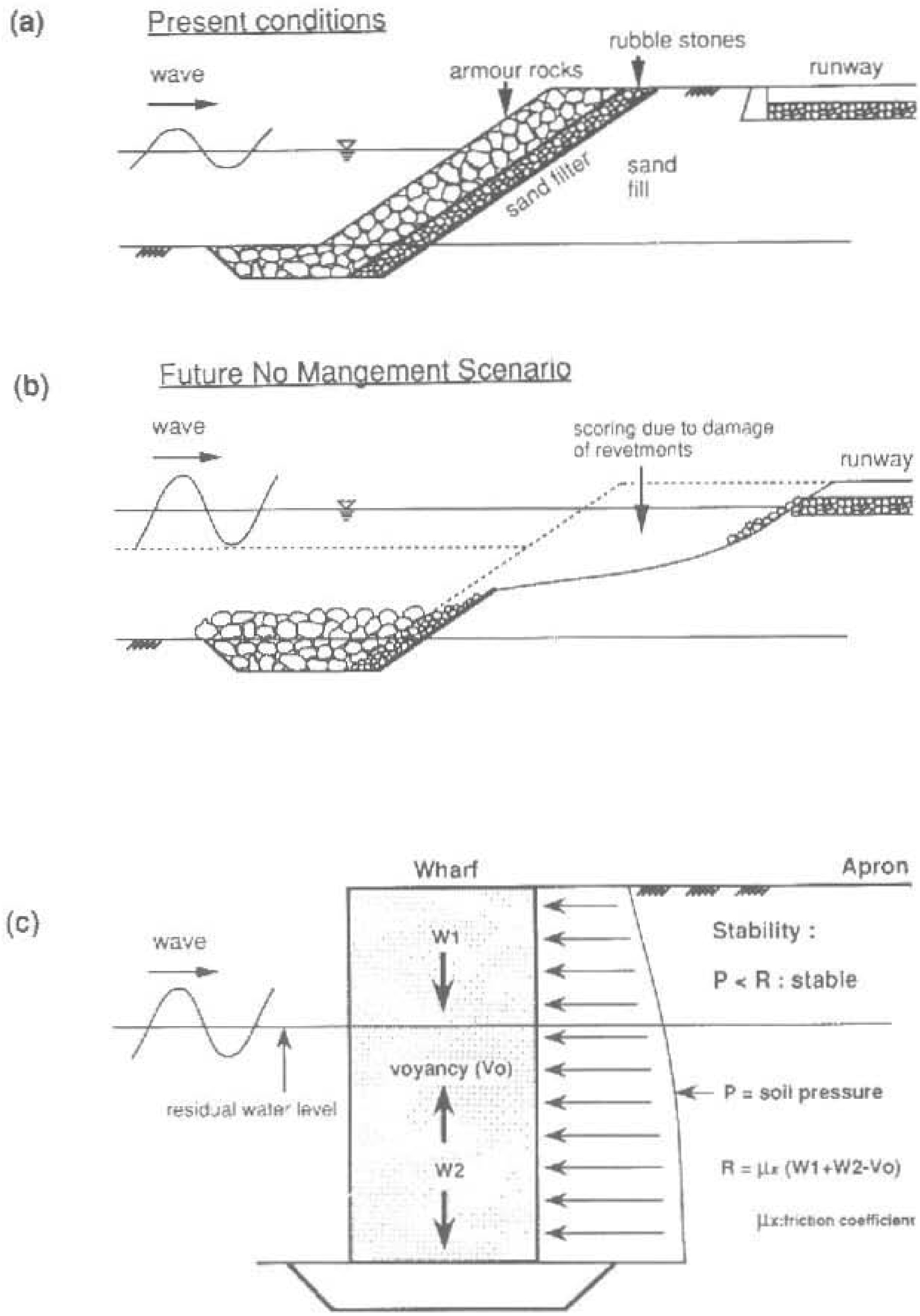

Figure 5.4. *Engineering Considerations for the Airport and Wharf as a Result of Sea-level Rise.*

Part of the downward force maintaining the stability of the Wharf is the its weight submerged below sea-level (W_2 in Figure 5.4.c). The downward force of the submerged weight of the Wharf is reduced because of the buoyancy (or vuoyancy) effect of sea water. Consequently, a future rise in sea-level would increase the submerged part of the Wharf, thereby reducing the downward force exerted by the weight of the Wharf. Higher future sea-levels could also increase the frequency of overtopping which would erode the apron of the Wharf, also decreasing stability.

It is recommended that the sensitivity of the Mulifanua Wharf be further investigated in Phase II. The results of this investigation should be included in any plans the upgrade the Wharf as part of initiatives to modernise Savai'i. This recommendation is made in Section 8.

6. Technological Case Study: Initial Testing of the Use of a Geographic Information System (GIS)

Geographic Information Systems (GIS) are powerful analytical tools enabling the rapid processing of large sets of data stored in a geographic form. GIS are often used as computer mapping tools, by simply storing mapped information in a computer. However, GIS can also be used to model complex issues which require the spatial-processing of large volumes of data. It is the latter capability of GIS which holds promise for the assessment of coastal vulnerability and resilience to external and internal stresses.

A GIS was tested for its ability to assist in the analysis of the vulnerability and resilience of Coastal Systems to external and internal stresses. The GIS software was ARC INFO housed on a computer operating under UNIX . The GIS was located within the offices of Pacific Consultants Co. Ltd. in Tokyo, Japan. A survey of additional sources of digital and analogue data relevant for future GIS work was also undertaken. Finally, a brief analysis of the present GIS capability within Western Samoa was carried out.

Topographic maps of the whole of 'Upolu Island at a scale of 1:20,000 were digitised to form the data set used for the initial GIS testing. Fifteen "layers" of geographic data for 'Upolu were digitised from these maps (Table 6.1). Each layer is a separate data set. The GIS system can overlay these data to produce composite digital maps. Because the maps are held in digital form, the GIS allows a range of analyses to be rapidly undertaken.

The 50 ft. (= 15 m) contour line was the first contour above the zero ft contour. The zero ft contour used to define the coastline. Thus, the land between 0-50 ft is a measure of the extent of coastal lowland in the coastal zone. The lagoon, reef and nearshore "wet" part of the coastal zone were not considered in this initial GIS analysis. Table 6.2 shows selected indices of the concentration of layer-attributes between the 0-50 ft contours calculated from the digital mapping process.

Layer	Description
A	Coastline
B	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
0	Airports

Table 6.1. Layers digitised from 'Upolu 1:20,000 scale topographic maps into the Geographic Information System (GIS).

Layer	Whole Island	0-50 feet	% 0-50 ft
Length of coast line (km)	249.36	-	-
Area (km^2)	1,127.57	99.32	9
Mangroves (km^2)	2.02	2.02	100
Swamps (km^2)	6.64	3.39	51
Schools (number)	126	89	71
Churches (number)	301	234	78
Springs (number)	17	11	65
Wells (number)	5	5	100
Length of sealed road (km)	162.22	85.28	53
Length of metalled road (km)	543.51	111.97	21

Table 6.2. Selected layer attribute summaries for 'Upolu as a whole and between 0-50 ft obtained from GIS analysis.

The summary data in Table 6.2 clearly show the strong coast-dependence of the infrastructure and services in 'Upolu. While only 9% of the land area of 'Upolu is between 0-50 ft, 71% of the schools and 78% of the churches are within the coastal lowland area. Church parishioners 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 0-50 ft gives a general indication of the overall density of household infrastructure within the coastal lowland zone. This proportion of household infrastructure within the coastal lowland area may be between 70-80% (Table 6.2).

The area of coastal lowland, and the population, services and infrastructure within the coastal lowland, give a general indicator of the island's coastal dependence. However, the definition of coastal lowland as the area between 0-50 ft cannot be correlated directly with the exposure to external or internal stresses, including future sea-level rise and climate change. As, a result additional GIS analysis is required to analyse the potential direct exposure of Coastal Systems to stress.

Cyclone Ofa, for example, produced a storm tide of 1.6m, whereas a 1 in 100 year cyclone (1% annual occurrence probability) surge tide of 2.3 m is predicted (Rearic 1990). Thus, areas directly at risk from cyclone flooding are those less than 5 m above mean sea-level. In contrast, the areas affected by salt spray during Cyclone Val were many hundreds of metres above sea-level which included most of the island. GIS analysis can be used to assist disaster management by evaluating the extent of the areas 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 (Warrick and Orleamans 1990). Hence, studies using contour lines with close 0.5 m or 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.

The approach to GIS analysis using closely spaced contour lines (of 1.0 m spaced contours between 0 and 5 m) was used successfully on Tongatapu Island, Kingdom of Tonga (Fifita *et al.* 1992, 1993). Contour lines spaced at 1 m were drawn from the detailed analysis of aerial photographs. The GIS analysis of the contour maps estimated that 14% of the land area of Tongatapu, and 47% of its population, is presently at risk from the combination of a 2.8 m extreme cyclone-surge tide and the added future sea-level rise of 1.0 m by the year 2100. This information, especially the location of land at risk from direct inundation, is extremely valuable for the implementation of successful disaster management (Carter 1991, ADB 1991). Given the importance of cyclone-induced flooding in Western Samoa, the analysis of the extent of extremely low-lying coastal areas would be an important extension of the initial GIS analysis described above. GIS analysis of the low-lying land in Western Samoa is recommended as a Phase II research task.

This analysis of the extent of extremely low-lying land at risk from cyclone-induced flooding is recommended for Phase II of this project, in collaboration with the photogrammetry section of the Department of Lands and the Environment. This task will utilise four large-scale map sheets of central Apia which contain 0.5 m spaced contour lines. These maps were completed by the Department of Lands and the Environment. In addition, some of these contour maps were digitised as part of a UNEP-funded GIS training course (B. Crawley, SPREP - pers. comm; Chase and Veitayaki 1992). These data will be made available during Phase II.

A crucial data-base for further GIS development is the Land Resource Planning Study of Western Samoa, completed in 1990 for the Government of Western Samoa with funding from the Asian Development Bank. The data-base was compiled by ANZDEC Ltd. and the New Zealand Division of Industrial and Scientific Research (now Landcare Research Ltd.). The study was undertaken to assess the land capability for increased agricultural production of 'Upolu and Savai'i. The data-base uses ARC INFO GIS software on a computer operating under both UNIX and DOS.

There are three main "coverages" within the Land Resource Planning data-base. There is also a base coverage of cartographic data. Each coverage consists of a number of data layers. The three main data coverages are:

I- Vegetation;
II- Land tenure; and
III- Soil

The data layers within each coverage are listed in Appendix 4. The range and quality of the data sets listed in Appendix 4 will be vital to the future development of GIS work.

Another source of data is the 'Upolu coastal morphology mapping project undertaken by the South Pacific Geoscience Commission (SOPAC) (Richmond 1991). These 1:25,000 scale maps include information on shoreline features, coastal plain geology and reef features. A detailed list of the components of the maps is given in Appendix 5. The SOPAC maps were drawn using a computer-aided mapping system. SOPAC is currently developing its GIS capability, and there are plans to transfer the 'Upolu coastal morphology maps onto GIS (R. Smith, SOPAC - pers. comm.). These data would form an important part of future GIS development in support of coastal vulnerability and resilience assessment.

The development and implementation of the Land Resource Planning data-base has highlighted the capacity for GIS implementation in Western Samoa. The GIS data-base was completed in New Zealand, and transferred to the government on a personal computer. However, the computer was damaged in 1991 by Cyclone Val. The computer is now inoperable. Hence the data-base is not currently being used in Western Samoa.

In addition, there are several human resource constraints for the implementation of GIS technology in Western Samoa. There is currently a very small number of people in the country (estimated at less than 5), with GIS experience. The mobile population, and opportunities for computer operators in developed counties present an acute problem for the sustainable implementation of GIS technology in Western Samoa.

Engelen *et al.* (1992) are developing computer-aided modelling work in the Caribbean. The aim of this work is to provide a decision support system to decision-makers, which will facilitate the formulation of policies to mitigate adverse effects of climatic change. The work is in its early phases, and is analysing a hypothetical Caribbean island. Nevertheless, the research of Engelen *et al.* (1992) shows the potential of using GIS in a decision support role and the applicability to a "whole island" assessment of the impact of internal and external stresses.

In summary, the initial testing of the GIS in Western Samoa has produced some useful results. The survey of additional sources of data has also revealed important data-bases, which if combined with the existing GIS data will provide a powerful aid to Coastal System vulnerability and resilience assessment. The usefulness of GIS for coastal impact work is expanded by the potential for employing the modelling capability of GIS to evaluate the sensitivity of Coastal Systems to external and internal stresses. An immediate use of this GIS capability is in the support of disaster management in Western Samoa. However, the potential for GIS implementation in Western Samoa is severely limited by financial and human resource constraints. As a result, developing staff training and education programmes must be part of any future GIS development in Phase II of this project, recommended in Section 8.

7. The Implications of the Case Studies for Integrated Coastal Zone Management in Western Samoa

The vulnerability and resilience case study analyses described in Sections 5.1-5.3 have shown that there is considerable scope for the reduction of future sea-level rise impacts in Western Samoa by enhancing Coastal System resilience and reducing Coastal System vulnerability. The case study analysis assumed that the maximum reduction in future sea-level rise impacts would be through an "Optimal Management Response (OMR)". The OMR concept allows decision-makers to clearly view the benefits of implementing management initiatives, both for reducing the exposure of today's coastline to erosion and cyclones, and to future climate change and sea-level rise. The technological case study of the initial use of Geographic Information Systems (GIS) in facilitating the formulation of OMR strategies was described in Section 6.

The following Section describes the possible management approaches for achieving the maximum reduction in future coastal impacts within the case study areas.

The Coastal System vulnerability and resilience analysis undertaken in this report has highlighted the wide range of critical issues requiring the intervention of coastal managers. Critical coastal management issues occur in Western Samoa because of the impact of external and internal stresses on complex and strongly interacting Coastal Systems.

Important external stresses to the Coastal Systems of Western Samoa include: cyclones, tourists, fluctuations in global markets, aid donor requirements and remittances. Two additional external stresses, future sea-level rise and climate change are likely to add to the already extensive array of external stresses. Alone, these external stresses would create significant management problems. When these external stresses are imposed on Coastal Systems already stressed by considerable internal stresses, critical coastal management problems result. Important internal stresses in Western Samoa include: pollution; the social pressures of unemployment/underemployment, migration and poverty; cultural change; land reclamation; modernisation; and natural resource exploitation.

Critical coastal management problems that result from the interaction of internal and external stresses include: coastal erosion; flooding; and degradation of reefs, mangroves and coastal plains. In many cases coastal management problems result from the impact of more than one stress. Furthermore, internal and external stresses often interact and the resultant coastal impacts do not have clear cause and effect. As a result, formulating and implementing appropriate management responses is extremely difficult. For example, coastal erosion in rural 'Upolu is probably due to the combined impacts of many stresses. Some stresses which exacerbate coastal erosion include: cyclones, beach and lagoon sand mining; reduction in reef productivity due to overfishing and sediment runoff from poorly managed watersheds; and the construction by villagers of poorly designed seawalls.

However, despite multiple and interacting stresses there are significant opportunities for the effective and integrated management of the Coastal Systems of Western Samoa. This opportunity stems from both recent national government initiatives and the continued strength of involvement in the day-to-day use and management of coastal resources at the village level.

At the national level, the most recent Development Plan 1992-1994 (DP7) strongly advocates sustainable resource management (Government of Western Samoa 1992a). There is also a comprehensive array of environmental management legislation which may be enacted to achieve the goal of sustainable coastal resource management (see Appendix 1). In addition, a range of environmental and disaster management issues is being addressed through national government initiatives, including the National Environmental Management Strategy (NEMS) (Government of Western Samoa 1993) and those of the National Disaster Council (Government of Western Samoa 1992c). The Optimal Management Response for the reduction of the impact of stresses on Coastal Systems will require the integration of such environmental management, disaster management and development planning policies and initiatives (Figure 7.1). Effective implementation of national policies and strategies in urban Apia will require the creation of the proposed Apia Municipal Authority.

The customary ownership of much of 'Upolu's coastal land, and the traditional ties of coastal villagers with coastal land and water, also provide a significant coastal management opportunity. Western Samoans retain strong links to coastal resources through subsistence economic exploitation. In addition, the decision-making powers of village councils remain strong. Consequently, there is scope for villagers to develop, implement and enforce coastal resource management strategies through village rules and traditional methods of enforcement. If villagers do not feel that they are responsible for the success of a coastal management strategy, it is likely to fail. Therefore, the success of nationally conceived coastal management strategies in Western Samoa is likely to be greatly enhanced through the sharing of coastal management strategy development with village decision-makers.

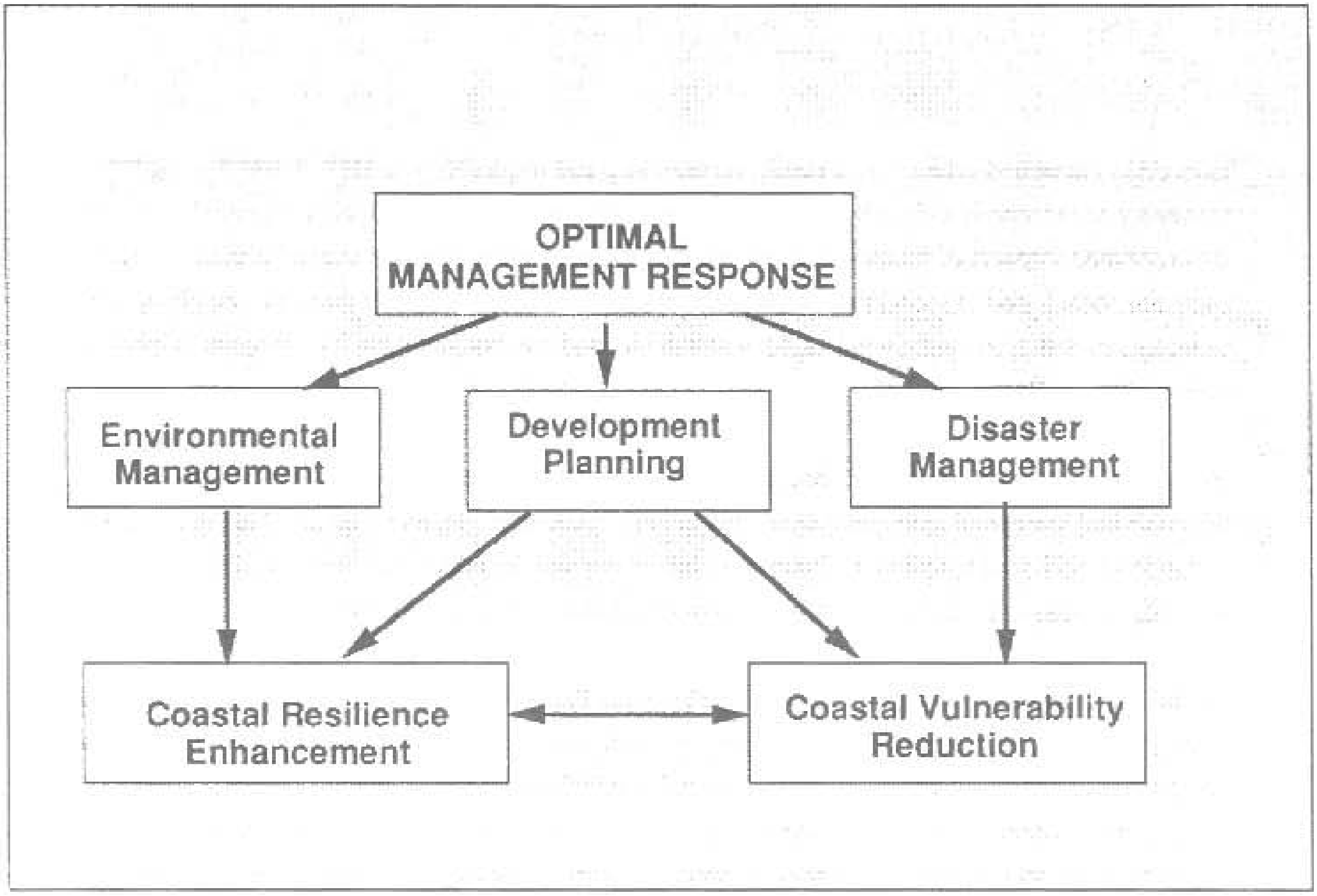

Figure 7.1. Conceptual Optimal Management Response Implementation pathway.

Unfortunately, notwithstanding the opportunities for effective and integrated coastal zone management in Western Samoa, there are important constraints hindering effective policy development and implementation. There are two critical constraints; first, the financial and human resource constraints of key central government agencies such as the Division of Environment and Conservation, and second, the poor linkage between national and village levels of decision-making (Section 3.3). That poor linkage of national and village level decision-making will result in sub-optimal policy implementation, assuming national government staff will be provided with enough resources to develop such coastal management strategies. The limited resources in central government mean that the development of an integrated coastal zone management plan in Western Samoa will be a slow and frustrating process. Specific recommendations made in order to alleviate these constraints are given in Section 8.

8. Recommendations

Phase I of this project, reported in this document, has focussed on the development, and initial testing, of a new approach to the assessment of the potential future impacts of sea-level rise and climate change on Coastal Systems. This approach considers sea-level rise and climate change as two additional external stresses to an already existing range of internal and external stresses.

Initial testing of the new approach has shown its applicability for Western Samoa. It is recommended that this initial phase is followed immediately by an approach development and implementation phase, to be undertaken in Phase II. The specific tasks recommended for Phase II are given in Section 8.3, which are designed to achieve the recommended Phase II objectives listed in Section 8.2.

In addition, the research undertaken in Phase I has revealed a number of issues requiring immediate action. Recommendations for immediate actions are given in Section 8.1. These actions are required to reduce the significant impacts of external and internal stresses to Western Samoan Coastal Systems.

8.1. Recommendations for immediate action

General recommendations

A.I Expedite proposed national environmental management plan amendments to Part VIII of the Lands, Surveys and Environment Act to allow better linkage between national government and village level decision-making.

A.II Improve the coordination of, and communication between, government agencies responsible for environmental management, development planning and disaster management.

A.III Build awareness of, and support education on, issues of Coastal System vulnerability reduction and resilience enhancement.

A.IV Implement the recommendations made by Chase and Veitayaki (1992) in their report on the implications of sea-level rise and climate change on Western Samoa. These recommendations are:

(1) Upgrade the meteorological station.

(2) Improve knowledge of Western Samoa's reefs.

(3) Develop a land- and coastal water-use plan.

(4) Establish a regional information system on the effects of climate change.

(5) Undertake a number of desk-studies, including Coastal System sensitivity studies, studies which identify indicators of climate change impacts, improvement of climate models, the study of cyclone frequency and intensity, and analysis of historic meteorological records.

Specific Recommendations resulting from case study analysis

Recommendations AI-AIV have general applicability in Western Samoa. In addition, the case studies require that a number of specific recommendations are made for each study site.

Apia	B1	Expedite the establishment of the proposed Apia Urban Authority and associated planning legislation.
	B2	Initiate a comprehensive programme of mangrove protection, and the limitation of new reclamation (especially in Vaiusu Bay).
	B3	Approve and initiate the Apia Sewerage Project as soon as possible.
Safata Bay	B4	Support and expedite the South Pacific Biodiversity Conservation Programme project for Sanapu-Safaua/Safata Areas.
Safata Bay and Saleapaga to Lalomanu	B5	Direct the Western Samoa Visitors Bureau to investigate and include the Safata Bay and Saleapaga to Lalomanu coasts in the proposed ecotourism pilot project.
	B6	Direct the Fisheries Division (in conjunction with the Division of Environment and Conservation) to investigate the potential of aquaculture development.

Faleolo Airport and Mulifanua Wharf	B7	Direct the Public Works Department (in conjunction with the Division of Environment and Conservation) to begin investigations on Optimal Management Strategies, including: options for upgrading the Airport's sea-walls; upgrading the Wharf; reducing wave energies through reef and lagoon management; and reducing pollution entering the lagoon from the Airport and Wharf.

8.2. Recommended objectives for Phase II

I That the concepts and principles outlined in this report are to be further developed and implemented.

II That Phase II be undertaken within the ongoing projects of the Government of Western Samoa, specifically the Division of Environment and Conservation.

III Phase II is to support the formulation of vulnerability reduction and resilience enhancement plans and policies appropriate to Western Samoa.

IV Phase II activities are to enhance the internal capacity of Western Samoa to implement and monitor the recommended outcomes of Phases I and II of this project.

V Build awareness and support education on issues of Coastal System vulnerability reduction and resilience enhancement within Western Samoa.

8.3. Recommended research tasks for Phase II

Five research tasks are recommended for Phase II. All five research tasks support the Phase II objectives listed above. The research tasks are:

I Development and implementation of the vulnerability and resilience assessment approach outlined in this report.

The initial testing of the new approach has proved successful. However, the approach requires further development if it is to be directly applicable to Western Samoa or other countries in the region. Phase II work should include: rigid analysis of the factors contributing to vulnerability and resilience scoring decisions; development of guidelines for making scoring decisions; methods of combining Coastal System scores, including limiting factor techniques. The feasibility of linking the Systems approach to Impact Zone and Connected Area Analysis (IZCA) should also be addressed.

II Stress identification.

A tentative list of external and internal stresses to the Coastal Systems of Western Samoa has been created. Stress identification requires further analysis. Also, the relative strengths of internal and external stresses in different parts of the coast require additional work.

III Development and implementation of the Optimal Management Response (OMR) concept.

The OMR concept has proved to be a useful device for clarifying the range of management actions required to achieve the maximum reduction of stress-induced impacts on Coastal Systems. Further development of the OMR concept is to be be undertaken. Also, strategies for implementing OMR requires further analysis.

IV Investigation of Coastal System interconnectedness.

The Coastal Systems of 'Upolu have been shown to be highly interconnected. The strength and spatial extent of Coastal System connection requires additional research.

V Geographic Information System (GIS) analysis of the low-lying land in Western Samoa to support disaster and environmental management.

Initial testing of GIS has shown its value for the support of Coastal System vulnerability reduction and resilience enhancement. Extension of the GIS work by integrating existing GIS data-bases and photographic data is required. The GIS research should be integrated with the development of GIS staff training and education programmes to increase the GIS capacity within Western Samoa.

9. References

The references are divided into two sections. The first section lists references cited in the report. The second section lists references used as background literature.

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Appendix 1 Western Samoan Acts of Parliament Relevant to Coastal Management

The Acts of Parliament with relevance for coastal management in Western Samoa are listed in approximately descending order of importance.

I The **Lands, Surveys and Environment Act (1989)** contains a suite of legislation covering natural resource protection, environmental management and pollution controls. In particular, Division 5 of Part VIII specifies controls on all development on foreshores and the sea-bed;

II The **Village Fono Act (1990)** gives the weight of law to the decisions of village Council of Chiefs and Orators (Fono) which affect village land and village members by recognising the village Fono's decisions in court;

III The **Taking of Lands Act (1964)** allows government to take or exchange any type of lands for public purposes. Thus government has the power to take customary or private land for the mitigation of external and internal stresses, including sea-level rise;

IV The **Water Act (1965)** prohibits cultivation within 60 metres of streams and provides also for the withdrawal of land for soil and water protection purposes;

V The **National Parks and Reserves Act (1967)** provides for the setting aside of government land (including the sea-bed) for conservation and protection;

VI The **Forest Act (1967)** provides for declaring protected areas and controls logging;

VII The **Water Resources Act (1985)** provides for planning, implementation of water resources development, pollution control, conservation and protection of watersheds;

VIII The **Exclusive Economic Zone Act (1977)** prohibits foreign craft from fishing in the Western Samoa Exclusive Economic Zone unless they have been issued with a licence under the Act;

IX The **Fish Dynamiting Act (1972)** which prohibits dynamiting of fish; and

X The **Police Offences Act (1964)** which provides for the prosecution of beach sand miners.

Appendix 2 National Environment and Development Management Strategies (NEMS) Critical Environmental Issues

The National Environment and Development Management Strategies (NEMS) (Government of Western Samoa 1993) identified twelve critical environmental issues, or Target Environmental Components (TECs) facing Western Samoa.

"The twelve TECs aim to reduce sectoral interests, and increase cooperation between agencies. In this way it recognises the complex and interactive nature of environmental issues and problems" (Government of Western Samoa 1993 - Executive Summary).

The twelve TECs are:

I Management of population dynamics and change;
II Protection of the quality and supply of fresh water;
III Protection of the sea and marine resources;
IV Management of waste;
V Combating deforestation;
VI Development of appropriate land use practices;
VII Conservation of biological diversity;
VIII Protection of the atmosphere;
IX Planning for climate change;
X Preservation of traditional arts, culture, and history;
XI Development of human resources; and
XII Promoting sustainable economic growth.

Appendix 3 Equation for Calculating the Minimum Weight of Rubble for a Sloping Seawall Revetment

The weight of rubble or concrete blocks covering the slope surface of a structure receiving the action of a wave force may be calculated by the formula:

$$W = \frac{g_r . H^3}{K_D (Sr - 1)^3 \cot a}$$

where:

- W: Minimum weight of rubbles or concrete blocks (tonne force)
- g_r: Unit weight of rubble or block in air (tonne force/m^3)
- Sr: Specific gravity of rubble or block to sea water
- a: Angle of the slope to horizontal plane (degrees)
- H: Wave height (m)
- K_D: Constant determined by the armouring material and damage rate

Appendix 4 Data Coverages Within the Land Resource Planning Study of Western Samoa

The data base was complied by ANZDEC Ltd and the New Zealand Department of Industrial and Scientific Research on behalf of the Government of Western Samoa, and funded by the Asian Development Bank (ANZDEC 1990). The data-base covers 'Upolu and Savai'i islands.

Data is contained in three separate polygon coverages for each island; vegetation, land tenure and soil. There is also a base cartographic data-base which contains contours, roads, place names, rivers and the coastline. The three coverages, and the layers within each coverage are listed below.

Vegetation

Layer ID	Layer description
1	Coconut
2	Cocoa
3	Banana
4	Coffee
5	Indigenous forest
6	Production forest
7	Livestock
8	Coconut with livestock
9	Coconut with cocoa
10	Coconut with other tree crop (e.g. coffee)
11	Swamp
12	Other land use (e.g. lava fields, community areas etc.)

Land tenure

Layer ID	Layer description
1	Government land
2	Freehold land
3	Forestry blocks on government land
4	Forestry blocks on leased customary land
5	Western Samoa Trust Estates Corporation (WSTEC)
6	Customary land
7	Apia land district

Soil

The number of layers for soil is much larger than the above lists, and so the same listing approach cannot be used. In the soil coverage each polygon (discretely defined area in the GIS) has a unique identifier (ID). The attributes of the ID for each polygon are as follows:

Attribute description
Complete soil label
Primary soil label
Soil drainage
Moisture deficit (3 classes)
Erosion hazard (4 classes)
Nutrient status (3 classes)
Surface rock outcrops (4 classes)
Potential rooting volume (5 classes)
Salt spray/salinity (4 classes)
Slope class (8 classes)
Surface stoniness (4 classes)
Soil pH (7 classes)
Soil texture class (10 classes)
Soil capability class
Primary soil class (1-197)

Appendix 5 Information Mapped on the 1:25,000 Scale 'Upolu Coastal Morphology Maps

The 'Upolu coastal morphology mapping project was undertaken by the South Pacific Geoscience Commission (SOPAC) (Richmond 1991). These 1:25,000 scale maps include information on shoreline features, coastal plain geology and reef features. A detailed list of the components of the maps is given below.

Shoreline features

Manmade structures
Rock outcrops
Unconsolidated sediment
Inferred direction of longshore transport

Coastal plain geology

Tafagamanu Sand (Holocene)
Alluvium (may contain swamp deposits and Tafagamanu Sand)
Reclaimed areas
Coastal cliff
Mangrove and/or swamp

Reef features

Coral / Algal / Pavement
Sediment covered
Marine flora
Reef slopes / Blue holes
Reef flat lineations