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Coastal Protection

BEST PRACTICES IN THE PACIFIC

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Cover Photos

(Top): A view of natural mangroves taken from Navulivatu, Fiji. (Bottom Left): Natural coral taken at Funafuti, Tuvalu. (Middle): Concrete slope wall, Solomon Islands. (Bottom Right): Concrete walls in front of Thurston Garden, Suva.

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BEST PRACTICES IN THE PACIFIC

Acknowledgement

On behalf of PaCE-SD, we would like to acknowledge the leadership and vision of the PaCE-SD Director and Professor in Climate Change, Elisabeth Holland for initiating the 'fantasy dream' of creating best practice reports on coastal zone engineering. The publication of Coastal Protection: Best Practices from the Pacific report is the first in a series of similar reports to follow.

It is equally important to mention the supporting role played by the United States Agency for International Development (USAID) with their funding support.

Thank you also to those who have contributed by sharing their experiences over the Pacific Solution Exchange (PSE) network. (Featured in Chapter5).

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Last but not least, the PaCE-SD core Task Force who worked really hard to produce this report are acknowledged with admiration and appreciation. They are Prof Elisabeth Holland, Stephen Smith, Sarah Hemstock, Morgan Wairiu, Viliamu Iese, Hélène Jacot Des Combes, Antoine De Ramon N'Yeurt, Aliti Koroi, Priya Sharma, Ashmita Devi, Luke Paeniu, Nicholas Hobgood, Isoa Korovulavula and Teddy Fong.

Acronyms

C-CAP	Coastal Community Adaptation Project
CTI	Coral Triangle Initiative
EIA	Environmental Impact Assessment
ENSO	El Niño and Southern Oscillation
ESD	Ecologically Sustainable Development
ESCAP	Economic and Social Commission for Asia and the Pacific
FSM	Federated States of Micronesia
GIZ	Deutsche Gesellschaft fur Internationale Zusammenarbeit
ICZM	Integrated Coastal Zone Management
IPCC	Inter-governmental Panel of Climate Change
JICA	Japan International Cooperation Agency
LMMA	Locally Managed Marine Area
MMA	Marine Managed Area
MPA	Marine Protected Area
PACC	Pacific Adaptation to Climate Change
PaCE-SD	Pacific Centre for Environment and Sustainable Development
PIPA	Phoenix Island Protected Area
PNG	Papua New Guinea
PSE	Pacific Solution Exchange
SOPAC	South Pacific Islands Applied Geoscience Commission
SPC	Secretariat of the Pacific Community
UK-SPEC	United Kingdom- Standard for Professional Engineering Competence
UNDP	United Nations Development Programme
USP	The University of the South Pacific
4AR	Fourth Assessment Report (IPCC)

Note from the Director

I am pleased to present another shining milestone of PaCE-SD's continuous efforts in striving for excellence. This Best Practice publication is a unique collaborative undertaking. The report provides a foundation to guide coastal managers, coastal planners, coastal engineers, decision makers and disaster managers throughout the Pacific in their efforts to find solutions. The goal is to devise 'no regret' strategies using effective interventions to protect the Pacific coasts, ecosystems and basic vital infrastructure.

The document is not intended to provide easy answers with the right coastal protection interventions for every location. Every location has its own unique challenges and problems. Solutions are co-learning opportunities and should be generated locally and designed with local input with all possible options. This document is only a guide to the options.

I want to express my appreciation to those who willingly shared their expertise and experiences via the Pacific Solutions Exchange (PSE) network. The report is a truly collaborative product working across projects and the Pacific Islands to generate effective options for the 15 Pacific Island countries we serve

It is interesting to note that the experiences shared in this document were a combination of those shared in the PSE network and those primarily collected from over 70 Pacific literatures. The Pacific Islands region has rich sources of constructive and vital knowledge on how to protect the coast, and our Pacific based solutions are something to be proud of. We have tried to bring if not all but most of these experiences in one single document for ease of reference.

It is my intention, that this document could become a living document that would be referred to and revised when the need arises.

I commend the core Task Force of PaCE-SD for the hard work and dedication in producing this important document. Thank you awesome shining stars.

Professor Elisabeth Holland
Director, Pacific Centre of Environment
and Sustainable Development (PaCE-SD).

Executive Summary

Pacific coasts are constantly changing as a result of natural processes such as tides, strong currents, rain, storm surges, strong wind, cyclones and sea level rise. With increasing human activities within the coastal areas in terms of human settlement, land use changes, flow of solid and liquid waste and coastal developments such as beach ramps, jetties, causeways, coastal protection structures, reef mining and extractions of sand and beach aggregates, there is ever increasing change along Pacific coasts. In addition, climate change and climate variability and extreme weather events have exacerbated the rate of change of Pacific coasts.

The coast has been defined as the zone where the land and sea meet. The main features of Pacific coasts are dominated by coral reefs, reef ridges, inter-tidal ridges, beaches, cliffs, wave actions and mangroves. Pacific coasts are designated important areas for providing vital Pacific livelihood. The coastal ecosystems, human settlement and other major supporting services and basic infrastructure are centred on the coastal zone. Coasts are being used for many reasons. The underlying problem is that Pacific coasts are in a state of crisis. A number of human engineering interventions over the past decade have contributed and accelerated the coastal erosion problem in the Pacific region. The Pacific coastline is over 50,532 km long. Both natural processes and human engineering work are blamed for causing coastal erosion. This guide has been produced to inform and assist coastal experts, managers, and Pacific communities understand the various measures they can take to reduce coastal erosion.

Coastal protection interventions in the Pacific basically fall into two categories: non-structural adaptation and structural adaptation approaches. The best practices on coastal protection that are viewed as non-structural were identified as:

- Knowledge of coastal processes
- Policy on working alongside with nature and not against it
- Retreat, accommodate and protect approach
- Environmental Impact Assessment framework
- Foreshore regulation
- Locally Managed Marine Areas, Marine Protected Areas and Conservation Areas
- National Biodiversity Strategy and Action Plan
- Integrated Coastal Zone Management approach
- Adopt 'ridge to reef' approach
- Established engineering standard framework
- Active Building Code

Interventions that were classified as structural fall into two parts: The soft measures and the hard measures. The soft measure approaches identified included:

- Maintaining a healthy reef islands and islets
- Protection and restoration of sea grass and algal ecosystems
- Maintaining healthy fringing and barrier coral reefs
- Planting Mangroves
- Planting coastal vegetation (littoral plants)
- Stabilizing Coastal beaches
- Beach nourishment

The hard measure approaches were:

- Seawalls
- Groynes
- Revetments
- Gabions
- Breakwaters
- Geotextile Containers

Selected examples of current coastal protection interventions are presented in pictorial forms. These included examples from the Cook Islands, the Federated States of Micronesia, Fiji, Guam, Kiribati, Nauru, Niue, the Northern Marianas, Samoa, the Republic of Marshall Islands, Palau, Papua New Guinea, Tonga, Tuvalu, the Solomon Islands, Vanuatu, and Timor Leste. Some examples of unsuccessful interventions were also captured.

The report is intended as a general guide to coastal protection practices in the Pacific region. The options presented in this guide should be examined carefully by qualified engineers prior to selection and implementation.

The report ended with excellent experiences shared through the PSE network and some important case studies.

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CHAPTER 1: INTRODUCTION

by Luke Paeniu, Dr Hélène Jacot Des Combe, Ashmita Devi and Priya Sharma

1.1 Definition: What do we mean by Coast?

Coast is a broad term that can be defined by: “the part of the land adjoining or near the sea” (Oxford online dictionary).

In this report, we will use the term Pacific Coast which in this context means the zone where the ocean and land interact. This zone is the area impacted by marine factors such as waves, wind, salt sprays, and saltwater intrusion. This zone is exposed to sea level rise, extreme weather events (storm and cyclones) and tidal events, coastal development and marine pollution. For some atoll countries, almost the entire islands and associated islets may be defined as coastal area. The distinction between Pacific coasts as compared to coasts in most developed countries lies in their characteristics. In the Pacific region, coastal physical features include:

- “Coral reefs [1] which are a common and often dominant feature
- Wave conditions which vary significantly in time and location throughout the region
- Water levels and currents in the coastal zone which are strongly modified by fringing reefs
- Natural beach material which is commonly and often dominantly supplied from carbonate sources
- ...Mangroves, where they occur, are a prominent and important feature of the coast.”[2]

1.2 Why are Coasts Important?

The Pacific region’s coasts are well known for the aesthetic beauty of their pristine sandy beaches; crystal clear waters, naturally formed rocks and limestone and they are blessed with colorful coral reefs.[3] They are rich with diverse coastal habitats and ecosystems.

---

[1] Bryne (1994)

[2] SOPAC (1994)

[3] ibid

However, Pacific coasts are also providing room for human settlements: houses and vital basic infrastructure and assets such as roads, power stations, wharves, hospitals, schools etc., are located within the coastal areas.[4] It is estimated that the population of Pacific Islands which numbered around 8.6 million in 2000 is currently closed to 10 million (SPC, 2013) and that "more than 80 % of Pacific Islanders live in or near coastal areas".[5] In fact, *"almost 100 % of Pacific islanders (excluding those in Papua New Guinea) live within 100 kilometers of the coast."* [6]

These human activities and the coastal ecosystems provide the support for Pacific livelihoods, either through traditional activities such as fishing or more modern type of employment in industry and services.

> *"These fragile ecosystems not only support the fisheries and agriculture that the people of the [Pacific] region depend on for food and income, they also provide shoreline protection, places for recreation, [shared] cultural heritage, and many other benefits all of which are at risk from climate change and local stress caused by human activities."* [7]
>
> *"The shallow ecosystems and productivity of mangroves, seagrass beds, coral reefs and inter-reef seabed are critical natural assets for food production, food security, cultural and recreational activities and livelihoods for many people in Pacific Island States. They also provide important ecosystem services in protection of coasts against storm surges and in production of carbonate sands and debris to nourish beaches and maintain islands. These ecosystems are easily damaged through reclamation, drainage, pollution and destruction of critical habitats for fish and other food species. Once destroyed, these ecosystems are not readily or cheaply restored or replaced."* [8]
>
> *"The vital commercial and national assets, essential infrastructure, and populations of most Pacific Island Countries lie in the coastal zone."* [9]

However, the development of human activities around the coastal areas is blamed for degrading coasts of the Pacific region.

[4] SOPAC (1994)
[5] Howarth (2010)
[6] Ram Bidesi et al. (2011)
[7] Keener et al. (2012)
[8] Kenchington (2009) p.1
[9] SOPAC (1994)

"Given that most of the region's population is settled in coastal areas, changes in population density combined with new technology and changing development priorities have had a significant impact on coastal environments in the last decade" [10]

Pacific coasts, and most specifically coastal ecosystems such as mangrove forests and coral reefs also provide protection for the land by acting as first natural lines of defense.

To summarize, people are motivated to live on the coast for a number of reasons. Coasts offer *"fertile lowland, abundant marine resources, water transportation, aesthetic beauty, and intrinsic values".* [11] The coast is the centre of major activities that include "commercial, recreational, and subsistence fisheries; ports and industrial facilities that rely on shipping facilities; and tourism, agriculture and forestry…" [12]

However, over the years, this natural beauty and ecosystem integrity has slowly eroded as coasts have been changed, modified, degraded and re-shaped. Both natural processes and human intervention are involved in the changes of the Pacific Coasts.

The importance of the coasts can be reflected in the way humans use the coast. Here are some of current uses of PICTs shorefront that were recorded in Maharaj (2000):

- Mariculture (pearl and shellfish) e.g. in the Cook Islands,
- Subsistence reef fishing, e.g. in all PICTs,
- Fill sites, e.g. in mangroves systems throughout the PICTs,
- Liquid waste (effluent) disposal, e.g. in industrial areas such as Lami, Fiji Islands,
- Maritime and land defense, e.g. Fiji Navy, FSM Patrol in Kolonia, Pohnpei,
- Recreation and tourism development, e.g. tourist resorts like Sheraton's Denarau Island Resort in the Fiji Islands,
- Land reclamation, fill and housing development, e.g. in parts of almost all mangrove areas throughout the PICTs such as in Kosrae and Yap States, FSM,
- Construction of cooling water inlets and outlets e.g. Nauru Power Facility, Nauru,
- Construction of sewage outfalls/outlets, e. g. on the west coast of Nauru,
- Construction of tidal inlets and river-mouth engineering works, e.g. Rewa River, Fiji Islands,
- Construction of coastal protection structures like sea walls, groynes, revetments, breakwaters, gabion baskets and bioengineering protection, e.g. generally common throughout the PICTs,
- Construction of promenades and infrastructure facilities, e.g. coastal roads in Nauru, FSM, Fiji, Kiribati, New Caledonia, Cook Islands and Solomon Islands,
- Construction of jetties, boat channels and mooring facilities, e. g. Honiara, Solomon Islands and Port Vila, Vanuatu,
- Construction of industrial and recreational ports and harbors (commercial ports and yacht clubs),e.g. Suva Yacht Club, Fiji Islands,
- Construction and laying of undersea telecommunication cables, e.g. Cable and Wireless undersea fiber optic telecommunication cables, Laucala Bay, Fiji Islands,
- Construction and laying of pipelines for fluid transfer (oil and gas, water, industrial products and waste), e.g. Vuda Point, Fiji Islands and Kolonia, FSM,

[10] Howarth (2010) p.9
[11] Gilbert and Vellinga (1990)
[12] ibid

- Construction of residential and commercial buildings, e.g. throughout the PICTs,
- Marine aggregate extraction (sand, gravel, boulders and coral-mining), e.g. throughout the PICTs,
- On land quarry operations, e.g. Vanuatu, Fiji Islands and FSM,
- Metalliferous mining and hydrocarbon exploration and production, e.g. Papua New Guinea,
- Agriculture and forestry, including timber and coconut production, e.g. and Fiji Islands and the Solomon Islands
- Protection and natural resource conservation (marine parks and protected areas), e.g. in New Caledonia and French Polynesia

1.3 The Problem: What's wrong with Pacific Coasts?

1.3.1: The issue

Looking at the global scenario, the world's coasts are in crisis because of the increasing human population living in coastal areas (Hinrichsen 1995). The author also argued that the coasts are *"over-developed, over-crowded and over-exploited."* [13] In the Pacific region, coasts are definitely in a state of crisis as well. The Pacific region is made up of 23 nations [14]: American Samoa, Cook Islands, Fiji, The Federated States of Micronesia, Guam, Kiribati, The Marshall Islands, New Caledonia, Niue, The Northern Mariana Islands, Nauru, Pitcairn, Palau, French Polynesia, Papua New Guinea, Samoa, The Solomon Islands, Timor Leste Tokelau, Tonga, Tuvalu, Vanuatu and Wallis and Futuna, that are scattered over a vast Pacific Ocean of some 30 million km^2 (Figure 1). [15]

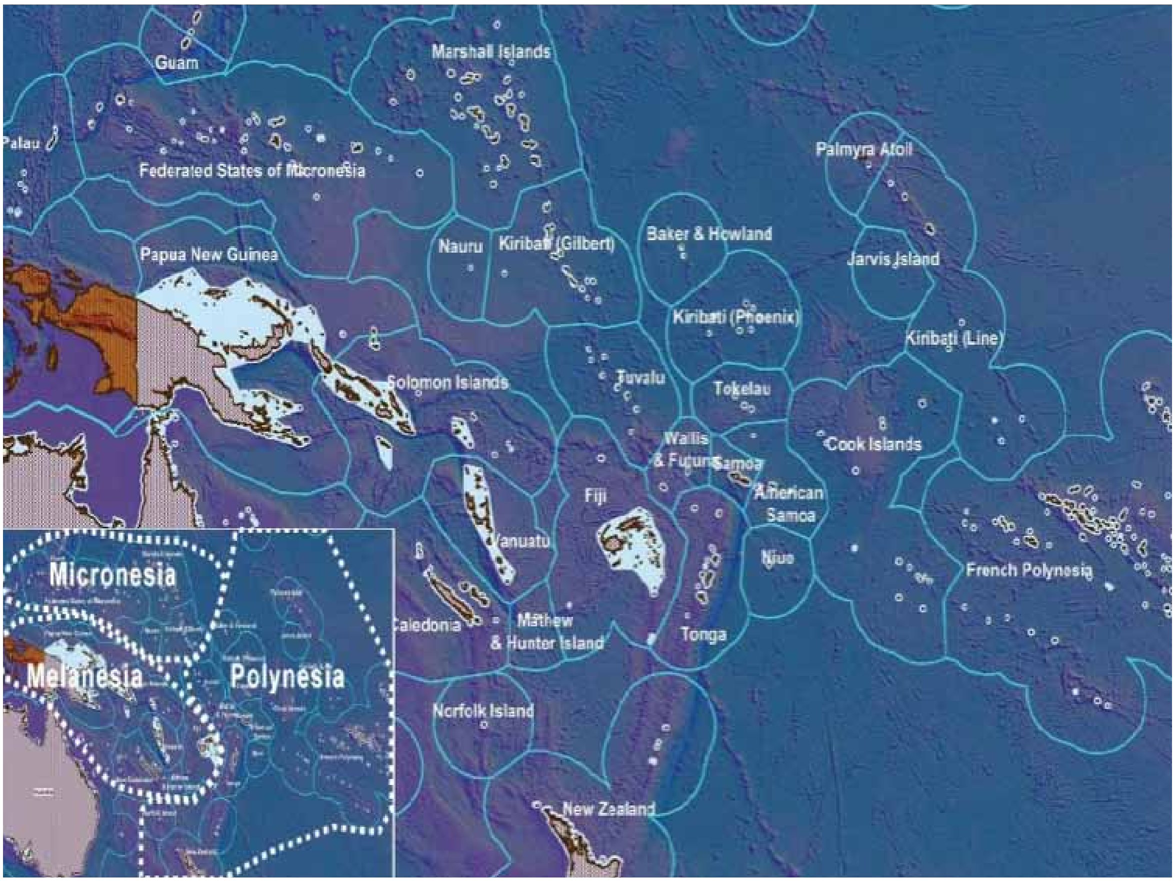

Figure 1 Map of the Pacific region. Adapted from Govan (2009) p.13.

[13] Hinrichsen (1995)

[14] SPC (2013)

[15] Haberkorn (2008)

Table 1: Marine Areas, Reef Areas and Coastlines in PICTs (Modified from Govan at al 2009 SPREP)

PICTs	Marine Area (km^2)	Reef Area (km^2)	Reef at Risk (%)	Coastline (km)
American Samoa	390,000	67	42	116
Cook Islands	1,830,000	212	57	120
Fiji	1,217,000	10,020	68	1,129
FSM	2,980,000	3,172	45	6,112
Guam	218,000	183	100	126
Kiribati	3,800,000	1,967	48	1,143
RMI	2,131,000	1,995	3	370
New Caledonia	1,740,000	4,573	13	2,254
Niue	390,000	15	43	64
Northern Mariana Islands	1,823,000	102	0	1,482
Nauru	436,000	10	100	30
Pitcairn Island	800,000	39	0	51
Palau	601,000	709	0	1,519
PNG	2,366,000	13,840	46	20,197
French Polynesia	5,030,000	3,000	29	2,525
Samoa	120,000	200	95	403
Solomon Islands	1,630,000	5,750	46	9,880
Tokelau	290,000	97	0	101
Tonga	700,000	3,587	46	419
Tuvalu	757,000	872	15	24
Vanuatu	680,000	708	70	2,528
Wallis and Futuna	300,000	425	26	129
Timor Leste	n/a	35	n/a	735

Table 1 above shows some interesting statistics. Papua New Guinea has a huge coastline of 20, 197 km followed by Solomon Islands with 9, 880 km and FSM with 6, 112 km. Tuvalu has the smallest coastline of only 24 km followed by Nauru with 30 km. In terms of marine areas, French Polynesia has the biggest area with 5 million km^2 while Kiribati has 3.8 million km^2 and FSM with 2.98 million km^2. Countries with reefs at high risk are Nauru and Guam followed by Samoa and Vanuatu.

These 23 nations were home to a population of 8.6 million in 2000 [16] and this population increases regularly. It is estimated that the current population of the Pacific is more than 10 million and projections for 2035 will increase this to 15 million people. [17] Out of the 8 million people in 2000, PNG has a share of 70%. Melanesian's countries had the highest share of the population of 88%, compared with Polynesian islands with 7% while Micronesian's nations had 5%. [18]

Major infrastructures that are important in supporting basic services for Pacific populations are also located within the coastal areas. [19] Therefore, the escalating Pacific population not only puts extreme pressures on resources within the Pacific coasts; human activities such as coastal engineering work on the coasts (building wharves, sea walls, beach ramps and revetments) all play a major role in the changing nature of the Pacific coasts. [20]

> The *"introduction of hard-engineered structures has exacerbated island erosion and degraded ecological process."* [21]

[16] SPC (2013)

[17] ibid

[18] ibid

[19] SOPAC (1994)

[20] Ocean Policy Research Foundation (2009)

[21] Kench (2009) p.22

1.3.2: The Causes

Gillie (1997) stated that Pacific coasts are subject to continual change. Both natural processes and human activities contribute to severe beach erosions in the Pacific. [22] The shape of the coastline depends on the balance between material deposit and removal. Natural processes such as waves, water currents and extreme events such as cyclones are the main factors affecting the coast.

> *"Coastal processes are hydraulic and sedimentary process driven by tides, currents, waves, coastal winds and tsunamis. Forces exerted by wind and water act on the ocean floor and shore face to drive currents, move sediments, erode exposed bedrock and shape the coastline, estuaries and the nearshore seabed."* [23]

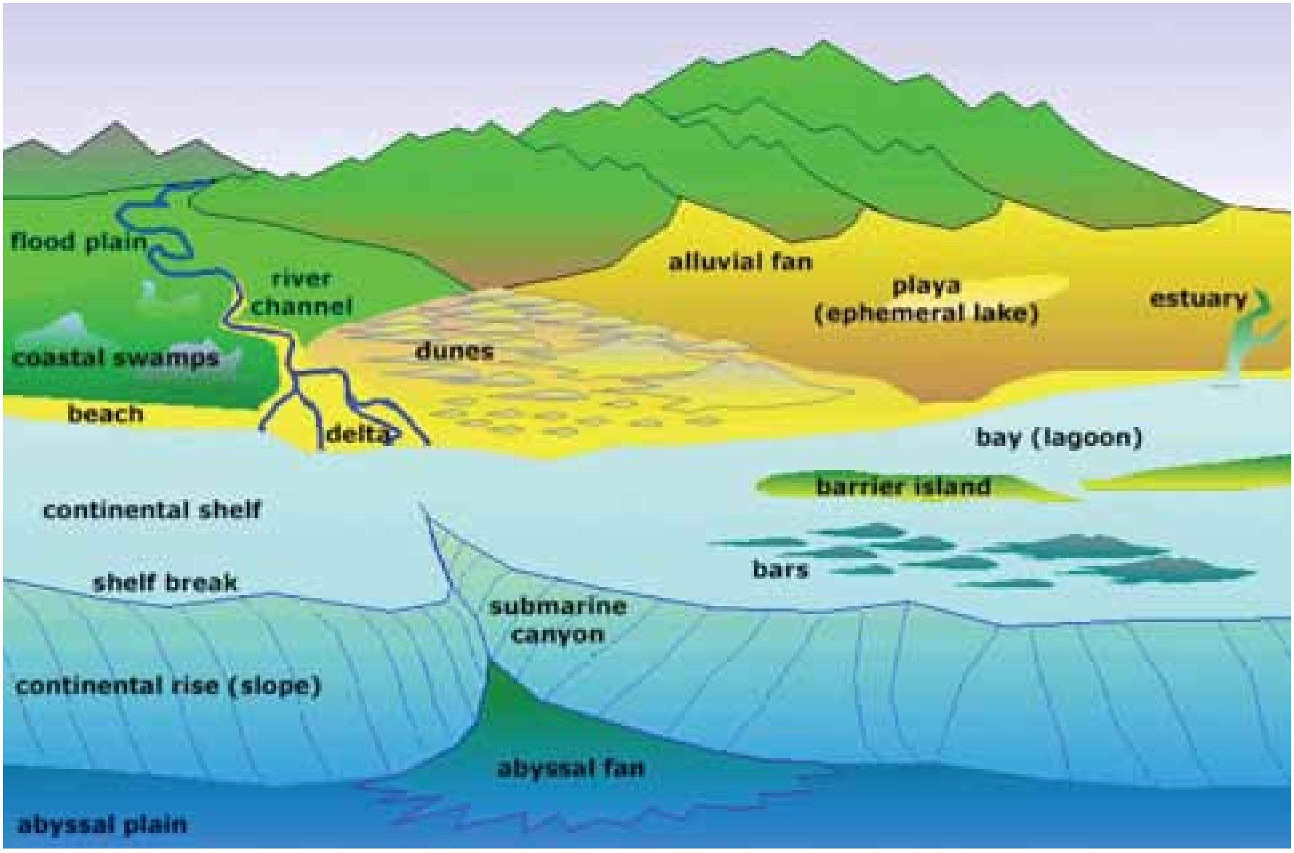

Figure 2: The depositional environments (GeologyCafe, 2012)

The materials that are transported get deposited to a particular location, during the deposition process. Deposition can include sand, sediment and shingle. There are four main deposition environments: beaches (deposition of sand, singles etc. between the high tide and low tide mark), spits (long-term deposition that forms long narrow ridge from the coast line), bars (grow like spits but join to headlands) and tombolos (spit grows outward joining offshore island and land) (Gore, 2010).

[22] Gillie (1997)

[23] Cummings et al. (2012) p.9

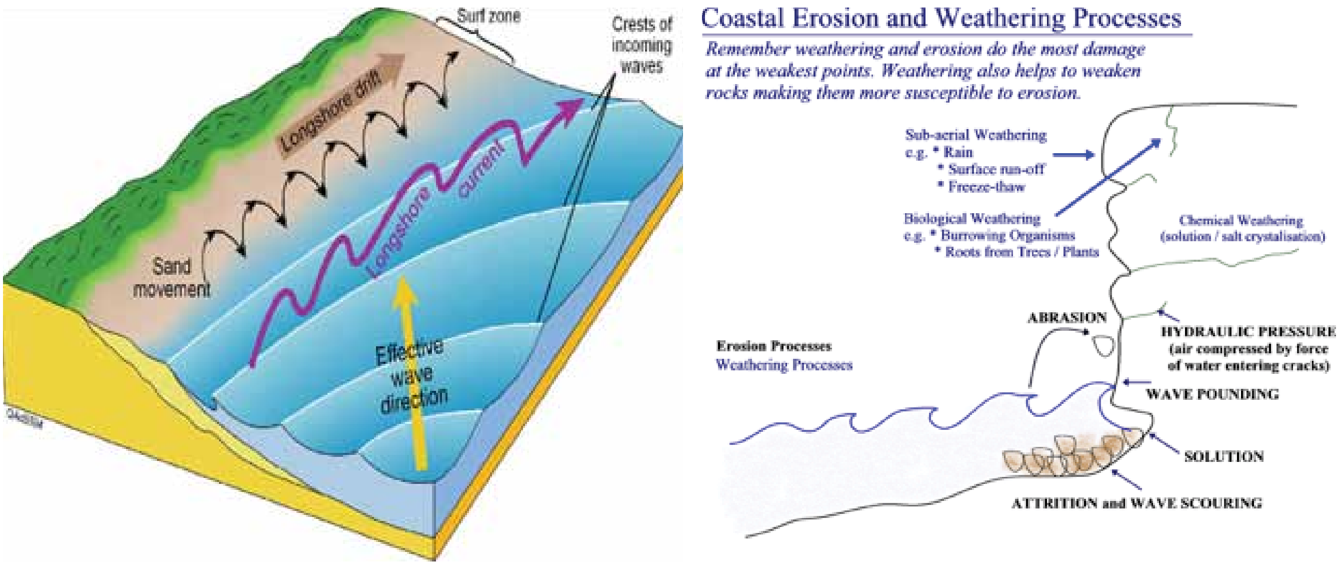

Figure 3: Longshore drift current (RegionWorld, 2007) and causes of erosion on cliffs (Geographypods. 2012)

The sea is constantly modifying the shape of the Pacific coastline. This is happening due to wave actions in eroding, transporting and depositing materials. When waves approach from the deep ocean they move in circular forms known as swells. As they approach shallow water, waves become steeper and eventually collapse creating a swash (the white foam that reaches the beach). The return wave is known as the backwash. On beaches, when wash is strong, it brings material that feeds the beach, while this material can cause erosion at the base of cliffs (Figure 3). Strong backwash will remove material from the beaches and cause coastal erosion.

A longshore drift occurs when waves enter towards the coastal zone at an angle. The swash waves moves up the beach, carrying the material up and along the beach. On the other hand, the backwash carries materials back down the beach at right angles. This process causes a slow movement of the material along the beach. Longshore drift links the erosion and deposition processes by causing erosion of materials at one place, which is then transported and deposited at another location (RegionWorld, 2007).

Any change in coastal ecosystem such as mangrove forest destruction, or building of structure on the coast will affect these natural processes and may lead to more rapid erosion

> *"Shoreline alterations, mangrove and coral harvesting, dredge and fill activities, sand and gravel extraction and disposal of waste in the marine environment all result in changes to the natural character of the coast."* [24]

Coastal erosion and change in shoreline can be observed on many islands in the region.

[24] Gilbert and Vellinga (1990)

Figure 4: Examples of coastal erosion in the Pacific Island countries. a) Fiji: severe coastal damage at Laucala Beach Estate, Suva following cyclone Mick in December 2009; b) Palau: eroded coastline in Koror State; c) Kiribati: unprotected coast at Ewena Village, Abaiang Island; d) Tonga: beach erosion exacerbated by construction of jetty at Ha'afeva, Ha'apai

1.3.3 Some Examples of Coastal Protection

Because of serious concerns of the changing nature of Pacific coasts, the Pacific region was under extreme pressure to look for quick easy fixes to the degrading coast, and became the hub of what is believed to be a testing ground of hard engineering structures. Pacific nations deliberately take on board some of the soft and hard engineering structures with the primary aim to protect the adverse effect of eroded coastlines and to maintain its original natural beauty.

Chapter 4 contains many illustrations of the types of coastal protection practices used in Pacific Countries.

There were 'failure' and 'success' stories of these engineering interventions in the region in which constructive lessons and best practices measures have surfaced. Gillie (1997) argued that coastal geology and coastal engineering in the Pacific are site specific because of the large scale geographical variations in natural processes and responses. This was confirmed by the information collected through the PSE network, confirming that coastal protection intervention is not a 'one size fits all' strategy that may be applied across Pacific communities.

In addition to present natural processes and human interventions, climate change, sea level rise and extreme weather events exacerbate the degrading coasts. The projections concerning low-lying coasts presented in the Inter-governmental panel of scientific scientists on climate change (IPCC) AR4 are equally of concern to the Pacific region:

1. *"Coasts are experiencing the adverse consequences of hazards related to climate and sea level (very high confidence)."*
2. *"Coasts will be exposed to increasing risks, including coastal erosion, over coming decades due to climate change and sea-level rise (very high confidence)."*
3. *"The impact of climate change on coasts is exacerbated by increasing human-induced pressure (very high confidence)."*
4. *"Adaptation for the coasts of developing countries will be more challenging than for coasts of developed countries, due to constraints on adaptive capacity (high confidence)."* [25]

In terms of Natural hazards, the Pacific region ranks among the most vulnerable in the world. [26] In terms of changes to coastlines, the most damaging hazards are tropical cyclones, floods, storm surges and tsunami [27]. Unfortunately, these hazards are quite frequent in the region, with several tropical cyclones (e.g. TC Evan in Samoa and Fiji in 2012 and TC Ian in Tonga in 2014) and tsunamis (Samoa and Tonga 2009, Solomon Islands 2007 and 2013). Floods change the coastline by depositing more material on the coast but also by damaging coastal ecosystems and structures (e.g. floods in Nadi and Ba, 2011 and 2013).

1.4 The Purpose: What is this report for?

We have described the importance of Pacific coasts and the problems they are facing in the previous sections. The purpose of this document is to provide genuine information and guidance on Best Practices that may be used by Pacific Communities to improve their resilience to the impact of climate change, sea level rise and extreme weather events with reference to coastal adaptation protections measures.

Best practices in this context refers to a process or intervention that has stood the test of time and has been proven to work over long periods. Some of the criteria used include being an effective, successful and sustainable intervention, it has to be environmental friendly, technically feasible, economically affordable and involve the key stakeholders- (FAO Good Practices).

This guide has been produced to help coastal experts, managers, and Pacific communities understand the various measures they can take to reduce coastal erosion. The guide has been made to be user-friendly and was based on long term experiences of Pacific Countries. It is intended for Pacific communities, local authorities, national governments, donors, coastal engineers, coastal managers, non-government organizations, and stakeholders involved in planning, and designing, implementing coastal protection interventions. It is primarily designed as a reference for coastal practitioners involved in designing coastal protection interventions in the Pacific. The guidelines provided are broad, generic and non-prescriptive.

[25] Nicholls, et al. (2007) chapter 6

[26] Bettencourt et al. (2006)

[27] Ibid

The rationales behind the conception of this guide are many fold:

- Pacific coasts are in crisis
- There is an urgent and increasing need for Pacific communities to adopt quick fix solutions to their degraded coastal ecosystems
- Many of the current coastal protection interventions are ineffective
- Coastal erosion and degraded coastal ecosystems are contributing to an alarming increase in the frequency of coastal hazards
- Pacific coasts are a source of food and livelihood security
- The vital basic infrastructures, assets and coastal populations in Pacific countries are at great risk and future projections are quite alarming.
- Population growth, extreme weather events, climate change and climate variability are exacerbating the risk of coastal erosion and degraded coastal ecosystems in the Pacific.
- Endangered coastal assets will render impossible efforts by Pacific countries to meet their MDGs goals, in particular those related to poverty alleviation.

1.5 The structure of the report

The structure of this report is designed in a way that it will help guide Pacific communities, coastal engineers and managers to plan future coastal protection interventions. The report includes:

Chapter 1 - Brief explanation of why Pacific coasts are important, the problems facing Pacific coasts, the purpose of the report, structure and methodology;

Chapter 2 - It provides best practices on non-structural engineering structural options;

Chapter 3 - Structural engineering options (soft and hard measures);

Chapter 4 - Update on selected examples of current structural coastal interventions in the Pacific; and

Chapter 5 - Selected examples of Pacific experiences in coastal protections. Most of the information gathered through the PSE network is shared in this chapter.

1.6 Methodology

The principal aim of this research is to consolidate as many best practices from around the Pacific, as possible, on effective coastal engineering interventions for protecting the Pacific coast. The research begins with a query posted through the climate change experts' network - the Pacific Solution Exchange. The two main queries that were made were:

- Share experiences (good practices and lessons learnt) on coastal protection measures and suggest some solutions to the problem
- Provide examples (tool kits, technologies etc.) for designing and implementing coastal protection measures.

The next approach was to conduct a literature review of coastal engineering work in the Pacific. In- Country Coordinators (ICCs) from 15 Pacific islands countries were tasked to update parts of Chapter 4 in this report. PaCE-SD has been instrumental in establishing a review committee to produce this report.

CHAPTER 2: NON STRUCTURAL INTERVENTIONS

by Luke Paeniu, Viliamu Iese and Priya Sharma

2.1 Non-structural Options:

Many interventions on developing coastal protection methods in the Pacific region provide lessons from both good and bad experiences in the field. Some of the adaptation approaches that have been introduced in the Pacific fall into two separate categories: Non-structural options; and structural options. Non-structural options are interventions that are extremely useful and are required in protecting the coastline from both human induced and natural shocks. These are instruments to safeguard the natural coastline zones and promote the resilience and offer protection of coastline systems. Furthermore, they are also important pre-requisites (planning and management processes) put in place to guide and ensure human interventions to safeguard the coastline systems are carried out in a more efficient, effective and sustainable way. It also encourages the change in individual behavior and attitude.

2.1.1 Understanding the way coastal processes work

Pacific communities must first attempt to, as a pre-requisite, obtain information on coastal processes and try and understand how they work before developing the idea of applying structural options to protect the coast. Collating this basic information is vital, as it will help contribute towards designing a better adaptation approach to coastal protection for the community. Some of these processes are highlighted below:

Coastal environments are influenced by astronomical processes (effects of gravitational forces), meteorological processes (interaction of storms, rainfall and climate change), tectonic movements; hydrological processes (interactions of waves and currents and water levels), sediment processes (waves and currents and transport sediments) and social processes (anthropogenic influences).

"Coastal processes are hydraulic and sedimentary process driven by tides, currents, waves, coastal winds and tsunamis. Forces exerted by wind and water act on the ocean floor and shore face to drive currents, move sediments, erode exposed bedrock and shape the coastline, estuaries and the near shore seabed." [28]

It would be ideal to understand that there is a physical process that involves wind, waves, tide temperature and sea level rise. There is also a biological process which involves coral and marine species. Coastal processes help break sediments and transport it along the shoreline.

There are three main processes that alter and support the formation of the coastal zone: erosion, transportation and deposition (Summerfield, 1991) that are discussed in detail in this section. Erosion is a process of geological features being gradually worn away. It is usually caused by the action of winds and the currents on the rocks and sediments. Deposition is the accumulation of sediment on the seafloor, lakes and rivers (or of solid particles from the atmosphere onto the land or ocean surface) (Segar, 2007). Transportation is the work of waves and tides in transferring the broken materials on the beach somewhere else (NSIDC, 2008).

Formation of coasts

Most of the coasts are classified as either erosional or depositional coasts depending on their formation factor being either from erosion or deposition of sediments. Erosional coasts develop where the shore is actively eroded by wave action or where rivers or glaciers caused erosion when sea level was lower than it is now. Depositional coasts develop where sediments accumulate either from a local source or after being transported to the area in the rivers and glaciers or by ocean currents and waves (Segar, 2007). Volcanic eruptions and earthquakes can cause instant formation of coasts. However, sea level change and coral reef growth cause slow coast formation.

[28] Cummings et al. (2012)

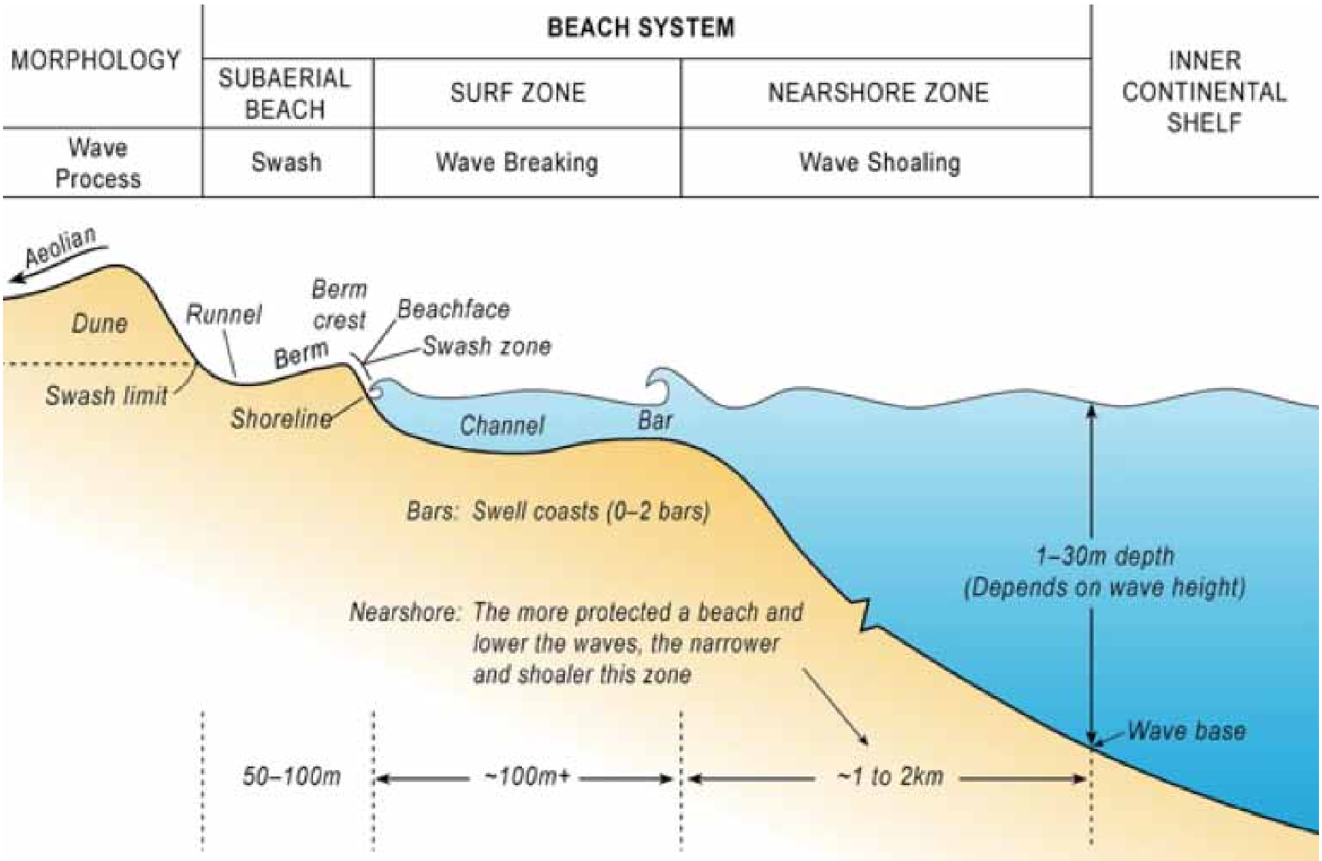

Figure 5 Typical beach systems (Short, 2012)

Hydrodynamics of Oceans waves - it is useful to understand how waves operate. Waves are created when wind blows over the surface of the ocean. The important factors that determine the features of waves are:

> *"the strength of the wind*
> *The distance of the water*
> *The length of time for which it blows"* [29]

All the above do influence the height of waves. In addition, the depth of water is also a factor that influences wave height. This is important for low-lying coral reef islands. The wave formed along a coral reef depends on the level of offshore waves, which is normally between 0.2- 0.5 m. The wave's height at some distance from the ridge is close to 0.55 -0.65 m. Fringing reefs are useful in reducing wave energy and wave heights (SOPAC, 1990). As waves approach the shore, they make contact with seabed, reefs and island. The waves change in the form of refraction (waves bend in line with seabed contours) or reflection (waves are reflected back when blocked by solid object) or diffraction (waves spread out behind breakwater or island) or friction (wave energy and height are reduced close to shore) or shoaling (waves increases in heights from deep water levels until they break and then reduces rapidly in height.) [30] So it is important that we know how the changes that we make at the coast will affect and cause changes in wave patterns.

The sea is constantly modifying the shape of Pacific coastlines. This is caused by actions of waves in eroding, transporting and depositing materials. When a waves approaches from deep ocean it moves in circular form known as swell. As it approaches shallow water, the waves become steeper and eventually collapse creating a swash (the white foam that reaches the beach). The return wave is known as the backwash. Waves are caused by wind blowing over the surface of the water.

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[29] Byrne et al. (1990)
[30] ibid

According to Gillie (1997), the Pacific Ocean is dominated by four major wave components:
Prevailing northeast to southeast seas and swells accompanied by easterly trade winds; westerly seas; short term, large seas and swells generated from cyclones and storms; seasonal south and north swell waves created by mid-latitude storms. [31]

Waves, currents, storm surges and tropical cyclones can in one way or the other cause damage to structures, flooding of the coastal zone but also contribute to replenishment of materials in coastal areas.

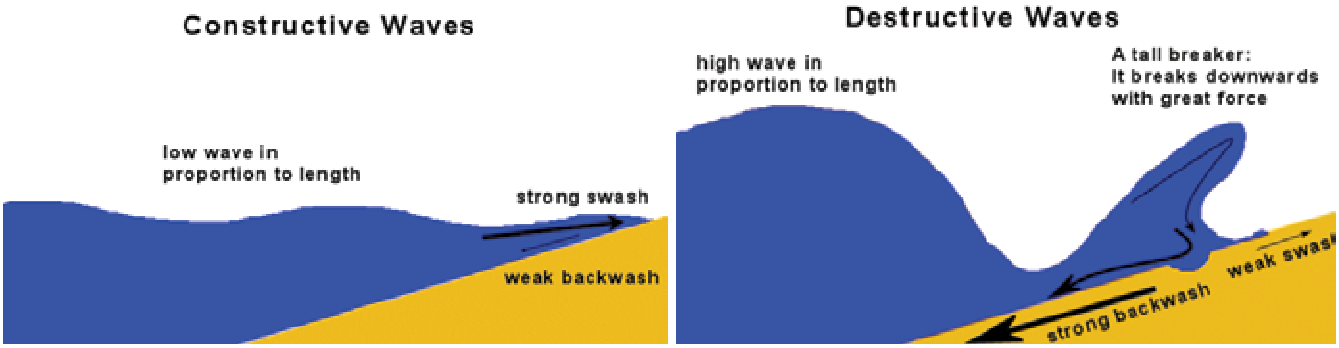

Figure 7 Constructive and destructive waves that alters the coastline (Geographypods. 2012)
Figure 6: Constructive and Destructive Waves

Causes of erosion - Erosion is a combination of many factors such as: - sea level long term trends, cyclical events such as ENSO episodes, result of human activities and severe storms. [32] We need to understand the movements of waves (swash and backwash). There are constructive waves where the swash is strong and brings material to the beach. In this case materials are transported and deposited on the beach. On the other hand we have destructive waves and these waves caused erosion because swash waves are weak but strong backwash takes away materials. The backwash will eventually take away material from the beach.

The main causes of sea erosion are natural and human induced ones.

"Natural causes include short term beach dynamics, changes/cycles in long-term weather patterns, natural shoreline evolution or re-alignment, sea level rise and catastrophic geoharzards in the coastal zone. Human induced causes include beach sand extraction, the effect of sand-trapping structures and the reclamation of shorefront land, and the constructions of sea walls." [33]

There are four known ways that coasts are eroded:

1. Attrition is the process where waves cause the rocks and pebbles to collide and break up.
2. Corrosion (solution) is chemical weathering where the slight acidity of seawater causes the gradual dissolution of the pieces of cliffs.
3. Hydraulic pressure where the seawater and air gets trapped in cracks in the rocks, which build up pressure and causes them to break.
4. Corrasion (abrasion) – this process is driven by the waves. Waves pick up the pebbles and rocks and hurl them at the cliff base, thus breaking them (NSIDC, 2008).

[31] Gillie (1997) p.181
[32] SOPAC (1990)
[33] Gillie (1997) p.174

Transportation

The waves cause the movement of the beach materials. This movement along the coast is known as longshore drift. Longshore drift occurs when waves enter towards the coastal zone at an angle. The swash waves moves up the beach, carrying the material up and along the beach. On the other hand, the backwash carries materials back down the beach at right angles. This wave action is owing to the gravitational effect. This process causes a slow movement of the material along the beach. Longshore drift links erosion and deposition process by causing erosion of materials at one place, transportion and then deposition at another location. Some means of transportation are: solution, saltation, suspension and traction (RegionWorld, 2007).

Deposition

The materials that are transported get deposited to a particular location, known as deposition process. Deposition can affect sand, sediment and shingle. There are four main deposition environments: beaches (deposition of sand, singles etc. between the high tide and low tide mark), spits (long-term deposition that forms long narrow ridge from the coast line), bars (grow like spits but join to headlands) and tombolos (spit growing outward joining offshore island and land) (Gore, 2010).

Corals

Corals are one of the main features of Pacific countries. There are four types of coral reefs found in the Pacific:

- Fringing reefs
- Barrier reefs
- Atoll reefs and
- Reef islands [34]

Coral reefs are important because they act as line of defense in protecting all islands in the Pacific. [35]

> “Coral reefs are important because of the way they produce characteristic coastal morphological structures, affects water levels and currents within the coastal zone, and ultimately supply beach materials (sand, pebbles and boulders) from which beaches, small islands(islets, motu or cays), and long length of shorelines are constructed.” [36]

Coral reefs also play an important role in reducing wave energy.

Other Factors

Tides are driven by gravitational forces, which alter the coastal process. The low tide exposes the shore to become dry after the high tide and promotes shoreline weathering. Tidal range plays an important role in controlling the vertical distance over high waves and currents that shape the shoreline. Tsunamis are large waves caused by tectonic movements that can change the coastline structure within minutes to hours. Relative sea level determines the shoreline; rise or fall of sea level changes the shoreline (Summerfield,1991).

[34] Gillie (1997) p.182

[35] ibid p.183

[36] ibid p.183-p.184

2.1.2 Adopt a policy of working with nature as the best way forward

There are normally two options. You either work along with nature or you work against nature. Pacific countries are urged to work along with nature.

> "Working with nature will prove much more successful than working against nature". [37]

Pacific communities tend to follow a similar pattern, when it comes to protecting the coast, the very first thing that springs to mind is to strengthen sea walls, offshore breakers, and revetments. It is about time we change this paradigm. We need to first protect nature which in turn will protect our communities and families. There is a strong need to protect our ecosystems. Restore our wetlands, forest and our marine reefs. We should not disturb our coastal processes, and avoid disturbing the natural hydrological cycle.

Some meaningful examples that we may take on board are protecting our reefs, and planting of mangroves.

2.1.3 Adopt Adaptive Response strategies: retreat, accommodate or protection approach

There are three main types of adaptation response strategies that can be considered for reducing coastal erosion, protection of human life and ecosystems – retreat, accommodate or protect. In a *retreat* approach, coastal systems processes will remain undisturbed. Coasts dynamic will continue as business as usual. People, infrastructure and habitats may have to move inland or relocate to higher grounds. In an *accommodate* approach, again coasts dynamics continue as business as usual while land use will be changed. Using a *protect* approach, protection options are identified which may be in the form of soft or hard engineering strategies.

> *"Retreat involves no effort to protect the land from the sea. The coastal zone is abandoned and ecosystems shift landward. This choice can be motivated by excessive economic or environmental impacts of protection. In the extreme case, an entire area may be abandoned. Accommodation implies that people continue to use the land at risk but do not attempt to prevent the land from being flooded. This option includes erecting emergency flood shelters, elevating buildings on piles, converting agriculture to fish farming, or growing flood- or salt-tolerant crops. Protection involves hard structures such as seawalls and dikes, as well as soft solutions such as dunes and vegetation, to protect the land from the sea so that existing land uses can continue."* [38]

[37] Murray Ford and Consultants NZ Ltd (2003)
[38] Gilbert and Vellinger (1990)

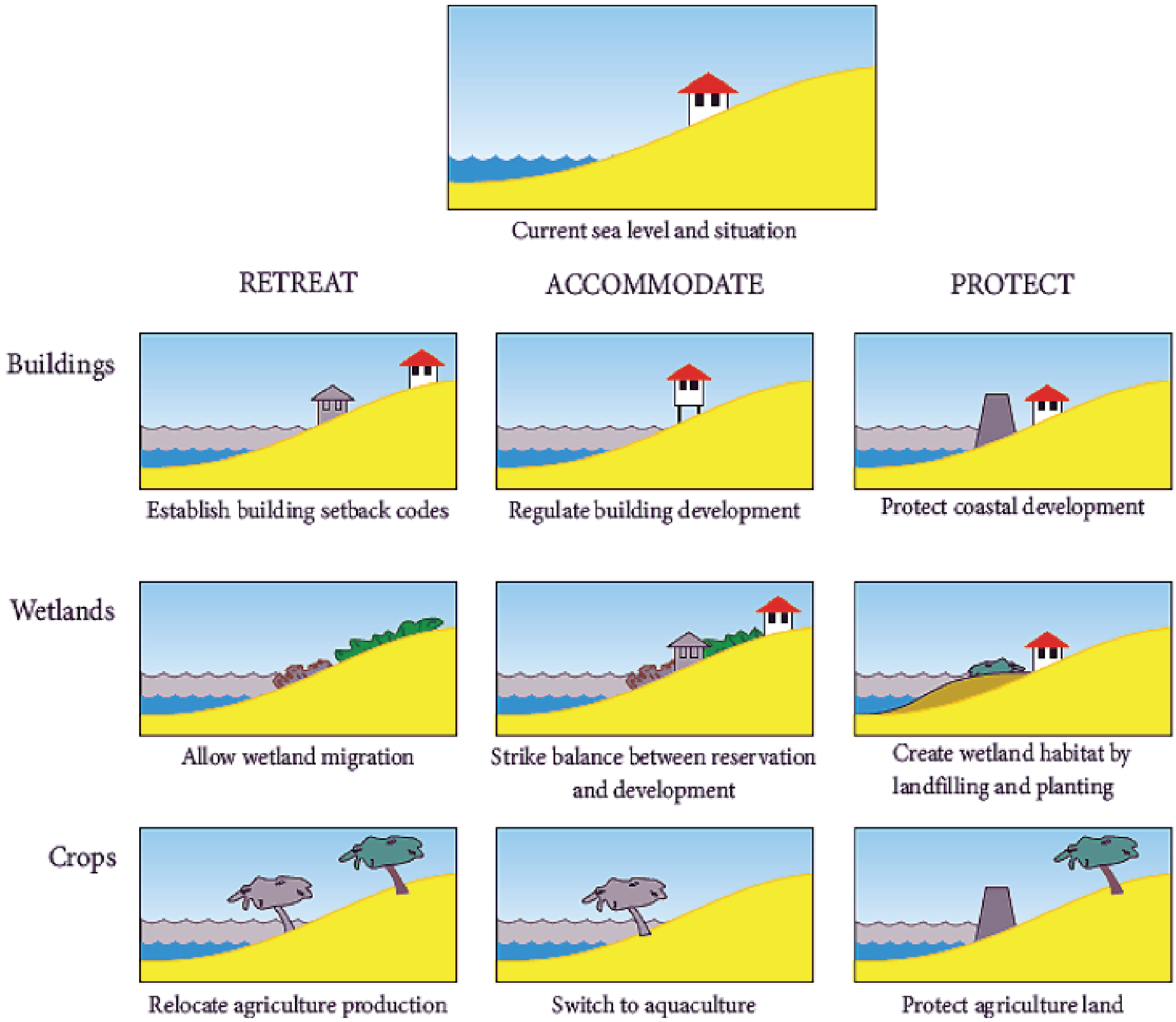

Figure 7: Retreat, Accommodate and Protect strategies (Taken from Dorst in Robbert (ed) (2011)

2.1.4 Conduct an Environmental Impact Assessment

The Environmental Impact Assessment (EIA) is *"an activity designed to identify and predict the impact of a project on bio-geo-physio-chemical environment and human health so as to recommend appropriate legislative measures, program and operational procedures to minimize the impacts."* [39]

Pacific communities should make it a practice to first conduct an EIA before implementing a coastal protection intervention; they should conduct an EIA first. The result of the EIA will help formulate strategies that minimize damages to the environment. An EIA is usually conducted before any project is implemented. This will ensure that we will be able to detect or forecast any harm to the environment. The good thing about an EIA is that it also considers other possible alternatives.

[39] Anjaneyulu and Manickam (2007)

2.1.5 Enforce Foreshore Regulations

One serious factor causing foreshore erosion is beach mining. Sand and aggregate on the foreshore are positioned in such a way to protect the land from forces of nature. If we continue to remove them we are contributing to exposing land to forces of wind and waves. The best thing to do is to control the continuous extractions of materials from the foreshore as well as in the inter-tidal zone and on the sea bed. The important strategy is to develop a constructive foreshore law that takes into account management and control of foreshore and coastal zone.

> *"sand extraction through beach mining for construction and reclamation purposes often results in long term depletion of sand resources on beaches and significantly reduces the natural protection that beaches provide."* [40]

2.1.6 Adopt Marine Protected Areas (MPAs or MMA)

Marine Protected Areas (MPAs) or Marine Managed Areas (MMAs) whether legal or traditional are initiatives created as no-take zones. These approaches are helpful in stabilizing and protecting coastlines. The mining of sand and aggregate in any given coastal area exposes that community to beach erosion. By prohibiting the use of a particular spot helps in protecting the coral reefs and seagrasses from damage. MPAs or MMAs are important in enhancing ecosystems within the area. Almost all PICTs have MMAs as depicted in table 2 below:

PICTs	MMA	MMA Area (Km^2)	Active MMA
American Samoa	19	174	0
Cook Islands	39	19	24
Fiji	246	10,880	217
FSM	12	23	0
Guam	11	170	0
Kiribati	15	411,304	0
RMI	1	701	0
New Caledonia	0	0	0
Niue	3	31	0
Northern Marianas Is.	8	13	0
Nauru	0	0	0
Palau	28	1126	0
PNG	166	3764	80
French Polynesia	10	2837	0
Samoa	84	209	54
Solomon Islands	127	1381	113
Tokelau	3	1	0
Tonga	18	10,009	6
Tuvalu	10	76	4
Vanuatu	55	89	20
Wallis & Futuna	0	0	0
Timor Leste	N/A	N/A	N/A

Table 2 Comparison of Marine Managed Areas in the Pacific region. Source: Extracted from Govan et al. (2009). Status and potential of locally managed marine areas in the South Pacific.

[40] Gillie (1997)

One of the greatest achievements in the Pacific was the development of MMAs. These locally managed areas were implemented over more than 500 communities and cover more than 15 PICTs. In Table 2, Kiribati's marine managed areas is the biggest in the Pacific with 411,304 km^2 while Tonga ranked second with 10,009 km^2. Fiji has the highest numbers of MMAs with 246, followed by PNG with 166 and Solomon Islands with 127. Fiji has the highest numbers of active MMAs with 217 and Solomon Islands have 113 active MMAs.

The importance of establishing locally managed marine areas is basically because of their social, cultural, economic and ecological benefits for those communities. Their major contributing factors towards coastal protection are based on the conservation of the first and second line of defense of the island from ocean waves and extreme cyclone and storms. Undisturbed coral and seagrass ecosystems act as buffer zones reducing the incident wave energy.

2.1.7 Adopt National Biodiversity Strategy and Action Plan (NBSAP)

NBSAP is an action plan devised to effectively conserve and safeguard the over-extraction of biodiversity and ecosystems which human populations rely on for their livelihood. The strategies help in controlling the use of resources and minimize the disturbances of crucial ecosystems. The Convention on Biological Diversity (CBD) demands that each country develop a NBSAP. These are national strategies, plans or programmes to conserve and sustainably use biological diversity. NBSAP gives opportunities to protect and conserve important ecosystems such as coral, seagrass, algal and seaweed that are important natural lines of defense. Protection of land- based vegetation is a part of the conservation measures. Pacific countries that have produced their NBSAP are Cook Islands, Fiji, Kiribati, Marshall Islands, Micronesia (FSM), Nauru, Niue, PNG, Samoa, Solomon Islands, Tonga, Timor Leste, Tuvalu and Vanuatu. The three most important aspects of CBD are (1) the conservation of biological diversity; (2) the sustainable use of biological diversity and (3) the sharing of benefits arising from conserving biological diversity. Having a NBSAP gives the opportunity for engaging stakeholders, assessing vital ecosystems, mapping ecosystem services and identifying economic services indicators. Some good practice lessons derived from NBSAP are the creation of clear governance structure, there is a good common understanding amongst the key stakeholders, more focus and a strategic plan, a combination of top down and bottom up approach, and the use of traditional knowledge. The Pacific has a rich and diverse biological diversity. Most of the Pacific countries NBSAP provide strategies to protect marine and terrestrial ecosystems, natural resources and endangered species.

2.1.8 Adopt an Integrated Coastal Zone Management Approach (ICZM)

What do we mean by an Integrated Coastal Zone Management (ICZM)? It is "a comprehensive, multi-sectoral, integrated approach to the planning and management of coastal areas. It includes the process of planning and management for sustainable development, multiple use and conservation of coastal areas." [41]

No one will deny the critical importance of coastal environments in the Pacific region. Ram Bidesi et al. (2011) argued that:

> *"Healthy marine and coastal environments are fundamental to the long term sustainability of island societies, as well as providing the basis for their livelihoods and economic development."*

The fundamental challenges facing Pacific countries are that these healthy coasts are quickly becoming over exploited, ecologically degraded and will likely become unsustainable in the near future. A word of advice is to 'adopt an integrated coastal zone management approach' to safeguard coastal resources and maintain life supporting systems in coastal areas. Ram Bidesi et al. (2011) has also summarized the various threats affecting Pacific Coasts. Most coasts in the Pacific are experiencing a decline in coastal resources. This is attributed to pollution. The competing uses for development purposes and climate change are amongst the major threats. Overfishing, destroying habitats, invasive species and multiple stressors are some of the important threats. [42]

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[41] SOPAC (1994)

[42] Ram Bidesi et al. (2011)

If we are planning for adaptation measures it is always wise to take into account Ecologically Sustainable Development (ESD) and ICZM framework. The idea of this integration is to provide a framework that combines the management of broad drivers, interrelationships, and effects of ecological, social and economic forces and interactions with the economy. [43]

SOPAC (1994) also recommended that Pacific countries adopt the integrated coastal zone management approach as a planning and management tool for coastal protection.

"The goals for Integrated Coastal Zone Management for the Pacific should:

- *Sustain natural systems by ensuring sustainability of coastal resources, protecting critical systems, and recognizing the inter-relationships between natural, social, economic and cultural systems.*
- *Be determined by locally identified needs and be appropriate to local social, cultural, political and economic systems.*
- *Balance local, provincial, regional and national goals.*
- *Provide for economic and social needs and aspirations of communities.*
- *Encourage integrated coastal management and strategies at appropriate levels of decision making.*
- *Incorporate measures for capacity building, including training and education at all levels, strengthening institutional capacity, improving information and data bases, and improving the exchange of information, experience and expertise." (SOPAC, 1994).*

Cummings et al. (2012) recommended as well the adoption of an ESD and ICZM framework too.
The case study introduced by Post and Lundin (1996) on Guidelines for Coastal Zone Management in small island states is worth taking on board. It provides a guide on integrating coastal zone management principles. Pacific countries are expected to design their own ICZM frameworks that suit their needs. The main objectives of ICZM are threefold:

- *Reinforcing coastal management through training, legislation and building human resources capacity*
- *Conserving and protecting biological diversity of coastal zone ecosystems*
- *Promoting rational development and promote sustainable uses of coastal resources*

The main characteristics of ICZM are:

- *Move away from traditional approaches of managing single factor but promote a whole sector approach*
- *Promotes the analysis of priorities, trade-offs, problems and solutions*
- *Continues managing the use, development and protections of coastal resources*
- *Uses multi-disciplinary approach*
- *Maintain the balance between protecting valuable ecosystems and the development of the economy*
- *Operate within the coastal zones as prescribed by law*
- *Seeks stakeholders input in coastal management*
- *Seeks solutions to various complex issues*
- *Integrate sectoral and environmental needs*
- *Provide conflict management*
- *Promote awareness at all level.* [44]

[43] ibid
[44] Post and Lundin (1996)

The theory of ICZM was raised in the 1970s as a "dynamic process in which a coordinated strategy is developed and implemented for the allocation of environmental, sociocultural and institutional resources to achieve the conservation and sustainable multiple use of the coastal zone" [45].

The ICZM principle and concept are also supported by Kay (2005).

The importance of ICZM is threefold. 1.- develop an understanding of systems and processes; 2- using knowledge to enhance sustainable long term environmentally acceptable plans and 3- implementing and enforcing as well as educating the people.

> *"ICZM is widely recognized and promoted as the most appropriate process to deal with climate change, sea-level rise and other current and long-term coastal challenges".* [46]

The three coastal zone management principles are:

1. Avoid development in areas that are vulnerable to inundation
2. Ensure that critical natural systems continue to function and
3. Protect human lives, essential properties, and economic activities against the ravages of the seas [47]

2.1.9 Adopt 'Ridge to Reef' approach

The 'ridge to reef' concept was developed as a component of the wider Integrated Water Resources Management (IWRM) framework. The major idea is to understand how human activities that do take place at water sources in the 'ridge' area (in-land or higher altitude) play a crucial role in degrading the watershed or catchment at the 'reef' area causing damages to marine life and coral ecosystems. Basically the ridge to reef approach is a holistic appreciation of a high island ecosystem where all biomes and their interactions are considered. For instance, something happening uphill (the ridge) will eventually affect something downstream (the reef). A typical example is deforestation of agriculture in the hills that input sediment loads into rivers that eventually make it to the lagoon and choke corals and other organisms, reducing reef productivity.

It is very important for communities to understand this concept, which traditionally, Polynesians used to practice. Sometimes they wonder why their lagoons are less productive but do not realize that it is through their own destruction of coastal wetlands and alpine forests, uphill animal husbandry, poor farming practices, excessive uses of fertilizers etc. A healthy rainforest and watershed equals a healthy lagoon and reef system. (N'Yeurt, 2014. pers. com.)

The importance of ridge to reef approach is similar to efforts undertaken in similar frameworks such as ICZM, Integrated Catchment Management (ICM), the Integrated Watershed Management, the Community Based Ecosystem Approach and the National Biodiversity Strategy and Action Plan (NBSAP). All of these frameworks ensure that ecosystems and biodiversity are conserved and protected.

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[45] Farhan and Lin (2010)

[46] Nicholls et al. (2007)

[47] Gilbert and Verllinger (1990)

2.1.10 Setting engineering standards, taking responsibilities and complying with codes of ethics

The guidelines proposed in Cummings et al. (2012) is instrumental in taking the lead role within the Pacific region. It has become a model for Pacific countries by setting a good example. While the guideline was specifically targeted at Australian engineers practicing coastal engineering work, it is equally relevant for Pacific countries to consider. Before a country thinks about putting in place a coastal protection intervention, the essence of taking full responsibility for your actions, and complying with best international engineering standards and code of ethics are crucial. Australia has in place a code of ethics for practicing engineers and a sustainable charter and a coastal zone policy which could form the basis of adoption by most Pacific countries, which lack these vital instruments.

Many will wonder why it is important to comply with these frameworks. First and foremost, these instruments may be regarded as disaster risk reduction measures. It is worth investing in these instruments to avoid paying the expensive cost of ecological and environmental damage caused by unprofessional behavior. Donors, communities and in most cases political pressure often lead to these types of unprofessional behavior in the region.
The lesson given by Cummings et al. (2012) was to establish an adaptation decision framework using both local knowledge and scientific knowledge. The following coastal management process was offered:

- Step 1- conduct literature review
- Step 2- assess and understand coastal processes
- Step 3- define past and current hazards
- Step 4- conduct risk assessment
- Step 5- evaluate all feasible options
- Step 6- develop management strategy plan
- Step 7- adopt management plan
- Step 8- implement management plan
- Step 9- conduct monitoring and evaluation [48]

Setting standards is a must in order to reap the benefits. Some countries have an engineering council that sets these engineering standards. Engineering Technicians have to be registered so that they carry out due responsibilities with due care and observe the approved code of conducts. Pacific countries could tap UK-SPEC as a guide in setting these standards. [49] The main features of 'code of ethics' enables coastal practitioners to "demonstrate integrity, practice competently, exercise leadership and promote sustainability." [50] Code of ethics are designed in such a way that individuals and organizations follow some form of rules that leads to honesty, integrity and professionalism. Coastal practitioners should uphold the principle of 'duty of care' at all times as this is promoted under the law of negligence. [51]

Planning for future coastal protection interventions must be based on a sound understanding of coastal processes and factors affecting the coastal environment. [52]

Human activities within the coastal environment often lead to damages of ecological systems in those areas. This is why it is useful to develop and implement the concept of Ecological Sustainable Development. The prime objective of ESD is to ensure that developments safeguard the welfare of future generation, protect biological diversity and maintain fundamental ecological processes and life support mechanisms. [53] It is also common among Pacific countries to conduct comprehensive Environmental Impact Assessment (EIA) for any future coastal interventions.

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[48] Cummings et al. (2012)
[49] http://www.engc.org.uk/ecukdocuments/internet/document%20library/UK-SPEC.pdf
[50] ibid
[51] Cummings et al. (2012)
[52] ibid p.5
[53] ibid p.6

2.1.11 Adopt a proper Building Code

The purpose of having a building code is to protect the life, health and safety of individuals who will be occupying the buildings

> *"The purpose of various Building Codes is to provide minimum standards to safeguard life or limb, health, property, and public welfare by regulating and controlling the design, construction, quality of materials, use and occupancy, location and maintenance of all buildings, structures and certain equipment within this jurisdiction."* [54]

Pacific communities would benefit tremendously if they put in place a building code. Infrastructure would meet some form of minimum standards.

Table 3: Comparison of benefits and limitations of Coastal frameworks

Framework	Benefits	Limitations
Undisturbed Coastal processes	• Cheap • Resources are accessible • Easy to use local capacity	• Erosion continues • Infrastructure at risks • Sea overtopping • Sea damaging vegetation
Working with Nature policy	• Cheap • Use of local resources • Within local capacity	• Require regular maintenance • Lack of community interest
Retreat, Accommodate and Protect policy	• Easy to implement • Benefit community	• Lack of interest
EIA	• Avoid environmental effect • Minimized environmental effect at early stage • Involve all stakeholders	• Costly • Delays project implementation • Capacity may be absent
Foreshore Regulation	• Protect and enhance natural environment and cultural values of the coastal zone • Minimize damaged to the coast • Provide safe foreshore environment • Infrastructure do not pose damage to coastal area • Provides sustainable use of the foreshore	• Poor enforcement • Law breakers continue mining
LMMA/MPA	• Increase stock abundance • Preserve spawning times • Provide spillover of juvenile fish • Reduce overfishing	Poor enforcement

[54] Taken From http://www.ci.san-ramon.ca.us/codeforce/bldcodes.html

	• Ecosystem management • Maintain coastal processes • Provide coastal protection	
NBSAP	• Protect biodiversity loss • Reform of land tenure • Change in ownership users right • Equitable sharing of resources • Biodiversity management	Poor enforcement
ICZM	• Preserve nature and resource for future generation • It helps preserving and promoting social equity • Helps protecting traditional • Uses and rights • Promote equitable access of coastal resources • Pro-active planning saves money • Promotes sustainable development	• Poor enforcement • Lack of political will • Lack of community interest
Complying with Engineering standards	• Quality designs are adopted • Community safety • Community receive top quality advice • Funds are not wasted	• Very few professionals around • Too many amateur professionals • Absent of engineering standards laws/policy
Building codes	• Provides safety measures prevention is better than cure) • Reducing the risks • Prevent injuries and death • Structures withstand storm	• Cost of complying may be a problem • Weak enforcement

Table 3 Comparison of coastal protection frameworks

Table 4: Comparison of PICTs having basic coastal protection frameworks

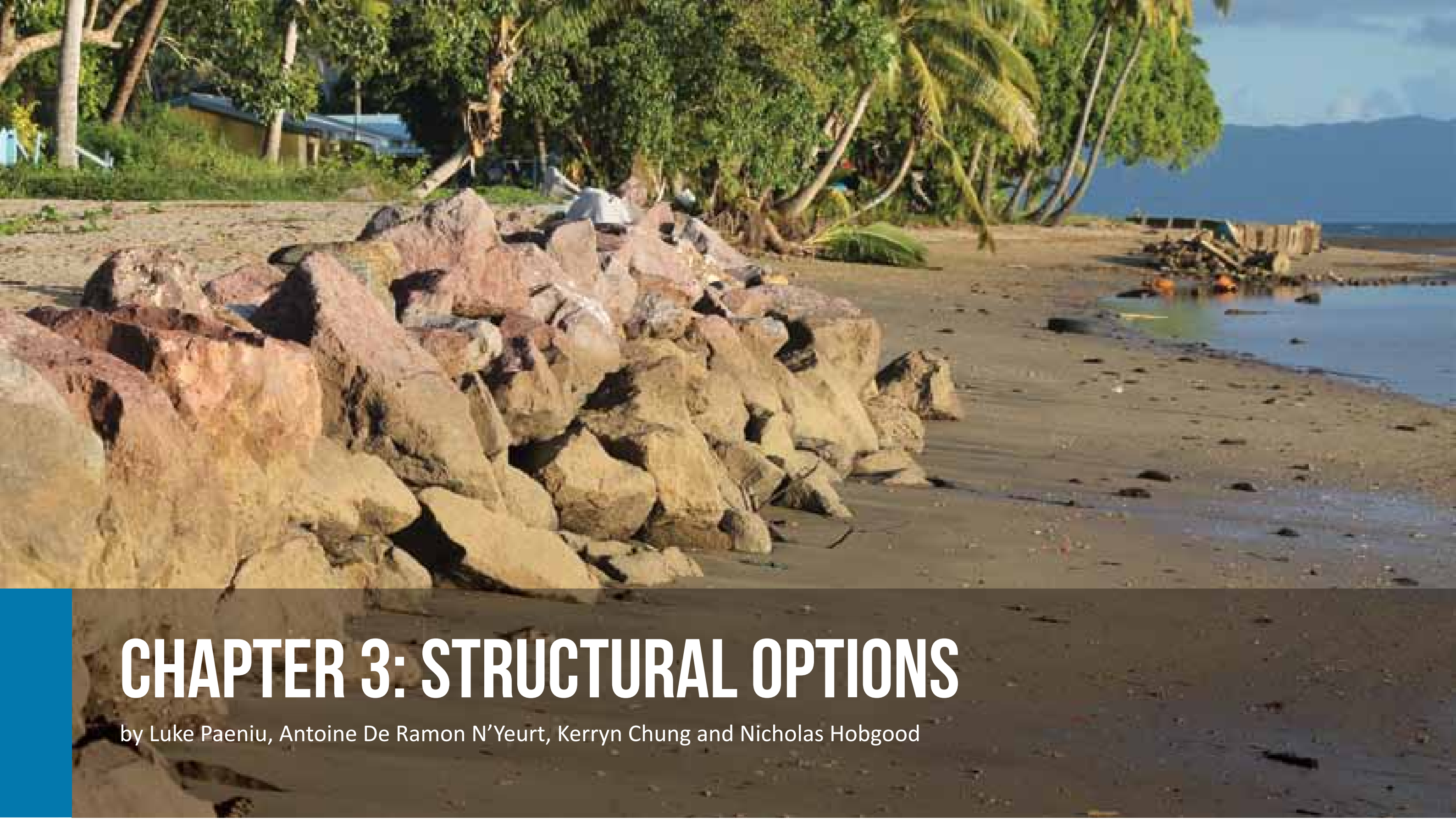
PICTs	Engineering Standards/ Code of ethics	ICZM Plan	LMMA/ MPA	Building Codes	EIA	Foreshore Regulation	Coral Protection
American Samoa	➤	➤	✓	➤	➤	➤	➤
Cook Islands	✓	✓	✓	✓	✓	✓	✓
Kiribati	➤	✓	✓	✓	✓	✓	➤
Fiji	✓	✓	✓	✓	✓	➤	✓
FSM	➤	➤	✓	➤	➤	➤	➤
Guam	➤	➤	✓	➤	➤	➤	➤
New Caledonia	➤	➤	●	➤	➤	➤	➤
Niue	➤	✓	✓	✓	✓	➤	●
Northern Marianas	➤	➤	✓	➤	➤	➤	➤
Republic of Marshall	●	●	✓	✓	●	✓	✓
Palau	➤	➤	✓	➤	➤	➤	➤
PNG	✓	✓	✓	✓	✓	✓	✓
Pitcairn Island	➤	➤	✓	➤	➤	➤	➤
Nauru	●	●	✓	●	●	●	●
Samoa	✓	✓	✓	✓	✓	✓	✓
Solomon Islands	✓	●	✓	✓	✓	●	✓
Tokelau	➤	➤	✓	➤	➤	➤	➤
Tonga	✓	✓	✓	✓	✓	✓	✓
Tuvalu	●	●	✓	✓	✓	✓	✓
Vanuatu	➤	➤	✓	➤	➤	➤	➤
Wallis Futuna	➤	➤	●	➤	➤	➤	➤
Timor Leste	✓	✓	✓	✓	✓	●	✓
French Polynesia	➤	➤	✓	➤	➤	➤	➤

Table 4 Comparison of PICTs with or without coastal protection frameworks

Key:

- ✓ Country has framework in place
- ● Country has no framework in place
- ➤ No clue

In Table 4, Tonga, Samoa, PNG, and Cook Islands are already way ahead of others of having these basic coastal management instruments in place. Fiji, Kiribati and Timor Leste are also heading in the right direction.



CHAPTER 3: STRUCTURAL OPTIONS

by Luke Paeniu, Antoine De Ramon N'Yeurt, Kerryn Chung and Nicholas Hobgood

3.1 Introduction

There are many examples of structural engineering interventions that have been implemented in the Pacific region. This chapter will share some of the experiences of good practices of providing effective coastal protections that are of structural approach. Coastal structures can be in the form of man-made interventions or naturally formed. In this chapter we will identify two sets of engineering structures; those that are referred as 'soft measures', and those that are known as 'hard structures'.

3.1.1 Structural Engineering Options:

3.2 Soft structural engineering options:

Soft structural engineering options are interventions that maintain and strengthen the natural form of the coastline. In this connection, the adoption of ecological principles and practices to reduce erosion and achieve stabilization and safety of shorelines are preferred. Soft engineering methods work best when working in harmony with nature. They also protect habitats, improve aesthetics and are cheap to construct. Natural materials are normally used, such as coral, sand and vegetation. We shall look at natural soft engineering structures first.

3.2.1 Natural Soft Engineering Structures:

Nature has constructed vital coastal and marine resources such as mangroves, coral reefs, seagrass beds and algal forest and beds which provide productive and diverse marine ecosystems. These ecosystems provide vital habitats, feeding grounds, and nurseries for many marine species. These resources also play a useful role in providing natural protection as a first line of defense.

"The shallow ecosystems and productivity of mangroves, seagrass beds, coral reefs and inter – reefs seabeds are critical natural assets for food production, food security, cultural and recreational activities and livelihoods for many Pacific Islands States. They also provide important ecosystems services in protection of coasts against storm surges and in production of carbonate sands and debris to nourish beaches and maintain islands." [55]

3.2.1.1 Maintaining healthy reef islands and islets

Pacific coasts can best be protected by having healthy coral reefs. Low lying islands are formed from coral cays made up of limestone skeletons of corals, coralline algae, and other shallow marine life. [56] Fujita (2009) states that reef islands are normally formed over reef flats of atolls. These islands are low lying, flat and small. Because of their small size and isolation, they are also very vulnerable to the effects of over-population and climate change. Severe weather events such as tropical cyclones and natural disasters like earthquakes and tsunamis can have disastrous impacts, totally redistributing the sediments and changing the profile, even location, of the reef island.

For very small reef islands nations like Tuvalu and Kiribati, it is extremely important to maintain a healthy reef ecosystem to avoid issues of eutrophication of the lagoon, overgrowth of coral reefs by algae, loss of fishing grounds, and contamination of the freshwater lens. Even so, these islands are threatened by sea-level rise due to global warming, which pollutes the little-available soil and freshwater supply with saltwater intrusion. King tides and storms further add to the saltwater load on the fragile terrestrial ecosystem.

One of the biggest concerns on such small reef islands is the proper disposal of wastes, especially sewage (both human and from animals) and domestic effluents. The high loads of nitrates and phosphates in these effluents, which eventually all percolate through the porous atoll sandy soil and end up in the lagoon, have disastrous effects on the shallow water table of the atolls, and their coastal environment. The most conspicuous manifestation of such pollution is usually the appearance of algal blooms, which can take the form of micro- or macro-algal proliferations (for instance invasive Sargassum spp. which has become a great problem in Funafuti, Tuvalu following a drought in 2011). The synergy of weather events like droughts and anthropogenic factors such as the direct dumping of sewage into the lagoons and use of the sea for cleaning and washing further exacerbates the issue. Ocean acidification as a result of higher CO_2 loads in the atmosphere stemming from the burning of fossil fuels threaten to fragilize the calcified algal ridges of atoll coral reefs, making shorelines more vulnerable to wave surges, tsunamis and coastal erosion.

The main thing to remember in this situation is that anything that is done on land (be it the improper disposal of wastes or sewage, the over-use of chemical fertilizers, the burning of fossil fuels) will soon show up in the marine environment, and negatively impact the lagoon and coral reefs which ultimately sustain and maintain the reef island and the life that dwells on it, both biologically and geologically. Proper management practices need to be learned and implemented by local communities, such as sustainable energy sources (biofuel, photovoltaics), recycling of wastes (mulching, composting) and the avoidance of the use of non-degradable chemicals and fertilizers.

[55] Kenchington (2009)

[56] ibid p.1

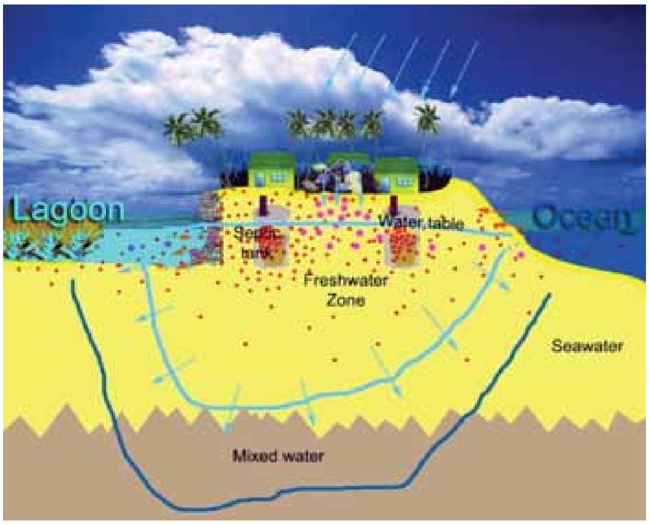


Figure 8: Left: Example of a polluted coastal environment in Fongafale, Funafuti, Tuvalu leading to a brown belt of Sargassum seaweed facing populated areas. Right: Schematic of how anthropogenic effluents enter the lagoon of a reef island, leading to algal blooms and reduced productivity (Source: Funafuti Master Plan http://bluesquid.net/Funafuti%20Masterplan.html)

3.2.1.2 Improve seagrass and algal/seaweed ecosystems

Seagrasses are an important part of marine ecosystems. [57] They are higher flowering plants which have re-adapted to grow submerged in shallow marine waters. Seagrasses are important as a source of food for marine organisms such as turtles and manatees and provide habitats and nursery for countless invertebrates and vertebrate species. [58] They contribute greatly to the primary productivity of coastal ecosystems, and their roots which grow vertically as well as horizontally help withstand the strong energy of waves and currents. Apart from their functions of stabilizing the coastal seabeds, seagrasses also trap sediments and filter nutrients that flow down from the land, effectively acting as a sediment barrier that protects and buffers the coral reefs from being overwhelmed by particulate matters from the land. Removing seagrasses from coastal areas would contribute to the destabilization of the coastal zone and degradation of the coastal marine ecosystem. So it is wise to maintain seagrasses as a natural form of stabilizing the Pacific Coasts. Seagrasses are present in almost all the islands of Micronesia and Melanesia, Kiribati, Wallis and Futuna, Western Samoa and Niue but are absent in the regions of Tuvalu and Tokelau, Phoenix, and the Cook islands. A single species occurs in the Society group of French Polynesia; normally as we go further West, more species are found, for instance 1 species in Rotuma, 3 species in Wallis, 5 in Fiji, 10 in the Solomon Islands. [59]

In many Pacific Islands such as Fiji, the importance of seagrass areas are overlooked, and they are often the victims of coastal development and pollution. Being not as visible as mangroves, their role in the marine ecosystem is not as often well understood by the local communities. Furthermore, the removal through commercial fishing of other organisms usually associated with seagrass beds (e.g. holothurians such such as Bêche-de-mer, *Holothuria atra*) further contributes to the loss of productivity of coastal ecosystems in the region.

[57] Taken from http://myfwc.com/research/habitat/seagrasses/information/importance/
[58] ibid
[59] Short et al. (2001)

Figure 9: Left: The seagrass Syringodium isoetifolium*, the only one found in Rotuma Island, Fiji. Middle:* Halophila ovalis*, a common seagrass species on the Suva foreshore area in Fiji (credit: SeagrassWatch). Right: Extensive seagrass beds of* Halodule uninervis *in Naselese, Taveuni, Fiji.*

A proper approach to the protection of seagrass ecosystems could start at the community level, by raising the awareness of the importance of these marine communities to the overall productivity of the reef, on which coastal communities highly depend for livelihood. Having a healthy seagrass ecosystem will in turn contribute to a healthy and structurally strong coral reef ecosystem, reinforcing the coastal protection of Pacific shorelines.

3.2.1.3 Maintain healthy fringing and barrier coral reefs

Coral reefs help in protecting the island from waves and tsunami. Coral reefs are normally found in warm tropical and sub-tropical waters. Most of the coral reefs are found in the Pacific Ocean while some are found in Indian, Caribbean and Atlantic Ocean. Coral reef development falls within the 20^0 C isotherm limits where most of Pacific Islands are located. [60] Coral reefs ecosystems grow best in low-nutrient, shallow waters. According to Yamamoto and Esteban (2011), coral reefs are formed from microscopic algae and skeletal structures of calcium carbonate.

> *"Coral reefs are characterized by a high level of biodiversity and elaborate specialization of resident species, and provide many ecosystem services that economically support nearby human populations. They also offer some level of protection from natural disasters such as waves or tsunamis."* [61]

Reef health is a combination of factors, and is intimately linked to the health of the ecosystems of the entire island that the reefs surround ("Reef to Ridge" concept, launched by the IUCN in 2010).

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[60] SPREP 2001.*Island Ecosystems: Pacific Region*

[61] Yamamoto and Esteban (2011) p.5

Figure 10: Left: A healthy island reflects into a healthy reef system. Right: The Reef to Ridge Concept.
(Source: Left-Wikipedia Commons; Right-Micronesia Conservation Trust).

In order to ensure that reefs are healthy, land-based influence needs to be kept to a minimum. Unchecked deforestation for firewood and commercial timber exploitation on the hills of high islands will lead to heavy sediment loads into water catchments leading into the lagoon, carrying particulate matter that can smother fragile coral polyps. Likewise, the excessive use of fertilizers on farmlands located on riverbanks will leach chemical compounds such as nitrates and phosphates into the waterways; tourism developments such as golf courses also leach lots of fertilizers into the water table. Eventually all of these nutrients will accumulate into coastal areas, causing eutrophication and algal blooms. Heavy sedimentation will also kill seagrass beds and severely harm mangroves habitats, with the unchecked fine soil particles making their way to the coral reefs and harming the reef-building polyps which play such an important role in protecting shorelines from incoming wave energy.

3.2.1.4 Planting Mangroves

Mangroves are forms of natural tropical coastal vegetation that are adapted to grow well under saline conditions. Protecting mangroves help in protecting the coast. Mangroves can reduce the impact of wave erosion by trapping sand. They also help in extending the coastline as the mangroves grow and extend. They have long curved roots that props up from the ground; these roots help in trapping sediments and sand and reduces coastal erosion. Mangrove diversity is greatest in the Western Indo-Pacific, with Fiji for instance having the third largest mangrove area in the Pacific with 517 km^2 and eight different species. They grow extensively on sedimentary shorelines such as deltas, and have very high sediment accretion rates and sub-surface carbon storage capabilities. [62] As we go East into the Pacific mangrove species diversity gets less, and they are naturally absent from eastern Polynesia although a few introduced stands exist in Bora Bora and Tahiti (N'Yeurt, pers. obs.). In addition to their role as sediment and carbon traps, mangroves offer a very effective nursery areas for the larvae and juveniles of fish and countless other marine organisms, playing a very important role in the restocking of near shore island fisheries. Many food species such as oysters and clam shells grow on mangrove roots, and are traditionally harvested for subsistence purposes by local communities, who also depend on mangrove ecosystems for fishing and firewood.

While rising sea-levels will have some impact on the survival of coastal mangroves (especially on high islands without river systems and little sedimentary areas), the greatest imminent threat to these ecosystems is from human activity. Coastal development has cleared vast areas of mangrove forests from Pacific Island countries before regulatory measures were in place, and even now there is much illegal cutting of mangroves for the sale of firewood, mostly by low-income communities that depend on these resources for a livelihood. In some areas, mangroves are also used as convenient rubbish dumps.

[62] Ellison, J. (2010)

The role of mangrove areas in coastal protection cannot be overlooked; in one study following the Asian tsunami of 2004 it was seen that coastal areas immediately behind even relatively small mangrove areas suffered minimal damage and loss of life compared to areas without any mangroves . [63] While this finding was later disputed by some other researchers as too naïve, it is clear that mangrove areas play an important role in dissipating and breaking up wave energy, up to a certain limit (of course not for a very large tsunami with waves higher than the height of the mangrove trees, for instance). However, by combining several wave energy breaking systems such as revetments, mangroves and rows of coastal vegetation, much of the damage to the shoreline can be effectively mitigated.

Because so much of the coastal mangrove areas of the Pacific have been lost to various forms of development and have also been cut down for firewood or simply because of the wrong notion that they are 'unhealthy' and foster disease (a legacy of ill-informed colonial era administrators), there is an urgent need to carry out replanting projects, preferably involving entire communities in the context of awareness exercises as to the importance of mangrove ecosystems. Such replanting has already been done in island countries such as Fiji and Kiribati, although they have been less successful in areas where white sandy beaches are predominant and soft sedimentary mud are absent.

Figure 11: Left: Planting mangroves in Tuvalu to protect the shoreline from erosion (Source: Japan International Cooperation Agency - JICA). Right: the dense and complex aerial roots of mangroves are very effective sediment traps that reduce coastal erosion, and also serve to dissipate wave energy in such events as tsunamis.

One has to be mindful when planting juvenile mangroves not to plant in high energy zones and the best sites are those with low energy traffic. Kiribati's recent mangrove planting is the best illustration where the sites at Bonriki and Temaiku were selected. These are sites where currents are weak as the longshore drift and normal wind face opposite directions.

[63] Danielsen et al. (2005)

Figure 12: Left: These mangrove roots (Rhizophora stylosa) *trap sediments at the Nasese foreshore in Suva, Fiji. Right: Extensive mangrove areas such as this one in New Caledonia act as nurseries for a wide range or marine organisms (Photo by Joyce Avaemai).*

3.2.1.5 Stabilizing Coastal Beaches

> *"Sediments of these islands consist of unconsolidated of bioclastic sands and gravels. Particularly, the upper part of subsurface sediments and surface sediments are mainly composed of foraminiferal sands."* [64]

Foraminiferal sands are parts of reef sands, they are either disc-shaped or star-shaped sand. These foraminiferas are organisms found in coral reef. According to Fujita (2009):

> *"foraminiferas are now being recognized as important sand producers for the maintenance of reef islands".*

In Tuvalu, the JICA-funded Foram Sand Project, the first phase of which was implemented on the 1st of April 2009 and ended on March 31st 2014, had the objective "to increase the resilience of the Tuvalu coast against sea level rise through ecosystem rehabilitation and regeneration and through engineering support for sand production and sedimentation processes". The project's purpose was to develop a model of the sand production and transportation processes in the Tuvalu lagoon, taking into account human activities and global warming. Following this, specific eco-engineering techniques were to be developed to create and/or restore sandy beaches eroded by coastal processes. The capacity and awareness of the local communities, fisheries and Government staff was also improved to enable conservation of the coastal environment and ecosystems.

[64] Fujita (2009)

Figure 13: Left: The Tuvalu Foram Sand Project. Figure 14: Right: Foraminifera, or 'star sand' (Source: http:// cdn.physorg. com).

Initial results of the first phase of the Foram Sand project, while very encouraging in terms of the ability to culture and reproduce foraminifera in the Tuvalu environment, indicate that this bio-engineering technique is still not mature in terms of the cost-effectiveness on a large scale, and further research is still needed to make it practical to implement in the climate-change threatened atoll nation (Dr. Akihiro Kawada, pers. com.).

3.2.1.6 Planting Coastal Vegetation (littoral plants)

The coastal littoral vegetation is often neglected by the communities and coastal plants are often the very first to be removed without assessing the important part they play in stabilizing and protecting the beach and coastline. Coastal littoral vegetations are shrubs, grasses, plants and trees that grow adjacent to the coastal areas. Human activities near the coasts are the prime reasons for damaging and unnecessarily removing of these vegetations. Most Pacific countries have their own natural littoral vegetations but in some cases similar plants are common in most Pacific countries. There is a strong suggestion to grow and re-plant these types of vegetation for stabilizing the coasts.

3.2.1.7 Beach Nourishment

Beach nourishment is an intervention used to rebuild an eroding beach or lost shoreline or to create a new shoreline. Materials are taken from a different source and filled in the affected shoreline to widen the beach. Sand is simply added to the affected beach. It involves the depositing of volumes of sand with or without supporting structure along the shoreline to widen the existing beach.

3.3 Hard structural engineering options

The application of 'hard engineered' solution refers to the design, construction and maintenance of man-made engineered infrastructure to mitigate the detrimental impact of climate change and protection of the natural environment. Typical coastal protection hard engineering structures are built primarily to prevent the risk of further scouring along the shoreline in order to protect the existing topography and infrastructure.

Types of hard engineered structures commonly used in the Pacific Islands include seawalls, revetments, gabions, Reno mattresses, riprap, and breakwaters. The current coastal protection innovation was the development of the geotextile containers such as the Elcorock product (Hornsey, et al., 2011).

While the hard engineered solutions may propose a longer design life compared to soft engineered solutions, there are many critical factors that contribute to the sustainability of each structure. Furthermore, the detailed design solution will vary case by case taking into account the existing features of the area and the available resources.

Therefore, communities are advised to outweigh the following options accordingly to ensure adequate cohesion with the existing environment to optimize a feasible solution.

	HARD ENGINEERED SOLUTIONS	Alternatives						
		Concrete	Steel	Rock	Timber	Gabion	Reno Mattress	Geo Container
Category	Seawall	●	●			●		●
	Revetment	●		●			●	●
	Groynes			●	●	●		●
	Breakwater			●				●

Table 5: Hard Engineered Solution Alternatives

3.3.1 Seawalls

A seawall is the most easily identified hard engineered structure in the Pacific Islands. When the word 'seawall' is mentioned, majority of those hearing it immediately picture a vertical concrete or rock wall alongside the coastal embankment. Seawalls are constructed parallel to the shoreline, sandwiched by the existing landform or reclamation on one side while exposed to ocean waves or river currents on the other (Cummings, et al., 2012).Like any structure, a seawall will require thorough geotechnical testing and subsurface investigation to assess the existing conditions in order to proceed with the design accordingly. An environmental impact assessment (EIA) is also conducted to ensure that there is minimal disturbance to the existing ecosystem and/or the natural flora and fauna is enhanced.

The seawall category branches out into different types based on the type of material used and formation of the structure. These include concrete wall, sheet piling, gabions, and geotextile containers of which the two commonly used are concrete and sheet piling.

Components of seawall design include location of the seawall, height, weight of the structure, structural connections, fill material (landward of the seawall face), seawall cap, provisions for subsoil drainage, and toe protection (ODNR, Office of Coastal Management, 2011).

a) Concrete seawall – this type of structure is built in two ways. Either by dredging and pouring fresh concrete on site or placing precast concrete blocks and interlocking them in sequence. Construction of the foundation is the most critical and complex component of the entire structure.

Concrete seawalls are expensive to implement but depending on the design they can sustain tremendous load capacity from wave conditions and have longer design service life compared to other alternative materials.

b) Sheet Piling- this type of structure is made of steel sheets which are aligned together to form a pile wall along the embankment. The steel sheets are driven into the ground at the depth required and each interlocks with the adjacent sheet accordingly. The method of constructing this type of structure offers temporary detrimental impacts to the surrounding community which include noise, medium to high traffic management due to the use of heavy plant and machinery (depending on the location), and air quality. These factors have to be strictly monitored and mitigated. The design of sheet pile must be adhered to during construction, particularly, in the preparation of the sheet piles to ensure its adaption and suitability to the coastal (saline) environment. Drilling methodology and sequence of forming the sheet piles is another critical aspect because it directly affects the design life of the structure.

The critical factors that need to be considered in the design of seawalls are as follows:

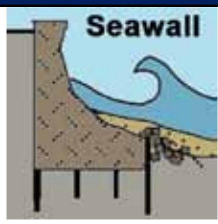
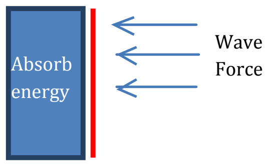
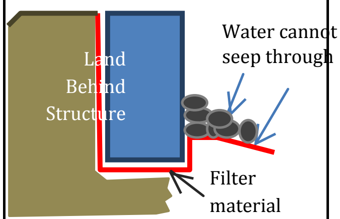
No.	Component	Purpose	Diagram
1	Toe scour protection	• To prevent undermining of the structure	 http://perfectionseawalls.com/build-a-seawall-bulkhead/
2	Material type	• To withstand impact of waves or currents • To ensure sustainability (balance of obtaining optimum design service life and low maintenance)	
3	Filter system	• To prevent loss or scour of land behind the structure	
4	Crest height	• To limit wave overtopping which may be damaging to the structure	 http://www.stabroeknews.com/2009/archives/12/31/spring-tides-overtop-seawall/
5	Splash apron		
6	Land use	• Safe use of land directly behind the structure must be adhered.	 http://geography.wr.usgs.gov/pugetSound/

Table 6: Seawall Components

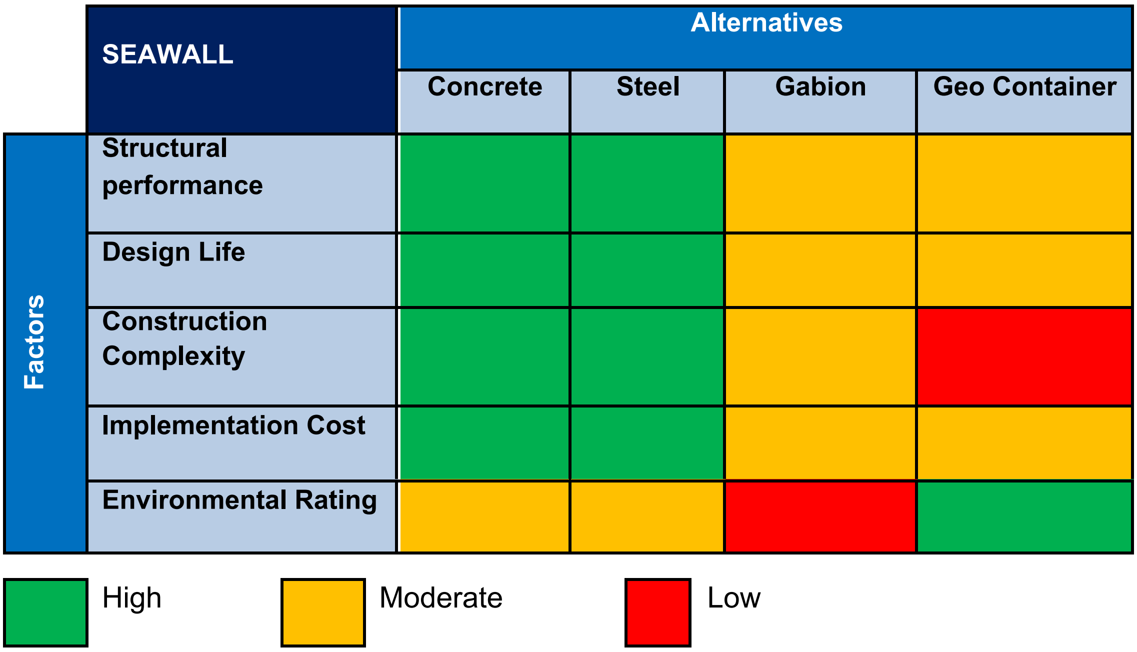


Table 7: Seawall Alternative Comparison Summary
**Ratings shown are indicative only and are subject to final design, availability of materials, and site specific environment conditions.*

3.3.2 Revetment

Revetment structures are similar to sea walls. The only distinctive characteristic is that unlike seawalls, which are vertical in nature, revetments are inclined at a more horizontal slope. Revetment types include concrete, riprap or rock (armor) revetments, Reno mattresses, and geotextile containers. However, the two most common types that have been used are rock revetments and Reno mattresses.

Geotechnical testing and subsurface investigation and preparation is not as complex as that of seawall. However, environmental implications remain similar.

> ***a) Riprap or rock (armor) revetment*** – this structure is one of the simplest forms of coastal or river bank protection. The major factors are subgrade preparation (with geotextile filter), and the size and placement of the rocks. This is a more natural approach to reducing direct impact of wave energy against the embankment and enhances sustainability or potential growth of natural flora and fauna. However, continuous monitoring and possible need for constant future extensions may prove costly in the long term (Coates, et al., 2000).
>
> Components of a typical rock revetment are armor layer, filter layer, toe, crest, and splash apron (optional) shown in Figure 1.

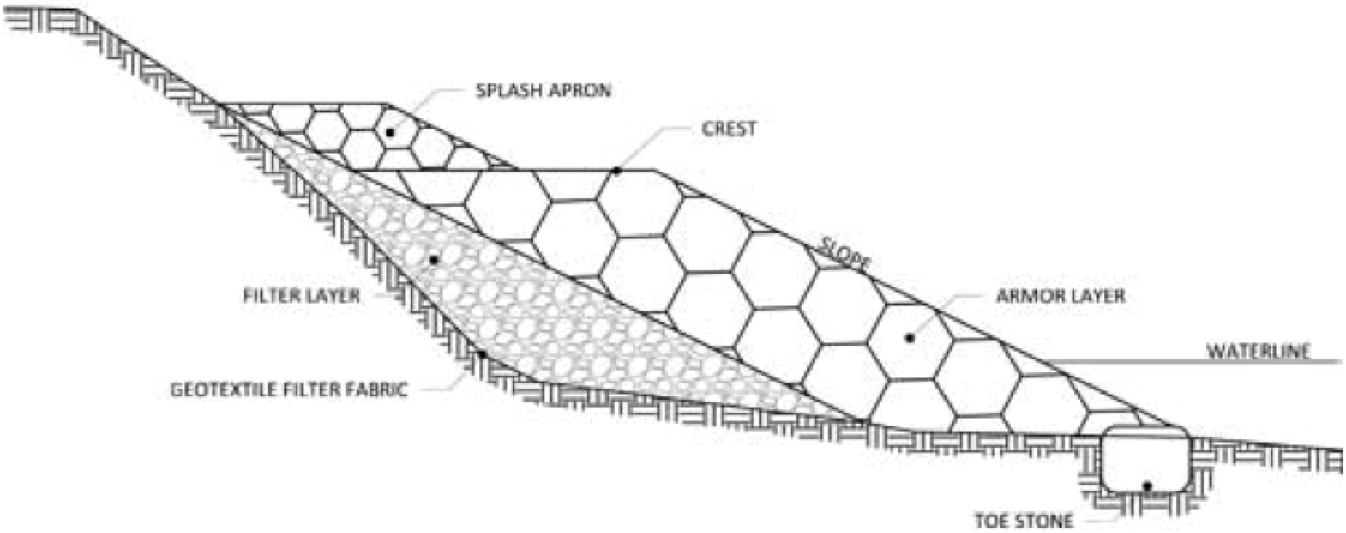


Figure 15: Typical Rock Revetment Section
Source: (ODNR, Office of Coastal Management, 2011)

b) ***Reno Mattresses*** – this structure offers improved structural stability compared to rock (armor) revetments. Reno mattresses are made of wire framed mattresses which are filled with suitably sized rocks. Therefore, rocks are more susceptible to remain intact structurally with the boundary of the wire mattress compared to typical rock revetments. The thickness of the mattress, which is less than 0.3m, (Maccaferri, 2013) and its form enables its unique structural flexibility to be placed at a vertical radius to form a crest apron at the top of the structure and continue over the embankment slope.

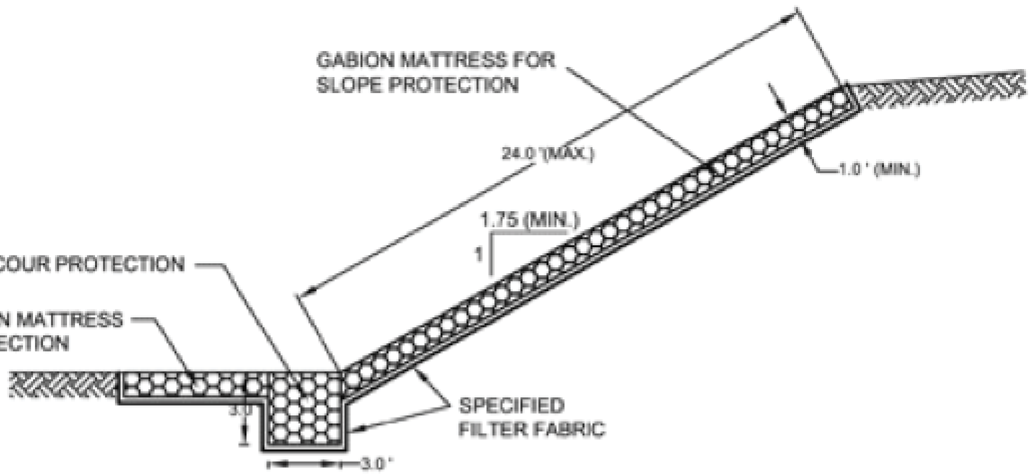


Figure 16: Reno Mattress Section Example
Source: http://www.terraaqua.com/bank-paving.php [Accessed 11 February, 2015]

	REVETMENT	Alternatives			
		Concrete	Rock	Reno Mattress	Geo Container
Factors	Structural performance				
	Design Life				
	Construction Complexity				
	Implementation Cost				
	Environmental Rating				

Table 8: Revetment Alternative Comparison Summary
**Ratings shown are indicative only and are subject to final design, availability of materials, and site specific environment conditions.*

3.3.3 Groynes

Groynes are structures built perpendicular to the coastline to manage the coastal erosion by interrupting the direct impact of longshore waves. The implementation of groynes is usually accompanied by beach nourishment. The groynes cause sand accretion on the up drift shoreline and concurrently reduce the sand feed to the down drift area which causes the erosion (Cummings, et al., 2012). The reduced down drift erosion is then further mitigated by beach nourishment. This effect is shown in Figure 3.

Groynes need to be placed in appropriate locations in order to maximize environmental opportunities in reducing the dependency on sand nourishment which in turn reduces the overall disturbance of the shoreline (Coates, et al., 2000).

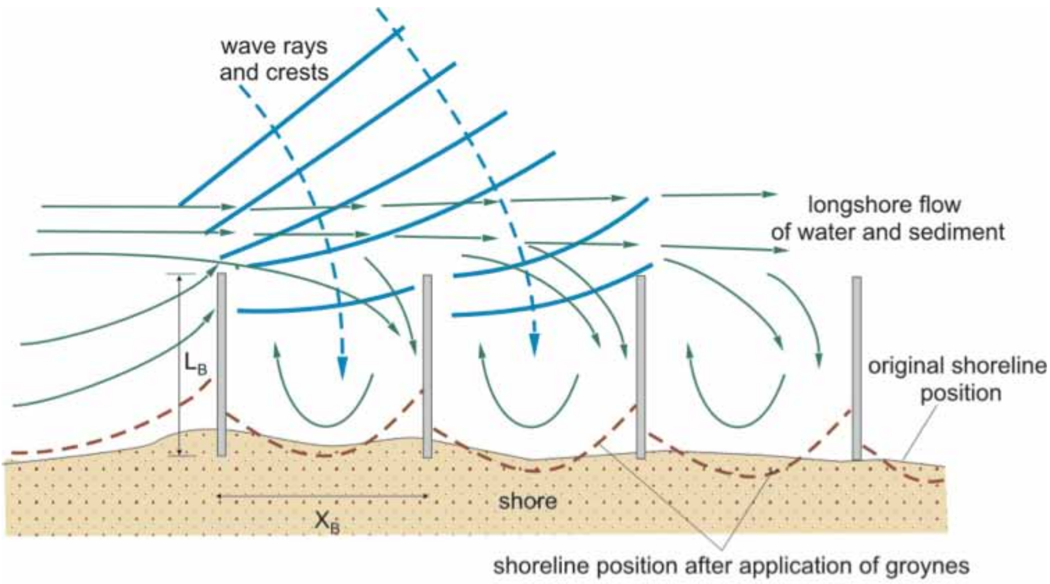


Figure 17: Scheme of interaction of groynes, waves, currents and shore
Source: http://www.coastalwiki.org/w/images/8/84/File1.jpg [Accessed 11 February, 2015]

The type of groyne is dependent on the material type. For examples, groynes can be made of timber, concrete, sheet piles, rocks, gabion baskets or geotextile containers. The type of groyne to be used depends on the existing environmental condition and availability of materials. However, the most common type of groyne constructed is the rock groyne.

Timber groynes in the form of hardwood have been initially used. However, timber groynes do not absorb the wave energy but instead reflect it which makes it to be far less effective than that of rock groynes. Furthermore, structural failure is more likely to occur with timber groynes due to the scour channels at the seaward ends. (Coates, et al., 2000)

Therefore, ideal groyne structures normally include the use of large rocks or boulders.

a) Rock Groynes – this is a common type of groyne which has proved its effectiveness over the years in terms of absorbing wave energy and structural stability. Unlike rock revetments, rock groynes use much larger size rock or boulders. The size selection is to ensure stability considering the potential of the wave impact especially during storm surges and structural settlement caused by large sediment movements.

Figure 18: Rock Groyne Example
Source: http://www.stacey.peak-media.co.uk/EastonBavents/EastontoSizewellDec08/EastontoSizewell08.htm [Accessed 29 January, 2015]

Factors	GROYNE	Alternatives			
		Rock	Gabion	Geo Container	Timber
Factors	Structural performance	Moderate	Moderate	Moderate	Low
	Design Life	Moderate	Moderate	Moderate	Low
	Construction Complexity	Low	High	Low	Moderate
	Implementation Cost	Low	Moderate	Moderate	Low
	Environmental Rating	Moderate	Moderate	High	Moderate

High Moderate Low

Table 9: Groyne Alternative Comparison Summary
**Ratings shown are indicative only and are subject to final design, availability of materials, and site specific environment conditions.*

3.3.4 Breakwaters

Breakwaters are generally designed parallel to the shoreline and in some cases attached to the shoreline (U.S. Army Engineer Research and Development Center, 2015) Breakwaters tend to change the coastal dynamics by reducing the amount and direction of wave energy directly impacting the coastline (Cummings, et al., 2012).

The structural design tools for breakwaters are similar to seawalls and groynes such as the armor type and size, filtering requirements, toe protection, and overtopping (Cummings, et al., 2012). Refer to Figures 5 and 6for example.

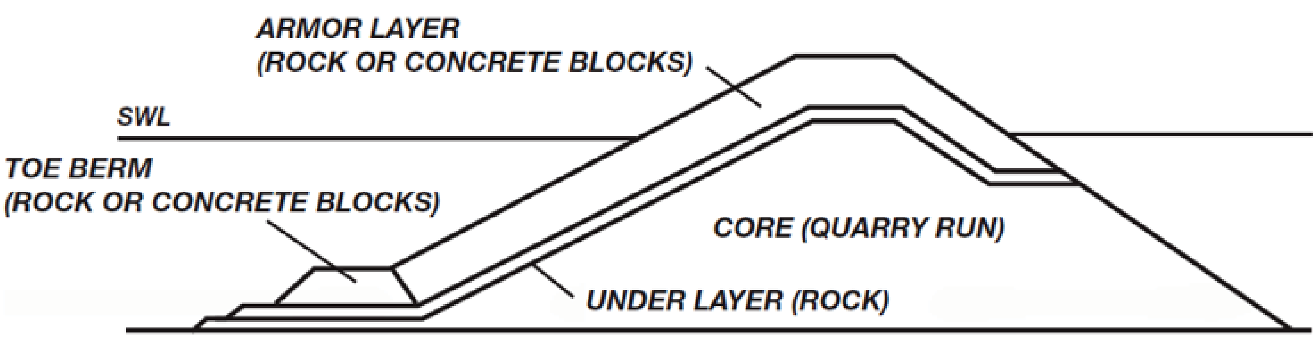


Figure 19: Conventional Multi-Layer Rubble Mound Breakwater
Source: (Cummings, et al., 2012)

Figure 20: Rock Breakwater Example
Source: http://www.svsarah.com/Sailing/AtlanticCircle/Images/Angra%20Marina%201.JPG [Accessed 11 February, 2015]

Typically, breakwaters are constructed in high wave energy environments and are made up of large armor rocks or precast concrete blocks. For lower wave energy environments, gabions or geotextile containers may be used (U.S. Army Engineer Research and Development Center, 2015).

	BREAKWATER	Alternatives			
		Concrete	Rock	Gabion	Geo Container
Factors	Structural performance				
	Design Life				
	Construction Complexity				
	Implementation Cost				
	Environmental Rating				

Table 10: Breakwater Alternative Comparison Summary.

3.3.5 Geotextile Containers (Innovative Solution)

Traditional coastal erosion protection system has revolved around the use of rock and concrete which while structurally effective is not considered environmentally or user friendly. This had therefore led to the development of innovative products such as the geotextile containers (Hornsey, et al., 2011).

Geotextile containers are made up of geotextile material that is filled with sand (or locally approved material). After filling, the containers are closed by sewing the open end with an industrial machine on site and then placed in layers according to the design.

These container types hold several advantages over rock structures which include its cost effectiveness, rapid and reversible construction method, provision of marine life habitat, and its natural aesthetics (Mocke, et al., 2008).

However, the use of sand filled containers has limitations with respect to the wave conditions and is recommended for mild or limited wave climates (Cummings, et al., 2012). As a result, there has been continuous development of specialized materials that have the capacity to withstand harsh conditions experienced in exposed environments (Hornsey, et al., 2011).

Today, with improved geotextile materials, these sand filled containers have proven their effectiveness in the various forms of coastal protection namely, groynes and revetments (Figure 21 and Figure 22). They have also been used as breakwaters and seawall structures in a few cases as shown in Figures 8 and 10 .

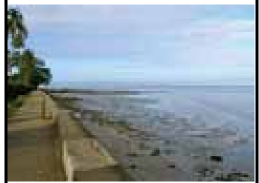
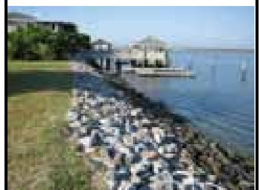
Figure 21: Geotextile Sand-filled Container (Elcorock) Groyne Example
Source: http://www.elcorock.com/case-studies/maroochydore-protected-elcorock [Accessed 29 January, 2015]

Figure 22: Geotextile Sand-filled Container (Elcorock) Seawall Example
Source: http://www.elcorock.com/case-studies/maroochydore-protected-elcorock [Accessed 29 January, 2015]

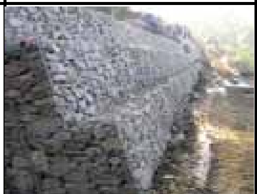
Figure 23: Geotextile Sand-filled Container (Elcorock) Revetment Example
Source: (Hornsey, et al., 2011)

Figure 24: Geotextile Sand-filled Container (Elcorock) Breakwater Example
Source: (Hornsey, et al., 2011)

3.3.1 Table 11: Hard Engineered Solutions Overview

Hard Engineered Solutions	Photograph	Major Components	Wave Condition Limit 1	Constructability	Environmental Impact	Cost Implication 2	References
Concrete Seawall	 https://www.flickr.com/photos/raobhask/sets/72157619303670268/page2/	• Made up concrete and steel reinforcement • Thickness and shape of wall depends on the design which is subject to location • Wall thickness less than 0.5m average. • Concrete strength ranges from 20-50MPa • Design life of 50 years	• Medium to Strong wave conditions	• Complexity level – high • Geotextile layer is placed prior to the placement steel • Depth of foundation depends on soil condition • Concrete maybe poured on site or pre-fabricated off site and constructed on site in sections	• Seawall material shall be designed to suit marine environment	Initial cost – high Low maintenance	(Royal HaskoningDHV, 2012)
Sheet piling	 http://www.asceoc.org/images/uploads/030.JPG	• Made up of sheet piles that are designed to resist corrosion in constant exposure to marine environment • Sheet piles can be made of PVC, fiberglass or steel • Design life 50 to 75 years	• Medium to Strong wave conditions	• Complexity level – high • Sheet piles are driven at a significant depth below seawater level to ensure structural stability • Depth of sheet pile depends on existing ground conditions • Anti-corrosion measures such as paint applications are applied to the steel sheet piles. • Heavy machinery (pile drivers are used) to drive the piles in sequence which are then interlocked.	• Seawall material shall be designed to suit marine environment • Short-term environmental disturbance such as noise and dust to be mitigated during construction.	Initial cost – high Low maintenance	(American Society of Civil Engineers, 2013)
Rock revetment	 http://www.mr-ideahamster.com/howto/kayak/images/revetment.jpg	• Made up of direct placement of suitably sized rocks • Rock size depends on wave height, period and direction and slope • Revetment crest can be structure into a public walkway • Design life 3-5years	• Mild wave condition	• Complexity level – low • Geotextile layer is placed prior to the placement of rocks • Rocks placed at inclination or batter slope to merge with the existing landform • Crest must be above high water mark or largest projected storm wave impact	• Dissipate wave energy preventing scouring • Effectiveness may decrease overtime if continued foreshore erosion • Large rock revetment can be a hazard due to potential buildup of algae	Initial cost – medium Medium maintenance (Continuous extension along adjacent properties may be required)	(Coates, et al., 2000)

3.3.1 Table II: Hard Engineered Solutions Overview

Hard Engineered Solutions	Photograph	Major Components	Wave Condition Limit 1	Constructability	Environmental Impact	Cost Implication 2	References
Reno Mattresses	 http://www.geofabrics.com.au/products/products/36-renotrade-mattresses/overview	• Made up of wire mattresses which are filled with stones • Thickness of mattress ranges from 0.17m to 0.3m • Stone sizes are 80mm to 150mm • The wire basket has a PVC coating which protects it against corrosion. • Design life 5-10 years	• Mild wave condition	• Complexity level – medium • Geotextile layer is placed prior to the placement of the mattress • Mattress is a flexible structure that can be placed at a radius to merge with the existing landform • Subgrade to be stabilized prior to placement of mattresses.	• Stabilizes slope or embankment • Provide interlocking throughout the protected area. • Enables growth of local flora and fauna	Initial cost – medium Low maintenance	(Maccaferri, 2013)
Gabions	 http://www.fostersupply.com/Products/Erosioncontrol/GabionBaskets.aspx	• Made up of wire baskets which are filled with rock pieces. • Rock sizes are 100mm to 200mm • The wire basket has a PVC coating which protects it against corrosion. • Design life 5-10 years	• Mild wave condition	• Complexity level – medium to high • Structure is inclined (4-10°) as shown in the figure to enhance stability • Backing earth (batter slope) must be stabilized prior to erection of structure. • Gabion baskets stretched prior to filling of rock materials. • Filled gabion basket surfaces (all round) must not allow potential breakout of individual rocks.	• Stabilizes slope or embankment • Prevent soil erosion • Absorb wave energy • Can be detrimental if not designed and constructed properly	Initial cost – medium Low maintenance	(Maccaferri, 2013) (Coates, et al., 2000)
Geotextile Containers Example: Elcorock NEW!	 http://www.geofabrics.com.au/about-geofabrics/international	• Sand containers made of geotextile material. • Fill material made up of locally sourced sand • Can be used in various forms: seawall, revetment, groynes, and breakwaters • Available in two sizes 0.75m3 and 2.5m3 • The geotextile material provides high durability enhancing better design life • Design life 5-10 years	• Limited wave condition	• Complexity level – low • Filling frame is used (purchased together with Elcorock geotextile) • Filling of bags must not be done in wet or windy weather conditions. • Bags placed in layers • Placement of bags to be done at low tide • Proper embedment of toe containers is critical (approximately 0.5m deep)	• Prevents scouring by absorbing wave energy • Damaged sand bags affect stability of entire structure • Bags provide enhances natural aesthetics	Initial cost – low to medium Low-medium maintenance	(Maccaferri, 2013) (Coates, et al., 2000) (Cummings, et al., 2012) (International Coastal Management, 2012)

CHAPTER 4: SELECTED EXAMPLES OF CURRENT INTERVENTIONS IN THE PACIFIC

by Luke Paeniu and Aliti Koroi

This section will provide a brief update of baseline information on current coastal protection interventions around some of the countries in the Pacific region. The various engineering approaches used by different countries in the region will be presented.

4. 1 Cook Islands

In the Cook Islands, the engineering approaches used are concrete sea walls, rock boulder revetments, groynes, rock breakwater, and beach replenishment. Specific locations of interest are the beach replenishment at the Northern coastline and rock mounted breakwater at Avatiu. Below are some examples of engineering works in the Cook Islands:



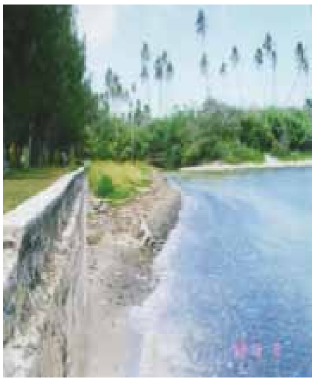



Figure 25 Rock riprap wall, Figure 26 Avarua rock groynes, Figure 27 Gabion basket wall, Figure 28 Ngatangiia concrete wall (Source: Fig.25-28: He, 1999).

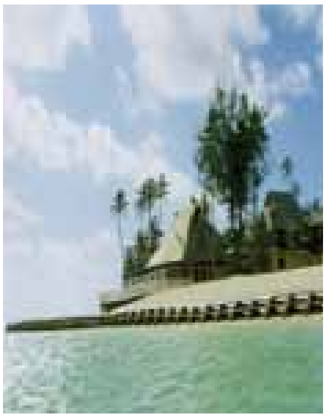



Figure 29 Concrete Revetment west of airport. Figure 30 Rarotonga Hotel concrete revetment. Figure 31 Avarua Harbor seawall and revetment. Figure 32 Reclaimed Coast Protection: Te Tautua Village, Penrhyn Island, Cook Island. (Source: Fig.29-32: He, 1999).

4.2 East Timor (Timor - Leste)

Wave breakers in front of the port of Dili and Dili Airport, mangroves, coastal and Marine Protected Areas on some of Timor Leste's coast are common coastal engineering approaches found in Timor Leste. Recently, big stones from rivers have been placed on stretches of beach called "Pantai Kelapa" to serve as low-cost wavebreakers. The mangrove planting site of the EU-GCCA project is in Ulmera village, sub-district Bazartete and district Liquica, though mangrove conservation is also one of the priorities for the Government and Non-Governmental organizations in Timor-Leste. In addition to that, Timor-Leste is working on ICM within the context of the Coral Triangle Initiative (CTI). The country also has many national parks, both marine and terrestrial among which is a community based national park called 'Nino Konis Santana'

Figure 33 Mangroves in Ulmera village

Figure 34 Wave breakers at port Dili, Timor Leste

4.3 Federated State of Micronesia (FSM)

Seawalls, causeways and groynes are common engineering structures found in FSM.
Shown below are some of the engineering structures in FSM:



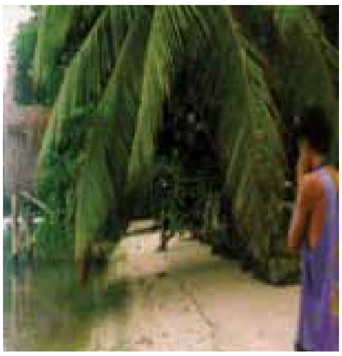



Figure 35 Concrete coral seawall. Figure 36 Coral rubble seawall. Figure 37 Coral seawall. Figure 38 Coral rubble seawall
(Source: Fig. 35-38: Maharaj, 1998)

4.4 Fiji

In Fiji, causeways, bridges and seawalls are being used. Fiji has an Integrated Coastal Zone management Plan in place. Protected coastal areas are the Great Astrolabe Reef in Ono island, Kadavu; Nadi Bay (Tai, Levuka, Vomo Sewa islands fringing and offshore reef areas); Namenalala fringing and barrier reefs; Yadua Taba fringing reefs and surrounding waters; and Lau Group.

The protected mangrove areas are Ba Delta-Nawaqarua-Natutu; Rewa Delta-Muanicake-Nasoata river; Labasa Delta-Labasa river and Labasa delta mouth. [65]

Some of current engineering structures found in Fiji are presented below:



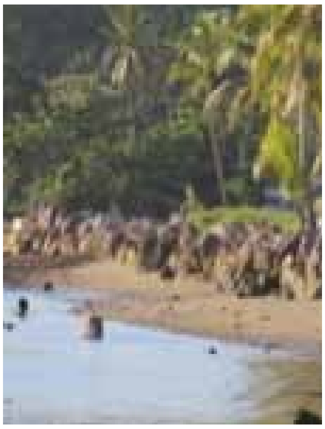



Figure 39 Navulivatu concrete seawall. Figure 40 Lomeri concrete wall. Figure 41 Lomeri Rock wall. Figure 42 Lomeri rock wall.

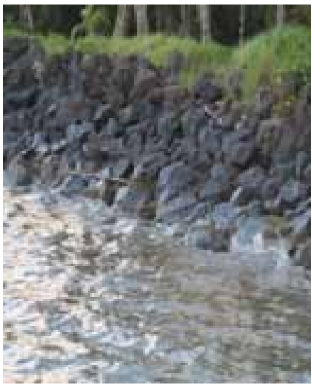
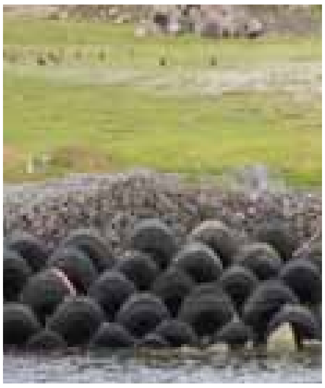





Figure 43 Naitonitoni rip rap rock wall. Figure 44 Naitonitoni rock wall. Figure 45 Lami rubber tire wall. Figure 46 Lami Gabion basket wall.



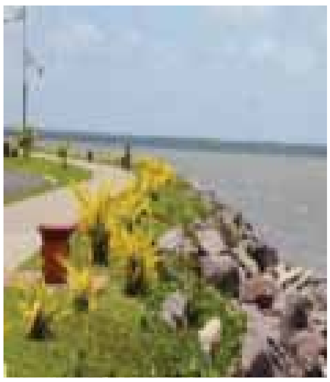



Figure 47 Concrete wall in Suva Wharf. Figure 48 Concrete wall in front of Civic Centre. Figure 49 Concrete wall in front of the President's Residence. Figure 50 Rock wall at Suva Grammar beach front.

[65]Department of Environment, (2011)

Department of Environment, (2011)



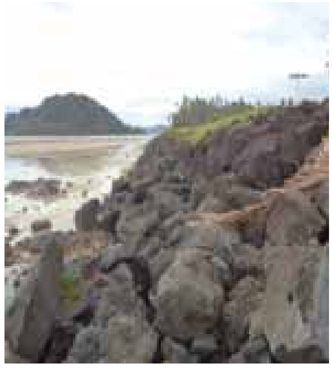



Figure 51 Naselesele bridge. *Figure 52 Rock wall.* *Figure 53 Naselesele rock wall.* *Figure 54 Rip rap rock revetment.*

Some of the natural coastal protections



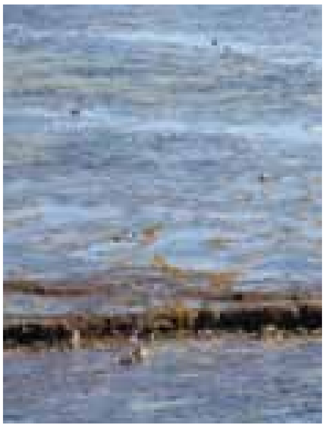
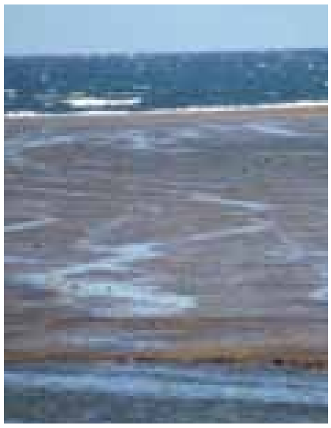
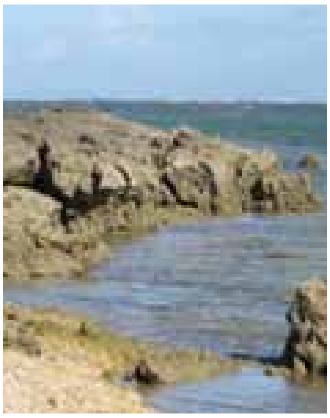



Figure 55 Korotogo Mangroves. Figure 56 Korotogo juvenile mangroves. Figure 57 Namada reef flat. Figure 58 Namada inter-tidal reef.



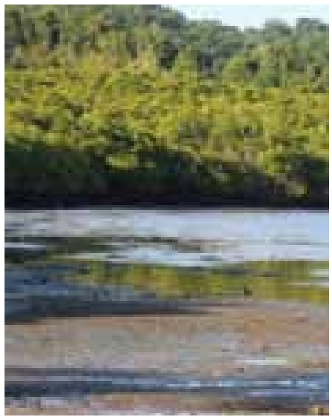



Figure 59 Namatakula Beach rock. Figure 60 Namatakula beach rock. Figure 61 Namatakula beach rock.
Figure 62 Navulivatu Shoreline Mangroves.


Figure 63 Mangroves at Naselesele. showing aerial roots trapping sediments. Figure 64 Naselesele Mangroves, Taveuni

4.5 Guam

The common coastal engineering approaches found in Guam are revetments, seawall at East Agana, Vegetation at Cocos Island, coral boulder revetment, concrete and rock seawall.

4.6 Kiribati

The types of interventions found in Kiribati are vertical coral rock seawalls, cement vertical coral rock wall, Gabion basket filled with coral, sandbags, cement front wall, sloping coral rock wall with cement, motorways and causeways. Some examples of seawalls in Kiribati are presented below:



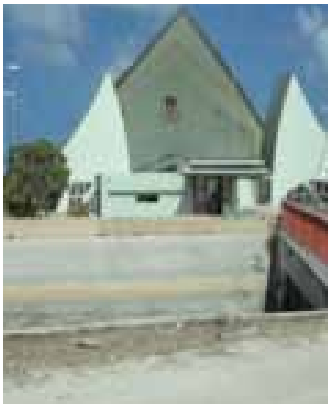



Figure 65 Concrete Sandbag wall. Figure 66 Rock wall. Figure 67 Causeway Concrete wall. Figure 68 Concrete revetment wall at Parliament House.



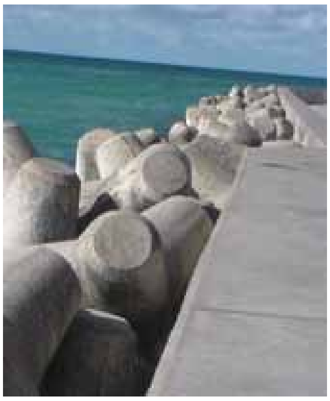



Figure 69 Bonriki Sloping sandbag wall. Figure 70 Concrete slabs at Oceanside of Bonriki airport. Figure 71 Sloping concrete wall at Red Beach, Betio. Figure 72 Wave Breakers at Betio Wharf.




Figure 73 Mangroves and sand bags wall at Bonriki. Figure 74 Dainippon Causeway Bairiki to Betio. Figure 75 Private land-reclaiming project using sand bags wall at Bairiki. Figure 76 Sloping cement wall protecting Parliament House.



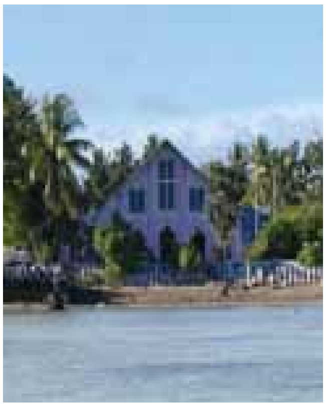
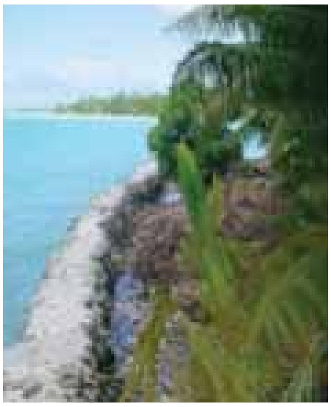



Figure 77 Concrete wall. *Figure 78 Rock Wall* *Figure 79 Rock and concrete wall.* *Figure 80 Concrete wall.*

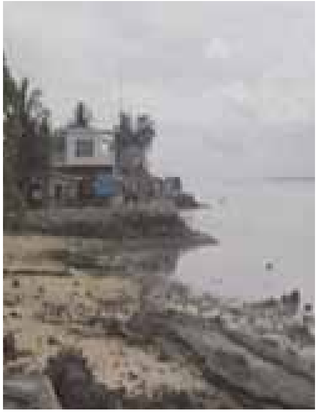



Figure 81 Nanikai Stone wall. Figure 82 Tarawa sea wall. Figure 83 Mormon Church seawall. Figure 84 Reclaim seawall extend to lagoon. (Source: Fig.77-84: Woodroffe and Biribo, 2011)

Kiribati uses mangroves as a protective measure for the coasts. The President of Kiribati H.E. Dr Anote Tong has been instrumental in empowering Kiribati youth to plant mangrove seedlings as effective measures in protecting eroded beaches.



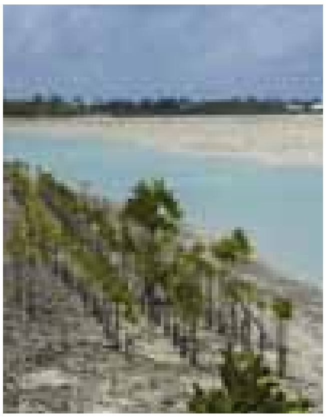
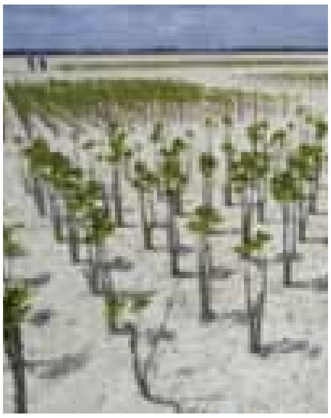



Figure 85 Mangroves. *Figure 86 Mangrove project.* *Figure 87 Mangroves planted in lines.* *Figure 88 Juvenile Mangroves.*

4.7 Marshall Islands

Generally speaking, coastal protection in the RMI is intended to "hold the line" and maintain a fixed shoreline, i.e. limit erosion and to a lesser extent limit flooding and inundation. This is particularly evident in the populated centers of Majuro and Ebeye where coastal protection is largely ad hoc and undertaken at the level of individual landowners. Other than the revetment and seawall at the Majuro airport, there have been few coordinated or centralized coastal engineering interventions post-independence. Typically landowners will armor shorelines using any available material. Those with access to technical and financial resources will use rip-rap revetment and vertical concrete block or cemented coral walls. Gabion baskets filled with coral gravel are also used. More frequently, a mix of inorganic debris including tires, scrap metal and old heavy machinery is used. Recently the RMI endorsed guidance in the form of a publication on options for coastal protection for landowners.

University of Hawaii Sea Grant in association with RMI agencies is working with communities to broaden the options to include softer ridge-building and re-vegetation techniques, along with a more concentrated approach to reef and reef flat protection. While ongoing work in the outer atolls is still focusing on harder fortification measures and road elevation along causeways, the approach is becoming more integrated and innovative in terms of combining options where possible. This will have long term benefits of mainstreaming with other resource management objectives (e.g. reef protection) and making it more likely that benefits from limited adaptation funds can be used over a larger area.

Figure 89 Rip-rap rock wall

(Source: Fig 89 - 91: Karl Fellenius)

Figure 90 Sand bags

Figure 91 Concrete stone wall

Figure 92 Concrete wall

(Source: Fig 92 -94: Karl Fellenius)

Figure 93 Seawall structure

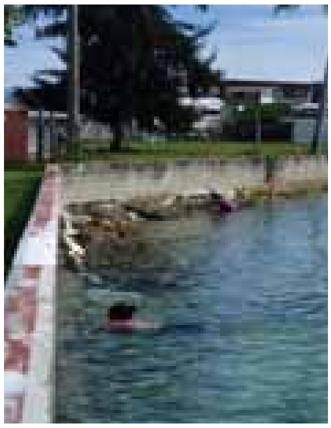


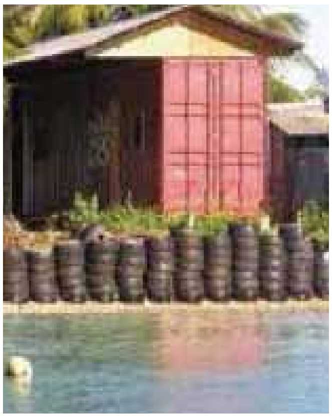
Figure 94 Concrete wall


Figure 95 Seawall in Majuro. *Figure 96 Seawall protecting huge buildings*

(Source: Fig.95 - 96: Murray Ford and Coastal Consultants NZ Ltd, 2013).


Figure 97 Seawall placed on rock. *Figure 98 Breakwaters in Majuro.*

(Source: Fig.97 - 98: Murray Ford and Coastal Consultants NZ Ltd, 2013)



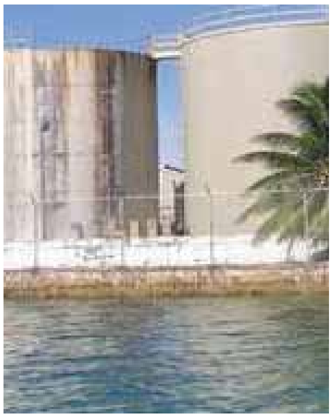


Figure 99 Vehicle tire neatly stacked as seawall. *Figure 100 Concrete wall.* *Figure 101 Seawall protecting oil tanks.*

(Source: Fig.99 - 101: Murray Ford and Coastal Consultants NZ Ltd, 2013).

4.8 Nauru

The coastal engineering approaches used in Nauru are Coral boulder revetment and concrete and rock seawalls. The two major coastal engineering works done on Nauru include the extension of the airport runway and the construction of the new boat harbor in Anibare Bay. Here are some examples of engineering work in Nauru.




Figure 102 Rip rap rock revetment. Figure 103 Concrete wall. Figure 104 Long concrete wall. Figure 105 Concrete wall with rocks at basement. (Source: Fig.102 - 105: Maharaj, 2000).




Figure 106 rock revetment. Figure 107 layout of rock revetment. Figure 108 rock wall. Figure 109 rock wall protects a house (Source: Fig.106 - 109: Maharaj, 2000)

Figure 110 Nauru new wharf

Figure 111 Rip-rap rock wall

(Source: Fig 110 - 111: Maharaj, 2001).

Figure 112 Boat ramp and rip-rap rock wall

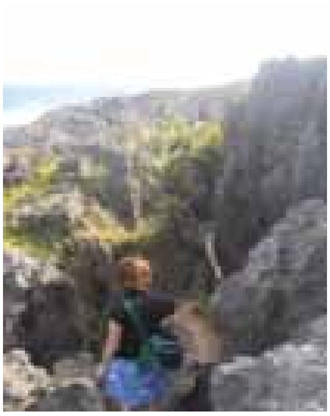
Figure 113 Rip rap rock wall

(Source: Fig 112 - 113: Maharaj, 2001)

4.9 Niue

Niue is surrounded by natural high cliff structures which protects the island from waves and strong winds. A seawall was constructed at Avatele Bay. There are two MPA's one in Alofi and one in Makefu. (from Niue ICC Ms Birtha Togahai)

Figure 114 High Cliff of Tamakautoga, Niue *Figure 115 High cliffs of Niue*
(Source: Fig 114 - 115: Susanna Sionetuato)



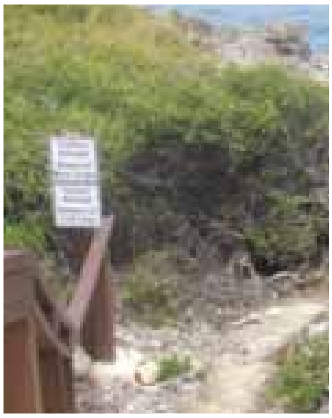


Figure 116 Walking down the cliff, Niue. Figure 117 Waves cuts the cliff below-Avatele Bay. Figure 118 Pathway down the cliff

Figure 119 Tall Concrete wall at Avatele Bay. Figure 120 Concrete Beach ramp, and seawall. Figure 121 Stone wall at Anaana point, Tamakautoga.

4.10 Northern Mariana Islands

The coastal engineering structures found are seawalls, bulkheads, and beach nourishment at Beach Road.

4.11 Palau

The shoreline of Melekeok state in Palau consists of mangroves, sandy beaches, seawalls, reclaimed land at the marina, and groynes. Here are some examples of engineering work in Palau:

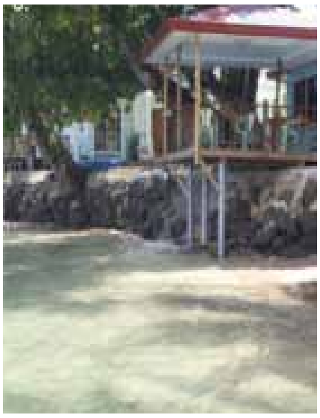


Figure 122 Rip rap rock wall.

Figure 123 Grouted rock wall.

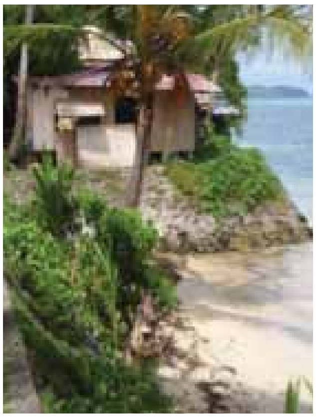


Figure 124 Rock wall

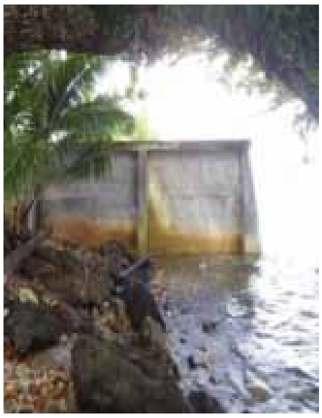


Figure 125 Concrete wall

(Source: Fig.122 - 125: Kench, 2008)

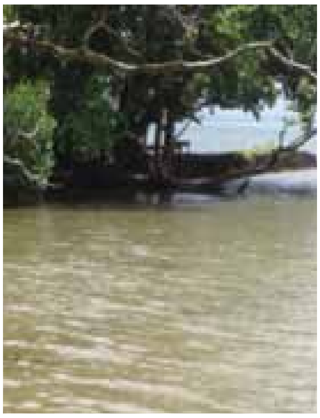


Figure 126 Ngerubesang rock groyne.

Figure 127 Concrete groyne.

Figure 128 Long groyne.

Figure 129 Rock groyne at dock area

(Source: Fig.126 -129: Kench, 2008)

Figure 130 Melekeok rock wall protecting the road

Figure 131 Ngermelech rock wall

(Source: Fig. 130 - 131: Kench, 2008)

4.12 Papua New Guinea

In Papua New Guinea, coastal engineering approaches used are bricks and rock seawalls, dry stone seawalls, coral seawalls and boulders.

Figure 132 Dry stone seawalls at Gapagapa village, central province, PNG



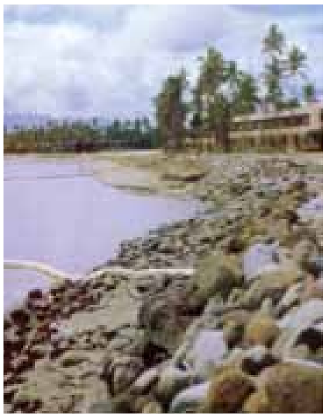



Figure 133 Stone wall at Mou Kele village. Figure 134 Sandbag and tree trunk wall. Figure 135 Rock wall at Gilibwa village. Figure 136 Gabion Basket wall at Los Negros Island.

4.13 Samoa

In Samoa the coastal engineering approaches are stone walls, volcanic boulders at Lufilufi, Vaiala beach seawall, semi vertical seawall at Tusitala Hotel, revetment at Aggie Grey's Hotel, groynes at Mulinwu Peninsula, large rock at old Hideaway Hotel at Mulivai, Revetment and beach replenishment, Chinese funded seawall at Apia water front and at the beach.

The main approaches used in Samoa are hard structural armor rock revetments or seawalls and soft measures such as planting of mangroves and other salt tolerant coastal plant species. The designs and constructions of these interventions are done on an ad hoc basis. One standard design uses compacted backfill scoria material, geotextile cloth, secondary and primary armor rocks placed at right slope and height. (Taken from Ms. Moira Faletutulu of the Ministry of Natural Resources and Environment, Samoa), Here are some examples from Samoa:

Figure 137 Partial concrete revetment at Piula.

Figure 138 Rock wall at Sataoa.

(Source: Fig.137 - 138: Moira Faletutulu)

Figure 139 Aerial view of groynes along Mulinuu Peninsula shoreline.

Figure 140 Rock wall and vegetation.

(Source: Fig.139: National Mapping Services, MNRE, Samoa. Fig. 140: Moira Faletutulu)

4.14 Solomon Islands

The most popular low cost engineering approach in the Solomon Islands for coastal protection is the use of seawalls. These are built from rock boulders from the surrounding coastal environment. As shown in Figure 141, where the seawall is vulnerable to relatively intense wave action, it is reinforced by wooden pillars impaled into the benthos. Because the life span of pillars is not that long therefore it requires community or family effort to maintain them.

Some seawalls are made of coral boulders from the reefs reinforced by logs. Figure 142 below shows such a wall at the Southern end of Nola Hamlet in Ngawa Islet (Reef Islands grouping of Temotu Province). Seawalls like this are also reinforced by the roots of Abalolo trees that interlock the rocks together.

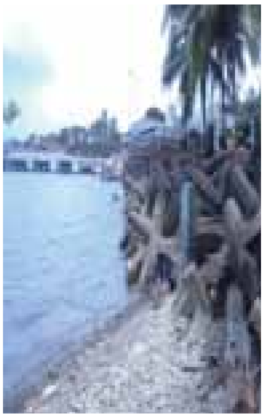
Mangrove forests also plays a major role in coastal protection in the Solomon Islands, unfortunately their exploitation have seen dramatic increase in densely populated areas around the country. The Langalanga Lagoon in Malaita the Solomon Islands has seen a great deal of mangrove deforestation in the last 15 years, increasing coastal erosion. In Ngawa Island in the Reef Islands, the community in an attempt to protect their coasts from erosion, decided to plant mangrove trees, along their coast in the intertidal zone. According to the villages, the mangroves have started helping the retrieval of the coast line (see figure, 143). Initiatives like these can only be easily pursued and achieved through greater community participation as the processes of planting and caring for the mangroves has to come from the community as a whole.



Figure 141 Rock Boulders seawall *Figure 142 Rock seawall* *Figure 143 Mangrove Planting*

The use of concrete seawall often requires major investments. They can be very costly to build, thus are only suitable and practical in urban areas and areas which have some level of development. In Solomon Islands examples includes, the Honiara Ports Area, Honiara Central Market and major hotels that occupy the coastline which have concrete seawalls. Despite their costliness, they are proven to be more disaster proof.

Seawalls which use gabion nets are also effective and costly but unlike concrete seawalls, their lifespan depends on the ability of the wires to resist corrosion, their exposure to physical forces of nature such as large ocean swells and the chemical properties of the ocean or estuary (An update from Research Assistant John Whaleneanea).



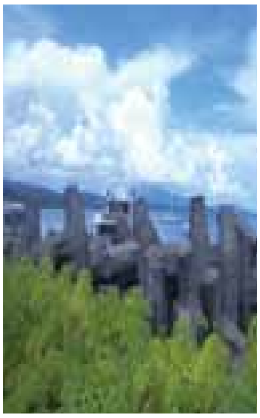
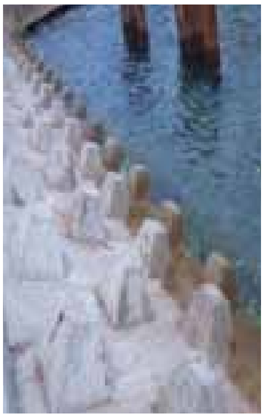
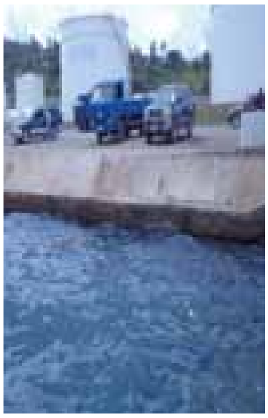




Figure 144 Breakwater structure. Figure 145 Gabion structure. Figure 146 Breakwater structure. Figure 147 Concrete revetment. Figure 148 Concrete seawall.

Figure 149 Mangroves in Ulmera village

Figure 150 Wave breakers at port Dili, Timor Leste

4.15 Tonga

In Tonga, limestone boulder seawall at Nukualofa beachfront, and beach sand seawall at Hihifo in the western area are used. Breakwater in Eua Island. The seawall at the waterfront of Nukualofa was constructed after cyclone Isaac of 1982 and completed around 1985-86. This was considered highly successful in protecting the beachfront in the capital area. The Kanokupolu Seawall was constructed by the villagers themselves with some assistance from NGOs, Governments and Donors. This has been very successful at preventing further erosion at the site, but once again a major headache at the edge of the seawall where the neighboring villages are now facing coastal inundation at a greater magnitude and frequency. Soft engineering approaches have been conducted in more sheltered lagoon site villages such as Lapaha on the main island of Tongatapu. Mangrove replanting and coastal plant reforestation is ongoing as they attempt to reduce the impacts of inundation and coastal erosion. The use of sand bags was piloted by one community in Ha'apai. This project was not so successful as they used bags that were not durable, however the concept has its merits in terms of the availability of resources locally, and just needs further modifications to get it right (An update from In Country Coordinator- Mr. Tevita Fakaosi).

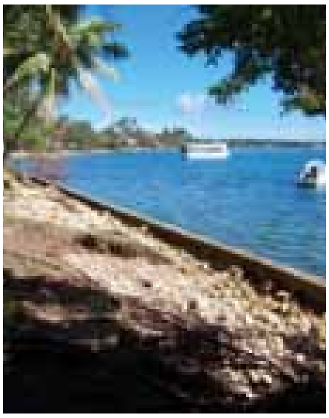


Figure 151 Concrete seawall.

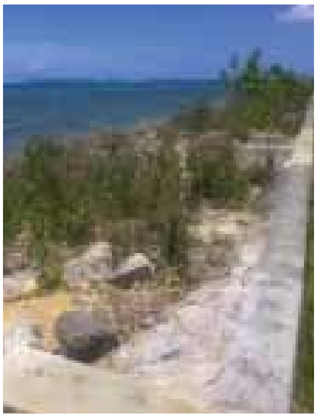


Figure 152 Waterfront seawall.

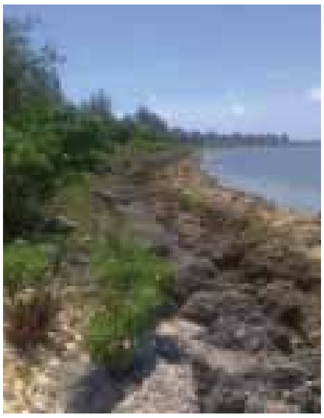


Figure 153 Rock seawall.

Figure 154 Sandbag seawall-Tonga

(Photo credit: Fig.151 -154: Tevita Fakaosi)

4.16 Tuvalu

In Tuvalu, the common engineering approaches are seawalls, gabion basket of stones, and concrete cube revetment.



Figure 155 Concrete wall behind the boat. *Figure 156 Concrete wall at Wharf.* *Figure 157 Concrete cubes beach ramps.*



Figure 158 Private wall made up of 44-gallon drums filled with concrete. Figure 159 Concrete wall in front of Hotel. Figure 160 Nukufetau jetty and reef channel. (Source: Fig 158: Ms. Makereta Komai. Fig 160: Temata Shozo)



Figure 161 Niutao causeway and Mangroves. Figure 162 Nukulaelae beachramp. Figure 163 Concrete wall in Funafuti.

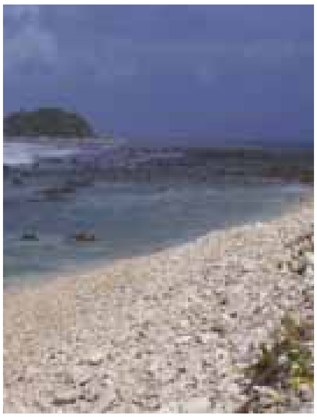
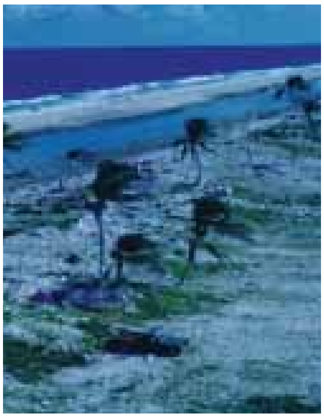





Figure 164 Stone beach south Fogafale. Figure 165 Stone beach and reef. Figure 166 Storm Bank just after Hurricane Bebe 1972. Figure 167 Nukulaelae storm bank. (Source: Fig.166: Tuvalu Meteorological Station)



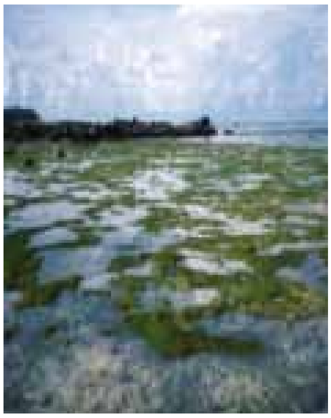



Figure 168 Vaitupu Fisheries Harbor. Figure 169 coral rubble at Vaitupu. Figure 170 Vaitupu reef. Figure 171 Vaitupu seagrass. (Source: Fig.168 -171: Xue, 2002).

4.17 Vanuatu

In Vanuatu there is a seawall in Port Vila Harbor which was damaged by a cyclone. Vanuatu comprises of over 83 inhabited islands. Most people living on the coast have more or less ignored or done nothing in the name of engineering to counter the rising sea level and, or coastal erosion. Some – on coastal calm waters – have resorted to piling up rocks collected from the sand. This is not very effective as it is easily washed away during storms. Others who have extra funds to spend might be able to, or have built concrete walls or use cement to hold the rocks together to form a seawall. This again is not very effective either during rough storms and over time when the water digs around the walls. Yet others with funds and or with external sponsorship lay out gabion baskets and fill them up with rocks. In Luganville and Port Vila some portions of the coasts have been buried (land reclamation) and concrete and metal walls have been constructed. These engineering works were done during the colonial era and mostly by the Americans during their brief stay in the country during the second world war. A lot of money was put into this initiative and also because the water conditions in these two locations is normally calm, these structures have been in place for quite a while and can still be seen today. Sea level rise and frequent cyclones in the 90s have eroded the metal walls in Luganville and recent storms have damaged parts of the concrete/metal sea wall in Port Vila. Almost all the attempts discussed occur where the water is usually calm. Areas constantly exposed to rough seas largely ignore any engineering work at all as people know their efforts will be futile. (An update from Vanuatu ICC-William Bani Arudovo).


Figure 172 Concrete structure at Vanuatu. *Figure 173 Same concrete structure.*


Figure 174 Vetiver Grass at Piliura village on Pele Island. *Figure 175 Gabion basket at Worasiviu.*
(Source: Fig.174 -175: Christopher Bartlett - SPC/GIZ)

4.18 Interventions that did not work

Let's now turn our attention and try and capture interventions that did not work in some of the selected Pacific countries. Photos below will tell the story:

Examples from Cook Islands:



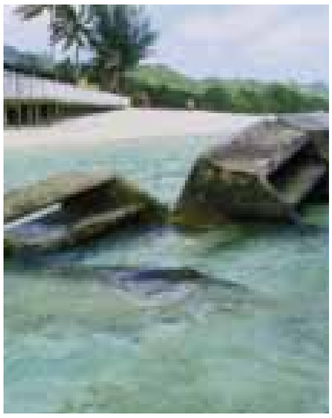


Figure 176 Sea erosion caused by failed seawall. Figure 177 Collapsed seawall in Cook Islands. Figure 178 Collapsed groyne at west end.
(Source: Fig. 176 -178: He, 1999)

Examples from Fiji



Figure 179 Part of seawall at Lomeri High School collapsed. Figure 180 Same seawall looking from seaside. Figure 181 Poor engineering work



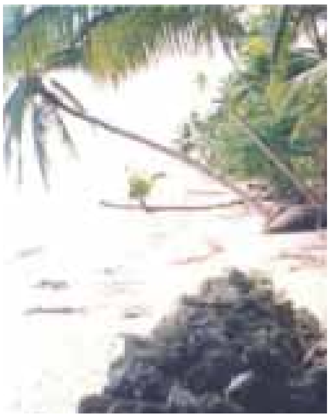
Figure 182 Tire wall collapsed at end of seawall. Figure 183 Tire wall was ineffective. Figure 184 Vehicle tire wall at end collapsed

Examples from FSM

Figure 185 Polap Island erosion at toe of seawall. (Source: Fig 184 -185: Maharaj, 1998).

Figure 186 Collapsed seawall at Satawan Island.

Examples from Kiribati



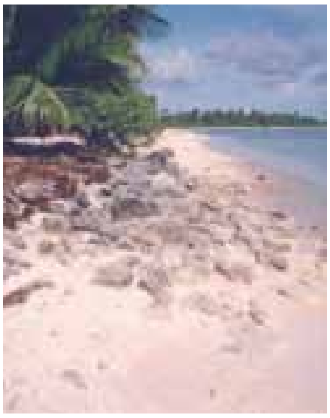


Figure 187 Erosion at end of seawall-Eita, Tabiteuea North. Figure 188 Collapsed seawall-Tewai school, Tabiteuea South. Figure 189 Collapsed seawall at Temotu island, Nonuti. (Source: Fig. 187 -189: Gillie, 1993).



Figure 190 Collapsed wall at Rotima, Nonouti. Figure 191 Eroded road and seawall collapsed at Rotima..Figure 192 Collapsed concrete filled sandbag wall at Nonouti. (Source: Fig.190 -192: Gillie, 1993).

Figure 193 Collapsed seawall in Abemama. (Source: Fig.193-194: Gillie, 1993).

Figure 194 Collapsed seawall in Kuria.



Figure 195 Erosion of important monument. Figure 196 Remains of stone wall. Figure 197 Gabion basket -broken wire.



Figure 198 Erosion begins where wall ends. Figure 199 Erosion at end of seawall. Figure 200 Erosion seen at toe of sandbag wall.

Examples from Samoa

Figure 201 Collapsed seawall in Samoa (Source: Yamamoto and Esteban, 2011)

Examples from Tuvalu



Figure 202 Collapsed Concrete cube Seawall at Nanumaga. Figure 203 Collapsed Concrete cube revetment at Funafuti. Figure 204 Collapsed Gabion basket wall and Tree Trunk wall at Nukulaelae. (Source: Fig.203: Tuvalu NBSAP)

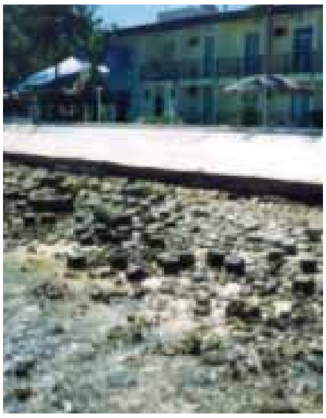


Figure 205 Damaged boulders at toe of concrete seawall, Funafuti. Figure 206 Damaged seawall at Vaiaku Lagi Hotel. Figure 207 Collapsed concrete cubes revetment. (Source: Fig.205 -207: Xue and Malologa, 1995).

CHAPTER 5: SELECTED EXAMPLES OF PACIFIC EXPERIENCES

By Luke Paeniu, Viliamu Iese and Isoa Korovulavula

Based on the previous chapters, this chapter provides a summary of key Pacific and other small island developing states experiences of the various coastal adaptation system and processes. The following are selected case studies that illustrate some of the promising coastal adaptation systems and processes. These systems and processes are:

- Hard coastal structures;
- Soft coastal structures;
- Bio-physical structure and
- Coastal adaptation mechanism.

5.1 Hard Coastal Structures

Solomon Islands

Building Stone Walls (Tony Wale, Aoke, Langalanga Apex Association, Honiara, Solomon Islands)
This simple method has worked for the community of Langalanga Lagoon. They are seeing sand deposited at the coast and their beach gradually being replenished; mangroves will be replanted along the stonewall to create a buffer zone for their shores.

Samoa

Groynes (from Kevin Petrini, United Nations Development Programme Pacific Centre, Suva, Fiji)
In Samoa they were opting for construction of groynes which might prove to be a “lengthy and relatively expensive” intervention.

Nauru

Rock Extensions (Godfrey Waidubu, Medical Officer (Climate Change), Nauru)
In Nauru, the erection of what was considered a minor seawall i.e. rock extensions to the reef in the short term would provide the necessary protection. However, in the long term it would cause the movement of sand in large volumes to other areas. Hence, most of the sea walls or extensions would become bare without sand on both sides and depend on the coastal processes in that given area. As in the case of Nauru, the sand started to accumulate again.

Murray Ford and NZ Consultants Ltd (2013)

In a recent publication "A Landowner's Guide to Coastal Protection", some important tips were shared:
In designing seawalls- it is better to have walls that are higher than the waves height, especially king tide and storm waves. Ensure that the toe of the seawall is built in a way that it is not scoured. The wall should be extended long enough to protect adjacent coasts and not only infrastructure on the site. The seawall should be built to withstand wave energy and debris transported by wave actions and current.

In cases of revetment, walls should be high enough to avoid waves overtopping. Placing of filter cloth is necessary before building a revetment. Ensure the foundation is protected from being eroded. The slope of the revetment should be 1:2 or at 30^0 angle. The structure should be strong enough to withstand high energy waves. Groynes are built to be high enough to trap sand and sediment transported along the beach. The groynes should be extended long enough to capture the sand movement. Spacing out groynes is important and the preferred option is to have them three times the length of the groynes. Breakwater structures should be built to be higher than the storm waves height so that it breaks off the incoming waves. Breakwaters built far from the beach will help reduce the waves energy and help build a beach on the leeward side. The use of filter cloth is recommended when built on a sandy beach. It is also wise to build breakwaters that are submerged in the sea.

5.2 Soft Coastal Structures

Federated States of Micronesia

Replanting Mangroves and Pandanus (Vita Akapito Skilling, Secretary of Health and Social Affairs, Federated States of Micronesia)

In attempting to dissipate the energy from the waves that erode the shore, women of Kosrae are replanting mangrove forest along the coastline. In Pohnpei, the women are planting pandanus trees along the coast, especially on the atoll islands in the hope of slowing down the erosion and provide vitamin A rich foods for the people residing on the islands.

Tuvalu

"Foraminifera" in Tuvalu (Shigeki Ishigaki, Japanese International Cooperation Agency (JICA), Suva, Fiji)
The Foram Sand Project is a joint research project by Japanese and Tuvalu research organizations and was launched with the support of Japan International Cooperation Agency (JICA) and Japan Science and Technology Agency (JST). This project aims to reproduce local species of foraminifera (a type of microscopic marine organism with a silica-based cell wall) to produce new 'foram sand' that can be used to replenish eroded areas. The downside of this initiative is the high cost involved and slow growth.

Samoa

Community Based Adaptation Initiatives (Kevin Petrini, United Nations Development Programme Pacific Centre, Suva, Fiji)

As part of their CBA proposal, some of the soft solutions related to watershed management and marine protected areas were identified. For hard solutions, however, they were opting for construction of groynes which might prove to be a "lengthy and relatively expensive" intervention. Relocation and continuing with other soft measures remain as the best practices for coastal protection.

Caribbean Barbados

The 3 Strands Strategy (Lorna Inniss, Coastal Zone Management Unit, Barbados)
In Barbados, a best practice in this area of coastal climate change adaptation consists of three (3) strands: Protection, conservation, restoration of the five natural lines of defense against high water level (mangrove swamps and other coastal vegetation, beaches and sand dunes, sea grass beds, fringing reefs, and bank reefs), Control of human behavior through a rigorous regulatory framework and as the last resort use targeted, well-designed, science-based shoreline stabilization "hard" structures such as groins, breakwaters and revetments.

Vanuatu case study - Traditional Marine Protected Areas

(William Bani Arudovo In-Country Coordinator, Vanuatu)

A palm leaf erected on the coast like the one in the photo below signifies a taboo and could mean either of two things:

- someone is disputing ownership of this particular coastal area and hence, this prohibits usage of resources and, or stops any development that is likely to take place in the area

- This signifies a taboo (stop) to the harvest of marine resources in the area (MPA) until such time when the palm leaf is removed by whoever placed it. There would usually be a number of leaves erected for this purpose to indicate the boundary of the MPA.

One has to ask around within the community in order to know the exact purpose of the leaf that was erected.

Figure 208 Traditional MPA in Vanuatu

Papua New Guinea case study - Marine Protected Area (MPA)

(Rose Godana, PNG)-Out of the 52 protected areas, there were nine MPA in PNG. In Madang province there were three sites- Baqiai (13,760 ha); Crown Island Wildlife sanctuary (58,969 ha) and Ranba (41,922 ha); Kamiali of Morobe province (65,541 ha); Maza of Western province (184,230 ha); Ndrolowa of Manus province (5,850 ha); Pirunq of North Solomon province (43,200 ha); Talele Island National Park Reserve of Eastern New Britain (12 ha) and Tavalo of Eastern New Britain (2000). PNG is included in the Coral Triangle Initiative (CTI). There are four CTI demonstration sites. They are located in Manua, Kimbe, Milne Bay and Madang provinces. The Kimbe Bay Marine Management Area is a network composed of 11 locally managed marine areas where CTI is working at.

Samoa case study – Marine Protected Area (MPA)

Samoa has MPAs in Aleipata and Safata. The project goal was to provide for the sustainable use and protection of coastal marine biodiversity which is under threat in these two locations. In Aleipata district, protection was focused on coral reefs, nesting ground of seabirds and feeding and nesting grounds for turtles. In Safata conservation measures are targeting coral reefs, lagoon and mangroves habitats.

Fiji- LMMA

Fiji has initiated a network of Locally Managed Marine Areas (LMMA) around the region. The idea is to share experiences on how member countries in the Pacific conduct their own LMMA. Some examples of LMMA are found in PNG, where they have M'buke Ailan Marin Menesmen Eria, Manus Province. In the Solomon islands they have Community Based Management of Marine Resources in Jorio, Vella Lavella. In Vanuatu, they have integrating natural resource management, ecosystems with social, political, economic, environmental elements at Marou and Emua, North Efate. In Fiji, they have the Namena Marine Reserve, Kubulau, Bua Island. In the Cook islands, they have the Aiutakitrochus management experience of controlling overharvesting of trochus shells. In Tuvalu, they have Island Conservation Areas in Tuvalu, an improvement of marine resource management. In Samoa, they have the Community based Fisheries Management Programme. In the Marshall Islands, they have Reimaanlok-Developing a national conservation area strategy. While in French Polynesia, they have the Mana and Biosphere conserve natural biodiversity, ecosystems and land and seascape programme.

Tuvalu case study - Planting of Coastal littoral vegetation

Like all Pacific countries, there are natural coastal littoral vegetation. There are grasses and plants grown on beach areas, followed by plants and trees beyond the high water mark in land. These littoral vegetation are natural formed of coastal engineering structures that helps in protecting the island. In a recent publication of the Plants of Tuvalu written by Thaman et al. (2012), the creeping vine known as beach morning glory *(Ipomoea pes-caprae)* are normally found on coral rampart of ocean coast of Fogafale, Funafuti. Beach heliotrope *(Tournefortia argentea)* are common in beaches of Tuvalu plays important role in stabilizing beaches and protecting coastlines. Saltgrass, swamp couchgrass and seashore paspalum *(paspalum vaginatum)* are dense grasses formed near beaches in Tuvalu. Burr grass *(Cenchrus echinatus)* is a weedy grass often found in sandy areas near the coast in Tuvalu. Another common shrub *(Scaevola taccada)* is found in abundant in coastal littoral vegetation. The large trees that help protect the beaches in Tuvalu are *Calophyllum inophyllum, Barringtonia asiatica, Thesapesia populnea, Cordia subcordata and Luumnitzera littorea*. [66]

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[66] Extracted from Thaman et al. (2012)

Tonga case study- Coastal reforestation in Tonga to protect coastlines

(Prof. Randy Thaman, Andrew Smith and Tevita Faka'osi) . [67]

Over 30 indigenous species were planted in three phases over a 2 km of coastlines in Tonga. These species included coconut palms, Panadanus tectorius, Hibiscus tiliaceus, Excoecaria agallocha, Calophyllum inophyllum, Hernandia nymphaeifolia, Terminalia catappa, Tournefortia orgentea, Barringtonia asiatica and Neisosperma oppositifolium and other species. They planted casuarinas in two rows as wind breakers and on the leeside of these casuarinas they planted 30 indigenous coastal trees. After six months they planted less tolerant trees. Finally they planted hard trees to increase diversity.

Vetiver grass

(Dr Christopher Bartlett, SPC/GIZ Coping with Climate Change in the Pacific Islands Region, Vanuatu) [68]

The SPC/GIZ joint initiatives hope to enable local communities to cope in ways that are not prohibitively expensive and are locally implementable. These initiatives include land use planning, sand/aggregate mining control, rehabilitating/replanting coastal areas with indigenous terrestrial vegetation such as creeping vines and planting of 'vetiver' grass to control both inland and coastal erosion. Also included in the program are hard technologies such as Gabion baskets.

The planting of Vetiver grass is a successful one in Fiji especially close by the river bank. The soil is rich enough to assist in the growth of the vetiver grass.

Figure 209 Vetiver grass fully grown.
(Source: Photo credit Mr. Leone Limalevu)

Figure 210 Planting of Vetiver grass near river bank

More information on Vetiver grass can be found in the manual by *Fenemor et al., (2010)- Vetiver: The proven soil conservation technique. A training manual for communities and field workers.*

Vanuatu case study- A revegetation technique to prevent sediment damage to fringing reefs in Vanuatu.

(Don Miller and James Comley).

Severe soil erosion over the steep slopes of Aneityum in Vanuatu over many years have caused damaged to the fringing reef at sea. The solution was the use of effective Vetiver plants- *Chrysopogon zizanioides*. They were planted around hill slopes to hold back the soil from erosion. This revegetation technique was a successful one as it reduces sedimentation erosion and improve coral reef health.

[67] Wilkinson and Brodie (2011) p.82-82
[68] Wilkinson and Brodie (2011) p.58-59

Fiji Case study- Implementing Ecosystem-based management (Stacy Jupiter) [69]

The Wildlife Conservation society, Wetlands International Oceania and the WWF South Pacific programme developed and implemented EBM within the Vatu I Ra and Cakaulevu region of Vanua Levu. They produced the Kubulau EBM Plan.

Fiji case study- Integrated Coastal Management in Vanuaso Tikina, Gau Island.
(Dr Joeli Veitayaki) [70]

The villagers were able to develop their resource management plan to preserve their environment resources. Among their activities they wanted to conserve parts of their fishing grounds using their traditional rights, prohibiting the use of destructive methods, protecting and rehabilitating mangrove forests and coastal vegetations, and many more. The ICM was successful as they declared a no-take zone in six villages, they built stone breakwaters to protect the coasts in Naovuka and Lamiti, replanting of coastal forests, restocking of giant clams in protected areas, replanting of mangroves etc.

Niue Sustainable Coastal Development Policy
Niue is moving in the right direction with its sustainable coastal development policy. Its vision is 'a safe, productive and sustainable coastal environment for Niue". It has six major thematic goals:

1. Upholding coastal areas as national Taoga for all Niue
2. Integrated coastal planning, management and development
3. Pollution control and waste management
4. Sustainable management and development of coastal resources
5. Disaster risk reduction and disaster management
6. Strengthening governance and capacity building [71]

5.3 Biophysical Structures

Niue case study

Niue, 'the island of the rock' has cliffs that offer best examples of natural forms of coastal protection structures.

Figure 211 Niue cliff with wave actions

Figure 212 Niue High Cliffs

Figure 213 Niue's cliff as front-line of defense

[69] ibid p.74-75
[70] ibid p.72-73
[71] SOPAC (2008)

5.4 Coastal Adaptation Mechanism

This section will present three of the main coastal adaptation mechanisms. These mechanisms are:

- Participatory approach;
- Tools and Designs;
- Relocation.

5.4.1 Participatory approach

One of the most effective means of ensuring sustainability of any coastal adaptation initiatives is the involvement of affected stakeholders in particular the coastal communities. Therefore, participatory approaches have been proven to be a very effective means of ensuring that the affected communities are involved in the implementation, maintenance and rehabilitation work of their built and/or natural coastal protection initiative.

Vanuatu - 'Community Participatory Model' on Epi Island (from Ian Ierct, Pacific Adaptation to Climate Change Project, Public Works Department, Port Vila, Vanuatu)

The 'Community Participatory Model' became a workable intervention on Epi Island due to proper consultations with the community leaders and a better physical overview of the road issues. They in turn, identified the affected areas around the coast and agreed to give ' for free' their land and resources for PACC project implementation on Epi. It is hoped that this model is replicated in other islands in Vanuatu and other countries.

Coral Triangle Initiative (CTI)

Five Pacific countries are within the Coral Triangle Initiative (CTI), which include Timor Leste, Papua New Guinea, Fiji, Vanuatu and the Solomon Islands. The CTI programs would lead to improving marine and coastal ecosystems which in turn enhance food security and build capacity in integrated coastal resources management in these countries. In Timor Leste, CTI will introduce integrated coastal resource management and ecosystem based fisheries management in Batugede and Atauro Islands. In PNG, CTI will undertake coastal resources management in Kimbe bay and Manus Island. In Fiji, CTI will introduce Locally managed marine area community based management model in Ra Province. In Vanuatu, CTI will develop planning in coastal communities. The Coral Triangle Initiative will focus attention in Malaita and Isabel Province.

Fiji - Linking initiatives to Livelihoods and Well-being

(Floyd Robinson, United Nations Development Programme Multi Country Office, Suva, Fiji)

A critical factor when working with communities is linking initiatives to their livelihoods and wellbeing. Community support is enhanced once they understand and identify the link between the establishment of no fishing zones and replanting (mangrove plants not only protected the coast line but also attracted certain fish species like mullets and crabs).

5.4.2 Tools and Designs

There are many types of tools identified that have been put to use in the Pacific for coastal protection and they include the coastal calculator, GIS, mapping tool, GPS, the coastal protection guideline and fact sheets. Some designs of seawalls are also identified.

Cook Islands

'Coastal Calculator' (Paul Maoate, Pacific Adaptation to Climate Change Project, Ministry of Infrastructure and Planning, Cook Islands)

The creation of the 'Coastal Calculator' is an ideal example of PACC Cook Islands' effort to incorporate climate change risks into sustainable development programmes.

It was designed to help engineers determine wave run-up during storms and hurricanes, as well as allow them to include sea-level rise projections in the designs of harbors and coastal infrastructure.

Collect good quality maps and aerial photographs

It is important to gather digital images of 'hot spots' or problematic areas of the coast. The use of digitized satellite images through GIS (geographical information systems) technology, GPS and Google Earth. Mapping of the important areas provides vital information to guide decision making. In most cases the local community does not enjoy access to these technologies so outside help might be sought after in such cases. A good case study was that written by Lauretta Burke and Zachary Sugg (Watershed-based threat analysis for the Mesoamerican reef: Using the power of satellites and GIS technology to tackle problems). The information gathered from GIS technology was helpful in recommending best practices to reduce erosion and pollution.

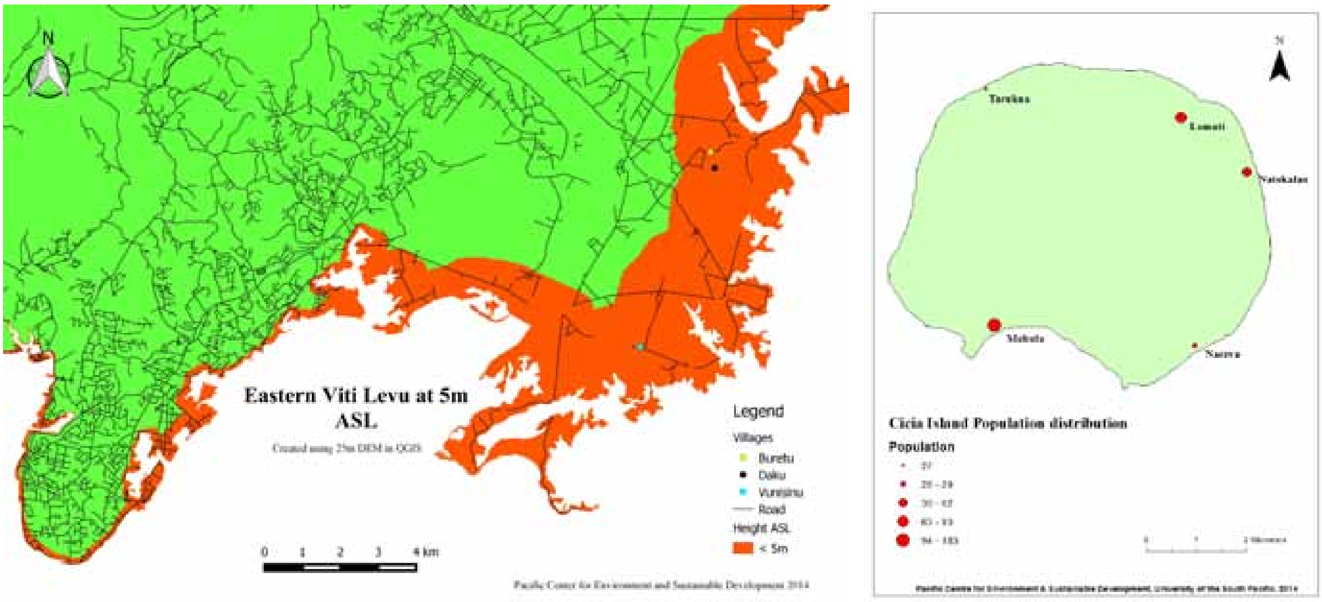

Figure 214 Using GIS as a tool to highlight at risk areas by calculating height above sea level. (Image by Siu I Fanga Pouvalu , Kevin Maitava, Andra Whiteside and Mavis Yuen).

Kiribati case study

Kiribati has a Coastal protection guideline developed with the assistance of Beca International Consultant Ltd in 2010 to protect coastline. The following are essential steps taken:

Step 1 - identify coastal hazards and coastal processes
Step 2 - assess the coastline
Step 3 - choose high risk site
Step 4 - collect essential information
Step 5 - observe current status (existing environment)
Step 6 - review information collected
Step 7 - decide what to do
Step 8 - Consider all options
Step 9 - Profile survey
Step 10 - outline design
Step 11 - compare design
Step 12 - obtain approvals
Step 13 - detail design and pre-construction
Step 14 - quality control during construction

Kiribati has created the World's largest marine protected area. The Phoenix Islands Protected Area (PIPA) covers an area of 410,500 km^2.

SOPAC Fact Sheet

SOPAC has developed a Fact sheet No.7 where they provide information about coastal erosion in the Pacific. This is one way of building awareness in the region on coastal erosion, coastal protection and advice on erosion. Some tips shared were:

What you should do about erosion?:

- Comply with building codes and zoning plans
- Consider all options and plan effective strategy
- Understand your coastal processes
- Use GIS and map out the affected area
- Do not build adjacent to beach leave a reasonable space

What to avoid?:

- Do not disturb the movement of sand and waves
- Avoid building too close to the beach
- Avoid building seawall unless necessary
- Avoid dumping of solid waste on beach

(Source: SOPAC (2007)).

Kiribati Seawall designs

The use of sand bags as seawalls:

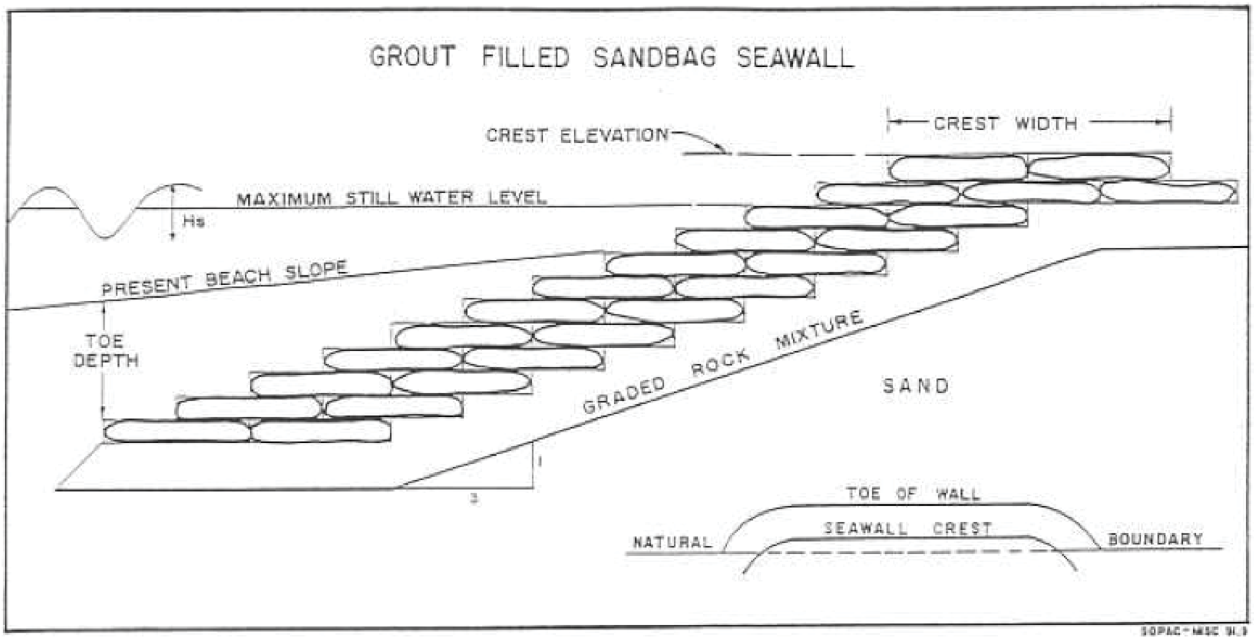

Figure 215 Design of sandbag seawall in Kiribati. (Source: Holden (1992))

Beca International Consultants Ltd was successful in introducing some creative seawall designs for Kiribati as part of KAP II project. These include the use of sand bag seawalls, reinforced concrete walls, and planting of mangroves. To cite more seawall design options see the KAP II report by Beca International Consultant Ltd.

5.4.3 Relocation

Fiji – Relocation

For the first time Vunidogoloa village under the Province of Cakaudrove in Vanua Levu, Fiji was relocated through the government new climate change program. The Vunidogoloa village relocation project was completed in 2014 and was officially opened by the Prime Minister Voreqe Bainimarama. The village is located close to the sea. The reason behind the relocation was due to sea level rise where the village easily gets flooded during high tide. Quite a few other relocation programs facing almost the same problems are in the pipeline in Fiji

Figure 216 Relocated Homes

Images By. Teddy Fong

Figure 217 Top of cliff looking down to the sea,Niue

Niue – Relocation

Higher Ground (Haden Talagi, Pacific Adaptation to Climate Change Project, Department of Environment, Alofi, Niue)

Relocation was found to be the most suitable coastal protection measure in Niue. This entailed moving from the lower terrace to the upper terrace, 20 meters to 30 meters above sea level and also relocating further inland. This measure is cost effective as compared to building infrastructure that can withstand a Category 5 cyclone, similar to the one that hit Niue in 2004.

Samoa – Relocation

(Kevin Petrini, United Nations Development Programme Pacific Centre, Suva, Fiji)
In Samoa relocation and continuing with other soft measures remain as the best practices for coastal protection.

5.5 Assessment of Coastal Erosion in FSM

(Recommendations offered by Maharaj (1998)

- Do not construct seawalls and Groynes
- Do not reclaim beaches, mangroves and reef areas
- Do not mine the beaches surf zone or back reef areas
- Do not blast the reef or cut reef channels
- Do not build along the beachfront
- Buildings should be set back from the shoreline
- Do not destroy shoreline vegetation

- Re-vegetate the coastline
- Do not dispose of waste and garbage in mangroves and reefs
- Obtain aggregate from adjacent uninhabited islands or the mainland
- Nourish beaches where possible
- Airport construction should be preceded by EIA's and EIS
- Relocate and redistribute population in crowded areas
- Educate public on the use and management of coastal resources.

5.5.1 Scientific approaches to Coastal Management

Pacific countries could benefit from adopting scientific approaches to the management of coastal zones. Some of these approaches are integrated coastal zone management (ICZM); Ecosystem based management (EBM); Marine spatial planning (MSP); Ecological modelling; and mapping tool. ICZM is a dynamic process whereby both human and ecological dimensions are considered for sustainable use and protection of coastal zones. The EBM takes into account the cumulative interactions of different activities and impacts and defines the strategic objectives to sustainably manage them. MSP actually focus on planning of different uses of coastal and marine ecosystem and finding solutions to these problems. Ecological modelling helps in creating understanding of how models and process contribute to effective coastal management. [72]

[72] Nobre (2011)

CHAPTER 6: CONCLUSIONS

By Luke Paeniu, Viliamu Iese and Isoa Korovulavula

In this report we have defined the coast as the zone where waves and land interact. We have also described why coasts are important in satisfying human needs in terms of how Pacific Islanders use the coast for many purposes. The problem facing Pacific countries with regards to the deterioration of their coastlines are also on the rise as they continue to be populated, while these coastlines keep changing as a result of the natural climate and especially as a result of the human engineering interventions that have taken place.

The primary aim of this report was to provide important guidelines and lessons of coastal processes and beach dynamics, different types of interventions and how to develop effective coastal protections in future. These guidelines and lessons were collected from numerous literatures within the Pacific region. The approached used to collect these important knowledge were through posting and sharing of views in the Pacific solution exchange network hosted by UNDP and obtaining relevant information from SOPAC library and literature search through USP library and Google search.

The report identified non-structural and structural coastal protection interventions. Non-structural interventions include- knowledge of coastal processes, policy on working with nature, retreat, accommodate and protect approach, Environmental Impact assessments framework, Foreshore regulations, Locally managed marine areas, NBSAP, integrated coastal zone management plans, Adopt ridge to reef approach, established engineering standards and building codes. Examples of structural interventions found in the Pacific were Maintaining healthy reef islands and islets; protection and restoration of seagrass and seaweed systems; maintaining healthy fringing and barrier coral reefs; planting of mangroves; stabilizing coastal beaches and beach nourishment. Hard structures are seawalls, groynes, revetments, gabions, and breakwaters.

The report was able to capture some examples of these structural interventions in some Pacific countries, through photographs.

Some selected Pacific experiences were shared on hard and soft structures, biophysical structures, coastal adaptation mechanism, participatory approach, tools and designs and relocation options.

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