Survey of Climate Change Adaptation Measures in Maldives

Final Report

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Ministry of Housing and Environment

Integration of Climate Change Risks into Resilient Island Planning in the Maldives Project

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Note: Cover Image – Portrait Gallery

Executive Summary

The ‘Integration of Climate Change Risks into Resilient Island Planning in the Maldives’ (ICCRRIP) Project seeks to elaborate, demonstrate and promote community based and other climate change adaptation measures used in the Maldives. The purpose of this survey is to provide baseline information on adaptation activities in Maldives, and to identify adaptation options currently being used that may be suitable for replication in the project. This survey was conducted between October and December 2010 in 40 islands spread across Maldives, including 25 residential islands and 12 resort islands and 3 infrastructure islands. The specific objectives of this project are (i) to compile information on the variety of adaptation measures currently being taken to address coastal erosion, flooding and other climate related risks in different residential and resort islands; (ii) to assess the relative effectiveness and costs of the adaptation measures and the factors those appear to affect performance of these measures; (iii) to assess the potential for implementation of ‘soft’ adaptation measures and the major barriers, constraints and opportunities at the island level.

Methodology

The methodology used to address the objectives of this report involved a mix of field data collection, questionnaire surveys and review of existing technical information. The framework for the assessment is essentially divided into 8 main components: 1) identifying potential survey islands; 2) preparing the survey instruments; 3) pre-testing the survey instruments; 4) implementing the survey; 5) compiling and analyzing survey results; 6) preparing a draft report; 7) reviewing draft report and preparing final report, and 8) preparing a compendium with illustrations of examples of ‘soft’ measures.

Types of Adaptation Measures

This assessment is divided into two broad groups of coastal adaptation measures: ‘hard’ and ‘soft’ engineering measures. A *hard engineering* method is generally used to describe traditional civil engineering works which are designed to abate the impacts of natural forces (e.g. Sea wall). *Soft engineering* methods are used to describe construction methods that attempt to enhance the natural features or processes as an option for adaptation (e.g. beach replenishment).

Hard Engineering Measures

'Hard' engineering measures are further classified as shown in Table below.

Erosion control and prevention	Access Infrastructure	Rainfall flood mitigation	Reducing land shortage	Others
Fore shore seawalls or bulkheads Near shore breakwater Revetments Gryones *Adhoc* reclamation	Breakwater Quay wall Groynes Jetty	Artificial wetland drainage Temporary drainage Roads	Land reclamation	Causeways Bridges

Amongst these, this study focuses on the erosion control and prevention measures and rainfall flood mitigation measures, as they are the most commonly used types of climate change adaptation measures in Maldives.

There are two classes of hard engineered erosion and flood prevention measures: armouring and shore stabilization structures. *Armouring structure*s consist of measures to guarantee no further retreat of existing beach line and wave overtopping. They include seawalls, bulkheads and revetments. *Shoreline stabilization* measures are designed to modify the coastal processes to achieve shore stabilization. The most common materials used for construction are dead coral, sand-cement bags, concrete piles, armour rock and sheet piles. Coral mounds are no longer used due to a ban on coral mining. The table below summarizes the key types and material used.

Class	Armouring Structures			Shore stabilization	
Type	**Seawall**	**Bulkheads**	**Revetment**	**Breakwater**	**Groynes**
Geometry or location	Vertical	Crib Tie-backed	Sloped	Detached Single System Submerged	System (field) Single Straight line Shaped (T, L or lollypop)
Construction Materials	Sand cement bags Armour rock Coral mound Geo-bags Jumbo Bags Empty concrete Oil drums	Steel Sheet piles Timber piles Concrete spun piles	Concrete S-blocks Sand-cement Bags Geotextile	Sand cement bags Armour rock Coral mound Sand-cement bags with in-filling Geo-bags Concrete-earth filled cubes	Sand cement bags Armour rock Coral mound Geo-bags Empty concrete Oil drums

The costs of hard engineering measures vary and are linked to durability of construction material. Concrete 'tetra pods' are the most expensive structures used in Maldives, at a cost of Rf64,000 per linear m (in 2011 prices). Other costly but durable options include sheet piles (Rf40,000 per m), armour rocks (Rf 37,000) and concrete piles (Rf36,000). Efficient low cost options such as sand filled geotextile bags (geo-bags) cost Rf26,000 per linear meter. The most commonly used sand-cement bag costs have increased to about Rf30,000 per m for a breakwater, a figure higher than geo-bags. Newly introduced revetments promises to be a much more cost effective solution to high energy zones, particularly sand-cement bag type (Rf9,600 per m) and concrete Z-block type (Rf10,000 per m). Low durability options such as coral mounds, sand-cement bag seawalls and new innovations like concrete filled barrels and jumbo bags, costs a fraction of the cost of durable material, but their maintenance costs are prohibitively higher in the long run. Low cost options are preferred when upfront financing is an issue, especially in community funded projects.

When these figures are used to calculate the likely cost of protecting entire length of shorelines in all inhabited islands, the costs exceed US$8.7 billion using high cost concrete tetrapods and US$1.6 billion using sand cement bags. If the protection of settlements or inhabited areas only is considered, the figures reduce to US$5.5 billion using tetra pods and US$1.0 billion using sand-cement bags.

The effectiveness of adaptation measures are difficult to determine as most of the measures are highly effective when used in the right conditions and, designed and constructed appropriately. Perception of effectiveness also varies depending on the site conditions. However, in general, it can be deduced that coral mound and sand-cement bag constructions are considered ineffective for breakwaters and to some extent in seawalls. Armour rocks are now accepted as the most durable and cost effective material for breakwater construction. New revetment designs based on sand-cement bags and concrete blocks are also considered very cost effective, especially in high energy zones, as they can replace the costs of armour rocks or concrete breakwaters. Revetments have been identified in this study as one of the key measures to promote and replicate across islands.

There are a number of issues and challenges in hard engineering measures used in the Maldives. They include:

i. Poor design and construction
ii. Mismatch between site condition and design (for example, a generic template is used across all islands regardless of the hydrodynamic conditions and sediment flow patterns)
iii. Inadequate maintenance
iv. Less durable material like sand-cement bags
v. Ad hoc replication of design across islands without considering their applicability to a new setting.
vi. Erosion prevention measures are usually implemented in the 'last-minute', making the use of 'hard' measures compulsory.

Soft Engineering Measures

'Soft' engineering measures presented in this report are classified as follows:

Quick Fix' measures	'Long-term' measures
Beach Replenishment	Land use controls & setbacks
Temporary seawalls and groynes	Coastal vegetation retention
Ad hoc seawalls and ridges	Ridge maintenance
	Artificial reefs
	Drainage adjustment
	Coastal structures on stilts
	Submerged sand-filled geotextile tubes

The most commonly used soft adaptation measures in Maldives are: beach replenishment; construction of temporary sea walls or groynes using sand bags; land use controls and setbacks; *ad hoc* seawall and ridges constructed from construction debris; coastal vegetation retention; construction of coastal structures on stilts; maintenance of coastal ridges and preservation of coral reefs. Amongst these, planned implementation is considered only in beach replenishment, temporary seawalls, land use setbacks and construction on stilts. Other options could be described as being 'subconsciously' implemented as indigenous adaptation measures against natural hazards.

Most planned soft adaptation measures are implemented in resort islands. For example, beach replenishment, construction on stilts, artificial reefs and, to some extent, temporary seawalls are almost exclusively used as adaptation measures in resort islands. Inhabited islands generally use coastal vegetation retention, *ad hoc* seawall construction, ridge retention and land use controls and setbacks.

The upfront cost of soft engineering measures is generally lower than hard structures but involves continued commitment to maintain the measures over a long period of time. The cost of soft measures range from Rf1873 per linear m for submerged geo-tubes and Rf1,625 per m for replenishment to Rf720 per m for temporary seawalls.

The main challenge for using soft adaptation measures in Maldives is the lack of awareness and lack of foresight to consider erosion mitigation measures before it becomes a threat to existing property. Soft measures have not been properly demonstrated in Maldives, particularly in inhabited islands making developers and communities reluctant to use them.

The general perception of new resorts islands are very much in favour of using soft measure and against using hard measures. In contrast, the older resorts, which currently have a number of hard measures, are reluctant to remove them. In inhabited islands, perception towards soft engineering measures is mixed. Most people can immediately identify the benefits of soft measures through their indigenous knowledge of the environment. However, they are generally reluctant to consider an 'invisible' protection measure against erosion and flooding. They perceive such measures to be most suitable to resort islands who are mostly concerned with retention of beach as a product. This is partly linked to the perception that coastal protection is the responsibility of the Government. Hence, when Government provides an investment they prefer those measures to be hard engineered structures. However, perceptions do vary depending on the hazard exposure of islands.

Despite these challenges, there is a real opportunity to raise awareness and increase the acceptance of soft measures, as the locals can easily identify with the benefits of such measures.

Similar to hard engineering measures, it is difficult to determine the effectiveness between soft measures as each of these is highly effective, provided they are used in the right purpose, conditions and appropriate designs. However, in general, most resort islands consider beach replenishment, artificial reefs and temporary seawalls as the most cost effective due to: (i) the relatively small total cost of implementation; and (ii) high value of benefits from reduced erosion on tourism products and improved aesthetics.

Recommendations

The key recommendations are as follows:

1. Success stories in various adaptation measures need to developed, promoted and replicated across islands.
2. New guidelines need to be prepared and best practices need to be conveyed across islands, coastal engineers, contractors, developers and administrators.
3. Changes are recommended to the existing regulations on beach replenishment and land use setbacks.
4. Awareness programmes need to be conducted to convey the concept, benefits and effectiveness of soft adaptation measures.
5. Training programmes need to be conducted to select groups who are directly involved in the design, decision making and construction of adaptation measures (e.g. resort engineering staff, island administrators and key contractors)
6. New studies need to be encouraged, incentivized, facilitated and funded to increase the knowledge base in the field.

In conclusion, this report has presented a compendium of coastal adaptation options used in the Maldives. Numerous gaps in information, weaknesses in existing measures and a major weakness in transfer of coastal adaptation technology across islands have been identified. The good news is that most of these weaknesses could be overcome with simple measures such as proper dissemination of information, guidelines and awareness raising activities.

1 Introduction

The ‘Integration of Climate Change Risks into Resilient Island Planning in the Maldives’ Project seeks to elaborate, demonstrate and promote community based and other climate change adaptation measures used in the Maldives. Particular attention is given in the project to assess and promote ‘soft engineered’ or ‘soft adaptation’ measures. A preliminary requirement of the project is to determine the baseline conditions in relation to the exiting coastal adaptation measures, their effectiveness and challenges.

This component of the project has been commissioned to undertake an assessment that could provide a rapid assessment of the baseline conditions. Hence, the purpose of this survey is to provide baseline information on adaptation activities in Maldives, and to identify adaptation options currently being used that may be suitable for replication in the project. The output of this survey is a compendium of adaptation measures that can be implemented by communities, highlighting the features of each measure, their strengths, weaknesses, and providing illustrated examples across Maldives.

This survey was conducted in 40 islands spread across Maldives and included 25 residential islands and 12 resort islands and 3 infrastructure islands. The survey was conducted between October and December 2010.

The specific objectives of this project are:

1. To compile information on the variety of adaptation measures currently being taken to address coastal erosion, flooding and other climate related risks in different residential and resort islands.
2. To assess the relative effectiveness and costs of the adaptation measures and the factors those appear to affect performance of these measures.
3. To assess the potential for implementation of ‘soft’ adaptation measures and the major barriers, constraints and opportunities at the island level.

2 Coastal Adaptation Concepts

This section summarizes some of the key concepts used in this report.

Adaptation Strategies

There are four broad planning strategies commonly prescribed for adaptation to climate change and sea level rise in coastal states: **i) do nothing; ii) accommodate; iii) defend or; iv) retreat** (IPCC, 1990, IPCC, 2007). Amongst these, the only viable options for small island states are mainly to defend and to some extend accommodate (Tompkins et al., 2005). The adaptation measures found in the 40 surveyed islands broadly belong to these two categories.

Hard vs. Soft Engineering

The construction methods used in coastal adaptation could be broadly classified into **'hard engineering'** or **'soft engineering'** measures. A hard engineering method is generally used to describe traditional civil engineering works which are designed to abate the impacts of natural forces. For example a foreshore breakwater is designed to prevent erosion from proceeding beyond the defended line and thereby ensuring permanency of the land behind it. Soft engineering methods, in contrast, are used to describe construction methods that attempt to enhance the natural features or processes as an option for adaptation (Billy L. Edge et al., 2003). For example, beach replenishment, coastal vegetation enhancement or coral reef enhancement. They also represent a significant shift in approach from a*d-hoc* response to coastal hazards to the adoption of a more holistic and proactive approach (Dean, 2002, Williams and Micallef, 2009).

Soft Adaptation

A related concept to soft engineering is **'soft adaptation'**. 'Soft adaptation measures' are broadly used to refer to a range of non-construction activities such as capacity building, legal framework enhancement and public awareness raising, to enhance and encourage effective adaptation to climate change. 'Soft engineering' measures are generally considered as part of soft adaptation measures.

3 Methodology

The methodology used to address the objectives of this Report involved a mix of field data collection, questionnaire surveys and review of existing technical information. The framework for the assessment is essentially divided into 8 main components: 1) identifying potential survey islands; 2) preparing the survey instruments; 3) pre-testing the survey instruments; 4) implementing the survey; 5) compiling and analyzing survey results; 6) preparing a draft report; 7) reviewing draft report and preparing final report, and 8) preparing a compendium with illustrations of examples of 'soft' measures.

Each of these components is described below.

3.1 Assessment Framework

3.1.1 Identifying potential survey islands

A list of 50 potential survey islands was provided by the Ministry of Housing and Environment (MoHE) or the project (See Appendix A). However, MoHE requested to cross-check this list and suggest alterations based on the consultants expert opinion. A preliminary assessment of sample survey islands including were undertaken using an existing costal infrastructure database and a GIS. The island selection report is attached in Appendix B.

The guidance parameters for island selection considered both physical and socio-economic parameters.

<u>Physical Considerations:</u> The islands of Maldives are generally considered to have uniform physical features: low-lying islands with unconsolidated sediments spread across a fairly constant reef depth. However recent studies on geomorphology and disaster risks of Maldives have revealed significant variations in island hazard exposure and physical response. Some of the key studies are summarized below.

i. Physical variation in reef characteristics and climatic forcing across the Maldives archipelago. These include differences in wave regimes between the north/south and east/west of Maldives (Naseer, 2003) and; variations in reefs numbers sizes and reefs with islands (Woodroffe, 1993).
ii. Geomorphological variations in the location of islands within an atoll (Kench et al., 2006).
iii. Variations in (geomorphological) types of islands (Ali, 2000, Kench, 2010b).
iv. Variations in hazard exposure of islands to coastal flooding, erosion and storm events across the archipelago (UNDP, 2006, Shaig, 2009).

v. Variations in coastal flooding and erosion hazard exposure of islands based on their island size, location in the archipelago or within atoll, island shape, orientation, distance between shoreline and, oceanward reef edge and reef-island ratio (Shaig, 2009, UNDP, 2007).
vi. Differences in erosion hazard based on the extent of coastal modifications (Kench, 2010b, Shaig, 2009, Kench et al., 2003).
vii. Natural coastal protection phenomena such as coastal mangroves and high coastal dunes are sparse in Maldives. However, islands blessed with such features enjoy reduced exposure to hazards.

Socio-economic Considerations:

a) Islands in Maldives are generally used explicitly for a single land use. The general land use categories are: i) human settlements; ii) infrastructure islands (such as airports, waste disposal, oil storage); iii) economic islands (such as tourism, agriculture, fisheries); iv) stewardship or varuvaa; v) recreation islands; and vi) special administrative islands (Shaig, 2006a). The types of coastal adaptations used in these various land uses differ as the size of economic investments and risk taking patterns of the investor or inhabitants differ.
b) The population density varies significantly across the islands. The coastal adaptation measures undertaken in densely populated islands may differ significantly from low density islands (Shaig, 2006a, Shaig, 2006b), due to limited coastal buffer areas.
c) The atoll capital islands usually enjoy a higher level of public investment on coastal protection than other islands.

Table of guiding parameters

Based on the above physical and socioeconomic aspects and discussions with Ministry of Housing and Environment, the following parameters and minimum sample size has been proposed for this project.

Parameter	Minimum sample size (islands)
Island Land use	Inhabited islands (18); Economic Islands (resorts 18, Other industrial 1); infrastructure islands (2)
Location within Archipelago	North (7); North central (7); Central (10); South Central (2); South (7) Note: The number of islands in the south central islands are proportionally smaller compared to other regions
Island Types	Circular atoll lagoon islands (5); Mixed shape, atoll rim small islands (10); Mixed shape, atoll rim large islands (10); Oceanic Islands (2);
Rim location within archipelago	Eastern rim (8); Western rim (8); eastern rim of western line atolls (3); western rim of eastern line atolls (3);
Island Size	Large >100 Ha (5 islands); Medium <100 and > 50 Ha (10 islands); Small <50 ha (10 Islands).
Island Orientation	East-west (5); North-South (5); Circular (5)
Population Density	High >30 person/Ha (5); Low <30 persons/Ha (5)
Inhabited island administrative status	Capital Islands (5); Others (5)
Existing major coastal modification	Reclaimed islands (5); Island with harbors (5); Islands with hard engineered erosion protection measures (5);Islands without significant coastal modifications (5).
Presence of coastal mangroves or high dunes	Mangroves (2); High Dunes (2)
Disaster risk assessment information	Island with detailed risk assessment (5)

Final List of Survey Islands

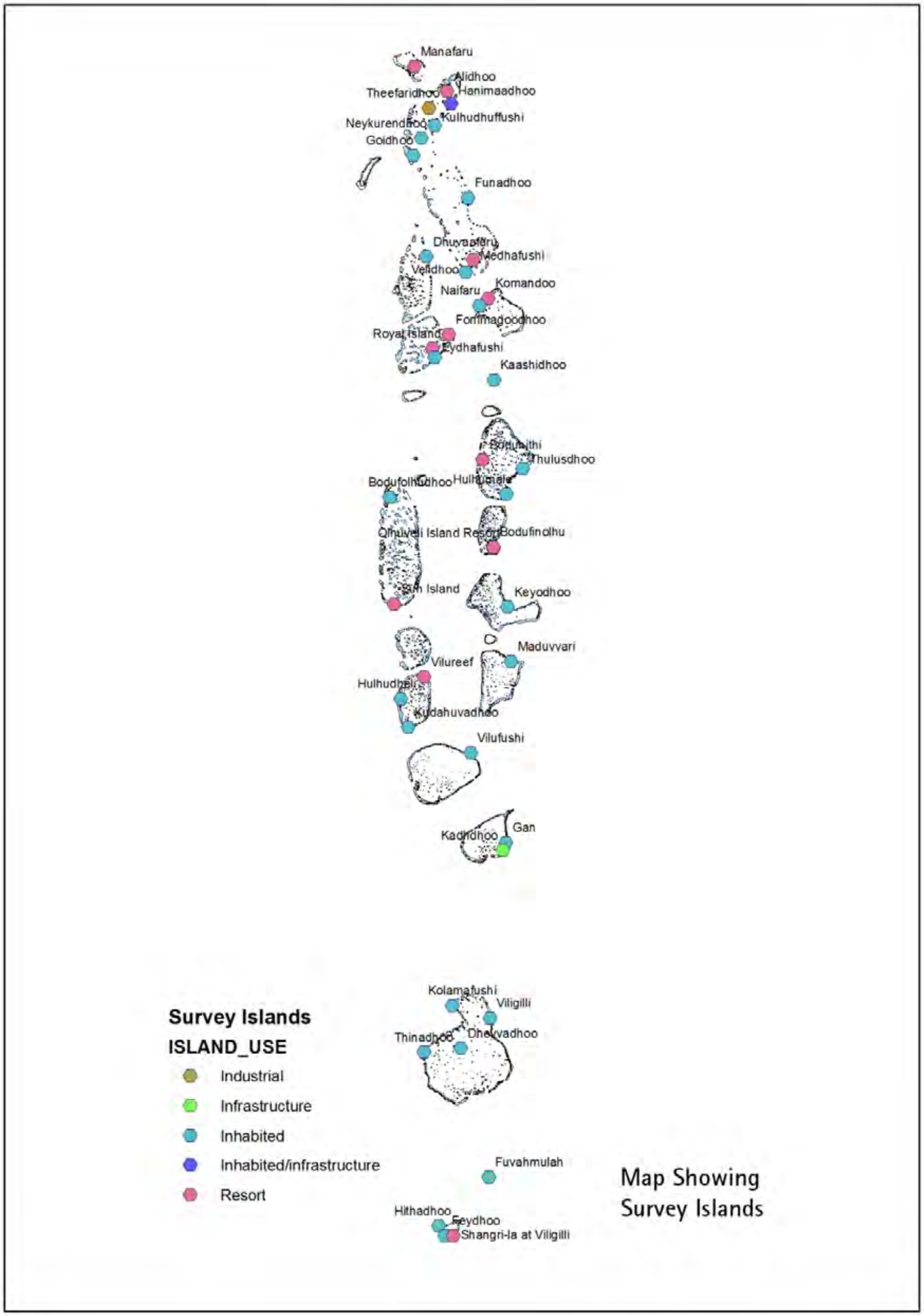
A list of islands derived from the above activity was compared with the list proposed by MoHE. Based on the findings a new list was proposed to MoHE for their considerations. After internal consultations in MoHE, the following list was issued as the final list for surveying. The maximum sample size was reduced to 40 islands.

Ministry selection	Island Code	Island	Atoll	Island use
1	1003013	Manafaru	Haa Alifu	Resort
2	1003034	Alidhoo	Haa Alifu	Resort
3	1103006	Theefaridhoo	Haa Dhaalu	Industrial
4	1103007	Hanimaadhoo	Haa Dhaalu	Inhabited/infrastructure
5	1103021	Kulhudhuffushi	Haa Dhaalu	Inhabited
6	1103027	Neykurendhoo	Haa Dhaalu	Inhabited
7	1203007	Goidhoo	Shaviyani	Inhabited

Ministry selection	Island Code	Island	Atoll	Island use
8	1203035	Funadhoo	Shaviyani	Inhabited
9	1303047	Medhafushi	Noonu	Resort
10	1303071	Velidhoo	Noonu	Inhabited
11	1403007	Dhuvaafaru	Raa	Inhabited
12	1503020	Fonimagoodhoo	Baa	Resort
13	1503034	Royal Island	Baa	Resort
14	1503040	Eydhafushi	Baa	Inhabited
15	1603007	Komandoo	Lhaviyani	Resort
16	1603015	Naifaru	Lhaviyani	Inhabited
17	1703004	Kaashidhoo	Kaafu	Inhabited
18	1703020	Boduhithi	Kaafu	Resort
19	1703025	Thulusdhoo	Kaafu	Inhabited
20	1703058	Hulhumale’	Kaafu	Inhabited
21	1703084	Kandoomaafushi	Kaafu	Resort
22	1703091	Bodufinolhu	Kaafu	Resort
23	1803013	Bodufolhudhoo	Alifu Alifu	Inhabited
24	1903053	Sun Island	Alifu Dhaalu	Resort
25	2003011	Keyodhoo	Vaavu	Inhabited
26	2103002	Maduvvari	Meemu	Inhabited
27	2303001	Vilureef	Dhaalu	Resort
28	2303021	Hulhudheli	Dhaalu	Inhabited
29	2303049	Kudahuvadhoo	Dhaalu	Inhabited
30	2403011	Vilufushi	Thaa	Inhabited
31	2503041	Gan	Laamu	Inhabited
32	2503042	Kadhdhoo	Laamu	Infrastructure
33	2603015	Kolamafushi	Gaafu Alifu	Inhabited
34	2603020	Viligilli	Gaafu Alifu	Inhabited
35	2603048	Dhevvadhoo	Gaafu Alifu	Inhabited
36	2703003	Thinadhoo	Gaafu Dhaalu	Inhabited
37	2803001	Fuvahmulah	Fuvahmulah	Inhabited
38	2903023	Hithadhoo	Seenu	Inhabited
39	2903026	Feydhoo	Seenu	Inhabited
40	2903028	Shangri-la at Viligilli	Seenu	Resort

Additional changes to the list were required due to difficulty in getting permission to access Kandooma Island Resort. The replacement island was K. Olhuveli Island Resort.

Figure 3.1: Map showing the distribution of survey islands



3.1.2 Designing Survey Instruments

Interview questionnaire

The survey questionnaire was designed based on the information requirement identified in the interviews with MoHE and preliminary questionnaire provided by MoHE. The survey questionnaires consist of structured and semi-structured interview questions and are divided into four Forms:

- Form A: Obtained information from Government agencies in Male' (See Appendix C – Form A).
- Form B: This form obtained/verified general information about the island. This form was targeted to the administration staff of the island or resort (see Appendix C - Form Bi).
- Form C: Main adaptation survey questionnaire (see Appendix C – Form Ci ad Cr).

The main adaptation survey questionnaire was divided into three parts, as follows:

- Part I: This section will focused on gathering basic facts about the historic and current coastal protection measures such as the type and scale of adaptation measures, area under protection, materials and methods used, and estimated costs of the measures.
- Part II: This section is designed to collect information on perception of effectiveness of current and historic hard engineered adaptation measures to determine the success or failure of the adaptation measures and the timeframe and sustainability of the measures. This section also collects information on issues to determine the reasons for success or failure of measures, identifying barriers and constraints as well as lessons associated with potential for replication of the measure.
- Part III: This section will provide information on 'soft' adaptation measures and will aim to obtain perception towards 'soft' adaptation measures, experience of these measures, and barriers and constraints for implementing such measures.

Field review template for selected measures

A field review template was developed for all hard and soft engineering measures. The template is included in Form Ci and Cr (see previous section).

3.1.3 Pre-testing the survey instruments

The survey instruments (the interview questionnaire and the field review template) was pre-tested in three islands (B. Reethibeach, B. Eydhafushi and B. Royal Island) to determine the effectiveness of these instruments. Pre-testing determined the strengths and weakness of the survey questionnaire concerning question format, wording and order. The primary weaknesses were identified as follows:

i. Inapplicability of large sections of the form depending on the activities undertaken on the island.

ii. Difficulties in undertaking a questionnaire based surveys. Semi-structured interviews appeared to provide the best results as the interviewees tended to give information as stories of hazards followed by narratives of adaptation measures.

The survey questionnaire and the field review template were revised based on the result of the pre-test. A more semi-structured approach was adopted for the rest of the surveys

3.1.4 Implementing the survey

The field surveys were conducted between 23rd October and 12th December 2010. Field visits were undertaken to all 40 islands. Generally, a team of two persons visited each island with one person carrying out field review of adaptation measures and the other conducting interviews with the island officials and locals. An extensive logistical operation was required to arrange, schedule and visit all these islands. There was strong support from the visited islands to carry out the survey. Only two islands – Kandooma Island Resort and Theefaridhoo Island – refused to allow access for this study.

The scheduling suffered setback due to the November Eid holidays both due to unavailability of island officials to meet and due to pressure on transportation systems country wide. It was also difficult to access inhabited islands during weekends as the island offices were generally closed during these days. All in all about 30 days were lost from the project schedule due to holidays and week-ends. Additional days beyond the estimated 90 days were required to complete the project.

3.1.5 Analyzing survey results

Results from the assessment were compiled and analysed in Male', generally parallel to the survey activities, where possible. Delays in the completion of field assessment led to postponement of the analysis stage.

3.1.6 Preparing a draft report and compendium with illustrations of examples of 'soft' measures

The survey results were used to prepare a draft report. The report is divided into 6 main sections: 1) introduction; 2) methodology; 3) findings or results of the field assessments; 4) Discussions and conclusions, and 5) recommendations. The recommendation section of the report will detail how the ICCRRI project should promote appropriate adaptation measures. In addition, a compendium of soft adaptation measures has been compiled based on the experiences recorded from the 40 survey islands.

4 Adaptation Measures – Hard Engineering Solutions

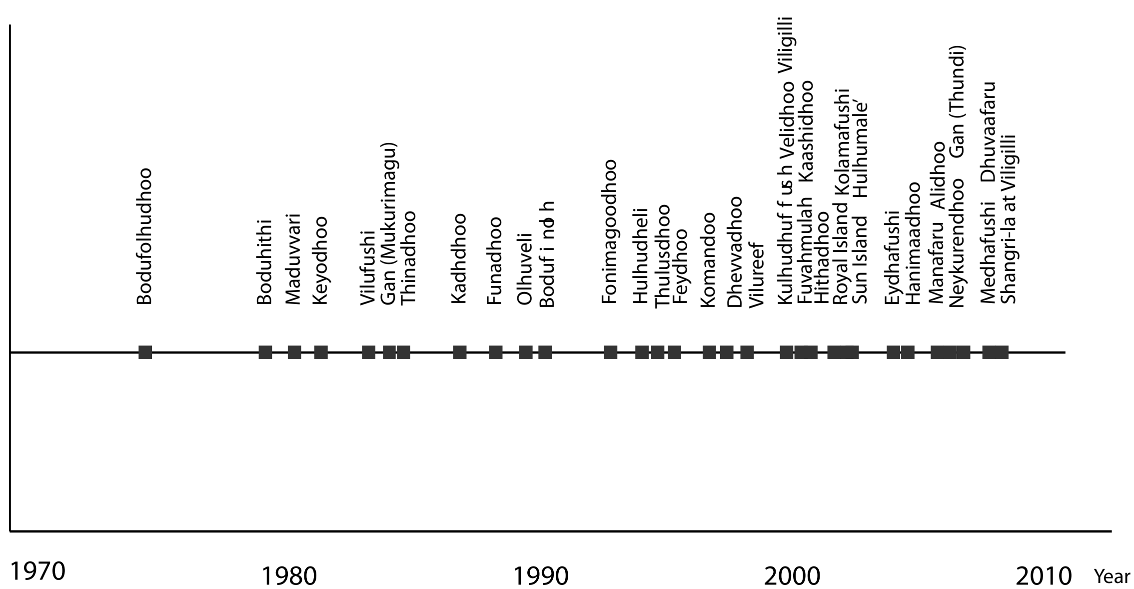
4.1 Introduction

A key objective of this study is to prepare a compendium of coastal adaptation solutions used in the Maldives. This section compiles and presents the hard engineering solutions used for adaptation in the survey islands. The findings are presented in a number of parts. First, important observations about the historical use of hard engineered structures are presented. Second, the types of hard engineering measures are explored. Third, effectiveness of hard engineered solutions in the surveyed islands is explored. Fourth, perceptions toward hard engineering solutions for adaptation are gauged. Finally, key issues in using hard engineering options as portrayed by locals are presented.

4.2 Historical Perspective

Interviews with locals reveal that coastal protection has been constructed in some inhabited islands as early as the 1970s, as a measure against perceived coastal erosion. The common characteristics of these islands were their small size, high density and proximity of settlement edge to high tide line. The list of islands in this category includes Adh. Bodufolhudhoo, V. Keyodhoo, Lh. Naifaru and M. Maduvvari. Most islands were not able to pinpoint the exact dates of earliest coastal protection measures. The table below shows a chronological chart of when erosion became a significant issue in the surveyed islands. Note that only islands which reported the dates are included in this chart.

Figure 4.1: Chronological chart showing reports of erosion as a significant problem on the survey islands



Erosion has generally been a significant problem in all small inhabited islands. Coastal protection emerged in most islands after the 1990s. Erosion in larger inhabited islands in most cases coincides with coastal developments like harbour (for example L. Gan, Sh. Neykurendhoo and Hdh. Hanimaadhoo). In most resort islands surveyed erosion has been identified as an issue since the resorts opened. Adaptation measures in recently opened resorts have appeared immediately after opening.

Another key observation is the *ad hoc* replication of adaptation measures between islands. Coastal protection measures used in one island were replicated between islands based on simple visual observation. Sometimes the contractors who worked in one island were hired to complete coastal works in another island based simply on their experience in construction works. There was no emphasis on proper engineering design. These practices were most common in resort islands where coastal protection works in one or two islands in Male' Atoll was copied without proper engineering designs. Designs were often provided verbally by the engineering department of the resort or resort head office, usually by someone without proper coastal engineering training. The groyne design and near shore breakwaters in islands like Boduhithi, Lh. Komandoo and Dh. Vilureef are examples of such developments. However, development undertaken in most resorts after 2008 appears to have been properly designed by engineers. Examples include structures in Shangri-La at Viligilli, Manafaru, Royal Island and Reethi Beach. In inhabited islands designs are usually not prepared but experienced 'Maamigili construction groups' were contracted. These groups usually use a standard design for all islands.

4.3 Types of Hard Engineering Adaptation Measures

Hard engineering adaptation measures are the most common method of adaptation, particularly coastal adaptation in the study islands. Numerous types of hard engineered adaptation measures were observed and almost all islands have one more measures. For the purposes of this assessment, these measures can be grouped as i) erosion mitigation measures; ii) access infrastructure; iii) rainfall flood mitigation measures and; iv) measures to reduce land shortage.

A summary of the hard engineered adaptation measures in the survey islands are present in Table 4.1. The most common hard engineered adaptation measure for erosion prevention is foreshore breakwaters or seawalls, followed by near shore breakwater and groynes. Harbor infrastructure comes in a standard design and hence is uniform in most inhabited islands. Rainfall flooding mitigation measures are present only in the southern islands, which usually experience high rainfall and have numerous wetlands. Land reclamation is present in almost all inhabited islands, usually associated with harbor development projects. Details of these adaptation measures are presented in the following sections.

Table 4.1: Summary of hard engineered adaptation measures in surveyed islands

				Hard Engineered Adaptation Measures										
No	**Island**	**Atoll**	**Island use**	**Foreshore Breakwater**	**Near shore breakwater**	**Revetment**	**Groynes**	**Adhoc Reclamation**	**Quay wall**	**Harbour Breakwater**	**Entrance Channel Protection**	**Over flow channels**	**Land reclamation**	**Bridge / causeway**
1	Manafaru	HA	Resort		Y									
2	Alidhoo	HA	Resort				Y			Y				
3	Theefaridhoo	HDh	Industrial						Y	Y			Y	
4	Hanimaadhoo	HDh	Inhabited/infrastructure	Y					Y	Y	Y		Y	
5	Kulhudhuffushi	HDh	Inhabited	Y					Y	Y	Y		Y	
6	Neykurendhoo	HDh	Inhabited	Y	Y				Y	Y	Y		Y	
7	Goidhoo	Sh	Inhabited						Y	Y	Y		Y	
8	Funadhoo	Sh	Inhabited						Y	Y	Y		Y	
9	Medhafushi	N	Resort	Y	Y									
10	Velidhoo	N	Inhabited				Y		Y	Y			Y	
11	Dhuvaafaru	R	Inhabited	Y					Y	Y	Y		Y	
12	Fonimagoodhoo	B	Resort	Y	Y		Y							
13	Royal Island	B	Resort		Y									
14	Eydhafushi	B	Inhabited	Y					Y	Y	Y		Y	
15	Komandoo	Lh	Resort	Y	Y		Y							
16	Naifaru	Lh	Inhabited	Y	Y			Y	Y	Y			Y	
17	Kaashidhoo	K	Inhabited						Y	Y			Y	
18	Boduhithi	K	Resort	Y	Y		Y							
19	Thulusdhoo	K	Inhabited	Y	Y		Y							
20	Hulhumale’	K	Inhabited	Y		Y	Y	Y	Y	Y	Y		Y	
21	Olhuveli	K	Resort	Y	Y		Y		Y				Y	
22	Bodufinolhu	K	Resort	Y			Y						Y	

				Hard Engineered Adaptation Measures										
No	Island	Atoll	Island use	Foreshore Breakwater	Near shore breakwater	Revetment	Groynes	Adhoc Reclamation	Quay wall	Harbour Breakwater	Entrance Channel Protection	Over flow channels	Land reclamation	Bridge / causeway
23	Bodufolhudhoo	AA	Inhabited	Y			Y	Y	Y	Y	Y		Y	
24	Sun Island	ADh	Resort	Y	Y		Y		Y				Y	
25	Keyodhoo	V	Inhabited	Y			Y	Y	Y	Y	Y		Y	
26	Maduvvari	M	Inhabited	Y			Y	Y	Y		Y		Y	
27	Vilureef	Dh	Resort		Y		Y				Y			
28	Hulhudheli	Dh	Inhabited				Y		Y	Y	Y		Y	
29	Kudahuvadhoo	Dh	Inhabited						Y	Y			Y	
30	Vilufushi	Th	Inhabited	Y				Y	Y	Y	Y		Y	
31	Gan (Mukurimagu)	L	Inhabited						Y	Y	Y		Y	
31	Gan (Thundi)	L	Inhabited						Y	Y	Y		Y	
32	Kadhdhoo	L	Infrastructure	Y			Y		Y	Y	Y		Y	Y
33	Kolamafushi	GA	Inhabited	Y					Y	Y	Y		Y	
34	Viligilli	GA	Inhabited	Y					Y	Y	Y	Y	Y	
35	Dhevvadhoo	GA	Inhabited	Y					Y	Y	Y		Y	
36	Thinadhoo	GDh	Inhabited	Y				Y	Y	Y			Y	
37	Fuvahmulah	Gn	Inhabited	Y					Y	Y	Y	Y	Y	
38	Hithadhoo	S	Inhabited	Y		Y			Y		Y	Y	Y	
39	Feydhoo	S	Inhabited	Y				Y	Y	Y		Y	Y	Y
40	Shangri-la at Viligilli	S	Resort	Y			Y		Y					

4.3.1 Erosion Mitigation Measures

4.3.1.1 Fore shore Breakwaters or Seawall

Fore-shore breakwaters or seawall are the most common type of coastal erosion mitigation measure used in the surveyed islands. Their designs, types, etc.. are summarized below.

Usage

Commonly used as harbor quaywalls in the past but also used as an easily constructible erosion mitigation measure. Used in all types of islands including inhabited, resort and infrastructure islands. Mainly used in erosion hotspots in close proximity to land based developments. Used as a last resort in most inhabited islands. Some resorts use sea wall as a backup structure to prevent erosion in coastal developments, if erosion do take place. Commonly found in very small inhabited and resort islands with high population densities. This is the most commonly used erosion prevention measure in community financed coastal adaptation projects.

Material

A number of materials have been used in sea walls. The most common material found in the survey and example sites are listed below.

Construction Material		Examples
a.	Coral mound (plastered)	K. Boduhithi
b.	Coral Mound (Unplastered with netting)	Lh. Komandoo, K. Thulusdhoo, V. Keyodhoo, Gdh Thinadhoo
c.	Sand-cement bags (plastered)	M. Maduvvari, AA Bodufolhudhoo
d.	Sand-cement bags (unplastered)	M. Maduvvari
e.	Sheet piles	K. Fun Island, ADh. Sun Island
f.	Wooden piles	N. Medhafushi
g.	Boulders	Th. Vilufushi, S. Feydhoo
h.	'Jumbo Bags' or geobags	R. Dhuvaafaru, Gdh Thinadhoo
i.	Concrete filled barrels	AA Bodufolhudhoo, GA Kolamaafushi, M. Maduvvari

Design and construction

The design height of the structures is fairly constant with about 0.5 to 1 m above high tide. The seaward slope of the structures varies from island to island particularly between resorts and inhabited islands. The use of Maamigili Island Contractors in most of the projects has ensured that the standard elements of the design remain the same.

The designs also differ depending on the type of construction material. Generic designs for a fore shore breakwater is shown from figure 4.2 to 4.4. The Coral mound and sand cement bags (figure 4.2) are the most commonly used construction material and both has almost identical designs. The reasons cited during the survey was the use of contractors previously experienced in coral mound breakwaters to construct sand-cement bag structures. There are no formal designs for these structures.

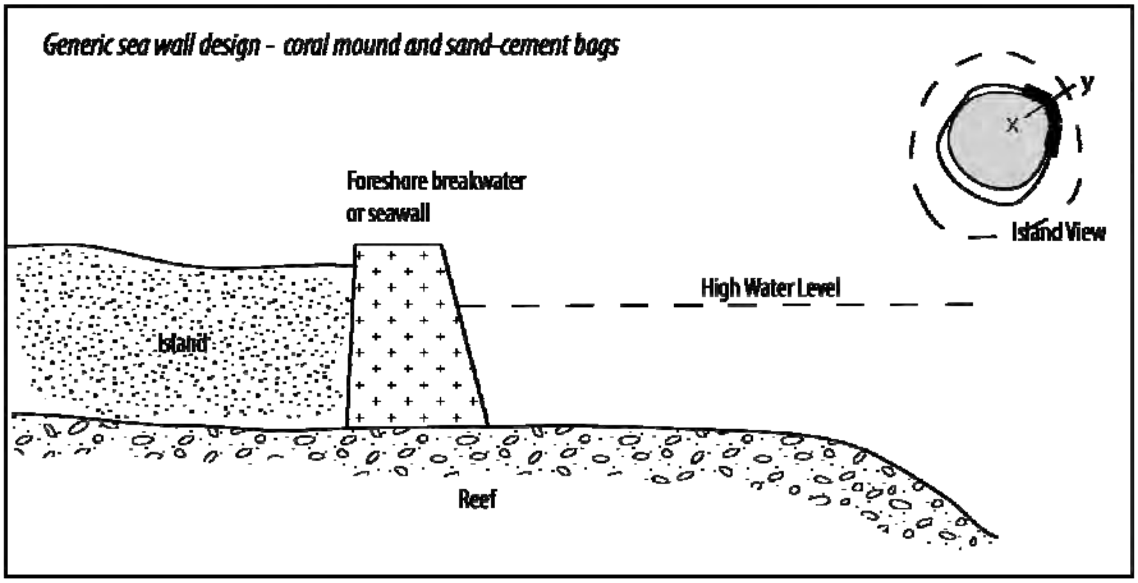
The sheet pile seawalls (figure 4.3) are generally constructed for multi-purpose usage of the shoreline, usually as a quaywall. Sheet piles are driven to the reef bed and a capping concrete beam is constructed. Its usage is restricted due to high costs.

The use of armour rock as a foreshore breakwater is a recent development and present mainly in internationally funded projects like Th. Vilufushi redevelopment, Ga. Viligilli redevelopment and Addu Link Road development. The aim of these structures is to prevent erosion and coastal flooding. Structures constructed under the 'safe island concept' have heights reaching +2.4 m MSL while that of S. Feydhoo is barely +1.6 m MSL. Designs are generally similar to sand-cement bags but the sloping and use of geo-textile material between shoreline and the structure are different. In the case of S. Feydhoo an additional sand cement bag sea wall appears to have been used in some areas, in addition to an outer boulder sea wall.

Innovative materials have been introduced recently as seawall. The use of large nylon or 'jumbo bags' filled with sand was used successfully in R. Dhuvaafaru while concrete filled empty oil barrels were used in AA. Bodufolhudhoo, with mixed results. Some resorts have opted for 'geo bags' or sand filled bags made of geo-textile material. No specific designs have been prepared for these structures.

In addition to these a number of *ad-hoc* seawalls have been constructed by individuals and organizations trying to save their property. Examples of such measures include use of walls, corrugated sheets and PVC pipes (see examples below).

Figure 4.2: Generic sea wall design for coral mound, sand-cement bags, sheet and wooden piles



Note: Design adopted from (Kench, 2010a)

Figure 4.3: Generic sea wall design for coral mound and sand-cement bags

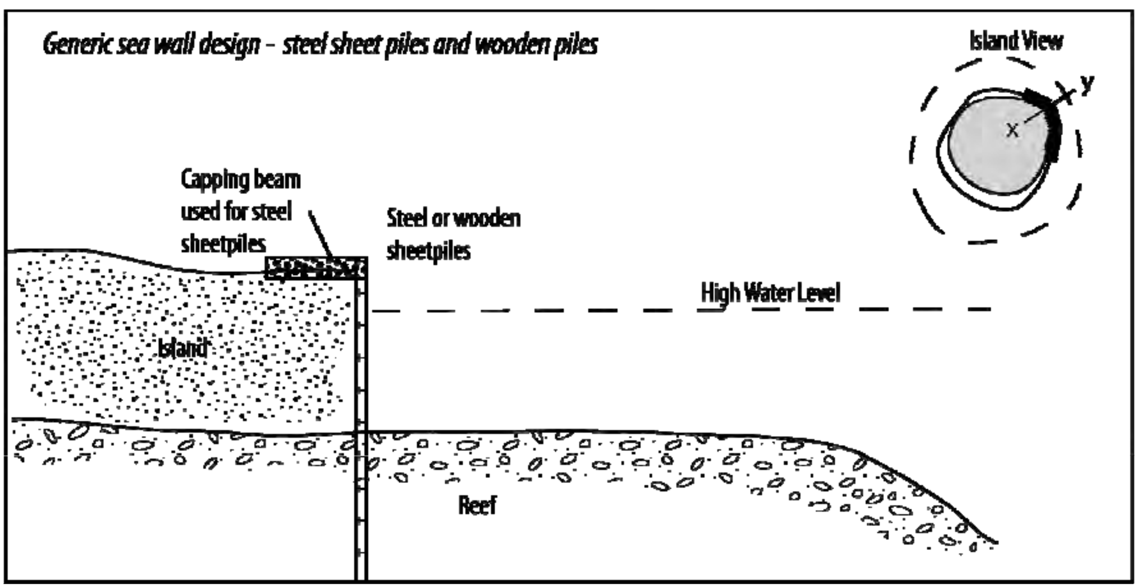


Figure 4.4: Generic sea wall design for rock boulders

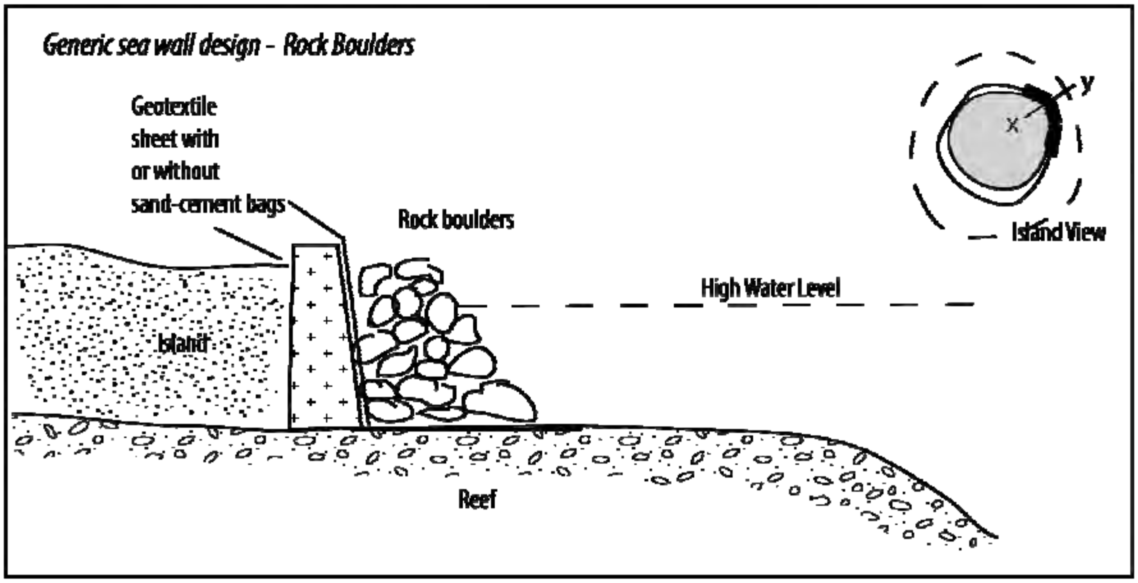


Figure 4.5: Generic sea wall design for 'Jumbo bags'

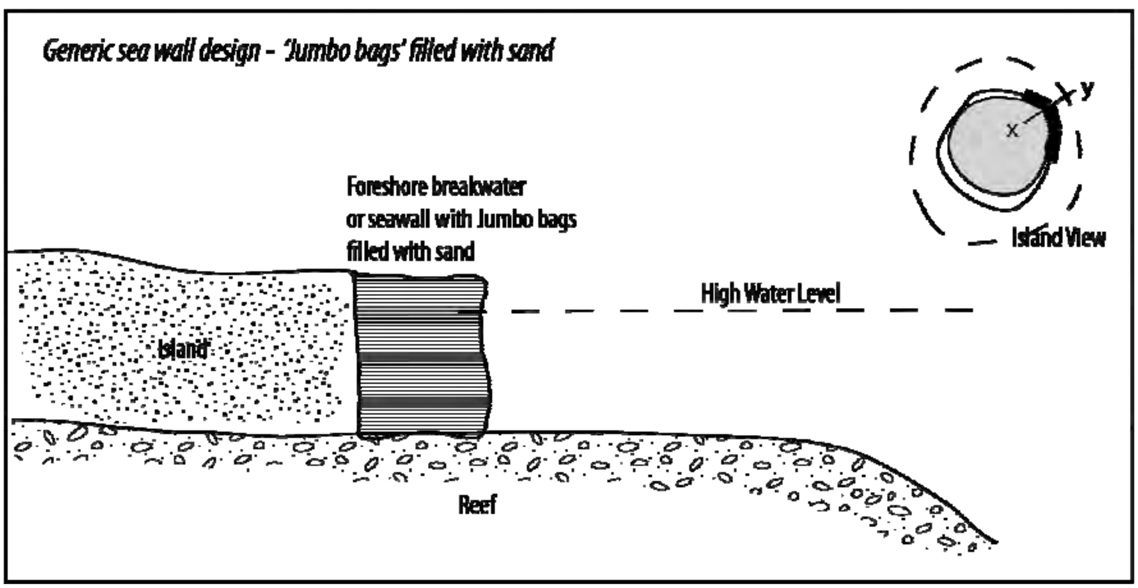
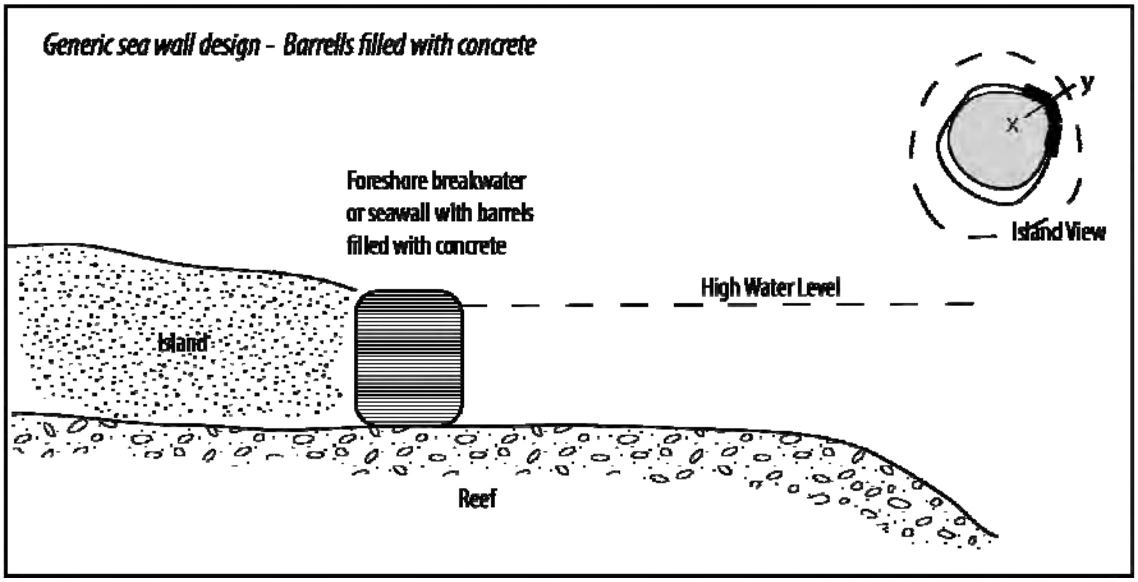


Figure 4.6: Generic sea wall design for 'barrels filled concrete'



Issues and challenges

Some of the common issues identified regarding fore-shore breakwaters during the survey are summarized below.

a. There are no formal designs in most cases, particularly for the coral mound and sand-cement bag structures. The existing design have numerous faults such as a generic slope and height regardless of the wave conditions, poor or no foundations, no suitable toe protection, no provision for drainage of rainwater and overtopped seawater, presence of voids and measures to fix the structure to the island. This has led widespread failure of such structures and trial-and-error corrections to the design.
b. A large portion of the surveyed structures have been constructed or assisted by experienced contractors from South Ari Atoll, particularly Maamigili and Fenfushi Islands. Designing is generally not a required when working with these groups as they claim to have enough experience to develop such structures. Proper knowledge of coastal engineering design and the need to change designs based on site conditions among these groups could have assisted in developing more robust structures across Maldives.
c. The sea walls, if designed improperly, can interfere with sediment flow around the island and are known to have detrimental effects if improperly designed (Kench, 2010a, Kench, 2001, Kench et al., 2003, Kraus and McDougal, 1996). Most structures (for examples in M. Maduvvari and Hdh. Neykurendhoo) have been designed without the knowledge on physical processes operating around the island leading to knock-on effects on the island coastal system.

d. The construction methods of some of these structures are poor. Apart from the apparent faults in design, the workmanship has also been blamed for the failure of structures. Examples of such failures can be found in V. Keyodhoo, Gdh. Thinadhoo and M. Maduvvari.
e. Construction of geo bags or jumbo bag based structures tends to mine sand from the beach to acquire fill material. This in turn reduces the sediment budget of the island.

Effectiveness

Foreshore breakwaters have generally been very effective in controlling erosion. The physical barrier prevents any interaction between the coastal processes and beach, effectively eliminating erosion in the targeted area. Most seawalls are not designed to prevent flooding and therefore are generally ineffective as a flood mitigation measure. Seawalls are usually constructed at the height of the island (for example, K. Bodihithi, and M. Maduvvari) allowing water to overtop during heavy seas and storm events.

While seawalls are effective in serving the purpose they were designed to, they have led to a number of additional issues on the respective islands. These include erosion around the ends of the seawall and aesthetics issues related to the physical structure. It also does not tackle the causes of erosion nor does it assist in rejuvenating the beach around the seawall area.

Opportunities

a. Foreshore seawalls have been effective in controlling erosion but do not in itself provide a method of rejuvenating the beach. There is an opportunity to use seawall in combination with other measures such as beach replenishment. In such cases, sea walls will merely be used as a backup protection measure.
b. The construction of these structures a usually undertaken by limited specialists groups, particularly from South Ari Atoll. Training these groups with best practices and engineering aspects of seawall design could help to drastically improve the conditions of new seawalls.
c. The use of innovative methods such as wooden piles and geo-bags offer a more aesthetically pleasing structures when compare to the common types.

Costs

a. The unit costs (per linear m) are presented in table 4.2 below. The costs are shown as average, estimated highest and estimated lowest. The figures calculated on 2011 values and are based on field data, additional research into Government public expenditure projects, figures provided by Ministry of Housing and Environment and actual quotations acquired from contractors.
b. The assumptions used in the costing are presented in Table 4.3:
c. There were difficulties in getting the exact values during field surveys as documentation of old projects were poor or unavailable due to change in administration (inhabited islands) or management or owner (resort islands).

Table 4.2: Summary of costs for various seawall options

		Rate MRF		
	Unit	**Average cost**	**Low Cost**	**High Cost**
Coral Mound (Unplastered with netting) [1]	m	3,280.00	3,445.00	4,264.00
Sand Cement bags (unplastered)	m	11,925.00	7,748.00	15,502.50
Sand Cement bags (Plastered)	m	13,250.00	7,710.00	17,225.00
Sheet Piles	m	40,000.00	30,000.00	67,000.00
Rock boulders (seawall)	m	36,391.00	27,000.00	48,000.00
Jumbo Bags	m	3,562.50	1,388.50	4,600.00
Concrete filled barrels	m	3,677.00	950.00	4,800.00

Table 4.3: Summary of rates and assumptions for various seawall options

Construction Material or method	Dimensions[2]	Volume per m	Rate
a. Coral mound (Unplastered with netting)	H 2.5 m; B 2.5 m ; T 1.2 m	7.5 m^3; 265 ft^3	Labour cost only Rf12 per ft^3
b. Sand-cement bags (plastered)	H 2.5 m; B 2.5 m ; T 1.2 m	7.5 m^3; 265 ft^3	Turn-key Rf50 per ft^3 Labour cost only Rf15.50 per ft^3
c. Sand-cement bags (unplastered)	H 2.5 m; B 2.5 m ; T 1.2 m	7.5 m^3; 265 ft^3	Turn-key Rf45 per ft^3 Labour cost only Rf15 per ft^3
d. Sheet piles	Pile length 9 m; Pile width 0.4 m; thickness 13.1 mm		Turn key Rf40,000 per linear m
e. Boulders (with geotextile)	H 2.5 m; B 2.5 m ; T 1.2 m	5.625 m^3;	Turn-key: 6,401 m^3
f. 'Jumbo Bags' or geobags	H 2.0 m; B 1.0 m; T 1.0 m (one layer of bags only)	2 m^3	Turn-key Rf45 per ft^3 Labour cost only Rf12 per ft^3
g. Concrete filled barrels	H 2.0 m; B 1.0 m; T 1.0; barrel volume 0.17 m^3; 5 barrels per m^3	2 m^3	Turn-key Rf45 per ft^3 Labour cost only Rf12 per ft^3

[1] *Coral mining is banned in Maldives and therefore only reuse of existing coral mound material is allowed.*

[2] *Note: Height (H) from lagoon bottom; Base (B); Top (T); Width (W)*

Table 4.4: Estimated maintenance cost over 20 year period in strong wave conditions

	Average Maintenance requirement	Estimated % of actual cost per maintenance	Cost of maintenance / year / m	Cumulative cost 20 years / m
Coral Mound (Unplastered with netting)	Every year	20%	656.00	13,120.00
Sand Cement bags (unplastered)	Every year	20%	2,385.00	47,700.00
Sand Cement bags (Plastered)	Every 2 years	20%	2,650.00	26,500.00
Sheet Piles	Every 20 years	5%	2,000.00	4,000.00
Rock boulders (seawall)	Every 50 years	5%	1,499.51	1,499.51
Jumbo Bags	Every 2 years	20%	712.50	7,125.00
Concrete filled barrels	Every 2 years	20%	735.40	7,354.00

d. There is a marked variation in the upfront cost per linear m of various sea wall options. These values are generally dependent on the durability of the structures. The commonly used high maintenance options such as coral mounds or sand cement bags costs 40-50% less than the more modern low maintenance options such as armour rock or sheet piles. The modern options have prohibitive costs when considering a long shoreline. The more recent innovations such as use of jumbo bags and concrete filled barrels cost 90% less than an armour rock structure. However, their durability is yet to be tested.

e. It should be noted that costs vary depending on the method of contracting. Turn-key projects are often very expensive. Usually, some level of contribution is provided by locals to contractors to reduce the costs, for example the provision of food and accommodation. This is one main reason why Government implemented turn-key erosion mitigation projects are expensive compared to projects funded by the community or resort developers.

f. There are also specific minimalist aspects of the design which makes option like jumbo bags and concrete filled barrels cheaper. Their durability is questionable, however.

g. Costs can be further reduced dramatically if the community undertakes the construction work and purchase their own material. A number of seawalls, particularly sand cement bags and coral mounds, have been constructed in this manner with at least 40-50% reduction in the total cost. Construction of these structures does not require extensive use of heavy machinery, reducing the operational, mobilization and demobilization costs.

h. The maintenance costs of low durability structures vary depending on the hydrodynamic conditions of the site. In high impact zones, maintenance may be required every year costing approximately 15-20% of the original cost. At this rate, the expenditure on the structure is doubled within 5-7 years. In similar hydrodynamic conditions, a rock boulder breakwater may be expected to last up to 50 years with minimal maintenance every 10 years. Hence, such high durability structures a much cheaper in the long run under certain conditions.

Examples

Figure 4.7: Examples of Seawall structures: semi-plastered coral mound seawall in Boduhithi

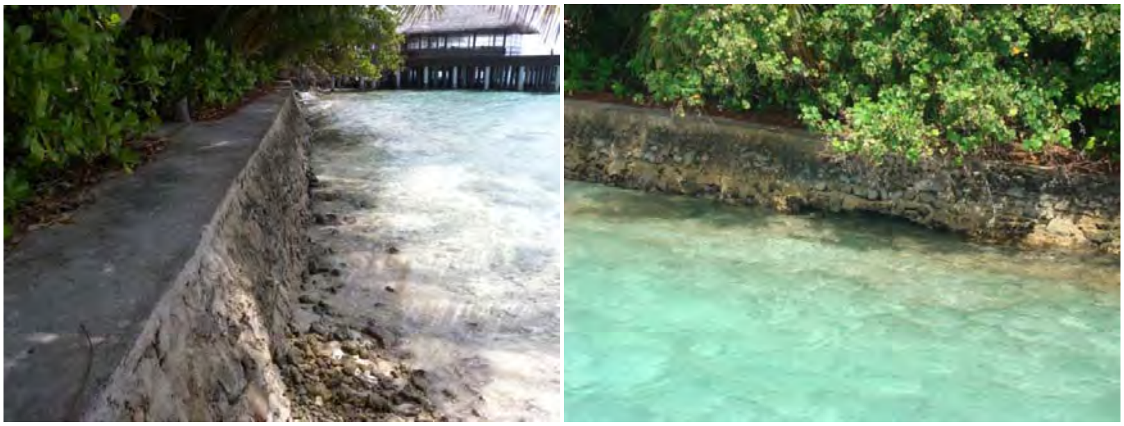


Figure 4.8: Examples of Sewall structures: unplastered coral mound seawalls in M. Maduvvari and Lh. Komandoo

Figure 4.9: Examples of Sewall structures: unplastered sand cement bag seawall in M. Maduvvari and Sun Island Resort

Figure 4.10: Examples of Sewall structures: Sheet piles in Fun Island Resort and wooden piles in Irufushi Resort

Figure 4.11: Examples of Sewall structures: rock boulders in S. Feydhoo and Th. Vilufushi, B Eydhafushi and GA Viligilli

Figure 4.12: Examples of Sewall structures: 'Jumbo bags' in R. Dhuvaafaru

Figure 4.13: Examples of Sewall structures: concrete filled barrels in AA Bodufolhudhoo and GA Kolamaafushi

Figure 4.15: Examples of Sewall structures: Geo-bags in GDh Thinadhoo

Figure 4.14: Adhoc seawalls in (clockwise from left) GA. Dhevvadhoo , GDH Thinadhoo, GA Kolamaafushi and B. Eydhafushi

4.3.1.2 Near shore breakwater

Usage

Commonly used as a protection of the harbor (see next section) but also used as an erosion mitigation measure where practical and feasible. Most commonly used in resort islands and inhabited islands with severe erosion. Also, commonly used in high energy zones.

Construction Material

The most common material found in the survey and example sites are listed below.

Construction Material	Examples
a. Coral mound (plastered)	K. Thulusdhoo
b. Coral Mound (unplastered)	Dh. Vilureef,
c. Sand-cement bags (plastered)	Lh. Naifaru
d. Sand-cement bags (unplastered)	M. Maduvvari, HDh Neykurendhoo
e. Boulders	N. Irufushi, Ha Manafaru, Dh. Vilureef
f. Geobags	B. Reethi Beach

Design

Similar to fore shore breakwaters, the designs are fairly constant between islands. There generally two variations to the design: i) breakwater raised above high tide level or; ii) below high tide or mean sea level (see figure 4.16 and 4.17). The base is generally 2-3 times wider than the top and the height depends on water depth. The better designs have a base 5 times wider than the top and are sloped on the oceanward side. The coral mound and sand cement bags generally have a 1:3 slope and the rock boulder designs have a 1:5 slope on the oceanward side. Coral mound breakwaters generally have mesh around it to prevent collapsing. This is a recent change to the breakwater design.

The submerged breakwaters perform similar functions but have been highly successful in preventing erosion in Ha. Manafaru and B. Reethi Beach. The submergence of breakwater is primarily a result of aesthetic concerns by resort islands.

Figure 4.16: Generic near shore break water design - raised type

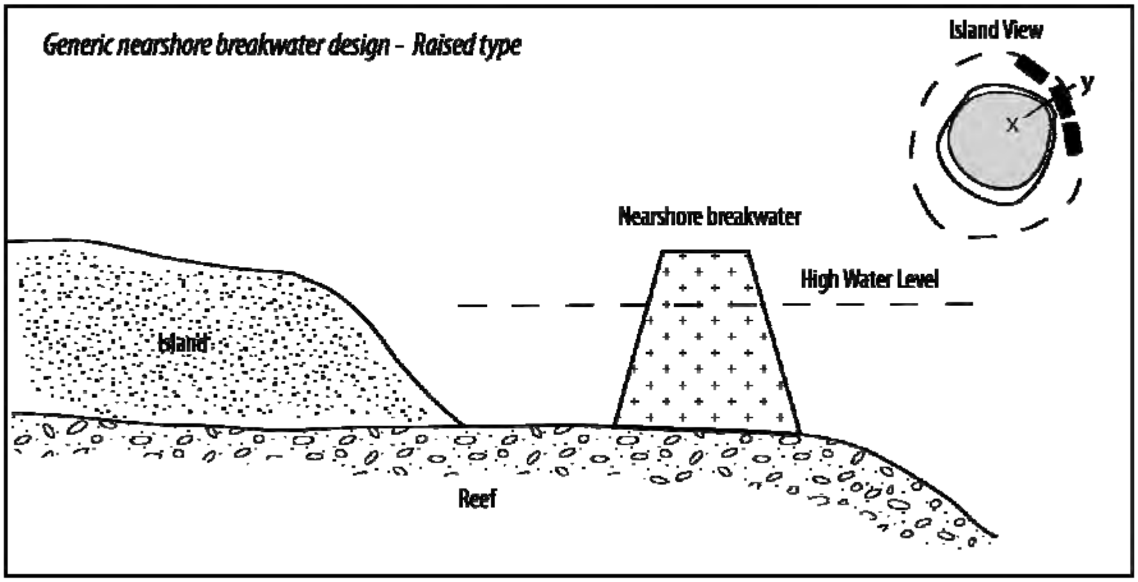
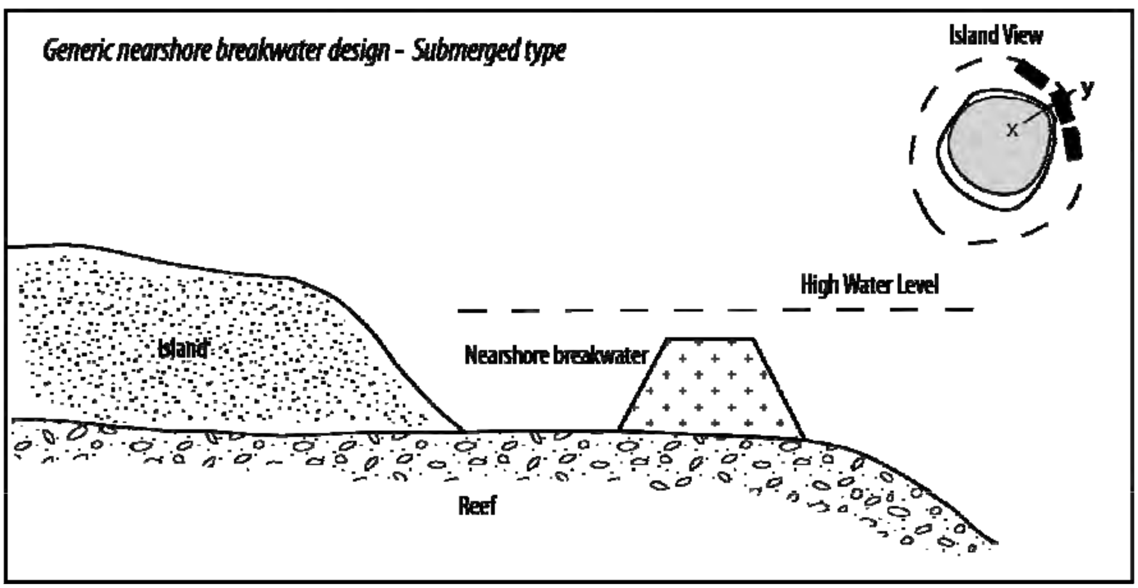


Figure 4.17: Generic near shore break water design - Submerged type



Issues and challenges

Some of the common issues identified regarding near shore breakwaters during the survey are summarized below.

a. There are no formal designs in most cases, particularly for the coral mound and sand-cement bag structures. The existing design have numerous faults such as a generic slope and height regardless of the wave conditions, poor or no foundations, no suitable toe protection, and presence of voids. This has led widespread failure of such structures and trial-and-error corrections to the design (for example: H.Dh Neykurendhoo and K. Thulusdhoo).
b. A large portion of the surveyed structures have been constructed or assisted by experienced contractors from South Ari Atoll, particularly Maamigili and Fenfushi Islands. Designing is generally not a required when working with these groups as they claim to have enough experience to develop such structures. Proper knowledge of coastal engineering design and the need to change designs based on site conditions among these groups could have assisted in developing more robust structures across Maldives.
c. The sea walls interfere with sediment flow around the island and are known to have detrimental effects if improperly designed (Kench, 2010a, Kench, 2001, Kench et al., 2003, Kraus and McDougal, 1996). Most structures have been designed without the knowledge on physical processes operating around the island leading to knock-on effects on the island coastal system.
d. The construction methods of some of these structures are poor. Apart from the apparent faults in design the workmanship has also been blamed for the failure of structures.
e. Availability of appropriate material from Maldives is major challenge construction and design. Durable materials like armour rock, geo-textile and cement has to be imported, adding to the costs. Common material available in the Maldives is increasingly becoming sparse in some areas and additional costs are incurred to acquire them from longer distances.

Effectiveness

a. Foreshore breakwaters have also been effective against erosion in most islands where they were deployed. They have helped to control wave activity in high energy zones and slowed down erosion.
b. However, breakwaters have also been known to cause significant side effects on the beach system particularly due to improperly designed structures. In certain geophysical settings like circular islands in atoll lagoon (e.g Boduhithi and Royal Island Resort), placement of a breakwater in one area of the island results in erosion in another section of the island. Subsequently, based on trial-and-error, a new section of the reef has to be protected. Most such islands end up placing breakwater right around the island (e.g. Irufushi and Vilureef Island Resort) The effects on elongated islands are less dramatic (e.g. Olhuveli Island Resort) but unplanned changes to remaining exposed sections of the island were common in all islands with breakwaters surveyed.

c. Occasionally, foreshore breakwaters have been used in places where alternative measures would have sufficed (e.g Olhuveli Island Resort and Royal Island Resort). In such circumstances, breakwaters should be considered an over-design.
d. Effectiveness varies seasonally in most islands.

Opportunities

a. Foreshore breakwaters when designed properly and used in the required conditions can be highly effective. For example, it use has been most effective in high energy zone where breaking waves had to be controlled and least effective in low energy zones within the atoll lagoon. Awareness on the proper usage of such structures will help prevent its misuse.
b. The construction of these structures a usually undertaken by limited specialists groups, particularly from South Ari Atoll. Training these groups with best practices and engineering aspects of seawall design could help to drastically improve the conditions of new seawalls.

Costs

a. The unit costs (per linear m) are presented in table 4.5 below. The costs are shown as average, estimated highest and estimated lowest. The figures calculated on 2011 values and are based on field data, additional research into Government public expenditure projects, figures provided by Ministry of Housing and Environment and actual quotations acquired from South Ari Atoll contractors.
b. The assumptions used in the costing are presented in Table 4.6.

Table 4.5: Summary of costs for various nearshore breakwater options

		Rate MRF		
	Length	**Average cost**	**Low Cost**	**High Cost**
Coral Mound (Unplastered)	m	7,264.00	7,761.00	9,443.20
Sand Cement bags (unplastered)	m	26,865.00	16,119.00	34,924.50
Sand Cement bags (Plastered)	m	29,850.00	17,910.00	38,805.00
Rock boulders	m	64,012.50	35,000.00	83,216.25
Geo Bags	m	25,661.45	20,000.00	33,359.89
Concrete Tetrapods	m	160,625.00	140,065.00	208,812.50

Table 4.6: Summary of rates and assumptions for various nearshore breakwater options

Construction Material or method	Dimensions[3]	Volume per m	Rate
a. Coral mound (Unplastered with netting)	H 2.5m; B 4.5 m; T 1.5 m	16.9 m^3; 597 ft^3	Labour cost only Rf12 per ft^3
b. Sand-cement bags (plastered)	H 2.5m; B 4.5 m; T 1.5 m	16.9 m^3; 597 ft^3	Turn-key Rf50 per ft^3 Labour cost only Rf15.50 per ft^3
c. Sand-cement bags (unplastered)	H 2.5m; B 4.5 m; T 1.5 m	16.9 m^3; 597 ft^3	Turn-key Rf45 per ft^3 Labour cost only Rf15 per ft^3
d. Armour Rock	H 2.5m; B 6.5 m; T 1.5 m	10 m^3;	Turn-key: 6,401 m^3
e. Geobags	H 2.5m; B 5.0 m; T 1.0 m	7.5 m^3	Turn-key Rf25,000 per m
f. Concrete Tetrapods	-	-	Turn-key Rf45 per ft^3

Table 4.7: Estimated maintenance cost over 20 year period in strong wave conditions

	Average Maintenance requirement	Estimated % of actual cost per maintenance	Cost of maintenance / year / m	Cumulative cost 20 years / m
Coral Mound (Unplastered with netting)	Every year	20%	1,452.80	29,056.00
Sand Cement bags (unplastered)	Every year	20%	5,373.00	107,460.00
Sand Cement bags (Plastered)	Every 2 years	20%	5,970.00	59,700.00
Rock boulders (seawall)	Every 50 years	5%	3,200.63	0.00
Geo Bags	Every 15 years	20%	5,132.29	15,396.87
Concrete Tetrapods	Every 50 years	5%	8,031.25	0.00

a. Cost of breakwaters is difficult to average out due to significant variations based on site conditions like wave height, bathymetry and accessibility. The above figures represent an attempt to create an average based on standard dimensions and not site conditions.
b. Most breakwater projects are turn key projects.
c. The most expensive option used in the Maldives is concrete tetra pod as designed for Male' southern side.

[3] *Note: Height (H) from lagoon bottom; Base (B); Top (T); Width (W)*

d. Armour rocks have been used as a breakwater, other than for harbours, only in a few resort islands. Its costs are prohibitively high for longer reef or shorelines.
e. The use of geobags is an interesting option as its costs are below a full scale sand-cement bag breakwater.
f. The availability of sand is a key cost variable in sand-cement bag and geo bag breakwaters. They are often linked to harbor development projects.
g. Maintenance cost is highest in low durability options such as sand-cement bags and coral mound. The use of geobags is new in Maldives and is yet to be seen how long they last in abrasive coral environments. This study assumes maintenance every 15 years at 20% of the original length. High durability options like armour rock breakwaters are maintenance free for a 20 year period.
h. Submerged breakwater costs aren't readily available due to limited use. Generally, the costs are assumed to 40-50% lower than a normal structure.

Examples

Figure 4.18: Generic fore-shore break water design – coral mound in (Clockwise from left) Dh. Vilureef , Lh. Komandoo and K. Boduhithi

Figure 4.18: Generic fore-shore break water design – Raised rock boulders in (Clockwise from left) Dh. Vilureef , N. Irufushi, B. Royal Island and HA Alidhoo Island.

Figure 4.18: Generic fore-shore break water design – Sand Cement bags in AA Bodufolhudhoo and Neykurendhoo

4.3.1.3 Revetment

Usage

Revetments appear to be a rarely used but a highly effective erosion prevention measure in the surveyed islands. The most notable revetments were identified in Hulhumale' Island and S. Hithadhoo. Revetments are generally sued in high energy zones, usually on the ocean ward side beach, as direct measure to mitigate erosion and beach retreat. The two islands with revetments has had successful implementation, with the Hulhumale' Island far exceeding expectations. Hulhumale' Island now has an extensive beach on top of the revetment, which apparently has formed from natural processes.

Construction Material

The most common material found in the survey and example sites are listed below.

Construction Material	Examples
a. Coral mound (plastered)	K. Boduhithi
b. Sand-cement bags	K. Hulhumale'
c. Concrete interlocking blocks	S. Hithadhoo and L. Kadhoo

Design and construction

The surveyed revetments in Hulhumale and Hithadhoo are based on engineering designs prepared by professionals from the former Ministry of Public Works. Two type s of designs were used: i) sand cement bags and; ii) concrete interlocking blocks. The sand-cement bag option has been designed by the former

Sand cement bag design consists of an existing sand beach (either natural or artificial), a layer of geotextile material placed flat on the entire width of the shoreface , densely packed sand cement bags and toe protection. Construction method involves sloping the initial beach to the appropriate angles, placing geotextile material and orderly placement of sand-cement bags. Construction is largely manual.

The design of concrete interlocking involves Z- or S-shaped blocks which are placed in an interlocking manner on top a sheet of geotextile material. The blocks are usually about 2 ft wide to facilitate manual placement. The construction method is similar sand cement bag revetment construction. First the underlying beach slope is adjusted to the required slope using fill material either from the site or acquired from elsewhere. Second, the geo textile material is arranged along the width of the shoreface. Finally, the concrete blocks are prepared on site or as prefabricated units and placed in the geotextile material. The blocks are either prepared using river sand ad aggregate and coral sand, or coral aggregate. The former is more durable. Toe protection is provided and on some occasions, a capping beam is used on the land ward end of the revetment. All work is undertaken manually but excavators may be used to place the blocks in place. The process is fairly simple and easily transferrable to construction workers.

Details of the generic designs are presented in figures 4.19 and 4.20.

Figure 4.19: Generic revetment design – Sand-cement bag type

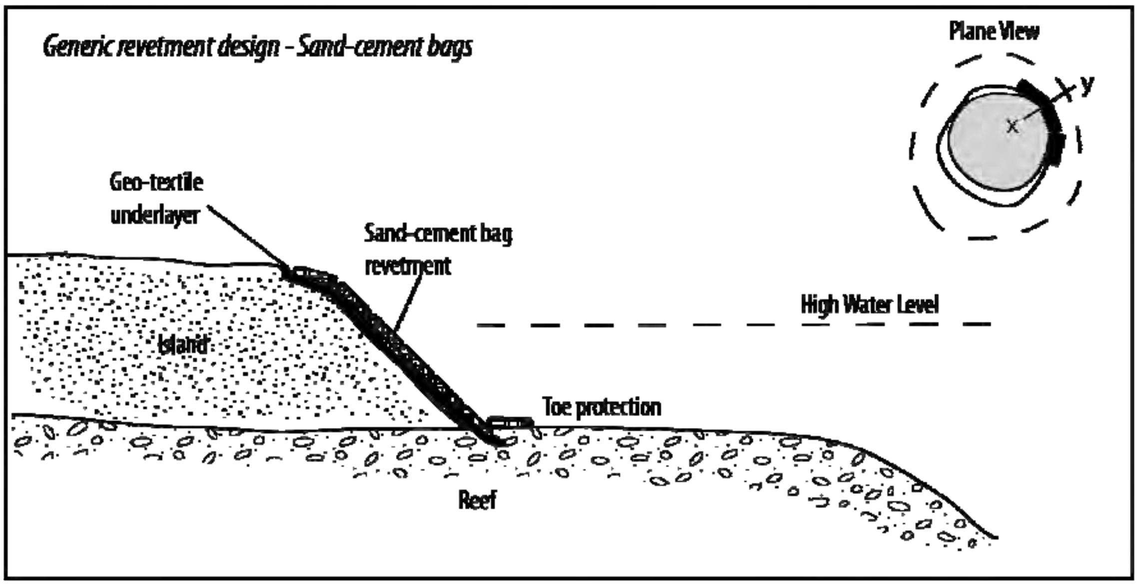
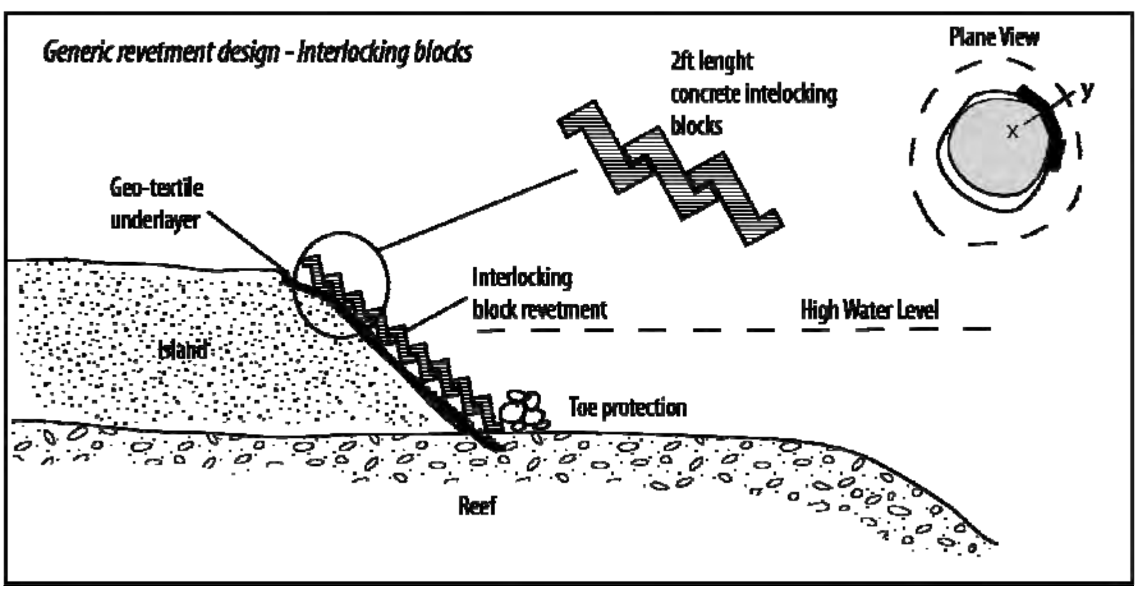


Figure 4.20: Generic revetment design – Interlocking concrete blocks



Issues and challenges

Some of the common issues identified regarding revetments are summarized below.

a. The structure sin both Hulhumale' and Hithadhoo has been damaged in some sections indicating instability of the design under certain conditions. The failure of the Hithadhoo revetment appears to have been due to lack of side protection. The damages in Hulhumale' appears to have been related to strong wave activity and failure to maintain the structure following minor damages. Both these designs have the tendency to collapse very quickly if one unit of construction (sand-cement bags or block) is dislodged.
b. The failed structures in some resort islands are accredited to poor design particularly the design slope.
c. Availability of construction material, particularly geotextile, river sand and aggregate is a concern and generally increases the cost of construction depending on the location in Maldives.
d. Availability of sand to prepare appropriate slope of the shoreface is a concern. Unless associated with a dredging and reclamation project, it may be difficult to acquire volume of sand necessary for backfilling. This issue was encountered in S. Hithadhoo and sand had to be acquired separately from another ongoing project with the help of another Government Agency. The case of Hulhumale' was different as they had ample material for construction.

Effectiveness

Foreshore revetments are amongst the most effective hard engineered adaptation options observed in the study for the oceanward side of an island. In particular, the effectiveness of the sand-cement bag revetment in Hulhumale' Island in absorbing wave energy and facilitating seasonal sand accretions, should be considered as one of the most successful applications of revetments as an adaptation measure in Maldives.

Opportunities

As noted above, revetments based on the specific designs and hydrodynamic conditions have been highly successful in Hulhumale' and S. Hithadoo. Hulhumale' design offers a cheap and effective revetment that could be replicated to other islands with similar conditions. The designs can be communicated to other islands including the key parameters such as slope, material and construction method.

Costs

a. The unit costs (per linear m) are presented in table 4.8 below. The costs are shown as average, estimated highest and estimated lowest. The figures calculated on 2011 values and are based on field data, additional research into Government public expenditure projects, figures provided by Ministry of Housing and Environment, Hulhumale' Development Cooperation and actual quotations acquired from South Ari Atoll contractors.

b. The assumptions used in the costing are presented in Table 4.9.

Table 4.8: Summary of costs for various revetment options

		Rate MRF		
	Unit	**Average cost**	**Low Cost**	**High Cost**
S-Block Revetment	m	10,400.00	10,400.00	13,520.00
Sand Cement bags revetment	m	9,585.00	7,748.00	12,460.50

Table 4.9 Summary of rates and assumptions for various revetment options

Construction Material / method	**Dimensions[4]**	**Volume per m**	**Rate**
a. S-Block revetment	Distance 10 m; H 2 m; Slope 12 m	183 ft^3	Turn-key Rf57 per ft^3 Labour cost only Rf20 per ft^3
b. Sand cement bags revetment	Distance 10 m; H 2 m; Slope 12 m	183 ft^3	Turn-key Rf52 per ft^3 Labour cost only Rf20 per ft^3

Table 4.10: Estimated maintenance cost over 20 year period in strong wave conditions

	Maintenance requirement	**% of actual cost per maintenance**	**Cost of maintenance / year / m**	**Cumulative cost 20 years / m**
S-Block Revetment	Every 10 years	20%	2,080.00	10,400.00
Sand Cement bags revetment	Every 7years	20%	1,917.00	13,692.86

c. Cost of both revetment types are similar due to equal volume, similar material, equipment and constant labour costs.

d. Cost of construction will vary based on location, community contribution and changes to design.

e. The number projects implemented with revetments was minimal and are considered new concepts in coastal adaptation. Therefore, costs may vary as contractors try and establish suitable market rates.

f. The maintenance costs are higher for sand-cement bags as evident from Hulhumale' Island project. In the long run, sand-cement bags may therefore be costlier than S-blocks.

[4] *Note: Height (H) from lagoon bottom; Base (B); Top (T); Width (W)*

Examples

Figure 4.21: Generic revetment design – Interlocking concrete blocks in S. Hithadhoo

Figure 4.22: Generic revetment design – Sand-cement bags in Hulhumale'

Figure 4.23: Generic revetment design – Rubble slope with concrete plastering in K. Boduhithi

4.3.1.4 Groynes

Usage

Exclusively used for erosion mitigation and prevention of sediments from seeping into harbor basins. Mostly used in resort islands where beach is a premium product. Used sparsely in some inhabited islands mostly as ad-hoc measures rather than a planned erosion mitigation activity. Found in all part of Maldives although the densest concentration is Male' region and in the older resorts.

Construction Material

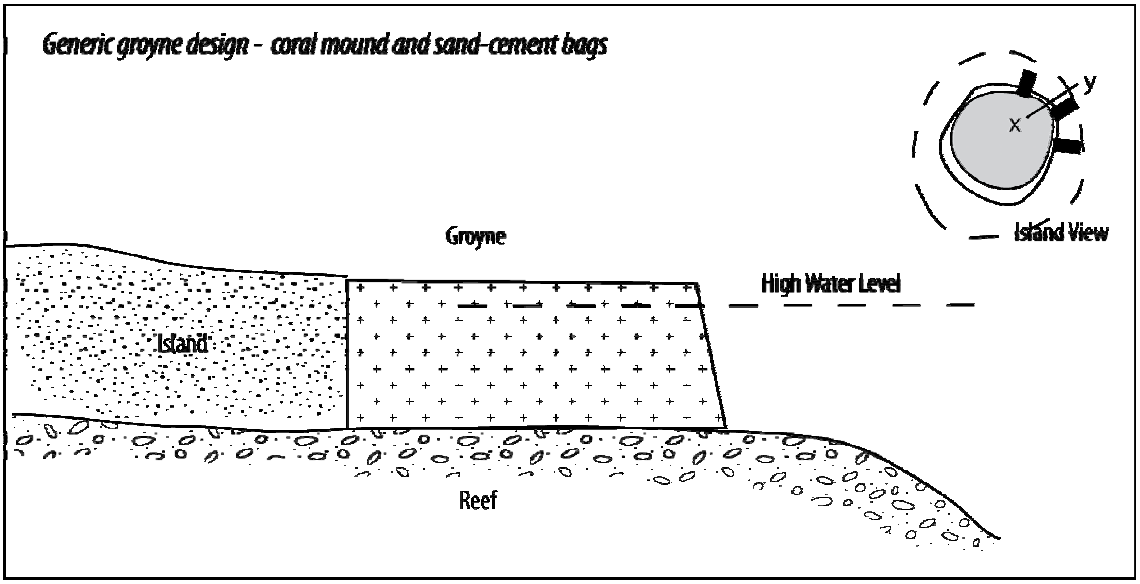
The most common material found in the survey and example sites are listed below.

Construction Material		Examples
a.	Coral mound (plastered)	K. Thulusdhoo
b.	Coral Mound (unplastered)	Dh. Vilureef,
c.	Sand-cement bags (plastered)	Lh. Naifaru
d.	Sand-cement bags (unplastered)	M. Maduvvari, HDh Neykurendhoo
e.	Boulders	B. Reethi Beach
f.	Geobags	Ha. Alidhoo

Design

The design of groynes appears to be the same across Maldives. It is essentially a shore perpendicular structure designed to trap sand as it flows around the island. Basic design includes a structure extending into the lagoon above high water level. The length of the structures vary and does not appear be based on any engineering principles but rather on trail-and-error basis. Variations to the to the design are mainly in the seaward head. Circular heads are common in resorts often with the inner area filled with sand. They are designed to 'improve the aesthetics' of the otherwise visually intrusive structures. The original design for the groynes could be traced back to the earliest resorts in Male' Atoll and Ari Atoll. The subsequent adaptations of groynes appears to have been blindly replicated to other islands without due consideration to physical processes of the site. The generic groyne design is presented in Figure 4.

Figure 4.24: Generic Groyne design



Issues and challenges

Some of the common issues identified regarding groynes are summarized below.

a. Groynes do not solve the cause of erosion and modifies the coastal processes in other parts of the island leading a transfer of erosion hotspots to unaffected areas of the island. Subsequently, islands opting for groynes end up putting up shore parallel structures right around the island. The impact on small circular islands within the atoll lagoon is much higher than elongated islands on the atoll rim (for example K. Boduhithi)
b. Groynes do not appear to have reduced gross erosion in the surveyed islands. However, sparse uses of groynes have yielded good results for example in B. Reethi Beach.
c. The older resort island generally tends to have groynes as a common adaptation measure. There are number of reasons for their adaptation but the most common reason is expected to be the limited knowledge on adaptation options for erosion prevention. At present, these resorts, like Boduhithi, are not willing to remove the structures for the fear of future erosion. Some of these resorts may no longer need the groynes and may be replaced by more effective and aesthetically pleasant measures appropriate for resorts. However, convincing them to switch is expected to be a major challenge.
d. Similar to other structures, availability of material is a major challenge particularly since coral can no longer be mined in Maldives.

Effectiveness

a. Groynes have been effective in seasonally arresting sediments in severely eroding areas of most island in which they were deployed.

b. However, some islands appear to have used groynes in settings where they are not suitable, particularly in very small islands (e.g. K. Boduhithi Island). Once constructed in a small island, erosion tends to pick up in exposed areas and subsequent construction of additional groynes becomes necessary. Eventually, a considerable number of groynes are required to control erosion permanently.
c. The negative aesthetic impact of groynes is significant in resort islands with a number of complaints from tourists visiting those resorts (e.g. Reethi Beach Resort).
d. Effectiveness varies seasonally most islands.

Costs

a. The unit costs (per linear m) are presented in table 4.11 below. The costs are shown as average, estimated highest and estimated lowest. The figures calculated on 2011 values and are based on field data, additional research into Government public expenditure projects, figures provided by Ministry of Housing and Environment and actual quotations acquired from South Ari Atoll contractors.
b. The assumptions used in the costing are presented in Table 4.12.

Table 4.11: Summary of costs for various groyne options

		Rate MRF		
	Length	Average cost	Low Cost	High Cost
Sand Cement bags	m	10,550.00	7,950.00	13,715.00
Coral mound	m	3,898.00	2,743.00	5,067.40

Table 4.12 Summary of rates and assumptions for various groyne options

Construction Material / method	Dimensions[5]	Volume per m	Rate
a. Sand cement bags	H 2m; B 2.5 m; Top 1.2 m;	211 ft^3	Turn-key Rf50 per ft^3
			Labour cost only Rf20 per ft^3
b. Coral mound	H 2m; B 2.5 m; Top 1.2 m;	211 ft^3	Labour cost only Rf18 per ft^3

[5] *Note: Height (H) from lagoon bottom; Base (B); Top (T); Width (W)*

Table 4.13: Estimated maintenance cost over 20 year period in strong wave conditions

	Maintenance requirement	% of actual cost per maintenance	Cost of maintenance / year / m	Cumulative cost 20 years / m
Sand Cement bags	Every 2 years	20%	2,110.00	21,100.00
Coral mound	Every 2 years	20%	779.60	7,796.00

c. The current cost of a groyne is about Rf10,500 per m. The old groyne systems used coral mounds but are no longer considered for new developments. Coral mounds have been rearranged or reused in some islands at a cost of Rf 780 per m.
d. Availability of sand is a critical cost variable for sand cement bag constructions.
e. The maintenance costs for sand-cement bag groynes in strong wave conditions are quite high over a longer period. The cumulative costs per meter of groynes over twenty years could be well over Rf21,000.

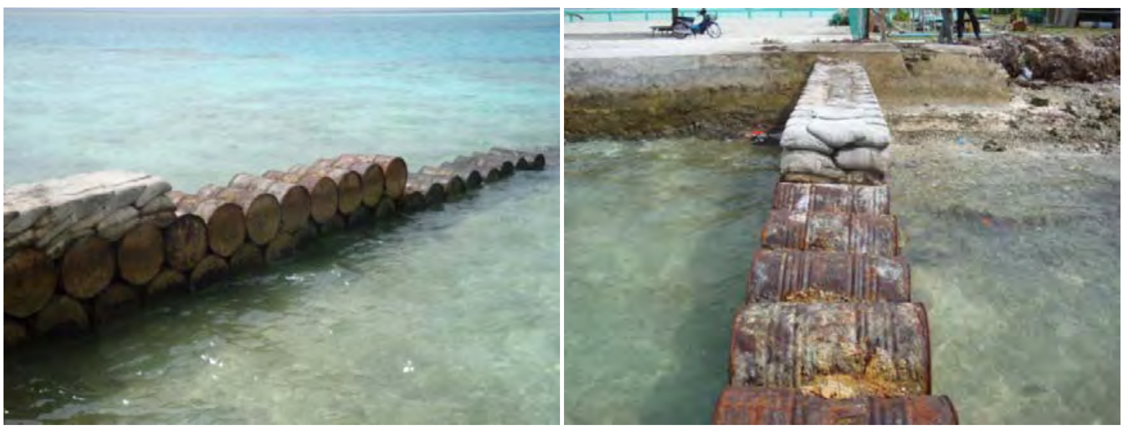
<u>Examples</u>

Figure 4.25: Groynes used for erosion mitigation in K. Boduhithi

Figure 4.26: Sand cement bag and coral mound groynes in Sun Island Resort

Figure 4.27 Groynes constructed from coral rubble in B. Reethi beach and AA Bodufolhudhoo

Figure 4.28 Groynes constructed concrete filled empty oil barrels in M. Maduvvari



4.3.1.5 Adhoc reclamation

Ad hoc reclamation using solid waste is a less common option used by islands like Sh. Funadhoo and AA Bodufolhudhoo for erosion mitigation. The rationale behind this activity is that solid waste management itself is a serious issue in most islands and that an option which can combine erosion mitigation and solid waste disposal should be welcomed.

In addition, the use of construction debris to permanently reclaim erosion hotspots is wide spread practice in the inhabited islands surveyed. These activities are detrimental marine environment and perhaps coastal processes around the island done improperly. Such activities are usually carried out on the 'back side' of the island or away from the harbor side.

4.3.2 Island Access Infrastructure

Island access infrastructures are critical facilities in any inhabited island due to its importance in the economic growth of an island. These structures themselves are not adaptations to natural hazards but their design have been adapted to suit the natural hazards facing the island. Key infrastructure usually associated with a harbor are quay walls, break water, a harbor basin and an entrance channel. Harbours likes these have been considered as a primary contributor in exacerbating coastal erosion problems in coral islands (Kench et al., 2003, UNDP, 2007).

Figure 4.29 Harbour breakwater in Neykurendhoo Island

Figure 4.30 A modern quay wall in Hulhumale' constructed from sheet piles and concrete

4.3.3 Rainfall Flooding Mitigation Measures

Rainfall flooding is major hazard in some islands of the Maldives. It is most prevalent in the southern atolls of Maldives where rainfall is comparatively higher and larger islands contain extensive wetland or low lying areas. Developments or expansion of settlements into the low lying areas have caused occasional severe flooding in these islands. Sometimes these effects are exacerbated due to improper reclamation. There were three islands with significant erosion mitigation measures in the study islands. They are Gn Fuvahmulah, S. Hithadhoo and Ga. Viligilli. The common method for flood mitigation is to construct flood ways or channels from the affected wetland area or low lying area to the sea. This option is explored in detail below.

Usage

Rainfall flood mitigation measures are mainly used severe rainfall hazard islands in the Maldives. Floodways are used mainly during periods of heavy rainfall and excessive tides.

Construction Material

The most common material found in the survey and example sites are listed below.

Construction Material		Examples
a.	Sand-cement bags	S. Hithadhoo
b.	Concrete	Gn. Fuvahmulah
c.	Unsealed floodways	Ga Viligilli and GDh Thinadhoo

Design

The designs in Hithadhoo and Fuvahmulah are constructed as sealed channels linked to the sea. The Hithadhoo structure is constructed from sand cement bags and is always connected to the sea. The Fuvahmulah structure is constructed from concrete and has manual door which is generally opened during period of high rainfall. The reason for a sealed door is to prevent waves from rushing into the water lense. Hithadhoo has only flood way and Fuvahmulah has four operational floodways.

The floodways in GDh Thinadhoo is an excavated channel and becomes active during times of flooding. The facility requires annual maintenance particularly after heavy rainfall. Similarly, the structures in Viligilli were constructed as simple ditch with no seals. The purpose of this structure was to prevent flooding between the lower exiting island and the higher newly reclaimed land on the eastern side of the island.

Issues and challenges

Some of the common issues identified regarding rainfall flooding mitigation measures are summarized below.

a. Maintenance of flood mitigation measures have been a challenge particularly in Fuvahmulah Island. The floodways can regularly accumulate debris including sand, rubble and domestic waste. They need to be removed in a timely manner, particularly before the rainy season. Failure to do so results in the blockage and flooding on the island. Clean up has been generally restricted due to lack of municipal cleaning services.
b. Dumping of waste into the floodways has also been identified as a challenge in Hithadhoo, Fuvahmulah and Viligilli.
c. Design and implementation of floodways has had difficulties in some islands especially when they pass through existing properties. Provisions have to be made to acquire those properties by the state or use additional technology to divert the floodways under the roads.
d. Similar to other structures, availability of material is a significant challenge.

Effectiveness

The flood mitigation measures in Hithadhoo and Fuvahmulah are reported to be very effective during periods of heavy rainfall. The key feature responsible for long-term stability of the structure is the concrete or sand-cement bag channels used as flood over channels.

The main difficulty with the existing systems in both islands lies in maintenance. In Fuvahmulah, two of the overflow channels were blocked with debris and there is an expectation that the Government should provide assistance in cleaning them and upgrading them. Islands close to the wetloand in Fuvahmuah reported that flooding was common during periods of heavy rainfall and that occasionally the flood over flow channels failed to prevent flooding. Channels without a properly constructed basin, for example in G.Dh Thinadhoo and Ga. Viligilli, require heavy community maintenance.

Costs

The costs for rainfall mitigation structures are not available. Estimated costs based on market rates for construction of structures like revetments are between Rf10,000 and Rf16,000 per linear meter.

Examples

Figure 4.31: Flood mitigation measures in S. Hithadhoo and Gn Fuvahmulah

Figure 4.32: Rainfall flood mitigation measures in Ga. Viligilli

4.3.4 Measures to reduce land shortage and coastal flooding

4.3.4.1 Land reclamation

Land reclamation has generally been used as an option to reduce land shortage and is occasionally combined to alleviate erosion problems in island. Almost all inhabited island surveyed has been reclaimed but are usually associated with harbor development projects. Land reclamation specifically for land expansion has been undertaken in Lh. Naifaru, N. Velidhoo, B. Eydhafushi, Th. Vilufushi, Hulhumale, S. Hithadhoo, L. Kadhoo, Ga Viligilli and Hdh Kulhudhuffushi. Land reclamation can be considered an adaptation measure particularly when the new reclamation projects consider raising the island to prevent coastal flooding. However, reclamation projects are almost guaranteed to result in short-term severe erosion unless hard engineered coastal protection measures are utilized.

Land reclamation has as number of issues in its present design and implementation which has repercussions on the hazard exposure of islands (UNDP, 2007).

4.3.4.2 Bridge / Causeway

Bridges and causeways have been used to link islands in Laamu and Addu Atolls. Their purpose is primarily to establish a physical link between two islands or a set of islands. The initial developments in both Laamu and Addu atolls were constructed with no openings, preventing water flow from the oceanward side to the lagoonward side and vice versa. As a result erosion and coastal flooding became more common due to 'pile-up' of water or wave setup next to the shoreline. Subsequently, redevelopments of the causeways were undertaken with bridges or ducts to facilitate water flow. While the causeways and bridges were not constructed as adaptation measures, the new developments explicitly modified the structure as an adaptation measure against flooding and erosion in the neighboring islands.

4.4 Perception towards hard engineering solutions

Perceptions towards hard engineered adaptation measures were recorded using interviews with island administrators, resort developers and locals. The main findings are summarized below:

4.4.1 Resort Islands

a. The response towards using hard engineered options for erosion prevention was mixed. Most resorts wanted a permanent solution to erosion problems and some of them believed that hard engineered structures offered the best solution. About 40% of the resorts were generally not in favour of hard engineered solution. However, amongst these, most resorts managements reported that they would consider hard engineered structures, if required. A limited number of resorts were against using any hard or permanent structures on their islands. Such resorts had a strong environmentally conscious management and contracted environmental consultants.
b. Most resorts considered the aesthetic disadvantage of hard engineered structures as significant and was one of the main reasons for considering alternatives.
c. The older resorts were generally in favour or indifferent on using hard structures. New resorts were generally in favour of soft or aesthetically appropriate measures. This may be due to: (i) the extensive use of hard structures in old islands and inability to remove them; (ii) the natural beauty of newly selected islands for resort development compared to older islands in poor condition, especially in Male' and Ari Atoll.
d. Resorts which have used hard structures noted that they had no other choice but to construct them in the face of severe erosion. However, their use of hard structures came after erosion reached a critical stage. No other planned soft or hard measures were tried before adopting hard structures like seawalls.
e. Older resorts did not usually consider that proper designing was necessary. They usually contracted out construction groups with experience and left the designing for them.
f. Some resorts reported that hard structures required high maintenance, particularly if constructed from sand-cement bags or as a coral mound.
g. Most resorts with hard structures were reluctant to remove them due to fears of severe erosion. They are also unwilling to consider alternatives which recommend removing the existing seawalls or breakwaters.
h. Most resorts which have constructed hard measures felt that they gave them value-for-money.

4.4.2 Inhabited Islands

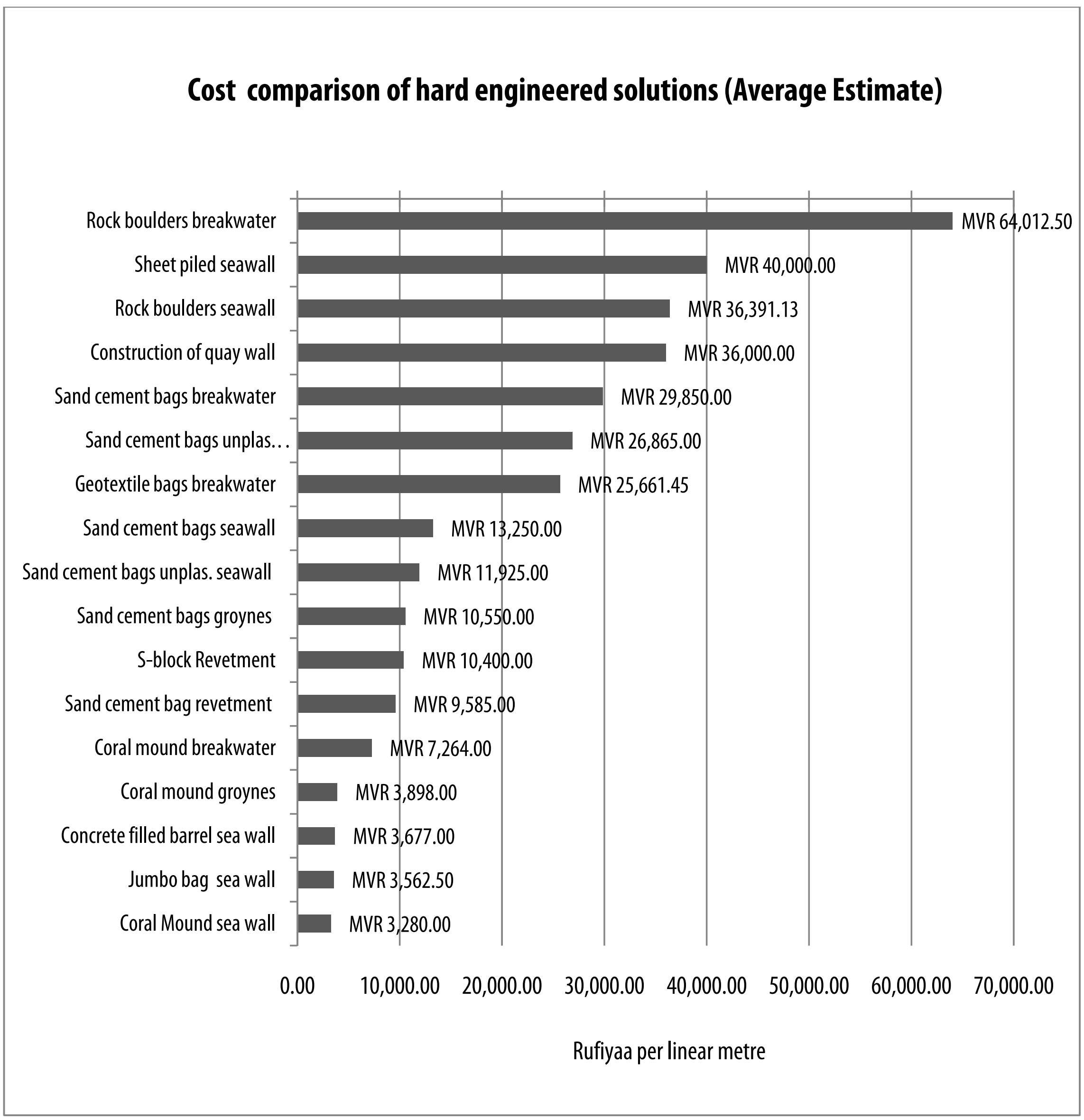
a. Almost inhabited islands considered hard engineering options as the permanent solution for erosion mitigation.
b. There is a general feeling that it is the responsibility of the Government to provide coastal adaptation. Community expenditure on coastal protection when properties are at risk.

c. Both Government and community expenditure on coastal protection is considered only when erosion reaches a critical level.
d. Failure of hard structures is generally seen as a fault with workmanship. However, in reality, most failures are equally related to poor design.
e. Most islands considered that the hard structures gave them value-for-money and would not consider removing them, unless damaged.

4.5 Cost comparison and cost effectiveness of hard engineering measures

A comparison of the average costs of hard engineering measures is presented in Figure 4.33 below. Key findings from cost comparison are summarized below.

Figure 4.33: Comparison of hard engineered adaptation measures



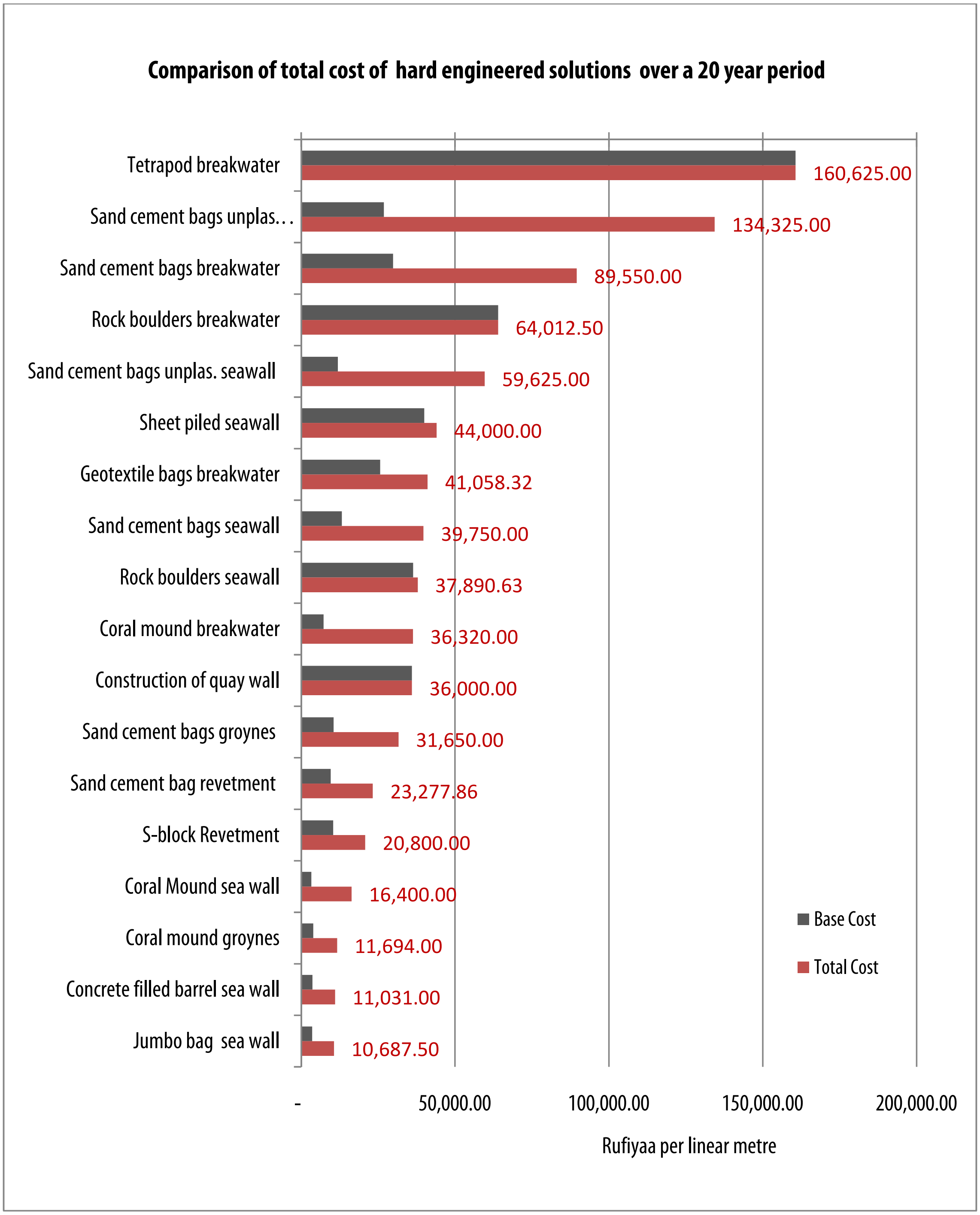
a. The most expensive hard engineering option used in the Maldives is concrete tetrapods, costing over Rf160,000 per linear m. This figure has not been included in the above graphic to improve clarity.
b. In general, the costs of seawalls and breakwater are higher than options like revetments and groynes.
c. The costs, as expected, are directly linked to the durability of materials and options used. Armour rock breakwaters and seawalls, and sheet piled structures provide durable long term options which require minimal maintenance. One exception is the use of revetments, which costs 70% less, for example compared to armour rock seawalls, but are known to provide similar levels of effectiveness (see next section) in certain conditions.
d. Geotextile bags promises to be a durable and aesthetically pleasant option for breakwaters and are about 60% cheaper than armour rock breakwaters. However, due to the requirement of large volumes of sand, geo-bag options may need to be associated with dredging projects for it to be cost effective.
e. The most commong methods for seawall and breakwater construction are sand-cement bags. They are usually cheaper but the increased costs of acquiring sand have raised the costs closer to an armour rock seawall.
f. Small communities often prefer cheaper options and new innovations like the use of jumbo bags and empty barrels seems to provide some of the cheapest options used for erosion prevention.

The real costs of adaptation measures include maintenance costs over the designed lifetime of the project. Figure 4.34 shows a comparison of hard engineering solution costs including maintenance costs over a 20 year period. These costs do not account for climate change and associated increase in sea level rise. The following findings were noted:

a. The cost effectiveness of commonly used coastal adaptation options, namely sand cement bags and coral mounds are very poor. While their base costs are over 80% smaller than the most expensive durable options, their total costs may be higher than all other adaptation options, except concrete tetra pods. This finding is based on a number of assumptions and cost effectiveness will vary depending on factors like hydrodynamic condition of the site, appropriateness of designs and quality of workmanship.
b. The low durability options are used due to their low upfront costs. For resorts, it is financially less taxing to consider maintenance from yearly budget. For inhabited islands, the prohibitive upfront costs of more durable options forces the Government to consider low cost and low durability options. Community financed project also face a shortage of upfront financing.
c. It was noted that the cost effectiveness in strongly linked to the design and construction of the structures. There are cases of under design or poor designs (designs which do not match the prevailing conditions and causes of erosion) which ended up in high maintenance costs and limited practical effectiveness. Examples of such structures can be found in the seawalls of R.

Maduvvari, V. Keyodhoo and AA. Bodufolhudhoo, and near shore breakwaters of HDh. Neykurendhoo, K. Thulusdhoo, K. Olhuveli Resort and Dh. Vilureef resort.

Figure 4.34: Comparison of base and total cost of hard engineered adaptation measures over 20 years



d. There are also occasions where some islands had over designed the structures, which have resulted in arresting erosion in some areas but at a higher cost than what may be necessary in the medium term. Examples of such structures are foreshore breakwaters in B. Royal Island and N. Irufushi Island; and foreshore breakwaters in S. Feydhoo, Th. Vilufushi Island and K. Olhuveli Resort. However, evaluations such as these cannot be generalized and need specific studies to determine their cost effectiveness.

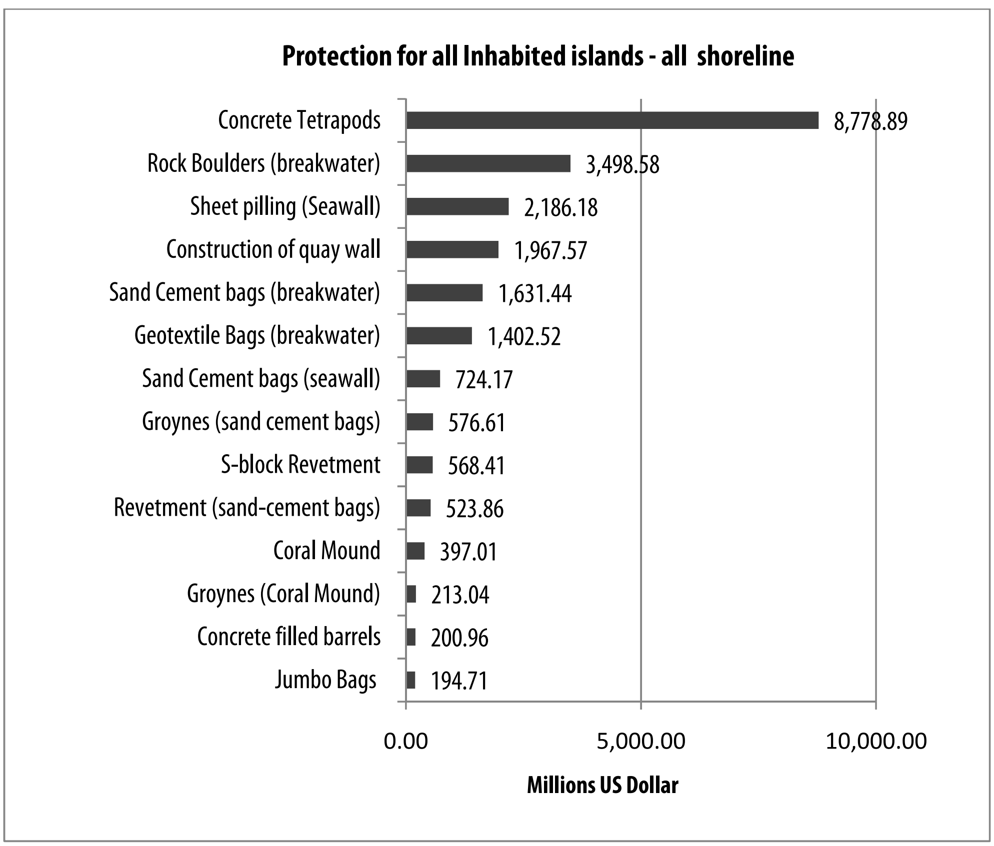
e. In islands that have adopted the proper responses, design and construction methods appears to have played a significant role in cost effective adaptation measures. These include the revetments in Hulhumale' Island and S. Hithadhoo, submerged breakwaters in Ha. Manafaru Island, groynes in B. Reethi Beach and foreshore breakwater in K. Thulusdhoo Island. All these islands considered their adaptation measures as providing good value for money.

f. Based on these finding, it's difficult generically pinpoint the cost effectiveness of specific types of structures. As noted above, it depends on a number of factors which are implementation specific. However, properly designed low cost revetments and foreshore breakwaters could be identified as the most cost effective in the right conditions.

4.6 Estimates for coastal adaptation of all islands using hard engineering measures

An estimate of the scale of costs involved in adaptation of all islands of Maldives using the above discussed options is presented in figure in 4.35 below.

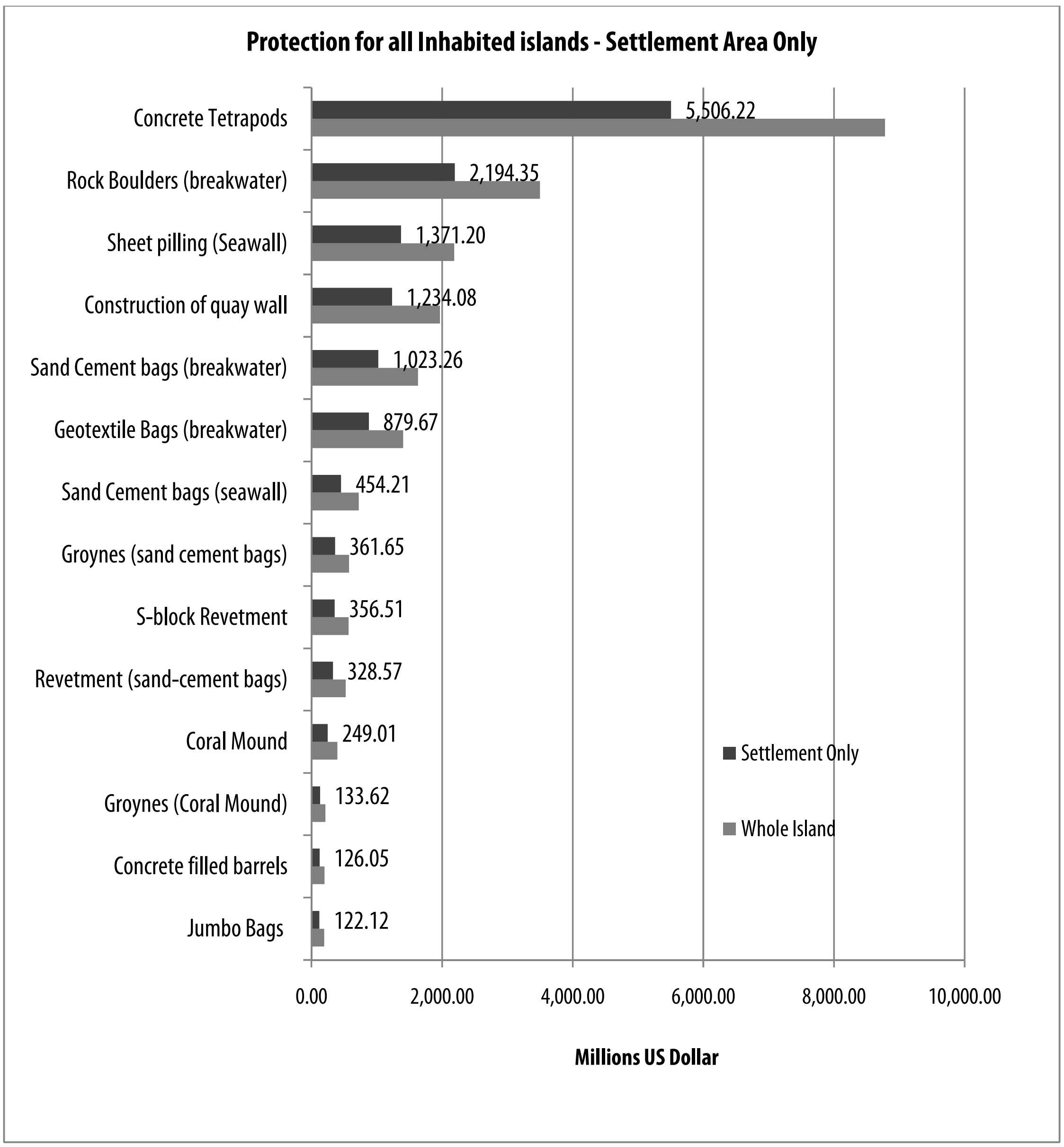
Figure 4.35: Comparison of coastal protection costs for the entire coastline of inhabited islands



The estimated total cost of coastal protection of all inhabited islands and their entire shorelines range from US$524 million and US$8,779. This assumption excludes groynes, jumbo bags, coral mounds and concrete filled barrels described above since they are yet to be fully tested for their effectiveness against multi-hazards. Coral mounds can no longer be considered since coral mining is banned.

Coastal protection measures can either be considered for the entire island shoreline or in areas surrounding the settlement. Quite often settlements in larger islands are concentrated in only a small area, making protection of the entire island unnecessary. Hence, an assessment of the costs involved in protection of the current settlement areas only is presented in Figure 4.36 below.

Figure 4.36: Comparison of coastal protection costs for the entire coastline and settlement area of inhabited islands



The cost of protecting settlements only is significantly lower than protecting the entire coastline. Costs vary between US$329 million to US$5,506 million, a reduction of 37% from protecting the entire coastline of inhabited islands. These figures do not include costs of protecting resort islands as the use of extensive hard structures may not be an option for what is mainly considered as beach and reef tourism. Alternative measures are required for such islands.

The figures are estimates only and could vary between 15-25%. The most practical approach would be to combine different methods of protection which could give a clearer picture of actual costs. Such an assessment is beyond the scope of this study and an additional study is recommended to achieve this using the information provided in this report.

5 Adaptation Measures – Soft Engineering Solutions

5.1 Introduction

This section compiles and presents the soft engineering solutions used for adaptation in the survey islands. One of the main observations of this study is that soft engineering options are generally not preferred by locals in inhabited islands. The resorts are generally more positive towards soft engineering solutions but are skeptical about their effectiveness and value for investment. Soft adaptation measures implemented in inhabited islands are not always intended as an adaptation measure but end up being good practices. The resorts on the other hand undertake planned and designed soft adaptation measures.

The findings are presented in a number of parts. First, important observations about the historical use of soft engineered structures are presented. Second, the types of hard engineering measures are explored with an emphasis on creating a compendium of information on such structures. Third, effectiveness of soft engineered solutions in the surveyed islands is explored. Fourth, perceptions toward hard engineering solutions for adaptation are gauged. Fifth, Key issues in using soft engineering options, as portrayed by locals, are presented. Finally, some best practices and examples are presented.

5.2 Historical Perspective

As noted above, soft engineering options are generally not used as a planned adaptation measures in inhabited islands. However, a number of traditional practices could be classified as soft adaptation measures undertaken by local communities. Firstly, the most common measure is the use of setbacks and preservation of coastal vegetation, particularly on the oceanward side of an island. These measures are generally taken due to strong salt spray, potential for erosion and fear of flooding. There is no set standard or length for setbacks but the most commonly used guideline is 100-150 ft. Second, preservation of natural ridges have always been given priority most islands particularly those experiencing strong wind and wave activity. Thirdly, houses in low lying areas raise their floor level or entrance *(olhigandu)* to prevent flooding. Fourthly, large trees are often planted in front of houses facing an exposed western shoreline to prevent wind damage and salt spray. Finally temporary erosion prevention measures using sand bags and coral rubble has been undertaken in some islands. Remnants of these practices are still visible in islands like AA Bodufolhudhoo.

5.3 Types of Soft Engineering Adaptation Measures

A summary of the soft engineering adaptation measures is presented in table 4.2. There are two types of soft adaptation measures: i) ‘quick fix’ measures deployed in a short-timeframe when severe erosion is ongoing and; ii) ‘long-term’ adaptation measures deployed over a longer timeframe where potential for erosion and flooding exists. The most common quick-fix soft engineering adaptation measures undertaken in the survey islands are beach replenishment, temporary seawalls or groynes, *ad hoc* sea walls and revetments, and submerged geo-textile tubes. Long-term adaptation measures include land use controls or setbacks, coastal vegetation retention, coastal ridge maintenance, coastal structural design changes, natural drainage and artificial reefs. In addition, the use of sea grass and mangrove vegetation as an adaptation measure is explored. Details of these measures are presented in the following sections.

5.3.1 Beach Replenishment

Beach replenishment is one of the most commonly used soft adaptation measures in Maldives, particularly in resort islands. It has been carried out in 25 out of the 40 islands surveyed.

Usage

The primary rationale for beach replenishment is to mitigate or compensate for erosion or loss of beach. Although beach replenishment itself does not address the causes of erosion, it is seen as a temporary fix which, in aesthetic terms, provides value for money, particularly for resort islands. Replenishment in these projects both target erosion mitigation and creation of a new beach. Other rationales for beach replenishment include creating a new beach in previously rubble environments and to create a buffer between infrastructure or property and beach. In the past replenishment has been used as an excuse for land reclamation making it difficult to determine the ideal width for a replenishment project. The EPA of Maldives has designated 10 m from the existing shoreline as allowable width for replenishment. This figure is deficient for some island settings and should be reconsidered based on the physical environment and historical erosion rates in a given site.

Beach replenishment in inhabited islands isn’t generally concerned about the quality of the beach but rather the presence of a buffer between existing shoreline. They usually prefer hard engineering options such as land reclamation or foreshore breakwaters. It is rare that a Government funds a beach replenishment project in an inhabited island. Even project that were designated as beach replenishment, like the Dh. Hulhudheli Project, end up being a land reclamation project due to public demand. It is also noteworthy that most replenishment activities in inhabited islands are the byproducts of harbor development activities.

Table 5.1: Summary of soft engineered adaptation measures in surveyed islands

				Soft engineered Adaptation Measures								
No	**Island**	**Atoll**	**Island use**	**Beach Replenishment**	**Land use controls/ setbacks**	**Artificial Reefs**	**Temporary Seawalls / Groynes**	**Adhoc Seawalls/ revetments***	**Coastal Vegetation retention**	**Coastal structural Design Changes**	**Raised Ridges / Dunes**	**Natural Drainage**
1	Manafaru	Haa Alifu	Resort	Y	Y	Y	Y		Y	Y		
2	Alidhoo	Haa Alifu	Resort	Y	Y		Y		Y	Y		
3	Theefaridhoo	Haa Dhaalu	Industrial		Y				Y			
4	Hanimaadhoo	Haa Dhaalu	Inhabited/infrastructure		Y		Y	Y	Y			
5	Kulhudhuffushi	Haa Dhaalu	Inhabited	Y	Y			Y	Y			
6	Neykurendhoo	Haa Dhaalu	Inhabited	Y	Y			Y	Y			
7	Goidhoo	Shaviyani	Inhabited		Y				Y			
8	Funadhoo	Shaviyani	Inhabited		Y				Y	Y		
9	Medhafushi	Noonu	Resort	Y	Y		Y		Y	Y		
10	Velidhoo	Noonu	Inhabited		Y			Y				Y
11	Dhuvaafaru	Raa	Inhabited	Y	Y			Y	Y			
12	Fonimagoodhoo	Baa	Resort	Y	Y		Y		Y	Y		
13	Royal Island	Baa	Resort	Y	Y		Y		Y	Y		
14	Eydhafushi	Baa	Inhabited		Y			Y	Y		Y	
15	Komandoo	Lhaviyani	Resort	Y	Y		Y		Y	Y		
16	Naifaru	Lhaviyani	Inhabited					Y				
17	Kaashidhoo	Kaafu	Inhabited		Y				Y			
18	Boduhithi	Kaafu	Resort	Y	Y		Y		Y	Y		
19	Thulusdhoo	Kaafu	Inhabited	Y	Y		Y	Y	Y	Y		
20	Hulhumale'	Kaafu	Inhabited		Y				Y			Y
21	Olhuveli	Kaafu	Resort	Y	Y		Y		Y	Y		
22	Bodufinolhu	Kaafu	Resort	Y	Y		Y		Y	Y		

				Soft engineered Adaptation Measures								
No	**Island**	**Atoll**	**Island use**	**Beach Replenishment**	**Land use controls/ setbacks**	**Artificial Reefs**	**Temporary Seawalls / Groynes**	**Adhoc Seawalls/ revetments***	**Coastal Vegetation retention**	**Coastal structural Design Changes**	**Raised Ridges / Dunes**	**Natural Drainage**
23	Bodufolhudhoo	Alifu Alifu	Inhabited	Y	Y		Y	Y	Y	Y		
24	Sun Island	Alifu Dhaalu	Resort	Y	Y	Y	Y		Y	Y		
25	Keyodhoo	Vaavu	Inhabited	Y	Y			Y	Y		Y	
26	Maduvvari	Meemu	Inhabited	Y				Y				
27	Vilureef	Dhaalu	Resort	Y	Y							
28	Hulhudheli	Dhaalu	Inhabited		Y		Y		Y			
29	Kudahuvadhoo	Dhaalu	Inhabited		Y			Y	Y			
30	Vilufushi	Thaa	Inhabited		Y			Y	Y		Y	Y
31	Gan (Mukurimagu)	Laamu	Inhabited		Y			Y	Y			
31	Gan (Thundi)	Laamu	Inhabited	Y	Y			Y	Y			
32	Kadhdhoo	Laamu	Infrastructure	Y	Y		Y	Y	Y			
33	Kolamafushi	Gaafu Alifu	Inhabited	Y	Y		Y	Y	Y			
34	Viligilli	Gaafu Alifu	Inhabited	Y	Y			Y	Y		Y	Y
35	Dhevvadhoo	Gaafu Alifu	Inhabited	Y	Y		Y	Y	Y			
36	Thinadhoo	Gaafu Dhaalu	Inhabited		Y			Y	Y			Y
37	Fuvahmulah	Fuvahmulah	Inhabited		Y		Y				Y	Y
38	Hithadhoo	Seenu	Inhabited		Y				Y			
39	Feydhoo	Seenu	Inhabited	Y	Y			Y	Y		Y	
40	Shangri-la at Viligilli	Seenu	Resort	Y	Y		Y		Y	Y	Y	

* *Refers to ad-hoc coastal protection measures like the use of construction waste and green waste*

Design and construction

Among the surveyed islands, beach replenishment projects were rarely designed in detail by an engineer. Most projects are undertaken by a contractor who is given a fixed width and height to fill. Hence, past replenishment activities have mostly been based on a trial-and-error basis. There are critical design aspects which have been missed in most replenishment projects. They include:

a. Estimation of maximum fill possible for a given sediment system
b. Consideration of material size in relation to the existing sediment
c. Proper sourcing and matching of sediment
d. Proper beach profiling
e. Timing of activities
f. Environmental impact mitigation measures to minimize negative environmental impacts.

Beach replenishment is a temporary solution to the loss of beach and does not address the causes of erosion. The natural processes operating around the island dictates the stability of the fill material and beach profile in the post replenishment stage. The general beach replenishment stages and natural adjustment processes are summarized in Figure 5.1. Replenished profiles are rarely perfect and they may undergo rapid erosion in the first few months until a naturally adjusted or an 'equilibrium profile' for the monsoon period is reached. If an area has been replenished due to severe erosion, the area may continue to erode after replenishment, if the causes of erosion have not been addressed. Hence, the absence of designs and engineering considerations for most replenishment projects may have significantly contributed to faster than normal loss of replenished sand and unwanted environmental impacts.

As noted above the regulatory limitation for new beach replenishment projects are 10 m from the existing shoreline. There are no design guidelines for height and replenished beach profile. Proper designs have been prepared for the recent beach replenishment projects in Shangri-La at Viligilli Resort and Reethi Beach Resort.

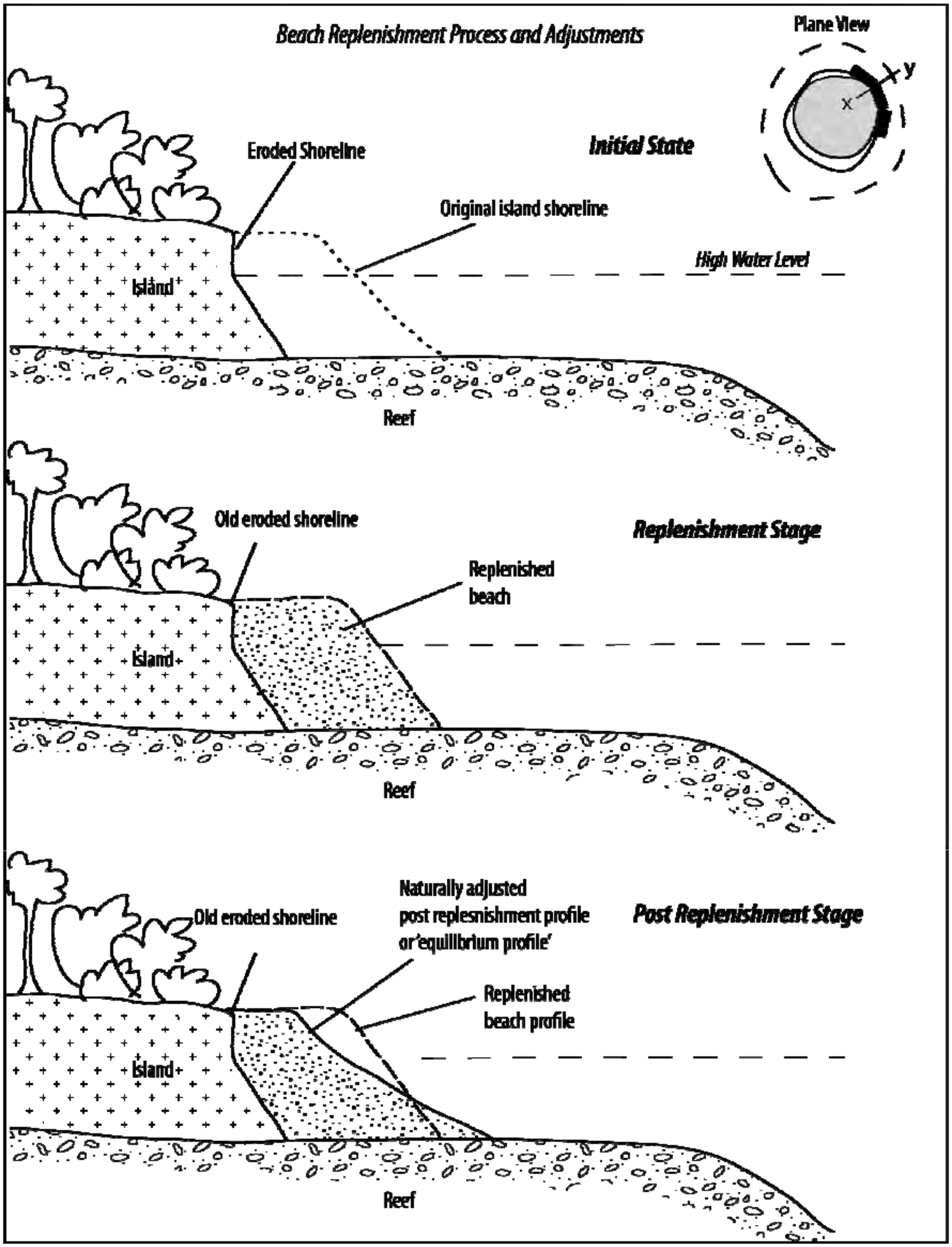
A number of resorts now have their own sand pumps and conduct regular or periodic replenishment. The basic design principle for these islands is to pump sand to wherever erosion in prevalent. A specialized team is employed, usually in the maintenance department, to undertaken this activity. Costs for these activities are usually budgeted annually.

The general method of beach replenishment construction is to deploy a sand pump on a floating barge within a distance that matches the technical limits of the sand pump and to pump sand directly onto the beach. Loaders are used to distribute the sand and manual labour is used to profile the beach. Smaller projects may be implemented by a group of 5-10 people.

Larger projects may involve the use of multiple sand pumps, dredgers or excavators to dredge material from the lagoon, and loaders and bulldozers to place and profile the beach. Sometimes, like in

Shangrila at Viligilli Island Resort, sand may be sourced from a distant reef system and transported in barges to the destination beach.

Figure 5.1: Beach replenishment stages and adjustment process



Issues and challenges

a. Improper design and lack of engineering are the main short comings of beach replenishment activities in the surveyed islands (for example in Dhevvadhoo, Fun Island Resort and Olhuveli Island Resort).
b. Failure to implement mitigation measures, particularly for suspended sediments, can be singled out as one of the most critical environmental concerns for current beach replenishment projects.
c. Beach replenishment is generally considered a low impact activity if undertaken properly. However, depending on the site conditions, there is potential for serious damage to the marine environment. A number of beach replenishment activities have been undertaken without due consideration to physical processes and design elements outlined above leading to damages to the marine environment (e.g Herathera Island Resort, Fun Island and Sun Island Resort).
d. Burrow areas are a key concern. Most islands with replenishment activities have pumped or excavated sand from the lagoon close to the existing beach. Subsequently, sediments seep back into the holes left in lagoon to compensate for changes in bottom topography (for example, Herathera Island Resort, Irufushi and Olhuveli Island Resort).
e. The present regulatory guideline of a blanket 10 m for all replenishment projects is not adequate. Site conditions and historical rate of erosion determines the amount of sediment required for a site.
f. Replenishment at present is *ad hoc* and continuous in some cases. These activities need to be better controlled and monitored by Environment Protection Agency (EPA), including the options to register sand pumps for operation in resorts.

Effectiveness

Beach replenishment as a 'quick-fix' adaptation measure was popular in resort islands and appeared to successfully meet the objectives of rejuvenating an eroded beach system temporarily. Newly pumped sand generally lasted from 2-10 seasons and is dependent on the previous extent of erosion and existing site conditions (for example in B. Royal Island and N. Irufushi Island). Some islands like B. Royal Island beach replenishment ineffective if the first replenishment effort did not yield a permanent solution. Other islands sought to continue replenishment activity as part of general resort maintenance activity (for example, Shangrila at Viligilli, Irusfushi and Sun Island Resort). These islands consider beach replenishment as the most effective soft adaptation measure. The effectiveness of beach replenishment was high in most islands but the period of its effectiveness may have been dependent on a lot factors particularly, the prevailing hydrodynamic conditions, pumped sediment size compared the existing sediment size, beach profiling, sediment source or burrow area, width of replenishment and project timing, among others. The limited regulatory width of 10 m for beach replenishment was found to hinder the effectiveness of replenishment in some projects.

Costs

a. The unit costs per linear meter of replenished beach are estimated as Rf1,625 per linear meter.
b. This estimate is based on market rates of dredging and reclamation (Rf 65 per m3) and the following assumptions:
    a. Volume per linear m: 25 m3
    b. Dry beach width:10 m
    c. Beach active shore face slope width: 5 m
    d. Maximum Height: 1.5 m
    e. Minimum height: 0.1 m
    f. Average height 1.0 m
c. The average cost for establishing a beach replenishment setup, including a sand pump and a barge, is estimated between Rf900,000 and Rf1,500,000.
d. Maintenance dredging is required at a minimum of 2 years and a maximum of 5 years after the initial replenishment. Follow up replenishment intervals generally increase over time to an average of once every 5 years. The total volume of sand required for maintenance replenishment is estimated at 50% of the total volume. The total cost over a 20 year time frame including maintenance dredging is estimated at Rf4,875 per linear m.
e. Refer to section 5.12 for a comparison of costs among soft engineering measures.

5.3.2 Temporary Groynes or Sea walls

Usage

Temporary groynes are primarily used for emergency or seasonal erosion mitigation. This practice is most prevalent in resort islands, especially in resorts which are conscious about the aesthetic impacts of hard engineered structures. Temporary sea walls are also used during storm events when erosion is most dramatic.

The most important use of temporary groynes is to prevent the seasonal loss of beach in specific erosion hotspots. The rationale may be either due to concerns over damage to property or loss of beach as a tourism product in certain section s of the island. These structures are designed to arrest part of the sand migrating to other parts of the coastline. The structures are usually removed once the monsoon season reverts. This practice is usually found in resort islands who prefers to have year round beach.

Design

There are no standard designs for temporary seawalls or groynes. Each resort island tends to have their unique ways deploying, removing and arranging the structure. The most common material used for construction is nylon bags filled with sand. There are variations in the material ranging from coir weaved bags to geo-textile bags. The common features of these structures are that the individual modular units are small and can be easily transferred from one location to the other using manual labour.

Issues and challenges

The main issue relating to the use sand bags as temporary structures is the sourcing of sand from the existing beach (for example in Boduhithi Island). While this practice is practical, the negative impacts on the sediment budget may be substantial and may exacerbate erosion elsewhere.

The poor quality of bags used in some resort islands (eg. Royal Island) has resulted in damaged empty bags being littered on to the reef.

Availability of sand is the biggest challenge to using temporary sea walls. Sand will have to be bought from local suppliers and miners or pumped out from the lagoon system. Both these options require additional costs. Costs could increase dramatically depending on availability of mining sites in close proximity to the island.

Effectiveness

Temporary groynes and sea walls were also used effectively to mitigate seasonal erosion for example in K. Boduhithi and N. Irufushi. In the absence of any designs, the maintenance staff of resort islands has done an excellent job through trail-and-error. Some resorts can now anticipate seasonal erosion and prepare for the season by placing sand bags some designated meters from the beach line. Temporary seawalls constructed from sand were the most common and most effective. The purpose of these walls is to prevent erosion close to land based facilities and to maintain some beach. It is not the aim here to create a properly profiled beach. On the other hand, temporary groynes are placed specifically to trap sediments and maintain a beach. Again the effectiveness varied from location to location. Most likely factors controlling effectiveness are hydrodynamic conditions of the lagoon or reef flat, structure height, depth, arrangement, bag size and type of material used for bags.

For more detailed comparison of effectiveness amongst soft adaptation measures, refer to section 4.13.

Costs

a. The unit costs per linear meter of temporary sandbag seawall or groyne is estimated at Rf720 per linear meter.
b. This estimate is based on market rates of sand mining (Rf10 per bag or Rf180 per m^3) and the following assumptions:
    a. Volume per linear m: 2 m^3
    b. Maximum Height: 2 m
    c. Minimum height: 1 m
c. Maintenance is not required as new temporary seawall or groyne is placed every year.

Refer to section 5.12 for a comparison of costs among soft engineering measures.

Examples

Figure 5.3: Temporary seawalls constructed in B. Royal Island and N. Irufushi Island

Figure 5.2: Temporary groynes constructed in N. Irufushi Island

5.3.3 Land-use set backs

Usage

Land use set backs are used both as a voluntary adaptation measure and as a regulatory requirement. Almost all islands surveyed have land-use setbacks as an adaptation measure except for the densely population islands like M. Maduvvari and V. Keyodhoo. The regulatory requirement for tourism resorts is 5 m from the vegetation line and for inhabited islands are a minimum of 20 m from the vegetation line. In practice, most resorts construct more than 10 m inland, except when the island is very small.

The average distance between the vegetation line and nearest land buildings in the surveyed resort islands is 9.5 m and in the inhabited islands is 21 m. The details of the distance are provided in the Table 5.2 and 5.3 below. Generally, there is a difference in the setbacks between oceanward side and lagoon ward side of atoll rim islands. Set backs on the oceanward side is wider, especially in parts of Maldives with strong wave conditions and in islands with smaller distances between reef edge and oceanward shoreline. However, this difference in minimal if the island has high population density. There are two reasons for this pattern: i) community level adaptation to flooding and strong wind and; ii) settlement patterns in large islands with the initial settlement beginning from lagoonward side and expanding to oceanward side. The case of Fun Island among resorts is unique, as the island has undertaken land reclamation and hasn't yet built on the new land.

Table 5.2 Distance between vegetation line and nearest land based building in resort islands

					Distance to nearest building		
No	Island	Atoll	Island use	Location in Atoll	All sides of the island (m)	Oceanward side (m)	Lagoonward side (m)
1	Manafaru	Haa Alifu	Resort	Atoll Lagoon	15		
2	Alidhoo	Haa Alifu	Resort	Atoll Lagoon	10		
3	Medhafushi	Noonu	Resort	Atoll Lagoon	10		
4	Royal Island	Baa	Resort	Atoll Lagoon	10		
5	Komandoo	Lhaviyani	Resort	Atoll Lagoon	5		
6	Boduhithi	Kaafu	Resort	Atoll Lagoon	5		
7	Sun Island	Alifu Dhaalu	Resort	Southern Rim	15	15	15
8	Vilureef	Dhaalu	Resort	Northen Rim	5	5	10
9	Fonimagoodhoo	Baa	Resort	Atoll Lagoon	5		
10	Olhuveli	Kaafu	Resort	Eastern Rim	5	15	25
11	Fun Island	Kaafu	Resort	Eastern Rim	15	40	20
12	Shangri-la at Viligilli	Seenu	Resort	Eastern Rim	15	15	20

Table 5.3 Distance between vegetation line and nearest land based building in resort islands

No	Island	Atoll	Island use	Location in Atoll	Distance to nearest building: All sides of the island (m)	Oceanward side (m)	Lagoonward side (m)
1	Theefaridhoo	Haa Dhaalu	Industrial	Atoll Lagoon	40		
2	Kadhdhoo	Laamu	Infrastructure	Eastern Rim	20	40	80
3	Kulhudhuffushi	Haa Dhaalu	Inhabited	Eastern Rim	40	60	47
4	Neykurendhoo	Haa Dhaalu	Inhabited	Atoll Lagoon	30		
5	Goidhoo	Shaviyani	Inhabited	Atoll Lagoon	70		
6	Funadhoo	Shaviyani	Inhabited	Eastern Rim	15	15	20
7	Velidhoo	Noonu	Inhabited	Western Rim	15	20	15
8	Dhuvaafaru	Raa	Inhabited	Eastern Rim	Data not available		
9	Eydhafushi	Baa	Inhabited	Eastern Rim	10	15	30
10	Naifaru	Lhaviyani	Inhabited	Western Rim	Data not available		
11	Kaashidhoo	Kaafu	Inhabited	Oceanic Atoll	80		
12	Thulusdhoo	Kaafu	Inhabited	Eastern Rim		15	3
13	Hulhumale'	Kaafu	Inhabited	Eastern Rim		20	20
14	Bodufolhudhoo	Alifu Alifu	Inhabited	Atoll Lagoon	10		
15	Keyodhoo	Vaavu	Inhabited	Eastern Rim	10	15	30
16	Maduvvari	Meemu	Inhabited	Northen Rim	15	30	40
17	Hulhudheli	Dhaalu	Inhabited	Western Rim	20	100	20
18	Kudahuvadhoo	Dhaalu	Inhabited	Southern Rim	2	50	20
19	Vilufushi	Thaa	Inhabited	Eastern Rim	5	30	5
20	Gan (Mukurimagu)	Laamu	Inhabited	Eastern Rim		1000	70
21	Gan (Thundi)	Laamu	Inhabited	Eastern Rim	20	20	30
22	Kolamafushi	Gaafu Alifu	Inhabited	Western Rim	5	30	5
23	Viligilli	Gaafu Alifu	Inhabited	Eastern Rim	40	80	40
24	Dhevvadhoo	Gaafu Alifu	Inhabited	Atoll Lagoon	10		
25	Thinadhoo	Gaafu Dhaalu	Inhabited	Western Rim	3	30	30
26	Fuvahmulah	Fuvahmulah	Inhabited	Oceanic Atoll	30		
27	Hithadhoo	Seenu	Inhabited	Western Rim	3	3	30
28	Feydhoo	Seenu	Inhabited	Western Rim	15	15	25
29	Hanimaadhoo	Haa Dhaalu	Inhabited/ infrastructure	Eastern Rim	30	70	30

Design

The design of setbacks is usually incorporated into resort islands during the planning stage. In inhabited islands, island with land use plans tends to have setbacks incorporated in the designs. In islands without land use plans, the principles of setbacks are maintained by the island office. However, this practice is not uniform in unplanned islands.

Setbacks in inhabited islands are most strictly applied to housing plots. It was observed that infrastructure developments such as power houses and communication facilities were often allowed to get a lot closer to the vegetation line than housing plots.

Issues and challenges

a. Setbacks are difficult to implement in inhabited islands when there is a land shortage, especially if there is no land use plan (for example AA. Bodufolhudhoo or M. Maduvvari Island). This is due to public pressure and occasionally due to mismanagement by the island administrators.
b. Setbacks are not equally applied to infrastructure development (for example Communication facilities in Thulusdhoo, Power and water facilities in Thinadhoo, and Sewerage and waste facilities in Sh. Funadhoo).
c. Some of the developments close to the shoreline have been undertaken in the past. While setbacks are in effect for new developments, the presence of these old developments presents a challenge for adaptation. For example, oceanward coastline of S. Hithdhoo on average has about 50 m setback, apart 100 m strip along the coastline with no setback. As long as the old structures remain, the island offices are under pressure to release the area allocated for the setback.
d. The setback guidelines for resort and inhabited islands are inadequate. The physical condition and exposure of islands to various hazards vary depending on the location of the island and host of other geophysical features. Moreover, the oceanward and lagoon ward side or atoll rim islands usually have different hazard exposure patterns.

Effectiveness

The use of setbacks has also been proven as an effective method of adaptation in most islands (for example, HDh. Kulhudhuffushi, S. Hithadhoo and Dh. Hulhudheli). However, as noted before this method is dependent on the commitment by island administrators and developers to implement the land use planning guidelines. On a number of occasions new plots are allocated with limited setbacks and in erosion prone areas. Moreover, the setback guidelines are inadequate for some islands and in some environmental conditions. Guidelines should reflect the variations in hazard exposure patterns across Maldives and in various geomophological settings in an island.

Examples

Figure 5.4 Setbacks enforced in densely populated B. Eydhafushi Island

Figure 5.5 Poorly enforced setback in Dh. Kudahuvadhoo and Gdh. Thinadhoo

Figure 5.6 Old coastal developments with no setback in and S. Hithadhoo

5.3.4 Retention and replanting of Coastal Vegetation

Coastal vegetation is known to play a major role in reducing the exposure and impacts of natural hazards in the Maldives (UNDP, 2007). In the face of predicted intensity and frequency of natural hazards due to climate change, coastal vegetation may have a crucial role to play in the adaptation of small islands, particularly to coastal flood impacts and strong wind.

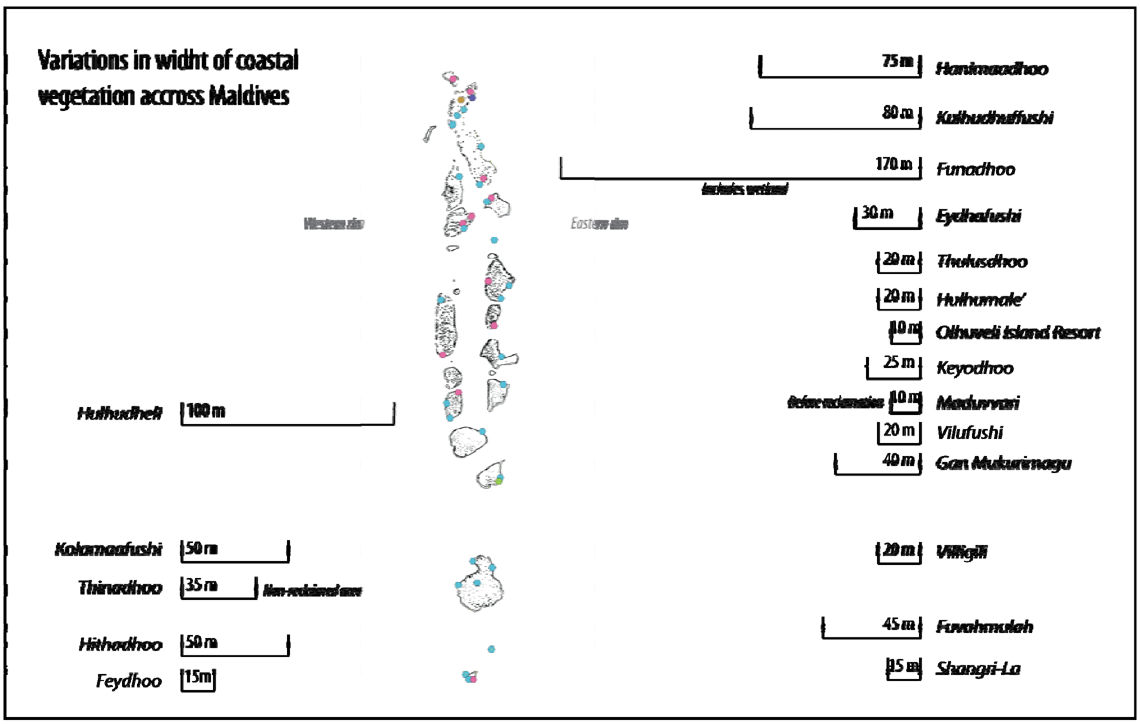
<u>Usage</u>

Coastal vegetation has been retained in most islands as a traditional adaptation measure against strong wind, resulting salt spray and occasional coastal flooding. There appeared to be a strong relationship in the study islands between retention of coastal vegetation and intensity of wave and wind activity. In general, the following preliminary findings could be deduced.

a. The oceanward shoreline of islands on the western rim of Maldives, exposed to strong winds and salt spray during Southwest Monsoon, have a wider coastal vegetation system (see Figure 5.7). The exception to this pattern is when the island has been reclaimed or has a very high population density. For example: S. Feydhoo, S. Maradhoo, S. Maradhoo-Feydhoo, GDh. Thinadhoo and B. Thulhaadhoo.

b. Similarly, the oceanward shoreline of islands in the north Maldives, particularly on the atoll rim, has a wider coastal vegetation system. This could either be related to strong wave activity during NE monsoon or due the relatively large size of the islands. However, that fact that high density islands like Kulhudhuffushi have retained a wide coastal vegetation system suggests that it is an adaptation to strong winds. This finding was confirmed by locals as well.
c. Islands in the central Maldives, which are less exposed to regular strong wave activity, have comparatively narrow coastal vegetation systems. This could either be related to the lack of need for a wide vegetation belt, relatively narrow width of islands and generally comparatively lower ridge (see next section).

Figure 5.7 Variations in coastal vegetation width across Maldives



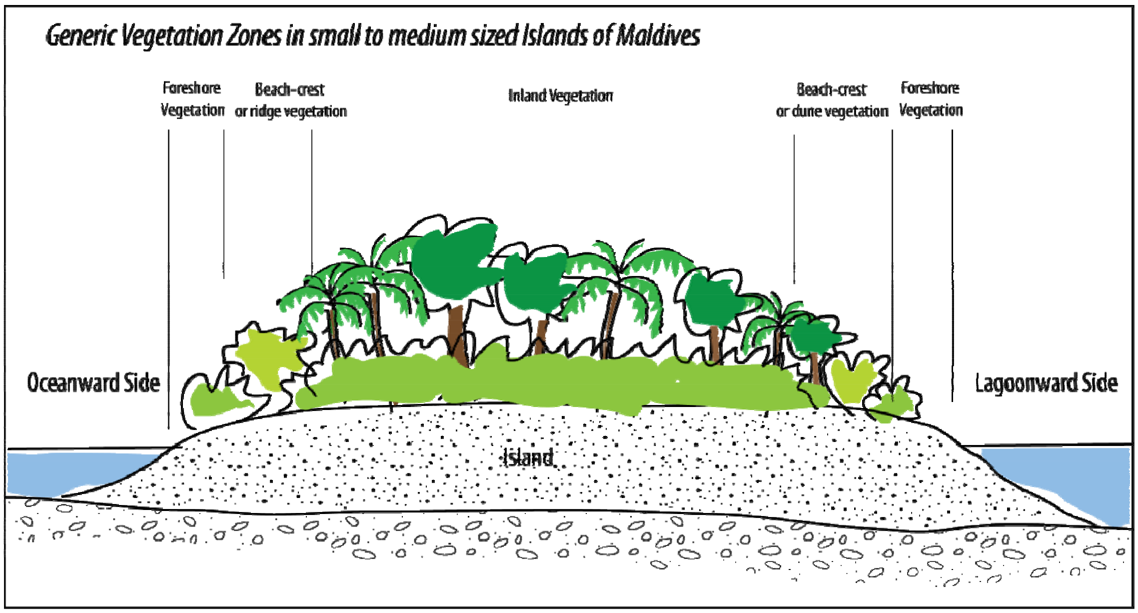
Coastal vegetation is generally retained as an adaptation measure in high exposure islands. In other island, particularly islands with beach replenishment or reclamation, vegetation is replanted. Replanting is generally done using common coastal vegetation species present on the island. Coastal vegetation retention is strongly linked to other soft adaptation measures such as land-use setbacks and preservation of coastal measures (see next section).

<u>Design aspects and natural patterns</u>

There is no specific design for the retention or replanting of coastal vegetation. However, specific vegetation patterns can be deduced from past vegetation studies and field work data. Some of these patterns are summarized below.

a. The general vegetation zones in small to medium coral islands in Maldives can be classified as: i) fore-shore vegetation; ii) beach-crest or dune vegetation; and iii) inland vegetation (see figure 5.8). Vegetation zones in large islands are a little different with easily delineable forest areas (like *Pisonia Grandis*), wetland vegetation zones (based on Newberry and Spicer (1979) and Stoddart (Stoddart, 1966). Amongst these zones, the fore shore and beach-crest vegetation can broadly be classified as coastal vegetation.

Figure 5.8 Vegetation zones in small to medium sized islands in Maldives



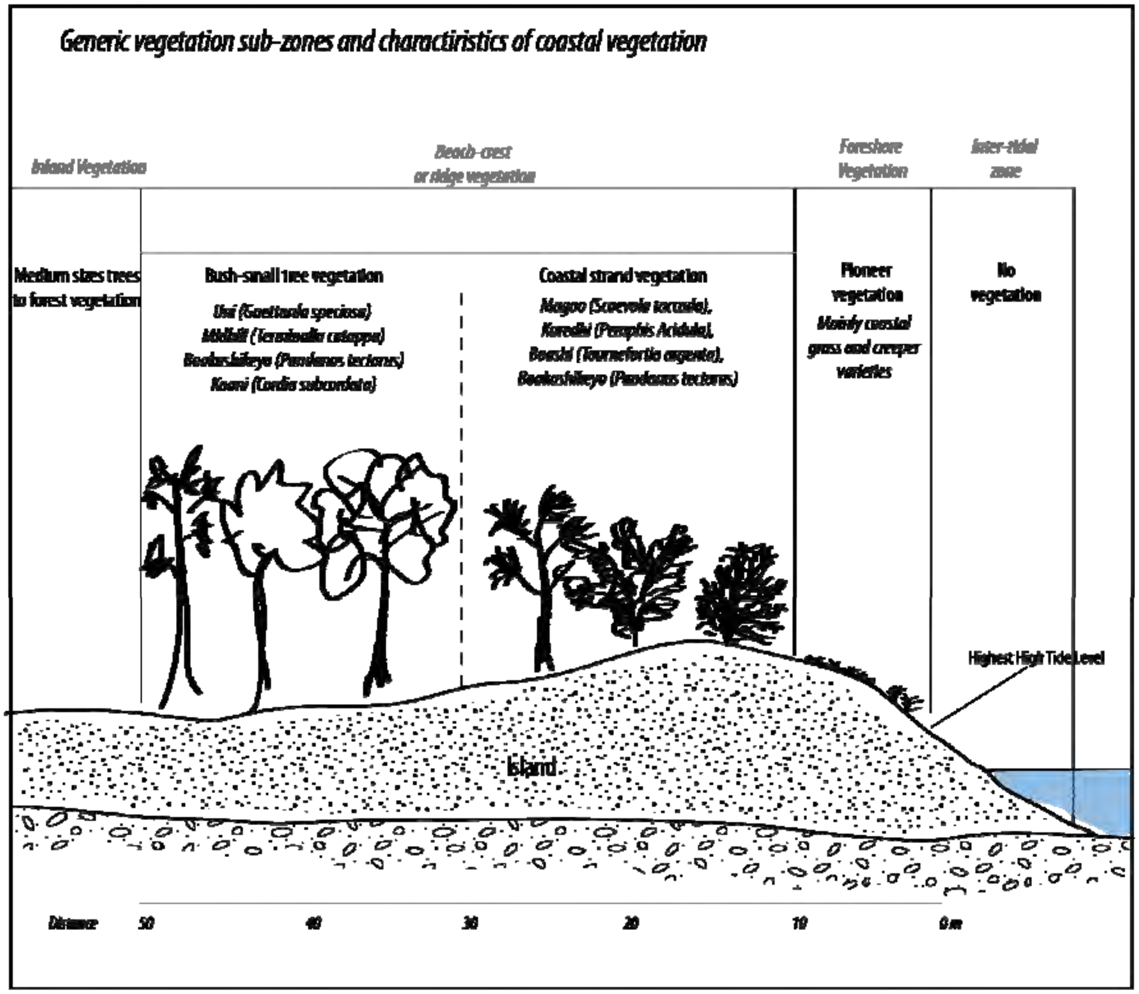
Note: Based on model proposed by Parham (1971) and adopted by Selvam (2007).

a. Broadly, the vegetation types in the coastal zone could be described as: i) pioneer vegetation; ii) 'coastal strand vegetation' and 'bush-small tree' vegetation (after Newberry and Spicer (1979)). Figure Pioneer vegetation comprise mainly of grass and creeper varieties. They act to stabilize new beach areas which have remained stable or uneroded for one or more monsoon seasons. Long term stability usually comes after at least two or more years of stability. The coastal strand vegetation varieties generally comprise of Kuredhi (*Pemphis Acidula*), Magoo Magoo (*Scaevola taccada*) and Boakashikeyo (*Pandanus tectorus*). In the northern parts of Maldives Boashi (*Tournefortia argenta*) is also commonly found in the strand. Bush-small tree vegetation is generally not well defined and may contain a mix of strand vegetation and inland vegetation. Common dominant species include Uni (*Guettarda speciosa*), Midhili (*Terminalia catappa*), Boakashikeyo (*Pandanus tectorus*) and Kaani (*Cordia subcordata*).
b. Coral islands in general tend to exhibit a strong environmental gradient from windward (oceanward) to leeward (Laggonward) side (Wiens, 1962). However this trend is reported to be generally minimal in the Maldives due to the variable nature of prevailing wind (Spicer and Newbery, 1979). Based on field assessment, the effects of environmental gradient is most

prominent on the islands on the western rim of Maldives. The effects of strong prevailing wind during SW monsoon coupled with strong wave activity and subsequent salt spray, has created a more dense, wider and specialized strand vegetation system (for example, S. Hithadhoo, natural areas [unreclaimed areas] of G.Dh Thinadhoo and Dh. Hulhudheli). In comparison the islands on the eastern rim, particularly in the comparatively calm central Maldives, tend to have a more generic pattern as shown in Figure 5.9. However, unlike the islands on the western rim, the lagoonward shorelines of some eastern rim islands have higher ridge and wider coastal vegetation systems. This may be due to the effects of prevailing SW monsoon winds. Nonetheless, re-vegetation as a human adaptation measure will need to take these natural adaptation trends into consideration for such measure to be effective.

c. The existing coastal vegetation on some islands may be misleading. Some islands at present have 'bush-small tree vegetation or medium sized inland vegetation as coastal vegetation. On most occasions this pattern has been related to severe erosion in the past in which the old strand vegetation was completely removed. Hence re-vegetation designs should still consider strand varieties in such situations.
d. Similarly, human activities has significantly modified coastal vegetation in inhabited islands through the enhancement of coconut groves for forestry and introduced vegetation.
e. The occurrence of certain species of strand vegetation appears to be linked to specific environmental factors. For example, Kuredhi becomes the dominant and often the only species in coral rubble beaches. Similarly, Boakashikeyo is the dominant species in windy, high salt spray prone areas, particularly the western shoreline of the western rim islands like Ga. Kolamaafushi, G.Dh Thinadhoo and Dh. Hulhudheli. These patterns give guidance to design re-vegetation activities. For example, for years G.Dh Thinadhoo has attempted, without success, to plant coastal strand varieties of Kuredhi and Magoo on the oceanward coastline of the newly reclaimed land. When we observe the existing coastal strand varieties in the original island or in nearby islands (Ga. Kolamaafushi) the dominant species is Boakashikeyo. Perhaps, they boakashikeyo is the only species that could naturally adapt to the specific environmental conditions.
f. Coastal vegetation appears to have a certain density of occurrence to perform their functions as a wind and salt spray barrier and as contributor to facilitating inland vegetation growth. Current practices in inhabited islands tend to clear the undergrowth of coastal vegetation for aesthetic reasons. Proper coastal vegetation design should address this short-coming

Figure 5.9 Generic vegetation sub-zones and characteristics of coastal vegetation



g. Coastal vegetation belt's functioning is inextricably linked to the dune or ridge system (see next section) and therefore should be treated together in artificial designs.
h. Replanting in newly reclaimed areas should consider the use of pioneer vegetation and artificial conditioning of soil system.

<u>Issues and challenges</u>

a. Local communities have a very good understanding of the composition, functioning and importance of coastal vegetation systems. However, they seem to lack information on plant density and width required for the proper functioning of the coastal vegetation system. As a result they tend to encroach very close to the vegetation line and remove undergrowth for aesthetic purposes. Even in island with wide coastal vegetation systems like H.Dh Kulhudhuffushi, the practice of clearing undergrowth and sometimes replacing coastal vegetation with coconut trees is a common practice. These practices reduce the effectives of the coastal vegetation system as an adaptation measures.

b. It is also clear that land shortage is often one of the main reasons for removing the coastal vegetation belt. Beach replenishment is required in these islands to restore the vegetation belt (for example in M. Maduvvari, V. Keyodhoo, S. Feydhoo, Lh. Naifaru and K. Thulusdhoo). In islands with existing vegetation systems, strict land use plan implementation is required to protect the coastal vegetation strip.
c. As noted above, the existing guidelines for building setbacks is inadequate for various environmental conditions. The extent of setback effectively determines the width of coastal vegetation belt. Guidelines need to be adjusted to take into consideration various climatic and geo-physical characteristics such as location of the island, ocenaward and lagoonward coastline differences and natural hazard exposure.
d. Solid waste disposal into the coastal vegetation is a major contributor to the degradation of the vegetation belt. Such activities were found in most islands including Dh. Kudahuvadhoo, Ga. Kolamaafushi, Sh. Funadhoo and N. Velidhoo).

Costs

The use coastal vegetation preservation and coastal ridge maintenance is the most common method used against coastal flooding and to some extent against erosion. The effectiveness of ridges and vegetation belt are felt significantly in high flood exposure zones like the northern and southern rim islands of Maldives. Major settlements in the north and south like S. Hithadhoo, Fuvahmulah, Sh. Funadhoo and Hdh. Kulhudhuffushi rely heavily on these natural adaptation features for protection. As noted before, the vegetation belts are generally narrow and coastal ridges lower in central parts of Maldives reflecting the comparative lack of flooding or storm hazards. However, given the success of ridges and coastal vegetation in the northern and southern islands, artificial development of such structures are expected to be highly successful in central Maldives against potential storm and flood events.

Costs

a. The unit cost per linear meter of new planted coastal vegetation is estimated at Rf900 per linear meter.
b. This estimate is based on market rates of plants (Rf10 per small tree) and the following assumptions:
    i. Density: 1-2 trees per m^2
    ii. Width of strand vegetation belt: 30 m
c. Maintenance does not involve any additional costs once matured.
d. Alternatively, a nursery could be established to produce plants and will involve the following costs and design aspects:
    i. Pit size 1 m x 1 m
    ii. Fertiliser per pit: Rf 65
    iii. Seedling per pit per cycle: Rf 30
    iv. A pit will produce 36 trees per cycle.

Examples

Figure 5.10 Pioneer vegetation growing on stable beach

Figure 5.10 Coastal strand vegetation: (clockwise from left) Magoo, Kuredhi, Boakashikeyo and boashi

Figure 5.11 Coastal vegetation restoration activities in Dh. Hulhudheli. G.Dh Thinadhoo, K. Hulhumale' and S. Feydhoo

5.3.5 Preservation of Coastal Ridges

Similar to coastal vegetation, coastal ridges are known to play a crucial role in the natural and planned adaptation to natural hazards in Maldives (UNDP, 2007).

Usage

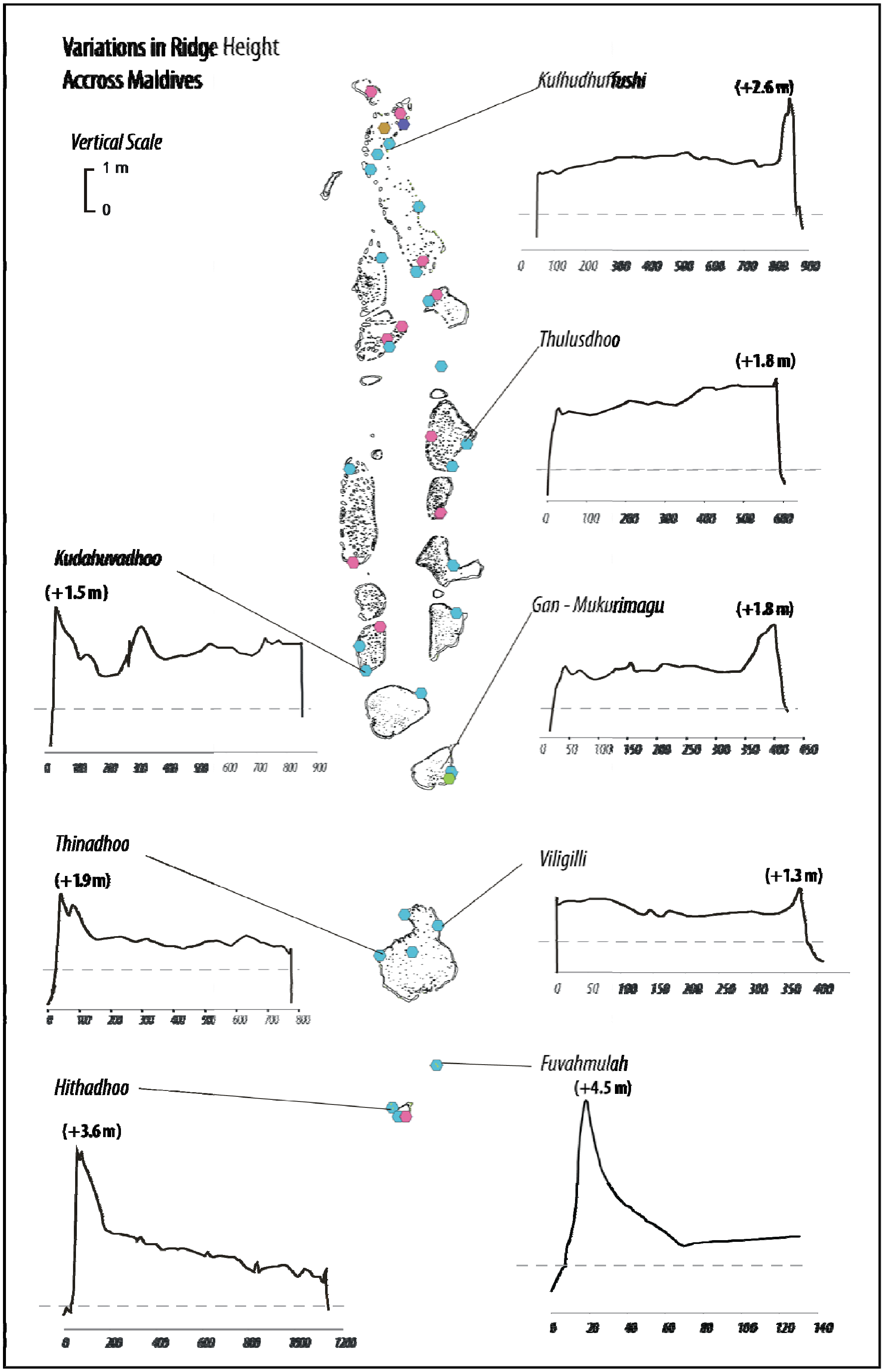
Ridges are a natural adaptation of the island coastlines to prevailing wind and wave conditions at the site (UNDP, 2007, Shaig, 2006a). They are generally left untouched, especially in islands high wind and wave exposure. Ridges are treated as part of the coastal buffer zone and are usually used as an adaptation measure with land use setbacks and coastal vegetation retention.

Not all islands have a well defined coastal ridge. Figure 5.12 shows a graphical summary of ridge height variations across the Maldives and among the study islands. There are significant variations in ridge height between the central and, northern and southern half of Maldives. The southern islands have some of the highest ridges particularly in Fuvahmulah (4.5 m) and S. Hithadhoo (3.6 m). Similarly, Kulhudhuffushi in the north has a ridge height of 2.6 m. The figures for central Maldives study islands are on average 1.6 m. There are a number of potential reasons for these variations but the most commonly known link is with the intensity of wave, wind and storm activity. The southern atolls of Maldives, particularly those on the western rim of southern half of Maldives are exposed to strong swell waves and a strong prevailing SW monsoon wind (UNDP, 2007, Shaig, 2009) . Similarly the northern half of Maldives is exposed to strong storm activity and swells during NE monsoon (UNDP, 2007, Shaig, 2009, UNDP, 2006). In addition, to exposure to storm activity, geophysical features such as proximity of the oceanward reef edge and oceanward coastline in northern and southern atolls may also play a role in variation of natural ridge heights (Shaig, 2009). Hence the use of coastal ridge as an adaptation measure is most crucial in northern and southern atolls. However, the use of artificial ridges as a human adaptation measure in all parts of the Maldives may drastically reduce the impacts of future coastal flooding from increasing abnormal climatic activity.

Artificial ridges have been used as an adaptation measure in the ‘Safe Island’ or ‘resilient island’ concepts of Maldives. The islands of Vilufushi and Viligilli, which were reconstructed as safe or resilient islands following the 2004 Indian Ocean Tsunami disaster, are reported to have 2.4 m high artificial ridges constructed from armour rock.

Similarly, rudimentary artificial ridges constructed from lagoon sand and construction debris have been used in islands with high population densities and land reclamation (for example in S. Feydhoo and V. Keyodhoo)

Figure 5.12 Variations in ridge height across Maldives and survey islands



Date source: UNDP (2007) and CDE (2006)

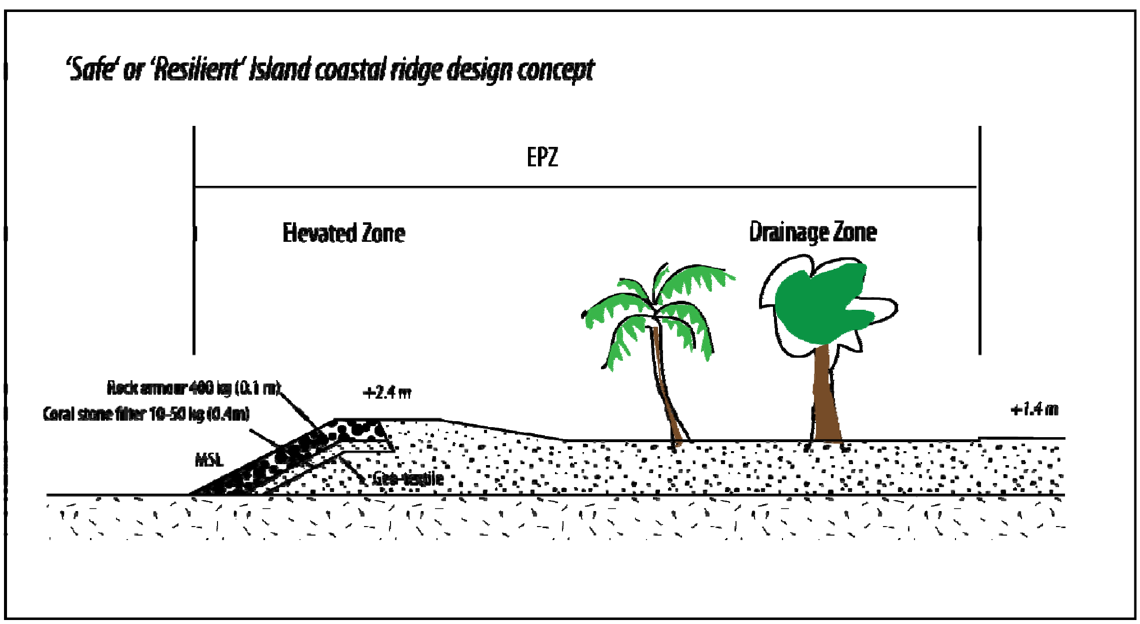
Design aspects and natural patterns

Similar to coastal vegetation system, there is no specific design for the maintenance of coastal ridges. As noted above it is generally a natural response by the island to adjust to prevailing storm conditions and will vary from location to location. Hence, maintenance of the existing ridges without degrading activities such as excavation, sand mining or construction activities is the most important principle in using ridges as an adaptation measures.

If artificial constructions of ridges are required, the basic components of a ridge are its height, width, slope and sediment composition. Soft engineering will generally involve the use of lagoon sand to enhance the ridge. The use of boulders, construction debris or other hard material generally falls under hard engineering solutions. The use of lagoon sand will require proper profiling of ridges and the use of sediments of larger or equal size. In addition, re-establishment of coastal vegetation is crucial to naturally stabilize the ridge.

Designs have been prepared for safe or resilient island ridges. The standardized height for the structure is +2.4 m MSL (see figure 5.13). The design incorporates artificial planting of coastal vegetation, drainage and construction setbacks as well, with a fixed width of 40 m. The design however involves hard engineered foreshore breakwaters due to their armour rock construction.

Figure 5.13 'Safe' or 'resilient' island coastal ridge design concept



Issues and challenges

a. Maintenance of coastal ridges is generally a low priority in inhabited islands. Developments on high ridges have so far been restricted (for example in Hithadhoo, Fuvahmulah and Kulhudhuffushi) due to the deep water table in this zone. Some islands consider the presence of ridges as an aesthetic issue as the sea is generally ‘not visible through the main roads’. Kulhudhuffushi Island for example had their 2.6 m ridge reduced to 1.3 m on the two main east-west roads since the high ridge was seen as an aesthetic issue by some. L. Gan has large areas of the ridge mined for sand during a road development project.

b. Land reclamation activities at present do not consider the implications of a coastal ridge. Islands which are reclaimed on the oceanward side closer to the reef edge will require adequate ridges to prevent flooding. It is known that in high energy zones, the ridge height is somewhat linked to the distance between oceanward reef edge and oceanward shoreline (UNDP, 2007). Failure to observe these natural adaptations have led to regular flooding, for example in Gdh. Thinadhoo.

c. The ‘safe’/’resilient’ island designs have a standard height and width for ridges. This is a major limitation in the design since the height, width and slope of ridge is dependent very specifically to the prevailing conditions at a site. The height of 2.4 may not be adequate for some site and will be an over design for others.

d. The standard setbacks used in land use planning are inadequate in some islands to maintain the ridge system.

<u>Costs</u>

a. The unit costs per linear meter of a raised ridge is estimated at Rf1,300 per linear meter.

b. This estimate is based on market rates for dredging and reclamation (Rf65 per m^3) and the following assumptions:
   i. Height of ridge: 2.5 m
   ii. Base height of ridge: 1.5 m
   iii. Additional reclamation height: 1.0 m
   iv. Width of ridge: 20 m

c. Maintenance does not involve any additional costs once ridge is established.

Examples

Figure 5.14 Artificial coastal ridges as an adaptation measure against flooding in Hulhumale' and S.Feydhoo

Figure 5.15 Natural high ridges in S. Hithadhoo (+3.6 m) and HDh. Kulhudhuffushi(+2.6 m)

5.3.6 Use of Construction Waste

Usage

Construction waste has often been used in the inhabited islands as temporary adaptation measure against severe erosion. Amongst the 26 inhabited islands surveyed 19 had some section of the island protected using construction debris. Their widespread use is mainly because they provide a no-cost adaptation option and it serves the additional purpose of construction waste disposal. The placement of debris is usually in severe erosion zones, particularly near coastal structures like harbours. Collection and placement of material is often left to the individuals but the location for disposal is usually identified by the island office. In some islands, this method has been used as a solution to construction waste disposal rather than as true adaptation measure.

Occasionally green waste or coconut tree trunks are used as along with or separately from construction waste.

Design

As an *ad hoc* adaptation measure, there is no specific design. Material is placed on the eroded slope either at the same height of the ridge or at a slightly raised level. There is a major aesthetic issue with these structures but locals generally feel that eroding areas are rarely used for any recreational activity.

Issues and challenges

a. The *ad hoc* placement of the debris often results in unwanted changes to other sections of the beach particularly on the edges of the placed material. This was observed in islands like DH. Kudahuvadhoo, B. Eydhafushi, Hdh. Neykurendhoo and TH. Vilufushi.
b. The unsorted disposal method of construction waste has the potential to cause negative environmental impacts on the marine environment and poses the risk of injury to locals (for example K. Thulusdhoo).
c. Once the construction debris is placed on the beach it is difficult to access those sections of the beach reducing the future recreational value.
d. The size of debris is not controlled and as a result large blocks may be placed in whole. This makes it difficult to remove these structures once erosion ceases. This was particularly observed in HDh. Kulhudhuffushi and Th. Vilufushi.

Effectiveness

Placement of construction debris or ad hoc seawalls in eroding areas was another 'quick-fix' solution that has been highly effective in controlling severe erosion in inhabited islands (for example, Dh. Kudahuvadhoo and B. Eydhafushi). This method helps to arrest erosion in selected high erosion zones and provide the island with a construction waste disposal method. However, the *ad hoc* placement of material, impacts on adjoining beach areas, potential marine environmental impacts, health and injury risks and aesthetic issues makes this adaptation method less desirable. However, this should be considered as one of the most cost effective and practical community level soft adaptation methods used in the inhabited islands against severe erosion.

Costs

There are no public costs involved in this measure as construction waste is transported by individuals at their own cost.

Examples

Figure 5.16 Use of construction debris as an adaptation measure against erosion in (clock wise from left) B. Eydhafushi, Th. Vilufushi, HDh. Neykurendhoo and Dh. Kudahuvadhoo.

Figure 5.17 Use of both construction debris to protect properties from flooding in S. Feydhoo

Figure 5.18 Use of green waste as an adaptation measure against erosion in HDh. Kulhudhuffushi and B. Eydhafushi

Figure 5.19 Use of both construction debris and green waste as an adaptation measure against erosion in HDh. Hanimaadhoo and V. Keyodhoo

5.3.7 Artificial coral reefs

Usage

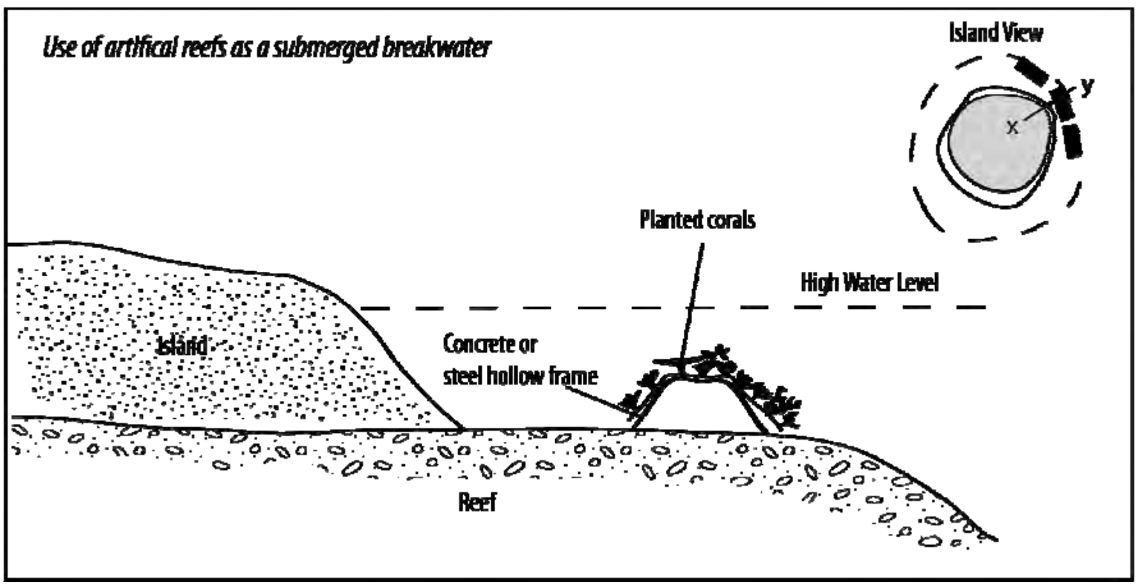
Artificial reefs are currently being used primarily to enhance the reef as a tourism product rather that than as a mitigation measure against climate change or natural hazard mitigation. There have been proposals to create submerged breakwaters in island like B. Reethi Beach, K. Fun Island and Ha. Manafaru, but the projects haven't come through yet.

Design and construction

There are no projects in implementation in the surveyed islands. However, the design from the proposals can be generalized as shown in the Figure 5.20. The construction of base material is generally from specially constructed concrete hollow blocks or steel frames. Concrete blocks come in propriety designs such as the reef balls or as custom made blocks. The most commonly used material in Maldives is steel frames welded especially for the purpose. The shapes of the frame generally tend to be close to the profile of a breakwater. Coral recruits are collected from a nursery or nearby reefs and pasted onto the frame using special glue. The coral growth timing varies but generally taken more than 2-3 years to mature.

The survival of the coral depends on the site conditions. The most important aspect of the design is to identify the correct locations, depths and type of coral that would best survive in the conditions. This is a cheap and creative adaptation measure that can be readily applied to most islands of Maldives with the proper awareness and capacity building programmes.

Figure 5.20 Generalized design for construction of artificial reefs as submerged breakwaters



Issues and challenges

a. The key issue with artificial reefs lies in the transfer to knowhow. Artificial reef structures are simple and cost-effective but require training to construct and maintain them successfully.
b. Artificial reef takes time to develop and become an effective adaptation measure. Most adaptation measures in Maldives are undertaken as a last resort hence, artificial reef projects are continuously postponed or not implemented efficiently.

Effectiveness

There has been no implementation of artificial reefs as an erosion mitigation measure yet.

Costs

a. The unit costs per linear meter of raised ridge are estimated at Rf1085 per linear meter.
b. This estimate is based on the following assumptions:
    i. Hollow concrete base with the following dimensions: 1 m x 1 m x 1m

ii. Volume of concrete required per m^3: 9 ft^3
iii. Construction rate: Rf5 per ft^3
iv. Professional fees: Rf3000 per 100 m
v. The locals or dive schools in resorts will carry out coral transplanting activities free-of-charge.

c. Maintenance does not involve any additional costs once reef is established.

5.3.8 Coastal developments on stilts

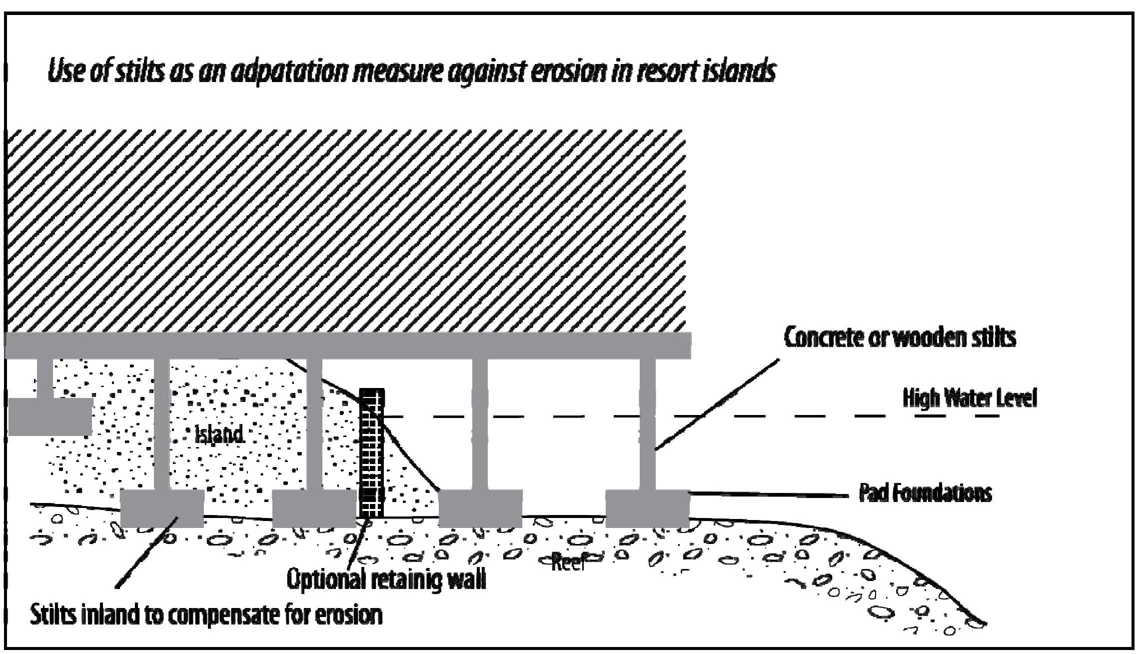
Usage

Construction close to the coastline, particularly in small islands makes them highly vulnerable to erosion and subsequent investment in mitigating erosion. Construction in resort islands adapts these risks by accommodating coastal changes and constructing the structures close to shoreline on stilts or with a retaining seawall. These practices are only found in resort islands. In inhabited islands, land based infrastrucuture constructed close to the beach such as power houses and communications facilities have their key equipments or whole buildings raised. However, this practice has become common only after the 2004 tsunami.

Design and construction

Designs are fairly constant for resort islands. Most constructions are on concrete stilts with pad foundations and raised to at least one m from the high water level. The stilts go at least 3-5 m inside the vegetation line.

Figure 5.21 Use of stilts as an adaptation measure against erosion



Effectiveness

Adaptation of coastal infrastructure against potential erosion impact has been the most successfully implemented design level soft adaptation measure in resort islands (for example in K. Boduhithi, N. Manafaru, Dh. Vilureef and K. Olhuveli). Coastal developments are usually built on concrete, wooden or steel stilts and occasionally with a cautionary sea wall well inside the beach line. Structures built without a cautionary retaining sea wall have been affected in the past due to severe erosion.

Costs

Costs for this adaptation measure are highly variable and depends on the size of the structure, weight and elevation of the island. Hence, a unit cost is not effective descriptor of the costs involved. In general, the costs of a over water structure is 20-30% higher than a land based structure due its use of piles, salt proofing and additional adjustments to mechanicals and electrical.

Examples

Figure 5.22 Use of stilts and retaining walls in Dh. Vilu Reef Resort

5.3.9 Submerged geo-textile tubes

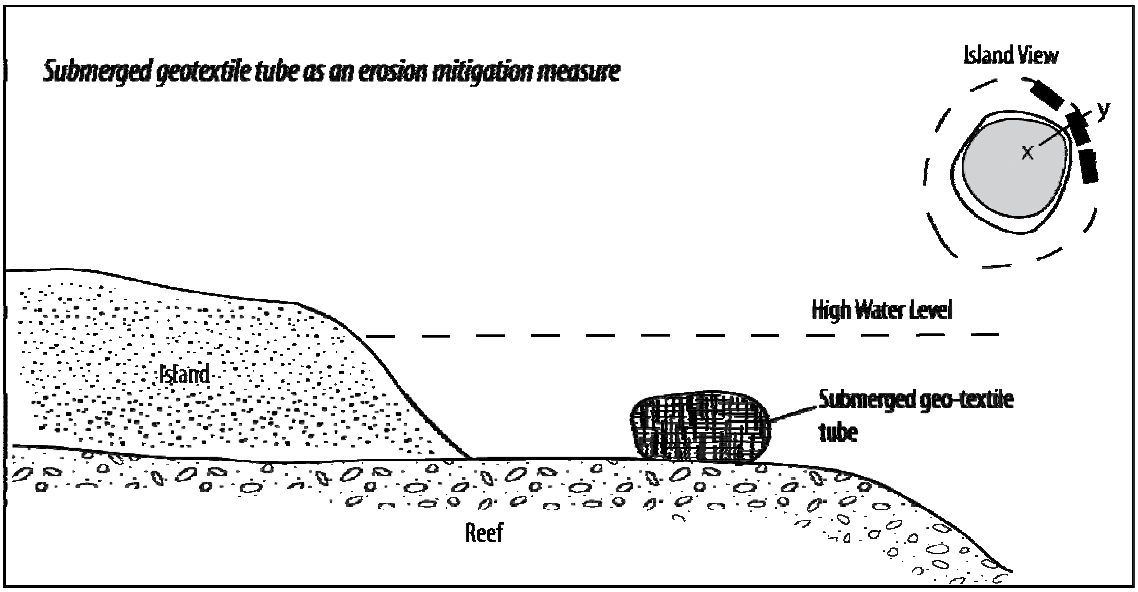
Usage

Submerged geo-textile tubes are a form of submerged breakwater but one which can be removed comparatively easily if no longer required. It has also been used as a measure to prevent sediment loss and to deep lagoon or reef slope after beach replenishment activity. The key advantages of geotubes are that it is easy to deploy, looks natural and can be removed. Examples of its use can be found in Shangri-La at Villigili and to some extent in B. Reethi Beach.

Design and Construction

The design involves placing sand filled geo-textile bags or tubes placed at a specific interval from the shoreline below high tide level. The bags are sewn from geotextile using a special sewing machine and filled using special equipment. Sand is usually placed using an excavator or dredger for larger projects. The tubes are placed using excavators or cranes mounted on a barge or sand bed.

Figure 5.23 Generic design of submerged geotextile tubes as a near shore structure



Issues and challenges

a. This method has not been widely adopted in Maldives yet. The reasons may be related to mix of costing, uses of specialized equipment and reliability. Most people interviewed are not aware of the durability of geo-textile material are concerned that it would break apart within a few years.
b. The tubes require filling using sand which involves dredging. Unless there is a dredging project, this method becomes unattractive for resort islands and Government agencies funding beach protection measures in islands. Moreover, the environmental impacts are generally higher due to the requirement for dredging when compared to other material such as armour rock.

Effectiveness

Effectiveness of submerged geo-textile tubes cannot be determined at present due to their lack of implementation.

Costs

a. The unit costs per linear meter of submerged geotubes are estimated at Rf1,873 per linear meter.

b. This estimate is based on the following assumptions and rates:
    i. Dimensions: 1 m x 1 m x 1m
    ii. Volume per linear m: 1 m^3
    iii. Labour costs: Rf1500 per m
    iv. Material costs: Rf373 per m
c. Maintenance does not involve any additional costs once the tube is constructed.

5.3.10 Sea grass beds

Seagrass beds have generally been regarded as natural protection measures against coastal erosion (Perrow and Davy, 2002, Fonseca, 1996). Its growth in Maldives have been widespread but it presence appears to diminish north of Noonu Atoll. The highest concentration is in the central and southern atolls.

The locals do not generally consider seagraas beds as beneficial in erosion prevention. In fact, they mostly see it as nuisance due to beaching and aesthetic issues associated with it. Islands with harbors often find it difficult to clean the harbor due to regular accumulation of dead sea grass in the harbor basin. Resort islands particularly consider sea grass beds as not compatible with the beach tourism offered in Maldives. Numerous resorts have invested in projects to remove seagrass from the lagoon (for example: Fun Island Resort) and for regular beach cleaning. Removal is generally not an option for inhabited islands due to prohibitive costs.

Nonetheless, islands with large seagrass beds are reported to enjoy a natural adaptation measure against erosion. However, while the case for sea grass as sediment stabilizing ecological setup is well-established in continental and large island settings, it is yet to be fully studied in the Maldives. The specific species present in Maldives and their growth in generally low energy zones raises questions about their efficiency in erosion mitigation. Moreover, there is a possibility that the sea grass beds are generally incompatible with the shallow reef and lagoon environment of Maldives due to their interference in coral growth and coral colony establishment (Miller and Sluka, 1999).

Hence, seagrass beds, for the time being, must be considered an asset against erosion unless proven otherwise by further research. However, its artificial plantation in seagrass free zones may not be advisable until more concrete evidence of its erosion mitigation benefits is available.

5.3.11 Mangrove and salt marsh vegetation

Similar to seagrass beds, wetland and salt marsh vegetation has been considered an asset against flooding and erosion (Perrow and Davy, 2002). However, the survey found no evidence of coastal mangrove vegetation specifically being responsible for erosion prevention. Moreover, growth of mangrove vegetation systems seems to be restricted to very specific site conditions. Their growth in high energy zones on the oceanward coastline is almost non-existent although they grow efficiently in protected environments. The role played by vegetation species like Kuredhi (*Pemhis Acidula*) appears to be much stronger due to their highly adaptive ability in both high and low energy zones.

On the other hand, the presence of a wetland has assisted in efficiently mitigating flooding in some islands. For example, presence of wetland on the oceanward side of Sh. Funadhoo saved the island from serious damage during the 2004 Tsunami UNDP, 2007). Similarly the presence of central wetlands in S. Hithadhoo and Gn. Fuvahmulah are known to play a crucial role in managing the water resources and drainage of the island. Maintenance of these wetlands should be a priority soft adaptation measure.

The current state of knowledge on mangrove and marshland vegetation and their role in mitigating erosion and flooding in Maldives is poor. In this state, it is not recommended to use artificial plantation of mangrove vegetation as an option to control erosion or flooding. It may be more useful to consider planting coastal vegetation as described in the previous section. The effectiveness of wetland systems on mitigating floods is well-known but it may be impractical to duplicate them artificially to other islands.

5.4 Perceptions towards soft engineering Solutions

Perceptions towards soft adaptation measures were recorded using interviews with island administrators, resort developers and locals. There were observed variations in perception amongst islands and particularly between inhabited and resort islands. The main findings are summarized below:

5.4.1 Resort Islands

a. Most resort islands are aware of soft adaptation measures but do not necessarily classify them as soft measures. Some resorts like Boduhithi, Reethi Beach Resort, Shangri-la, Manafaru and Irufushi have a strong exposure to soft adaptation methods and have implemented them effectively.
b. In general, new resorts are more welcoming towards soft adaptation measures and old resorts have reservations about using them. This is perhaps due to the extensive use of hard adaptation measures in these islands and lack of opportunities to reconsider new or soft erosion prevention measures. They usually fear the repercussions of removing the existing hard engineered structures. Moreover, since the investments in hard structures have already been committed, they are cautious in trying new measures.
c. Some resorts do not opt for soft adaptation measures since it is not a permanent solution towards erosion mitigation. Soft adaptation measures require continued investments, albeit, at a smaller scale over a longer period. This has been seen as negative aspect by some investments and opts for permanent solutions. Island like Royal Island, Fun Island and Vilureef are examples of such developments.
d. It was also observed that some resorts opt for hard engineered solutions or permanent solutions to reduce complications in sub-lease agreements. In sublease agreements, the case of erosion prevention measures usually falls on the main developer, particularly if the agreement is for management of the resort only. Under these conditions, it is easier for the developer to

provide a less complicated permanent solution with hard engineered structures. Irufushi island resort is one such example.

e. Some soft adaptation measures are seen as involving a high level of continued disturbance to resort operations. Activities such as beach replenishment and movement and temporary sand require closure of some sections of the beach or the island during the works. This is seen as unpractical by some resorts while other resorts successfully implement such activities during the night or during off-season.
f. About half of the resorts interviewed were skeptical about the effectiveness of soft adaptation measures and reported that they have tried such measure and were unsuccessful. Close examination of their activities showed fundamental flaws in design and implementation in most resorts. Moreover, they have tried coastal adaptation measures only when erosion became very severe and when properties were at risk. Under such conditions, simple soft adaptation measures may not have provided a comprehensive solution. Hence, in most resort islands, there is no ongoing beach monitoring programme and they are unable to predict when erosion would become severe. They generally wait until it is too late to consider soft adaptation measures and they end up constructing solid structures as a permanent solution.
g. Resorts and resort groups with a strong environmental consultancy backing have a high rate of soft engineering measure for adaptation. For example, resorts like Manafaru, Reethi Beach, Shangri-la and Boduhithi were observed to be fairly exposed to soft adaptation measures and were adamant on using those measure rather than hard structures.
h. Some resorts have managements that prefer soft adaptation measures but are restricted by the engineering decisions taken at the head office, particularly in resort groups like Champa Resorts, Universal Group and Villa Group).
i. Almost all resorts welcomed the idea for of soft adaptation measures once the types and benefits of soft adaptation measures were explained to them. This shows that they lack the necessary awareness to consider such measures.

5.4.2 Inhabited Islands

a. Soft adaptation measures are not generally understood in inhabited islands. Most administrators and locals have not been introduced to the concept. Locals in some islands with employment links to nearby resorts are aware of the concept but their knowledge is limited to a few measures like beach replenishment and use of temporary sand bags.
b. Once soft adaptation measures are explained to them the reaction was generally mixed.
c. First, most of them did not consider the usually ‘invisible’ soft options as true adaptation measures. Their views were influenced by hard structures visible to them, namely hard engineered structures like breakwaters and sea walls.
d. Second, some of them felt that this was an attempt by the Government to ‘come up with a story’ to avoid providing true coastal protection measures to the island.
e. Thirdly, some felt that these measures were most applicable to resort islands which are looking to maintain a good beach as opposed to inhabited islands that are looking to secure

their property and livelihood. They prefer a more solid and permanent structures that could make them 'comfortable' in the face of severe natural events like tsunamis and storm events.

f. Fourthly, they felt that some of the soft adaptation measures required continued funding to implement, for example beach replenishment. They reported that they are struggling to get basic services on the islands and to fund a large amount on beach management was impractical. Others disagreed and considered these options to be cheaper but even they had some reservations about their reliability.
g. Finally, the younger groups generally supported the idea of soft engineered structures mainly due to their concern about doing nothing while waiting for government sponsored hard engineering projects.
h. There were differences in perceptions amongst heavily reclaimed islands and less modified islands. Reclaimed islands like Lh. Naifaru, Th. Vilufushi and GDh. Thinadhoo generally felt that soft engineering measures may not be able to prevent erosion and flooding in those islands. Their perceptions are most likely to have been affected by the severe erosion that follows any reclamation project, especially in the first few seasons. Perceptions in less modified islands like Sh. Goidhoo, Sh. Funadhoo and Dh. Kudahuvadhoo island were either indifferent on more welcoming towards soft engineering measures.
i. All islands were in favour of building setbacks. Most of the islands which have recently breached the setback guidelines (for example, K. Thulusdhoo and Dh. Kudahuvadhoo) have done so with the Government promise of land reclamation in the near future.
j. The support for coastal vegetation belts and ridge maintenance as soft adaptation measures were very high in northern and southern islands. Perhaps, these islands are more exposed to severe hazards and have more experience of the benefits offered by soft adaptation measures. Moreover, these adaptation measures were most prominent in the northern and southern islands and they have managed to maintain them through generations.
k. Islands with severe erosion were generally against using only soft adaptation measures for coastal protection. They felt hard structures are compulsory for their situation. The response was a lot different in island with limited severe erosion. They welcomed soft measures but still specified some areas which will require hard protection. These were usually near the harbor.
l. There is a general feeling in all islands that coastal protection measures are the responsibility of the Government. Most islands have not and do not want to spend community money on coastal protection measures. If the Government is funding for protection, they generally feel that hard protection should be provided.

5.4.3 Industrial/Infrastructure Islands

a. Industrial islands were generally more welcome to various measures of coastal protection. Perhaps, this was because they had control over their expenditure on coastal protection when compare to inhabited islands.
b. Similar to inhabited islands, the managements of these islands felt that most soft engineering measures were suitable to resort islands.

c. Their concern for severe erosion was mainly in areas where infrastructure was in close proximity to shoreline. They feel that hard structures are required to guarantee protection for crucial facilities but soft measures could be considered for all other areas.

5.5 Challenges and Opportunities

5.5.1 Challenges

a. Soft engineering adaptation measures are a relatively new concept to the locals. In the absence of awareness, acceptance to these measures is limited and is met with skepticism both in resorts and uninhabited islands.
b. The effectiveness of soft engineering options has not been demonstrated well in the Maldives. Only a limited number of artificial measures have been used to date.
c. Coastal protection is usually considered a basic service that needs to be provided by the Government. They expect the Government to provide a permanent solution to hazards and prefer to see a visible development. Soft engineering is seen as 'invisible' and 'fancy' measures suitable mainly to tourist resorts.
d. Soft engineering may not be suitable as the only option for islands which have reached a critical level of erosion, particularly in close proximity to existing buildings. Most islands report erosion only when it becomes a very significant issue. Similarly, in resort islands erosion mitigation measures are generally considered when the erosion reaches a critical level, after which soft adaptation measures become unattractive as a permanent solution.
e. The old resort islands have constructed so many hard engineered structures that they are unwilling to risk removing them and consider soft measures.
f. Many of the soft adaptation measures are implemented without proper engineering, resulting in occasional failure and unwanted side effects like erosion in another section of the island. Most inhabited and resort islands consider that engineering services provided by professionals are expensive and unnecessary. Hence, they usually copy measures from another island without realizing that the conditions to which the original designs were made may not be applicable to their island.

5.5.2 Opportunities

a. Soft engineering measures are generally welcomed in islands when they are aware of their benefits, options, costs and methods of implementation. A well-targeted campaign in inhabited and resort islands is very likely to raise awareness and acceptance of soft measures.
b. There are a limited number of islands with effective soft engineering adaptation but they provide an opportunity to be used as success stories to communicate with other potential islands.
c. Design and construction methods for both hard and soft engineered solutions are generally copied from one island to another either through observation or by hiring the same contractor. Proper design and construction guidelines for soft adaptation measures will assist

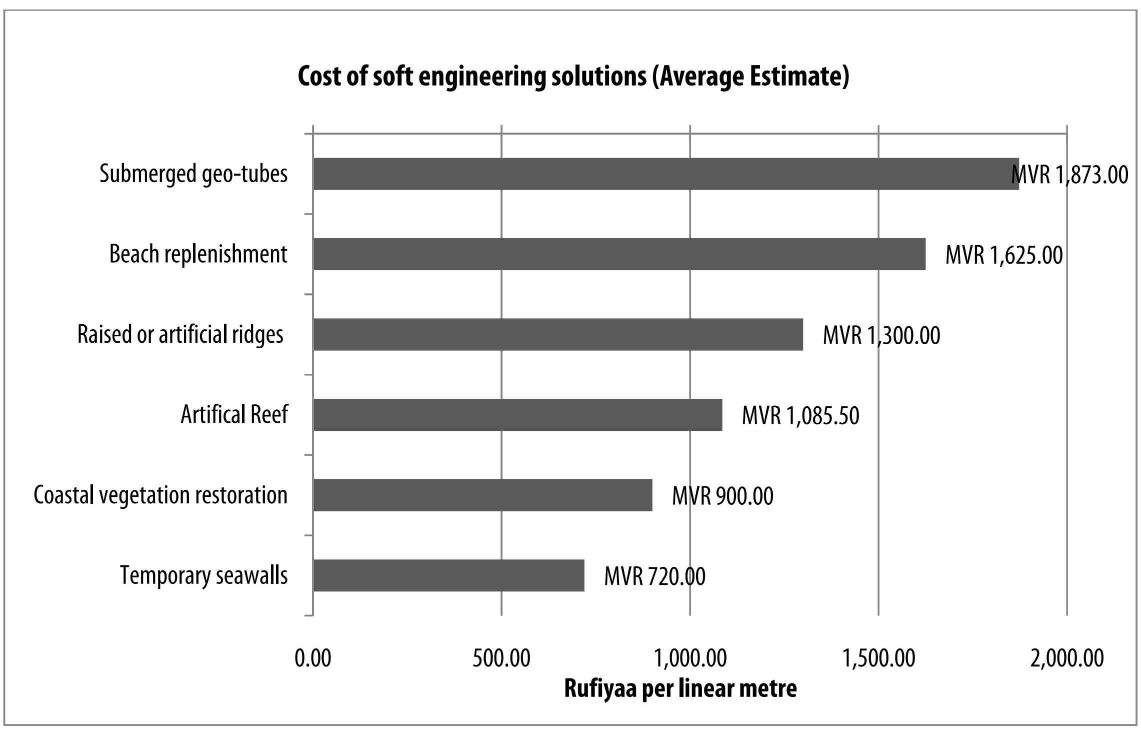
in the proper implementation of adaptation measures. In addition, training of key contractors like 'Maamigili and Fenfushi seawall specialists and coastal works companies can correct a lot of design mistakes.

d. Soft engineering measures work best over time. There is an opportunity to promote low cost long term measures before the worst hazards are realized. This will reduce the cost of adaptation and increase the preparedness of islands against ongoing hazards and predicted coastal impacts of climate change.
e. The existing guidelines for land use setbacks and beach replenishment have been found to have generic requirements for all islands. However, these need to be changed to reflect the variations in hazard exposure and geo-physical makeup of island.
f. Only a limited number of soft engineering measures are used in Maldives. There is an opportunity to introduced soft adaptation practices from other similar settings, for example from the pacific islands.

5.6 Cost comparison and cost effectiveness of soft engineering measures

A comparison of the average costs of soft engineering measures is presented in Figure 5.24 below. Key findings from cost comparison are summarized below.

Figure 5.24: Comparison of soft engineered adaptation measures



a. In general, the costs of soft adaptation measures are smaller than hard engineering options. Upfront costs for various option vary within RF1000 per linear m. The cheapest option recorded during the study was temporary sea walls.

b. Unlike most hard engineering options, maintenance costs are minimal for most soft engineering options. Amongst those surveyed, beach replenishment involved the highest maintenance cost reaching Rf4,875 per linear m over a 20 year period. This figure is still lower than the upfront costs of most hard engineering solutions.
c. The figures can vary between locations depending on site conditions and availability of suitable material such as sand, trees and healthy corals.
d. Cost effectiveness is highly subjective as it depends on the perceptions of effectiveness. However, in general the limited maintenance costs and nature's role in enhancing the soft adaptation measures over time makes all soft adaptation measures highly cost effective in the long-run.
e. The most important requirement for effective soft adaptation measures in proper design and construction. Properly designed measures like beach replenishment projects in Reethi Beach Resort and, Shangri-la Island has reported high success rate and good-value-for-money. In contrast, improperly implemented replenishment and measures resulted in a loss for B. Royal Island.
f. Beach replenishment has been considered by many resorts who implemented them properly as providing good value for money. Erosion issues cease to become a major issue and beach aesthetics are restored in most islands. However, poorly implement project like S. Herathera Island in Addu Atoll ended up having losses incurred for replenishment activities.
g. One of the most cost effective measures, with virtually no construction costs, is the use of construction debris by locals to prevent erosion. Construction material is transported at the cost of the person undertaking the demolition activity and requires no maintenance. This has been the most successfully implemented community level erosion mitigation measure in inhabited islands. However, the environmental and aesthetic impacts from this activity make the whole sale application of this method undesirable.

5.7 Effectiveness of soft engineered solutions

Determination of effectiveness is a difficult task since objectives and expected outcomes of various adaptations differ and depend on a number of factors including (i) the perceptions of the developer; (ii) the appropriateness of a selected adaptation option to the prevailing site conditions and; (iii) the appropriateness of designs and construction method. Moreover, the limited use of soft engineering measures as an explicit adaptation measure, particularly in inhabited islands, makes it difficult to determine past effectiveness. The general conclusion from this assessment is that effectiveness of options cannot be described generically and is dependent on the application in specific sites. All adaptation measures surveyed were found to be effective in the right condition.

5.7.1 General Findings on Effectiveness

Moreover, most measures target a hazard in a specific section of island but the coastal system around the entire island is intrinsically linked and changes to one area has knock-on effects on other sections of the island. Nonetheless, an evaluation of the general effectiveness of the soft adaptation measures was undertaken based on a 'snap-shot' survey and interviews. The key findings are as follows.

a. The effectiveness of soft adaptation measures vary across Maldives based on geomorphologic, climatic and hydrodynamic conditions. There are known environmental gradients across Maldives and between islands in any given atoll (Shaig, 2009, Kench, 2010a, Kench et al., 2006, Woodroffe, 1993). Some of the variations can be summarised as follows:
    i. Rainfall is generally higher and central wetlands in major islands are larger in the southern atolls. As a result, common soft adaptation measures against rainfall flooding generally used in the central and northern islands, like temporary overflow channels, are not adequate for the southern atolls. Islands like S. Hithadhoo, Gn, Fuvahmulah, S.Hulhudhoo-Meedhoo and Ga. Viligilli require permanent flood mitigation structures.
    ii. The options that could be effectively used to mitigate erosion in atoll lagoon islands (islands formed on reef patches inside the atoll) are in some instances ineffective in atoll rim islands. The coastal process operating in these two types of islands are often different (Kench et al., 2006) and hence require options most practical for each setting. For example, beach replenishment is not often used as an erosion prevention measure on the oceanward coastline, especially if wave energy is high and existing beach is formed of coral rubble. In contrast, a wider coastal vegetation belt, set-backs and preservation of ridges are more commonly used and found to be effective in such a setting, when compared to an atoll lagoon island.
    iii. These variations in atoll lagoon islands and rim islands are most prominent in the northern and southern atolls of Maldives.
    iv. The shape and orientation of the islands may also play a key role in the effectiveness of certain adaptation measures. Circular islands have a more dynamic coastal system and react dramatically to monsoonal environment forcing, moving sediments right around the island. Longer islands, especially those islands with a north south orientation and on the rim, have less movement right around the island but significant movement on any given side. Hence, effectiveness of beach replenishment project and temporary groynes may be immediate in circular islands.

b. The effectiveness of soft adaptation measures is also directly linked to the commitment by the community or developer to maintain them. Soft adaptation measures need to be whole heartedly implemented over a longer timeframe and often require working with natural processes. Periods of reduced hazard activity, such as erosion and flooding, have often been interpreted as permanent reduction in hazard exposure and the soft adaptation measures are dismantled. For example, increased accretion in a specific area for over 2 years may be seen as stable land developments may be extended to the new area. Subsequently, the return of erosion leaves the development at risk.

c. The effectiveness of adaptation measures also depend on adequate designs and guidelines. Most soft adaptation measures are undertaken without a specific design or guideline. The design is generally dictated by the physical conditions on the site. Adjustments are generally brought about on a trial-and-error basis. Some islands, particularly resorts islands, have perfected the effectiveness of soft adaptation measures to suit the conditions on the island. The existing guidelines, particularly for setbacks and beach replenishment, are also inadequate and ineffective in some settings.
d. The use of mangrove vegetation to protect coastlines has been advocated around the world and to some extent in the Maldives. However, no evidence was found in the study islands and in the authors experience in other islands where extensive mangrove vegetation belts protect coral island coastlines. Mangroves in Maldives commonly grow in protected environments (for example in S. Hithadhoo, and HDh. Kulhudhuffushi) and cannot be usually found in high energy zones. Other species like *Kuredhi* are more dominant and successful in protecting the coastline.
e. Similarly, there was no evidence that seagrass communities are effective as measure against erosion. Seagrass beds tend to grow only in low energy zones and often acts as a'parasite' sucking sand off the island sediment budget and smothering coral reef patches. More studies are required to confirm their role as a soft adaptation measure in the Maldives.

5.7.2 Comparison of Effectiveness

An attempt has been made to assess the effectiveness among various soft adaptation measures by comparing a set of criteria (see Table 5.4). The criteria are grouped into economic, social, functional, design and construction, shoreline dynamics and natural environment impacts. The criteria has been modified from Linham and Nichols (2010). The purpose of this assessment is not to pick the most effective option but to guide planners and professionals to choose options based on various objectives. Estimates have been made on the likely effect each of these measures would have on inhabited islands.

The findings from this assessment can be summarized as follows:

a. The cost effectiveness of key soft adaptation measures – beach replenishment, coastal vegetation restoration, artificial reefs and temporary seawalls – in resort islands are expected to be very high in terms of: (i) the relatively small total cost of implementation; and (ii) high value of benefits from reduced erosion on tourism products and improved aesthetics. In inhabited islands, beach replenishment, coastal vegetation retention, raised ridges and artificial reefs promises to be the most cost effective options due their relatively low costs and effectiveness in reducing erosion rate and flood prevention.

Table 5.4 Effectiveness of various soft adaptation measures

	Criteria	Beach Replenishment	Coastal vegetation restoration	Raised Ridges	Artificial Reefs	Temporary Seawalls	Submerged geotubes
Economic	Initial Investment costs (per m)	1,625.00	900.00	1,300.00	1,085.00	720.00	1,873.00
	Total investment costs per m (over 20 years)	6,500.00	900.00	1,300.00	1,085.00	2,880.00	1,873.00
	Value of erosion avoidance benefits	High	Moderate	Negligible	Moderate	High	Moderate
	Value of flood avoidance benefits	Moderate	High	Very High	High	Moderate	Negligible
	Effect on local (inhabited island) economy	Negligible	Positive	Negligible	Positive	Negligible	Negligible
	Effects on tourism products	Very Positive	Positive	Negligible	Very Positive	Negative	Negligible
Shoreline dynamics	Solves the cause of erosion	No	No	No	Yes	No	No
	Implications for monsoonal sediment supply	Positive	None	Positive	Positive	Negative	Negative
	Potential for island shoreline instability	No	No	No	No	No	Yes
Natural environment impacts	Impact on intertidal habitats	Negative	Negligible	Negligible	Negligible	Negative	Positive
	Impacts on coastal flora/fauna	Negative	Positive	Very Negative	Negligible	Negative	Negligible
	Impacts on Coral reef and lagoon environment	Very Negative	Negligible	Negative	Very Positive	Negligible	Negative
Functional	Functional effectiveness	High	Moderate	High	Moderate	Moderate	Moderate
	Durability/Maintenance requirements	High	Low	Moderate	Moderate	Very High	Moderate
	Flexibility in the face of climate change	Very High	Very High	Very High	Very High	Very High	Moderate
	Access to the shoreline	Very High	High	Moderate	NA	Low	NA
Design and Construction	Ease of construction	Moderate	Easy	Difficult	Moderate	Easy	Difficult
	Material Availability	Moderate	Moderate	Moderate	Easy	Easy	Difficult
	Degree of specialist knowledge/equipment required	High	Moderate	High	High	Low	Moderate
	Information and capacity requirements	Moderate	Moderate	Moderate	High	Low	Moderate
Social	Social acceptability (inhabited islands)	Low	Moderate	Low	Low	Low	Low

b. The direct inputs from the structures into the local economy (inhabited islands or inhabited islands near resort islands) in the form of income from sale of material and services are expected to be highest in beach replenishment and temporary seawalls. Usually, the cost of soft adaptation measures is small making direct contributions to the local economy limited. However, the indirect benefits from them are moderately high if increased tourism productivity and reduced hazard exposure of businesses, households and infrastructure are included. In particular, the indirect benefits from vegetation and ridge restoration are highest in inhabited islands.
c. In terms of the effectiveness against controlling the causes of erosion artificial reefs is the only effective option used in the study islands. Other measures are mainly used address the consequences of erosion.
d. Beach replenishment, raised ridges and artificial reefs have very positive effects on the availability and movement of sediment around the island. The only option which can cause significant negative effects both on sediment availability and long term stability of the island is the use of geo-tubes. This is mainly due to the sediment trapping ability of the geo-tubes, occasionally hindering sediment transport around the island unless complemented with an option to increase the sediment budget, such as beach replenishment. In fact, geo tubes have been mainly used in conjunction with replenishment projects, like in Shangri-la and Villigili Island Resort.
e. The natural environment impacts are highest in beach replenishment and raised ridges as they both involve dredging and reclamation. Both the borrow area and the replenished or reclaimed area is significantly affected. Continuous use of replenishment activities without proper mitigation measures are likely to have cumulative effects on the marine environment leading to irreversible damage.
f. Functional effectiveness is generally high in all adaptation options because if used properly and in the right conditions they do provide good protection.
g. All the soft engineering measures described in the table above are highly flexible to the predicted climate change and associated sea level rise. Since these measures are designed to work with the natural processes, adaptation to climate may generally be enhanced with time. More research is needed in the areas to determine the natural responses.
h. Durability and the need for maintenance is a key challenge in soft adaptation measures. Soft adaptation measures require a commitment to continuously monitor and maintain as they are likely to change over time. The measures which require highest maintenance in Maldives are beach replenishment and temporary seawalls. Options like raised ridges and submerged geo-tubes need to be undertaken once with limited maintenance while vegetation restoration and artificial reefs improves naturally over time.
i. In terms of ease of construction and requirement for specialist knowledge, vegetation restoration and temporary seawalls are considered the easiest. Artificial reef development, ridge development, geo-tubes and beach replenishment require specialist knowledge and often special equipment to construct. This makes them less effective in resource constrained small communities.

j. As discussed in the previous section, at present, the local awareness and acceptability of soft adaptation measures as a solution for erosion and flooding hazards in inhabited islands is somewhat limited.

6 Recommendations

6.1 General recommendations

1. Hard engineering adaptation measures need to be designed and constructed based on scientific studies, guidelines and best practices to increase their efficiency and reduce negative impacts on island environment. **New guidelines need to be prepared and best practices need to be conveyed across islands, coastal engineers, contractors, developers and administrators** (see next two sections for more details).
2. Soft adaptation is a relatively new concept, particularly in inhabited islands. **Awareness programmes need to be conducted to convey the concept, benefits and effectiveness of soft adaptation measures.**
3. It is generally felt that the Government is responsible for adaptation measures. **The concept of soft adaptation measures needs to be used to enhance the community initiatives and responsibility towards long-term adaptation.**
4. There is still a significant void in scientific studies required to understand the coastal processes and effectiveness of various adaptation measures in corals islands of Maldives. **New studies need to be encouraged, incentivized, facilitated and funded to increase the knowledge base in the field.**
5. There is a **need for a beach classification system and association of various adaptation measures with the system** to promote appropriate selection of adaptation measures at local level. For example, a low durability sand-cement bag sea wall is not applicable in high energy zones, like an oceanward shoreline in close proximity to reef edge, but continues to be constructed in various islands. Such a classification system should be based on existing research and could be continually modified and made available to professionals and public. The objectives of the classification system should be to identify various types of beach environments in Maldives and should be based on known hydrodynamic and geophysical characteristics. For example it could be based on factors like wave exposure, sediment composition, island shape, location in relation to climate and wave characteristics of Maldives and atolls, among others.

6.2 Regulations and guidelines

6. **Changes are recommended to the existing regulations on beach replenishment for resort islands and all islands in general**. The 10 m fixed width for beach replenishment in resort islands is inadequate in some instances and an over design other instances. For example, islands with severe erosion in the past require extension of beach line beyond

10 m to compensate of the area lost and prevent significant loss. Moreover, place of 10 m of beach does not compensate for potential immediate erosion following replenishment. In addition a new guideline needs to specify the following to facilitate best practices:

i. Beach width could be generally fixed at a figure but should have the flexibility to change based on submission of scientific evidence of past erosion and coastline changes.
ii. Sediment budgets on the existing island should be estimated
iii. The volume of sediments required to replenish should not be over designed and limited to a percentage of the sediment budget.
iv. Sediment source should be clearly identified and a minimum distance between shoreline and sediment source should be defined.
v. Material used for beach replenishment shall be larger than or equal to the existing beach material.
vi. Restrictions should be placed on replenishment activities in certain areas of the islands depending on seasons.

7. **Changes are also recommended to coastline-building setbacks used in the land use planning guidelines for inhabited islands.** The present fixed width recommendations of 20 m for all parts of the island are inadequate. Oceanward coastline on atoll rim islands requires a wider width than the lagoonward side. Islands in high wind and wave energy zones (particularly the western rim islands) generally require wider than normal setbacks due to heavy salt spray and potential for seasonal flooding. Hence, the minimum recommended setback width for oceanward coastline should be increased to atleast 30 m in all islands and 50 m in high exposure islands. In addition, newly accreted beach which temporarily become stable should not be considered as permanent land or developed for atleast 5 years. This applies to all types of islands including inhabited, resort and Industrial islands.

8. Similar to inhabited islands, **changes are recommended to coastline-building setbacks used in the planning guidelines for resort islands.** The fixed width of 5 m is inadequate for islands on the rim. The appropriate widths should be reviewed based on findings from this study and further studies. This is necessary to enhance the adaptation measures in resort islands prevent the necessity for hard engineered structures.

9. Land reclamation has not been considered as true adaptation measure in this study but the reclaimed islands need adaptation measures. **The first step will be establishing guidelines for land reclamation**. This should atleast include soft adaptation measures like a coastal vegetation belt, a raised ridge, rainfall flood mitigation measures, revegetation and appropriate building setback. The construction of hard engineered seawalls in islands planned for reclamation must also be reconsidered as they usually ended up as a 'wasted' expenditure (for example, the suggested reclamation of Vilufushi beyond the amour rock seawall). In the absence of regulations and guidelines, a number of islands have to bear the consequences of inappropriate land reclamation practices.

10. The use of sand pumps as a method of ongoing replenishment needs to be regulated. A number of resort islands are opting for sand pumping as an ongoing soft adaptation measure. Their use is generally not an issue. However, their frequent use is not generally subject to environment approvals resulting cases of over designed replenishment, undesired sediment sources and environmental impacts. Options such as approvals for ongoing replenishment works may be necessary keep track of modifications.

11. **New guidelines need to be developed for all types of islands on the preservation of coastal vegetation belt (heylhi) and ridges.** These guidelines can be incorporated into land use planning, land reclamation and other similar guidelines. The guidelines should contain aspects specific to various climatic and geo-physcial conditions like the choice of species, density, succession, canopy height, ridge height (in reclaimed areas), among others. However, they should be based on thorough studies of coastal strand vegetation and the role of coastal ridges in mitigating natural hazards in Maldives.

6.3 Promoting adaptation measures

12. Raising awareness should be considered a priority in promoting mitigation measures. As noted throughout this report one of the fundamental reasons for the use of inappropriate designs and construction in both hard and soft engineering options is the lack of knowledge on coastal processes and best practices. A well targeted nation-wide awareness programme is need and should include all or most of the following aspects.
    i. Information on basic coastal processes and concepts such as monsoonal variations in climatic hydrodynamic conditions, erosion and accretion patterns, beach and ridge profiles, coastal vegetation characteristics, among others.
    ii. Various climatic and geophysical gradients across the Maldives archipelago and information on high and low exposure zones for various hazards.
    iii. Information on various hazard zones in the archipelago.
    iv. Information on best practices in hard engineering solutions, basic design principles, effective construction material, common reasons for failure or success and applicable conditions.
    v. Introduction to the concept of soft engineering, it principles, benefits, effectiveness, applicable conditions, construction material design principles and examples of best practices.
    vi. Soft engineering measures will require a special approach to convince locals about its benefits and effectiveness. Given the strong association of coastal protection with hard engineering structures and reliance on Government funding for protection, there is potential to misinterpret the intention of an awareness programme or political manipulation public opinion.

vii. Information on how some of the existing inappropriate hard engineering structures could be gradually replaced with soft engineering measures to provide an aesthetic and a functional relief to the island environment.

viii. Awareness programs should target various groups separately. These include island administrators, investors and developers, resort managements, planners and decision makers (at central and local government level), contractors (especially construction groups from South Ari Atoll), coastal engineering and environmental consultants and general public. The level of information required for each group is different. Information on soft adaptation measures should be particularly targeted towards general public in outer islands.

ix. Awareness methods could include TV and radio programmes, awareness leaflets and posters, inclusion in school science fairs, workshops or public talks.

13. In addition to awareness, training programmes need to be conducted to select groups who are directly involved in the design, decision making and construction of adaptation measures. Some of the main target groups should be resort engineering staff, island administrators and key contractors. These training programmes should included modules of on environmental processes in Maldives, design principles and best practices.

14. The awareness and training activities should be complemented with guidelines published in Dhivehi. Guidelines are required for a number of aspects including design of engineering structures and those listed in section 6.2 above.

15. One of the most common methods of replicating adaptation in Maldives is by observing practices in other islands. It is therefore important to construct model adaptation measures in some islands and use them as best practice examples for other islands. Such projects could also be complemented by an ongoing research programme evaluating the effectiveness of specific measures implemented. In particular, the use of key soft adaptation measures need to be demonstrated for it become readily acceptable for both resort and inhabited islands.

6.4 Next Steps

16. This study has only looked at 40 islands in Maldives. This compendium could be further enhanced by adding various other types of measures such as those used in Male'.

17. A detailed assessment needs to be undertaken on how the existing adaptation measures will have to be modified against climate and change and related impacts like sea level rise.

18. New research needs to be conducted in areas relevant to the understanding of how adaptation measures work in the diverse geophysical environment of Maldives and possible changes expected with climate change.

19. The inventory of coastal adaptation measures can also be further enhanced by inclusion of data from other islands. It is also important to make such information publicly available so other could access and contribute to them.
20. A knowledge base needs to be developed on the internet where it could be accessible from all parts of Maldives. This specific website could become the centre for adaptation information dissemination.

7 Conclusions

This report has presented a compendium of coastal adaptation options used in the Maldives based on a representative survey of 40 islands. Some of the key conclusions can be summarized as follows.

a. The most widely used type of adaptation is hard engineered solutions, particularly in inhabited islands. Soft adaptation measures are explicitly used only in resorts. Inhabited islands constraint a number of soft adaptation measures but has not been categorically specified as an adaptation measure. The most popular hard engineering measures are seawalls, breakwaters and groynes. The most popular soft engineering solutions are beach replenishments and temporary seawalls or groynes.
b. Hard structures have been generally effective in serving their purpose but have caused unwarranted effects on the beach system of islands.
c. The key issues with existing structures are poor design, poor construction, inapplicability of design to site conditions and over-design.
d. The main challenges to promoting soft adaptation measures are the lack of awareness, its limitation in mitigating immediate severe erosion and perceptions of ineffectiveness.
e. The key opportunities are the low cost of soft adaptation measures, familiarity with natural adaptation measures and its benefits over the longer timeframe.
f. Awareness building is required immediately. Soft adaptation measures need to be introduced and design faults in existing hard engineering structures need to be conveyed to the public to avoid misuse of designs. In addition, training programmes and demonstration project need to back up the awareness activities.
g. The existing guidelines related to adaptation measures need to be reviewed and new guidelines need to be introduced for key adaptation measures.
h. Soft measures have been highly successful in places where it has been implement wholeheartedly, but there is a long way to go to convince people in outer islands to use them as an explicit adaptation measures in their islands.

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Appendix A - Initial List of islands

List Provided by Ministry of Housing and Environment

1. Manafaru (Resort)
2. Alidhoo (Resort)
3. Dhonakulhi (Resort)
4. **Hanimaadhoo**
5. **Kulhudhuffushi**
6. **Neykurendhoo**
7. Fonadhoo
8. Kudafunafaru (Resort)
9. Medhafushi (Resort)
10. **Dhuvaafaru**
11. Meedhupparu (Resort)
12. Landaagiraavaru (Resort)
13. Royal Island (Resort)
14. Sonevafushi (Resort)
15. Dhunikolhu (Resort)
16. Madhiriguraidhoo (Resort)
17. **Naifaru**
18. Lh. Komandoo (Resort)
19. Asdhoo (Resort)
20. Boduhithi (Resort)
21. **Thulusdhoo**
22. Vabbinfaru (Resort)
23. **Hulhumale'**
24. Emboodhoo (Resort)
25. Emboodhoofinolhu (Resort)
26. Fihalhohi (Resort)
27. **Thoddoo**
28. Kuramathi (Resort)
29. Bodufolhudhoo (Resort)
30. Nika (Resort)
31. Velidhoo Island resort (Resort)
32. Maayaafushi (Resort)
33. Lilybeach (Resort)
34. Vakarufalhi (Resort)
35. Sun Island (Resort)
36. **Maamigili**
37. **Keyodhoo**
38. Maduvvari (Resort)
39. **VIlufushi**
40. Vilureef (Resort)
41. Velavaru (Resort)
42. **Hulhudheli**
43. **Kudahuvadhoo**
44. **L. Gan**
45. **Viligilli**
46. **Thinadhoo**
47. **Dhevvadhoo**
48. **Hithadhoo**
49. **Feydhoo**
50. **Fuvahmulah**

Appendix B: Island Selection Note

Island Selection Note

Survey of Climate Change Adaptation Measures
Integration of Climate Change Risks into Resilient Island Planning in the Maldives Project

3 October 2010

Prepared by: Dr. Ahmed Shaig
Consultant to the Survey of Adaptation Measures Component

Introduction

This note provides a summary of rationales and used for island selection in the adaptation survey.

Approach

The general approach used in this task is to select a representative list of islands that captures the varying physical environmental, socio-economic and land use aspects of Maldives. The aim is to capture both soft and hard engineering coastal adaptation measures used in various island settings across Maldives. These aspects are summarized in the next section. The final list was modified by the Ministry based on their internal discussions.

Guiding Parameters for Island Selection parameters

Physical environment aspects

The islands of Maldives are generally considered to have uniform physical features: low-lying islands with unconsolidated sediments spread across a fairly constant reef depth. However recent studies on geomorphology and disaster risks of Maldives have revealed significant variations in island hazard exposure and physical response. Some of the key studies are summarized below.

i. Physical variation in reef characteristics and climatic forcing across the Maldives archipelago. These include differences in wave regimes between the north/south and east/west of Maldives (Naseer, 2003) and; variations in reefs numbers sizes and reefs with islands (Woodroffe, 1993).

ii. Geomorphological variations in the location of islands within an atoll (Kench et al., 2006).
iii. Variations in (geomorphological) types of islands (Ali, 2000, Kench, 2010b).
iv. Variations in hazard exposure of islands to coastal flooding, erosion and storm events across the archipelago (UNDP, 2006, Shaig, 2009).
v. Variations in coastal flooding and erosion hazard exposure of islands based on their island size, location in the archipelago or within atoll, island shape, orientation, distance between shoreline and, oceanward reef edge and reef-island ratio (Shaig, 2009, UNDP, 2007).
vi. Differences in erosion hazard based on the extent of coastal modifications (Kench, 2010b, Shaig, 2009, Kench et al., 2003).
vii. Natural coastal protection phenomena such as coastal mangroves and high coastal dunes are sparse in Maldives. However, islands blessed with such features enjoy reduced exposure to hazards.

Socio-economic aspects

d) Islands in Maldives are generally used explicitly for a single land use. The general land use categories are: i) human settlements; ii) infrastructure islands (such as airports, waste disposal, oil storage); iii) economic islands (such as tourism, agriculture, fisheries); iv) stewardship or varuvaa; v) recreation islands; and vi) special administrative islands (Shaig, 2006a). The types of coastal adaptations used in these various land uses differ as the size of economic investments and risk taking patterns of the investor or inhabitants differ.
e) The population density varies significantly across the islands. The coastal adaptation measures undertaken in densely populated islands may differ significantly from low density islands (Shaig, 2006a, Shaig, 2006b), due to limited coastal buffer areas.
f) The atoll capital islands usually enjoy a higher level of public investment on coastal protection than other islands.

Table of guiding parameters

Based on the above physical and socioeconomic aspects and discussions with Ministry of Housing and Environment, the following parameters and minimum sample size has been proposed for this project. The maximum sample size for the whole list is 40 islands.

Parameter	Minimum sample size (islands)
Island Land use	Inhabited islands (18); Economic Islands (resorts 18, Other industrial 1); infrastructure islands (2)
Location within Archipelago	North (7); North central (7); Central (10); South Central (2); South (7) Note: The number of islands in the south central islands are proportionally smaller compared to other regions
Island Types	Circular atoll lagoon islands (5); Mixed shape, atoll rim small islands (10); Mixed shape, atoll rim large islands (10); Oceanic Islands (2);
Rim location within archipelago	Eastern rim (8); Western rim (8); eastern rim of western line atolls (3); western rim of eastern line atolls (3);
Island Size	Large >100 Ha (5 islands); Medium <100 and > 50 Ha (10 islands); Small <50 ha (10 Islands).
Island Orientation	East-west (5); North-South (5); Circular (5)
Population Density	High >30 person/Ha (5); Low <30 persons/Ha (5)
Inhabited island administrative status	Capital Islands (5); Others (5)
Existing major coastal modification	Reclaimed islands (5); Island with harbors (5); Islands with hard engineered erosion protection measures (5);Islands without significant coastal modifications (5).
Presence of coastal mangroves or high dunes	Mangroves (2); High Dunes (2)
Disaster risk assessment information	Island with detailed risk assessment (5)

List of Proposed Islands for Survey

No	Selected	Island Code	Island	Atoll	Island use	Rationale for new island*
1	Y	1003013	Manafaru	Haa Alifu	Resort	
2	Y	1003034	Alidhoo	Haa Alifu	Resort	
3	Y	1103006	Theefaridhoo	Haa Dhaalu	Industrial	Industrial Island
4	Y	1103007	Hanimaadhoo	Haa Dhaalu	Inhabited/infrastructure	
5	Y	1103021	Kulhudhuffushi	Haa Dhaalu	Inhabited	
6	Y	1203007	Goidhoo	Shaviyani	Inhabited	Western rim; limited modifications; 2 islands from Shaviyani
7	Y	1203035	Funadhoo	Shaviyani	Inhabited	
8	Y	1303033	Maavelavaru	Noonu	Resort	Western rim
9	Y	1303047	Medhafushi	Noonu	Resort	
10	Y	1403007	Dhuvaafaru	Raa	Inhabited	
11	Y	1403075	Meedhupparu	Raa	Resort	
12	Y	1503034	Royal Island	Baa	Resort	
13	Y	1503039	Sonevafushi	Baa	Resort	
14	Y	1603007	Komandoo	Lhaviyani	Resort	
15	Y	1603015	Naifaru	Lhaviyani	Inhabited	
16	Y	1703004	Kaashidhoo	Kaafu	Inhabited	A better option for good distribution of samples across archipelago; easier logistics
17	Y	1703020	Boduhithi	Kaafu	Resort	
18	Y	1703025	Thulusdhoo	Kaafu	Inhabited	
19	Y	1703058	Hulhumale'	Kaafu	Inhabited	
20	Y	1703070	Emboodhoo finolhu	Kaafu	Resort	
21	Y	1703087	Fihalhohi	Kaafu	Resort	
22	Y	1803013	Bodufolhudhoo	Alifu Alifu	Resort	
23	Y	1803018	Maayaafushi	Alifu Alifu	Resort	
24	Y	1803018	Lilybeach	Alifu Dhaalu	Resort	
25	Y	1903053	Sun Island	Alifu Dhaalu	Resort	
26	Y	2003011	Keyodhoo	Vaavu	Inhabited	
27	Y	2103002	Maduvvari	Meemu	Resort	
28	Y	2303001	Vilureef	Dhaalu	Resort	
29	Y	2303021	Hulhudheli	Dhaalu	Inhabited	
30	Y	2303049	Kudahuvadhoo	Dhaalu	Inhabited	
31	Y	2403011	Vilufushi	Thaa	Resort	
32	Y	2503041	Gan	Laamu	Inhabited	
33	Y	2503042	Kadhdhoo	Laamu	Infrastructure	Infrastructure island
34	Y	2603020	Viligilli	Gaafu Alifu	Inhabited	
35	Y	2603048	Dhevvadhoo	Gaafu Alifu	Inhabited	
36	Y	2703003	Thinadhoo	Gaafu Dhaalu	Inhabited	

No	Selected	Island Code	Island	Atoll	Island use	Rationale for new island*
37	Y	2803001	Fuvahmulah	Fuvahmulah	Inhabited	
38	Y	2903023	Hithadhoo	Seenu	Inhabited	
39	Y	2903026	Feydhoo	Seenu	Inhabited	
40	Y	2903028	Shangri-la at Viligilli	Seenu	Resort	A resort islands from south; coastal mangrove; eastern rim resort
Other Islands considered						
41	N	1003036	Dhonakulhi	Haa Alifu	Resort	
42	N	1103027	Neykurendhoo	Haa Dhaalu	Inhabited	
43	N	1303017	Kudafunafaru	Noonu	Resort	
44	N	1503009	Landaagiraavaru	Baa	Resort	
45	N	1503048	Dhunikolhu	Baa	Resort	
46	N	1603013	Madhiriguraidhoo	Lhaviyani	Resort	
47	N	1703017	Asdhoo	Kaafu	Resort	
48	N	1703043	Vabbinfaru	Kaafu	Resort	
49	N	1703072	Emboodhoo	Kaafu	Resort	
50	N	1803001	Thoddoo	Alifu Alifu	Inhabited	
51	N	1803008	Kuramathi	Alifu Alifu	Resort	
52	N	1803011	Velidhoo Island resort	Alifu Alifu	Resort	
53	N	1803014	Nika	Alifu Alifu	Resort	
54	N	1903026	Vakarufalhi	Alifu Dhaalu	Resort	
55	N	1903059	Maamigili	Alifu Dhaalu	Inhabited/Infrastructure	
56	N	2303007	Velavaru	Dhaalu	Resort	

Note: *New islands outside the preliminary list of 50 islands are suggested to meet the requirements for representative sample selection. The new selections are highlighted in grey and rationales are provided for their consideration.*

Final List of Islands for Survey

Based on the list provided in the previous section, the following list was finalized for surveying after internal consultations in the Ministry of Housing and Environment.

Ministry selection	Island Code	Island	Atoll	Island use
1	1003013	Manafaru	Haa Alifu	Resort
2	1003034	Alidhoo	Haa Alifu	Resort
3	1103006	Theefaridhoo	Haa Dhaalu	Industrial
4	1103007	Hanimaadhoo	Haa Dhaalu	Inhabited/infrastructure
5	1103021	Kulhudhuffushi	Haa Dhaalu	Inhabited
6	1103027	Neykurendhoo	Haa Dhaalu	Inhabited
7	1203007	Goidhoo	Shaviyani	Inhabited
8	1203035	Funadhoo	Shaviyani	Inhabited
9	1303047	Medhafushi	Noonu	Resort
10	1303071	Velidhoo	Noonu	Inhabited
11	1403007	Dhuvaafaru	Raa	Inhabited
12	1503020	Fonimagoodhoo	Baa	Resort
13	1503034	Royal Island	Baa	Resort
14	1503040	Eydhafushi	Baa	Inhabited
15	1603007	Komandoo	Lhaviyani	Resort
16	1603015	Naifaru	Lhaviyani	Inhabited
17	1703004	Kaashidhoo	Kaafu	Inhabited
18	1703020	Boduhithi	Kaafu	Resort
19	1703025	Thulusdhoo	Kaafu	Inhabited
20	1703058	Hulhumale'	Kaafu	Inhabited
21	1703084	Kandoomaafushi	Kaafu	Resort
22	1703091	Bodufinolhu	Kaafu	Resort
23	1803013	Bodufolhudhoo	Alifu Alifu	Inhabited
24	1903053	Sun Island	Alifu Dhaalu	Resort
25	2003011	Keyodhoo	Vaavu	Inhabited
26	2103002	Maduvvari	Meemu	Inhabited
27	2303001	Vilureef	Dhaalu	Resort
28	2303021	Hulhudheli	Dhaalu	Inhabited
29	2303049	Kudahuvadhoo	Dhaalu	Inhabited
30	2403011	Vilufushi	Thaa	Inhabited
31	2503041	Gan	Laamu	Inhabited
32	2503042	Kadhdhoo	Laamu	Infrastructure
33	2603015	Kolamafushi	Gaafu Alifu	Inhabited
34	2603020	Viligilli	Gaafu Alifu	Inhabited
35	2603048	Dhevvadhoo	Gaafu Alifu	Inhabited
36	2703003	Thinadhoo	Gaafu Dhaalu	Inhabited
37	2803001	Fuvahmulah	Fuvahmulah	Inhabited
38	2903023	Hithadhoo	Seenu	Inhabited
39	2903026	Feydhoo	Seenu	Inhabited

Ministry selection	Island Code	Island	Atoll	Island use
40	2903028	Shangri-la at Viligilli	Seenu	Resort

8.1 References

See reference list in the main document.

Appendix C: Survey Forms

Form Bi – Inhabited island Information Form

Form Ci – Adaptation Measures Survey form - Inhabited Islands

Form Cr - Adaptation Measures Survey form - Resort Islands