Environmental Impact Assessment

for Proposed Deepening of Entrance-Channel

for Proposed Redevelpoment on

Halaveli, North Ari Atoll, Maldives.

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TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

LIST OF PLATES

1 INTRODUCTION

Halaveli is a small sand cay with about 4.7 Hectares in area and is situated inside the atoll closer to eastern rim (see Figure 1-1). It has its own oval shaped reef with a small outcrop on the southwestern side. The island has formed from a nodal point on the southeastern side of the reef system. Inside the reef system and close to the western coastline of Halaveli is a fairly large protected lagoon (vilu) with approximate depths of 3 to 3.5m. The existing entrance channel which is to be deepened is located on the north of this vilu on the narrowest area of the reef (see Plate 1-1).

Figure 1-1: Location of Halaveli Tourist Resort in North Ari Atoll

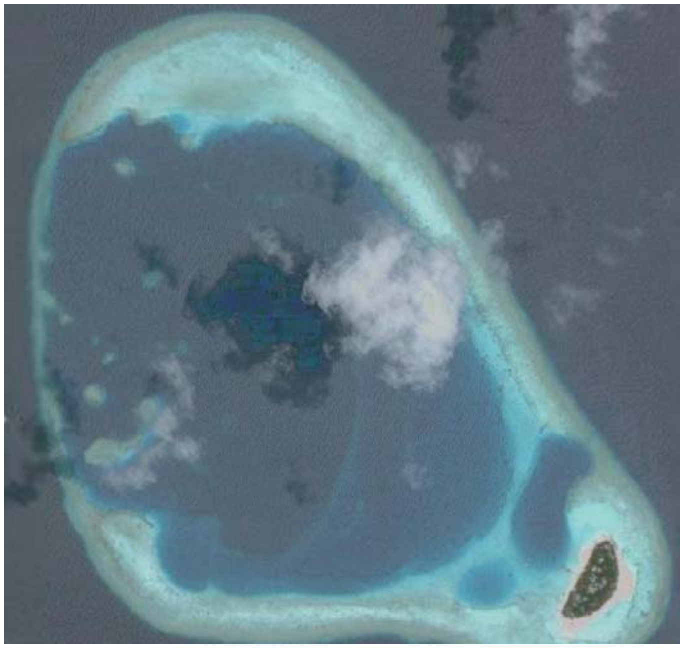


Plate 1-1: Location of Halaveli within its own reef system (Aerial photo) showing the project area

1.1 Purpose, Aim and Objectives

The main objective of the study was to identify appropriate measures to manage the existing beach on eastern side of the island as to increase the land area on north eastern end of the island and to develop an appropriate hard engineering structure as to retain the beach in a natural form on the island.

The report aims to provide appropriate options for coastal protection and management. In doing so, the options are considered for their appropriateness in terms of cost and most importantly environmental impacts. Visual impacts have also been considered. The objectives of this study were as follows:

- Identify environmentally acceptable options that do not entail excessive costs for the management of coastal environment of Halaveli;
- Identify the value and justification of the proposed activity;
- Describe the biophysical status of the marine and coastal environment based on the findings of the site visit;
- To recommend economically viable and environmentally less harmful ways to undertake the redevelop project on Halaveli.

The report focuses on the measures that can be taken to alleviate the problems caused by the existing coastal modifications and address coastal erosion concerns on the island. The report would also identify different feasible options for coastal modification at the island and how the proposed option would help to alleviate existing coastal erosion concerns which are currently been experienced at Halaveli. The report would explore the methods to replenish the beach as to facilitate carrying out the redevelopment project on land.

This report is structured into five chapters. Chapter 1 describes the aims, objectives of the study and the methodology adopted to undertake the study. Chapter 2 gives an account of the physical setting of the island providing detail description of the existing coastal system of the island. Chapter 3 describes the history of the coastal zone modification and management of the island which is important to understand how the system may respond to the proposed mitigation measures. Chapter 4 presents the different possible options for the coastal management, especially beach replenishment and coastal protection and costing of the project implementation. Chapter 5 presents the key recommendations for the beach replenishment and coastal protection. Chapter five also provides a comprehensive overview and strategies to monitor and mange data that will enable the developer to manage the island's coastal ecosystem.

1.2 Terms of Reference

The Terms of Reference (TOR) for the study is to undertake Site Inspection and assessment and to produce a report on finding of the study.

The specific task of the Site Inspection and Assessment is to

- Monitor beach composition and profiles around Halaveli
- Assess possible locations from which beach fill material can be obtained
- Assess neighbouring faros for availability and composition of fill material
- Assess marine water quality around Halaveli especially turbidity and nutrients at regular intervals for a period of one year
- Assess the condition of the housereef around Halaveli

- Propose measures to combact erosion around the island and manage beaches in an environmentally friendly and aesthetically acceptable manner.

- Recommend a coastal zone management plan and further monitoring requirements

The specific activities of the Reporting task includes:

- Report findings of site inspections and assessments

- Propose possible measures for beach replenishment

- Recommend a coastal zone management plan and further monitoring requirements.

1.3 Relevant Legislation and Policy Aspects

The proposed development, modification of the existing coastal environment through shore protection structures and beach replenishing activity in Halaveli is a significant size and are designed to reduce current environmental issues facing the island. The main purpose of the project is to ensure better quality beaches for the tourists and to protect the vegetation, property and investments.

The major activity of the project is enhancing the quality of product on the island by providing large beach area to the guest. Hence the beach replenishing and undertaking the coastal protection on the island by beach replenishment, protecting and maintaining the beach, vegetation and other vital infrastructures would help to enhance the quality of the product on the island. Since the tourism product is almost entirely dependent on the fragile ecosystem around the island, the Proponent needs to consider ways in which environmental impacts of the project could be reduced and mitigated as required in the Environmental Protection and Preservation Act (Law No. 4/93) of the Maldives.

In the absence of data and information and owing to the obvious consequences of certain projects that have not addressed the environmental concerns properly and effectively, strict measures are now in place to discourage modifications to the natural movement of sand around the islands. Therefore, Tourism Regulations require that special permission from the Ministry of Tourism and Civil Aviation be sought before commencing any coastal modification works on any tourist resort. It is also stated that hard engineering solutions are not encouraged and construction of solid jetties and groynes be controlled and shall only be undertaken after conducting an environment impact assessment study. Design of boat piers, jetties and other such structures shall be in such a way that these shall not obstruct current and sediment circulation patterns of the island.

There are also regulations on coral and sand mining and use. According to these regulations,

- coral mining is not to be carried out on island house reefs;
- coral mining cannot be carried out on atoll rim reefs and common bait fishing reefs;
- coral or sand mining is only allowed from designated sites, and approval from the concerned Atoll Office is required prior to the commencement of any mining operation.
- requests for coral or sand mining from residents of inhabited islands are required to be submitted to the Atoll Office through their respective island office
- the island office is required to estimate the quantity of corals required for the applied construction work and hence this ensures that permission is granted to mine just the required amount;
- every island is required to keep a log book of the amount of corals mined.
- sand mining is not allowed on the beaches of inhabited islands, islands leased for industrial developments and tourist resorts and within the lagoons adjoining these islands.

1.4 Methodology

Qualitative and quantitative methods were used in this study. Visual and photographic inspections of coastal features were carried out for the entire island including the natural physical geographic features, man-made features and coastal modifications.

Both qualitative and quantitative data were collected on the existing man-made features.

Beach and its immediate lagoon area were surveyed using differential GPS and a map was generated marking all features around the coastal environment including the vegetation line, beach line and reef line. Dumpy levels were also used to survey around the island and beach profiles were generated from these data.

Longshore currents were studied at designated locations using a drogue. The drogue was tracked using handheld GPS (Trimble GeoXT).

2 COASTAL ENVIRONMENT OF HALAVELI ISLAND

2.1 Environmental Setting and Location of Halaveli Island

Halaveli is a small sand cay with about 4.7 Hectares in area and is situated inside North Ari Atoll closer to eastern rim (see Figure 1-1). It has its own oval shaped reef with a small outcrop on the southwestern side. The island has formed from a nodal point on the southeastern side of the reef system. Inside the reef system and close to the western coastline of Halaveli is a fairly large protected lagoon (vilu) with approximate depths of 3 to 3.5m. The existing entrance channel which is to be deepened is located on the north of this vilu on the narrowest area of the reef.

Halaveli island system is situated inside the atoll closer to eastern rim. Marine environment of Halaveli can be categorized into two main components. They are the island lagoon system and the coral reef system. Three lagoon areas separated by reef are found within the island system. The lagoon system has shallower and deeper lagoon areas. It has a relatively large deep lagoon area surrounded by shallower lagoon and a reef system. The outer perimeter of the island system measures approximately 7 km.

The lagoon system of the island is complex with three lagoon areas separated by reef-flats. Deep and shallow lagoon areas are found within the system. The deep lagoon has an area of approximately 185 hectares. The shallower lagoon area has approximately 70 hectares. Two deeper lagoon areas are also found closer to the island on western and northwestern side of the island measuring approximately 2 and 6 hectares respectively.

Small knolls forming patch reefs area are found within deep lagoon. The lagoon bottom consisted of mainly fine sand, unconsolidated rubbles in some areas. Few dead coral boulders and patch reefs separated from the main reef system on the south-western areas. No other physical attributes were observed within the lagoon areas.

Two reef systems are attributed to Halaveli island system as it has a deeper lagoon in the center. The main reef system surrounds the entire island system. The second reef system is inside the main reef system, surrounding the deeper lagoon area. Each of theses reef systems has reef slope and reef-flat areas.

The reef system consists of a wider reef-flat on southern side of the system. This formation is mainly influenced by southwest monsoon currents. The substrate cover on the reef-flats is patchy and consisted of mainly dead corals and coral rocks. The reef slope consisted of more live corals. Reef slope is steeper on northern side compared to southern side and has drop-off in some sections in the northern areas.

The structure of the main buildings and the guest rooms are made from permanent materials. In order to cater for the needs of the tourism product, a breakwater was set up on eastern side of the island as a coastal protection measures as to reduce the beach erosion on the island. The beach replenishment, as a way to move the beach, is constantly carried out on the island.

2.2 General Climatic Conditions

General studies on the climatic conditions of the country were taken into consideration since there is very little variation in the climate and geomorphologic features of the country (see Figure 2-1).

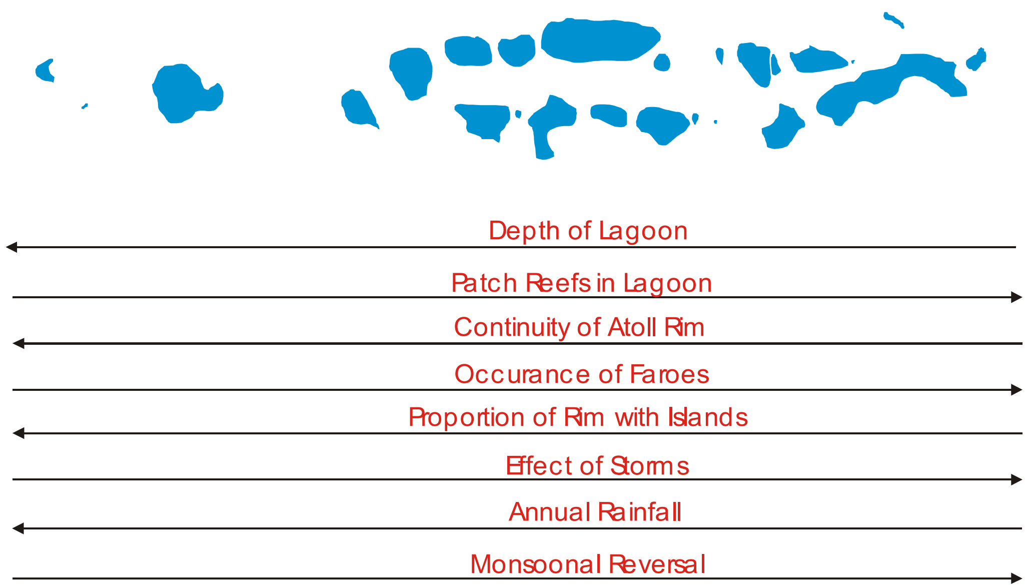


Figure 2-1: Trends in climatic and geomorphologic features across the Maldives

Maldives is in the Monsoonal Belt in the North Indian Ocean. Therefore, climate in the Maldives is dominated by southwest (*Hulhangu*) and northeast (*Iruvai*) monsoons. The southwest monsoon is the rainy season which lasts from May to September and the northeast monsoon is the dry season that occurs from December to February. The transition period of the southwest monsoon occurs between March and April while that of the northeast monsoon occurs from October to November. These monsoons are relatively mild due to the country's location on the equator and strong winds and gales are infrequent in the Maldives. However, storms and line squalls can occur, typically in the period May to July. The winds usually get stronger in the south west monsoon especially during June and July. During storms the impact is greater on the northern atolls than the southern atolls.

Maldives experiences a tropical climate with mean annual temperature of 30.8°C, daytime highest reach 32 °C but night time lows rarely drop below 25.5°C (SoE 1994). The average annual rainfall amounts to 1900mm, and there is an increase in the rainfall from north to south (see Figure 2-1). The average annual rainfall for north is 1977mm and for south, it is 2470mm (Pernetta 1993). This indicates that the south is wetter than the north, the wettest months are May, August, September and December; and the driest are January to April. Open water evaporation rates are in the range of 6mm per day and transpiration from plants is also high (SoE 1994). The relative humidity generally ranges between 75 to 80%.

2.2.1 Wind, Waves, Tides and Currents

Winds affect sedimentation process both during the formation and development of islands. Winds help regenerate waves that are weakened by travelling over reefs and also cause locally generated waves over lagoons. Figure 2-2 shows the wind direction pattern for Malé International Airport from National Meteorological Centre. Winds from the north-east and the east-north-east are predominant during December to February. During March to April the direction varies with the general direction being westerly. Strong winds are associated with the southwest monsoon season. Gales are uncommon, and cyclones very rare in the Maldives. The stormiest months are typically May, June and July. Storms and squalls producing wind gusts of 50-60 knots have been recorded at Malé.

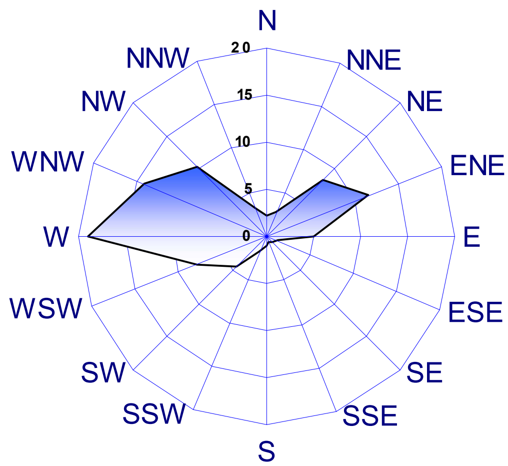


Figure 2-2: Percentage of average wind direction for Malé (1980-2003)

Ocean currents are driven by two monsoonal winds, namely the westerly and the easterly wind. The westerly flowing currents tend to dominate from January to March while the easterly currents dominate from May to November. The changes in current flow patterns occur in April and December. The ocean currents flowing through channels between the atolls are driven by the monsoon winds. Generally, the tidal currents are eastward in flood and westward in ebb. Tides in the Maldives are diurnal-semidiurnal types with a tidal range of about 1m and seasonal variation in the mean sea level in the Maldives is negligible. The highest astronomical tide is 0.64m above mean sea level (MSL) and the lowest astronomical tide is 0.56 below MSL.

Table 2-1: Tidal recordings from Malé International Airport (Source: SoE 2002)

Tide level	Reference to Mean Sea Level
Highest Astronomical Tide (HAT)	0.64
Mean Higher High Water (MHHW)	0.34
Mean Lower High Water (MLHW)	0.14
Mean Sea Level (MSL)	0.00
Mean Higher Low Water (MHLW)	-0.16
Mean Lower Low Water (MLLW)	-0.36
Lowest Astronomical Tide (LAT)	-0.56

The swells and wind waves experienced by the Maldives are conditioned by the prevailing biannual monsoon wind directions, and are typically strongest during April-July in the south-west monsoon period. During this season, swells generated north of the equator with heights of 2-3 m with periods of 18-20 seconds have been reported in the region. However, the Maldives also experiences swells originating from cyclones and storm events occurring well south of the equator. It is reported that the swell waves from southeast to south-south-east occur due to strong storms in the southern hemisphere in the area west of Australia with direction towards the Maldives. The swell waves that reached Malé and Hulhule in 1987 had significant wave heights in the order of 3 metres (JICA, 1987). Local wave periods are generally in the range 2-4 seconds and are easily distinguished from the swell waves.

The tides observed in the country are twice daily (semidiurnal/diurnal), and typical spring and neap tidal ranges are approximately 1.0m and 0.3m respectively (table 1). Maximum spring tidal range in the central and southern atolls is approximately 1.1m. There is also a 0.2m seasonal fluctuation in regional mean sea level, with an increase of about 0.1m during February – April and a decrease of 0.1m during September - November.

2.2.2 Geomorphology and Coastal Dynamics at Halaveli Island

Halaveli has been well formed within its own reef system. The reef extent around the island from north to south on the eastern side is quite small and the western side has a large enclosed lagoon or vilu, thereby limiting the possibility of the island to grow further. Sand spits are found on the northern and southern tips of the island. These sand spits used to grow seasonally on either end depending on the season. The northern sand spit retreats during the northeast monsoon and grows during the southwest monsoon and the southern sandspit grows and retreats in the opposite manner. However, these natural shoreline changes have been affected due to certain manmade changes to the coastal environment in the past. These have been described in chapter 3 of this report.

2.2.3 Sand deposition

Most beaches in the Maldives are formed from sand produced and delivered to the coast by healthy coral reefs mainly by the action of waves and reprofiled by the action of longshore currents. The supply of sand has now deteriorated with the island having grown close to the reef edge. Present day supplies of sand are modest.

Deposition occurs mainly during the northeast monsoon with reprofiling of the beaches during the southwest monsoon. Deposition from the eastern reef has been mainly responsible for the formation of the island.

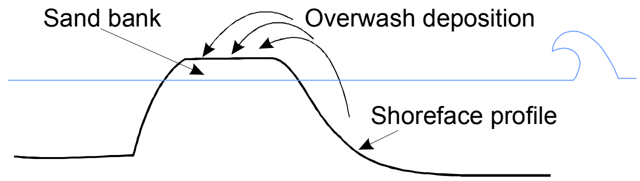


Figure 2-3: Schematic representation of barrier island processes

2.2.3.1 Loss of sand

Waves transport beach material into more sheltered areas or carry it offshore, to settle out on the seabed. In addition wave action slowly abrades even the hardest pebbles and sand grains, with the very fine particles being carried away by winds or currents either to seaward or landward. However, the strength of winds are too little in the Maldives for wind-generated erosion to occur. Sand is often held around the sand budget of the island in a natural equilibrium by the action of longshore currents around the island and sand loss is generally small. In places where strong rip currents may be formed through channels in the reef system, the net loss may be considerable. Rip currents are powerful, channelized currents of swiftly flowing water moving out to sea. They typically extend from near the shoreline, through the surf, and out past the line of breaking waves.

Slow and steady loss of sand into the vilu on the western side may be possible especially during the northeast monsoon as longshore currents converge at the arrival jetty area. However, no data exists to provide an analysis of such a hypothetical situation. Such a loss of sand would be very small as frictional forces act to disperse the sand longshore. These shore processes would be further investigated during the monitoring period.

A further cause of long-term shoreline retreat is the rise in mean sea level relative to the land. In recent centuries, Maldives may have slightly suffered from the increase in global sea levels, which has been averaging about 1mm to 1.5mm/year. This is because all islands of the Maldives are about a metre or two above mean sea level. As sea level rises relative to a beach, there is an inevitable tendency for the shoreline to move inland.

In the future, the consequences of atmospheric pollution, and hence global warming, may include an acceleration of the increase in mean sea levels around the world. As a consequence, large parts of the coast of Maldives may begin to experience a net increase in sea levels. However, there are also theories that support that a reduction in sea level may occur around equatorial zones as a result of global warming and subsequent increases in sea surface evaporation.

2.2.4 Currents

Currents which affect Halaveli Island can be expected to be one or more of tidal currents, wind-induced currents, wave-induced currents and oceanic currents. Available data indicate that wind driven currents are the dominant form of currents around Halaveli as in other islands of the Maldives. Wave induced currents in the form of overwashing, and in some locations longshore currents due to waves breaking on the reefs obliquely to the line of the reef could also affect the current regime. Due to limited tidal range, tidal currents generally have very weak influence on the overall current patterns within reefs and around islands. Also due to the shape of Halaveli island, the tidal component can be expected to be small. Generally, tidal component of the current is eastward during the flood tide and westward during ebb tide (Binnie Black and Veatch 1999).

Longshore currents around Halaveli were studied for a day during the field visit undertaken in May 2006. The results indicated that the nearshore and longshore currents can be highly variable but were in accordance with general current patterns during the northeast monsoon. Based on these and data from past projects and experience gained throughout the years, the current patterns can be expected to be predicted according to what is shown in Figure 2-5 and explained as follows:

- Nearshore or longshore currents around the island are affected by short, wind-generated waves within the atoll and tidal variations. Longshore currents are mainly affected by monsoonal winds. The effect of monsoonal winds is more prominent on the western and northwestern sides. During the southwest monsoon, longshore currents would be in an easterly direction and that during the northeast monsoon would be in a net westerly direction, with slight variations under the influence of tides.

- The shape of the island and its formation in the lee of two other reef systems and facing the atoll rim and at a considerable distance from Fussaru Kandu means that the effect of longshore currents on the movement of sediments in a net westerly direction during the northeast monsoon would not be generally influenced by oceanic swells or surf waves but by short wind-driven waves created within the reef flat of the rim reef. Therefore, together with the influence of tidal currents, the net current direction in the westerly direction during the northeast monsoon would be mainly responsible for the deposition of sediments and island formation. This strong net current during the northeast monsoon, especially during *iruvai halha* can cause severe erosion on this side. This is the reason why breakwaters have been erected on this side.

- Since the island is in an northeast-southwest orientation, the net effect of short wind-driven waves during the northeast and southwest monsoon would be quite strong on the eastern and western sides respectively. The net longshore currents would also have a great influence on the southern and northern ends of the island. The changes in longshore currents during the two monsoons would mean that sand spit on southern and northern ends may move according to the direction of longshore currents during the two monsoons. However, with the erection of breakwaters near the sand spits, the southern sand spit had joined with the breakwater affecting seasonal shift of the thundi or sandspits.

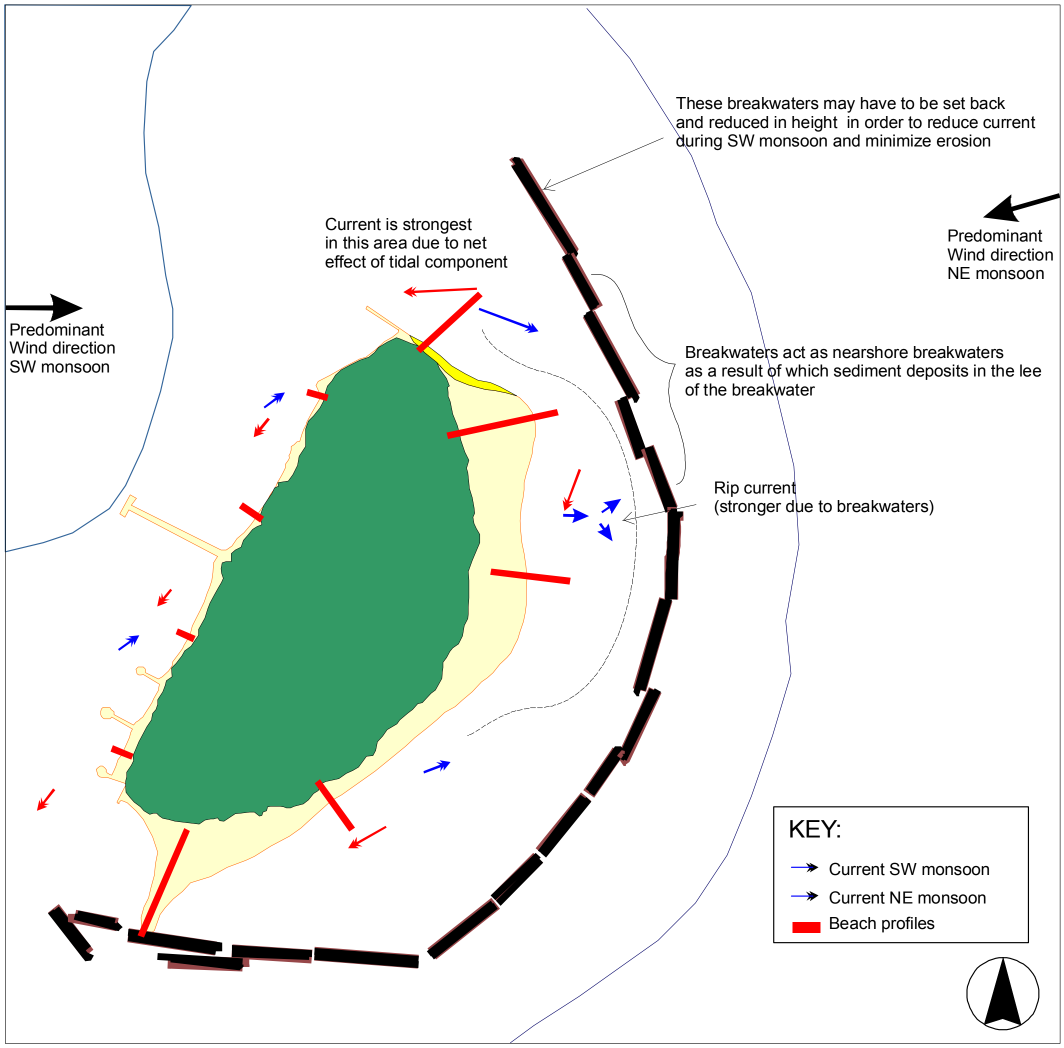


Figure 2-4: Nearshore currents around Halaveli and their influence on longshore sediment processes during both monsoons

2.2.5 Waves

Halaveli is generally exposed to short, wind-generated waves from the western side during the southwest monsoon and that from the eastern side during the northeast monsoon. Due to its location in the lee of two other reef systems it is sheltered from the effects of oceanic swells and surf waves during the northeast monsoon. For this reason, the western side can have more severe erosion during the southwest monsoon as a result of wave action than that on the eastern beaches during the northeast monsoon.

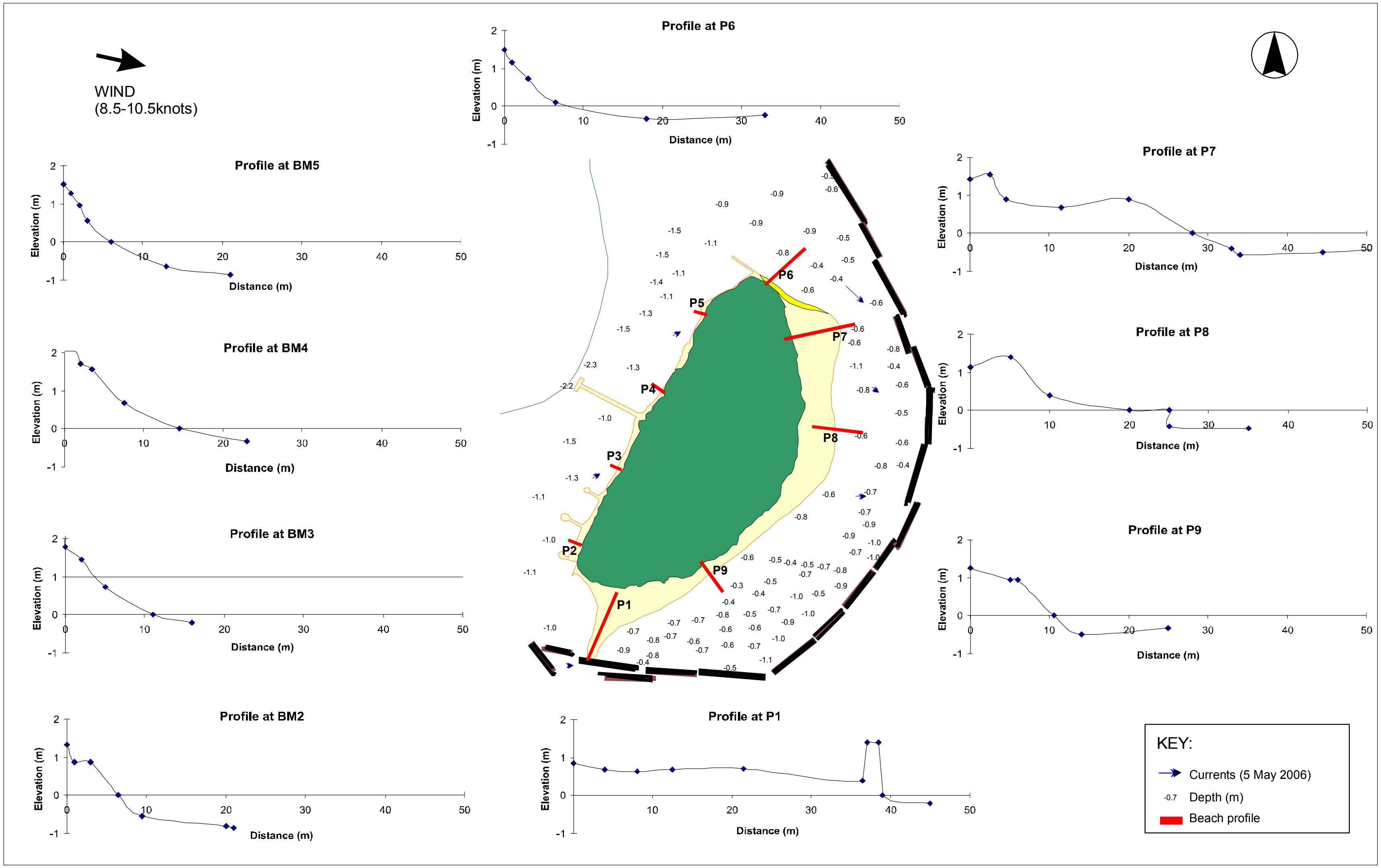


Figure 2-5: Schematic illustration of the existing coastal dynamics around Halaveli

2.3 Description of Existing Coastal Features

Figure 2-6 represents the existing condition of the coastal environment of the island during May 2006. There is severe erosion on the northwestern corner of the island with easterly winds causing about 0.5m high waves near the swash zone or the surf zone. The wave scour on the beach at this location is therefore causing quite prominent beach erosion. Erosion is also evident at the southwest corner. This is due to the southern sand spit joining with the nearshore breakwater at the location as a result of which longshore sediment transport is affected.

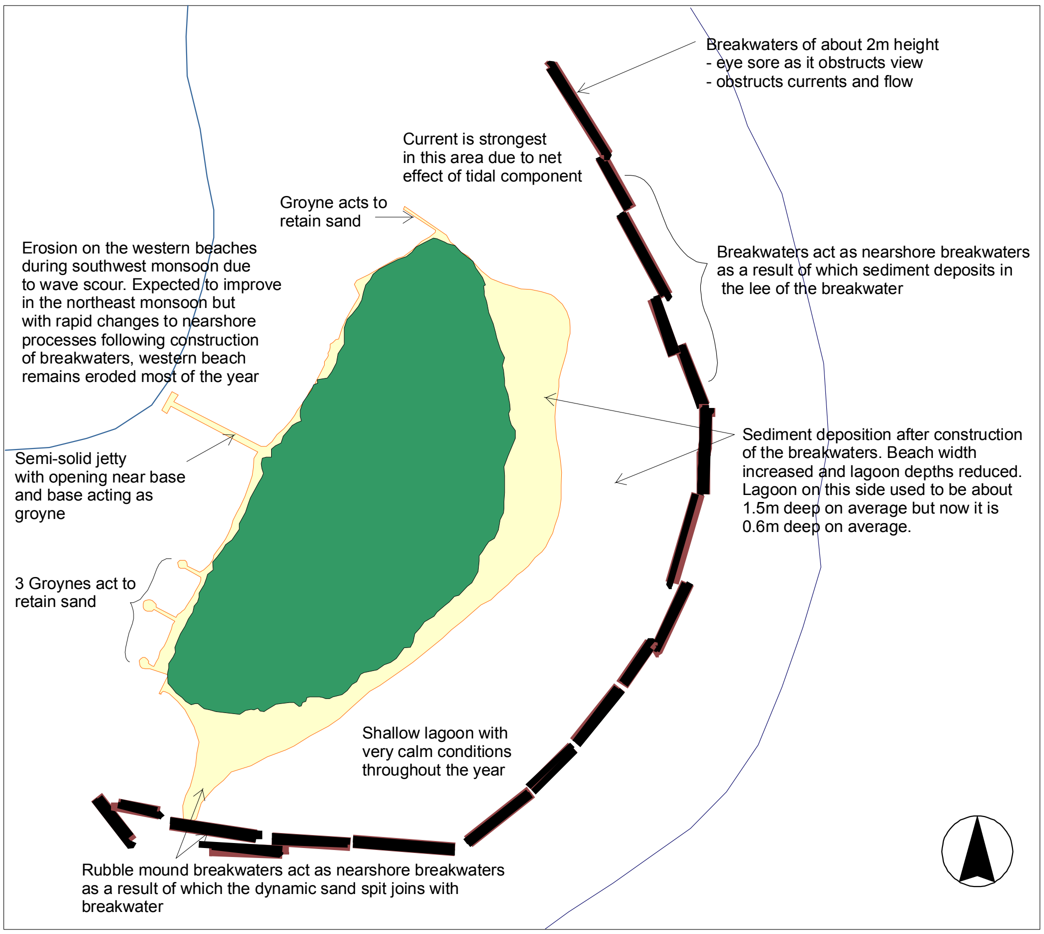


Figure 2-6: Illustration of the characteristics of the different coastal zones at Halaveli

Figure 2-6 illustrates the characteristics of the coastal zone and **Error! Reference source not found.** gives a photographic illustration of the existing coastal environment of Halaveli Tourist Resort (5 May 2006).

The formation of rip currents (see Figure 2-4) together with calm conditions due to construction of breakwaters at the north eastern corner of the island has caused extensive accretion at this location. This can be seen from the beach profile (Profile P7 in Figure 2-5) at this location. Such accumulation of sand can be observed throughout the entire perimeter of the eastern side which is protected by breakwaters. The breakwaters on this side are about 2.2m high and can be considered as inappropriate design and aesthetically unacceptable. The depths of the eastern lagoon have also been reduced due to sand accumulation on this side throughout the year since the construction of breakwaters. According to the Manager and other staff (Ibrahim/EB) they can vividly recall when the eastern side used to be about 1.5m deep.

Moving towards the southern sand spit it can be seen that due to the dynamic nature of sand at this location, the sand spit on the south had connected with the shore parallel, nearshore breakwater at this end.

3 HISTORY OF COASTAL MODIFICATIONS

3.1.1 The Management of Halaveli Beach

Since its inception in 1982, Halaveli Tourist Resort has experienced varying degrees of seasonal coastal erosion. The most prominent erosion has been occurring towards the northwestern tip of the island during the southwest monsoon.

3.1.2 Coastal conditions before resort development

Before the Halaveli was developed to a resort island, the island had two huge sand banks on either end of the island. Plate 3-1 shows that there were two beautiful sand spits on either ends of Halaveli even after the island was developed as a resort. However, as discussed in the following paragraph the coastal modifications that followed resulted in loss of northern sand spit and various other changes to the shoreline as described in this document.

Plate 3-1: Sand spits (thundi) on either end of Halaveli soon after resort development

3.1.3 Resort development and coastal modifications

The resort development on the island developed a number of coastal infrastructures on the island which induced beach erosion on North West and eastern side of the island. The coastal infrastructure included solid jetty on western side of the island which disrupted the near shore and long shore current and sediment movement on west side of the island.

Plate 3-2: Erosion on north western side of the island

The induced erosion on western side and northern side resulted in construction of a near shore breakwater on northern side of the island.

Plate 3-3: Breakwaters on north eastern side of the island

3.1.4 Recent coastal modifications

As a means of reducing beach erosion on the eastern side of the island, coral rubble breakwater was built on eastern side of the island. The breakwater reduced the sediment movement and current on eastern side. Construction of the breakwaters resulted in the sand spit on southern side to extend to the breakwater making the lagoon shallower on eastern side of the island. To mitigate the over accretion of materials on southern sand spit, a continuous sand pumping project started to allow a channel between the sand bank and the breakwaters.

Plate 3-4: Breakwaters on north eastern side of the island and southern thundi joined with the breakwater on the southern end

4 PREFERRED OPTIONS FOR COASTAL PROTECTION

There are a few practicable options not entailing excessive costs. Regular beach nourishment will be necessary whichever option chosen. This is because the sand budget of the island has been disturbed and for the system to come to a new equilibrium it will take more time than the operator can wait and watch. Therefore, regular beach nourishment would help to solve beach erosion problems and minimize the time needed for the beach to come to a new equilibrium. Further measures may be taken to improve the situation and minimize the frequency of beach nourishment. These measures/options are considered in the following subsections. These options considered in order of priority and cost is as follows:

1. Beach nourishment on the affected areas using recycled sand from the island sand budget. This includes creation of a long stretched sandbar or sandspit on the northern end.

2. Deepening of the eastern lagoon to have about 1.5m depths

3. Construction of submerged breakwater along the inner edge of the reef flat on the eastern side

4. Construction of a field of sundecks on the western side with wave breakers at the face of the sundeck head and submerged breakwaters below it.

5. Construction of a set of groynes on the northern and southwest ends of the proposed islet on the southwest of Halaveli.

4.1 Reclamation and Beach nourishment

4.1.1 Areas to be reclaimed and nourished

4.1.1.1 Reclamation on the northern end

The most prominent erosion is found on the northern end and northwestern side from the western end to the arrival jetty. There are also other eroding areas on the western side as there are no shore protection structures on this side and monsoonal erosion-accretion patterns have been affected by breakwaters on the opposite side. In order to improve the beaches the beach restoration on this end would be undertaken by reclaiming part of the northern thundi and nourishing the beaches around it.

4.1.1.2 Reclamation of sandbank on the southwest

A sandbank will also be reclaimed on the southwestern side of Halaveli at the proposed location of the spa. This has been proposed to be developed in the shape in which the proposed Spa has been designed. However, it may be difficult to achieve exactly that sort of shape (see Figure 5-3). Therefore, protection measures such as groynes may have to be constructed at the onset. Alternatively the reclaimed sandbank may be left to come to equilibrium before any protection measures are employed.

4.1.1.3 Beach replenishment of the main island and the reclaimed areas

The island beaches have been eroding on the western side and unparalleled accretion on the eastern side. Therefore, there is a need to reprofile the beaches by beach nourishment and regular beach management. In addition, replenishing beaches of the reclaimed land on the northern end and proposed sandbank on the southwest are also necessary in order to keep the reclaimed areas free of sharp corals and coral debris. Beaches of reclaimed areas would be replenished to a height of about 0.5m. Fill profile for islet and reclaimed area on the north are shown in Figure 5-3.

Beach nourishment shall be undertaken using manual methods. This will ensure that beach material is not compacted and beach is softer.

4.1.2 Locations from which fill material may be obtained

Fill material required for beach restoration including the beach replenishment on the proposed "reclamation" of the northern sand spit area and sand bank on the southwest could be obtained from the accreting beach on the south western end of the island and by dredging sand from the eastern lagoon which has accreted over 10,000m^3 of sand over the years following the construction of breakwaters on this side (see Figure 5-3). It is estimated that this is sufficient for replenishing beaches (Table 4-1). If excess material is required, it may be obtained by pumping sand from the edges of the existing *vilu* (see Figure 5-3) from which sand will be pumped for reclamation of northern sand spit and sandbank on the southwest.

Material required for the proposed reclamation of the northern sandspit and the sandbank on the southwest may be obtained from the edges of the adjoining deeper lagoon areas known locally as vilu (see Figure 5-3). These areas will provide sufficient material for the proposed reclamation.

It is generally considered appropriate that deposition of the recycled material should be along the upper beach, above the high water line and along the eroding berm face. Natural redistribution of the placed material alongshore and cross-shore will occur, particularly for sand. Recycling operations should anticipate this redistribution by ensuring that the volume deposited to the upper beach is in excess of the amount required for immediate protection of the dune.

4.1.3 Volumes of fill material

The volumes of material required for beach replenishment of 5-10m of lineal beach around the island (as shown by the preferred beach line in Figure 5-3) and "reclamation" of northern sand spit may be estimated as follows:

Table 4-1: Estimated quantities of sand required for the proposed works

Location	Area (m^2)	Approx. depth/height of fill (m)	Volume (m^3)
Northern end reclamation	10,000	2.3	29,900
Island beaches	5,000	2	11,000
Northern end beaches	5,070	0.6	3,346
Southwest islet reclamation	5215	2.5	15,645
Replenish islet beaches	2329	1.2	3,075

Note: The volume for northern end reclamation has been calculated by taking a 20-30% loss into consideration. Beach replenishment is also expected to have about 10% loss and this has been taken into consideration in calculating beach replenishment requirements.

4.1.4 Filling methods and strategy

Sand from the edges of *vilu* may be obtained by using excavator or pumped ashore using a 6 or 8-inch sand pump. Use of suction dredger may be costly. The 6-inch sand pump is recommended for reasons of cost and availability.

Reclamation occurs at the northern end and off the southwest coast of Halaveli. The reclamation works would be undertaken one at a time.

First, the northern end sandspit area would be reclaimed and the southwest sandbank will be done only after the columns and footings for the proposed spa and associated facilities in that location has been completed. The reclamation works for the northern end sandspit will be undertaken in the following manner. Similar approach will be undertaken for the proposed sandbank on the southwest lagoon.

- Mark the perimeter of the area to be reclaimed, which will have to be about 15m from the proposed structures in the area or about 7-10m from the proposed vegetation line in the area.

- Erect a temporary seawall of about 1.3m from MSL using sandbags on the eastern perimeter of the area to be reclaimed to minimize sediment flow onto the reef. The seawall can be similar to the proposed breakwaters.

- Pump sand within 5m from the sandbags to create an inner bund. This bund will continue upto the northeastern corner of the fill area.

- Move sandbags on the east to the west to create a seawall on that side.

- Continue the inner bund up to the end of the fill area on the west.

- Remove sandbags and keep aside on the beach for use in reclamation of the islet

- Start pumping sand from the vilu to fill the enclosed area. Sand will be pumped from the edge of the existing deep vilu using a 6" sand pump.

- Once reclamation works ceases, the area can be left to settle for about three months before commencing construction during which time freshwater will be allowed to percolate to form the freshwater lens and watering for landscaping will continue.

- Beach nourishment using fine sand may be done immediately after the filling or towards the end of the construction stage to minimize impacts on quality of the beaches due to mishandling of materials during construction.

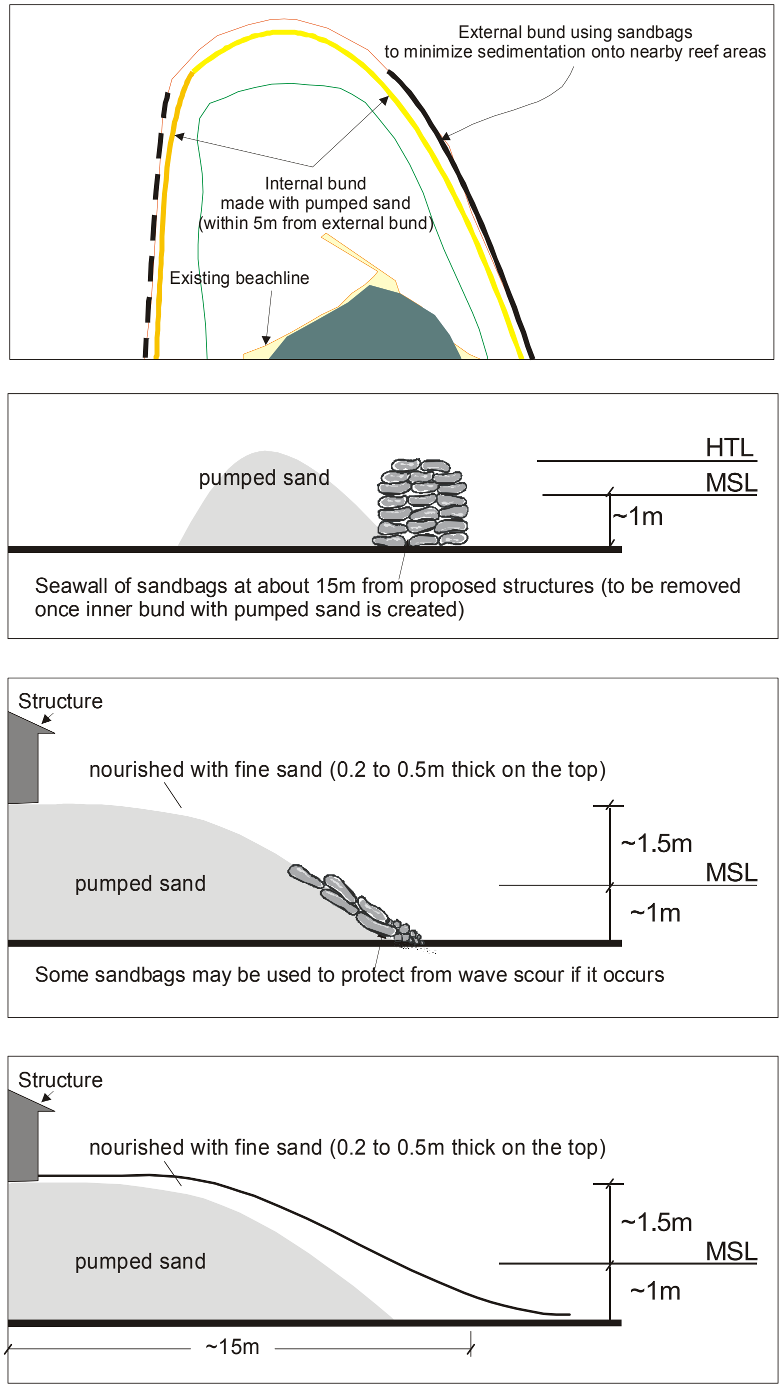


Figure 4-1: Fill method for the northern end fill area

The sand to be recycled from the eastern lagoon and southern sand spit would be best obtained by using a 4" sand pump of a smaller size. The beach replenishing works proposed at this stage would be undertaken as follows:

The beach replenishing works proposed at this stage would be undertaken as follows:

1. For the reclaimed area, once the reclamation is completed or at the end of construction stage, the beaches or the foreshore and swash zone must be filled with fine sand that is either sieved or transported from areas from which material is recycled. This will help to ensure that sharp coral debris is eliminated from the beach.

2. The sand recycled using sand pump as well as transported manually by handcarts may be evenly spread on areas requiring beach nourishment. Before nourishment of the western beaches, however, it may be necessary to create a bund with sand bags around the areas as the works will be undertaken during southwest monsoon. The sand bags will be removed once the replenishment works is completed.

3. It is recommended to make a sieve analysis in order to find out the actual beach material size naturally existed on that area and use appropriately sized mesh before directly filling the beach.

4.1.5 Impacts and Mitigation

Sedimentation will be the main impact of sand pumping/beach nourishment. Sedimentation results in the reduction of water quality in the lagoon, which affects benthic organisms and fish, and other natural processes. Since the reef extent is small on the areas to be nourished, the effects of sedimentation may also be felt on the reef. Therefore, to reduce sedimentation within the lagoon, beach filling will be undertaken by placing sand in an enclosed area embanked with sand bags. These sand bags will only be removed once the works are completed. This activity will be undertaken during calm weather at low tides.

The beach replenishment process is often responsible for increase in local turbidity levels, sediment dispersal, changes in salinity or reduction in dissolved oxygen levels thereby favoring anaerobic conditions. There is relatively less chances of moving suspended fines towards the reef on the eastern as this side is calm during the southwest monsoon during which the project will be implemented. Yet, the closeness of the reef to the replenishing area may be of concern and care must be taken in replenishing works to minimize sedimentation. On the western side, there is a considerable reef extent and any sediment is expected to move in and settle within the deep lagoon or vilu. Therefore, the impact of sedimentation on the western side would be negligible.

Beach nourishment by pumping sand onto the beach can create murky waters in the lagoon for a short period of time. Although sand pumps are quite suitable for small sand pumping operations and keeps sedimentation low, it is important to take appropriate measures to reduce sedimentation or siltation during the sand pumping process. Beach nourishment results also in smothered benthic communities, although the recovery of this following nourishment is reported to be generally rapid (USACE, 2001).

The sand pumping causes re-suspension of fine sediments and is often responsible for increases in local turbidity levels, changes in salinity, release of toxicants or bio-stimulants from fill materials, introduction of petroleum products or reduction in dissolved oxygen levels thereby favoring anaerobic conditions. However, most of these impacts would be minimal in this project since fill material would be obtained from the local environment, which is in pristine condition, except for small changes in water column's characteristics in some areas. These impacts would also be short-lived and ambient water quality conditions would rapidly return to normal.

Environmental impact analysis usually focuses on biological species that are rare, threatened or endangered and sensitive or highly productive habitats. Species of commercial or recreational importance are also of concern. At Halaveli, there are not any significantly important species while on the other hand the commercial value of the beach is quite considerable.

4.2 Reprofiling the eastern lagoon and southern sand spit

The eastern lagoon has been accumulating sand over the years since the construction of breakwaters on this side. Previously the eastern lagoon had average depths of 1 to 1.5m. Therefore, a reprofiling of the lagoon together with the redesigning and alignment of the breakwaters on this side is expected to reduce further sediment deposition on this side. This would also provide appropriate depths for swimming.

4.2.1 The area to be reprofiled

The entire area of the eastern lagoon behind the breakwaters would be reprofiled. The lagoon would be reprofiled evenly to a maximum depth of 1.5m close to the reef flat. An estimated area of about 25,000m^2 would be reprofiled from the eastern lagoon. The southern sand spit together with the southeastern lagoon would be included in the reprofiling activity. Sand from the southern sand spit would be best removed using handcarts or similar. Assuming an average dredge depth of about 0.8m in the area to be reprofiled and a loss of 20% upon sieving, a total volume of 16,000m3 of sand can be obtained. The 20% loss can be safely assumed since the area to be reprofiled is expected to be mainly fine sand.

4.2.2 Reprofiling methods and strategy

The reprofiling is not expected to yield sharpened coral debris as only fine sand would be pumped or transported. Therefore, sieving may not be required. A sand pump of about 4 to 6 inch would be able to undertake the reprofiling in a few weeks. Along with sand pumps, manual methods may be used to carry sand to affected areas.

4.2.3 Impacts and Mitigation

Sedimentation will be the main impact of sand pumping from the eastern and southeastern as well as southern lagoon too. Sedimentation results in the reduction of water quality in the lagoon, which affects benthic organisms and fish, and other natural processes. Since the reef extent is small on the eastern side, there may be some sedimentation on the eastern reef flat. However, this will be small as the area will be calm during the project implementation period, which is the southwest monsoon.

This activity shall also be undertaken during calm weather and at low tides.

4.3 Breakwaters

The existing breakwaters are the main cause of abrupt changes in coastal processes around the island. Breakwaters help to absorb the pounding of breakers or reflect waves back to sea. However, the quiet or still water behind the breakwater impounds sand drifting alongshore and denies this sediment to the downdrift portion of the shoreline. This is very much evident in Halaveli. Therefore, there is a need to reduce the sand trapping effect of the breakwaters by realigning and reducing their heights.

According to the US Army Corps of Engineers, traditional high-crested breakwaters may not be appropriate for a structure used to protect a beach or shoreline. Adequate wave protection may be more economically provided by a low-crested or submerged structure composed of a homogeneous pile of rubble or rock.

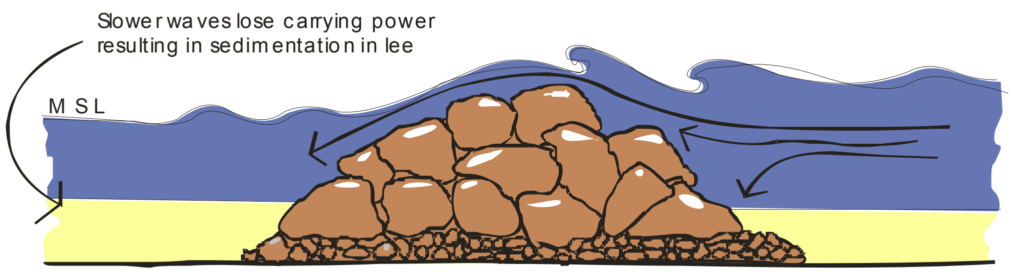


Figure 4-2: The effect of submerged, rubble-mound breakwater

Ideally, the breakwater field should be designed to alter the longshore transport so that the volume of sediment transported into and out of the breakwater field are equal. This can be achieved by varying the breakwater lengths and gap widths. However, the exact breakwater lengths and gap widths are difficult to determine at this stage due to lack of site specific longterm data. Hence, it has been proposed to maintain the existing alignment but move the breakwaters further away from the beach and reduce the height of the breakwaters so that they are hardly visible at tides above mean sea level.

Therefore, the following design has been suggested.

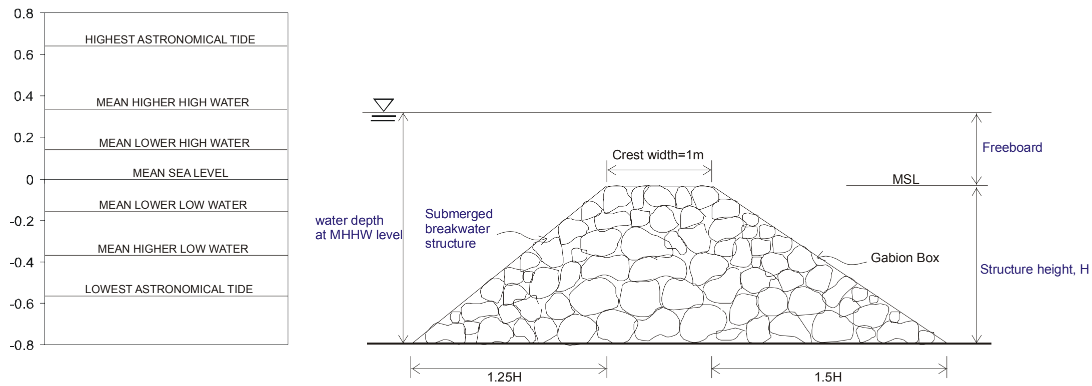


Figure 4-3: Design of proposed new breakwaters

The length of the new set of breakwaters is about 37m each and the gap between the breakwaters is about 2m. Figure 5-3 shows the location of the new set of breakwaters and their possible orientation.

It is also important to have flatter slopes for the breakwaters especially on the seaward side. According to the US Army Corps of Engineers (USACE), steeper slopes are subject to landslide type failures while flatter slopes may be prohibitively expensive. As a guide, USACE provides practical considerations for slopes to be between lV:1.5H and lV:2H for seaward side armour and 1V: 1.25H to lV:l.5H for harboured side armour. The proposed structure given in Figure 4-3 has been designed for as little slope as practicable to minimize cost.

4.3.1 Other breakwater structures

The following types of breakwaters may also be considered in the future. These will be evaluated in detail later upon longterm monitoring and evaluation of shore processes.

1. **Rubble mound submerged breakwaters using armoured stone:** Quite adaptable to different depths, suitable on nearly all foundations, produce less reflected waves than wall type and readily repaired. However, require larger amount of material than most other types. Interference with natural water circulation is minimal with submerged breakwaters because they allow water movement through the free board at high tide.

2. **“Reef ball” type submerged breakwaters:** If breakwaters were to be considered elsewhere, they may be designed as or similar to what is known as “Reef Balls” (see picture below). These structures are designed to attract fish

and would help create a living “artificial” reef. “Reef Ball” is an international trade mark, which may have suppliers in the Maldives. This can be useful in places where the reef has been deteriorated.

4.3.2 Impacts and Mitigation

Breakwaters help sedimentation in the lee of the breakwater and reduce wave action between the breakwater and the beach. However, breakwaters can be a disaster if they are not properly designed and constructed.

During the initial stages of the development of the breakwater or during the construction phase will bring the major direct short-term impacts and some secondary long-term impacts on both marine and coastal environment. Potential negative impacts on the reef system and beach environment from the proposed work are limited to a relatively small number of activities which include:

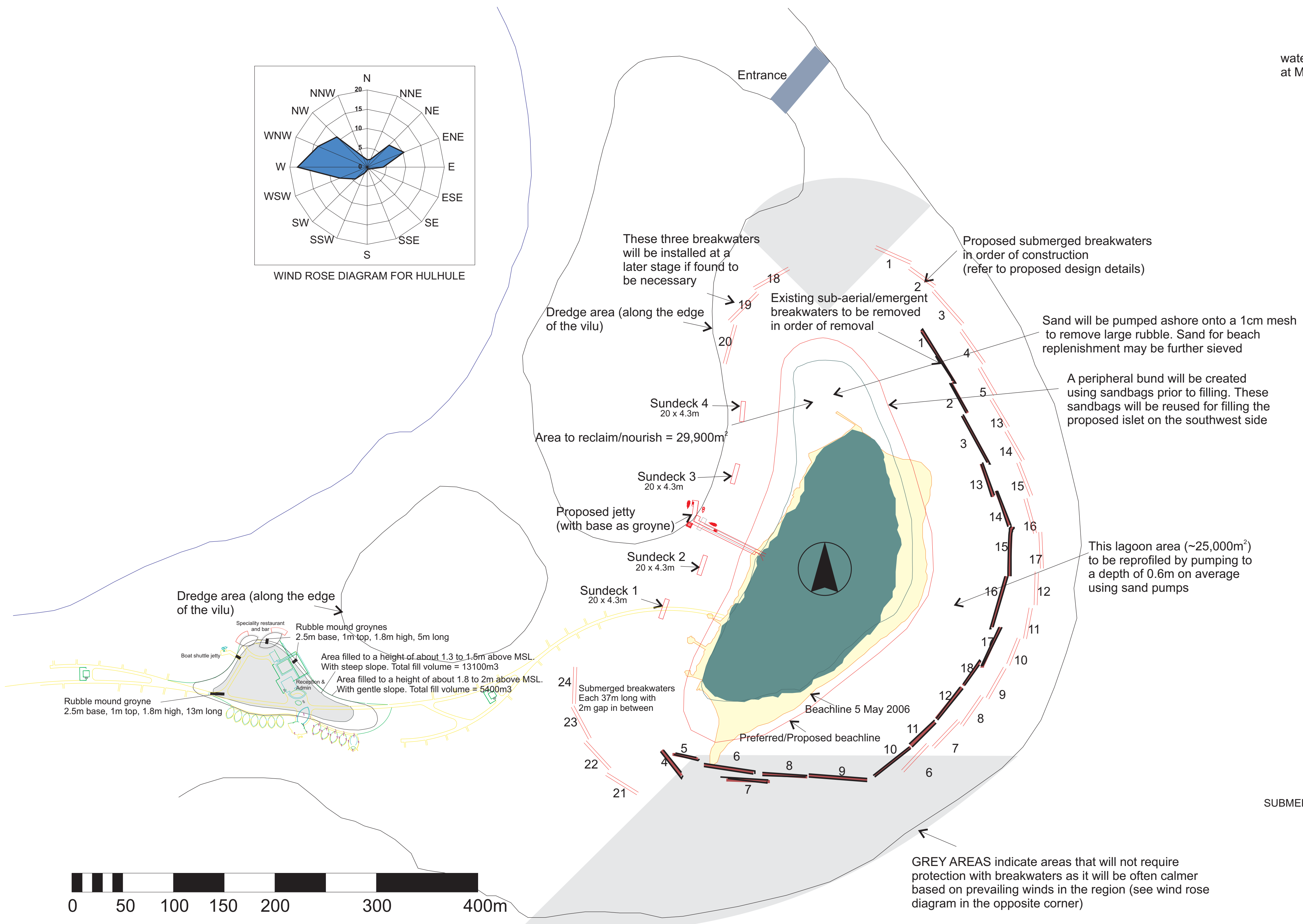
(i) Potential changes to the long shore transport and littoral regime of the island (considered a minor adverse impact if mitigation measures were taken).

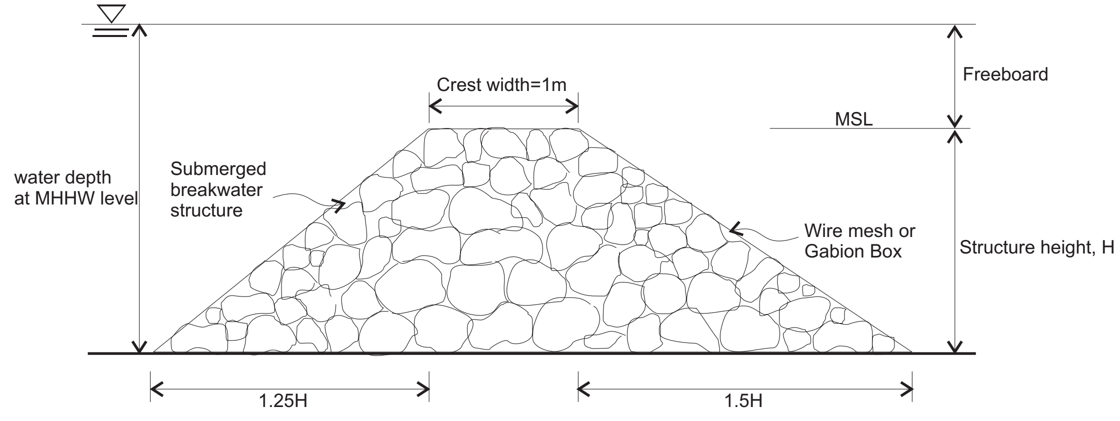
(ii) There would be some degree of sedimentation although it may not be as severe as beach replenishment or fill material disposal as discussed earlier.

(iii) Physical damage to the reef from equipment mobilization may also be severe if appropriate measures were not implemented.

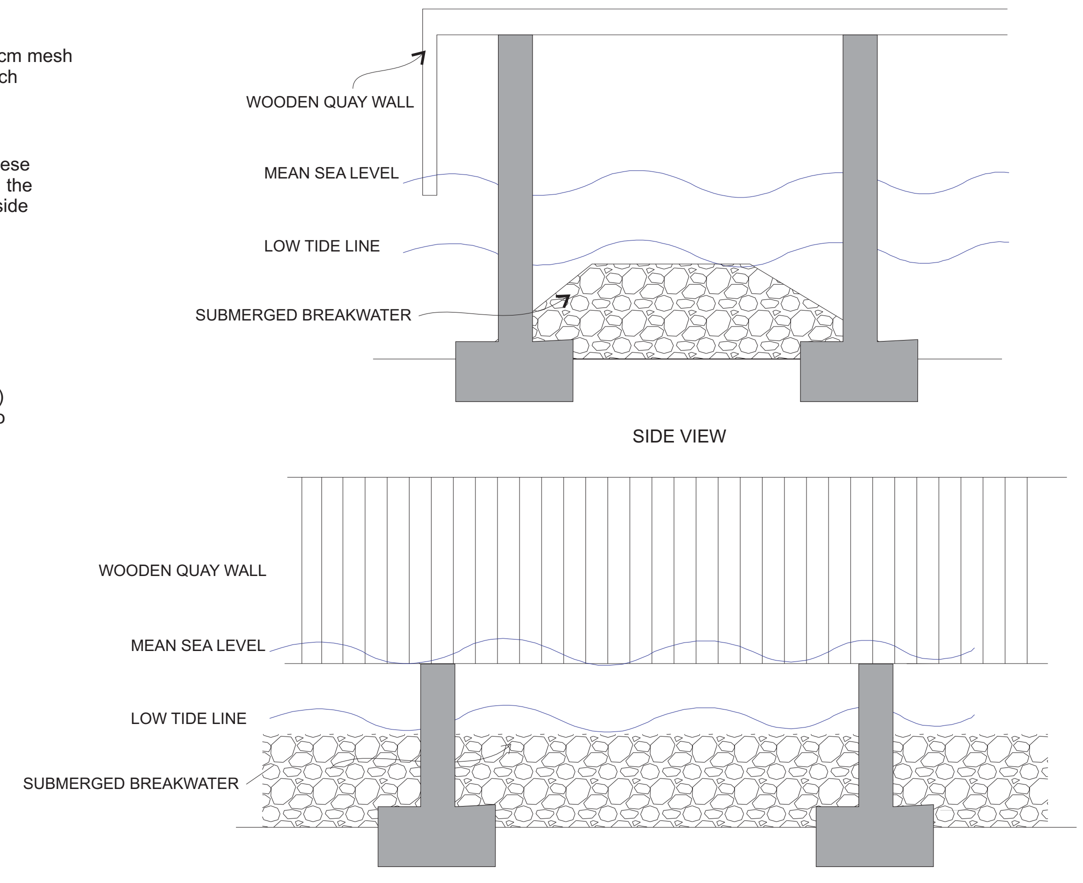
(iv) Potential increase in wave action at localized points due to improper placement of breakwater.

Figure 5-3: Proposed coastal protection measures



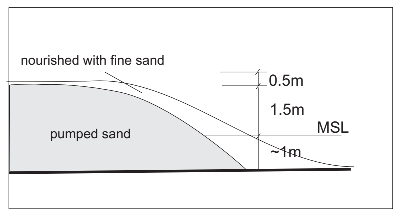


Proposed design for new breakwaters

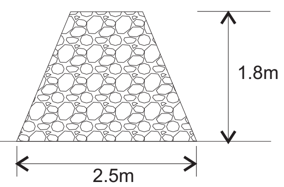


Proposed design for jetty head and sundeck breakwater with wave breaker

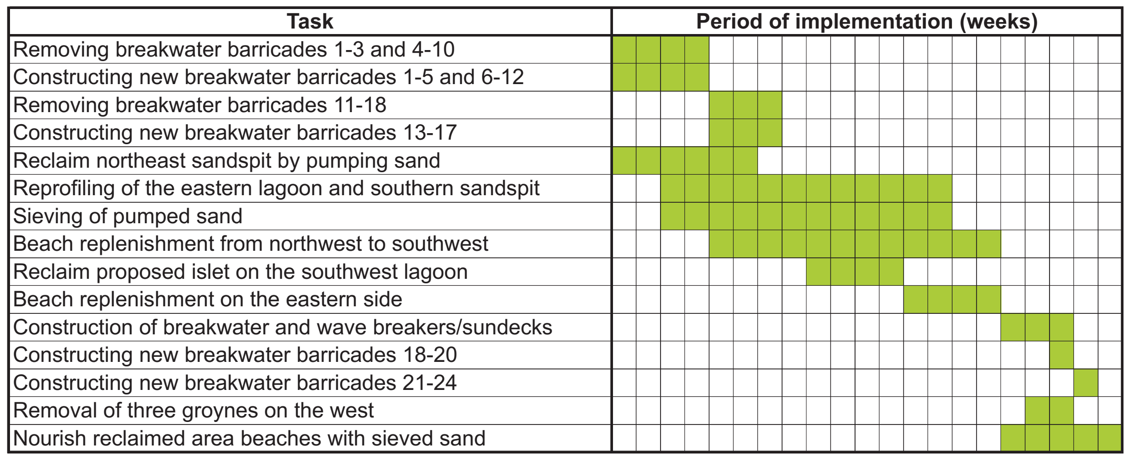
Item No.	Item Description	Unit	Qty	Unit Price (Rf)	Total Price (Rf)	Total Price (USD)
1	Demolish existing breakwaters, 715m x 3.3m²	m³	2,360	500	1,180,000.00	92,549.02
2	Construct new breakwaters, 890m x 2.375m²	m³	1,513	900	1,361,700.00	106,800.00
3	Jetty head breakwater, 30 x 1.125m²	m³	33.75	900	30,375.00	2,382.35
4	Jettyhead wavebreaker	m	45	500	22,500.00	1,764.71
5	Sundeck breakwater for Sundecks 2, 3 and 4	m³	16.875	900	15,187.50	1,191.18
6	Sundeck wavebreaker for Sundecks 2, 3 and 4	m	22.5	500	11,250.00	882.35
7	Sundeck breakwater for Sundeck 1	m³	24.1875	900	21,768.75	1,707.35
8	Sundeck wavebreaker for Sundeck 1	m	32.25	500	16,125.00	1,264.71
9	Groyne for proposed islet on the southwest	m³	89.6	500	44,800.00	3,513.73
	SUB TOTAL A				**2,703,706.25**	**212,055.40**
10	Reprofiling eastern lagoon using 4 or 6" sand pump	m²	25,000	50	1,250,000.00	98,039.22
11	Groyne demolition	Nos.	3	25,000	75,000.00	5,882.35
12	Beach nourishment around the island	m³	11,000	35	385,000.00	30,196.08
13	Reclamation on the northern end using 6" sand pump	m³	29,900	65	1,943,500.00	152,431.37
14	Nourishment/grooming of reclaimed area beach	m³	3,346	50	167,300.00	13,121.57
15	Bund around reclamation area (sand or sandbags)	m³	731	35	25,595.50	2,007.49
16	Reclamation of proposed islet on southwest	m³	15,645	65	1,016,925.00	79,758.82
17	Nourishment/grooming of reclaimed islet on southwest	m³	3074.5	50	153,725.00	12,056.86
	SUB TOTAL B				**5,017,045.50**	**393,493.76**
	TOTAL				**7,720,751.75**	**605,549.16**
	Contingency @ 10%				270,370.63	21,205.54
	Supervision and project management				385,500.00	30,000.00
	FINAL TOTAL				**8,376,622.38**	**656,754.70**



Fill profile for islet on the southwest and reclaimed areas



Cross-section of Proposed groyne for islet on the southwest



The use of Reef Balls to construct the breakwater provides an important positive impact by increasing coral growth in the area. The long-term impact of the Reef Balls is expected to be largely positive, given that most of the reef ball projects carried out around the world has had a high success rate. Coral growth will be increased in the area, improving the general health of the reef. The current speed and strength in the area will be reduced while the strength of the waves reaching the shoreline will also be drastically reduced. Therefore, it will help coastal coastal processes to stabilise quite soon. However, monitoring of the coastal conditions is essential to check any impacts on the coastal areas, especially those areas which are left unprotected.

Construction of a solid breakwater all along the entire eastern side has caused severe damage to the coastal environment of Halaveli, as described earlier. This was a result of poor design and lack of dialogue with environmental consultants. However, the impacts at Halaveli were less severe than many other islands in which such structures have caused sandspits at either ends to join with the breakwaters causing the lagoon inside to become murky as well as sand smothering of the reef flat at locations where the beach joined with the breakwaters.

Therefore, it is proposed to ensure that the breakwater is submerged at mean sea level or at least at low high tide level. Furthermore, the submerged breakwater must be of adequate length (of about 10-35m) with spaces in between barricades. These will ensure that these breakwaters do not act as nearshore breakwaters by filling in the area. The breakwaters should also not be placed too near to the accreting beach (*thundi*).

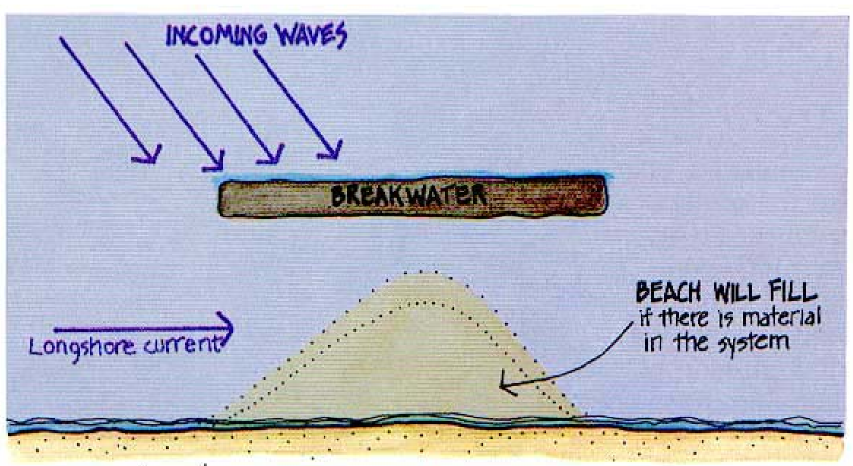


Figure 4-4: Plan view of a typical nearshore breakwater and the movement of sediment pattern around the breakwater.

4.4 Sundeck and jetty head wave breakers

The proposed sundecks (see Figure 5-3) will act as nearshore submerged breakwaters as well as wave breakers at tides above mean sea level. This is expected to minimize wave-induced erosion on the western beaches without adversely affecting longshore sediment transport patterns as with groynes. These structures would also be an attraction rather than an eyesore. The design of these coastal protection structures is shown in Figure 4-5.

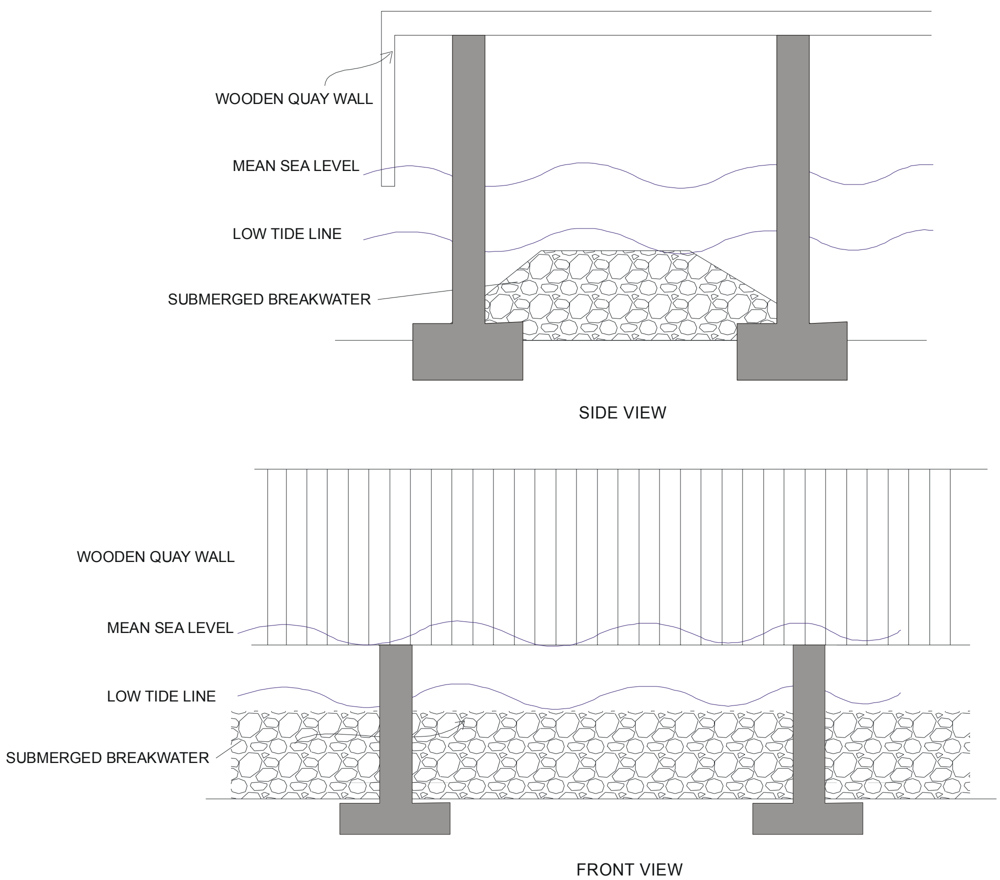


Figure 4-5: Design of wave breakers and nearshore submerged breakwaters for coastal protection from wave scour on the western side.

4.5 Groynes on the southwest sandspit

The southwest sand spit may be protected by groynes at the onset. However, this may be done after allowing the islet beaches to come to an equilibrium through natural forces. If the works can be undertaken as proposed, an equilibrium would be reached around end of February 2007. The cross section of the groynebeyonf the s and their orientation as well as locations in which these groynes may be placed are shown in Figure 5-3.

These groynes would be placed below the proposed decks and overwater structures to minimize any visual impact. However, it may be best to consider constructing these after evaluating the changes to the sandbank over a period of at least 6 months following reclamation.

5 ALTERNATIVE COASTAL PROTECTION MEASURES

5.1 Revetment or groyne head

Other proposed shore protection measure is the construction of a groyne head revetment. Figure 5-1 provides design or installation details for such a structure. These structures would allow deposition on the lee and also will prevent loss of sand around that area where beach nourishment activity has been undertaken

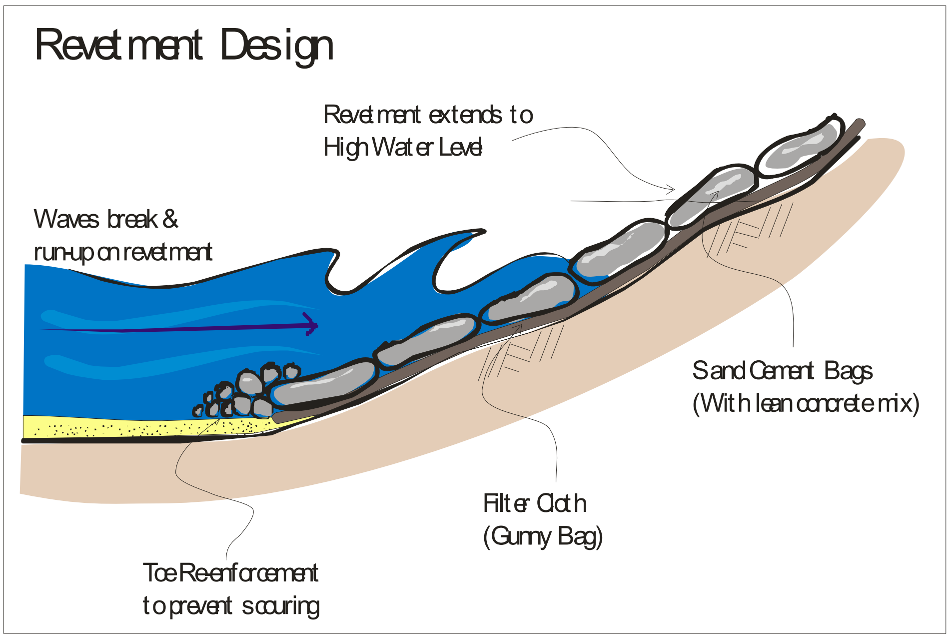


Figure 5-1: Revetment Design

5.2 Low retaining wall

A low retaining wall may be placed at the reclamation area on the northern end to ensure that the toe of the reclamation is protected thereby providing protection to the vegetation and structures built on the reclaimed land. This retaining wall would only be exposed following storms, otherwise remain unexposed.

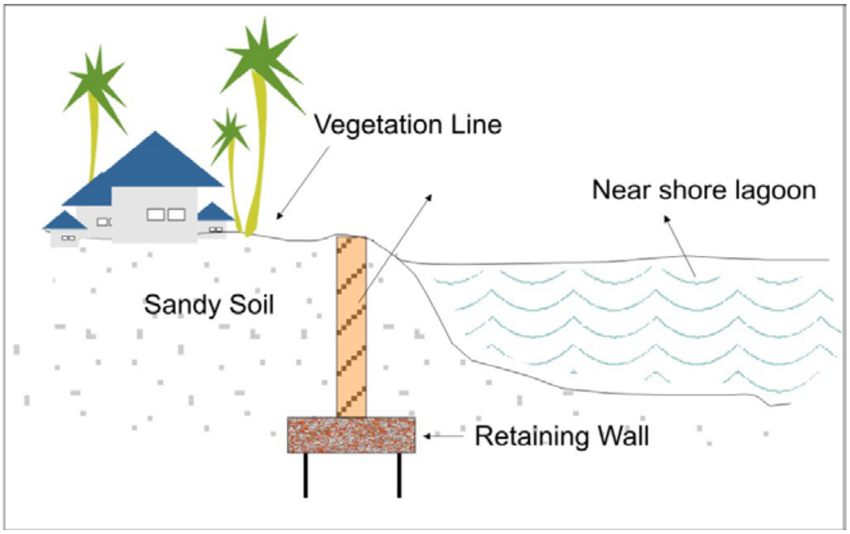


Figure 5-2: Retaining Wall Design

5.2.1 Impacts and Mitigation

The main impact of revetments and retaining walls would be that they may be an eye-sore in case of exposure due to erosion. This may, therefore, not be practicable in a tourist resort setting such as Halaveli except as immediate shore protection following storms or severe weather conditions or erosion. However, they will help to protect the properties behind them from the threats of erosion.

In order to mitigate the visual impacts of revetments and retaining walls, they may be constructed as submerged structures and by regular filling of the beach slope at a gradient of 1:10.

5.3 Groynes

Instead of the groyne head revetments proposed, groynes similar to existing groynes may be constructed as a groyne field on the nourished segments of the western beach. Groynes help to keep the nourished sand on the lee of the groyne by reducing the magnitude of currents on its lee. Therefore, groynes need to be constructed quite close to each other to ensure maximum beach width is preserved as a result of the groynes.

In stead of the proposed low retaining wall, the Developer may consider to construct a terminal groyne on the west and eastern ends of the northern sandspit after reclamation in order to prevent longshore losses.

5.3.1 Design Considerations for groynes

Groyne fields must also be designed in such a way that the number and length of groynes are kept to a minimum so as to reduce visual impacts. Groyne fields have greater visual impacts than revetment heads or submerged breakwaters. If coastal constructions such as more groynes on the western side are to be considered, it may be important to consider alternative construction materials in place of coral rubble from the housereef. For the selection of construction materials, there are a number of alternatives to the predominant use of coral rubble or coral detached from the housereefs. Alternatives include armour rock, wood pile, steel sheet pile, caissons and sand or (more effectively) cement bags.

Use of woody vegetation is also quite effective in beach stabilization. Maldives being a tropical country, native woody plant species such as some mangrove species can grow into the water. Mangroves help breakup wave action on shorelines, while at the same time they trap sediment and speed up development of fast land along the shore. This would also reduce the cost of beach nourishment. Some notable species that could be used would be *casuarinas, scaevula and terminalia*. However, this is something that requires assessment of its feasibility and practicality in the Maldives.

5.3.2 Impacts and Mitigation

Groynes are useful in maintaining sand in a particular area. However, as described above, the sand accumulates on the lee of the groin and the windward or driftward side of the groyne gets eroded. Therefore, this may become an eye-sore in case of exposure due to erosion. In order to mitigate the visual impacts of groynes, they may be constructed low and using appropriate material that suits the natural beach conditions. Use of vegetation as described above may be an advantage too.

5.4 Project Implementation

The project is expected to be implemented from July 2006 and most activities proposed here is expected to be undertaken during the southwest monsoon. The project will be undertaken in the order provided in the table below. The sequence of removal of breakwaters and installation of new ones are given in Figure 5-3.

Table 5-1: Sequence of implementation of project activities

Task	Period of implementation (weeks)																				
Removing breakwater barricades 1-3 and 4-10	■	■	■	■																	
Constructing new breakwater barricades 1-5 and 6-12	■	■	■	■																	
Removing breakwater barricades 11-18					■	■	■														
Constructing new breakwater barricades 13-17					■	■	■														
Reclaim northeast sandspit by pumping sand	■	■	■	■	■	■															
Reprofiling of the eastern lagoon and southern sandspit			■	■	■	■	■	■	■	■	■	■	■	■							
Sieving of pumped sand			■	■	■	■	■	■	■	■	■	■	■	■							
Beach replenishment from northwest to southwest					■	■	■	■	■	■	■	■	■	■	■	■					
Reclaim proposed islet on the southwest lagoon									■	■	■	■									
Beach replenishment on the eastern side													■	■	■	■					
Construction of breakwater and wave breakers/sundecks																	■	■	■		
Constructing new breakwater barricades 18-20																			■		
Constructing new breakwater barricades 21-24																				■	
Removal of three groynes on the west																		■	■		
Nourish reclaimed area beaches with sieved sand																	■	■	■	■	■

5.5 Cost Comparison of the Proposed Shore Protection Measures

Table 5-2: Cost estimates of the proposed shore protection measures

Item No.	Item Description	Unit	Qty	Unit Price (Rf)	Total Price (Rf)	Total Price (USD)
1	Demolish existing breakwaters, 715m x 3.3m^2	m^3	2,360	500	1,180,000.00	92,549.02
2	Construct new breakwaters, 890m x 2.375m^2	m^3	1,513	900	1,361,700.00	106,800.00
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5	Sundeck breakwater for Sundecks 2, 3 and 4	m^3	16.875	900	15,187.50	1,191.18
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8	Sundeck wavebreaker for Sundeck 1	m	32.25	500	16,125.00	1,264.71
9	Groyne for proposed islet on the southwest	m^3	89.6	500	44,800.00	3,513.73
	SUB TOTAL A				**2,703,706.25**	**212,055.40**
10	Reprofiling eastern lagoon using 4 or 6" sand pump	m^2	25,000	50	1,250,000.00	98,039.22
11	Groyne demolition	Nos.	3	25,000	75,000.00	5,882.35
12	Beach nourishment around the island	m^3	11,000	35	385,000.00	30,196.08
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16	Reclamation of proposed islet on southwest	m^3	15,645	65	1,016,925.00	79,758.82
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	SUB TOTAL B				**5,017,045.50**	**393,493.76**
	TOTAL				**7,720,751.75**	**605,549.16**
18	Contingency @ 10%				270,370.63	21,205.54
19	Supervision and project management				385,500.00	30,000.00
	FINAL TOTAL				**8,376,622.38**	**656,754.70**

All civil works in Table 5-2 includes supply, delivery, transportation, storage, installation, adjustment, testing and commissioning, and required materials, equipment and workmanship to execute the items of construction in accordance with the specifications, drawings and Supervising Engineer's instructions, complete, in place and ready for handing over, unless otherwise stated.

6 RECOMMENDATIONS

6.1 Choosing the appropriate option(s)

It is important for the developer to consider the most appropriate option by taking into account short term as well as long term costs to the operator. For instance, it may not be necessary to construct a low retaining wall at the edge of the proposed reclamation initially but only if it is found to be necessary over the construction period in which changes shall be monitored.

As indicated earlier beach nourishment shall be done whichever option is opted. The sand budget of the island has been dramatically changed over the past few years and nourishing eroding areas will help the system to come to equilibrium sooner.

Further measures that will help to reduce the frequency of nourishing and ensure that the beach material in the nourished segments is kept intact, in the order of priority, include:

1. Constructing submerged breakwaters on the northwestern area in order to protect the newly reclaimed sandspit, where severe erosion has been occurring over the past few years. For this location, it may be more appropriate to choose a type of breakwater such as "reef balls" which will help in developing an artificial reef.

2. A submerged breakwater similar to the one given in 1 above may also be considered for the southeastern side. These structures can be more submerged in order to reduce visual impact and may be kept below the proposed over water structures.

Further options may be looked at based on the findings of the proposed monitoring programme. Regular monitoring before, during and after beach replenishment and filling works shall be undertaken. The advantages and disadvantages of constructing the proposed coastal structures shall be evaluated based on such monitoring.

Revetments and retaining walls are not recommended due to their negative visual impact. Tourist satisfaction is an important factor in considering coastal protection works. Therefore, these options which may be an eyesore in case of erosion on the foreshore, shall be avoided as much as possible. Similarly, groynes shall also be avoided.

6.2 Recommendations for beach nourishment

Fill material for future beach nourishment may be obtained by pumping sand from the vilu. Also, in order to protect beaches from wave scour in future, it may be important to fill the beach in such a way that the post-fill profile does not return to the existing profile. In many beach replenishment projects it has been observed that the new fill profile is laid parallel to the existing profile, therefore, equilibrium is reached after the fill when the existing profile has been attained. Furthermore, if possible creating sandbars at low tide for the nourished segments on the western side may also be useful.

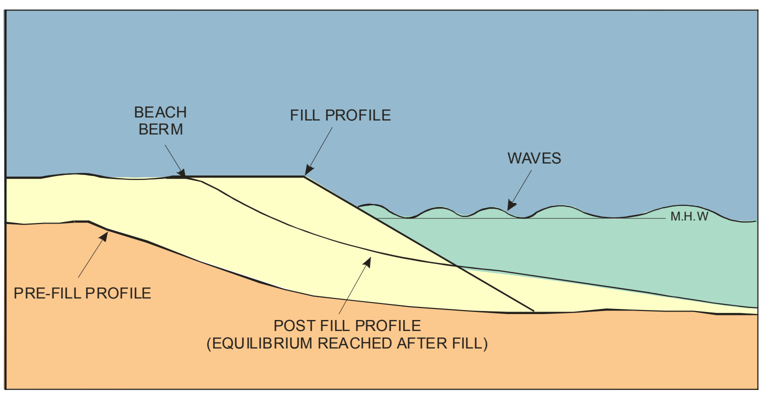

Figure 6-1: Side view - the fill profile changes after replenishment (USACE, 2001)

6.3 Management and Monitoring

Once the shore protection measures have been undertaken, it is necessary to properly maintain the shore protection structures and the beach, since the site will have some effects during development and operation phases in terms of changing the tidal and current patters within and around the lagoon and based on such effects the site cannot self-maintain. At the same time, it is important that aftermaths of the project are regularly monitored to ensure that future mitigation measures are based on site-specific data so that environmental impacts would be minimized thereby reducing the cost of maintenance.

Since environmental changes occur over a long period of time, it is important to keep on monitoring the coastal zone irrespective of the options chosen because no method or option particularly guarantees a stable coastline. Therefore, in order to understand or perceive environmental changes it is important to collect a useful set of data that can assist decision making. It is important to monitor the effects of development prior to, during and after project implementation.

It will also be important to ensure that environmental design criteria are met during construction. This can be achieved by inspections at appropriate intervals during the construction phase. Environmental supervision during project implementation was not practiced in the Maldives until recently. Recent environmental supervision or inspection has proven to be an effective tool in minimizing the impacts and in ensuring that appropriate caution and care is employed.

6.3.1 Monitoring Programme

The monitoring programme for the proposed project will include three monthly monitoring to cover the three stages of the project implementation, namely:

Stage 1: Immediately before starting proposed works

Stage 2: During proposed works

Stage 3: Post project stage

The monitoring needs of each stage are discussed in detail below:

<u>Stage 1</u>

- Percent live coral cover
- Water quality – Total Suspended Solids and turbidity
- Beach profiles at 50-m intervals
- Longshore currents around the island
- Bathymetry of the area to be filled and reprofiled
- Setup sedimentation traps on the reef to measure sedimentation rate

Stage 2

- Water quality – Total Suspended Solids and turbidity
- Sedimentation rate – every month
- Beach profiles monthly
- Longshore currents around the island

Stage 3

- Percent live coral cover
- Water quality – Total Suspended Solids and turbidity
- Beach profiles at 50-m intervals
- Longshore currents around the island
- Sedimentation rate – every month up to at least three months
- Bathymetry of the area to be filled

6.3.1.1 Monitoring Timetable

The following table shows the frequency at which the different parameters may be monitored. Each bar represents one week. Monitoring during the civil works and post civil works phase would continue in the given manner at the shown frequency.

Table 6-1: Proposed timetable for monitoring during and after construction period

		Civil works										Post civil works/operational									
Percent live coral cover	♦												♦								♦
Water quality	♦				♦				♦				♦				♦				♦
Beach profiles	♦				♦				♦				♦				♦				♦
Longshore currents	♦				♦				♦				♦				♦				
Bathymetry	♦				♦				♦				♦				♦				♦
Sedimentation rate	*				♦				♦				♦				♦				♦

* Setup sediment traps

6.3.2 Managing Monitoring Data

Halaveli has had a long history of beach erosion and management issues ever since construction of the resort began. The available data and information on coastal erosion in Halaveli has also been an important factor in determining the various options and recommendations in this report. It is therefore apparent that data and information is crucial to manage the coastline. Due to the dynamic nature of the island, the island's coastline is expected to undergo changes. A GIS is a very useful tool to track these changes and would be a very useful tool for management of the coastline. The monitoring programme recommended in this report will allow collection of useful data, but in order for these data to me made in to meaningful information, a GIS would be the appropriate solution. Therefore, it is strongly recommended to set up a GIS for Halaveli to manage the coastline. Additionally, GIS will have other benefits for the resort operation and not only for coastal management.

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