CHAPTER 6 BEACH DEFORMATION MECHANISM

6.1 Changes in Coastal Lines

6.1.1 Central part of Fongafale Islet

Figure 6.1 shows the comparison of an aerial photograph (upper, taken in 1984) and a satellite image (lower, taken in 2003, IKONOS) of the coastal line in the central part of Fongafale Islet. The upper photo is the 1984 photo with the 2003 coastal line superimposed on it. This shows that no significant change occurred in the coastal line during a period of about 20 years.

Figure 6.2 shows the 1943 and 1941 aerial photos with the 2003 coastal line superimposed on them. This shows that, although no significant difference is seen in the positions of the coastal line in 1943 and 2003, the coastal line advanced toward the lagoon side for about 30 m between 1941 and 2003, and there was a change between 1941 and 1943.

The cause for this change is as follows: During the Pacific War, Tuvalu was used by the American troops as the frontline base against Japan. The American troops excavated part of the lagoon-side reef and the islet in a large scale and, using these coral fragment as main banking materials, reclaimed land from coastal areas and swampy lowland to build an airfield of the air force and ancillary facilities.

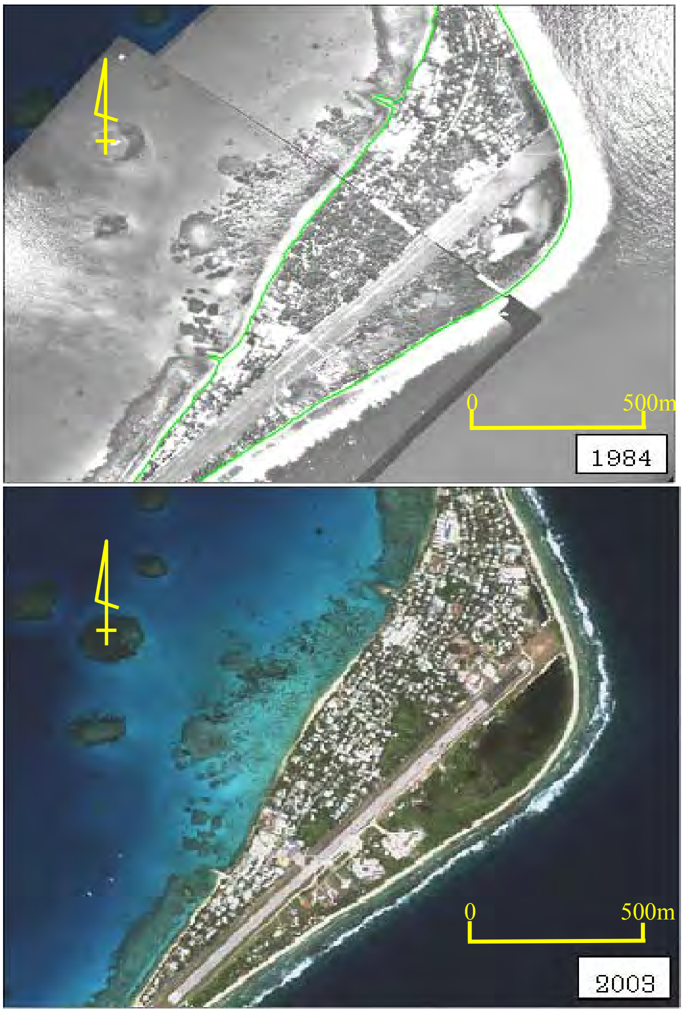
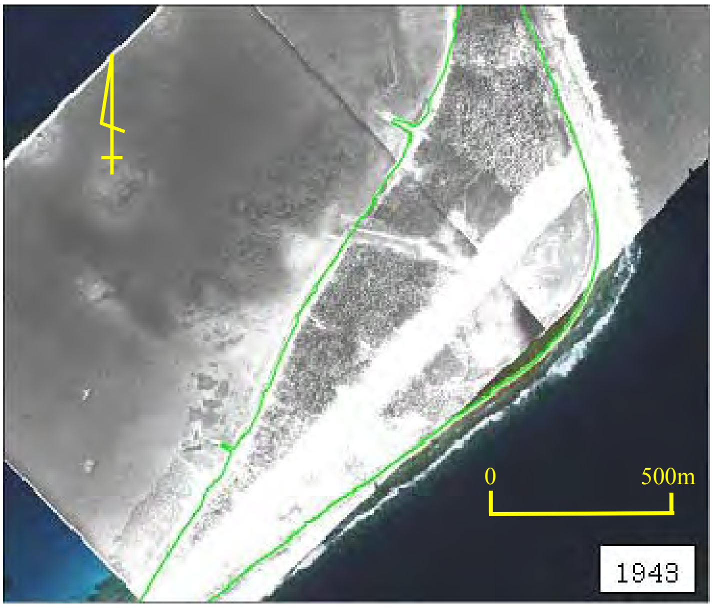


Figure 6.1 Changes in the Coastal Line between 1984 and 2003

Source: COASTAL CHANGE ANALYSIS USING MULTI-TEMPORAL IMAGE COMPARISONS – FUNAFUTI ATOLL, April 2006, SOPAC



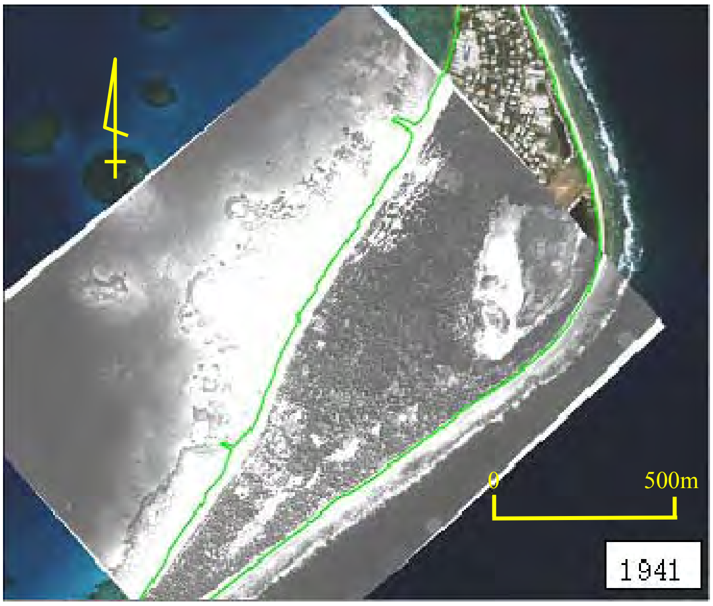


Figure 6.2 Changes in the Coastal Line between 1941, 1943 and 2003

Source: COASTAL CHANGE ANALYSIS USING MULTI-TEMPORAL IMAGE COMPARISONS – FUNAFUTI ATOLL, April 2006, SOPAC

6.1.2 Northernmost Tip of Tenkago Islet

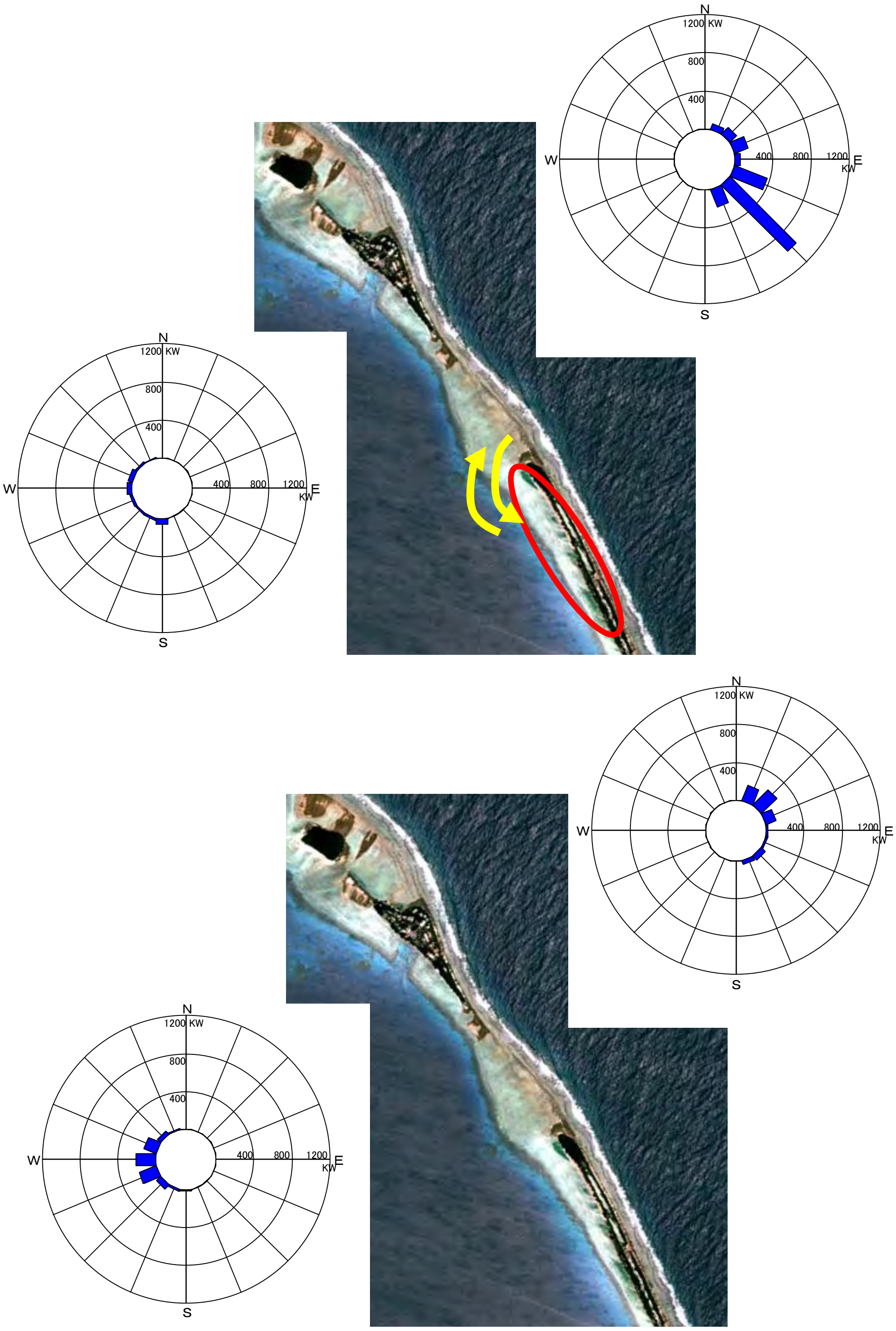
Table 6.1 shows the changes in the coastal line on the northernmost tip of Tekago Islet in the dry and rainy seasons. **Figure 6.3** shows the seasonal changes in the wave energy fluxes due to wind waves at this place.

Based on this data, it is deduced that earth and sand on the lagoon side is carried by westerly winds to near the tip in the rainy season and back to the lagoon side in the dry season. Furthermore, there is supply of earth and sand from the ocean to the lagoon side but the amount of it is not large when judged from the photos taken on the northernmost tip facing the ocean in the dry season. Part of earth and sand in a range enclosed in a red frame in the upper photo of **Figure 6.3** is considered to move depending on the season.

Table 6.1 Changes in the Coastal Line on the Northernmost Tip of Tenkago Islet

	Dry season	Rainy season
From the lagoon side facing the northernmost tip		
From the northernmost tip facing the ocean side		

Dry season



Rainy season

Figure 6.3 Wave Energy Fluxes at the Northernmost Tip of Tenkago Islet

6.1.3 Southernmost Tip of Fongafale Islet

Table 6.2 shows the changes in the coastal line on the southernmost tip of Fongafale Islet in the dry and rainy seasons. **Figure 6.4** shows the seasonal changes in the wave energy fluxes due to wind waves at this place.

Based on this data, it is deduced that earth and sand are pushed toward the lagoon side by the actions of waves from the ocean in the dry season and toward the ocean by actions of northwestern wind waves developed in the lagoon in the rainy season.

Table 6.2 Changes in the Coastal Line on the Southernmost Tip of Fongafale Islet

	Dry season	Rainy season
Conditions of the spit on the tip	 Inclined toward the lagoon	 Inclined toward the ocean

Dry season

Rainy season

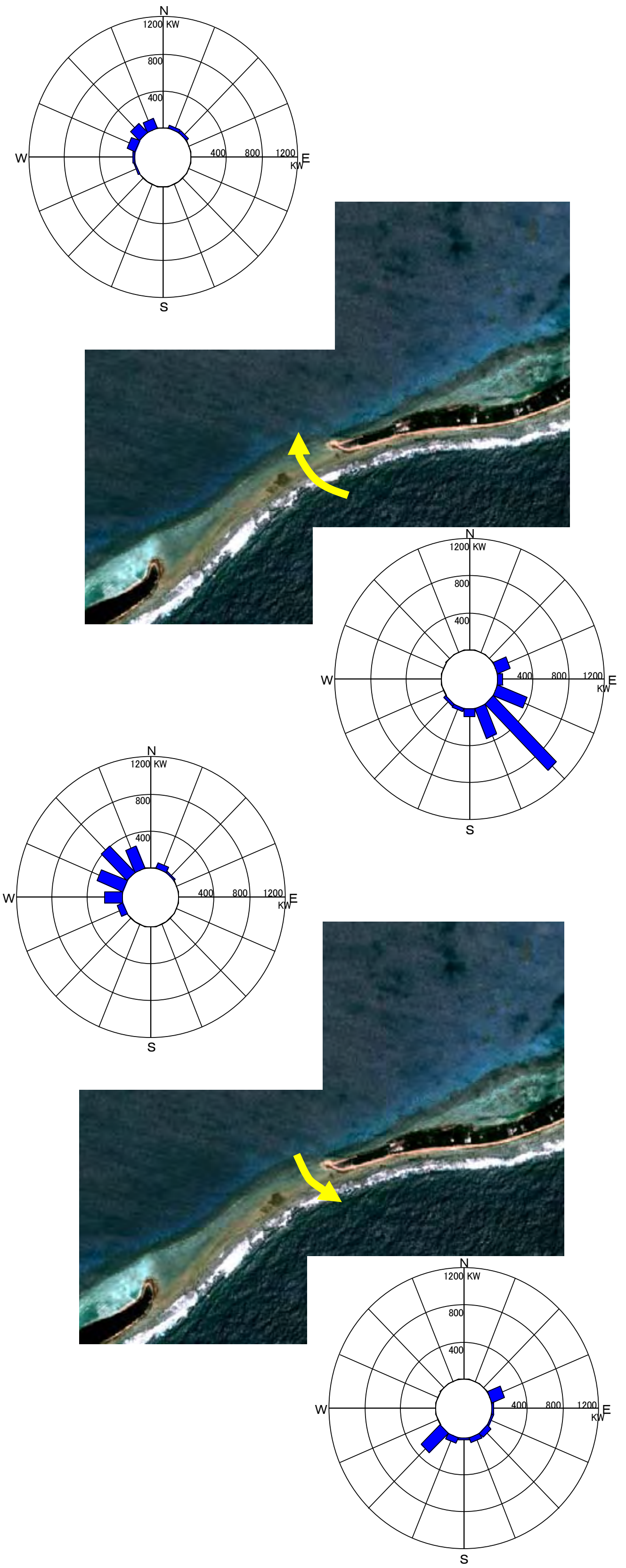


Figure 6.4 Wave Energy Fluxes at the Southernmost Tip of Fongafale Islet

6.1.4 Near the Structures

Figure 6.5 shows representative structures and distinctive topographical features that are useful in studying littoral drift.

Figure 6.5 Locations of Representative Structures and Distinctive Topographical Features

(1) New jetty of Funafuti Port

Table 6.3 shows the changes in the coastal line near the new jetty of Funafuti Port in the dry and rainy seasons. Figure 6.6 shows the result of measurement of sand beach distribution using TotalStation.

Considering that the new jetty is designed as a permeable type other than the seawall abutment, it is deduced that the movement of earth and sand are to the south in the rainy season and approximately neutral in the dry season.

Photo 6.1

Table 6.3 Changes in the Coastal Line near the New Jetty of Funafuti Port

	Dry season	Rainy season
South side		
North side		

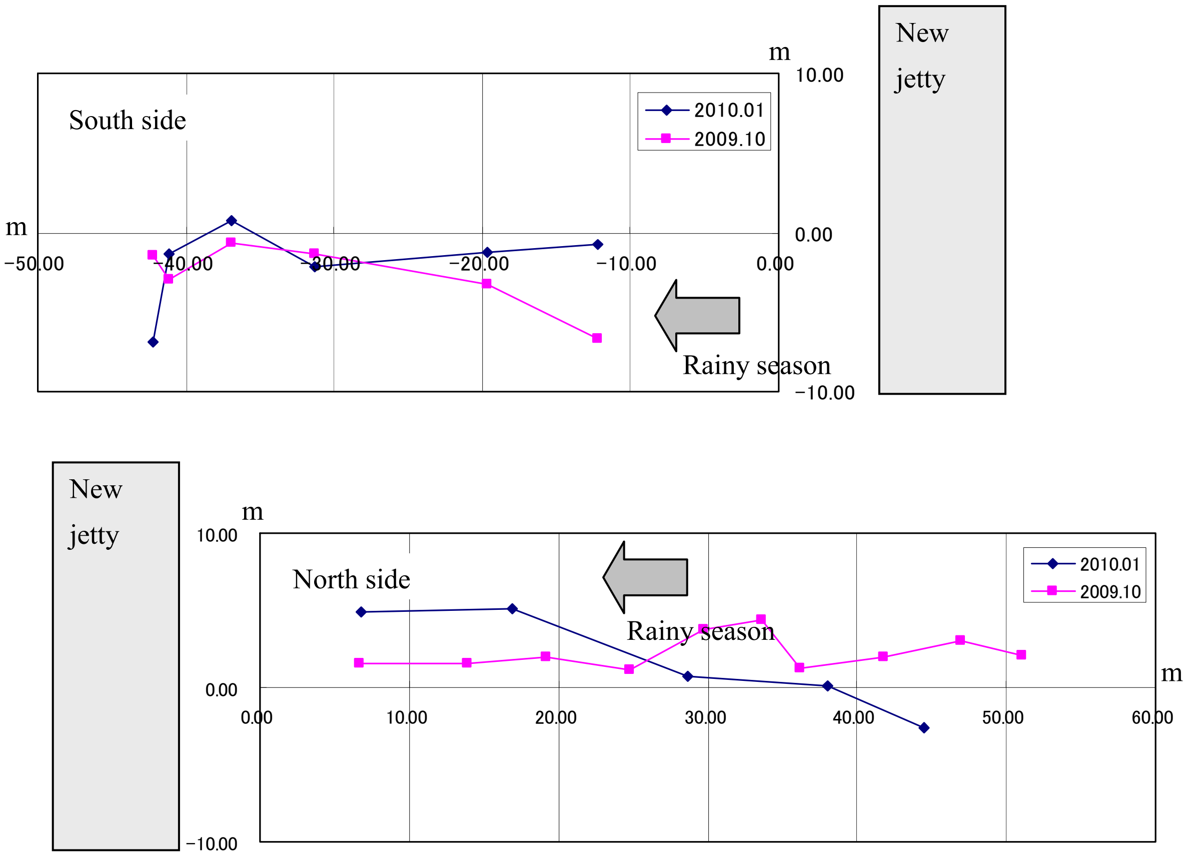
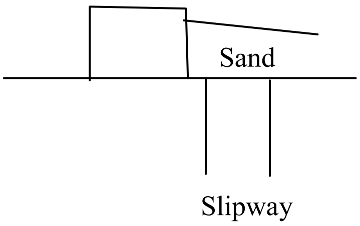
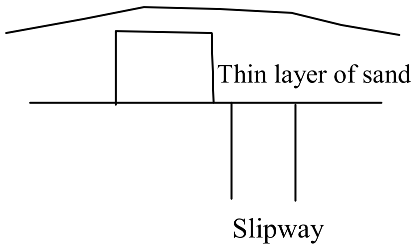


Figure 6.6 Changes in the Coastal Line near the New Jetty

(2) Area in front of the hospital

Table 6.4 shows the changes in the coastal line near the slipway in front of the hospital in the dry and rainy seasons.
In comparison with the dry season, the amount of sand deposited is larger in the rainy season, and it seems that littoral drift is active.

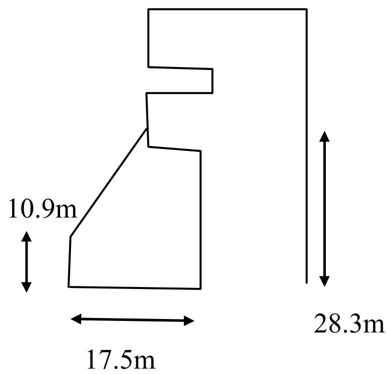
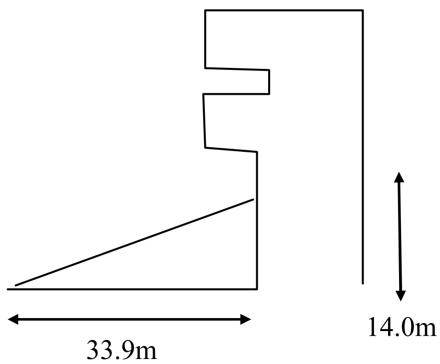
Table 6.4 Changes in the Coastal Line in Front of the Hospital

	Dry season	Rainy season
Photo		
Schematic diagram		

(3) Groin

Table 6.5 shows the changes in the coastal line near the groin in the dry and rainy seasons. Earth and sand are deposited on the south side both in the dry and rainy seasons, and not on the north side. Based on the deposition distribution on the south side, it seems that earth and sand deposited on the groin side in the dry season is carried back a little to the south in the rainy season.

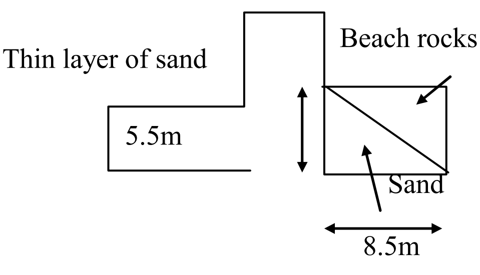
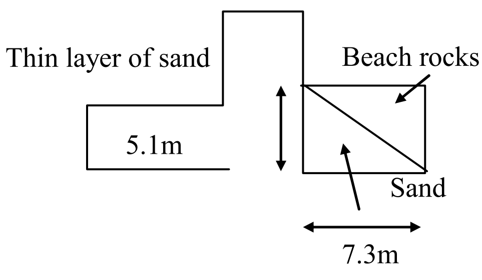
Table 6.5 Changes in the Coastal Line near the Groin

	Dry season	Rainy season
South side		
North side		
Schematic diagram		

(4) Slipway

Table 6.6 shows the changes in the coastal line near the slipway in the dry and rainy seasons. More sand deposition can be seen on the south side of the slipway than the north side, but in both the dry season and the rainy season a thin layer of sand is deposited on the beach rocks, and the amount of sand supplied as littoral drift is small, so there are no significant seasonal changes.

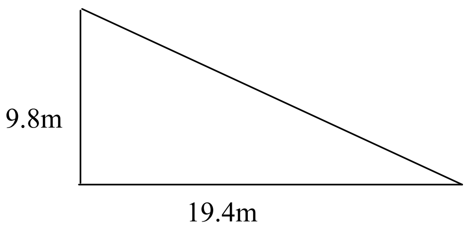
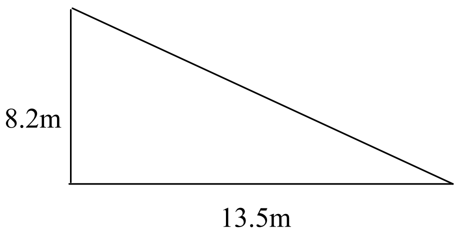
Table 6.6 Changes in the Coastal Line near the Slipway

	Dry season	Rainy season
South side		
North side		
Schematic diagram		

(5) Slipway near the southern tip of Fongafale

Table 6.7 shows the changes in the coastal line at a slipway near the southern tip of Fongafale Islet in the dry and rainy seasons.
The amount of sand deposited is a little smaller in the rainy season than in the dry season.

Table 6.7 Changes in the Coastal Line at Slipway near the Southern Tip of Fongafale

	Dry season	Rainy season
Photo		
Schematic diagram		

6.2 Beach Deformation Mechanism

6.2.1 Ocean Side

Table 6.7 shows a red circle that represents the observation point for wind data. Based on this data, wave prediction using the SMB method was conducted at the points marked in pink. Since there are "swells" in the ocean, the results of wave prediction using the SMB method are insufficient for assessment, but were used as indices for studying the beach deformation mechanism. **Figure 6.8** and **Figure 6.9** show the prediction results as the distribution of wave energy fluxes by direction in the dry and rainy seasons, respectively. From this data, it is estimated that, in the dry season, the islet is under the influence of two external forces that cause sediment movement as indicated by the vectors in Figure 6.8: A southward external force on the south of an eastward protrusion in the central part of Fongafale Islet and a northward external force on the north of it. On the other hand, it is estimated that, in the rainy season, the wave energy is smaller than in the dry season and, as shown by the vectors in Figure 6.9, the islet is under the influence of external forces that cause southward sediment movement on the northern side of Fongafale Islet. However, the ocean-side coast consists mainly of hard beach rocks and gravel, i.e., beach rocks crushed and washed ashore, and no significant change is observed except on the southernmost tip of Fongafale Islet. Therefore, it is deduced that the sediment balance is at a level where the spit on the southernmost tip is formed, and that the amount of coral and beach rocks crushed by waves and supplied to the coast is approximately balanced with the amount of littoral drift that flows out.

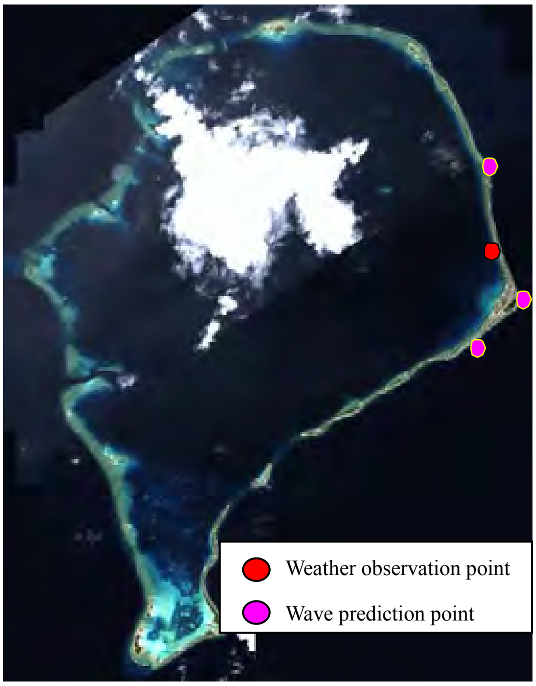


Figure 6.7 Wave Prediction Points on the Ocean Side

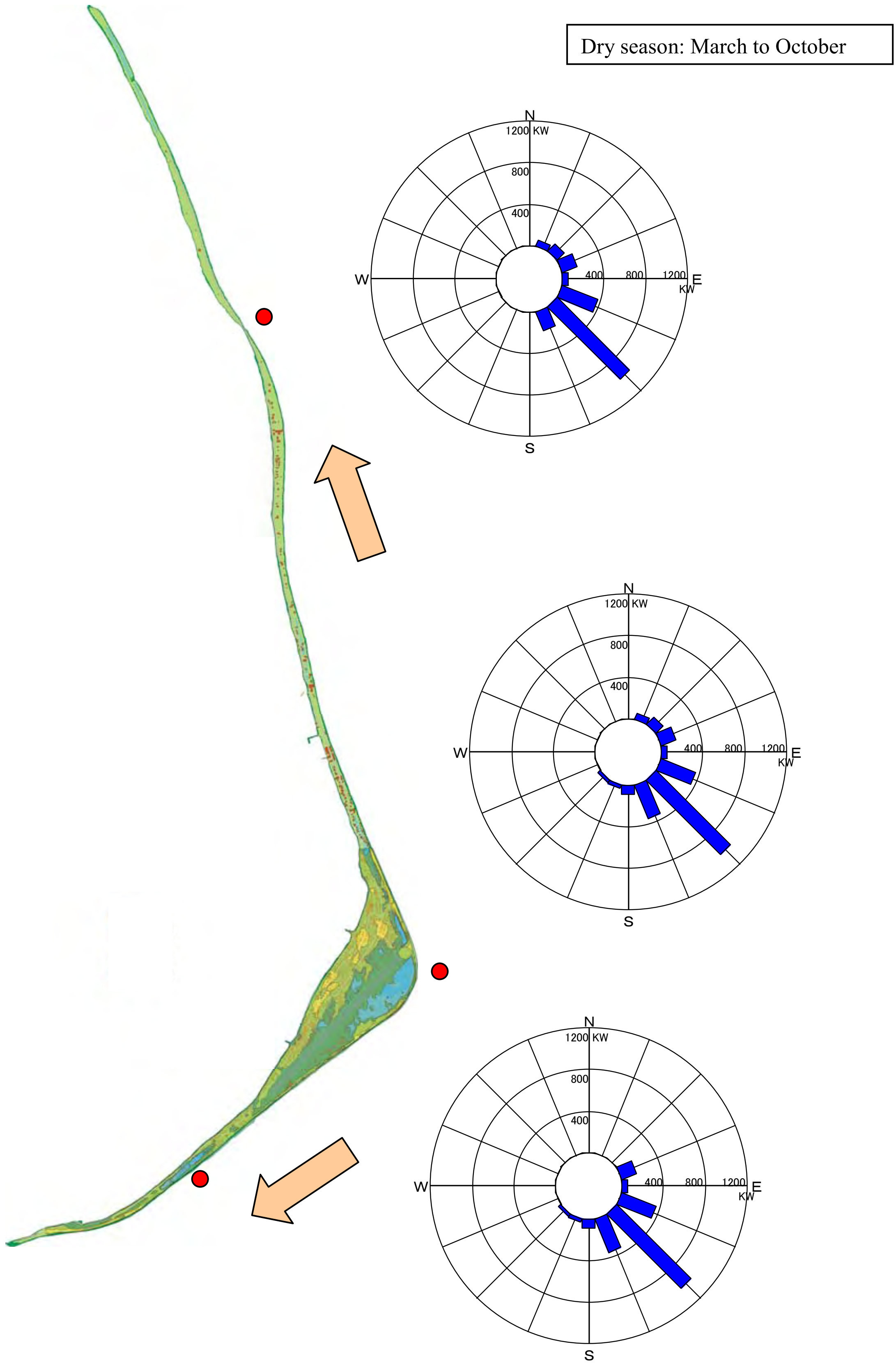


Figure 6.8 Distribution of Wave Energy Fluxes on the Ocean Side (Dry Season)

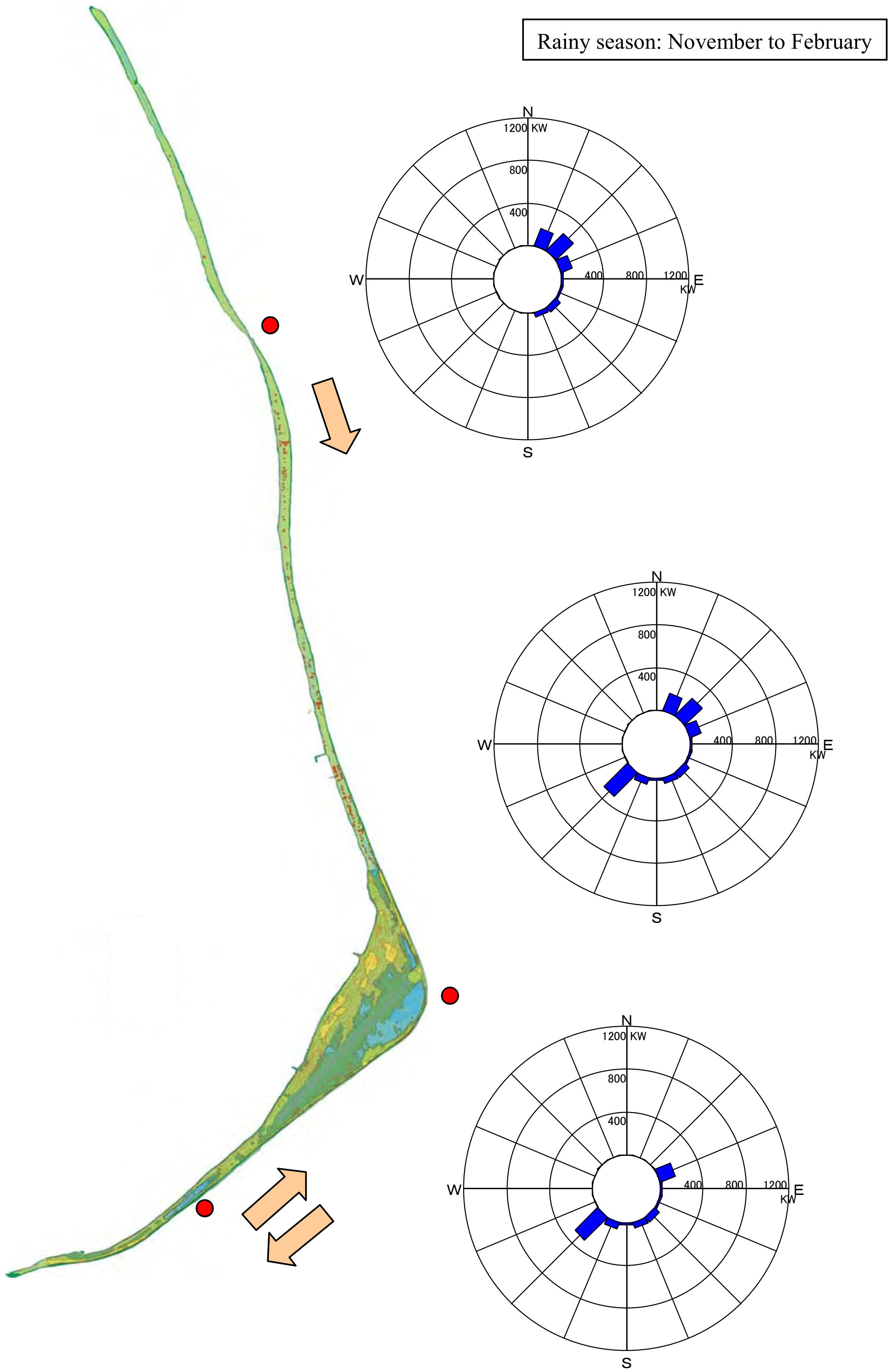


Figure 6.9 Distribution of Wave Energy Fluxes on the Ocean Side (Rainy Season)

6.2.2 Lagoon Side

Figure 6.10 shows a red circle that represents the observation point for wind data. Based on this data, wave prediction using the SMB method was conducted at the points marked in pink. **Figure 6.11** and **Figure 6.12** show the prediction results as the distribution of wave energy fluxes by direction in the dry and rainy seasons, respectively. From this data, it is estimated that, both in the dry and rainy seasons, Fongafale Islet is under the influence of external forces that cause sediment movement to the central part as indicated by the vectors in Figure 6.11 and Figure 6.12, and that the potential is higher in the rainy season than in the dry season.

However, the coast consists mainly of hard beach rocks and gravel, i.e., beach rocks crushed and washed ashore, except for a partial sand beach, and no part of the coast has significant erosion or deposition due to interruption of littoral drift by coastal structures, etc. Although there is a potential that can cause littoral drift, the amount of it is considered to be relatively small.

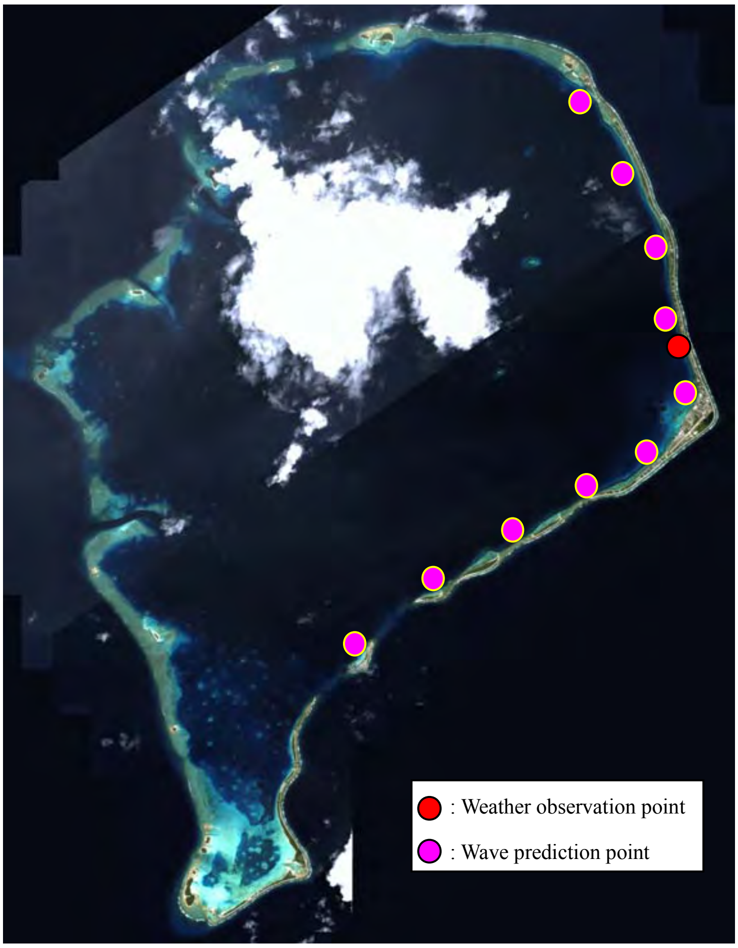


Figure 6.10 Wave Prediction Points on the Lagoon Side

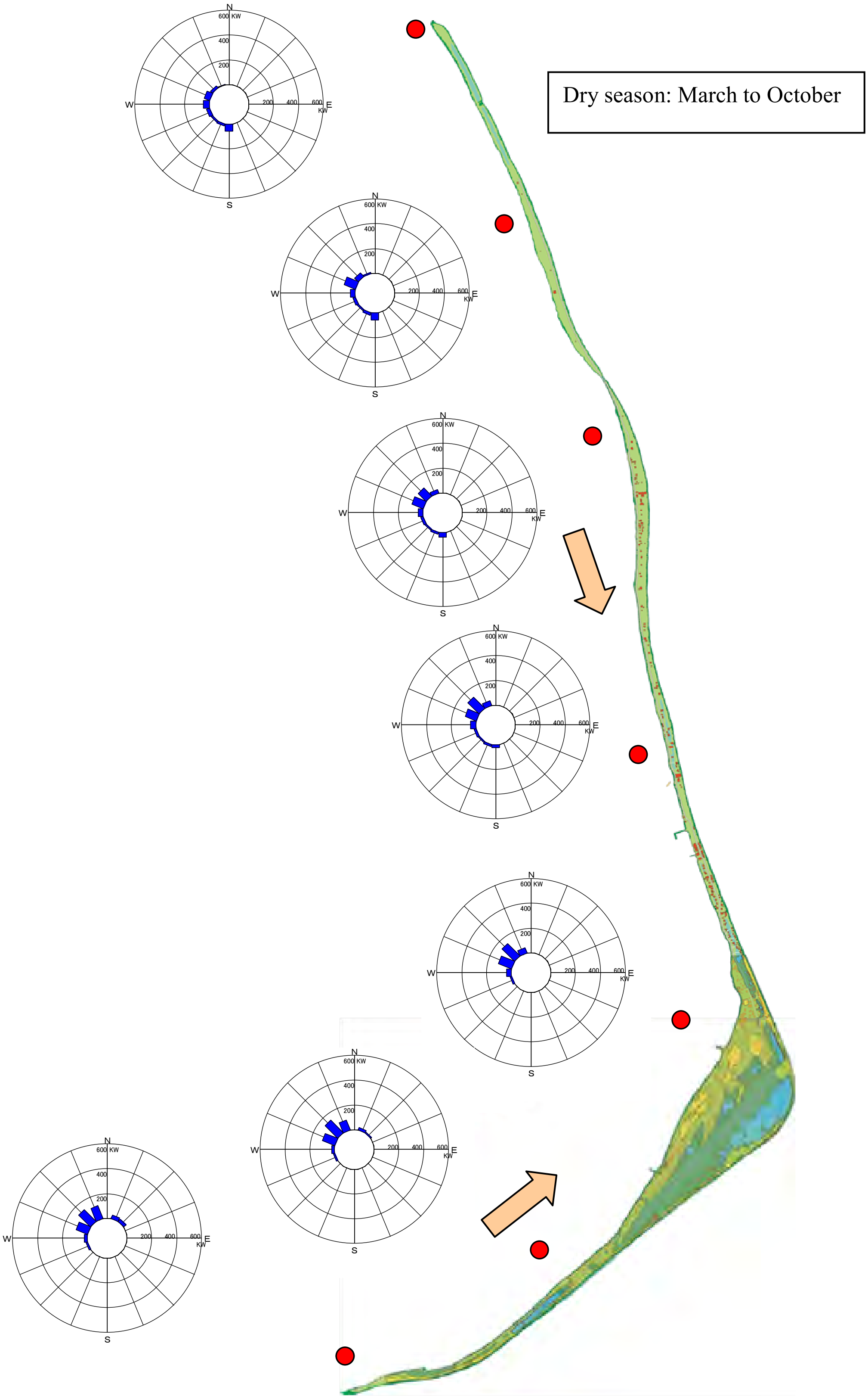


Figure 6.11 Distribution of Wave Energy Fluxes on the Lagoon Side (Dry Season)

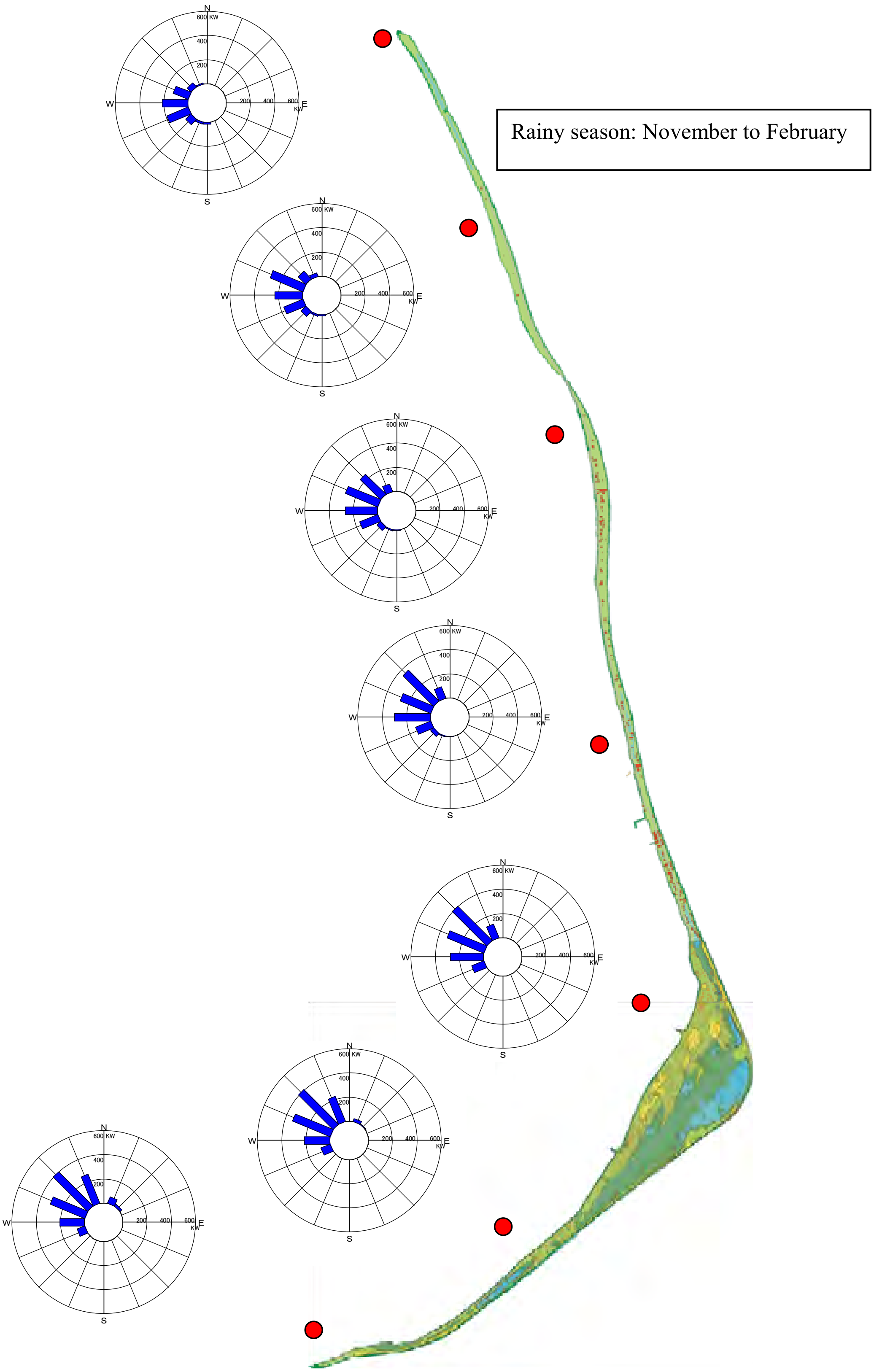


Figure 6.12 Distribution of Wave Energy Fluxes on the Lagoon Side (Rainy Season)

6.3 Amount of Littoral Drift

6.3.1 Lagoon Side

It is common to estimate the amount of littoral drift either based on the measured values of the amount of earth and sand deposited on the upstream side of a coastal structure and the amount of sediment deposited within the port, or estimate it using a drift estimation formula in which a wave energy flux is multiplied by the drift amount coefficient. However, it is difficult to estimate it from measured values in the study area because there are not as many structures as will influence the surrounding coast and no data is available to identify changes in topographical features near coastal structures. Moreover, it is difficult to apply the drift amount estimation formula. This is because, although the use of it requires setting of different drift amount coefficients according to the properties such as the grain sizes of bottom sediments, the bottom sediments in the study area consist mainly of beach rocks and gravel, generated when beach rocks were crushed, and the coefficients to be applied to them are still unknown. Moreover, there is little bottom sediment that moves as littoral drift.

Therefore, the wave energy flux in the coastal direction was estimated based on the wave data estimated on the lagoon side using the SMB method, and the amount of littoral drift was assessed as a potential that transports any bottom sediments that can be moved as littoral drift if available. Since the amount of littoral drift is proportional to the wave energy flux, the northernmost border in the rainy season is assumed as -1.0 to express it as a dimensionless parameter. Note that a negative value represents an amount of southward littoral drift.

Furthermore, the balances of dimensionless potentials of littoral drift were estimated for representative sections, and were assessed to find out if they were erosion conditions or deposition conditions. The results of estimation are provided in **Figure 6.13** and **Figure 6.14**.

Based on these results, it was deduced that, both in the dry and rainy seasons, there is a southward littoral drift from Tenkago Islet to the central part of Fongafale Islet, and the amount of it gradually increases as it approaches Funafuti Port. On the other hand, there is a northward littoral drift from the central part to the southernmost tip of Fongafale Islet, and the amount of it decreases as it goes south, and is larger in the rainy season than in the dry season.

As a result of sediment balance assessment, it was deduced that the central part of Fongafale Islet is under a deposition condition and other areas are under an erosion condition and that the influence is larger in the rainy season than in the dry season.

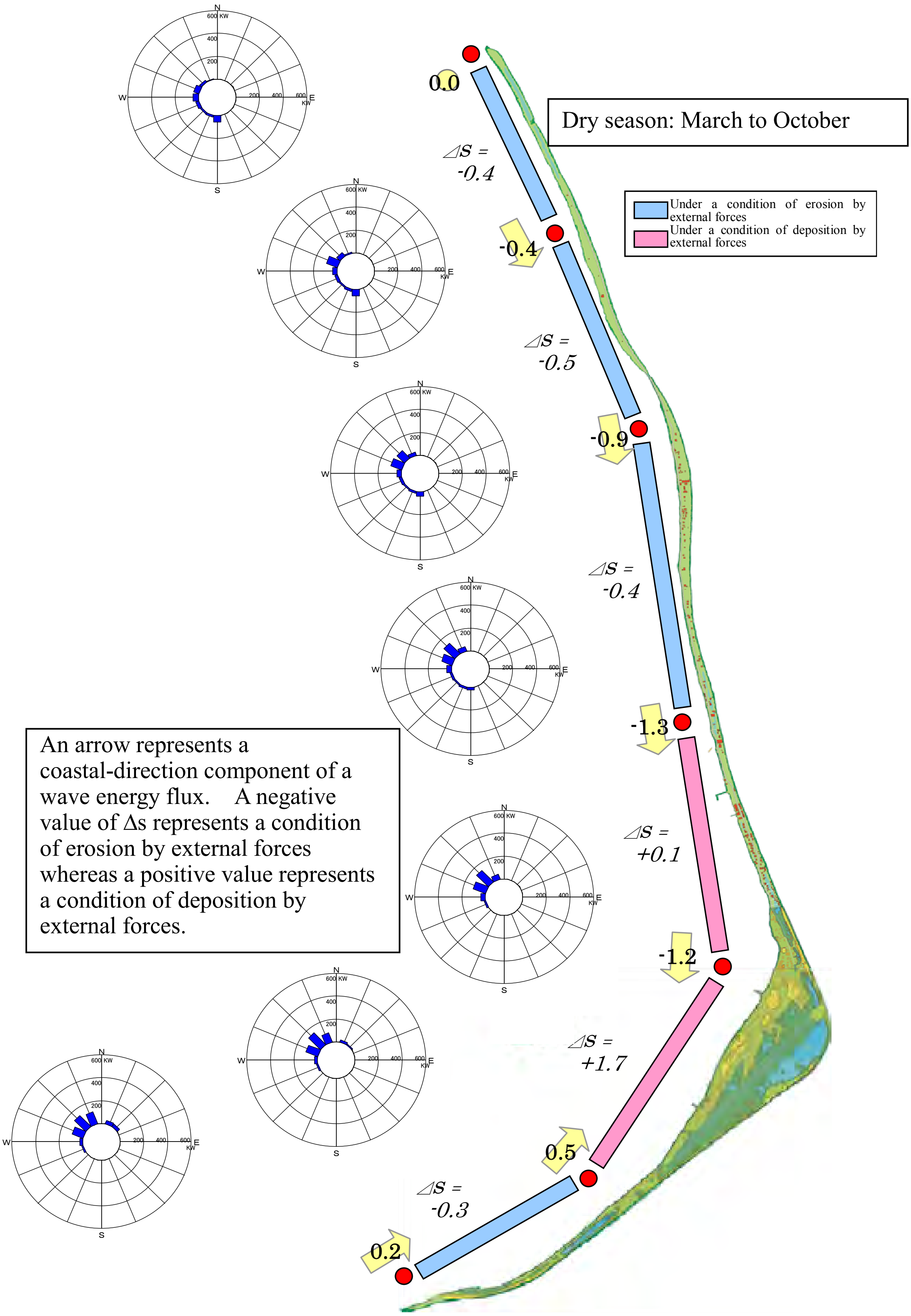


Figure 6.13 Sediment Balances on the Lagoon Side (Dry Season)

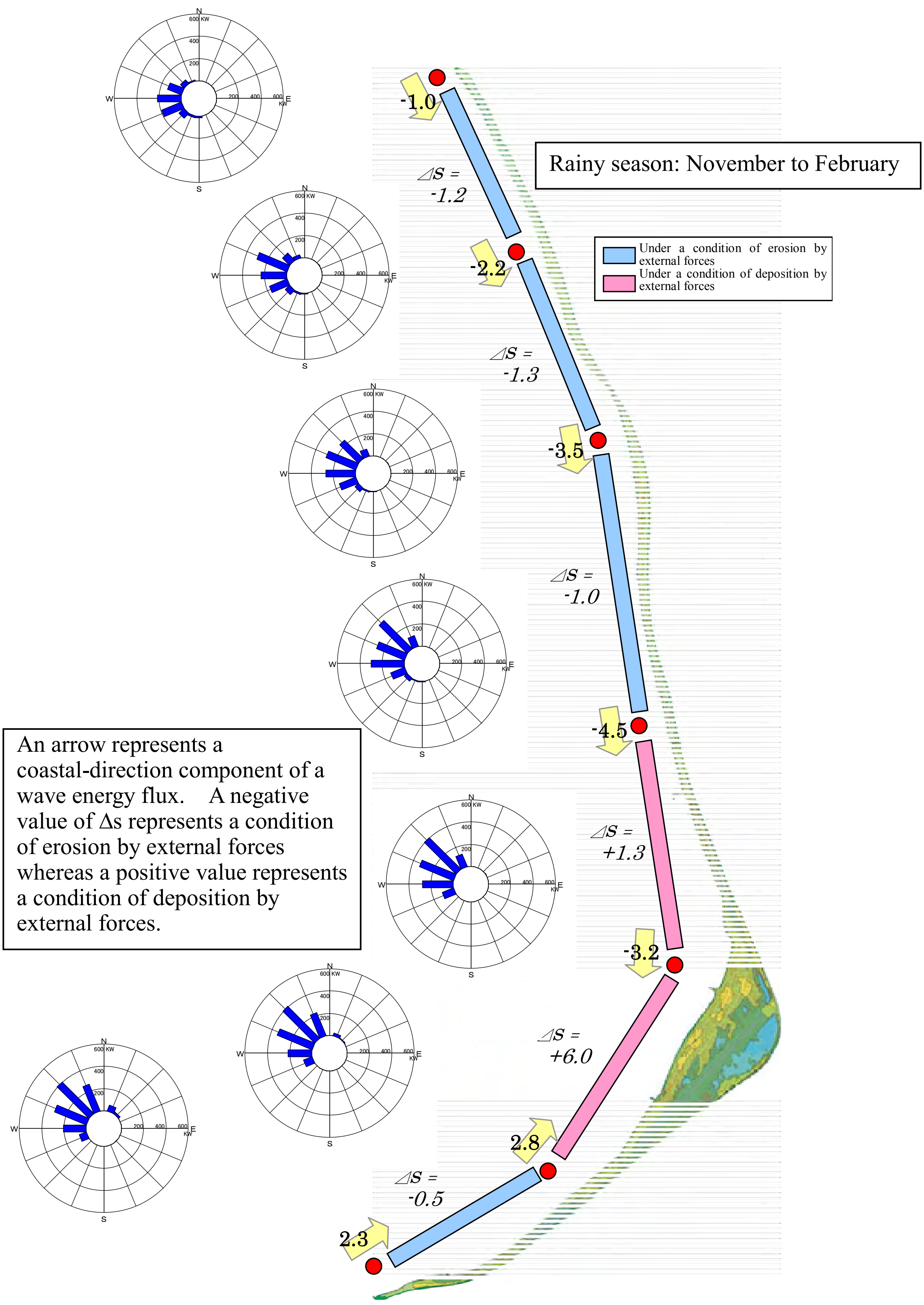


Figure 6.14 Sediment Balances on the Lagoon Side (Rainy Season)

6.3.2 Ocean Side

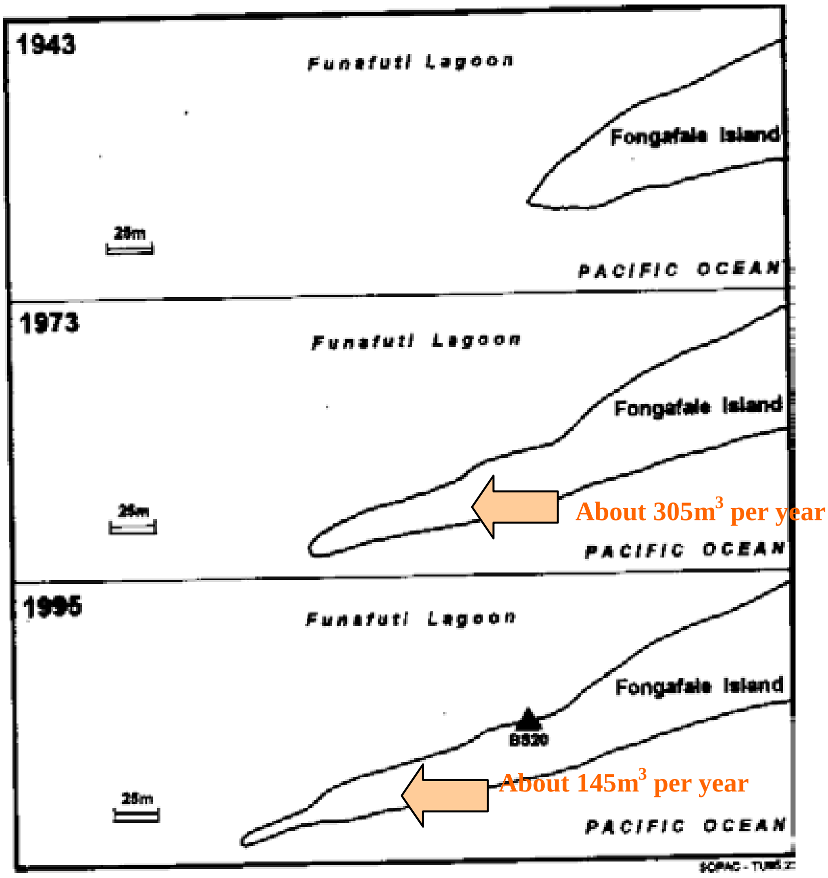
It is difficult to assess ocean-side waves based on wind data due to swells. Furthermore, it is deduced that the amount of littoral drift other than at the southernmost tip is small because there is no coastal structure on the ocean side, and no significant topographical change is observed except for the elongation of the southernmost tip of Fongafale Islet.

Therefore, it is assumed that significant littoral drift on the ocean side exists from the central part to the southernmost tip of Fongafale Islet. Furthermore, it was decided to estimate the amount of it based on the amount of growth of the spit.

Figure 6.15 shows the changes in the form of the spit on the southernmost tip of Fongafale Islet in 1943, 1973 and 1995. The earth and sand that constitute this spit seem to be supplied by ocean-side waves from the coast extending from the central part to the southern side of Fongafale Islet. Therefore, this is considered to be approximately equal to the amount of littoral drift in the southern part of Fongafale Islet on the ocean side.

The plane area of the southern tip in 1943, 1973 and 1995 is estimated to be about 4,557m^2, 8,215 m^2 and 9,486 m^2 from this map, respectively. Assuming that earth and sand are carried at a height of 2.5 m from the cross section diagram ○○, the amount of earth and sand deposited in 1943 to 1973 and 1973 to 1995 are, respectively, about (8,215-4,557)×2.5=9,145m^3 and (9,486-8,215)×2.5=3,177.5m^3. The annual amount of earth and sand, therefore, is about 305m^3 and 145m^3.

Next, comparing the satellite photograph from 2005 with the handy GPS measurement results taken on site in February 2010, it is estimated that the plan area is increased by about 1,185m2 from that in the diagram. Assuming the height of the sand moved was 2.5m, then the amount of sand deposited between 2005-2010 is about 2,960m3, which corresponds to 590m3 per year. Although there are problems of estimation accuracy, such as tide level correction, etc., it is estimated that the littoral drift on the ocean side of the south side of Fongafale Islet is in the order of several hundred m3 per annum.



Source: COASTAL SEDIMENTATION AND COASTAL MANAGEMENT OF FONGAFALE, FUNAFUTI ATOLL, TUVALU

Figure 6.15 Changes in the Spit on the Southernmost Tip of Fongafale Islet

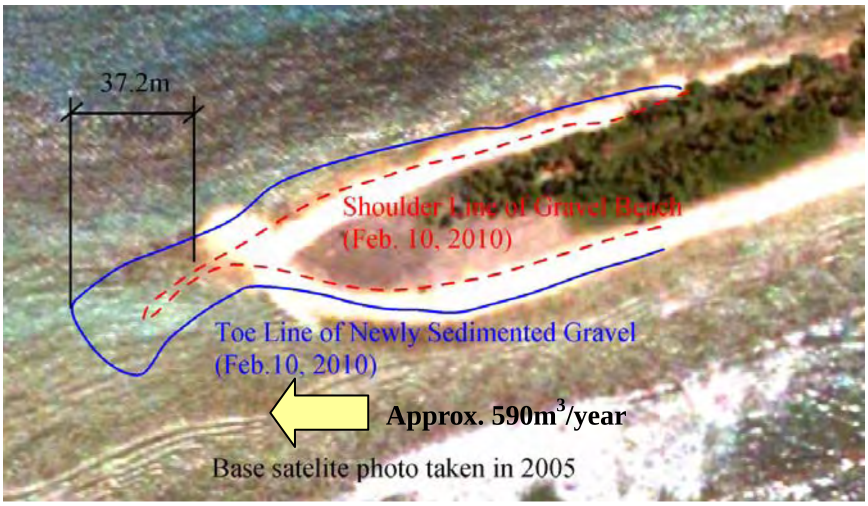


Figure 6.16 Extension due to Gravel Deposit on the Southernmost Tip of Fongafale Islet

(Comparison of satellite images of 2005 and Feb.10, 2010)

Source: SOPAC Technical Report 221 (Sept. 1995)

CHAPTER 7 A BASIC PLAN FOR ESTABLISHMENT OF A COASTAL PROTECTION AND REHABILITATION PLAN

7.1 Coastal Protection Areas and Coastal Protection Lines

7.1.1 Designation of Coastal Protection Areas

(1) Basic Policy on Selection of Coastal Protection Areas

When selecting areas for coastal conservation and a coastal protection line, priority was given to areas with important infrastructure (government offices, hospitals, schools, main roads and so on) in their hinterland and with high population density.

(2) Selection of Areas in Need of Measures

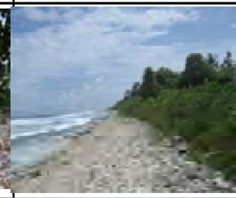
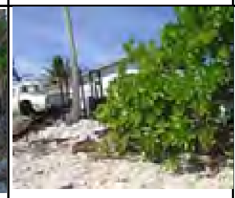
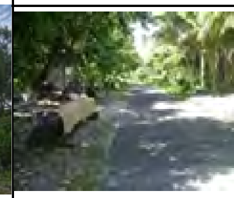
Areas in need of measures were selected by various means such as a field survey, results of a questionnaire on damage from coastal disasters, and the state of the hinterland. Moreover, areas for measures were narrowed down by conducting a wave overtopping fact-finding survey focusing on the areas where overtopping damage was reported in the questionnaire survey.

(3) Designation of Coastal Protection Areas

Coastal protection areas play a vital role in protecting the coastline from coastal disasters. So, initially, in order to establish coastal protection areas, the study area was divided into six areas, and various factors were ascertained such as the situation of the coastline, hinterland and coastal disasters in each area divided by into lagoon and ocean sides. This was undertaken based on the results of the field reconnaissance, questionnaire, and wave overtopping field survey. Then, based on these ascertained factors, the necessity of areas to be selected for coastal protection was investigated. The results are shown in **Table 7.1**.

Based on these results, the areas of coastal protection were selected as shown in Figure 7.1. The lagoon and ocean side coastlines in areas T and A, and the ocean side coastline in area D were excluded from coastal protection eligibility due to a lack of information on coastal disasters (wave overtopping and inundation) and the low population density.

Table 7.1 Conditions of Areas for Designation of Coastal Protection Areas

Target Area	Tengako Islet (T)		North Part in Lofeagai Area (A)		South Part in Lofeagai Area (B)		Fakai Fou Area (C)		Center Part in Fongafale (D)		Kavatoetoe Area (E)	
	Lagoon Side	Ocean Side	Lagoon Side	Ocean Side	Lagoon Side	Ocean Side	Lagoon Side	Ocean Side	Lagoon Side	Ocean Side	Lagoon Side	Ocean Side
Coast												
Hinterland												
	Note that this area has a road by northern rubbish disposal site but few houses.		Note that this area has a road between Tenkago and Fongafale Islets but few houses.		Houses are scattered across a road from the lagoon.		Houses continuously exist across a road from the lagoon. A road connects between Funafuti Port and the central part of Fongafale Islet.		Public facilities such as the government office buildings, schools, and hospitals are located next to the coast.	Public facilities and generating station are scattered across a road from the lagoon.	Houses are scattered across a road from the lagoon.	
Damage Conditions	Few notable damages (according to the questionnaire survey).	Few notable damage (according to the questionnaire survey). In part of storm ridge, the storm ridge is collapsing towards the borrow pit due to ocean waves.	Some inundation damage was reported according to the questionnaire survey but the field survey on wave overtopping did not confirrmed wave overtopping.	Few notable damage (according to the questionnaire survey).	Inundation and wave overtopping damage (according to the questionnaire survey). The field survey on wave overtopping also confirmed wave overtopping.	Inundation and wave overtopping damage (according to the questionnaire survey).	Inundation and wave overtopping damage (according to the questionnaire survey). The field survey on wave overtopping also confirmed wave overtopping at many places.	Inundation and wave overtopping damage (according to the questionnaire survey).	Inundation and wave overtopping damage (according to the questionnaire survey). The field survey on wave overtopping also confirmed wave overtopping at many places.	Few notable damage (according to the questionnaire survey).	Inundation and wave overtopping damage (according to the questionnaire survey). The field survey on wave overtopping also confirmed wave overtopping at some places.	Inundation and wave overtopping damage (according to the questionnaire survey).
Designation of Coastal Protection Areas	-	-	-	-	designate	designate	designate	designate	designate	-	designate	designate
Remarks	It is planned to backfill the borrow pit in EU project, so at present consideration of measures is outside the scope of this study.		As there are few houses and few notable damages, this area is omitted from designation of coastal protection areas.		These ares have in relatively large amount of house. Inundation and wave overtopping take place. These ares are designated as coastal protection areas.					As there are few houses and few notable damages, this area is omitted from designation of coastal protection areas.	Inundation and wave overtopping take place. These ares are designated as coastal protection areas.	

Areas for coastal protection on the lagoon side

Areas for coastal protection on the ocean side

In Japan, an area for coastal protection is determined to be within 50 m from the low-tide and high-tide coastal lines to the ocean and land sides, respectively. For the study area, however, an area for coastal protection should be up to the reef edge on the ocean and lagoon sides, and from the storm ridge or seawall line to a range as large as required for countermeasure works on the land side, in view of the complicated land ownership system.

Coastal lines in district T and district A, and coastal line on ocean side in district D are not designated as coastal protection area.

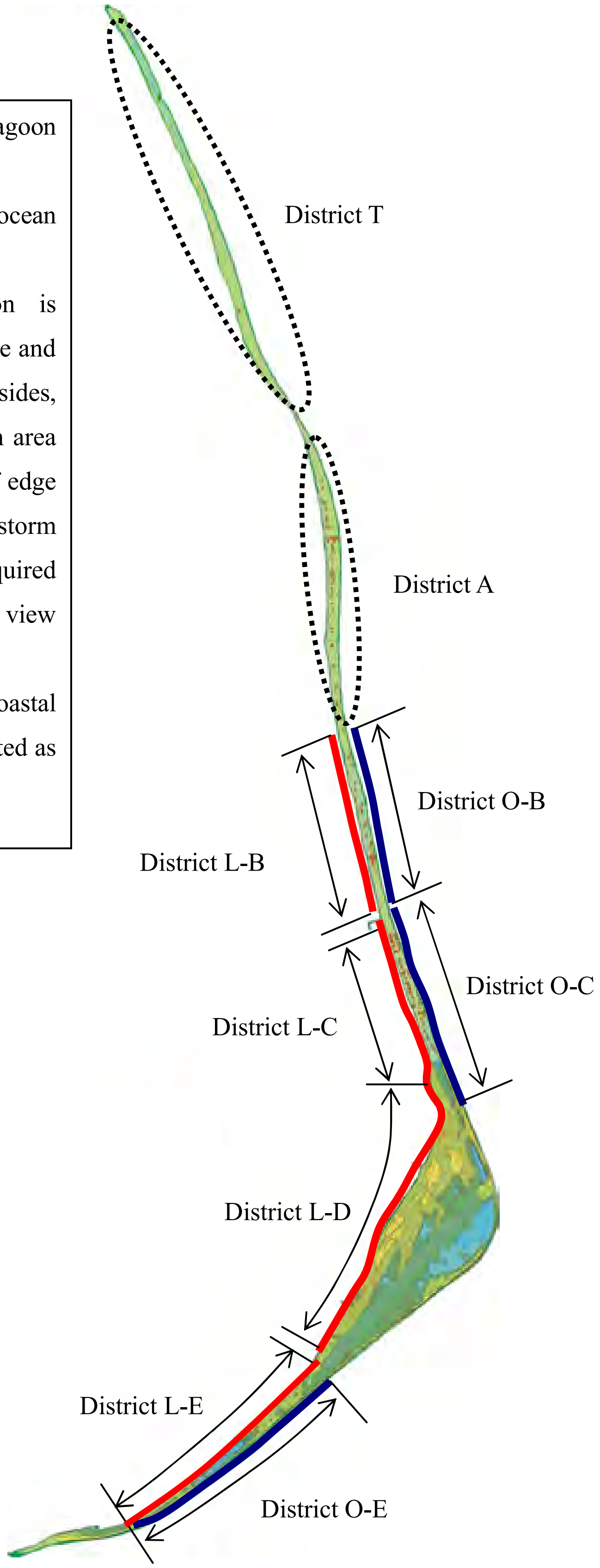


Figure 7.1 Designation of Areas for Coastal Protection

7.1.2 Designation of Coastal Protection Lines

(1) Policies for Designating the Defence Lines

It is necessary to determine the ocean-side boundary of a range in which lives and property should be protected from erosion and inundation, and define the positions of the normal line of seawalls and the target for erosion prevention. Therefore, the land boundary line to be protected is defined as a defence line. The defence line will be designated through examination of the topographical characteristics, land use of hinterland at present and in the future, use conditions of the coast, natural environment, etc.

(2) Designation of Defence Lines

Figure 7.2 shows the defence lines for two cases: One in which there is no structure on the coastal line and another in which there is a structure such as a seawall.

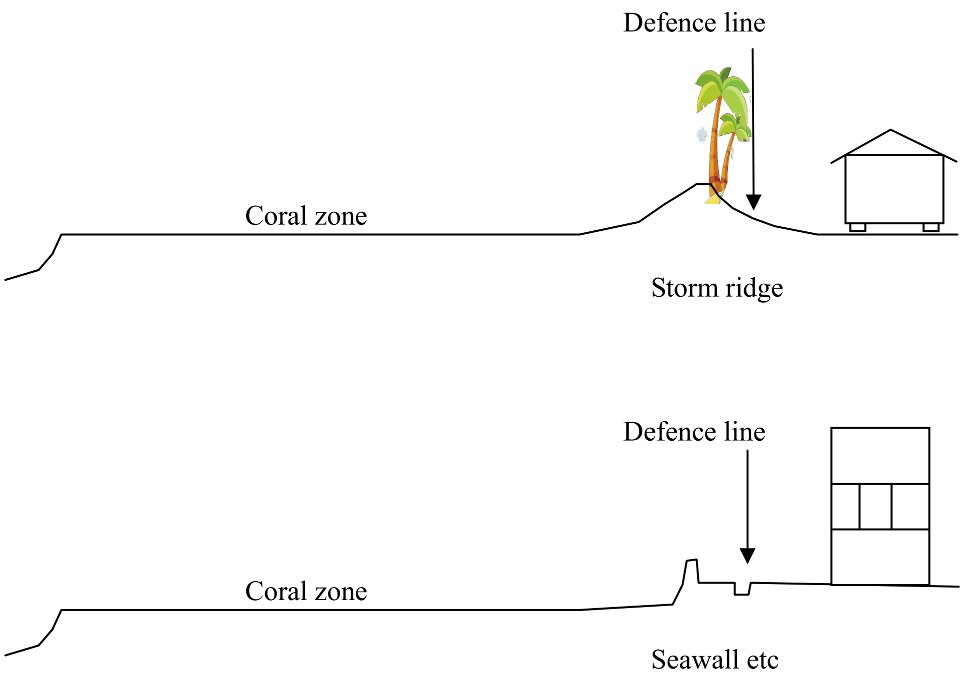


Figure 7.2 Designation of Defence Lines

7.1.3 Prioritization of Target Areas

The degree of urgency, ascertained from the level of damage, wave run-up height, and the state of the hinterland, is outlined in **Table 7.2**. As for level of priority, District L-D, in the center of Fongafale with important public facilities such as government agencies and schools, is of the highest priority, while District L-C, with the road that connects Funafuti port with central Fongafale, is the next highest.

Table 7.2 Prioritization by Degree of Urgency of Improvement

Area under consideration		Damage conditions Upper: Results of q+D14uestionnaire surveys Lower: Result of field surveys	Hinterland conditions	Priority	Degree of urgency
District A		Inundation damage (according to the questionnaire survey)	Houses are scattered across a road from the lagoon.	Low priority because there are few houses	Low
District B	District L-B Lagoon side	Inundation and wave overtopping damage Wave overtopping damage is moderate.	Houses are scattered across a road from the lagoon.	Relatively high priority because there is a road to schools and waste disposal site despite there are few houses	3
	District O-B Ocean side	Inundation and wave overtopping damage (according to the questionnaire survey)	Houses are scattered behind a storm ridge.	Low priority because there are few houses	4
District C	District L-C Lagoon side	Inundation and wave overtopping damage Wave overtopping damage is high.	Houses exist continuously across a road from the lagoon. A road connects between Funafuti Port and the central part of Fongafale Islet.	High priority because houses exist continuously and a road connects between Funafuti Port and the central part of Fongafale Islet	2
	District O-C Ocean side	Inundation and wave overtopping damage (according to the questionnaire survey)	Houses have been built by leveling off a storm ridge. Behind the houses, there is a pond created due to a borrow pit.	High possibility of wave overtopping disasters because people have moved in to dangerous places and house materials are taken from the storm ridge, almost inviting a disaster	3
District D	District L-D Lagoon side	Inundation and wave overtopping damage Wave overtopping damage is moderate.	Public facilities such as government offices, schools, and hospitals are located next to the coast.	High priority because there are important public facilities as described in the Basic Policies	1
District E	District L-E Lagoon side	Inundation and wave overtopping damage Wave overtopping damage is minor.	Houses are scattered across a road.	Low priority because there are few houses	4
	District O-E Ocean side	Inundation and wave overtopping damage (according to the questionnaire survey)	Houses are scattered behind a storm ridge.	Low priority because there are few houses	4

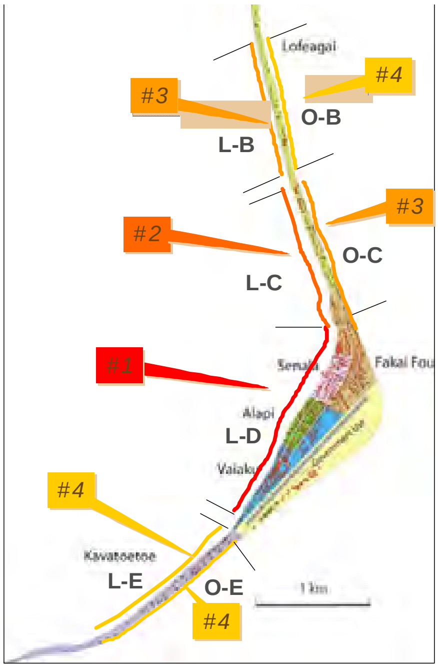


Figure 7.3 Target Area

7.2 Policy on Selection of Coastal Protection Measures and Comparison of Measures

7.2.1 Overseas Trends in Coastal Protection Measures

Each country undertakes coastal protection measures in light of their own specific circumstances such as their natural environment and history. Herein, some recent global trends in coastal management and examples of coastal protection measures from some leading industrialized countries will be given.

(1) Coastal protection measures in the USA

Coastal protection measures in the USA before the Second World War, as was the case in other countries, mainly involved structures such as breakwaters, revetments and seawalls. Since then, the function of seashores and beaches in protecting from disasters was reconsidered, leading to an understanding that measures that utilize their natural protective capacity are more economical and functional. **Figure 7.4** below shows how the US government's spending on coastal protection measures has changed from structures to beach nourishment since the 1960s, and that nourishment now accounts for approximately 90% of total actual cost.

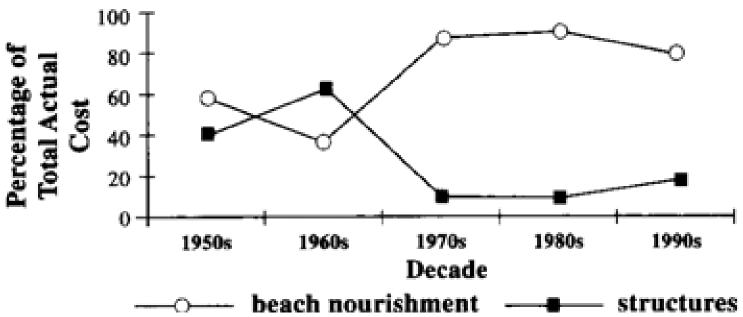


Figure 7.4 Change in Coastal Protection Measures in the USA

Source; Institute for Water Resources (1996): Analysis of the U. S. Army Corps of Engineers Shore Protection Program, IWR Rep. 96-PS-1.

(2) Coastal protection measures in the Netherlands

The Netherlands is a small country of which one quarter is below sea level and is surrounded by sand dunes along its coast. Coastal erosion measures before the 1980s consisted of the construction of structures such as storm surge barriers and dykes. Since then, with the publication in 1984 of a policy on assessing the safety of dunes (TAW: Guide to the assessment to the safety of dunes as a sea defense), the utility value of sand as a byproduct of dredging has increased and beach nourishment to protect the dunes has gained recognition.

(3) Coastal protection measures in Denmark

Denmark has an area, excluding Greenland, of approximately 44,000 km^2, which includes Zealand and Funen islands and the Jutland peninsular, with a total of 500 islands, 200 of which are inhabited. It has a total coastline of approximately 7,300 km. In particular, the central-western coast of the Jutland peninsular is experiencing severe erosion and it's coastal dunes and dykes need strengthening in order to protect from high tides and wave surges. Therefore, construction of artificial dunes and extending the beach in front of sand dunes with nourishment is being undertaken actively.

Coastal protection measures in Denmark, as can be seen in **Figure 7.5** below, consisted of breakwaters, revetments (dykes), artificial dunes and offshore breakwaters, however, since 1982 construction of hard structures has been decreasing and beach nourishment has been increasing.

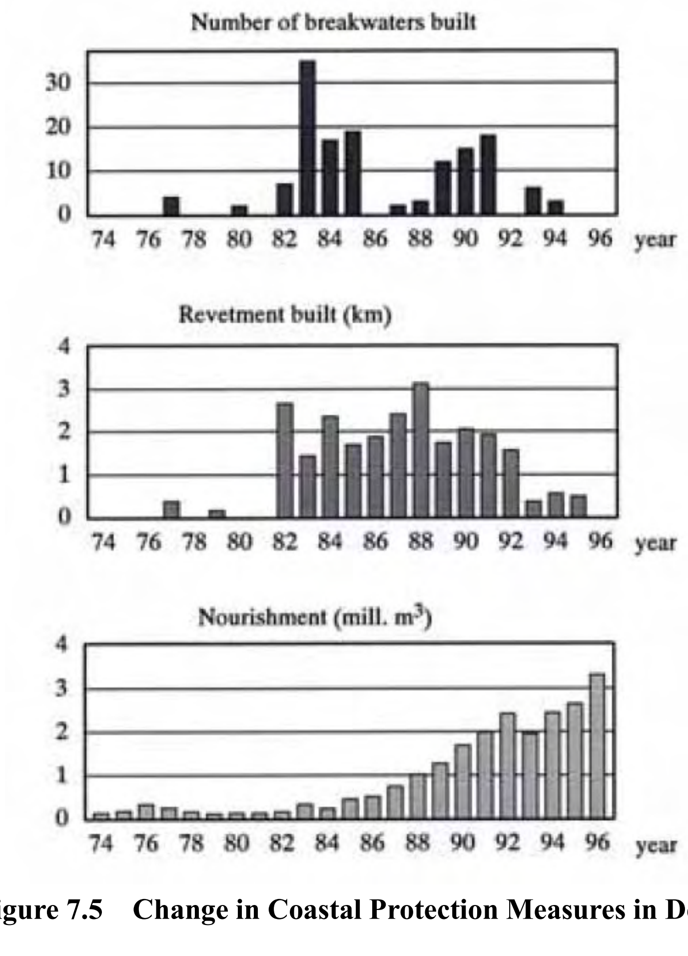


Figure 7.5 Change in Coastal Protection Measures in Denmark

Source; Christian Laustrup and Holger Toxvig Madsen (1998): Evaluation of the effect of 20 years of nourishment, Danish Coastal Authority.

(4) Trends in coastal management international society

Integrated Coastal Management (ICM) is a central concept for coastal and marine management on a national level, which gained much international attention as a result of the United Nations Conference on Environment and Development held in 1992. Chapter 17 of Agenda 21, which was adopted at this meeting, particularly emphasizes the necessity of new measures for the management of coastal and marine zones, with the following seven major programmes:

- Integrated management and sustainable development of coastal areas, including exclusive economic zones;
- Marine environmental protection;
- Sustainable use and conservation of marine living resources of the high seas;
- Sustainable use and conservation of marine living resources under national jurisdiction;
- Addressing critical uncertainties for the management of the marine environment and climate change;
- Strengthening international, including regional, cooperation and coordination;
- Sustainable development of small islands.

Although Agenda 21 outlines the necessity of ICM and directions for programmers, it lacks, however, as with other treaties and protocols, a definition of the ICM concept and a concrete discussion on its implementation.

After this, at the same time as accumulating practical experience and research regarding coastal management, there was an increased concern over the long-term effect of sea level rise and climatic change on the coastal zone. With this as a backdrop, an international meeting, the International Workshop: Planning for Climate Change through Integrated Coastal Management was held in 1997 in Taiwan. This meeting pushed strongly for ICM as a measure against the long-term effects of sea level rise and climate change on the coastal zone; and considered this concept and the issues and experiences of each country; and resulted in the formation of an ICM guideline.

This resulted in the following ICM principles regarding the field of coastal protection (measures for coastal erosion and high tides), and these can be considered to be the latest guidelines agreed upon by the international community.

- Because there is a high mobility and interdependency in the resource system of coastal zones, applying traditional land-based management methods is inappropriate.
- Coastal geomorphology (sand dunes, seashore, mangroves, coral reefs and so on), contributing to long term sustainability, and with its role as a buffer zone against erosion and sea level rise, need to be conserved and protected. For this, it is important to understand the natural processes of the ecosystems, and to maintain the resistance of these

geomorphologies and ecosystems.

- Design according to natural principles should be adopted.
- Inhibition of natural sand drift movements should be minimized.
- Possibilities for potential competition should be clarified at an early stage, and equitable solutions should be explored through policy to strengthen and protect the coast's public nature. The participation of communities adjacent to the coastal zone is important in all of the processes (planning, implementation, monitoring, and evaluation) of Integrated Coastal Management.

As mentioned earlier, recent international trends in coastal protection measures are changing from hard coastal structures such as breakwaters, revetments and dykes, to nourishment measures. This shift to nourishment can be considered in line with the abovementioned ICM principles, "protect coastal geomorphology," "design according to natural principles," and "minimize inhibitions to natural sand drift movements."

7.2.2 Analysis of the Occurrence of Coastal Disaster and Its Measure

The cause analysis of coastal disaster, which the residents of Fogafare islands are facing coastal disaster, is shown as **Figure 7.6**.
According to the research result, possible main coastal disaster in Fogafare island in the future, which might be tidal waves involving Hurricane caused by low pressure except Tsunami.
According to actual and questionnaires survey, flood damage in the different parts of the island caused by astronomical tide every year periodically and the damage caused by coastal erosion are rarely met. As previously explained, the vulnerability of the residents of Fogafare islands by the tidal waves is the following causes.

1. Expanding of the residential areas to the coastal areas: Although local residents lived in relatively high places at the lagoon side before world war□, they are presently living almost all parts of the island except around air-field at the center of island and governmental sites at ocean side areas.
2. Wave absorbing function was lost by the mass excavation of dune, sea sand, gravels on shallow areas, and corals and the collapse of simple landfill protection areas for military ships on the lagoon side by U.S military forces during world war□.
3. Behaviors involving the collapse of storm-ridge by excavation of the gravels on the ocean side and vegetation trimming to reduce the absorbing function of ocean wave have been frequently occurred.

Also, regarding countermeasure against coastal disaster in Tuvalu, solution analysis was conducted based on the causes analysis in **Figure 7.6**. As implemented soft components, the following factors were listed (referring to **Figure 7.7**).

① Countermeasure for illegal harvesting and implementation of planting design
② Implementation of countermeasure for illegal gravel excavation
③ Operation for countermeasure for residents in the dangerous areas (development of hazardous map)
④ Operation for awareness about source of the occurrence and safety countermeasures for coastal disaster

These soft components would be significant due to linking to the reduction of coastal disaster.

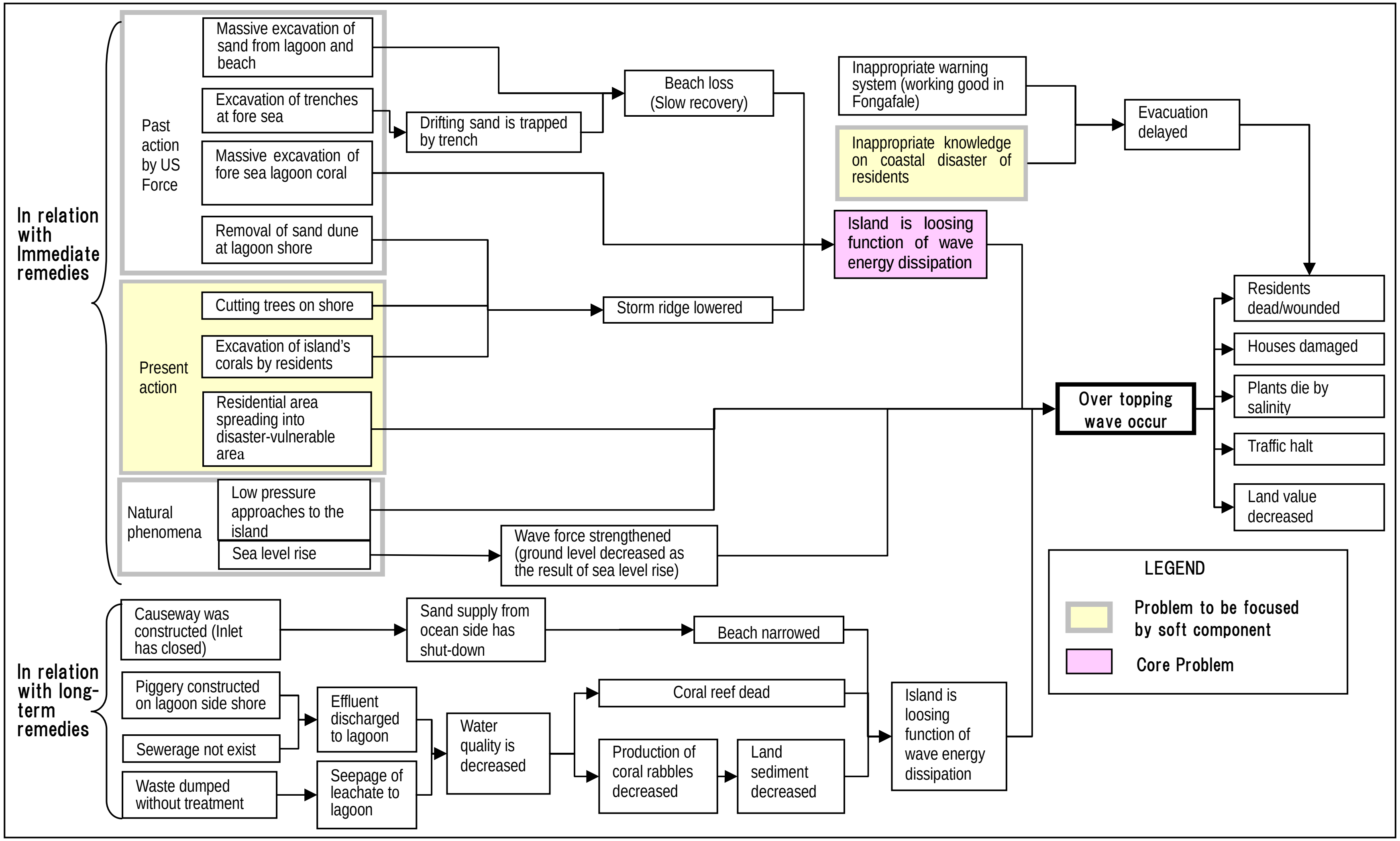


Figure 7.6 Problem Tree of Over-Topping Wave on Fongafale Island

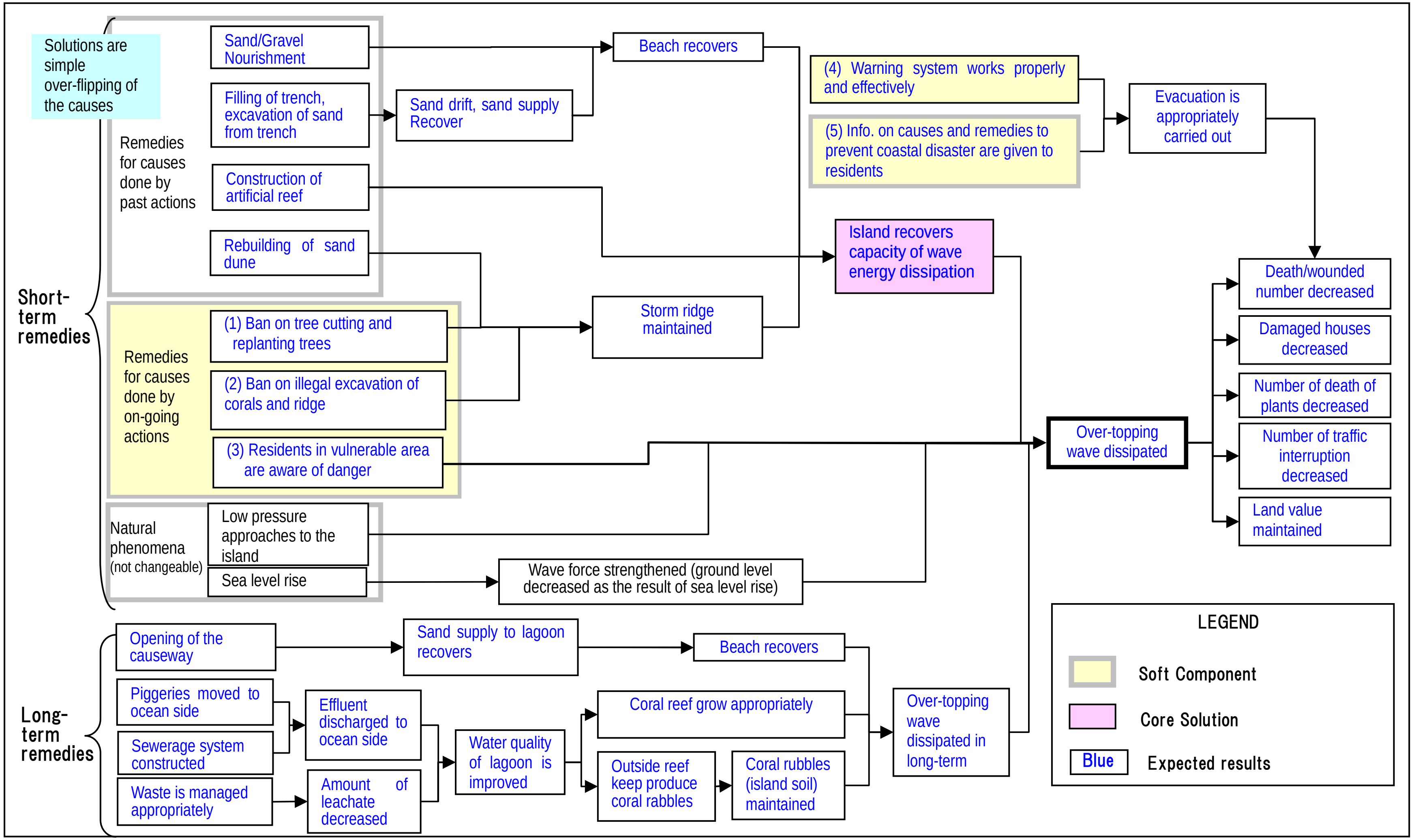


Figure 7.7 Solution Tree of Over-Topping Wave on Fongafale Island

7.2.3 Policy on Selection of Coastal Protection Measures in Tuvalu

(1) Basic policies for selecting protection works

Selection of measures in the target areas, while based on these results, is according to the following policies:

- The coastal protection measures shall be in accordance with traditional scenery of the Islet.
- The coastal protection measures shall promote the accretion of sand, while keeping to a minimum anthropogenic barriers to drift sand, with the aim of rehabilitating the coastline.
- The coastal protection measures shall take into consideration the area's natural environment, and local resident's use of the coastal area and of boats.
- In order to minimize the coastal disaster, non-structural measures that the residents work voluntarily shall be introduced as well as structural measures.

(2) Comparison of protection measures

At present, wave overtopping is the main cause of coastal disasters in the target area. Basically, there are three types of works to prevent wave overtopping: 1) offshore breakwaters, 2) seawalls, and 3) sand nourishment. **Table 7.3** gives a comparison of these protection works considered to be applicable in Tuvalu. As a result, this Study is to adopt beach nourishment of coarse grained gravel—particularly on the lagoon coastline where wave overtopping is common—as it can be expected to be effective as an emergency, short-term measure, and further, as it will contribute to the long-term countermeasures (beach rehabilitation) being promoted by the JICA-JST Science and Technology Research Partnership for Sustainable Development project for Eco-technological Management of Tuvalu against Sea Level Rise (hereinafter Foram Sand Project). Reasons for adopting these countermeasures are herein explained.

As can be seen in **Photo 7.1**, there are few sandy beaches on the lagoon side in the middle part of Fongafale Islet, however, the beaches are composed of gravel at a gradient from 1:4 to 1:6 on the shoreward side, and on the lagoon side the sand is deposited at a gradient of 1:12, namely it is a composite cross-section. Gravel deposited near the shore has a characteristic of being washed up landward during high wave action (Matsuura *et al.,* 2009), therefore, it functions similarly to a seawall. Further, in the case of gravel nourishment at Jinkouji coastline, Ibaragi Prefecture, Japan, it was reported that the nourished gravel—ø3-15 mm diameter, gradient of 1:6, in front of a seawall—has remained stable and sand has been accreting (**Photos 7.2, 7.3, 7.4**). The state of gravel deposition there is the same as that seen in **Photo 7.1** This shows that nourishment (coarse material nourishment) using gravel (beach rock and coral fragments) would also be effective in the target area. The advantages of this kind of gravel is that it would not be washed out into the lagoon and is easier than sand to obtain in Tuvalu.

Photo 7.1 Beach on Fongafale Islet's Lagoon Side

(High tide shoreline is gravel of 1:4 to 1:6 gradient, below which is a fine-sand beach of 1:12 gradient)

On the other hand, the ocean side coastline has very few structures to prevent coastal erosion compared to the lagoon side. Therefore, the storm ridge, made up of coral gravel, plays an extremely vital role against waves from the ocean. However, as mentioned in 5.5, ocean wave overtopping disasters are largely due to the residents in the hinterland cutting down vegetation growing near the storm ridge to expand the area of usable flat land and cutting away at the storm ridge to use the gravel for construction. As such, the main measures are to repair the storm ridge where it is low, and to restrict the removal of gravel and cutting of vegetation near the ridge.

Photo 7.2 Before Work on Jinkouji Beach (8 September, 2002)

Source: Public Works Research Center in Japan

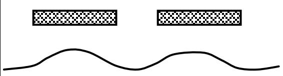
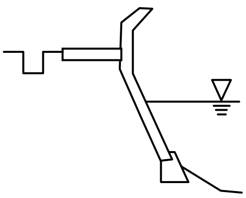
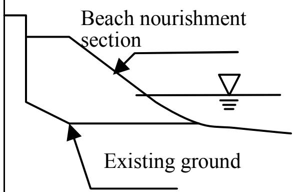
Photo 7.3 Two Months Later Work on Jinkouji Beach (5 June, 2008)

Source: Public Works Research Center in Japan

Photo 7.4 One Year Later Work on Jinkouji Beach (26 June, 2009)

Source: Public Works Research Center in Japan

Table 7.3 Result of Comparison of Coastal Protection Measures

Erosion control method (Schematic diagram)	Example (Image)	Characteristics of method in Tuvalu		
		Advantage	Disadvantage	Judgment
Offshore breakwater (plan view) 		- Control of wave overtopping through reduction of waves is expected. - Creates a quiet region behind it where sediment can be accumulated and maintained.	- Accumulation of sediment from the surroundings may result in erosion in the surrounding coasts, accumulation of waste, or deterioration of water quality. - Obstruction of coastal landscape	It is impractical to apply this method because installation of breakwaters would be required along the entire length of the coastal line. ×
Seawall (section view) 		- Direct effects against wave overtopping can be expected.	- May cause offshore transport of bottom sediments due to reflected waves, resulting in scouring in front of the facility and causing the sand beach to disappear. - May interfere with future regeneration of sand beaches with a supply of earth and sand. - The view and access from the land to the sea is obstructed.	This method will interfere with the regeneration of sand beaches under the Foram Sand Project. ×
Gravel beach nourishment (cross section) 		- There is little influence on the surrounding coast. - There is no hindrance to future regeneration of beaches with a supply of earth and sand.	- There is a need for auxiliary facilities in order to maintain the design section due to littoral movement of earth and sand. - Gravel may be washed up on beaches during storms.	This method is considered applicable with a limited number of auxiliary facilities, which would not interfere with the regeneration of sand beaches under the Foram Sand Project. ○

7.3 Basic Policy for the Coastal Protection and Regeneration Project

7.3.1 Project Objectives

The coastal protection and regeneration project formulated in this study comprises a short-term emergency project for preventing coastal erosion and a seashore improvement project aiming at the prevention of wave overtopping disasters caused by ten-year wave equivalents. The completion of the project is scheduled for 2020. In addition, this project is expected to enhance the long-term measures being implemented under the Foram Sand Project such as beach regeneration by alleviating the negative impact of factors adversely affecting the perpetual process of islet formation and maintenance.

7.3.2 Basic Policy for Project Implementation

In order to establish a sustainable coastal management system with a long-term perspective, including an evaluation of the effects of this project and a review of its planning, the basic policy of the project is implementation based on the adaptive management (PDCA) cycle shown in **Figure 7.8**.

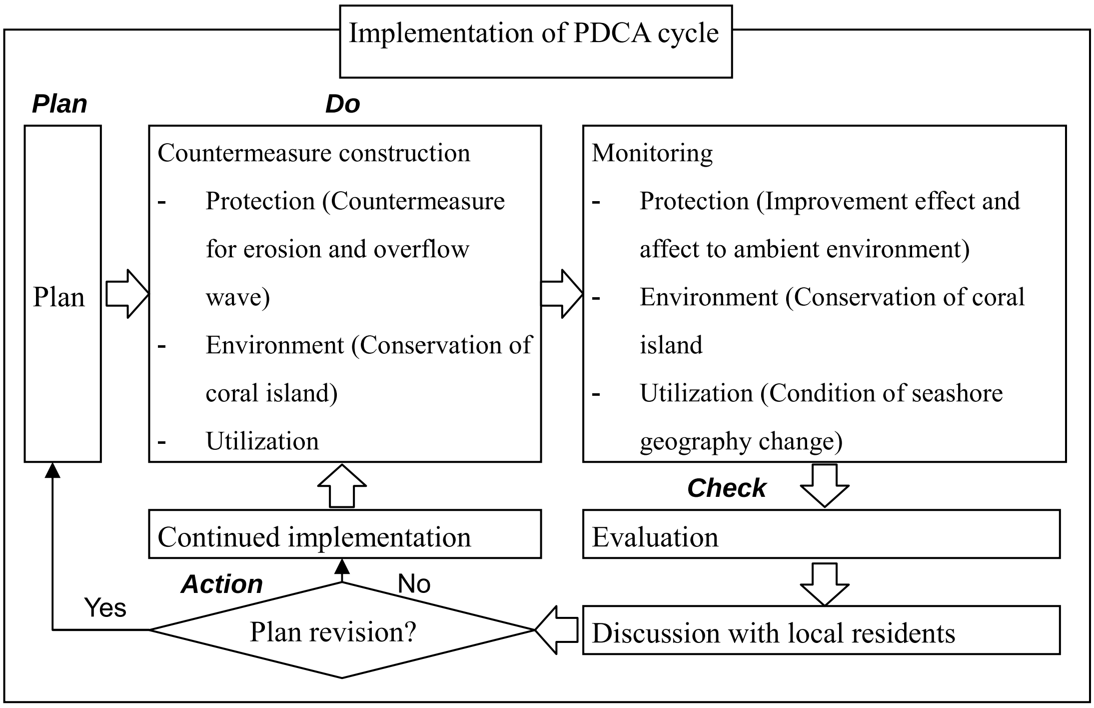


Figure 7.8 Schematic Diagram of Sustainable Coastal Protection and Regeneration using the Adaptive Management (PDCA) Cycle

7.3.3 Strategy for Each Area

The strategy for each area described in **Table 7.4** has been developed on the basis of the extent of coastal disasters and urgency required for coastal protection measures in each area shown in **Table 7.2.**

In short, both structural and non-structural measures will be implemented to prevent wave overtopping in areas with an urgency level of 1 to 3, while only non-structural measures will be implemented in the areas with an urgency level 4 or lower. Back-filling of coastal borrow pits, which is proposed as a countermeasure in areas with an urgency level 1 and 2 , is included in the plan because the back-filling is expected to enhance the effects described below. These coastal borrow pits were created when the US Armed Forces excavated earth and sand from reef flats on and off shore for the construction of a military base and airstrip during World War II.

1. Reduction of wave energy (enhancement of wave absorbing effect)
2. Facilitation of littoral movement and sedimentation of sand (At present, because of the coastal borrow pits, an offshore current can develop, which tends to transport sand offshore. The back-filling will create a littoral flow of sand and facilitate sedimentation of sand along the coast line.)

Hard countermeasures planned for wave overtopping on the ocean side are to repair the storm ridge where it is low (raising the crown height by stacking up rocks). Meanwhile soft countermeasures will mostly be activities to educate the local residents about causes of coastal disasters, illegal removal and excavation of gravel, and illegal cutting down of vegetation so as to prevent anthropogenic obstruction of natural processes that form the storm ridge (compaction of the storm ridge by vegetation and coral gravel wash-up). Moreover, repair of the storm ridge is relatively easy, and it can be sufficiently undertaken by the Tuvaluan side (PWD, Kaupule, residents).

Table 7.4 Strategy for Coastal Protection Measures in Each Area

Area under consideration		Priority	Degree of urgency	Coastal protection measures Upper: Structural measures Lower: Non-structural measures
District B	District L-B Lagoon side	Relatively high priority because there is a road to schools and waste disposal site despite there are few houses	3	･Partial restoration of the storm ridges (Raising of the storm ridges)
				･Regulatory measures against the illegal collection and excavation of gravel ･Regulatory measures against the illegal felling of vegetation ･Educational activities on the causes of coastal disasters and coastal protection measures
	District O-B Ocean side	Low priority because there are few houses	4	･Without facility-based measures
				･Regulatory measures against the illegal collection and excavation of gravel ･Regulatory measures against the illegal felling of vegetation ･Educational activities on the causes of coastal disasters and coastal protection measures
District C	District L-C Lagoon side	High priority because houses exist continuously and a road connects between Funafuti Port and the central part of Fongafale Islet	2	･Raising of the storm ridges or Gravel beach nourishment ･Back-filling of castal borrow pits
				･Regulatory measures against the illegal collection and excavation of gravel ･Regulatory measures against the illegal felling of vegetation ･Educational activities on the causes of coastal disasters and coastal protection measures
	District O-C Ocean side	High possibility of wave overtopping disasters because people have moved in to dangerous places and house materials are taken from the storm ridge, almost inviting a disaster	3	･Raising of the storm ridges
				･Regulatory measures against the illegal collection and excavation of gravel ･Regulatory measures against the illegal felling of vegetation ･Educational activities on the causes of coastal disasters and coastal protection measures
District D	District L-D Lagoon side	High priority because there are important public facilities as described in the Basic Policies	1	･Gravel beach nourishment ･Back-filling of coastal borrow pits ･Planting
				･Regulatory measures against the illegal collection and excavation of gravel ･Regulatory measures against the illegal felling of vegetation ･Educational activities on the causes of coastal disasters and coastal protection measures
District E	District L-E Lagoon side	Low priority because there are few houses	4	･Without facility-based measures
				･Regulatory measures against the illegal collection and excavation of gravel ･Regulatory measures against the illegal felling of vegetation ･Educational activities on the causes of coastal disasters and coastal protection measures
	District O-E Ocean side	Low priority because there are few houses	4	･Without facility-based measures
				･Regulatory measures against the illegal collection and excavation of gravel ･Regulatory measures against the illegal felling of vegetation ･Educational activities on the causes of coastal disasters and coastal protection measures

7.4 Plan Basic Design of Coastal Protection Facilities

7.4.1 Flow Diagram for the Consideration of Measures

Below is examined a standard section of gravel beach nourishment in District L-D and L-C with high priority. District L-D has the highest priority because of the existence of important public facilities such as government offices and schools located in the central part of Fongafale Islet. District L-C, with the road that connects Funafuti port with central Fongafale, is the next highest. **Figure 7.9** shows the process for the examination of a standard section of gravel beach nourishment.

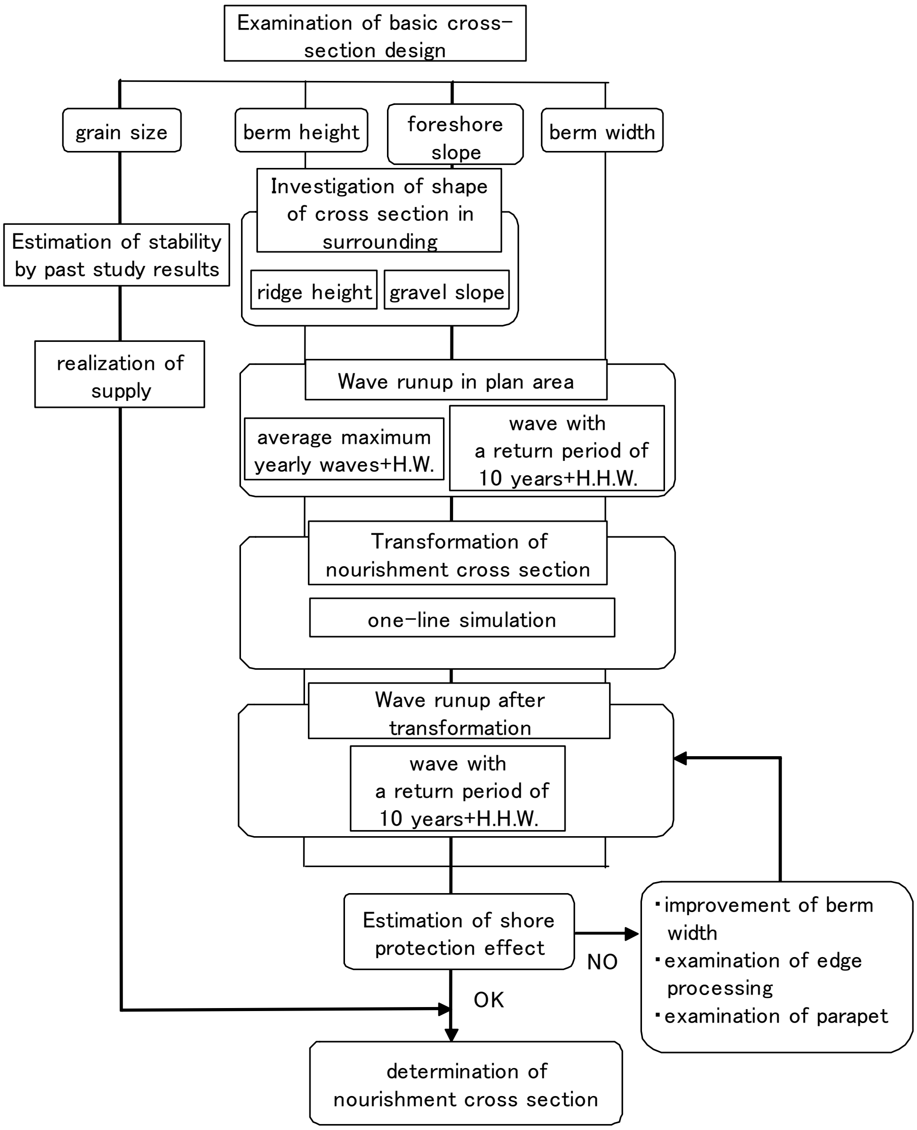


Figure 7.9 Flow Diagram for the Examination of a Standard Section of Gravel Beach Nourishment

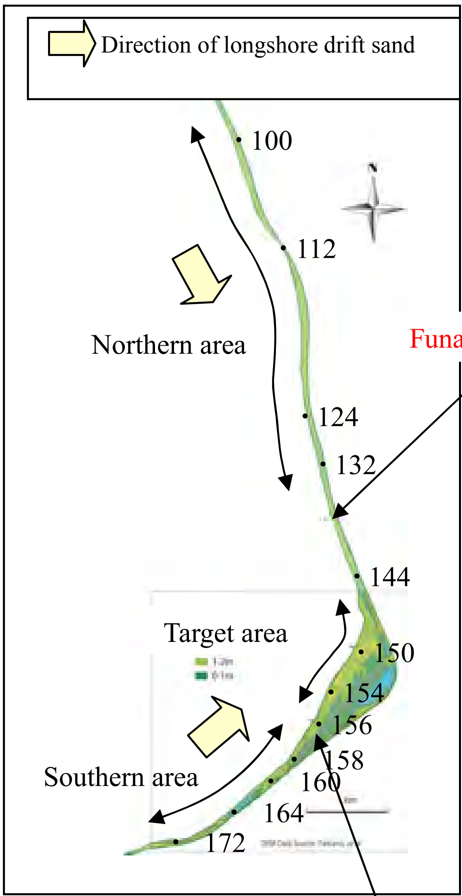


Figure 7.10 Area Map

Figure 7.11 Target Area

(1) Cross-sectional function of the coast around the target area

1) Northern area

Figure 7.12 shows the ridge height distribution. It is between 3.9 m and 4.9 m above chart datum level (CDL), 4.3 m on average. **Figure 7.13** shows a coral gravel gradient of between 1:3.5 and 1:4.5 in the northern end, and between 1:3 and 1:4 in the southern end.

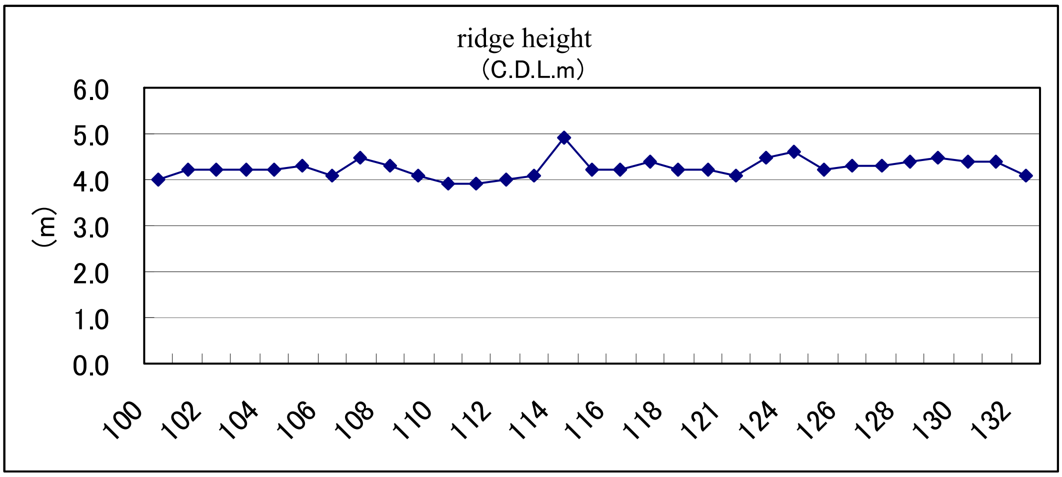


Figure 7.12 Distribution of Ridge Height

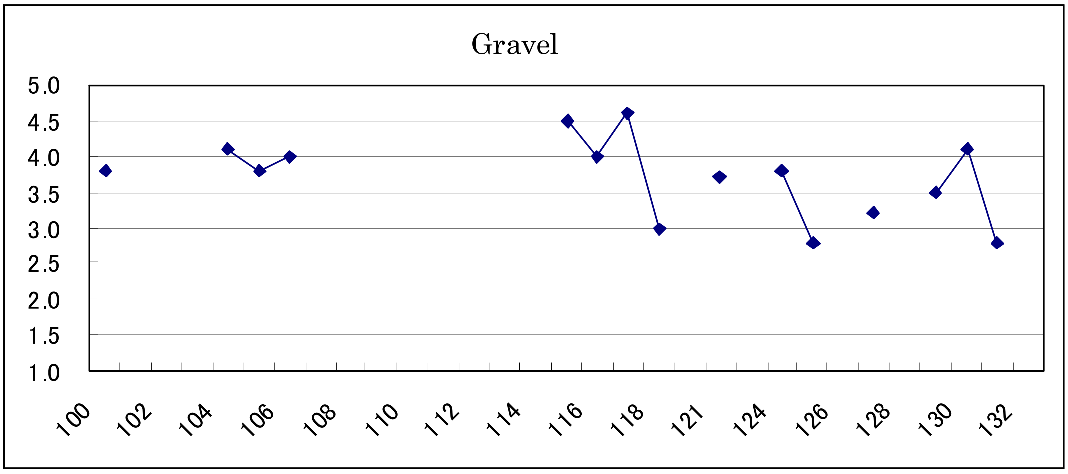


Figure 7.13 Distribution of Coral Gravel Gradient

2) Southern area

Figure 7.14 shows the ridge height distribution. It is between 3.7 m and 4.7 m above chart datum level (CDL), 4.1 m on average. The coral gravel gradient in **Figure 7.15** is roughly 1:4 on average.

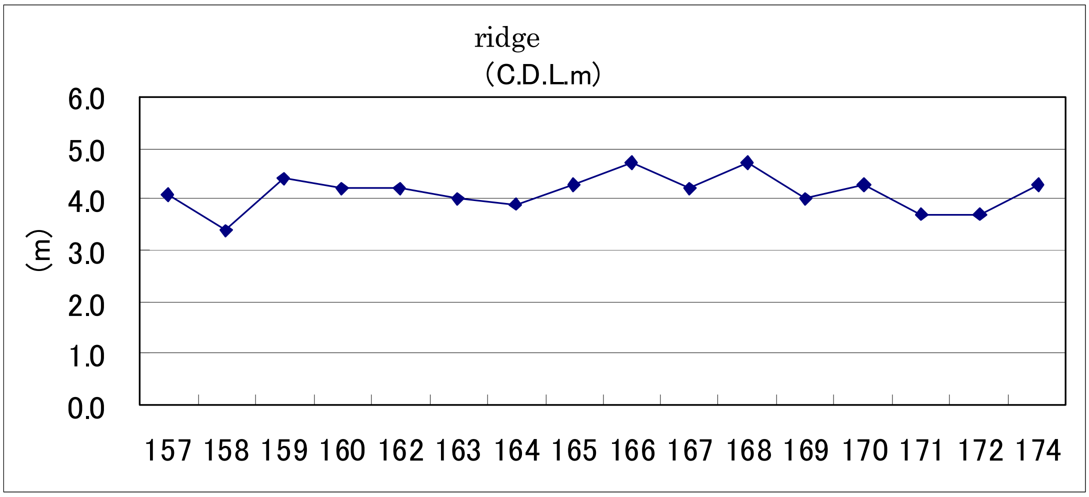


Figure 7.14 Distribution of Ridge Height

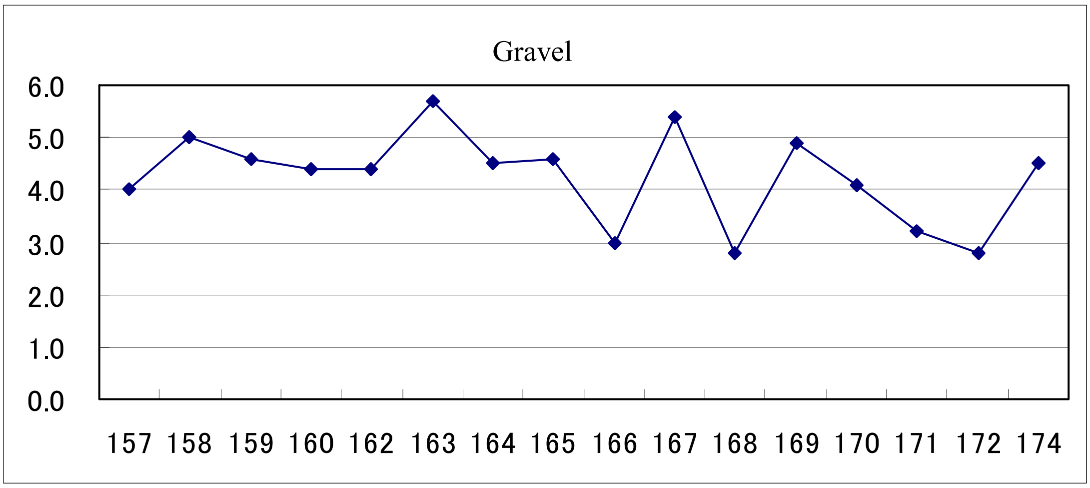


Figure 7.15 Distribution of Coral Gravel Gradient

(2) Wave run-up height in the target area

Figure 7.16 shows the distribution of wave run-up heights for a 10-year return period wave during Higher High Water (HHW), a wave run-up height of a wave with a probability of occurring several times per year during High Water (HW), and the ridge heights in the target area. The wave run-up heights were calculated using the Nakamura *et al.* revised imaginary slope method.

From this, except north side of area D-3 and area D-2 and, the wave run-up heights for a 10-year return period wave during Higher High Water (HHW) in the target area are non-satisfying.

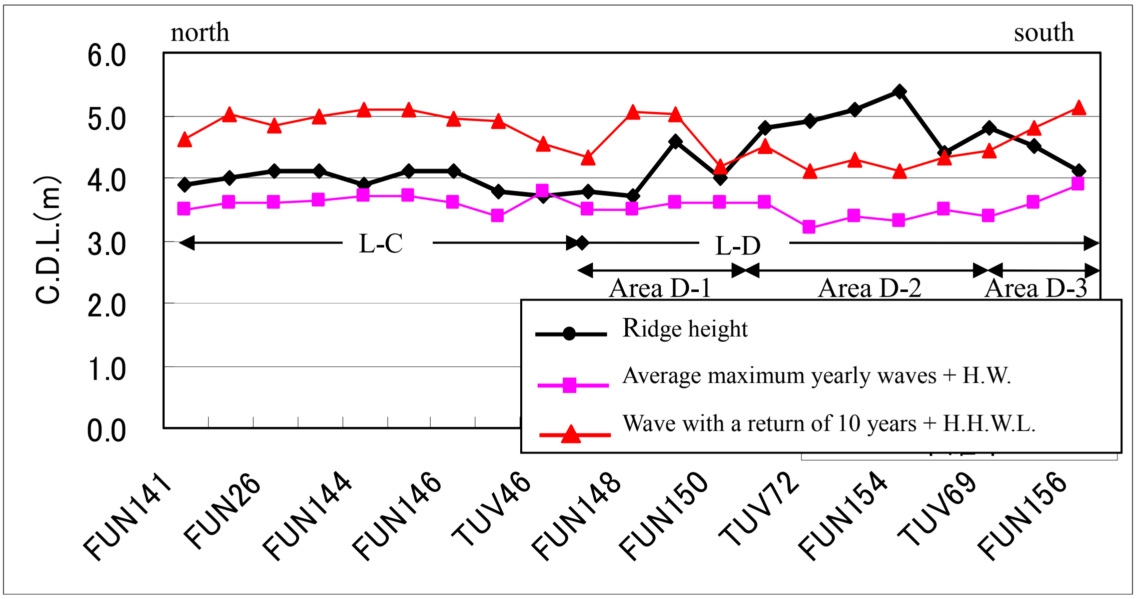


Figure 7.16 Distribution of Wave Run-up Heights in the Target Area

(3) Investigation of nourishment cross-section

1) Basic design of nourishment

The basic design of the beach nourishment is shown in **Figure 7.17**.

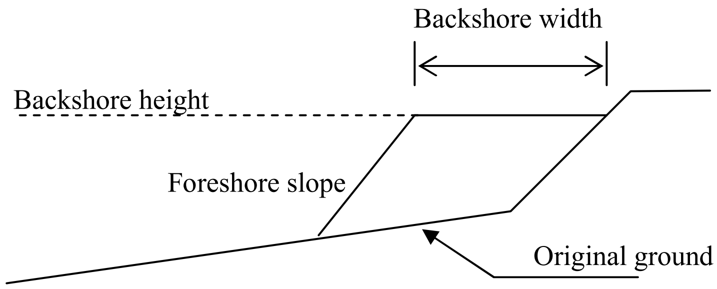


Figure 7.17 Basic Design of Nourishment

2) Grain size

This is to be decided based on indices derived from the results of past research, the actual composition of beach materials, and the availability of materials.

The target wave for the target area is set at a 50-year return period, detailed below, so as to mitigate outflow to the lagoon during the expected nourishment lifetime.

○ 50-year return period wave (Ho'=2.2m、To=5.6sec)

When deliberating the grain size, three indices--referenced in various standards as the output of research on the stability conditions of beaches--were used: a) Formation and spacing of beach cusps (Takeda, I., Sunamura, T., 1983); b) Foreshore sedimentation and erosion (Uda, T., *et al.*); c) Classification of beach erosion and sedimentation (Horikawa, K., *et al*.). [1]

The results of the investigation are shown in **Table 7.5**, while a stable grain size is as follows:

○d50=6.5mm (or larger)

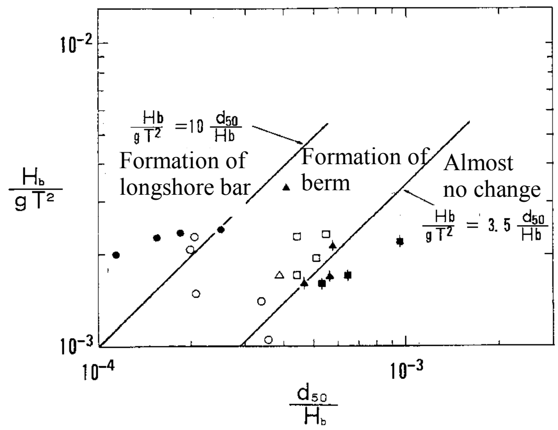
Table 7.5 Stable Grain Size d 50(mm)

	Stable grain size d 50(mm)
a) Formation and spacing of beach cusps (Takeda and Sunamura)	2.3〜6.5 or above
b) Foreshore sedimentation and erosion (Uda *et al.*)	0.8〜1.6 or above
c) Classification of beach erosion and sedimentation (Horikawa *et al.*)	3.7 or above

Therefore, the grain size, taking into consideration local availability and cost, will be set at.

[1] Manual for design of artificial reef (1992), National Association of Sea Coast in Japan

Takeda and Sunamura



Almost no change	■ ▲
Berm	□ △ ○
Longshore bar	▲ ●

Figure 7.18 Formation and Spacing of Beach Cusps

Uda *et al.*

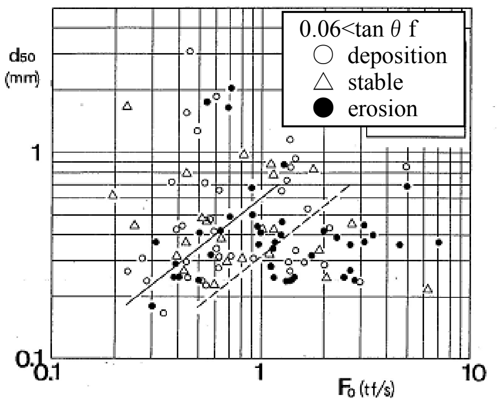


Figure 7.19 Foreshore Sedimentation and Erosion (0.06≦tanθ)

Horikawa *et al.*

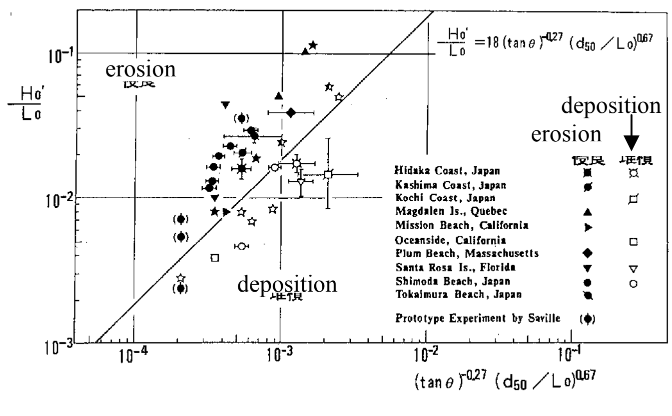


Figure 7.20 Classification of Beach Erosion and Sedimentation

a) Takeda and Sunamura

The Aida calculation diagram is used to obtain the wave-breaking height.

Ho'/Lo=2.2/48.9=0.045

From **Figure 7.21**: Hb/Ho'=1.20

Wave breaking height: Hb=2.2×1.20 =2.64(m)

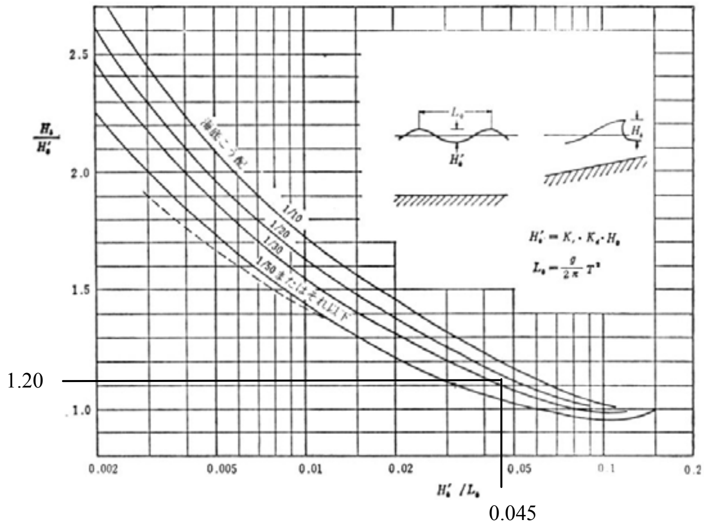


Figure 7.21 Relationship between Wave Steepness and Wave-Breaking Point

Using **Figure 7.18**, the following calculations are used to find the conditions of a berm formation that is almost completely stable:

$Hb/(gTo^2)=10d50/Hb$

$d50=Hb^2/(gTo^2)/10=2.64^2/(9.8\times5.6^2)/10=2.3\times10^{-3}(m)=2.3\ (mm)$

$Hb/(gTo^2)=3.5d50/Hb$

$d50=Hb^2/(gTo^2)/3.5=2.64^2/(9.8\times5.6^2)/3.5=6.5\times10^{-3}(m)=6.5(mm)$

Therefore, the median diameter for a berm, foreshore, that is almost completely stable is: d50 =2.3～6.5(mm)

b) Uda *et al.*

Calculation of incident wave energy flux (Fo):

$Fo = 1/8\rho_w\,(Ho')^2Cgo$

Where, Cgo = Group velocity of deep-water waves (=gT/(4π))

$Cgo = 9.8\times5.6/(4\times\pi)=4.37(m/s)$

$Fo=1/8\times1.03\times2.2^2\times4.37=2.72(tf/m)$

The foreshore slope is: $\tan\theta f=1/4=0.25$

Therefore, from**Figure 7.19**, the conditions of stability and sedimentation are:

$d50=0.31Fo=0.31\times2.72=0.8$

$d50=0.60Fo=0.60\times2.72=1.6$

Therefore, the median diameter for a stable foreshore where sedimentation will occur is: d50 = 0.8～1.6 (mm)

c) Horikawa *et al.*

From **Figure 7.20**, the conditions for sedimentation are:

$Ho/Lo=18(\tan\theta)^{-0.27}(d50/Lo)^{0.67}$

$d50=(Ho/Lo/18/(\tan\theta)^{-0.27})^{(1/0.67)}Lo$

$=(2.2/48.9/18/(1/4)^{-0.27})^{(1/0.67)}\times48.9=2.7\times10^{-3}(m)=3.7(mm)$

Therefore, the median diameter for a foreshore where sedimentation will occur is: d50 =3.7(mm)

3) Foreshore slope

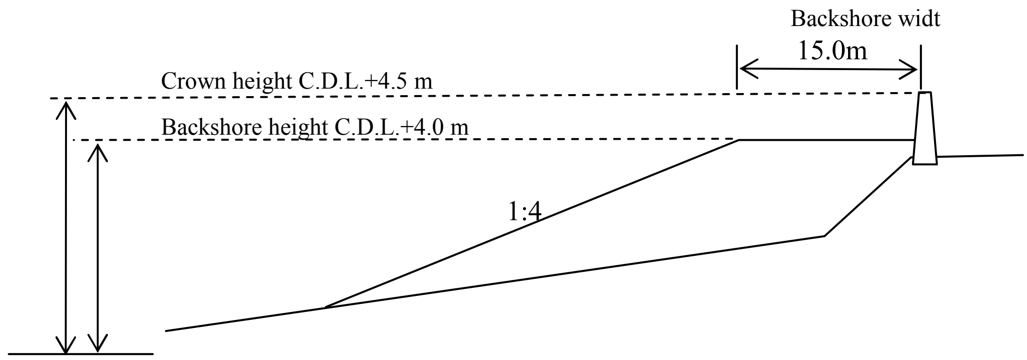
The gradient of the coral gravel in the northern end of the target area is 1:3.0 to 1:4.5, and in the southern end is 1:4; and as the vector of the shoreline and the target area are almost the same in the southern end, its value of 1:4 was used.

4) Backshore height and width

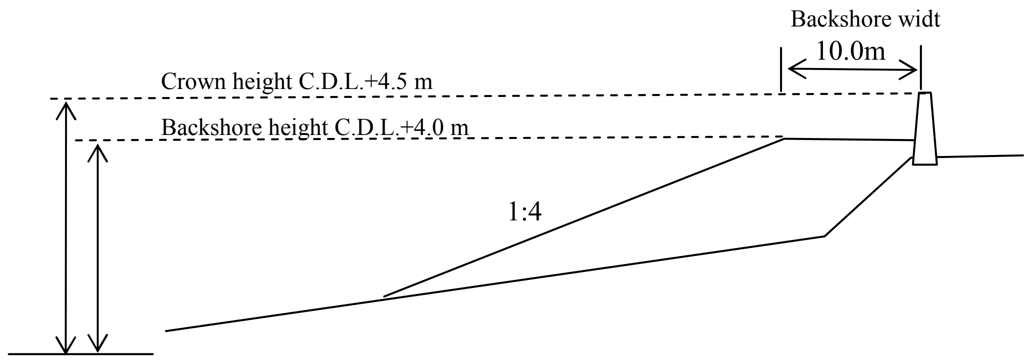
The height and width of the backshore was decided, taking into account the following points, in order to plan a coral gravel beach that fits the natural conditions and actual situation:

- consider the ridge height of the surrounding coastline in a near natural condition (northern end median, 4.1 m; southern end median, 4.3 m),
- backshore height and width that satisfy the wave run-up height at high water (HW) when a wave with a probability of occurring several times a year hits, and
- ridge height (where the backshore height is higher than the ridge height, this will be employed) and beach width that satisfy the run-up of a 10-return year wave at higher high water (HHW).

Table 7.6 shows the ridge height and for reference, the wave run-up height of the current cross-sections in the target area. From this, the necessary backshore heights and widths for coral gravel nourishment shows **Table 7.7**. Standard cross-section of gravel beach nourishment is shown in **Figure 7.22**. While **Figure 7.23-Figure 7.30** show the situation at each traverse line with photos and a cross-section.



Standard cross-section of Area D-1 in District L-D and in District L-C



Standard cross-section of Aare D-3 in District L-D

Figure 7.22 Standard Section of Gravel Beach Nourishment

Table 7.6 Setting the Backshore Height and Width

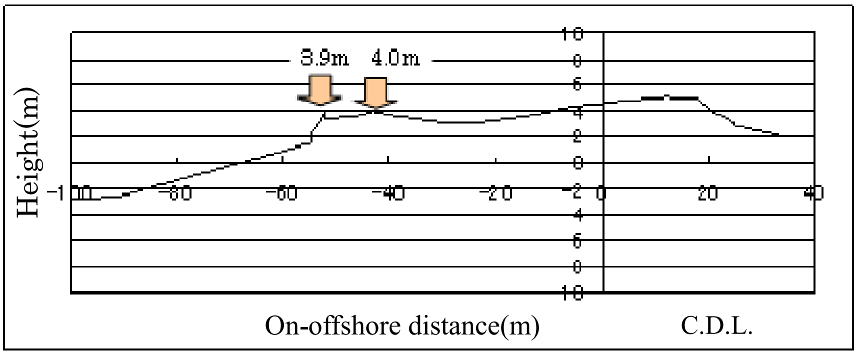
Area		Traverse line	Ridge height (C.D.L.m)	Backshore height (C.D.L.m)	Run-up height of 10-return year wave+H.H.W.L. (C.D.L.m)			Run-up height of wave probability several times per year+H.W.L. (C.D.L.m)
					Backshore width (m)			Backshore width (m)
					Current	10	15	Current
L-C		Fun141	4.0	4.0	4.6	4.1	4.0	3.5
		Fun142	4.0		5.0	4.2	4.0	3.6
		Fun26	4.1		4.8	4.2	4.0	3.6
		Fun27	4.1		5.0	4.2	4.0	3.6
		Fun144	3.9		5.1	4.1	4.0	3.7
		Fun145	4.1		5.1	4.1	4.0	3.7
		Fun146	4.1		5.0	4.2	4.0	3.6
		Fun147	3.8		4.9	4.1	4.0	3.4
L-D	D-1	Tuv46	3.7	4.0	4.6	4.1	4.0	3.8
		Fun30	3.8		4.3	4.2	4.0	3.5
		Fun148	3.7		5.1	4.1	4.0	3.5
		Fun149	4.6		5.0	4.4	4.0	3.6
		Fun150	4.1		4.2	4.0	—	3.6
	D-3	Tuv69	4.8	4.0	4.5	4.1	—	3.4
		Fun155	4.5		4.8	4.1	—	3.6
		Fun156	4.1		5.1	4.2	4.0	3.9

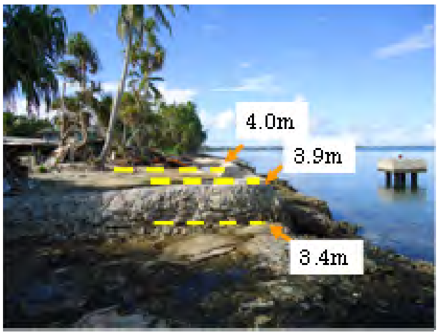
* The red run-up heights are non-satisfying, while blue are satisfying beach width run-up heights.

Table 7.7 Backshore Height and Width for Gravel Beach Nourishment

Area		Backshore Height (C.D.L.)	Backshore Width
L-C		+4.0m	15m
L-D	D-1	+4.0m	10m～15m
	D-2	No measures undertaken because the current state satisfies the run-up height.	
	D-3	+4.0m	0m～15m

Fun141





Fun142

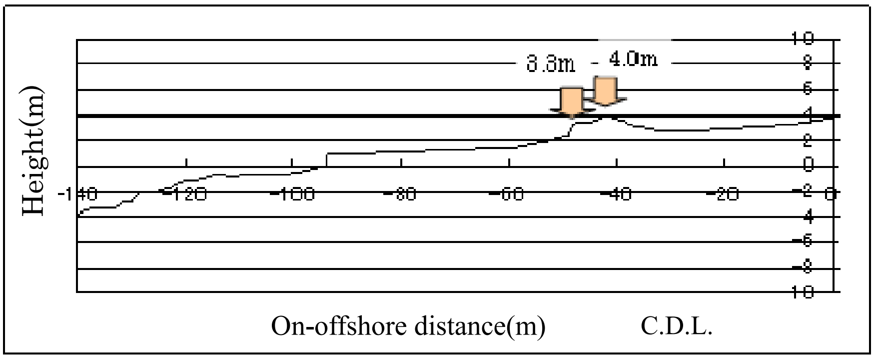
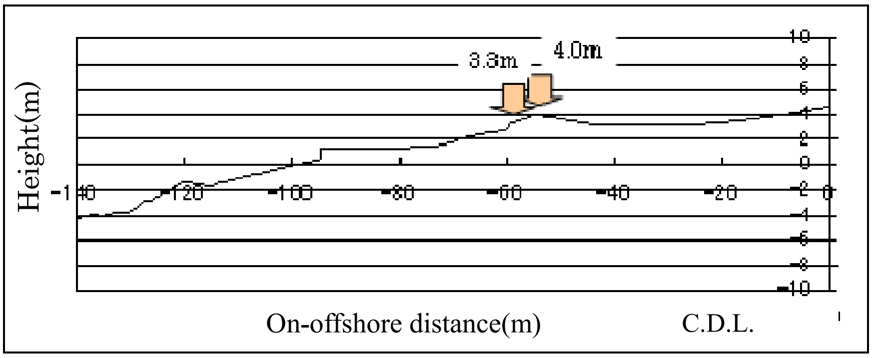


Figure 7.23 Traverse Line Situation

Fun26



Fun27

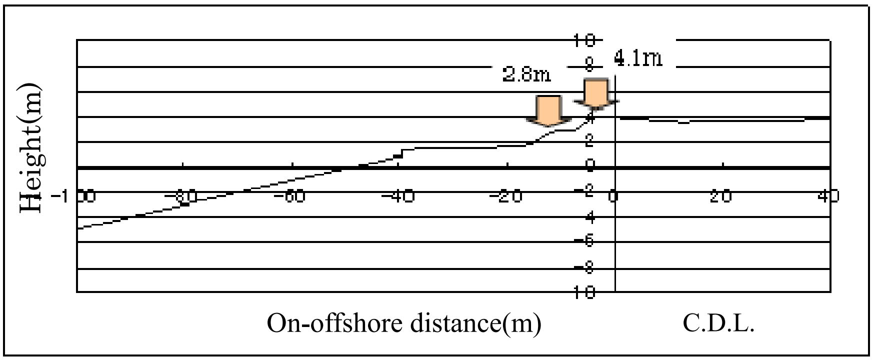
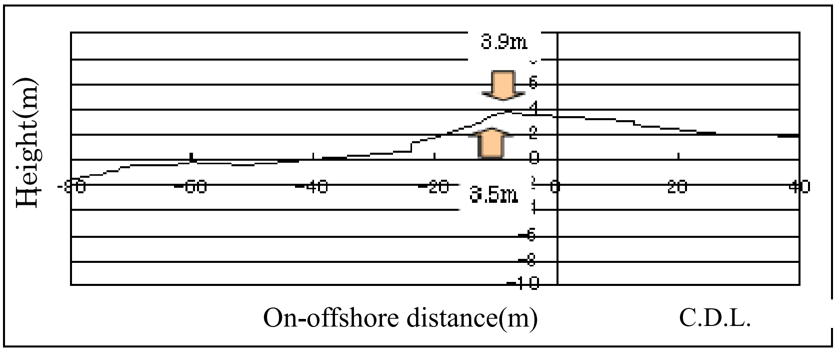


Figure 7.24 Traverse Line Situation

Fun144



Fun145

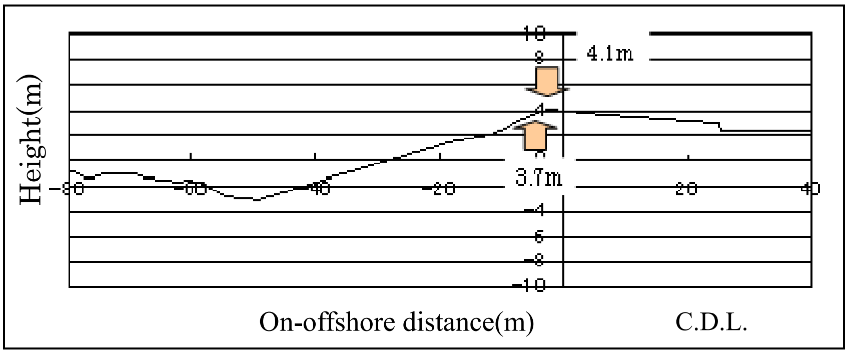
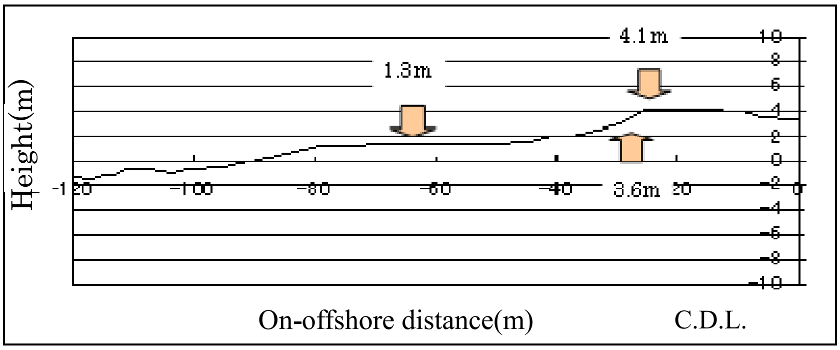
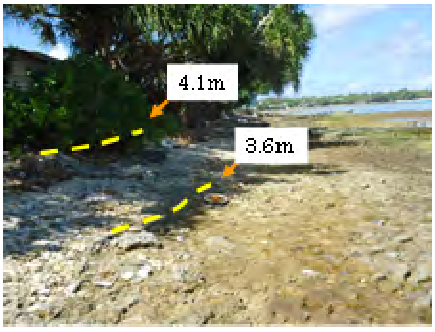


Figure 7.25 Traverse Line Situation

Fun146





Fun147

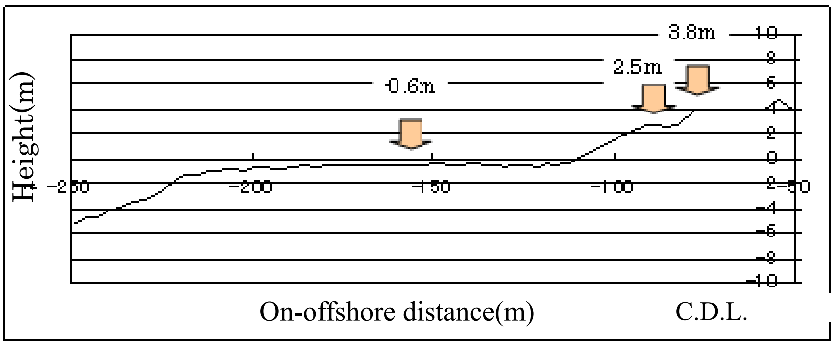
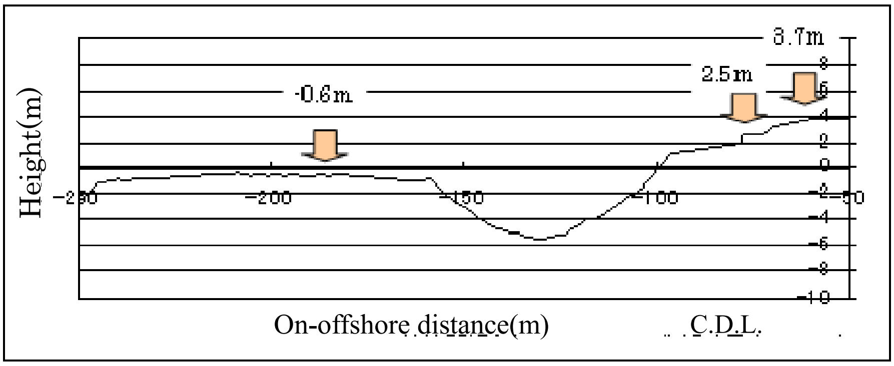
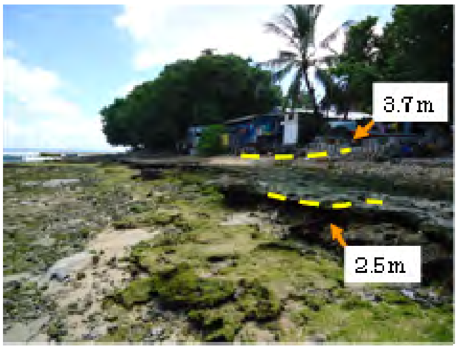


Figure 7.26 Traverse Line Situation

Tuv46





Fun30

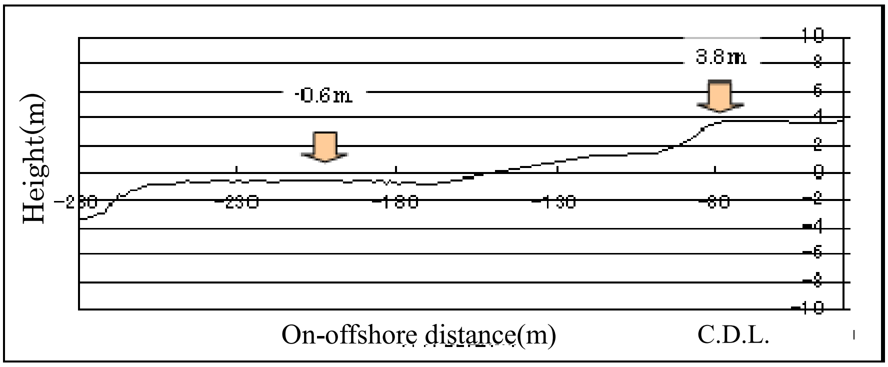
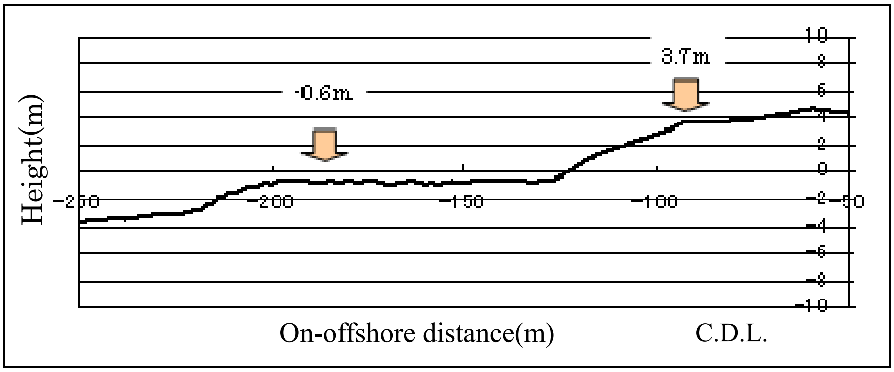
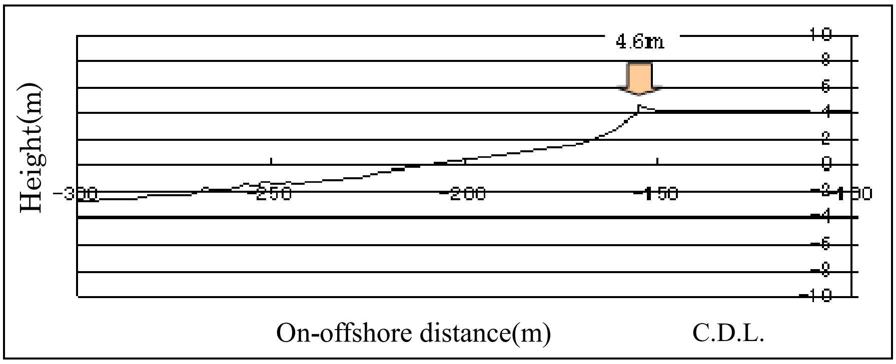


Figure 7.27 Traverse Line Situation

Fun148



Fun149



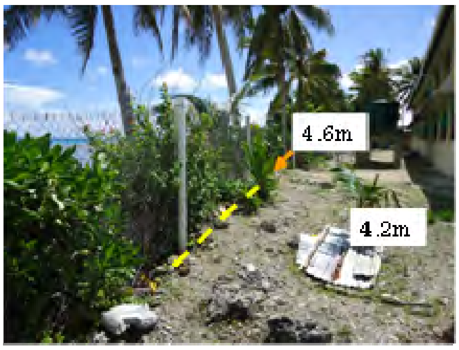
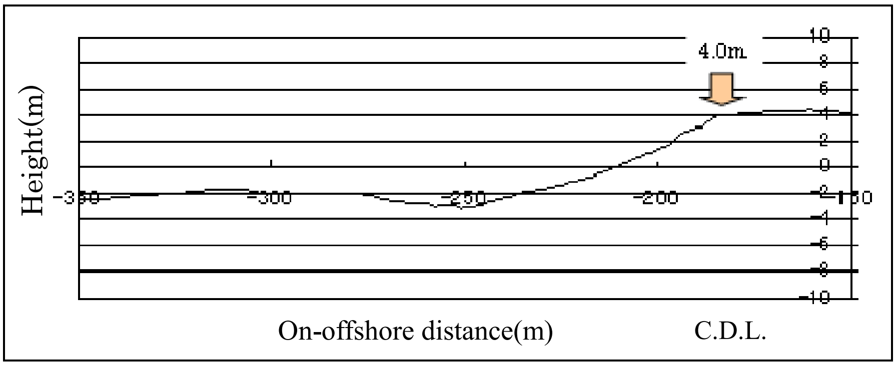


Figure 7.28 Traverse Line Situation

Fun150



TUV69

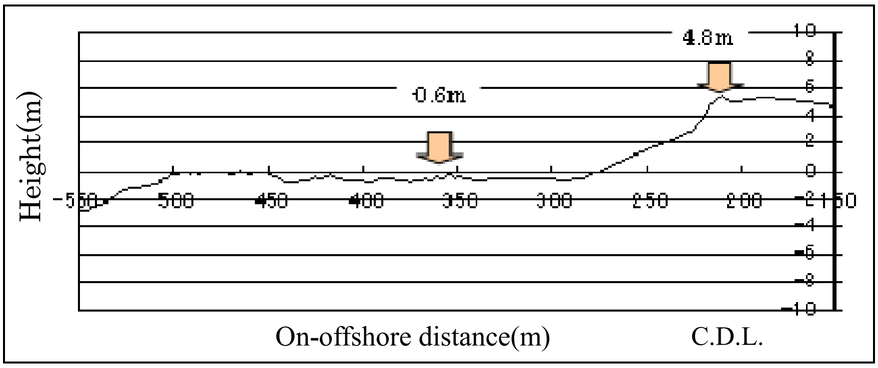
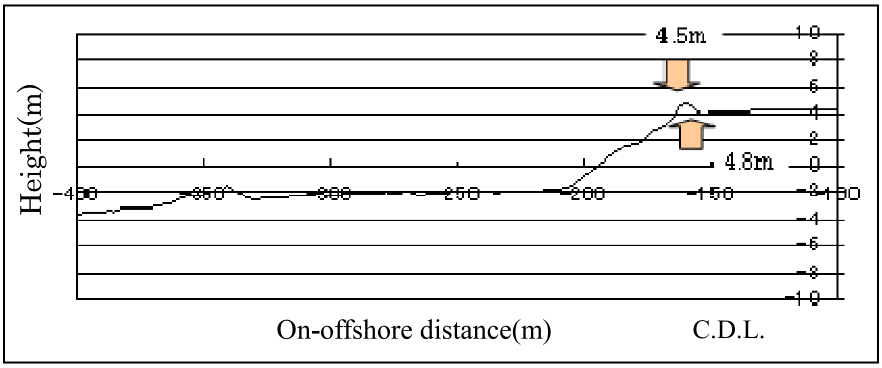
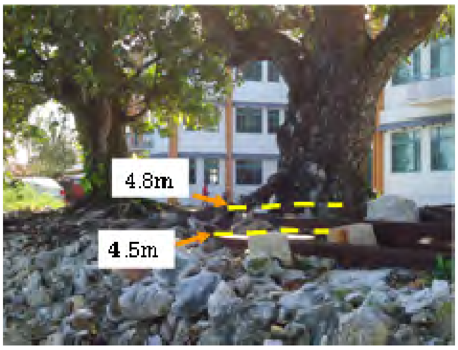


Figure 7.29 Traverse Line Situation

Fun155





Fun156

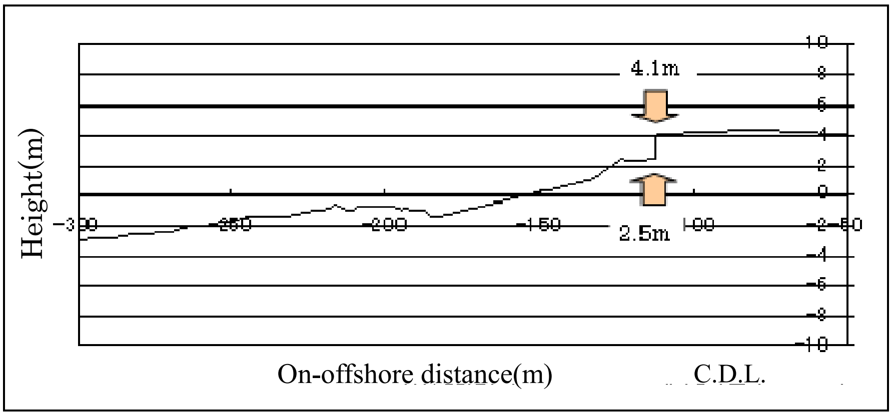


Figure 7.30 Traverse Line Situation