MINISTRY OF FOREIGN AFFAIRS,
ENVIRONMENT, TRADE, LABOUR
AND TOURISM,
GOVERNMENT OF TUVALU

THE STUDY FOR ASSESSMENT OF ECOSYSTEM, COASTAL EROSION AND PROTECTION/REHABILITATION OF DAMAGED AREA IN TUVALU

FINAL REPORT
[Volume I : Summary Report]

JANUARY 2011

JAPAN INTERNATIONAL COOPERATION AGENCY

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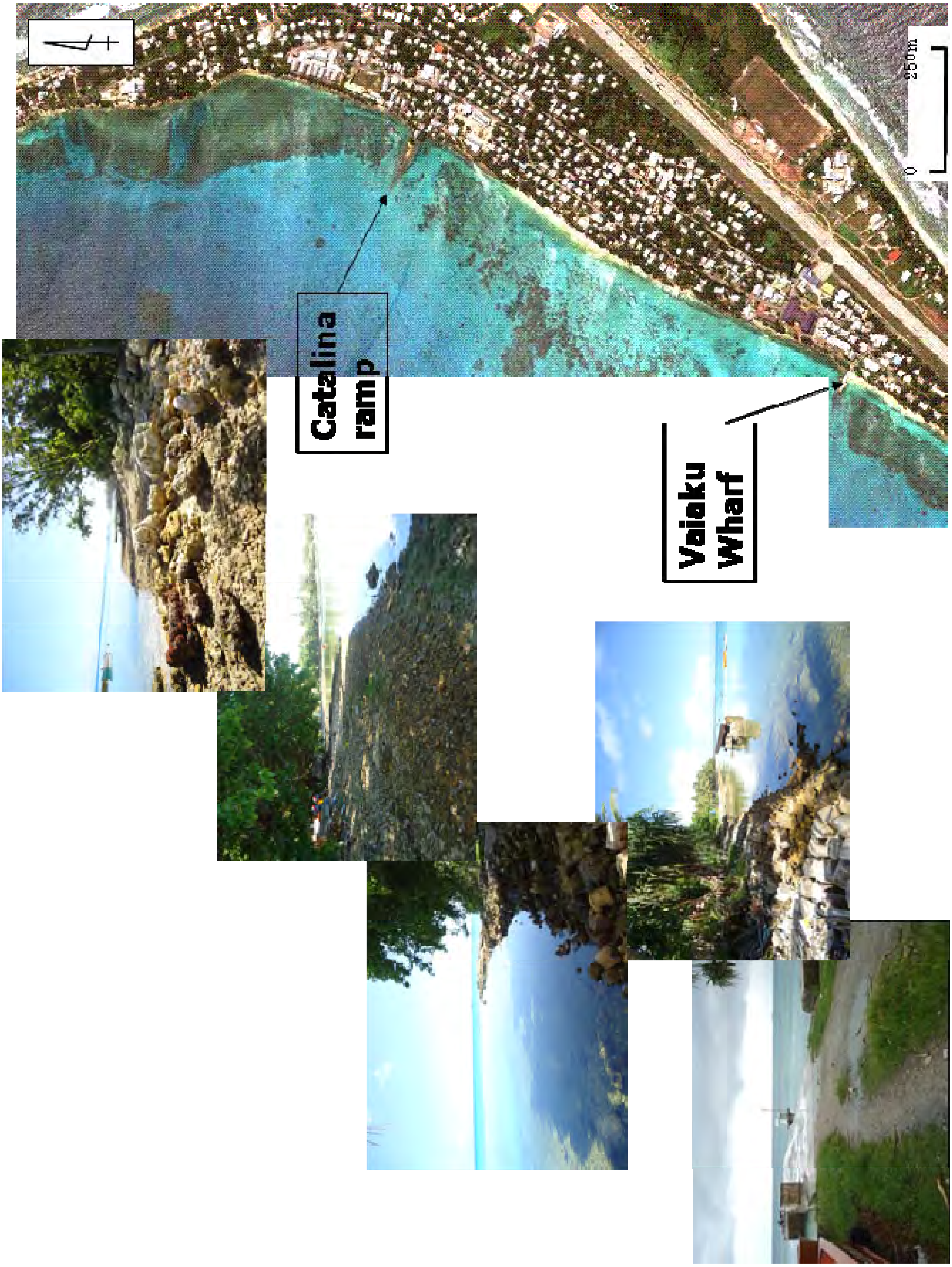
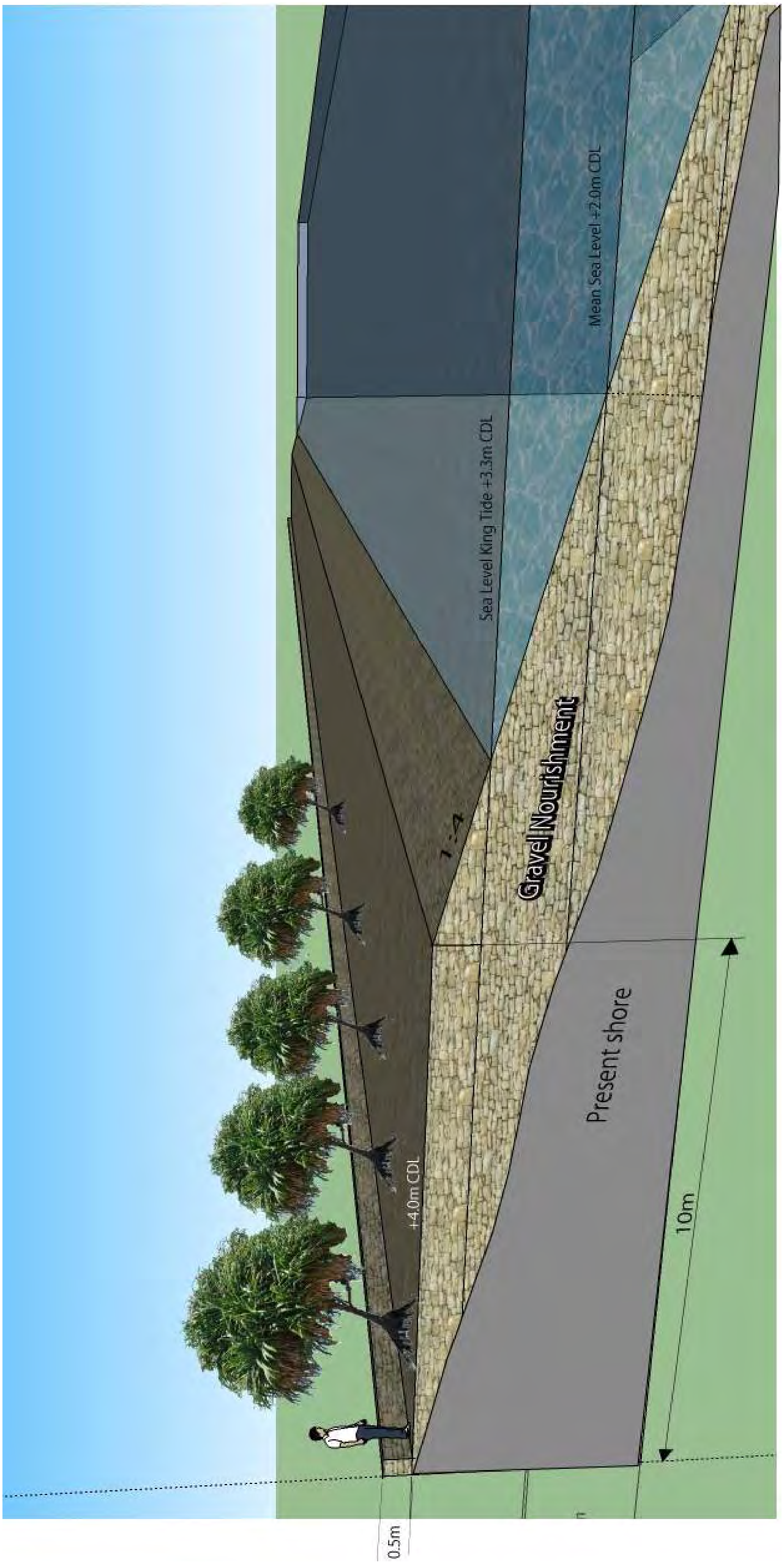
(As of November 2010)



Target Area (Photograph)



Bird's View of Completed Gravel Nourishment

Executive Summary

1. Coastal Protection Works Tailored to Each Area

The survey area of the Fongafale Island has been divided into seven sub-areas. For each sub-area, alternative measures for coastal protection, including zero option, have been prepared and scrutinized to select optimal plans. The respective coastal protection work to be implemented in alternative plans are shown in the following table.

Table 1 Coastal Protection Works in Alternative Plans

Coastal Protection Works	Plan-1	Plan-2	Plan-3	Plan-4
Gravel Beach Nourishment (D-1 & D-3 areas)	○	○	○	○
Gravel Beach Nourishment (C area)				○
Planting on back beach	○	○	○	○
Back-filling of the coastal borrow pits((in front of D-1 & D-3 areas)		○	○	○
Back-filling of the coastal borrow pits((in front of C area)		○	○	○
Stone Masonry (Parapet)	○	○	○	○
Partial Restoration of storm ridges			○	○

2. the Implementation Schedule

The implementation schedule of the Project is proposed as shown below.

The first year : A part of the work will be implemented as the pilot project
The second year : The area of the pilot project will be monitored, and reviewed the detail construction plan.
The third year : Construction work for other areas and monitoring during the work
The fourth year : Continue Construction work to complete and monitoring during the work
After completion : Monitoring shall be continued

3. Effects of the Project and the Expected Outcomes

The following effects and impacts are expected from implementation of the respective coastal protection measures.

Table 2 Effects Expected from the Coastal Protection Measures and Impact during and after Completion of the Works

Counter measure	Expected effects
Gravel beach nourishment	Prevention of wave overtopping Prevention of movement of gravel to the land Facilitation of transport and accumulation of sand.
Planting	Compacting of gravel beaches Improvement of the scenery
Back-filling	Prevention of wave overtopping Facilitation of transport and accumulation of sand

When the Project including these coastal protection measures has been implemented, and the effects have realized, the following outcomes are expected.

- Damages to the houses, to the furniture and household goods, to the assets for business, to the planting and to the infrastructure, which the residents in the coastal area of the lagoon side have been suffered from annual floods by ten-year equivalent wave, will be prevented.
- Risks to people, such as injuries, fears and stresses to the vulnerable residents in the coastal area of the lagoon side, due to floods by the waves not bigger than the once for ten years return period, will be prevented.
- After reclamation of gravel beach, about 20,000m^2 of land will be created in the coastal area of the lagoon side and an ancient landscape of the atoll beach will be restored, which will make the scenery of the landscape of Funafuti improved.
- The newly reclaimed land also could be used for sports and recreation for the residents. After accumulation of sand on the gravel beach in the future, the atoll sand beach could be an attractive tourist spot for visitors from overseas.
- With the nourishment of gravel beach, the existing lands will be protected and the coastal erosion will be prevented by the gravel beach which will weaken the wave strength.

4. Evaluation of the Project

The benefits of the Project will be measured as the direct disaster damages by flood to be avoided, the cost of emergency measures in household to be avoided, the intangible damages to be avoided and the value of the land to be created. EIRRs of the Project are estimated at 11.6 % for the Plan-1, 7.25 % for the Plan-2, and 6.77 % for the Plan-3, and these plans deem feasible except Plan-4, of which EIRR is estimated as low as 4.23%.

For implementing the Project, social influences such as relocation of the residents are not envisaged. In the public hearings conducted several times during the survey periods, most of the people attended expressed their wish for the earliest implementation of the Project. The environmental impacts of the Project are not deemed substantial, and impacts against the lagoon ecosystem with the construction works could be minimized to a recoverable extent, provided the coral transplanting and other measures would be applied.

The Project is a feasible coastal protection work for prevention of flooding due to overtopping waves, the environmental impacts of it to the lagoon ecosystem could be recoverable, and after completion of it, release from fear, stresses and traumas of the residents, in the atoll where no refuge is found, due to the flooding by overtopping waves which reach as high as the land of the residents could be secured. In consideration of the above, the earliest implementing of the Project is recommended.

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

MINISTRY OF FOREIGN AFFAIRS, ENVIRONMENT, TRADE, LABOUR AND TOURISM, GOVERNMENT OF TUVALU

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<FINAL REPORT>

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Abbreviations

ADB	Asian Development Bank
CBOs	Community Based Organizations
CDM	Clean Development Mechanism
DMO	Disaster Management Office
DOA	Department of Agriculture
DOE	Department of Environment
DOF	Department of Fisheries
DOLS	Department of Lands and Survey
EIA	Environment Impact Assessment
EU	European Union
F/S	Feasibility Study
GEF	Global Environment Facility
GIS	Geographic Information System
IEE	Initial Environment Examination
IGCI	International Global Change Institute
JICA	Japan International Cooperation Agency
O&M	Operation and Maintenance
PICCAP	Pacific Islands Climate Change Assistance Programme
PICs	Pacific island countries
PWD	Public Works Department
SOPAC	South Pacific Applied Geoscience Commission
SPREP	South Pacific Regional Environment Programme
STP	Sewage Treatment Plant
T-N	Total Nitrogen
T-P	Total Phosphorus
UNDP	United Nations Development Programme
USP	University of the South Pacific
NSDS	National Strategy for Sustainable Development
NAPA	National Adaptation Program of Action
AusAID	Australian Agency for International Development

SUMMARY

CHAPTER 1 BACKGROUND OF THE STUDY

Tuvalu has been brought to international attention as a country in danger of submerging due to the impact of global warming, because most of its landmass is low-lying atoll only 1 to 3 meters above sea level. On the other hand, a study report says that the main cause of the existing coastal erosion and tidal surge impact is the increase of environmental load by population growth (sand supply decrease due to deterioration of water quality, and constructing barriers for accretion of sand) and sprawl of residential area (inhabitation in flood prone areas, and extracting earth and sand from coastal areas) rather than precipitation change or sea level rise due to global warming. Therefore, a comprehensive study on the impact of human activities is needed for the island's long-term sustainability.

Previous studies have shown that coastal protection measures ignoring sand production/movement/deposition mechanisms of biologic origin, such as coral, run a high possibility of destroying the island's sustaining mechanisms in the long-term. Therefore, the implementation of measures based on these mechanisms is required to protect the atoll island. Additionally, it is necessary to increase the island's permanence by mitigating negative effects on these mechanisms considering future sea level rises. Long-term measures to increase the island's permanence must be considered. Nonetheless, the coast is already being eroded, with reports of residents' lives being affected. For these areas, urgent and short-term measures are required. Surveys on the impact of coastal erosion, and the planning of countermeasures to counter this, are particularly pressing in Fongafale Island, where the capital Funafuti is located, and 45% of Tuvalu's total population (9,652 persons: 2006, the secretariat of the pacific community) resides. Based on the result of the project formation investigation, first of all, the Tuvalu government requested international science and technology cooperation on global problems to clarify the mechanisms involved in the formation and sustainability of the island from a long-term perspective, which is called the Project for Eco-technological Management of Tuvalu against Sea Level Rise (hereafter, Japanese science and technology cooperation). Moreover, in terms of short-term aspect, Tuvalu requested Japanese technical cooperation for a development planning study proposing short-term measures for the prevention of coastal erosion.

In response to this request, M/M and S/W were signed on 22 January 2009 for the implementation of this study. This development planning study (the Study) aims to propose short-term coastal erosion countermeasures, working in coordination with the above Japanese science and technology cooperation, and based on the results of its long-term scientific research begun in April.

CHAPTER 2 OBJECTIVES OF THE STUDY AND STUDY AREA

2.1 Objectives of the Study

In recognition of the background mentioned above, the Objectives of the Study are set forth as follows:

(1) To assess ecosystem, coastal erosion and protection/rehabilitation of the damaged area
(2) To make a plan on sustainable measures for coastal protection/rehabilitation
(3) To strengthen capacity of institutions and communities for coastal management.

2.2 Study Area

The study covers the Fongafale Island and other islands of Funafuti atoll.

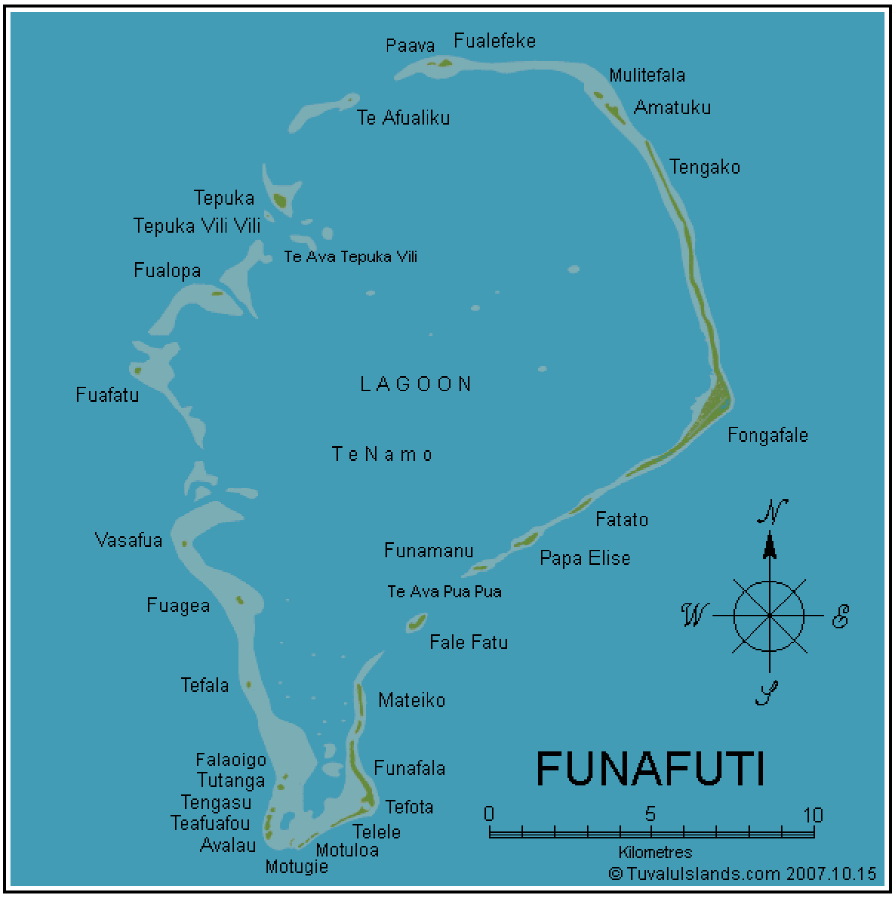


Figure 2.1 Study Area

CHAPTER 3 SOCIAL AND ECONOMIC CONDITIONS

3.1 Social Conditions

(1) Population structure

The total enumerated population of 9,561 included 9,359 permanent residents. The total population in Tuvalu increased by 5.7% (518) during the intercensal period, 1991–2002 (**Table 3.1**). Population trends are considerably different between the capital of Tuvalu, Funafuti, and the outer islands. The average resident population density of the outer islands was 236 people per square kilometer, while Funafuti had 1,420 people per square kilometer. In other words, more than 40% of total population is living in Funafuti which has a share of only 10% of total area, and Funafuti residents are surely living in a heavily populated area compared to the outer islands.

Table 3.1 Population Changes in Tuvalu (1991-2001)

	Area (km^2)	Total population		Population distribution (%)	Population growth rate (%) (1991-2002)	Average annual growth rate (%)	Density (person per km^2)
		1991	2002			2002	
Total population	25.6	9,043	9,561	100	5.7	0.5	365
Resident population		8,750	9,359		7.0	0.6	
Funafuti	2.79	3,576	3,962	42.3	10.8	0.9	1,420
Outer Islands	22.84	5,174	5,397	57.7	4.3	0.4	236

Source: Basic Table of Population and Housing Census 2002

(2) Development Plans

As structural weakness of the country: large and continuous trade imbalance, large public sector with a low productivity rate and lack of focus on customer services, pervasive government ownership of enterprise activities, many of which require fiscal concessions and (or) subsidies, small under-developed private sector which accounts for only one-quarter of GDP, underdeveloped financial system characterized with low domestic resource mobilization and so forth are listed. Under these circumstances, it places the following as eight strategic areas:

1. Good Governance.
2. Macroeconomic Growth and Stability.

3. Social Development: Health, Welfare, Youth, Gender, Housing, and Poverty Alleviation.
4. Outer Island and Falekaupule Development.
5. Employment and Private Sector Development.
6. Human Resource Development.
7. Natural Resources: Agriculture, Fisheries, Tourism, and Environmental Management.
8. Infrastructure and Support Services.

As for the environmental management, which is included in the Natural Resources area, it is said that it has to confront two key challenges:

1) the numerous issues arising from the growing urbanization of Funafuti, and
2) the national impacts associated with climate change and sea level rise, specifically salt-water inundation of pulaka pits, coastal erosion and flooding, which are blamed either wholly or partly on global warning.

3.2 Economic Conditions

(1) GDP

As the coral reef islands, land resources are scarce and high productivities of agriculture and fisheries are not expected. Due to the scarcity of domestic resources, the population relies heavily on imports in terms of foodstuffs and other daily necessities, and as a result the trade deficits are immense. GDP for 2002 was 27.5 million AU$ and GDP per capita was 2,814 AU$.

(2) Land Use

Land use of Fongafale Islet is either residential area or governmental land (leased from private land owners). The following are the uses of the central part of the islet . All areas of Alapi Village, the oldest village on the islet, are residential; Fongafale's main institutions are located in Senala Village, such as the Funafuti Council (Kaupule), Conference Hall of the supreme decision making body (Fale Kaupule), a church, a hospital, and a primary school. Buildings of the Tuvalu Government are concentrated in Vaiaku Village, and also the Prime Minister’s house. The south-eastern side of the airstrip is designated as government land. There are no residential houses, but a power plant, a prison, public works department, and meteorological bureau buildings. Numerous piggeries are built by the side of Tafua Pond; and there is a chicken battery. There are not many agricultural fields except swamps (*pulaka* pits) on the airfield side of Alapi and Senala Village, in which the residents grow taro potatoes; and the other is a Taiwanese technical assistance experiment farm, located at the southern end of the government-use land. Since there is no collective fish market system on the islet, and fishing is mainly for subsistence purposes, the fish are sold on a person to person basis. All solid waste is discharged into a borrow pit at the northern end of the Tengako Island (Asagatau Paka Village). There is another small dumping site at the south end of the islet (Kavatoetoe Village).

3.3 Water Supply, Sewerage and Waste

(1) Water Supply

Official figures cite 97% of households as having access to safe drinking water. Almost all households on Funafuti have rain-water tanks or cisterns, most individually owned but some shared by the community, and are using for drinking water, cooking, flush toilets, bathing, washing, etc. Cisterns are installed in the basements of major buildings such as the Princess Margaret Hospital and the Government Central Office. To maintain the water supply during droughts, two water desalinators were installed by Japanese donation.

(2) Sewerage

Most households have a basic sanitation system, unfortunately, the septic tank based system was introduced without regard to the geophysical characteristics of the atoll system, which is characterized by high groundwater level and it is subject to regular flooding, particularly in times of heavy rain and or king tides. The septic tanks are often poorly designed despite the presence of specific building codes and design specifications. Therefore, incompletely digested or untreated effluents seep out of the septic system and ultimately have resulted in high pollution of groundwater and the lagoon. The Department of Public Works has just commenced the Composting Toilets Promotion Program funded by GEF IW/EU Water Facility since 2009 on the recommendation of the report of Economic of liquid waste management in Funafuti. The program is aiming at promoting composting toilets as the preferred sanitation system for Tuvalu.

(3) Waste

The Survey on Kaupule collection waste stream composition conducted in the year 2000, found that the community roughly produces approximately 258 tones of solid waste a year. In Funafuti, the current rapid growth of population and changing lifestyle in recent years has intensified the tendency of Tuvaluan society to rely on imported products. There has been a distinctive change of the types of discharged waste towards plastics, glass and metals of which the treatment is difficult and such chemical solid waste as batteries, synthetic detergents and insecticides, all of which contain hazardous substances.

As a part of EU Tuvalu Waste, Water and Sanitation Project (TWWSP) activities, it is planned to improve the existing final disposal site. All the waste is currently dumped on the blind road, however, the new disposal operation is intend to dump the waste collected into the nearby borrow pit, and to reclaim by waste compressing to the side of borrow pit using heavy machines. There are some apprehensions for these landfilling procedures as follows:

1. Damage to storm ridge caused by the construction of access road,
2. Environmental impact on water quality and coral ecosystem caused by leachate from the landfill via the borrow pit, and

Impact on the coastal environment caused by the outflow of waste attendant to the breakdown of the storm ridge

CHAPTER 4 PRESENT SITUATION OF NATURAL AND ENVIRONMENTAL CONDITIONS IN STUDY AREA

4.1 Meteorological Phenomena

The annual wind data show the wind in Fongafale to be seasonal. We divided the wind conditions in the region into four (4) seasons, i.e. Summer/Wet Season from December to February, Winter/Dry Season from May to September, and two Transit Seasons from March to April and from October to November. From December to February during the summer season, north-easterly winds from N to ENE are predominant. Strong westerly winds reaching more than 15 m/sec are observed in this season including March. From May to September during the winter season, the easterly to south-easterly winds not exceeding almost 6 m/sec are dominant. In this season, strong winds more than 10 m/sec are very rare cases, only 12 times during 10 years. Wind characteristics in the transit seasons from March to April and from October to November show the intermediate conditions between the summer and winter seasons or the winter and summer seasons.

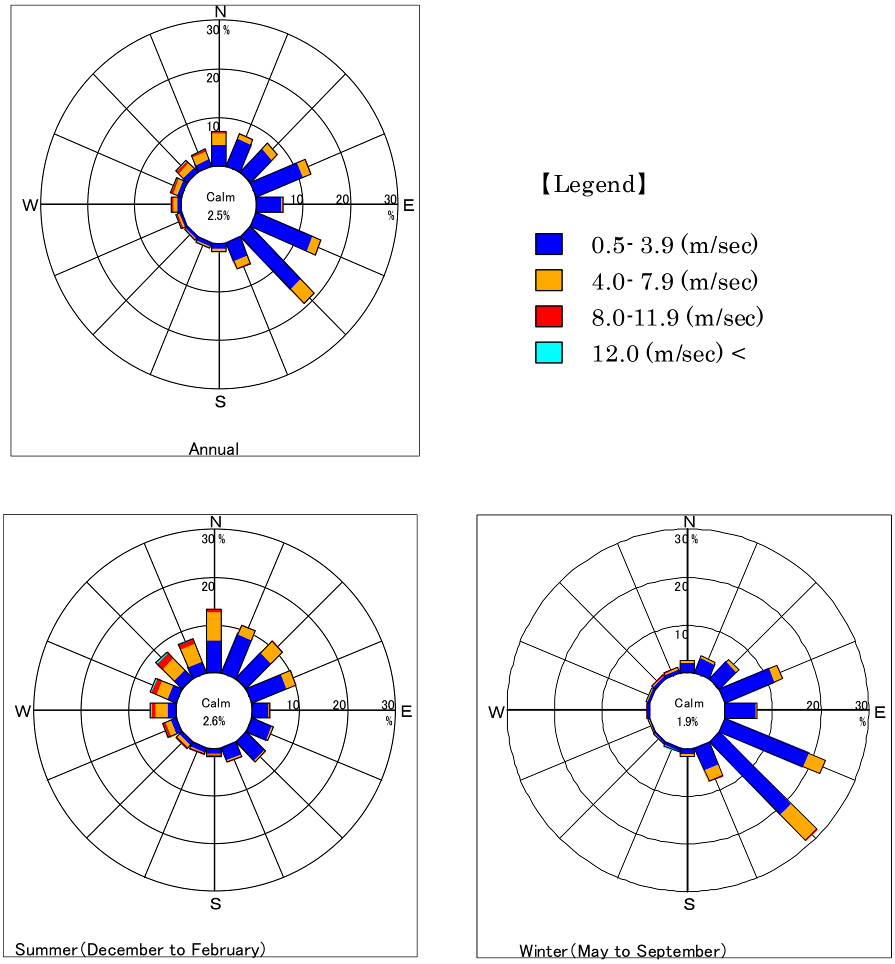


Figure 4.1 Wind Rose

4.2 Oceanographic Phenomena

(1) Sea Levels

The sea levels in the Pacific Islands are controlled by many factors, some periodic like the tides, some brief but violent like cyclones, and some prolonged like El Niño. El Niño's impact on the sea level is mostly felt along the "South Pacific Convergence Zone (SPCZ)", because of changes in the strength and position of the Trade Winds, which have a direct bearing on sea level, and along the equator, due to related changes in ocean currents. The most notable features of the monthly means are the annual peaks, which appear every year around February or March except in 1998, when a large drop in sea level was recorded during the 1997/1998 El Niño. The highest sea level recorded over the duration of the recorded is 3.42 m on 28th of February 2006.

(2) Sea Level Rise due to Climate Change

Using these ten years' mean sea level data during 1999 to 2008, we calculated the sea level rise at a SEAFRAME station in Funafuti as shown in **Figure 4.2**. The average rate of sea level rise was obtained to be 2.3 mm/year, which is in the range of IPCC (AR4) estimation 3.1±0.7 mm/year for the decadal period 1993- 2003.

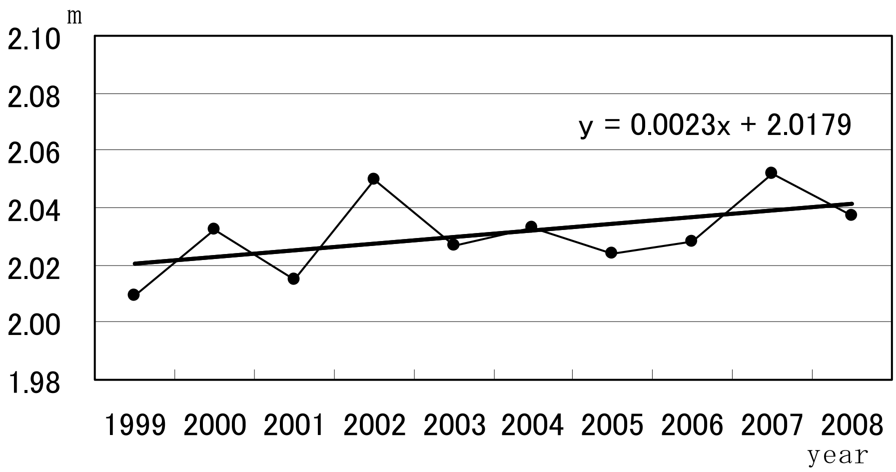


Figure 4.2 Yearly Mean Sea Levels during 1999 to 2008 at Funafuti

(3) Waves

1) Ocean Side

Wave measurements with a Waverider Buoy were carried out off the eastern coast of Funafuti Atoll between May 8th, 1990 and April 7th, 1992 with sampling interval of every 3 hours by Oceanographic Company of Norway AS (OCEANOR) as part of the Wave Measurement Program funded by the Norwegian Government Agency. Wave conditions of ocean side were as follows;

- The significant wave heights (H1/3) is remarkably constant throughout the year with an average of 1.8 m. The average wave period is 9.2 sec, in the main dominated by local wind seas.
- The highest measured sea state occurred in November 1990 when the H1/3 reached 3.4 m with a peak period (Tp) of 16.7 sec, partly as a result of swell arriving from Tropical Cyclone Sina to the south.

2) Funafuti Lagoon

Wave observation was conducted at two points: the frontage of Vaiaku Lagi Hotel on

Fongafale Islet (WG-1) and the sea area to the south of Tepuka Islet (WG-2), during field surveys by JICA Study (from September 2009 to February 2010). Wave conditions of lagoon side were as follows;

- Regarding the wave characteristics at the frontage of Vaiaku Lagi Hotel (WG-1), the range of significant wave height, wave period and wave direction (traveling direction) obtained from the first observation were respectively 0.2 to 0.3 meters (average: 0.2 m), 2 to 4 seconds (average: 2.5 sec) and 49 to 83 degrees with hydrographical convention (average: 70.7°). Comparing the results of the second and third observations with those of the first observation, it was indicated that the wave characteristics from the second and third observations were influenced more strongly by western wind or roar.
- Regarding the wave characteristics in the sea area to the south of Tepuka Islet (WG-2), the range of significant wave height, wave period and wave direction (traveling direction) obtained from the first observation were respectively 0.2 to 1.1 meters (average: 0.3 m), 5.3 to 14.9 seconds (average: 8.9 sec) and 22.4 to 310.1 degrees with hydrographical convention (average: 193.9°). Comparing the results of the second observation with those of the first observation, a marked difference in the wave height and wave period was not found. Regarding the wave direction, the occurrence frequency for significant wave with 220 degrees predominated.

(4) Currents

Current observation was conducted using two Sontek Acoustic Doppler Profilers (ADP) and one JFE-ALEC Electro-magnetic current meter (Infinity-EM AEM-USB) during the baseline data collection phase on the JICA Study. The current meters were deployed on the lagoon floor at three locations. Current conditions of lagoon side were as follows;

- The current speed at Vaiaku Station (CM- 1) was weak as a whole with maximum speed of 12cm/sec and mean speed of 2cm/sec, and an alternative motion to the direction of 90˚- 270˚ was observed at this point.
- The maximum speed of 45cm/sec during the observation period was recorded at Tepuka Vili Vili Station (CM- 2) with direction of 320˚ which means "going to outer ocean from lagoon" through the channel between Tepuka Vili Vili and Fualopa islet. The mean speed was also comparatively strong as 14cm/sec.
- At Causeway Station CM- 3, the maximum speed was 18cm/sec and direction was prevailed around 175˚ which means "going to inner lagoon side" along the coastal line. The mean speed was comparatively week as 5cm/sec.

4.3 Topographic and Geological Characteristics

4.3.1 Topographic Feature

Fongafale islet is a long and narrow strip of extremely low elevation with a broad "V" shaped outline. Rabbles of dead coral are piled up at ocean-side fringe of the islet up to 3 m above mean sea level, making the highest points of the islet. Other areas are below 2 m above mean sea level in large portion of the islet.

Senior residents remember that there was a long, low-gradient, sandy beach prior to the WW II . Modifications of the lagoon side of Fongafale islet during WW II include a 2.3 km long piece of reclamation with coral rock seawall, a long borrow pit (often called channel) beside the seawall, and other channels normal or parallel to the seashore. Observing the present state of the coastline along lagoon side in the central area of Fongafale islet, most of the beach is covered by beach rocks and the sandy beach extends with only 500 m length from the north of Vaiaku Lagi Hotel to the south of Catalina Ramp.

4.3.2 Bathymetric Feature

(1) Ocean Side

Figure 4.3 shows the bathymetry in the Funafuti atoll by SOPAC. The reef flat on the ocean side is about 100 m wide in front of storm ridge. Outside of reef edge increases rapidly depth and is over 1,000 m depth.

(2) Lagoon Side

The lagoon side reef flat is 55- 350 m wide including a 15- 25 m wide beach. Inside of lagoon, shallow places (Te Akaue) such as Te Akaue Fasua Kaupa, Loa, Pukeu, Tuluaga, Pusa, Fasua and Asano are scattered about. The water depth in the central part of lagoon is range from 40 to 50 meters and the maximum depth can be read

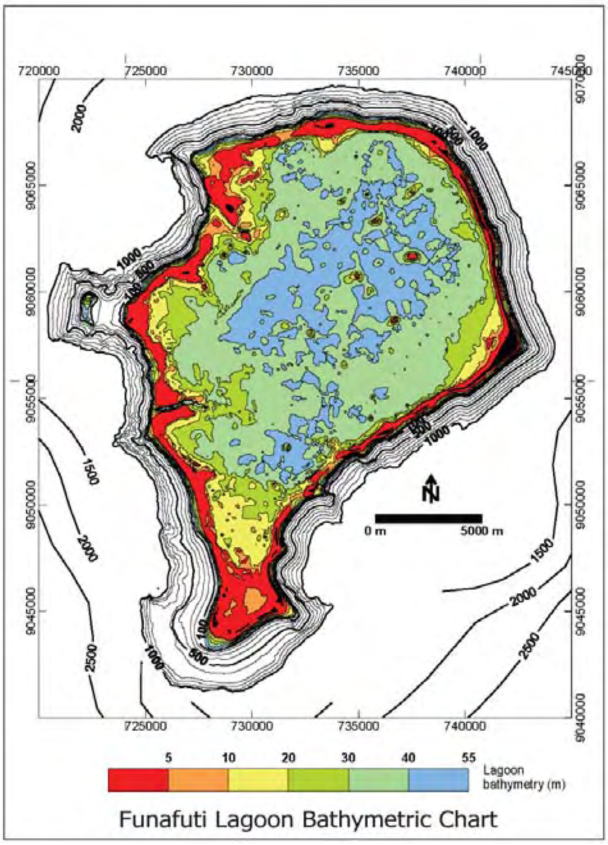


Figure 4.3 Bathymetric Map of Funafuti Atoll

as 49 meters on the existing chart (Funafuti Atoll, Chart No.83094).

4.4 Water Quality and Bottom Sediments

4.4.1 Water Quality

The water quality survey was conducted at 18 points on the entire Funafuti atoll, ocean, pond and groundwater during December 2009 to January 2010 of the baseline survey by JICA Study.

- In the study on the eutrophication of coral reefs, the following indexes have been proposed as threshold values for eutrophication): a chlorophyll-a concentration of 0.3 to 0.5 μg/l, a dissolved inorganic nitrogen (NH_4+NO_3+NO_2) concentration of 0.014 mg/l, and a dissolved inorganic phosphorus concentration (PO_4) of 0.006 to 0.009 mg/l in the seawater (Vecsei, A. 2003). The comparison of these threshold values and the water quality analysis results in this study revealed that both the concentrations of inorganic nitrogen (NH_4) and inorganic phosphorus (PO_4) exceed the threshold values at LW3 and LW9, points near the coast on the lagoon side. Thus, in some areas near the coast on the lagoon side, there are nitrogen and phosphorus concentrations that exceed Japanese water quality standards and threshold values of eutrophication, leading to fears about possible influence of eutrophication on the coral.
- The water quality comparison between groundwater (well water) and coastal seawater revealed that the T-N value of the former is 24 times higher and the T-P value is 6 times higher than those of the latter, showing that the well water is contaminated.

Table 4.1 Results of Water Quality Measurement Regarding Nitrogen and Phosphorus

Parameters	Units	Sea Water: Lagoon Side					Sea Water: Ocean Side		Groundwater
		LW-1	LW-2	LW-3	LW-9	LW-10	OW-2	OW-3	GW-2
T-N	mg/l	0.17	0.12	0.18	0.12	0.10	0.15	0.14	3.6
NH4-N	mg/l	0.03	0.04	0.06	0.11	0.05	0.06	0.10	0.02
NO3-N	mg/l	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	3.6
T-P	mg/l	0.015	0.015	0.065	0.034	0.008	0.015	0.011	0.14
PO4-P	mg/l	0.008	0.007	0.054	0.024	0.006	0.008	0.007	0.12

4.4.2 Sea Bottom and Shoreline Sediments

The sea bottom and shoreline sediments survey was conducted at 35 points (Sea bottom sediments; 15 points, Shoreline sediments; 20 points) on the entire Funafuti atoll on October 2009, as the baseline survey of JICA Study.

- The samples taken at all shoreline sediment sampling points consisted of coral fragments, foraminifera and shell fragments. Within the samples taken at sea bottom sediment sampling point, offshore samples in the central part to south part of Fongafale, and samples in the north part and the west part of lagoon also consisted of coral fragments, foraminifera and shell fragments.
- Whereas samples taken at sea bottom sediment sampling point in the north part of Fongafale (SB-2, SB-3), the north part of lagoon, the south and southeast parts of lagoon, and the offshore area of the lagoon consisted of 51 % to 91 % Halimeda as a dominant constituent.

4.5 Coastal Ecosystem Survey

Coastal ecosystem survey was conducted to identify the overview of the coastal ecosystem of Funafuti Atoll, the life and bottom sediment distribution information required to create a habitat map, and the population density information required to estimate the biomass of foraminifera. The ecological survey was carried out using the line census method on 16 traverse lines on the oceanic side and 15 traverse lines in the lagoon (at a water depth of 5 m or less). Before the survey, collection of existing information and interpretation of satellite image were made to determine the traverse lines.

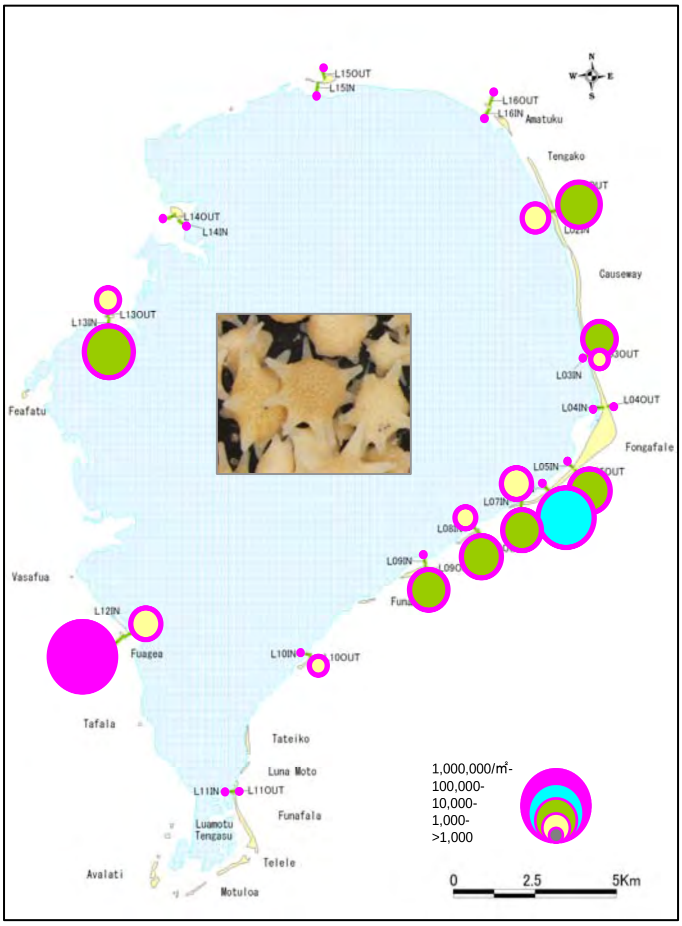


Figure 4.4 Foraminifera Occurrence Tendencies of Baculogypsina

According to the survey results, the occurrence conditions of larger foraminifera expected to have a high sand gravel production capacity were as follows: *Baculogypsina* and *Amphistegina* were found in high density, whereas *Calcarina, Sorites*, and *Marginopora* were not in such a large number. The occurrence tendencies of Baculogypsina is shown in **Figure 4.4**. The occurrence of this species is high on the ocean side of the atoll.

CHAPTER 5 PRESENT SITUATION OF COAST

5.1 Interview Survey

5.1.1 Purposes

Acquiring phenomenon of ongoing and past coastal and the hinterland's damages are especially useful when comparing the importance of subject areas and types of coastal protection measures for the purpose of the Study Team, establishing emergency coastal protection measures. This survey is to estimate the distribution and types of damages in the hinterland by interviewing the residents directly, and to get their geographic positions by GPS.

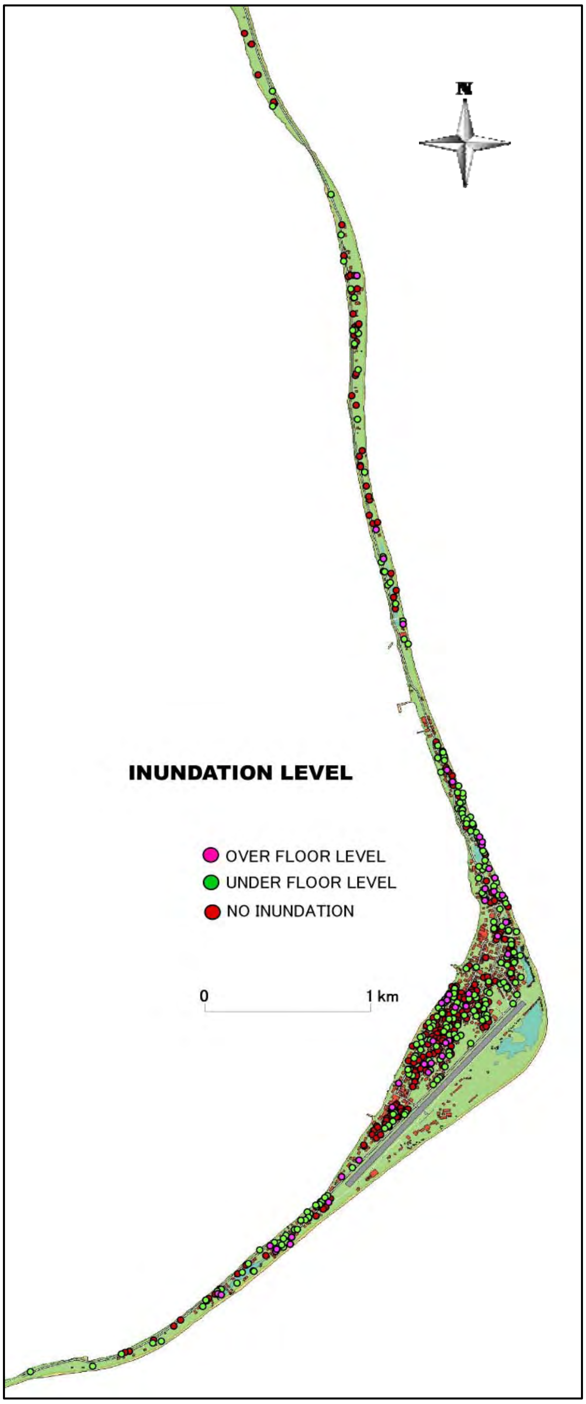
5.1.1 Results of Survey

The number of effective questionnaire collected was 592. It is the sum of almost all households in the Islet except vacancy house and long time on-leaves'.

Inundation Level and Distribution of Over-Topping Waves

Above, or below, floor level inundation is occurring in almost all residential areas, except most of Alapi Village.

There are three areas where over-topping of waves are concentrated: the central part of lagoon side, the north ocean side and the southern ocean side. Residences in the central part had experience(s) of evacuation. The cause is not known at this point; however, it may be the implying the incidents of hurricane Bebe in 1972 since the residents are living there for relatively long time.



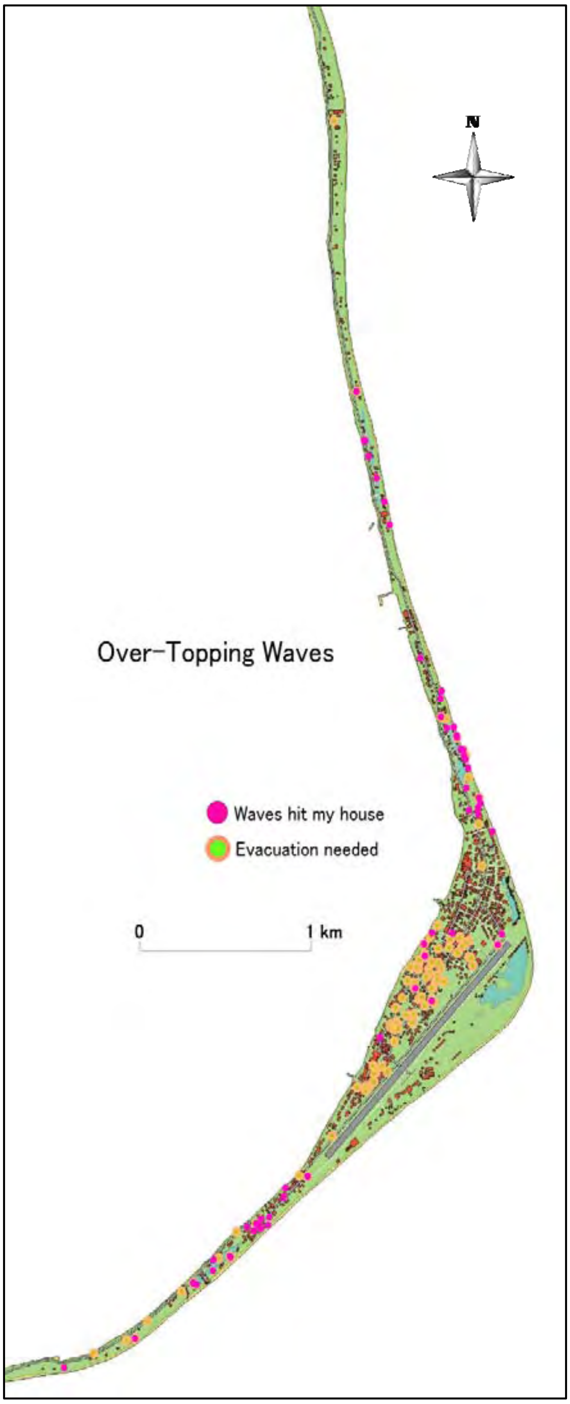


Figure 5.1 Inundation Level **Figure 5.2 Occurrence of Over-topping Waves**

5.2 Wave Overtopping Field Survey

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. When the wave overtopping survey was conducted on January 30, 2010, at 17:26, the high tide level was 3.24 m and the wind was westerly at approximately 10 m/s, causing wave overtopping all along the lagoon coast (**Figure 5.3**).

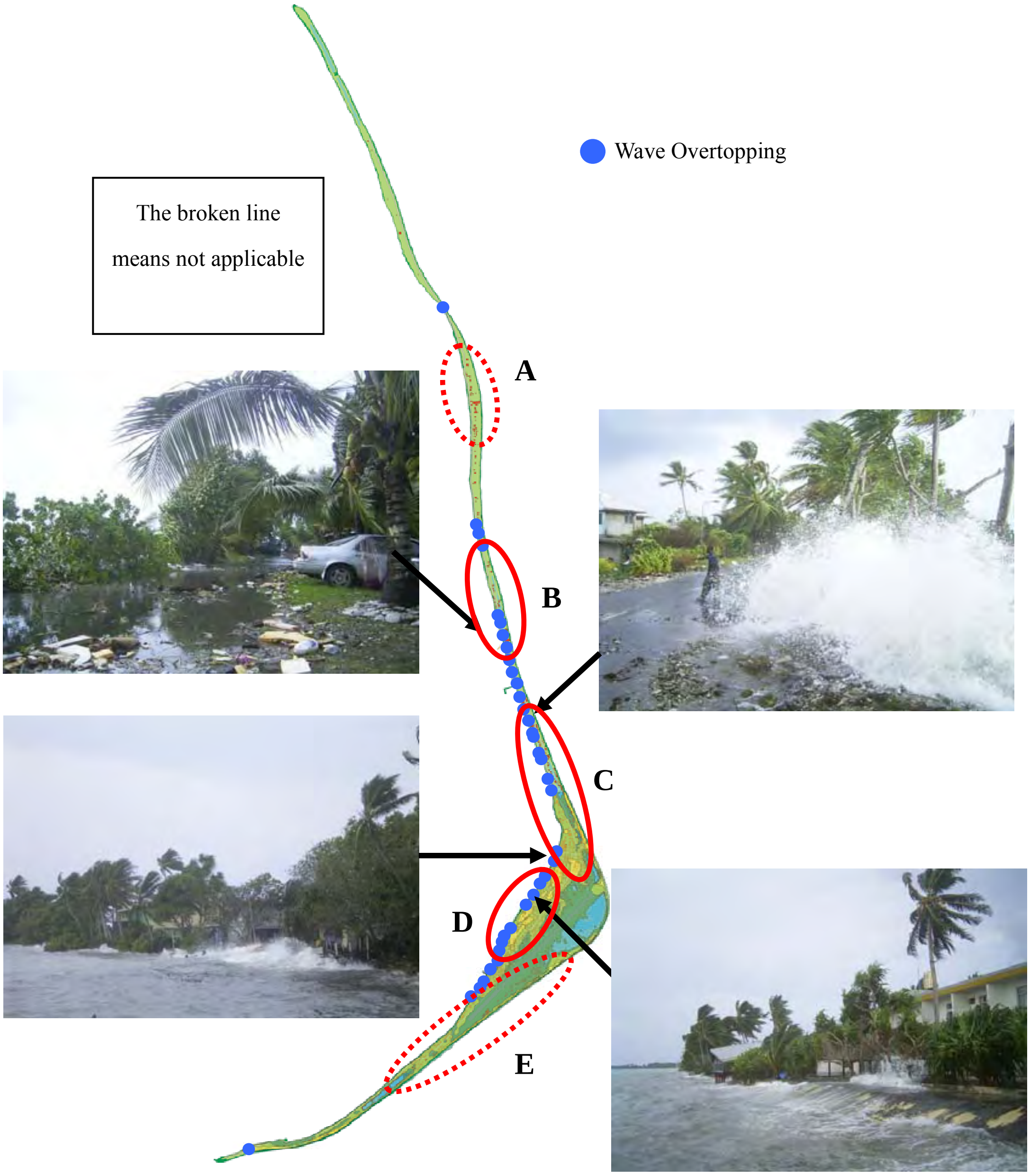


Figure 5.3 Distribution of Damage Levels Found in the Wave Overtopping Field Survey

5.3 Findings on Coastal Vulnerability

5.3.1 Lagoon Side

Areas that are currently experiencing overtopping damage on the lagoon side all have low storm ridges and low hinterland ground level. A major contributing factor to the wave overtopping in the central part of Fongafale in particular, where it occurs frequently, can be said to be the major changes to the coastal geomorphology that were made during World War II such as for the construction of various military installations and land reclamation to make seawalls. Waterways (borrow pits) were also dredged in the shallows during World War II.

Issues facing the facing the lagoon coast are:

1. Wave overtopping damage resulting from major changes to the coastal geomorphology during World War II.
2. Intensified wave and overtopping damage due to coastal borrow pits.
3. Coastal erosion and longshore drift inhibition due to private, haphazard landfilling and seawall construction.

5.3.2 Ocean Side

The areas currently being affected by ocean wave overtopping are where the storm ridge is relatively low. The main cause of this is the residents in the hinterland expanding the flat land on their properties by cutting down the vegetation growing around the storm ridge, leveling the ridge, and using gravel from it for construction.

Issues facing the ocean coast are:

1. Unregulated gravel extraction.
2. Unregulated cutting down of vegetation around the storm ridge.
3. Decreased storm ridge height due to land leveling.
4. Weakening of storm ridge due to excavation of its landward side.

CHAPTER 6 BEACH DEFORMATION MECHANISM

6.1 Changes in Coastal Lines

According to the comparison of aerial photographs (taken in 1941, 1943 and 1984) and a satellite image (taken in 2003, IKONOS) of the coastal line in the central part of Fongafale Islet, 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.

6.2 Beach Deformation Mechanism

6.2.1 Ocean Side

From the distribution of wave energy fluxes, it is estimated that, in the dry season (from March to October), the islet is under the influence of two external forces that cause sediment movement: 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 (from November to Fubruary), the wave energy is smaller than in the dry season and, the islet is under the influence of external forces that cause southward sediment movement on the northern side of Fongafale Islet.

6.2.2 Lagoon Side

From the distribution of wave energy fluxes, 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. 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.

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

7.1 Coastal Protection Areas

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.

7.1.2 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 7.1**. 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 7.1 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 B	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 C	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 E	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

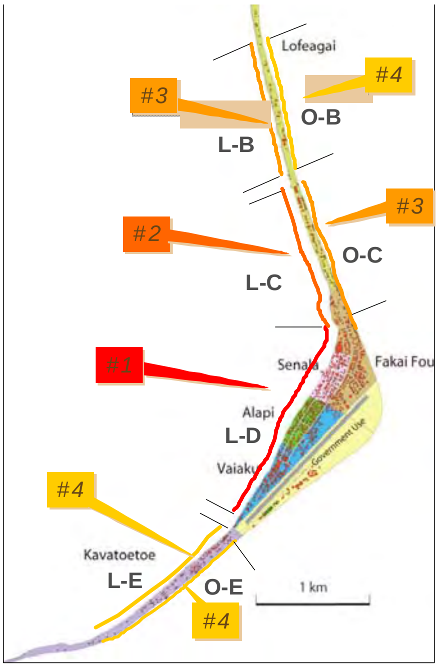


Figure 7.1 Target Area

7.2 Policy on Selection and Comparison of Coastal Protection Measures

7.2.1 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 enviroment, 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.

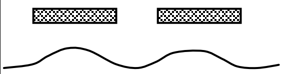
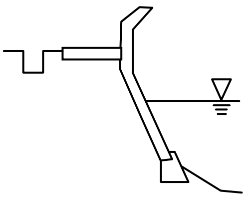
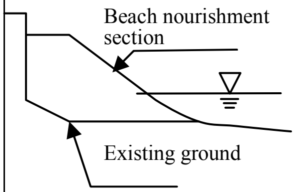
(2) Comparison of protection measures

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 7.2** 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).

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.

Table 7.2 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.

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.

7.3.3 Strategy for Each Area

The strategy for each area is shown in **Table 7.3**. 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).

Table 7.3 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 Examination of a Standard Section for Coastal Protection Facilities

A standard section of gravel beach nourishment in District L-D and L-C with high priority was examined. **Table 7.4** 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 7.5**.

Table 7.4 Setting the Backshore Height and Width

<table>
<tr><th rowspan="3" colspan="2">Area</th><th rowspan="3">Traverse line</th><th rowspan="3">Ridge height (C.D.L.m)</th><th rowspan="3">Backshore height (C.D.L.m)</th><th colspan="3">Run-up height of 10-return year wave+H.H.W.L. (C.D.L.m)
Backshore width (m)</th><th>Run-up height of wave probability several times per year+H.W.L. (C.D.L.m)
Backshore width (m)</th></tr>
<tr><th>Current</th><th>10</th><th>15</th><th>Current</th></tr>
<tr></tr>
<tr><td rowspan="8" colspan="2">L-C</td><td>Fun141</td><td>4.0</td><td rowspan="8">4.0</td><td>4.6</td><td>4.1</td><td>4.0</td><td>3.5</td></tr>
<tr><td>Fun142</td><td>4.0</td><td>5.0</td><td>4.2</td><td>4.0</td><td>3.6</td></tr>
<tr><td>Fun26</td><td>4.1</td><td>4.8</td><td>4.2</td><td>4.0</td><td>3.6</td></tr>
<tr><td>Fun27</td><td>4.1</td><td>5.0</td><td>4.2</td><td>4.0</td><td>3.6</td></tr>
<tr><td>Fun144</td><td>3.9</td><td>5.1</td><td>4.1</td><td>4.0</td><td>3.7</td></tr>
<tr><td>Fun145</td><td>4.1</td><td>5.1</td><td>4.1</td><td>4.0</td><td>3.7</td></tr>
<tr><td>Fun146</td><td>4.1</td><td>5.0</td><td>4.2</td><td>4.0</td><td>3.6</td></tr>
<tr><td>Fun147</td><td>3.8</td><td>4.9</td><td>4.1</td><td>4.0</td><td>3.4</td></tr>
<tr><td rowspan="8">L-D</td><td rowspan="5">D-1</td><td>Tuv46</td><td>3.7</td><td rowspan="5">4.0</td><td>4.6</td><td>4.1</td><td>4.0</td><td>3.8</td></tr>
<tr><td>Fun30</td><td>3.8</td><td>4.3</td><td>4.2</td><td>4.0</td><td>3.5</td></tr>
<tr><td>Fun148</td><td>3.7</td><td>5.1</td><td>4.1</td><td>4.0</td><td>3.5</td></tr>
<tr><td>Fun149</td><td>4.6</td><td>5.0</td><td>4.4</td><td>4.0</td><td>3.6</td></tr>
<tr><td>Fun150</td><td>4.1</td><td>4.2</td><td>4.0</td><td>—</td><td>3.6</td></tr>
<tr><td rowspan="3">D-3</td><td>Tuv69</td><td>4.8</td><td rowspan="3">4.0</td><td>4.5</td><td>4.1</td><td>—</td><td>3.4</td></tr>
<tr><td>Fun155</td><td>4.5</td><td>4.8</td><td>4.1</td><td>—</td><td>3.6</td></tr>
<tr><td>Fun156</td><td>4.1</td><td>5.1</td><td>4.2</td><td>4.0</td><td>3.9</td></tr>
</table>

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

Table 7.5 Backshore Height and Width for Gravel Beach Nourishment

<table>
<tr><th colspan="2">Area</th><th>Backshore Height (C.D.L.)</th><th>Backshore Width</th></tr>
<tr><td colspan="2">L-C</td><td>+4.0m</td><td>15m</td></tr>
<tr><td rowspan="3">L-D</td><td>D-1</td><td>+4.0m</td><td>10m～15m</td></tr>
<tr><td>D-2</td><td colspan="2">No measures undertaken because the current state satisfies the run-up height.</td></tr>
<tr><td>D-3</td><td>+4.0m</td><td>0m～15m</td></tr>
</table>

CHAPTER 8 CONSENSUS BUILDING WITH LOCAL RESIDENTS

8.1 Public Hearings for Local Residents

(1) Community Involvement in the Planning Process

The following figure shows the process for plan formulation from the perspective of community involvement (**Figure 8.1**). Public hearings were planned to be held two times, in June 2010 and in September 2010.

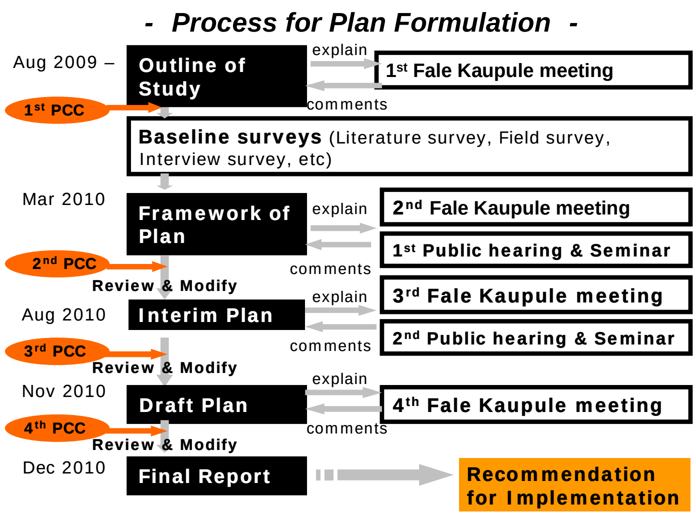


Figure 8.1 Community Involvement in the Planning Process

(2) Community Involvement in the Planning Process

The three areas at lagoon side in the central part of Fongafale Islet, including Senala, Alapi and Vaiaku areas, have been selected as the highest priority area according to the condition of the hinterland, disaster damage, and wave run-up. Five groups (1.Fale Kaupule (*Matai*), 2. Women's group, 3. Masaua (all residents/men), 4. Youth group and 5. Fishermen group) were targeted for the public hearings.

(3) Outlines of presentations

1) 1st Public hearing

At first, the presenter explained the outline of the study and the actual condition of coastal disaster in Tuvalu based on the results of the baseline study. Then, advantages and disadvantages of each coastal protection work, including seawalls, breakwaters and beach nourishment, were explained. Participants were requested to examine appropriate coastal protection work for the target area through the participatory discussion. Lastly, the study team asked participants some questions in order to grasp current usage of target area and their concerns regarding implementation of the Project.

2) 2nd Public hearing

The second public hearing composed of two sessions. The first session was a seminar on coastal disasters and their countermeasures in order to make people understand the actual situation of coastal matters. Presentation materials developed for the first public hearing were re-used. The second session focused on the matters which were discussed during the PCC and the first public hearing.

8.2 Ripple Effects and Conclusions

Some ripple effects and conclusions were gained through two public hearings as follows.

- Through the public hearings, participants understood the advantages and disadvantages of each coastal protection work, and lastly agreed that the beach nourishment which the study team proposed, should be implemented as the most appropriate coastal protection work for the target area.
- It was noted that the public hearings led to a more realistic plan that reflects various views given from different community's group - not only Fale Kaupule but other community groups like - men's group, women's group, youth and fishermen.
- The preparation and implementation processes made the staff of Funafuti Kaupule fully understand the real cause of coastal disaster and the appropriate countermeasures. They have also gained the capacity for explaining the Project to residents. Their knowledge and experiences gained through the implementation of public hearings will be useful for further Project activities such as consensus building with residents.

CHAPTER 9 Feasibility Study

9.1 Selection of Target Area for Priority Project

The level of priority of emergency measures for coastal protection areas was set in this study, whereby L-D area in central Fongafale was given highest priority, while L-C area—where the road connecting central Fongafale with Funafuti Port is located—was given high priority. Consequently, feasibility studies were conducted for these two areas.

9.2 Design of Coastal Protection Facilities

9.2.1 Consideration of Planar Shape of Nourishment

Even if nourishment is implemented to a cross-sectional shape that satisfies the wave runup height, longshore drift of gravel will reduce the cross-sectional area and its protective effectiveness. Therefore, a coastal change predictive model will be developed to predict changes to the coastline after the nourishment, and an appropriate planar shape that will provide effective protection will be considered. The consideration of planar shape—while aiming to secure a beach width so that the berm runup height of the nourished beach and/or the current ridge height is C.D.L. +4.0 m or less—took into account coastal use and economic factors such as obtaining gravel and edge treatment; wherein, a plan was made with the combined runup height of the nourishment and parapet being C.D.L. +4.5m or less. Outline of coastal protection facilities in L-C and L-D areas is shown in **Table 9.1**.

Table 9.1 Outline of Coastal Protection Facilities in L-C and L-D Areas

<table>
<tr><th colspan="2">Area</th><th>Backshore Height (C.D.L.)</th><th>Backshore Width</th><th>Parapet Crown Height (C.D.L)</th><th>Edge Treatment Dike</th></tr>
<tr><td colspan="2">L-C</td><td>+4.0m</td><td>15m</td><td>+4.5m</td><td>6 sets</td></tr>
<tr><td rowspan="3">L-D</td><td>D-1</td><td>+4.0m</td><td>15m</td><td>+4.5m</td><td>2 sets</td></tr>
<tr><td>D-2</td><td colspan="4">No measures undertaken because the current state satisfies the run-up height.</td></tr>
<tr><td>D-3</td><td>+4.0m</td><td>10m</td><td>+4.5m</td><td>1set</td></tr>
</table>

(1) Parapet

From the following reasons, a low parapet seawall is to be constructed on the shoreward side of the nourishment area.

- deal with increased wave overtopping as a result of anticipated sea level rise over the next 50 years between 11.5 (based on Funafuti Port data) and 19.0 centimeters (maximum value of IPCC fourth assessment report), and
- avoid having to undertake further nourishment to satisfy the wave runup.
- waves exceeding a 10-return year probability will wash the coral gravel onto the land, which will need to be cleaned-up.
- to clarify the boundary between the existing land and the newly nourished beach.

(2) Edge Treatment Dike

Judging from the calculation results by the coastal change predictive model, it was predicted that the protective function of the beach will decrease and the wave runup height will be not satisfied—due to longshore drift of nourished gravel. In order to prevent longshore drift of the gravel, it is necessary to construct the edge treatment dike. It is, however, preferable to make a final decision regarding the form of end treatment after the state of gravel transport has been confirmed in the field.

(3) Refilling of the Borrow Pits

Borrow pit is one contributing factor in wave overtopping, because waves runup directly onto the shore without their energy being dissipated due to the greater water depth. Further, in the long-term it will be preferable to refill these, when, in future, sand supply recovers, because they obstruct sediment transport. Target borrow pits are to be BP-1 and BP-2 in L-C Area, and BP-3-N in L-D Area, because of the anticipated sediment supply from the north.

9.2.2 Planting Design on Gravel Nourishment Areas

Planting is a part of artificial gravel nourishment. This planting will be carried out on the basis of community involvement from the stage of selection of planting species and construction. Operation and maintenance for planting is a sustainable activity for a prolonged period. Therefore, planting activities driven by voluntary participation of community resident will be promoted. Considering about the range and the shape of the gravel nourishment areas, 5 plots including one nursery are organized. The size of a plot is 20 square meters (2m×10m). The plot site is designed for coconut as principal tree at 1.0 m intervals. Around this principal tree "*Cocos*", *Scaevola taccada*" and "*Pandanus tectorius*" will be planted in the alternate shifts and aligned state.

9.3 Study on the Required Volume of Beach Nourishment Materials

9.3.1 Domestic Procurement of Gravel Material

It is expected that the beach nourishment materials would be procured as much as possible locally in Tuvalu. Regarding the places for domestic procurement of gravel material, the following places were selected.

a) Both ends of the islets in the southeast of Funafuti Atoll
(Funamanu Islet, Falefatu Islet and Mateika Islet)
b) Around the Existing Runway Area

9.3.2 Exploitable Gravel Volume and Actual Planned Gravel Mining Volume

The exploitable gravel volume and the actual volume of the planned mining gravel material for this plan are estimated as shown on **Table 9.2**.

Table 9.2 Exploitable Gravel Volume and Actual Planned Gravel Mining Volume

Item	Location	Exploitable Gravel Volume (m3)	Planed Gravel Mining Volume (m3)
B. Exploitable Gravel Resources			
B-1 Islets			
Funamanu Islet	North End	11,110	11,110
Funamanu Islet	South End	11,946	11,946
Falefatu Islet	North End	5,089	5,089
Falefatu Islet	South End	1,461	0
Mateika Islet	North End	4,915	0
	S/Total	**34,521**	**28,145**
B-2 Runway Area	(A) North End		
	(B)	5,355	5,355
	(C)	6,919	6,919
	(D)	1,680	1,680
	(E)	1,680	1,680
	(F) South End	9,138	9,138
	S/Total	5,950	5,950
B. Exploitable Gravel Resources Total		30,722	30,722
	Total	**65,243**	**58,867**

9.4 Proposed Works

The priority project to be implemented by this project, after considering its effectiveness as an overtopping countermeasure and issues regarding gravel procurement and its necessity, is the first recommendation in **Table 9.3**. If, however, the amount of gravel needed is expected to increase, other recommendations, from the second on, will be adopted in accordance

Table 9.3 Proposed Countermeasure Works

Work Item	Required Volume (m3)	Estimated Cost (Million Yen)	Plan-1	Plan-2	Plan-3	Plan-4
Direct Construction Cost						
L-C area						
Gravel Beach Nourishment	36,090	325.8				○
Parapet	1,077	36.3			○	○
Borrow Pit Backfilling BP-1	15,505	136.8		○	○	○
BP-2	7,119	62.8		○	○	○
L-D area (D-1, D-3)						
Gravel Beach Nourishment	52,191	134.8	○	○	○	○
Parapet	533	18.0	○	○	○	○
Borrow Pit Backfilling BP-3N	1,140	10.1		○	○	○
Direct Construction Cost (gravel mining, sand dredging)			248.6	308.2	324.5	324.5
Temporary Work, Indirect Cost and Engineering Fee			153.9	252.4	271.0	375.3
Total Required Volume (m3)			52,724	76,488	77,565	113,655
Estimated Cost (Million Yen)			555.3	923.1	994.3	1,424.4

to the amount. As the parapet work in L-C area by plan-3 achieves the effect of overtopping countermeasure in combination with nourishment work in L-C area by plan-4, this work is temporary work for plan-4. It notes that the wave runup height in L-C area will not be satisfied only by plan-3. **Figure 9.1** gives a plan view of the proposed works.

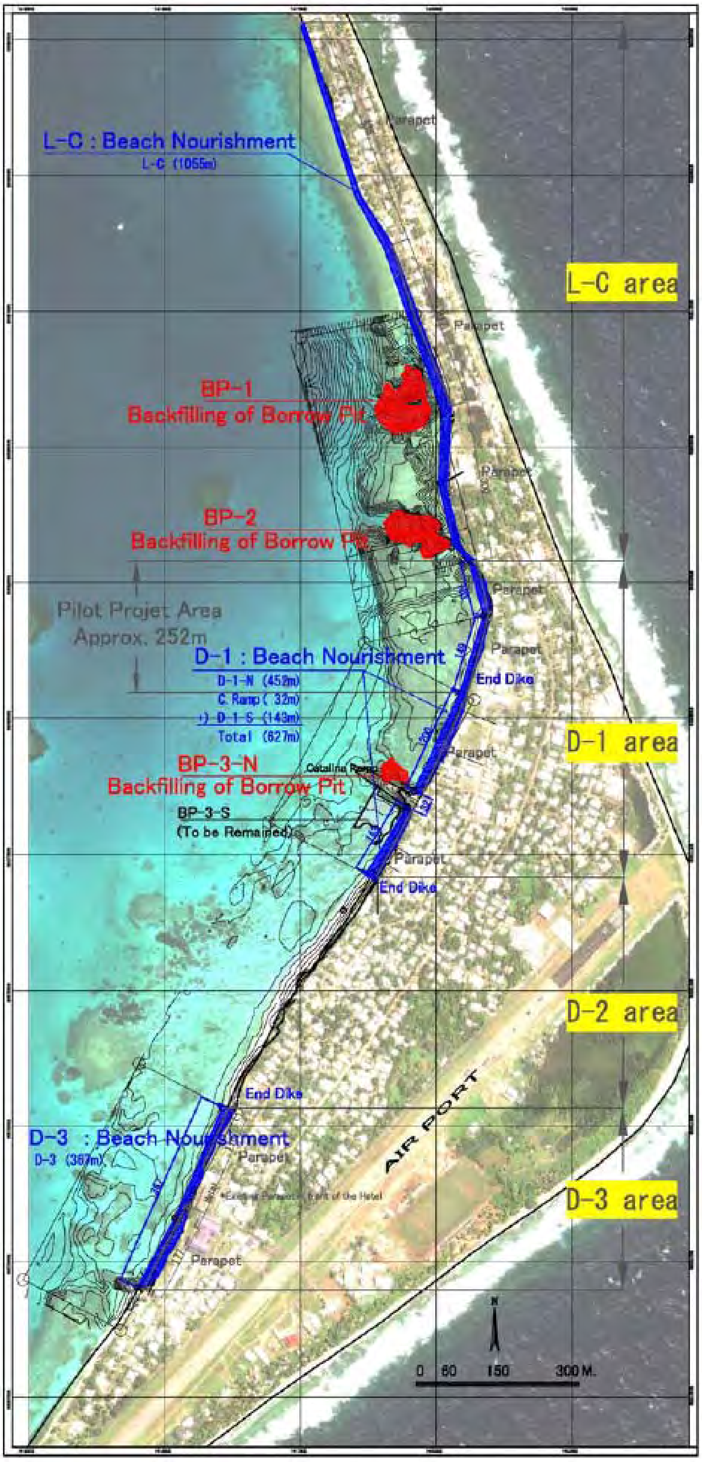


Figure 9.1 Plot Plan of Proposed Coastal Protection Measures

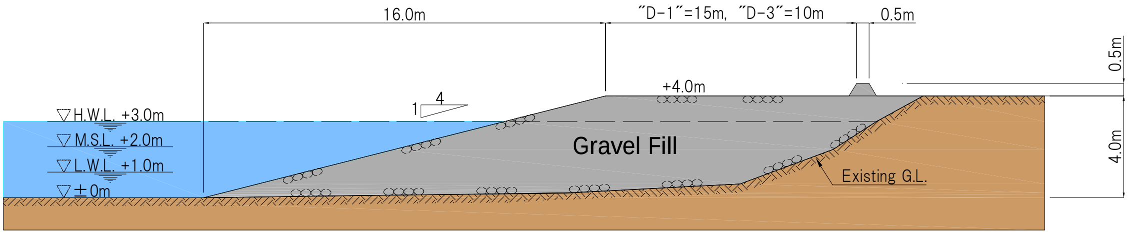
9.5 Construction Plan

9.5.1 Examination of Gravel Beach Nourishment Work

(1) Section of Gravel Beach Nourishment

Typical gravel beach nourishment work is as follows;

- The width of the back shore : 10m in the D-3 area and 15m in the D-3 area
- Crown Height : C.D.L.+4.0m
- Slope gradient: 1 : 4



(Note: Toe G.L. Depth ±0.0m, Highest Shore G.L.+4.0m)

Figure 9.2 Typical Section of Proposed Gravel Beach Nourishment Work

(2) Edge Treatment Dike (com fixed boat ramp)

This edge treatment dikes can be used as small boat ramps. Edge treatment dike (cum boat ramp) slope is designed as 1:6. Because Tuvaluan people push up wooden heavy boats by manpower, so it is difficult to set the boat ramp slope steeper than 1:6.

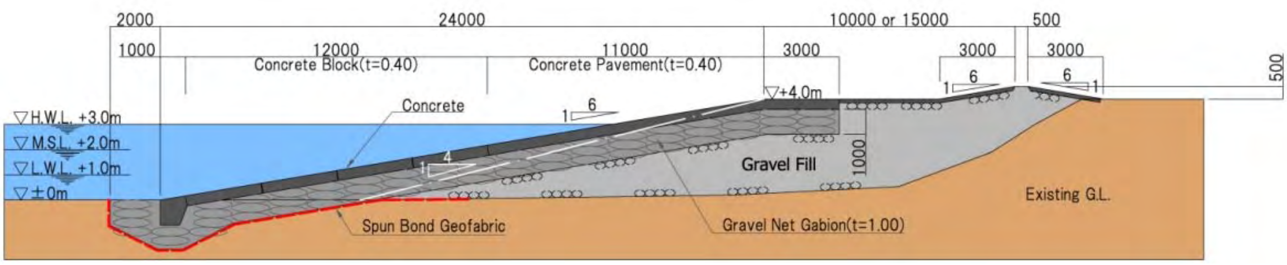


Figure 9.3 Typical Section and Plan of Proposed End Treatment Dike (Boat Ramp)

9.5.2 Borrow Pit Backfilling Work

When filling in the coastal borrow pits, basically, gravel is the safest and the most economical material. However in this project, due to lack of exploitable gravel volume (▲54,788m3) against required volume, it is necessary to use dredged sand as much as possible. When the dredged sand is backfilled directly in the coastal borrow pit, 1.Direct Backfilling Method, 2.Large sized Sand Bag Method and 3. Soil Cement Method are considered as the filling methods using the dredged sand for filling material. As any case of filling method is taken, it is necessary to protect sea side sloping entrance part and top flat surface by natural gravel of approx. 50cm in thickness to avoid erosion.

9.5.3 Material Collection Work

(1) Gravel Material Collection Work from the Existing Runway Area

The gravel collection work from the eastern side of the safety zone of the runway will be consisting of following works.

1. Excavation and taking out of gravel,
2. Replacing with dredging sand,
3. Leveling and Compaction and
4. Cleaning and withdrawal of equipment

(2) Gravel Material Collection Work from the Islets

The work includes; in southeastern islets of Funafuti Atoll (north and south end of the Funamanu Islet and north end of Falefatu Islet) , firstly, an excavator is unloaded from the barge, at high tide from the calm lagoon side. After the excavator lands on the gravel mining site, gravel is gathered by the excavator, it loads into a barge by dump tracks, and the gravel is transported by sea to Fongafale Island by a tugboat and a barge.

(3) Lagoon Sand Dredging

In the lagoon water area of Fongafale Island, a pilot dredging for experimental project had been carried out by SOPAC in the 1990's. This project included dredging lagoon sand and backfilling inland borrow pits, using a small dredging machine. So, it is planned to dredge sea sand from the lagoon bottom offshore of the Vaiaku Wharf where the pilot dredging had been executed by SOPAC. There are some dredging methods to be adopted for this size of the project, such as glove bucket dredging, sand pump dredging and air lifting dredging system. Therefore, a suitable dredging method is deemed to be an air lifting system, in consideration of operation and maintenance of equipment and cost. Dreading materials around this area are consisting of sand and some gravel fragments and/or fine fraction, but these are classified as (SF; Sand and Fine fraction), on the borderline between sand and silt, classified as (SF; Sand and Fine fraction). Therefore, it takes longer time to settle the impurity from dredging, and it diffuses to the larger area. In addition, there exist live coral patches and various livings in the vicinity. It should be planned to take necessary countermeasure to prevent impurity diffusion by such as silt protection fence.

9.5.4 Work Program

Work programs for each of the proposed projects are shown in **Figure 9.4**.

◆Plan-1 Gross Work Period: 11.5 months, Net Work Period: 9.0 months)

Item	Q'ty (m3)	Efficiency (m3/d)	Day	Month
Work in Local				9.0
Procurement, Preparation,Transport				4.0
Gravel Collection (Islets)	28,145	250	113	4.5
Gravel Collection (Runway)	18,923	250	76	3.0
Dredging	24,579	250	98	3.9
Beach Nourishment (Gravel)	46,535	500	93	3.7
Beach Nourishment (Sand)	5,656	160	35	1.4
Parapet	533	10	53	2.1
Borrow Pit (Gravel)	0	250	0	0.0
Borrow Pit (Sand)	0	250	0	0.0

◆Plan-2 Gross Work Period: 19.0 months, Net Work Period: 12.0 months)

Item	Q'ty (m3)	Efficiency (m3/d)	Day	Month
Work in Local				12.0
Procurement, Preparation,Transport				4.0
Gravel Collection (Islets)	28,145	250	113	4.5
Gravel Collection (Runway)	26,550	250	106	4.2
Dredging	48,343	250	193	7.7
Beach Nourishment (Gravel)	46,535	500	93	3.7
Beach Nourishment (Sand)	5,656	160	35	1.4
Parapet	533	10	53	2.1
Borrow Pit (Gravel)	7,627	250	31	1.2
Borrow Pit (Sand)	16,137	250	65	2.6

◆Plan-3 Gross Work Period: 21.5 months, Net Work Period: 15.0 months)

Item	Q'ty (m3)	Efficiency (m3/d)	Day	Month
Work in Local				15.0
Procurement, Preparation,Transport				4.0
Gravel Collection (Islets)	28,145	250	113	4.5
Gravel Collection (Runway)	30,722	250	123	4.9
Dredging	52,515	250	210	8.4
Beach Nourishment (Gravel)	46,535	500	93	3.7
Beach Nourishment (Sand)	5,656	160	35	1.4
Parapet	1,610	10	161	6.4
Borrow Pit (Gravel)	7,627	250	31	1.2
Borrow Pit (Sand)	16,137	250	65	2.6

◆Plan-4 Gross Work Period: 21.5 months, Net Work Period: 15.0 months)

Item	Q'ty (m3)	Efficiency (m3/d)	Day	Month
Work in Local				15.0
Procurement, Preparation,Transport				4.0
Gravel Collection (Islets)	28,145	250	113	4.5
Gravel Collection (Runway)	30,722	250	123	4.9
Dredging	52,515	250	210	8.4
Beach Nourishment (Gravel)	82,625	500	165	6.6
Beach Nourishment (Sand)	5,656	160	35	1.4
Parapet	1,610	10	161	6.4
Borrow Pit (Gravel)	7,627	250	31	1.2
Borrow Pit (Sand)	16,137	250	65	2.6

Figure 9.4 Work Program

9.6 Maintenance and Operation Plan

9.6.1 Maintenance Plan

(1) Items necessary for maintenance

For maintenance of the coastal protection works it is necessary to:

1. collect the gravel washed up onto land and return it back to the beach,
2. prohibit and policing of removal of sand and gravel from the coastal zone,
3. repair ancillary facilities such as the parapet and end treatment
4. policing of destruction of ancillary facilities such as the parapet and end treatment,
5. prohibit and policing of illegal acts such as dredging and coastal excavation that change the shape of the coast including storm ridge, and construction of seawalls, jetties, and breakwaters,
6. planting and recovery of coastal vegetation,
7. prohibit and policing of illegal cutting down of coastal vegetation, and
8. monitoring survey to grasp effect of works and environmental impact.

9.6.2 Monitoring Plan

(1) Items to be Monitored

A plan for the monitoring surveys as described below is required in order to understand the effects and impact of each of the erosion control works.

Table 9.4 Items to be Monitored and Outline of the Surveys

Survey item	Purpose and outline of the survey
Environmental Impact Assessment during the works (water quality, noise and vibration)	(Purpose) To understand the extent of spread of turbidity caused by the installation of gravel and noise created by the works (Outline) Turbidity and noise will be measured at representative points.
Topographic survey	(Purpose) To understand what changes in topography have been caused by the gravel beach nourishment (Outline) Topographic surveys will be conducted along representative lines stretching from roughly 30 m inland to roughly 200 m offshore from the shoreline, and fixed-point photography will be implemented.
Survey of sediment quality	(Purpose) To understand what changes in the condition of sediment quality, including changes in distribution of the gravel, have been caused by the gravel beach nourishment (Outline) Analysis and examination of grain size and composition, and photography with a selection of sediment samples collected at

	representative points.
Survey of marine organisms	(Purpose) To understand what changes in the state of marine organisms (including coral, algae and benthos) and of the seabed have been caused by the gravel beach nourishment (Outline) Divers will make visual observation of organisms and the condition of the sediment and take and maintain photographic and other records of changes in biota and sediment quality.
Survey of vegetation and scenery	(Purpose) To understand what changes in vegetation and scenery have been caused by the gravel beach nourishment (Outline) Photographic and other records of growth of the planted *Pandanus* and other plants and scenery will be taken at representative points and maintained.
Interview survey of coast users	(Purpose) To understand what impact this project has had on the conventional ways the coastal areas are used (Outline) Interviews will be held with fishery workers and local residents on the impact of this project. (Introduction of a monitoring system: Information will be collected from appointed Informants.)

(2) Monitoring Implementation Structures and Monitoring Plan

The organization described below is recommended for the implementation of monitoring after completion of the works. However, public institutions (governmental institutions and kaupules) in Tuvalu have little experience in monitoring these items. Local residents also have little experience in participatory projects and environmental monitoring. Therefore, the establishment of this kind of public-private partnership monitoring structure will require capacity development in

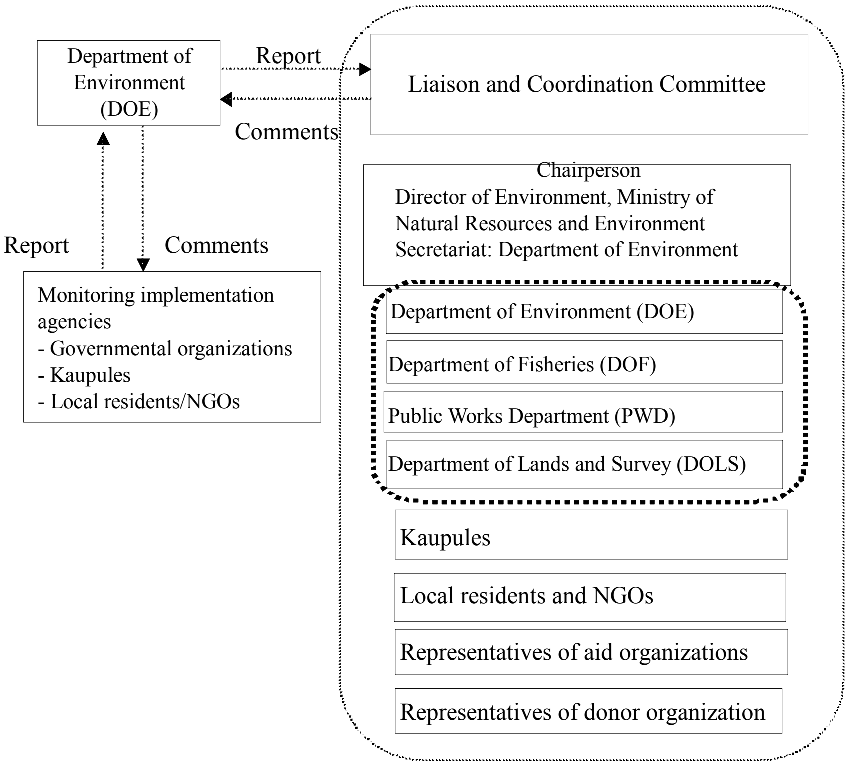


Figure 9.5 Structure of the Liaison and Coordination Committee for Continuous Monitoring

monitoring technologies.

The project schedule is to implement pilot works in the first year, to implement monitoring over the rainy season when high waves are generated in the lagoon, to evaluate the effect/impact of the gravel nourishment, to hold public hearings with residents, and where necessary to reflect these results in the project.

Table 9.5 Project Schedule

Content	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6 on
Works	(Apr.-Dec.) Pilot		(Apr.-Dec.) Main works	(Apr.-Aug.) Main works		
Monitoring (Stage 1)		(April-July)	(April-July)	(April-July)	(April-July)	
Monitoring (Stage 2)						(April-July)

9.6.3 Management Plan

Even if the Kaupule is enforcing the bans on illegal mining of the gravels and illegal cutting the plants and trees, they are not effective, because of people's superficial understanding of the adverse effects of the illegal mining and illegal cutting of the plants on the beach protection, and low awareness of the preservation of the beach. Strengthening the enforcement only will not make the bans effective. In addition to the cause and effect analysis, it was found that the residents have extremely limited knowledge about sea level rise; at the same time, there is serious fear of sea level rise. Therefore it is necessary that to hold awareness sessions on sea level rise and vulnerability of the islet against high wave, and after that, soft component as remedies for the real cause of the coastal disaster: high waves during high tide, by initiative of the ocean side residents.

The Government of Tuvalu is expected, on top of financial supports affordable by them for maintenance and management activities, to enact a statute which clearly defined that the ownership of the land to be reclaimed in the Project shall vest in the Crown and under the management of the Kaupule, as well as, to play the leading role in monitoring after completion of the work.

9.7 Cost Estimation

Necessary project costs for 4 alternative plans are shown in **Table 9.6**.

Table 9.6 Project Costs for 4 Alternative Plans

Work Item	Plan-1	Plan-2	Plan-3	Plan-4
Direct Construction Cost				
L-C area				
Gravel Beach Nourishment				○
Parapet			○	○
Borrow Pit Backfilling BP-1		○	○	○
BP-2		○	○	○
L-D area (D-1, D-3)				
Gravel Beach Nourishment	○	○	○	○
Parapet	○	○	○	○
Borrow Pit Backfilling BP-3N		○	○	○
Estimated Cost (Million Yen)	555.3	923.1	994.3	1,424.4

A pilot project is planned for the purpose of confirmation of opinions from local residents, and verification of water current and gravel behavior of the beach nourishment material in the borrow pit and of appropriateness of filling materials and work methods.
When gravel beach nourishment work is executed in D-1 area (approx. 252m), the necessary costs are estimated as follows.

Pilot Project Plan-1 (use runway gravel):	approx.153.4 millions Japanese Yen
Pilot Project Plan-2 (use islets gravel):	approx. 84.6 millions Japanese Yen
Pilot Project Plan-1 (use import gravel):	approx.117.0 millions Japanese Yen

CHAPTER 10 **FINANCIAL & ECONOMIC ANALYSES**

10.1 Policy of the Cost Benefit Analysis

10.1.1 Term of Evaluation

Although the target year of this project is 2020, the term of evaluation of this project is determined as fifty years because the nourished beach will remain.

10.1.2 Estimate of Amount of Damages

Benefits of measures for coastal defense are calculated based on the following equation.

Benefits of measures for coastal defense
=Benefit of defending from flood water + Benefit of defending from erosion + Benefit of defending from wind-blown sand and sea water spray + Benefit of coastal environment preservation + Benefit of good use of the coastal area + Benefit of Increased land

= Disaster damages to be avoided + Benefits to be created by implementation of the Project

= (Damage without measures for coastal defense – damage with measures for coastal defense) + Benefits created

Based on the data acquired in the Questionnaire Survey, applying the Economic Survey Manual for Flood Control Project in Japan, monetary values of losses will be estimated. Intangible losses such as human loss, injures and diseases during/after flooding will be estimated applying the guideline of Department of Environment, Food and Rural Affairs, UK.

10.2 Financial Analysis

It is recommended that the chosen discount rate for cost-benefit analyses of DRM measures in Pacific Island Countries be used on the rate chosen for previous similar studies elsewhere or using a domestic benchmark, such as the real interest rate in the country concerned. In “A preliminary economic analysis of extracting aggregate from the Funafuti Lagoon” by SOPAC 10 percent, 7 percent and 3 percent of the social discount rates are used. The interest rate for saving accounts of the Tuvalu National Bank as of September, 2010, is at 1.5 percent. In this analysis, we use 1.5 percent as the social discount rate.

10.2.1 Financial Internal Rate of Return

Internal Rate of Return is the discount rate which make equal the value of the present investment cost to the cash flow of NPV expected for the future. Financial Internal Rate of Returns (FIRR) of the alternative plans for the Project are shown as follows. The largest FIRR is that of Plan-1 and the smallest is of Plan-4.

Table 10.1 Financial Internal Rate of Return

	FIRR
Plan-1	9.60 %
Plan-2	5.93 %
Plan-3	5.42 %
Plan-4	3.25 %

10.3 Economic Analysis

10.3.1 Result of the Economic Analyses

Summary of the economic analyses are shown in the following table.

Table 10.2 Summary of Economic Analyses (In Case Gravel be Procured Locally)

	Plan-1	**Plan-2**	**Plan-3**	**Plan-4**
NPV (1.5 %)	Au$ 19,034,353	Au$ 16,896,621	Au$ 16,246,361	Au$ 11,390,156
CBR(1.5 %)	419 %	267 %	251 %	173 %
EIRR	11.60 %	7.25 %	6.77 %	4.28 %

The best EIRR is 11.6 % for the Plan-1. EIRRs for the Plan-2 and Plan-3 are over 6 % and these plans deem feasible, however EIRR for the Plan-4 is below 5 %, which seems rather low for an infrastructure construction project in the developing country.

Summary of the economic analyses in the case of importation of gravel are shown in the following table.

Table 10.3 Summary of Economic Analyses (In Case Gravel be Imported)

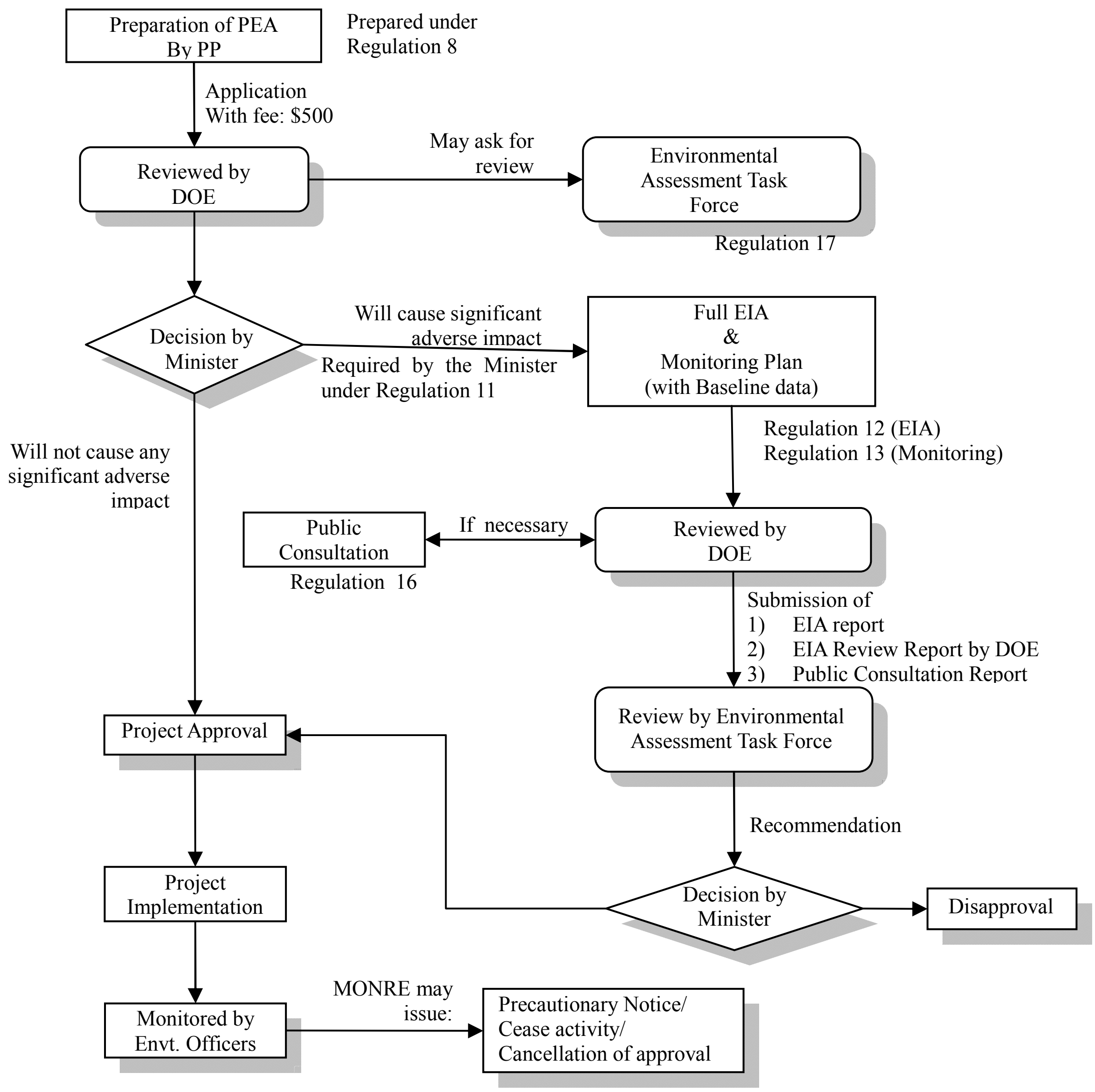
	Plan-1	**Plan-2**	**Plan-3**	**Plan-4**
NPV (1.5 %)	Au$ 18,009,842	Au$ 17,0869,842	Au$ 26,928,918	Au$ 26,928,918
CBR(1.5 %)	357 %	273 %	259 %	163 %
EIRR	9.86 %	7.41 %	6.99 %	3.95 %

In the cases gravel be imported, the best EIRR is 9.86 % for the Plan-1, though it is lower than the EIRR in the case gravel be procured locally. For the Plan-2 and Plan-3, EIRRs in case of importation of gravel are better than those of local procurement. However, it is necessary to have an EIA for dumping fumigated gravel in the lagoon on a massive scale, and a general consensus over whether it is appropriate to import the aggregate although it could be procured locally. For the Plan-4, as EIRR in the case of importation of gravel is lower than that of local procurement, it is found not feasible.

CHAPTER 11 ENVIRONMENTAL AND SOCIAL CONSIDERATION

11.1 Preliminary Environmental Assessment (PEA)

Preliminary Environmental Assessment (PEA) was submitted to Department of Environment (DOE) as an outline of the project is formulated. Preparation of an EIA report would be necessary if significant impact is expected by DOE, and so decided by responsible Minister.



DOE: Department of Environment, MONRE
EIA: Environmental Impact Assessment
Minister: Minister of MONRE
MONRE: Ministry of Natural Resources and Environment
PEA: Preliminary Environmental Report
PP: Project Proponent

Figure 11.1 Draft EIA Procedure of Tuvalu

11.2 Mitigation Measures

Followings in the Table below are particulars which may be affected by the project obtained by PEA. The mitigation measures for each is also shown considered.

Table 11.1 List of Impacts Mitigation is Required

Impacts on:	Phase		Negative Impacts
	Const-ruction	Opera-tion	
Existing infrastructures and services	-d	-b	(1) Enlarged beach and a parapet may be the obstacle to loading/unloading of fishing boats. The detail should be modified for the inconvenience. (2) Loosing deep areas used for mooring and navigation channel for fishing boats for dissipating waves should be understood and supported by the residents. (3) Gravel will bury Jetty for Amatuku commuting boats. The jetty must be replaced and the function has to be kept.
Local conflict of interests	-d	-a	(4) Land tenure of nourished area could well be controversial. Legal land owner and utilization rights must be clarified before construction.
Water usage, Water rights, Communal rights	-d	-b	(5) Commuting use, fishery use (including mooring), and free access to the beach should be maintained.
Flora, Fauna, Biodiversity	-b	-d	(6) When gravels are to transport from sand spit of Funamanu Islet, Falefatu Islet, and Mateika Islet, bulge might interfere with coral around of the islets. Appropriate transplanting work must be carried out.

Grade:
-a: Serious impact(s) is (are) expected
-b: Less serious impact(s) is (are) expected
-c: Impact not known without further research
Note: Progress of project itself may reveal the impact (further research is not necessary, in this case)
-d: Negligible impacts are expected or no impact is expected

11.3 EIA Procedures Followed

"Coral reef" is listed as a one of the most vulnerable area which may incur significant environmental by a project in JICA Guideline for Environmental and Social Considerations. At the stage of specification of the design are being formulated, following consideration should be taken for less impacts on the project site: specific dimension of gravel nourishment, structures for retaining gravels at the end, partial modification of parapet, areas of filling deep ditches which made by U.S. Navy, amount of excavation of gravel from islets, method of excavation, transplanting of living coral reef.

CHAPTER 12 RECOMMENDATIONS AND FURTHER ISSUES

Recommendations and further issues toward implementation of the Project are as follows;

(1) Clarification of Land Ownership of the Beach Reclaimed through This Project

(2) Gravel Collection Construction on the Safety Zone of the Runway and the Displacement Construction by Sea Sand

(3) Soft Components Countermeasure regarding Coastal Disaster

(4) Operation of Pilot Construction

(5) Development of the Organization of Operation and Maintenance

(6) Capacity Strengthening of Monitoring Technology

・Training technologies for Tuvaluan government and Fale Kaupule
・Training participatory monitoring
・Technological transfer for participatory planting on the coast

(7) Development of Environmental Impact Assessment in Tuvalu

(8) Setting the Ramp