4.4 Water Quality and Bottom Sediments

4.4.1 Water Quality

(1) Existing Data

On Funafuti, the domestic sewage (fecal and non-fecal wastewater) of about 5,000 people is seeping into the ground, either untreated or only after simple treatment. Many of the families keep swine, reportedly 4.2 pigs per household on average. Sewage from pigsties flows out mostly untreated into borrow pits and ponds and onto ground surface and seeps into the ground. At waste disposal sites, garbage is dumped mostly untreated and unsegregated. In Tuvalu where there are no large plants or farms, principal sources of water contamination are considered to be domestic sewage, animal sewage (pigsties), and sewage from the waste disposal site.

Thus, inappropriate sewage and waste disposal in the land area is considered to be affecting groundwater and coastal seawater. However, no water quality surveys have been conducted on groundwater, water in ponds, or coastal seawater. Only simple water analyses of conductivity are carried out in specific areas.

The waste disposal project supported by AusAID is conducting water quality surveys for E coli., nitrites, nitrates and phosphates on groundwater, coastal seawater on lagoon side, and water in rainwater storage tanks in June 2005 (Economics of Liquid Waste Management in Funafuti, Tuvalu; 2006). The result of this study suggests that the ground water is highly contaminated with faecal matter as shown in **Table 4.17**. However, this survey using a simplified water analysis kit has produced analysis results with low accuracy and hardly identified the water quality conditions of groundwater or coastal seawater.

Table 4.17 Water Quality Assessment in June 2005

Water Source	Bacterial Count	Nitrites	Nitrates	Phosphates
Ground water (North of Luck set)	>130	0	0	< 10
Lagoon water (old jetty)	> 62	0	0	< 10
Rainwater tank (Control) (Tausoa Lima, southern tank)	< 50	5	0	< 10

Source: Water Quality Report, June 2005, Waste Management Unit, Funafuti.

Conductivity measurements were carried out between January and April 2006 in order to monitoring increased salinity of groundwater in pits used to cultivate swamp taro or pulaka (Arthur Webb). This study attempts to determine, through accurate conductivity measurement, the present condition of groundwater quality (salinity) within the pits throughout Tuvalu.

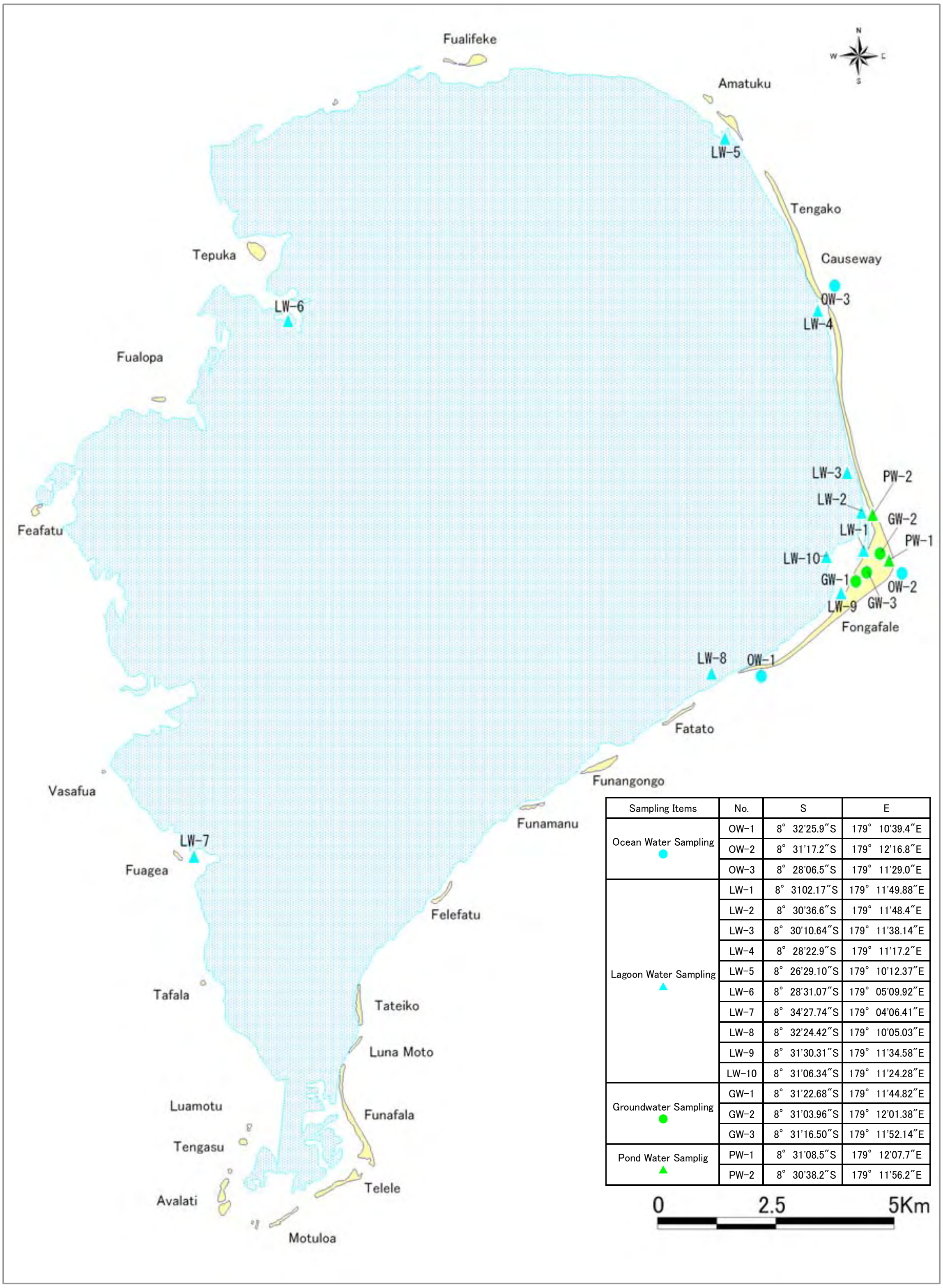
The water sampling was performed in the central part of Fongafale islet. Rainfall conditions during are though to reflect average conditions for this time over the year and as such the conductivity data collected should be a representative of ambient groundwater conditions. The results show too high salinity concentration ($>5.000\ \mu S\ cm^{-1}$) for successful swamp taro growth. This means that the swamp taro production is unlikely to succeed anywhere on Fongafale islet (SOPAC ER-75).

(2) JICA Study

The water quality survey was conducted at 18 points on the entire Funafuti atoll, ocean, pond and groundwater as shown in **Figure 4.34** and **Table 4.18** during December 2009 to January 2010 of the baseline survey by JICA Study. Collected samples were analyzed at laboratories in Fuji and Japan.

Table 4.18 Detailed Information of Water Sampling

Station No.		Main Study	Complementary Study	Remarks
Measurement/Analysis Items		Salinity, Chlorophyll, COD, T-N, T-P etc.	T-N, NH_4-N, NO_3-N, T-P, PO_4-P	
Ocean	OW- 1	○		Southern End
	OW- 2	○	◎	
	OW- 3	○	◎	Causeway
Lagoon	LW- 1	○	◎	
	LW- 2	○	◎	
	LW- 3	○	◎	
	LW- 4	○		Causeway
	LW- 5	○		Amatuku
	LW- 6	○		Tepuka
	LW- 7	○		Fuagea
	LW- 8	○		Fatato
	LW- 9	○	◎	
	LW-10	○	◎	
Groundwater	GW- 1	○		
	GW- 2	○		
	GW- 3	○		
Pond	PW- 1	○		
	PW- 2	○	◎	
Total		18 points	8 points	
Date of Sampling		January 6 to 10, 2010	December 13, 2009	



Sampling Items	No.	S	E
Ocean Water Sampling ●	OW-1	8° 32'25.9"S	179° 10'39.4"E
	OW-2	8° 31'17.2"S	179° 12'16.8"E
	OW-3	8° 28'06.5"S	179° 11'29.0"E
Lagoon Water Sampling ▲	LW-1	8° 3102.17"S	179° 11'49.88"E
	LW-2	8° 30'36.6"S	179° 11'48.4"E
	LW-3	8° 30'10.64"S	179° 11'38.14"E
	LW-4	8° 28'22.9"S	179° 11'17.2"E
	LW-5	8° 26'29.10"S	179° 10'12.37"E
	LW-6	8° 28'31.07"S	179° 05'09.92"E
	LW-7	8° 34'27.74"S	179° 04'06.41"E
	LW-8	8° 32'24.42"S	179° 10'05.03"E
	LW-9	8° 31'30.31"S	179° 11'34.58"E
	LW-10	8° 31'06.34"S	179° 11'24.28"E
Groundwater Sampling ●	GW-1	8° 31'22.68"S	179° 11'44.82"E
	GW-2	8° 31'03.96"S	179° 12'01.38"E
	GW-3	8° 31'16.50"S	179° 11'52.14"E
Pond Water Samplig ▲	PW-1	8° 31'08.5"S	179° 12'07.7"E
	PW-2	8° 30'38.2"S	179° 11'56.2"E

Figure 4.34 Location Map of Water Sampling

The results of water quality measurements were shown in **Table 4.19** for salinity, water temperature, turbidity, color and chlorophyll-a. **Table 4.20** and **Figure 4.35** show the analyzed result and distribution of nitrogen and phosphorus by the high-precision water quality analysis in Japan. A coral eco-system commonly distributed in an oligotrophic area is said to be seriously influenced by the eutrophication of the sea area due to the inflow of inland water that contains a large amount of phosphorus, nitrogen, etc.. For the conservation of coral reef, Japan has such environmental water quality criteria as T-N≦0.2 mg/l and T-P≦0.02 mg/l. When the coastal seawaters in the area concerned are compared with these criteria, all the T-N values meet the criterion but some of the T-P values on lagoon side near the coast (LW-3 & LW-9) do not meet the criterion.

Referring to the threshold values from the study on eutrophication of coral reefs in the Great Barrier Reef and the Caribbean Sea, the water quality analysis results in JICA Study revealed that both the concentration of inorganic nitrogen (NH_4) and inorganic phosphorus (PO_4) exceed the threshold values at LW-3 and Lw-9 points near the coast on lagoon side. Thus, the nitrogen and phosphorous concentrations are higher than the Japanese water quality criteria and threshold values of eutrophication at part of the area near the coast on lagoon side, leading to fears about possible influence of eutrophicatio on the coral.

Table 4.19 Result of Water Quality Measurements

Sample	Water Depth	Sampling Depth	Salinity (ppt)	Temperature (℃)	Turbidity (NTU)	Color	Chlorophyll-a (μg/ℓ)
PW1	0.5m	-	31	34.9	2.0	41.5	9.08
PW2	1m	0.5m	36	35.0	1.9	13.5	3.63
OW1	5m	2.5m	35	29.7	0	0	ND(<0.05)
OW2	15m	7.5m	37	29.2	0	0	0.22
OW3	12m	6m	36	29.1	0	0	0.15
LW1	3m	1.5m	36	30.7	0	0	0.11
LW2	7m	3.5m	37	30.9	0	0	ND(<0.05)
LW3	18m	9m	36	30.6	0	0	ND(<0.05)
LW4	7m	3.5m	37	30.6	0	0	ND(<0.05)
LW5	13m	6.5m	37	30.3	0	0	ND(<0.05)
LW6	15m	7.5m	35	30.8	0	0	0.11
LW7	2m	1m	37	32.2	0	0	ND(<0.05)
LW8	29m	14.5m	37	33.0	0	0	0.11
LW9	2m	1m	37	32.8	0	0	0.22
LW10	1m	0.5m	37	32.4	0	0	Sample lost
GW1	0.5m	-	21	28.8	0.8	6.5	0.91
GW2	0.5m	-	7	31.5	2.3	8.0	0.45
GW3	1m	0.5m	5	29.3	0	22	0.23

Table 4.20 Result of Water Quality Analyses (Complementary Study)

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

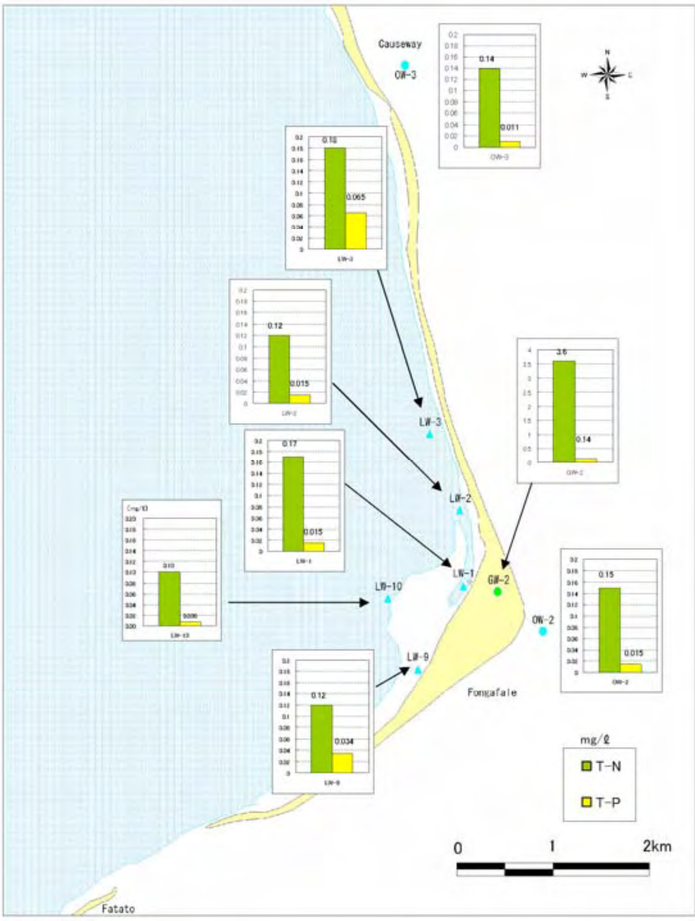


Figure 4.35 Distribution Map of T-N and T-P

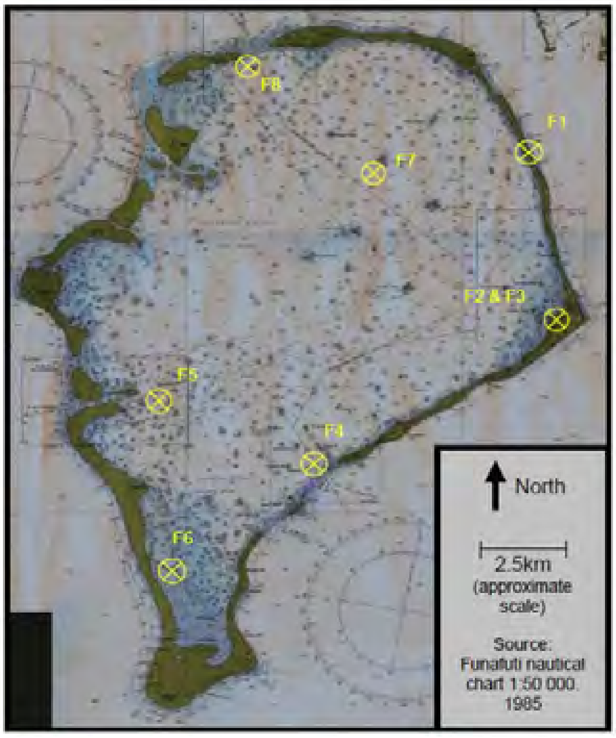
On the other hand, the chlorophyll-a concentration in seawaters is ≤0. 05 μ g/l or 0.1 to 0.2 μ g/l in the overall for the area, suggesting that eutrophication has not reached a level where it influences the growth of coral.

The quality of groundwater (well water) shows high values of T-N (3.6 mg/l) and T-P (0.14mg/l), meaning that the well water is contaminated.

4.4.2 Sea Bottom and Shoreline Sediments

(1) Existing Data in Lagoon and Tafua Pond

The study for the composition and grain-size analysis of sediment samples in Funafuti lagoon was carried out between September and October 2004 (Arthur Webb). Eight sand samples in Funafuti lagoon as shown in **Figure 4.36** were collected from the upper 15 cm (three samples were also collected in Vaitupu).



(Source: SOPAC ER-36)

Figure 4.36 Location Map of Sediment Samples in Funafuti Lagoon

The result of the sediment sample composition analysis shows a predominance of Foraminiferal tests (40–60 %) in shallow lagoon and terrestrial sediment from Funafuti. Otherwise, Halimeda greatly dominated the composition of deeper lagoon samples (**Figure 4.37**). On the other hand, the result of the grain-size analysis shows that F1 sample from land and F3 sample from beach deposit have comparatively low percentages of Halimeda and at least 60 % of these sands are composed of granules between 0.25 and 1.4 mm ϕ (**Figure 4.38**).

Deeper channel deposits F4 and F5 samples contained a large Halimeda component (>35 %) and also contained a greater percentages of coarse material (2 - 4 mm ϕ ; >35 %). F6 sands from the southern lagoon area contained a comparatively large percentages of fines (<0.125 mm ϕ ;

>60 %) and were almost entirely Halimeda-derived. The remaining samples F2, F7 and F8 are comparable to beach and land deposits in grain size (approximately 60 % lying between 0.25 and 1.4 mm ϕ) but had higher percentages of Halimeda (20–25 %) (SOPAC ER-36).

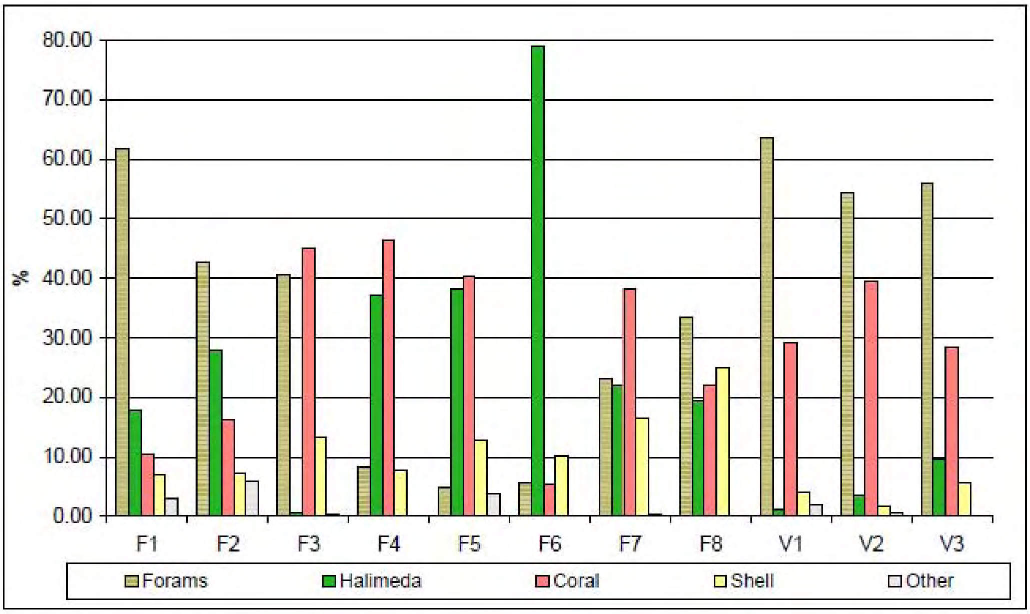
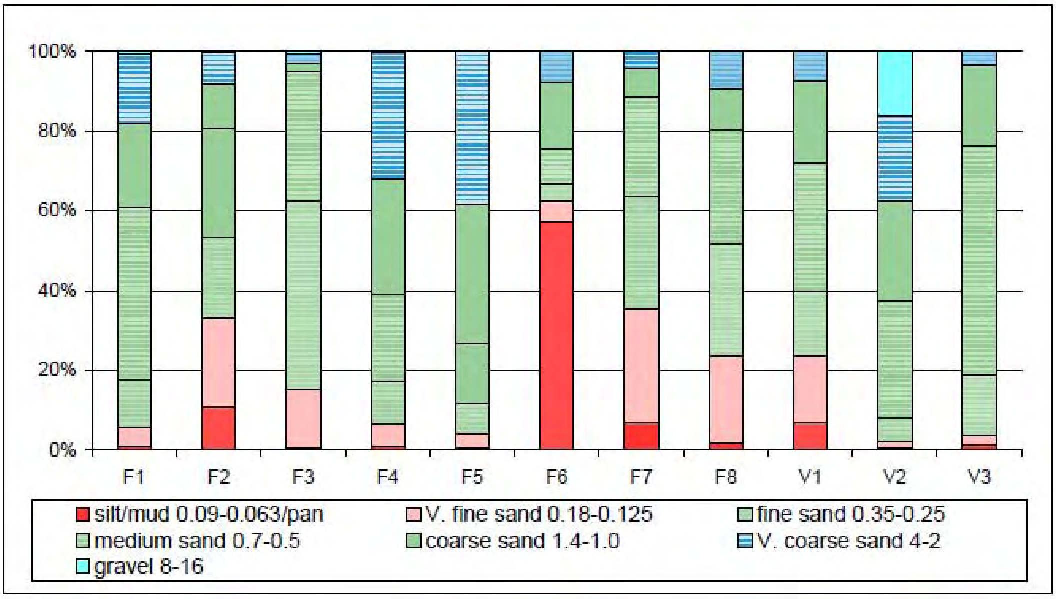


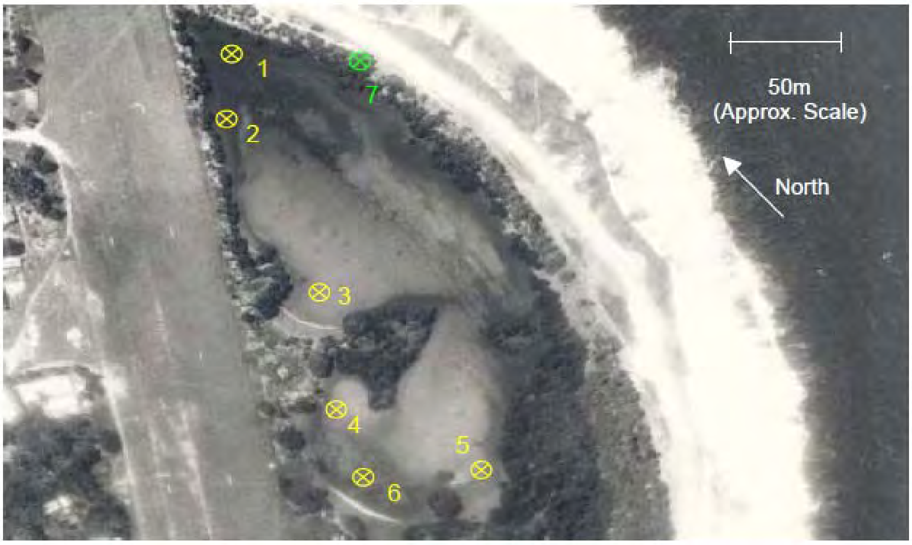
Figure 4.37 Comparative Composition of Sediment Samples



(Source: SOPAC ER-36)

Figure 4.38 Grain-size Analysis of Sediment Samples

On the other hand, the study for the analysis of nitrogen, lead and copper for sediment samples in Tafua pond was carried out by SOPAC in cooperation with TANGO and IWP (International Water Project) in September 2004. Seven sediment samples were taken from the western side. The 7th sediment sample was collected and analyzed as a control, which was collected from a comparatively undisturbed area on the leeside of the fore-dune between the pond and the ocean (site No.7 on **Figure 4.39**).



(Source: SOPAC ER-36)

Figure 4.39 Location Map of Sediment Samples in Tafua Pond

The results of the chemical analyses are shown in **Table 4.21**. Groundwater is no longer used for human consumption on Fongafale as it is often brackish but also because of the known risks of bacterial, metal and nutrient contamination. The IWP indicated that concentrations of both copper (Cu) and lead (Pb) have been found to be of concern in ground water samples elsewhere on Fongafale and the Tafua samples were analyzed for the presence of both metals (elevated concentration of Cu and Pb is presumably related to ordinance haphazardly dumped and buried by the US forces in the early 1940's).

It is important to consider the level of contamination of Tafua as it is possible that persistent metals may transfer up the food chain due to bioaccumulation in food species (milkfish) and become a human health issue. This is also an important consideration if tilapia are to be used as a pig food as a similar accumulation could occur.

Total nitrogen was also analyzed, as in brackish and marine systems the availability or nitrogen usually limits primary production (algal growth). Sediment-nutrient concentrations in turn can give an indication of the level of nitrogen enrichment in shallow systems as much of the organic matter produced and added to the system settles in the sediments. Once this material enters the sediment environment, redox (anoxic/oxic) reactions act to recycle and return the nitrogen to the water column for subsequent use by primary producers, or nitrogen may also be removed from the system by sedimentary processes.

Due to these processes and other factors (tide, rainfall, loading, weather, etc.) water column nitrogen concentrations may vary considerably in such as all water body over short time intervals and the storage of nitrogen in the sediments gives an overall indication of enrichment particularly when compared with the control sediments (SOPAC ER-36).

Table 4.21 Results of Total Nitrogen, Lead and Copper

Site	Unit	1	2	3	4	5	6	7(Ctrl)
T-N	mg/kg	180.0	8.3	23.2	22.7	17.9	7.6	0.5
Pb	mg/kg	45.7	50.0	37.3	21.2	21.6	19.0	16.7
Cu	mg/kg	125.7	72.2	94.1	60.6	54.4	34.4	16.8

(2) JICA Study

The sea bottom and shoreline sediments survey was conducted at 35 points on the entire Funafuti atoll as shown in **Figure 4.40** and **Table 4.22** on October 2009, as the baseline survey of JICA Study. Collected samples were analyzed at laboratories for the grain size analysis and the constituents analysis such as coral fragments, foraminifera, shell fragments and Halimeda.

Table 4.22 Detailed Information of Sediments Sampling

Samples	No. of Sampling Points	Sampling Station	Item of Analysis	Date of Sampling
Sea Bottom Sediments	15 points	SB- 1 to SB-15	Grain Size Analysis Constituents Analysis	Oct.22 to 30, 2009
Shoreline Sediments	20 points	SLS- 1 to SLS-20		
Total	35 points			

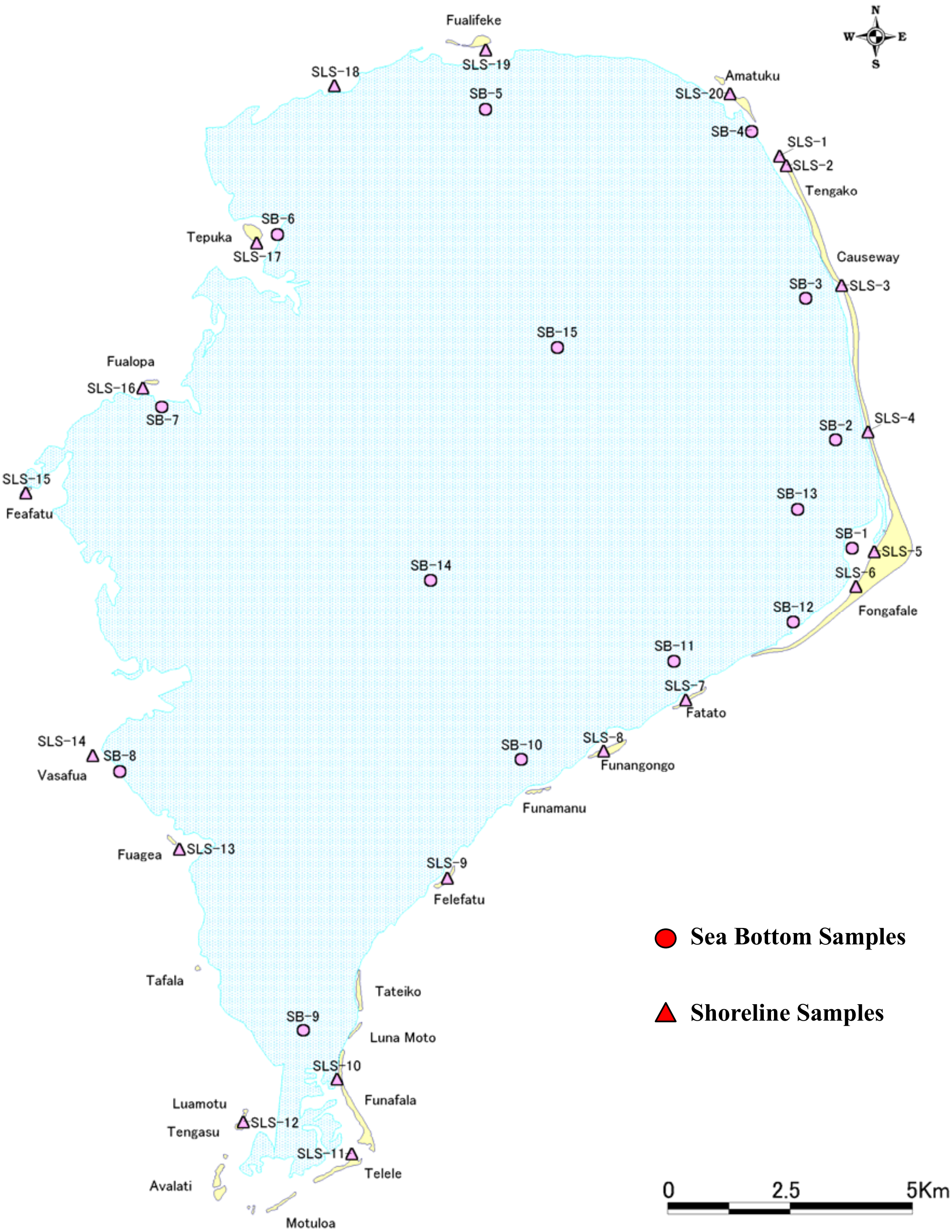


Figure 4.40 Location Map of Sediment Sampling

The results of the grain size analysis and constituents analysis are shown in **Figure 4.41** and **Figure 4.42**, respectively.

The distribution of the grain size composition (**Figure 4.41**) shows that the sea bottom sediments will be divided into three zones. The first zone is distributed in the north and west part of lagoon, and composed of fine to coarse sands, partly silts (SB-4 to SB-9). The offshore area from the central to south part of Fongafale islet is also included in this zone (SB-1, SB-12 & SB-13). The second zone is distributed in the offshore area of the north part of Fongafale islet (SB-2, SB-3) and in the southeast part of lagoon (SB-10, SB-11) , and composed of coarse to granule sands and pebble gravel. The third zone is widely distributed in the central part of lagoon and composed of granule sand and pebble gravel (SB-14, SB-15).

Regarding to the shoreline sediments, the distribution of the grain size composition shows that the shoreline sediments will be widely divided into two zones. The first zone is distributed in the northern part of Fongafale islet, and in the north and west part of lagoon, and composed of medium to granule sands and pebble gravel (SLS-1, SLS-2, SLS-13 to SLS-20 and SLS-7). The second zone is distributed in the shoreline area of Fongafale islet, and in the shoreline of the southeast and south parts of lagoon, and mainly composed of fine to coarse sands (SLS-3 to SLS-6, SLS-8 to SLS-12).

The distribution of constituents percentages(**Figure 4.42**) shows that 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 (SB-1, SB-12), and samples in the north part (SB-4) and the west part (SB-6 to SB-8) 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 (SB-5), the south and southeast parts of lagoon (SB-9 to SB-11), and the offshore area of the lagoon (SB-13 to SB-15) consisted of 51 % to 91 % Halimeda as a dominant constituent.

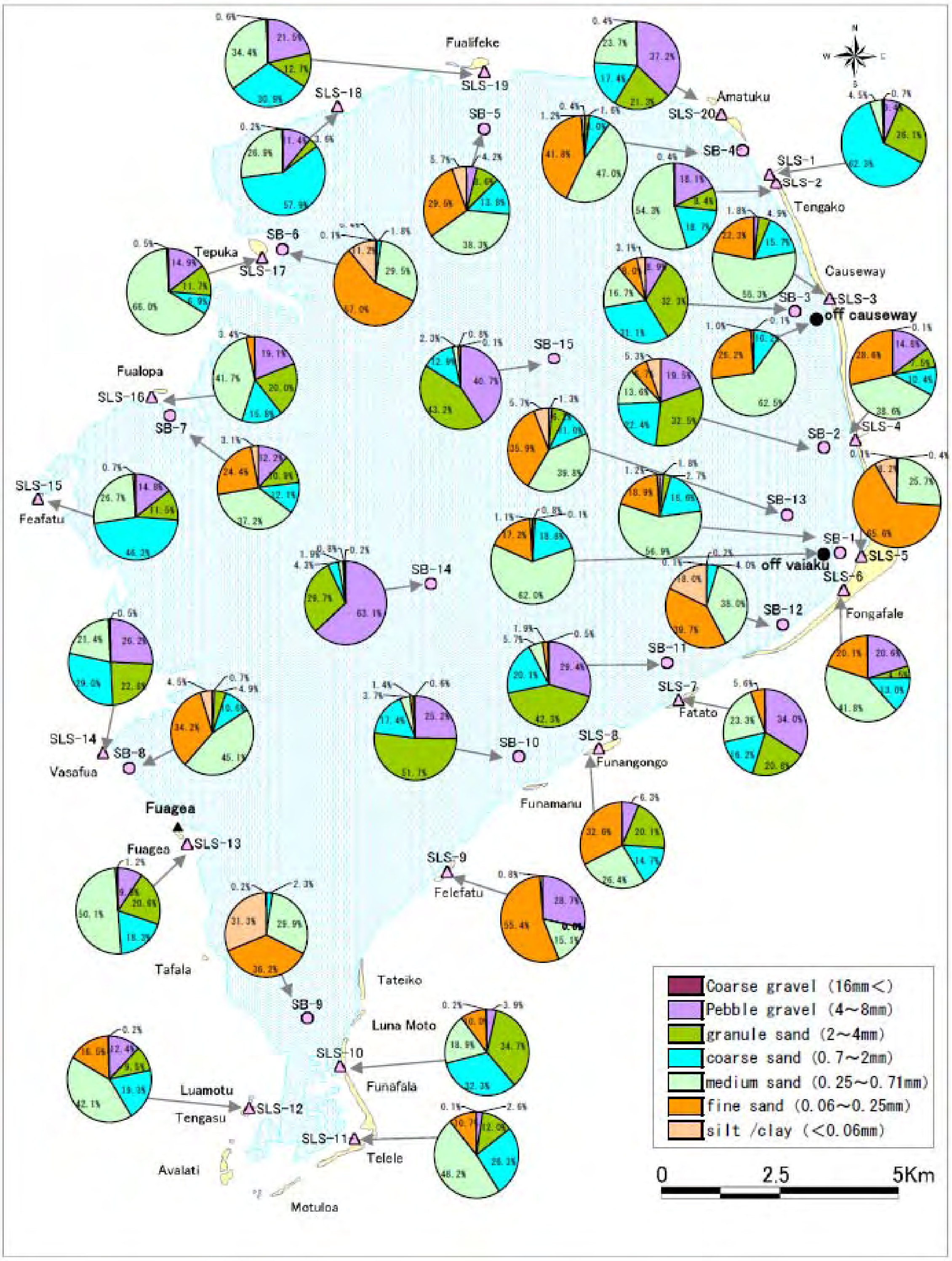
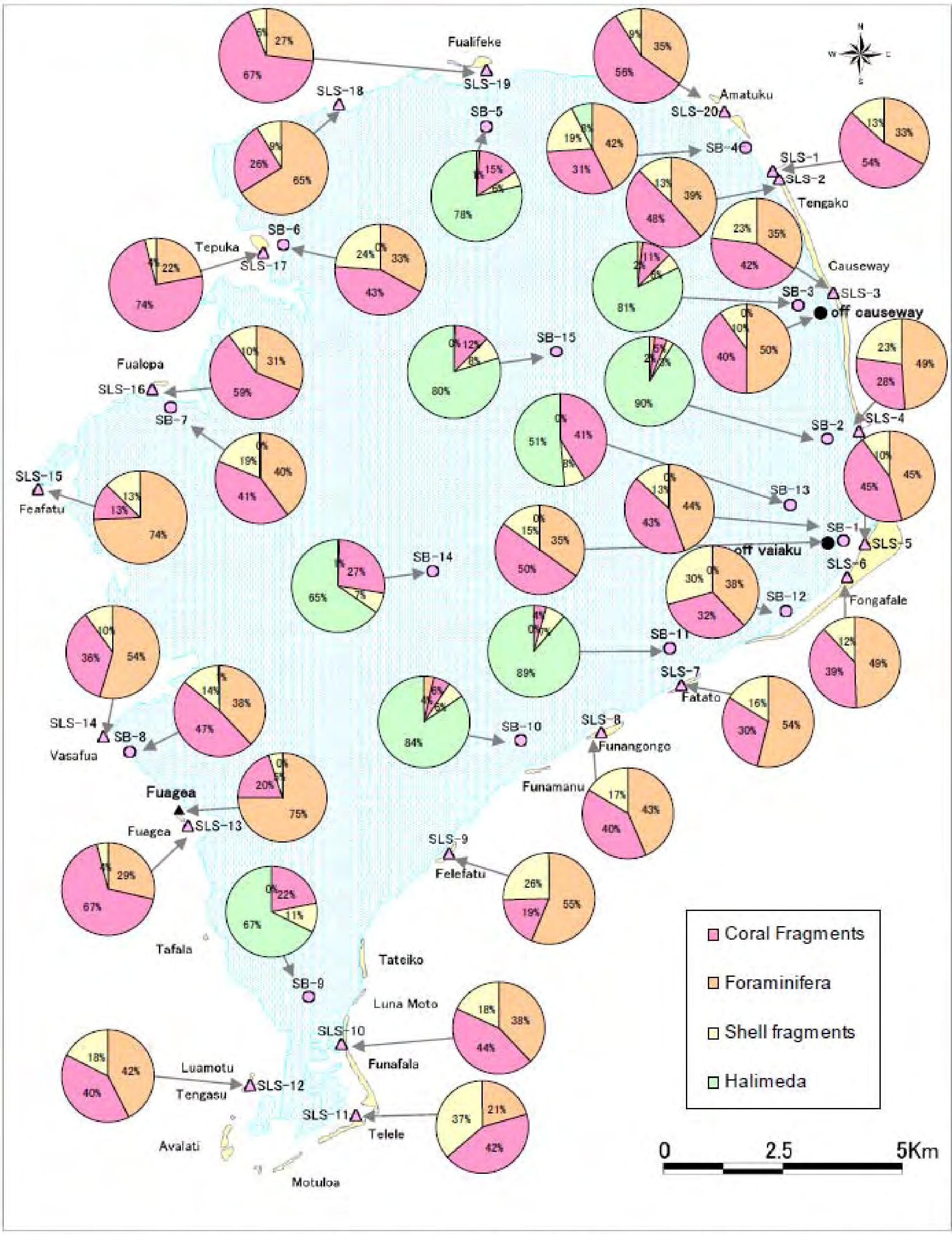


Figure 4.41 Distribution of Grain Size Composition



Note: The percentages for the three points, Off Causeway, Off Vaiaku, and Fuagea are the results of visual inspection.

Figure 4.42 Distribution of Constituents Percentages

4.5 Coastal Ecosystem Survey

4.5.1 Distribution of Foraminifera

(1) Line Survey on the Distribution of Foraminifera, etc.

1) Description of Survey

A line 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. **Table 4.23** shows the survey item and description.

Table 4.23 Survey Item and Description

Item	Quantity	Remarks
[Line survey] Survey line	A set of 31 lines	16 lines on the ocean side and 15 lines on the lagoon side Life form and bottom sediment distribution (Cross-section: Coverage distribution of foraminifera, coral, and marine algae and the distribution of species) Quadrat survey results (Identification and counting results)

2) Line Survey Area

The line survey was conducted on the 31 lines in the entire atoll of Funafuti shown in **Figure 4.43** .

3) Line Survey Duration

Table 4.24 shows the line survey duration.

Table 4.24 Line Survey Duration

Survey item	Observation duration
Line survey	17.09.2009 to 06.10.2009

Figure 4.43 Line Survey Location Map

4) Line Survey Method

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. The positions of laying the survey lines were measured using a simple GPS (geographical coordinate system: WGS84).

In the ecological survey, visual observation by divers (ecological research staff) was carried out as **Figure 4.44** below indicates in order to record the distribution (sectional distribution) of corals, algae, bottom materials (rocks, coral pieces, foraminifers and shell pieces). At the same time, the zonal distribution structures on each traverse line were taken down according to the distance from the strand line with coverage of the key species. We set the starting point of traverse line at the place where terrestrial plant is growing above the shore line. We determined the end point of the line at the place where coral zone is verified or water depth becomes deep rapidly. On each traverse line, we established 2 ~ 8 crop-cutting experiment point. We obtained a total of 90 specimens to grasp the growing condition of foraminifera and sea grass quantitatively (standing crop, identification and number count) on the points. We immobilized the samples and took them to our laboratory. We identified species of the samples and counted their number. We organized the current survey results, the existing document (the survey result by Japanese science and technology cooperation, the satellite images by IKONOS and the aerial photographs), the distribution density (coverage) of coral, foraminifera and seaweed bed, bathymetry and distribution of sediments to make the habitat map (such as marine environment information base chart). Explanatory note for profiles of the ecological survey on each traverse line are shown in **Figure 4.45**.

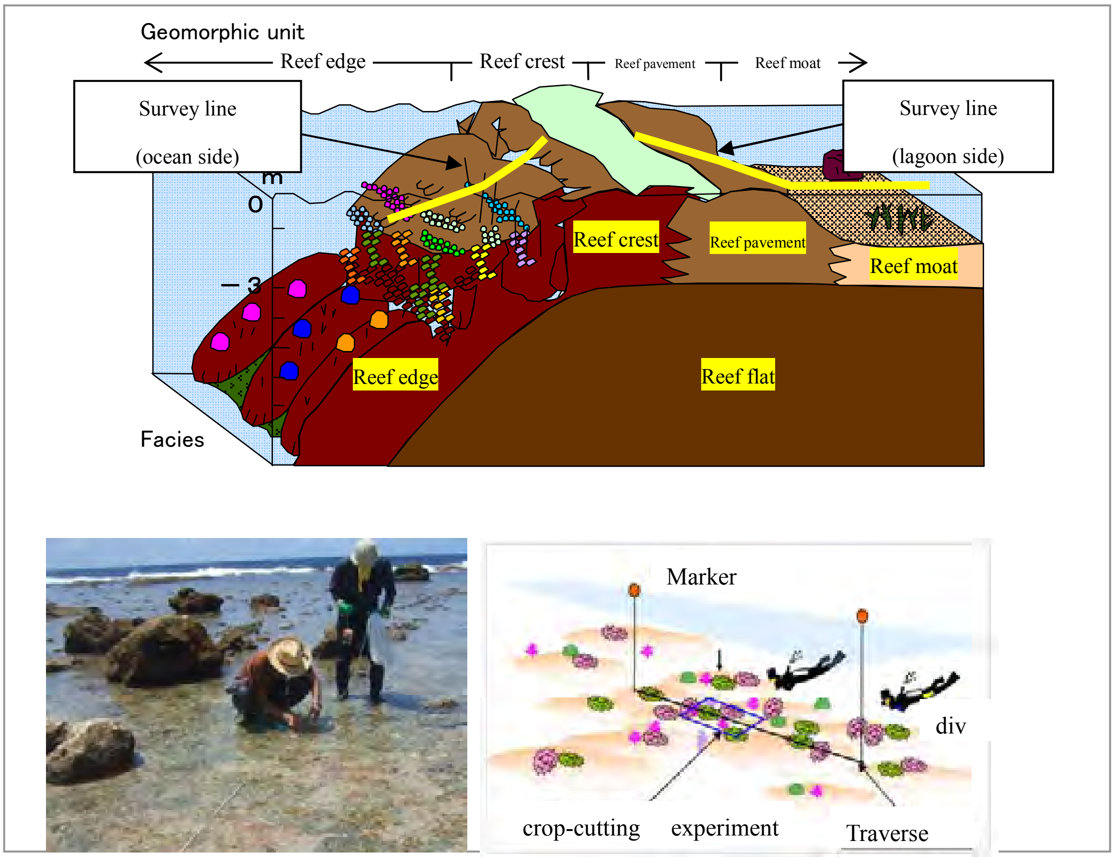


Figure 4.44 Conceptual Diagram of the Ecological Survey (Line Survey)

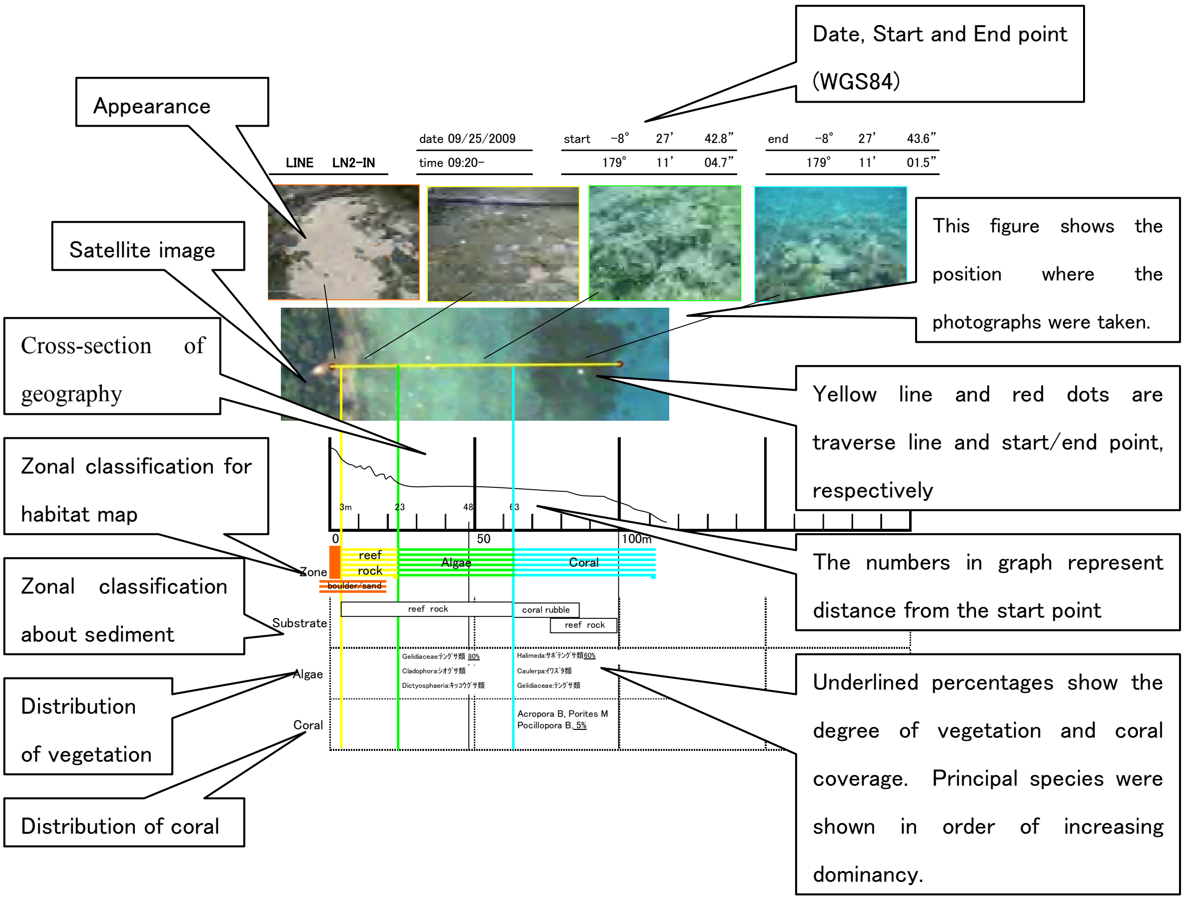


Figure 4.45 Explanatory Notes for Profiles of the Ecological Survey (Line Survey-Cross Section)

(2) Line Survey Results

The line-by-line profiles obtained in the line survey and the analysis results for foraminifera and turf algae obtained in the sampling survey are shown in Part II in Support Report.

Table 4.25 shows the overview of the observation results by survey line (zoning, substrates, and occurrence conditions of foraminifera, algae, and coral). **Figure 4.46** shows large foraminifera which were identified in the sampling survey and expected to have a high sand gravel production capacity.

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.

To analyze the occurrence tendencies of foraminifera, we selected points with a high density of foraminifera from those on each survey line and converted the total populations of the two major species, *Baculogypsina* and *Amphistegina*, into values per square meter. These values are listed in **Table 4.26** and **Table 4.27** (The occurrence tendencies on each survey line based on these results are shown in **Figure 4.47** through **Figure 4.49**).

Baculogiosina

Calcarina

Amphistegina lessoni

A. lobifera

Soritinae

Marginopora

Figure 4.46 Identification of Larger Foraminifera with High Sand Gravel Production Capacities

Table 4.25 Occurrence Tendencies of Principal Species of Foraminifera

	2 in	2 out	3 in	3 out	4 in	4 out	5 in	5 out	6 in	6 out	7 in	7 out	8 in	8 out	9 in	9 out
Baculogypsina	5,200	42,636	0	9,359	0	0	0	36,397	0	206,941	0	21,838	2,080	38,477	0	17,678
Amphistegina	55,115	11,439	585,467	5,200	14,559	1,040	728,974	35,357	0	15,599	0	0	0	20,798	2,080	11,439
total	69,675	49,916	585,467	14,559	14,559	2,080	742,493	68,634	2,080	220,460	0	21,838	2,080	53,035	4,160	63,434

	10 in	10 out	11 in	11 out	12 in	12 out	13 in	13 out	14 in	14 out	15 in	15 out	16 in	16 out	17 out
Baculogypsina	0	1,040	0	0	7,279	1,020,148	79,033	3,120	0	1,040	0	0	0	0	1,040
Amphistegina	0	6,239	0	0	2,080	441,961	22,878	13,519	5,200	20,798	0	3,120	0	32,237	3,120
total	0	15,598	3,120	0	16,638	1,491,226	105,031	17,679	9,360	48,876	4,160	9,359	2,080	32,237	9,360

Table 4.26 Overview of Line Survey Results (1)

Stn.	length(m)	Zone	Substrate	Foraminifer	Algae	Coral	Place (Island)
L02IN	98	boulder/sand reef rock Algae Coral	reef rock coral rubble	Baculogypsine 5200ind./m² Amphistegina 55115ind./m²	Gelidiaceae: 80% Cladophora: Dictyosphaeria: Halimeda: 60% Caulerpa: Gelidiaceae:	Acropora B, Porites M Pocillopora B, 5%	Fongafale
L02OUT	81	boulder reefrock Algae Foraminifera Coral	boulder reef rock Foram	Baculogypsine 42636ind./m² Amphistegina 11439ind./m²	Cladophora: 80% Turbinaria: 90% Dictyosphaeria: Caulerpa:	Acropora B 5%	
L03IN	71	boulder reefrock Algae Coral	boulder reef rock	Amphistegina 585467ind./m²	Cladophora: 90% Gelidiaceae: Padina: Dictyota: 60% Padina: Halimeda:	Acropora B Porites M 5%>	Fongafale
L03OUT	82	boulder reefrock Algae Coral	boulder reef rock	Baculogypsine 9359ind./m² Amphistegina 5200ind./m²	Cladophora: 80% Boergesenia: 80% Cladophora: Gelidiaceae: 70% Caulerpa:	Acropora B Montipora C 20%	
L04IN	189	boulder/sand Algae reefrock Coral	boulder sand reef rock rubble	Amphistegina 14559ind./m²	Cladophora: 80% Halimeda: 50% Padina: Halimeda: 30% Caulerpa: Halimeda: 60% Caulerpa:	Acropora B Pocillopora B Montipora C 5%	Fongafale
L04OUT	74	boulder reefrock Algae Coral	boulder reef rock	Amphistegina 1040ind./m²	Cladophora: 60% Caulerpa: 90% Boergesenia: Boodlea: Dictyota: 90% Boodlea:	Acropora B Pocillopora B Montipora C 5%	
L05IN	117	boulder/rubble/ sand Algae Sand Coral	rubble sand boulder reef rock	Amphistegina 728974ind./m²	Halimeda: 30% Padina: Caulerpa: Caulerpa: 60% Dictyota: Halimeda: Caulerpa: 80% Halimeda:	Acropora B Pocillopora B 5%>	Fongafale
L05OUT	74	boulder reefrock Algae Coral	boulder reef rock	Baculogypsine 36397ind./m² Amphistegina 35357ind./m²	Cladophora: 60% Gelidiaceae: 90% Caulerpa: Turbinaria: 70% Gelidiaceae:	Acropora B 5%>	
L06IN	161	boulder/sand Algae Coral	boulder sand reef rock coral rubble		Cladophora: 40% Caulerpa: Padina: Halimeda: Halimeda: 30% Caulerpa: Dictyota:	Acropora B 5%> Acropora B 10%	Fongafale
L06OUT	82	boulder Algae Coral	boulder rubble reef rock	Baculogypsine 206941ind./m² Amphistegina 15599ind./m²	Cladophora: 40% Gelidiaceae: 40% Cladophora Caulerpa Gelidiaceae: 40% Turbinaria Dictyota	Acropora B 5%>	
L07IN-S	83	boulder reefrock Algae Coral rubble	boulder reef rock sand coral rubble		Halimeda: 10% Padina Halimeda: 30% Dictyota	Porites M 5%> Acropora B Pocillopora B 5%>	Fongafale
L07OUT	84	boulder reefrock Coral	boulder reef rock	Baculogypsine 21838ind./m²	Turbinaria: 5% Corallinaceae: 80%	Acropora B 5%>	
L08IN-S	176	boulder Sand Algae Coral	boulder sand rubble reef rock coral rubble	Baculogypsine 2080ind./m²	Halimeda: 30% Caulerpa: Halimeda: 60% Caulerpa:	Acropora B・T 5%>	Fatao
L08OUT	82	boulder reefrock Algae Coral	boulder reef rock boulder	Baculogypsine 38477ind./m² Amphistegina 20798ind./m²	Corallinaceae: 90%	Acropora B Pocillopora B 5%	

Table 4.27 Overview of Line Survey Results (2)

Stn.	length(m)	Zone	Substrate	Foraminifer	Algae	Coral	Place (Island)
L09IN	157	boulder/rubble sand/rock Algae Coral	boulder rubble sand reef rock coral rubble	Amphistegina 2080ind./㎡	Halimeda: 50% Caulerpa: Halimeda: 50%	Porites M 5%> Acropora B・T 5%> Acropora B 50%	Funangongo
L09OUT	74	boulder reefrock Algae Coral	boulder reef rock boulder	Baculogypsine 17678ind./㎡ Amphistegina 11439ind./㎡	Corallinaceae: 80%	Acropora B 10%	
L10IN	126	Sand reefrock Algae Coral	sand reef rock coral rubble		Caulerpa: 30% Halimeda: Halimeda: 50% Caulerpa:	Acropora B・T Pocillopora B 5% Acropora B 50%	Falefatu
L10OUT	77	boulder reefrock Algae Coral	boulder sand reef rock	Baculogypsine 1040ind./㎡ Amphistegina 6239ind./㎡	Corallinaceae: 90% Caulerpa:	Acropora B Pocillopora B 10%	
L11IN	73	reefrock Algae	reef rock boulder sand		Halimeda: 20% Halimeda: 50% Caulerpa:		Funafala
L11OUT	86	boulder reef rock rubble Coral	boulder reef rock rubble		Halimeda: 5%>	Acropora B Pocillopora B 5%>	
L12IN	310	sand Algae Coral	sand reef rock coral rubble	Baculogypsine 7279ind./㎡ Amphistegina 2080ind./㎡	Jania: 70% Cladophora: 20% Halimeda: 30% Halimeda: 20% Caulerpa: Halimeda: 40%	Porites M Pocillopora B 5%>	Fuagea
L12OUT	457	sand Foraminifera low density Foraminifera high density Coral	sand reef rock (Foram Zone 疎) (Foram Zone濃) algal	Baculogypsine 1020148ind./㎡ Amphistegina 441961ind./㎡	Caulerpa:80% Gelidiaceae: Halimeda: 80% Caulerpa: Gelidiaceae: Corallinaceae: 90%	Porites M 10% Porites M, Acropora B, 5%	
L13IN	186	sand Algae Foraminifera Coral	sand reef rock rubble	Baculogypsine 79033ind./㎡ Amphistegina 22878ind./㎡	Halimeda:60% Caulerpa: Dictyosphaeria: Halimeda: 5% Caulerpa: 60% Halimeda: Caulerpa: 10%	Porites M Favia M 5%	Fualopa
L13OUT	160	sand reef rock Algae Coral	sand reef rock coral rubble	Baculogypsine 3120ind./㎡ Amphistegina 13519ind./㎡	Halimeda: 40% Caulerpa: Dictyosphaeria: Dictyosphaeria: 10% Halimeda:	Acropora B, Porites M, Pocillopora B, 5%> Acropora B・T 10%	
L14IN	255	sand Algae Coral	sand reef rock rubble	Amphistegina 5200ind./㎡	Cladophora: 10% Halimeda: 5%>	Acropora B・T, Porites M, 5%> Acropora B 5%>	Tepuka
L14OUT	250	sand Algae Coral	sand rubble	Baculogypsine 1040ind./㎡ Amphistegina 20798ind./㎡	Caulerpa: 10% Halimeda: 50% Caulerpa: Halimeda: 80% Jania: Caulerpa:	Acropora B Pocillopora B 5%>	
L15IN	229	sand sand/rubble Coral	sand coral rubble		Hypnea: 10%	Acropora B 5%>	Fualifeke
L15OUT	277	sand reef rock boulder Coral	sand reef rock boulder/rubble algal ridge	Amphistegina 3120ind./㎡	Corallinaceae: 80%	Acropora B, Pocillopora B Montipora C, 10%	
L16IN	255	sand rubble Algae Coral	sand rubble reef rock		Gelidiaceae: 70% Jania: 90% Gelidiaceae: Boodlea: Caulerpa: 90%	Acropora B 5% Acropora B 50%	Amatuku
L16OUT	243	sand reef rock boulder Algae Coral	sand boulder reef rock algal ridge	Amphistegina 32237ind./㎡	Corallinaceae: 80%	Acropora B Porites M Pocillopora B 5%	
L17OUT	86	boulder reef rock Algae Coral	rubble reef rock	Baculogypsine 1040ind./㎡ Amphistegina 3120ind./㎡	Cladophora: 90% Caulerpa: 90% Padina: Gelidiaceae:	Acropora B 10% Acropora B 30%	Fongafale

According to the total population figures shown in **Figure 4.47**, more than one million foraminifera per square meter were identified on line LN12, and several hundreds of thousand per square meter were identified around Fongafale Islet. According to the densities of Baculogypsina shown in **Figure 4.48**, one million per square meter were found on LN12, leading us to the conclusion that Baculogypsina is the foraminifera species with the highest density in Funafuti Atoll. **Figure 4.48** shows that the occurrence of this species is high on the ocean side of the atoll as well.

Figure 4.49 shows the densities of Amphistegina, which mark several hundreds of thousand on line LN12 and the lagoon side of Fongafale Islet. Among the genus Amphistegina, A. lessoni tended to exist on the lagoon side, and A. lobigera, on the ocean side, with neither of them showing zonation that was clear to the naked eye during observation. Since they tend to prefer inhabiting relatively deep-water areas, their dead shells are not expected to be gathered very efficiently near the shoreline. In other words, Amphistegina, one of the principal species in Funafuti Atoll, is expected to have an inferior sand production capacity to Baculogypsina. In fact, only a small amount of them were identified visually on the local sand beach.

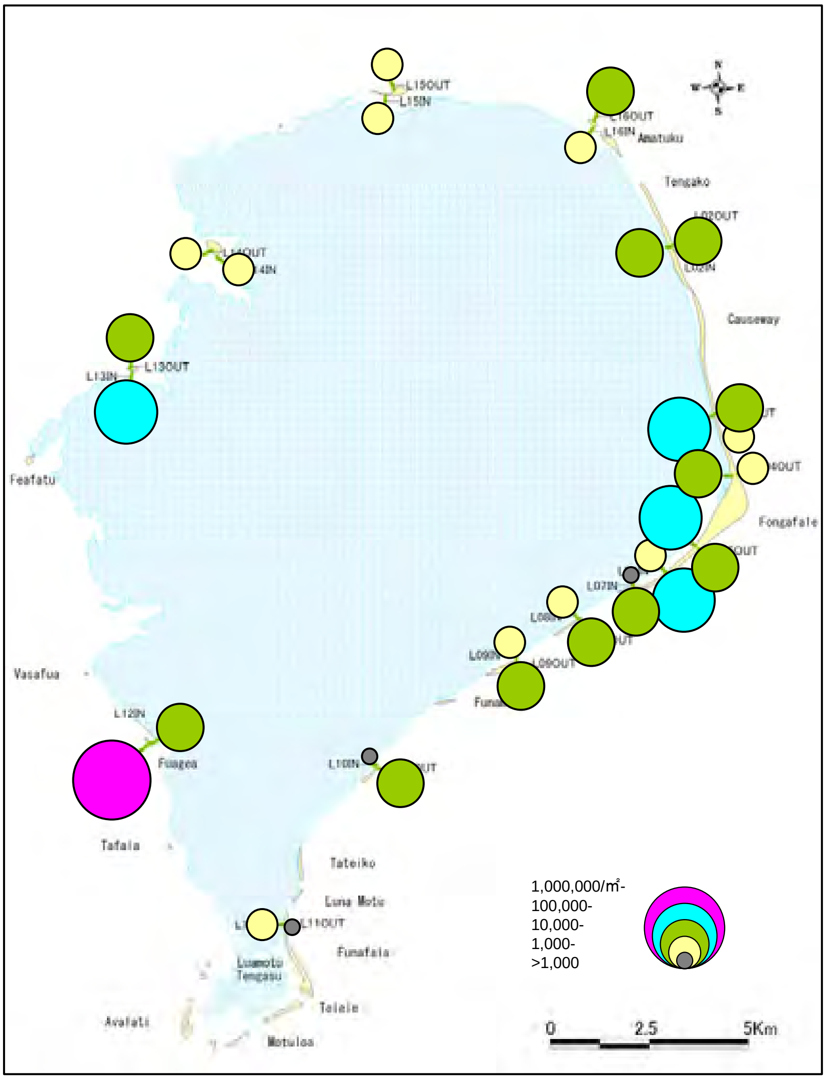


Figure 4.47 Foraminifera Occurrence Tendencies (Total Populations)

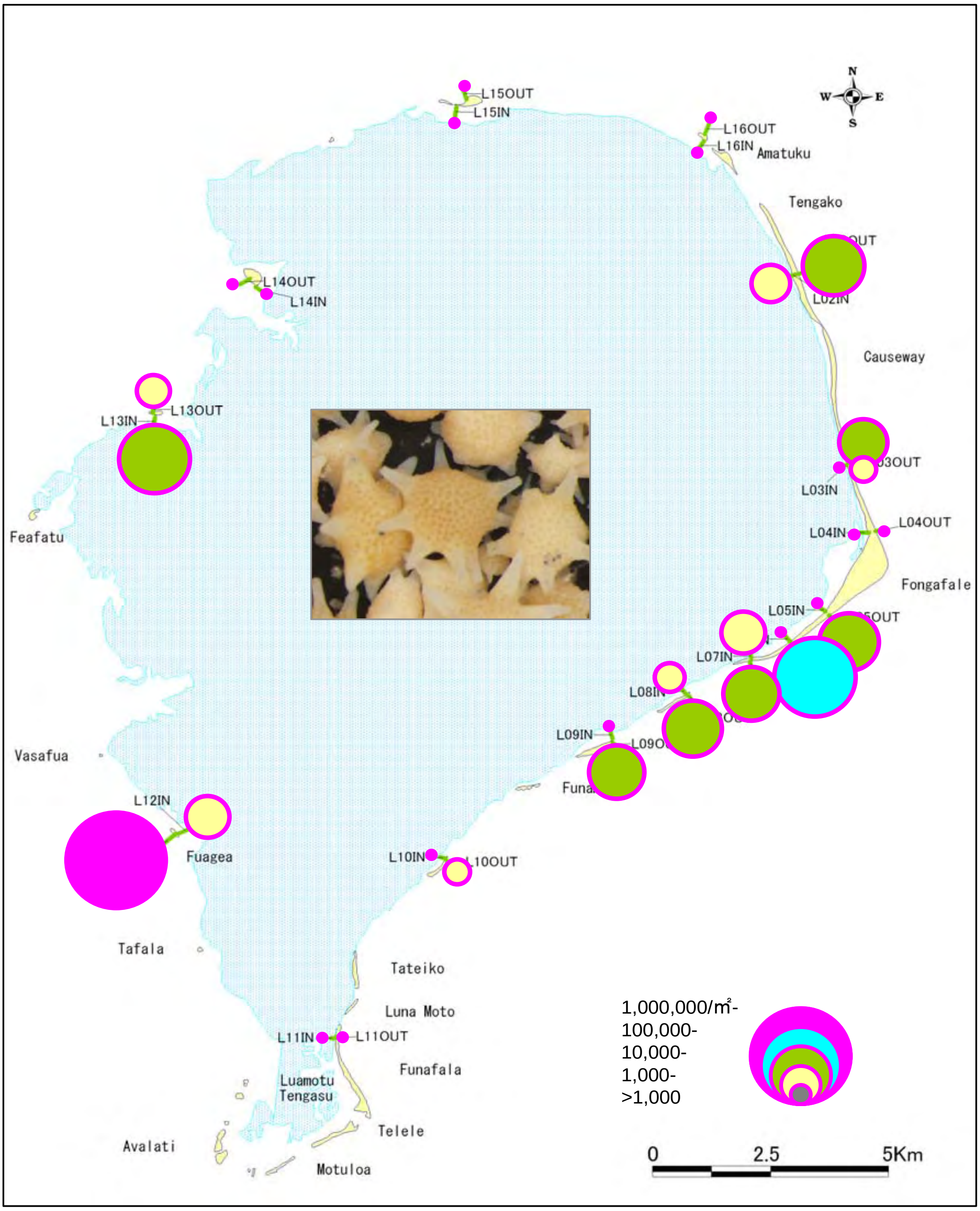


Figure 4.48 Foraminifera Occurrence Tendencies (Baculogypsina)

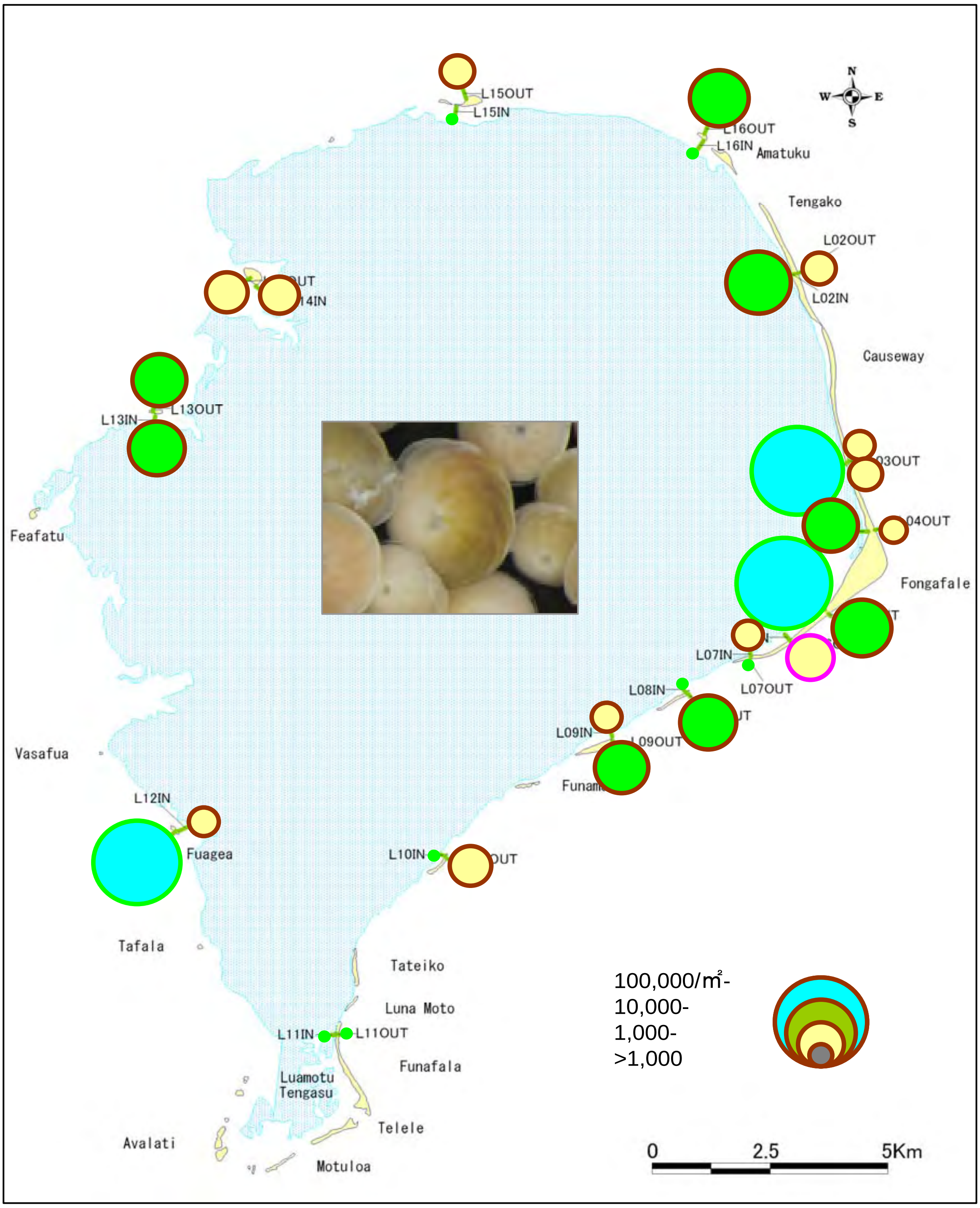


Figure 4.49 Foraminifera Occurrence Tendencies (Amphistegina)

4.5.2 Distribution Conditions of Coral, etc.

(1) Overview of the Distribution Survey on Coral, etc.

1) Description of Survey

A distribution survey through underwater visual observation was conducted to identify the overview of coral, underwater forests, etc. distributed along the coast of Funafuti Atoll. **Table 4.28** shows the survey item and description.

Table 4.28 Survey Item and Description

Item	Quantity	Remarks
[Distribution survey on coral, etc.] The entire atoll of Funafuti with a focus on the lagoon side of Fongafale Islet	1 set	Lagoon-side Distribution conditions of coral and underwater forests

2) Survey Area

The survey was conducted on the entire atoll of Funafuti with a focus on the lagoon side of Fonagale Islet.

3) Survey Duration

Table 4.29 shows the survey duration.

Table 4.29 Duration of Distribution Survey on Coral, etc.

Survey item	Observation duration
Distribution survey on coral, etc.	19.10.2009 to 28.10.2009

4) Method of Distribution Survey on Coral, etc.

The distribution survey on coral, etc. was conducted at given points mainly on Fongafale, etc. through underwater visual observation by divers and visual observation aboard a ship. The wave observation points were checked using simple GPS systems.

(2) Results of Distribution Survey on Coral, etc.

Figure 4.50 and **Figure 4.51** show the results of the survey on the distribution of coral, etc. According to these results, Funafuti Atoll was found to have patchy coral reefs scattered offshore from Fongafale and distributional areas with a coverage of over 50% around the area of

Fatato to Tateiko, Tepuka, and Fualifeke Islets. Regarding the coral distribution conditions in the area surrounding Fongafale Islet, the coral coverage was mostly below 20% in the coastal area from the causeway to the southernmost tip of Fongafale. However, the S.P.5 (patchy reef at the frontage of Vaiaku Lagi Hotel) and the northwestern coast of Fatato Islet were found to have distribution areas with coverages of 50% to 70%, in which ramiform staghorn coral is the principal constituent species.

Coral (a coral reef) has various functions deeply related to human activities such as coastal protection functions (e.g. wave reduction and the supply of sand) and fishery and biological reproduction. Therefore, it is concluded that a detailed study should be conducted in the future to learn about foraminifera and that measures for protection and nourishment should be implemented.

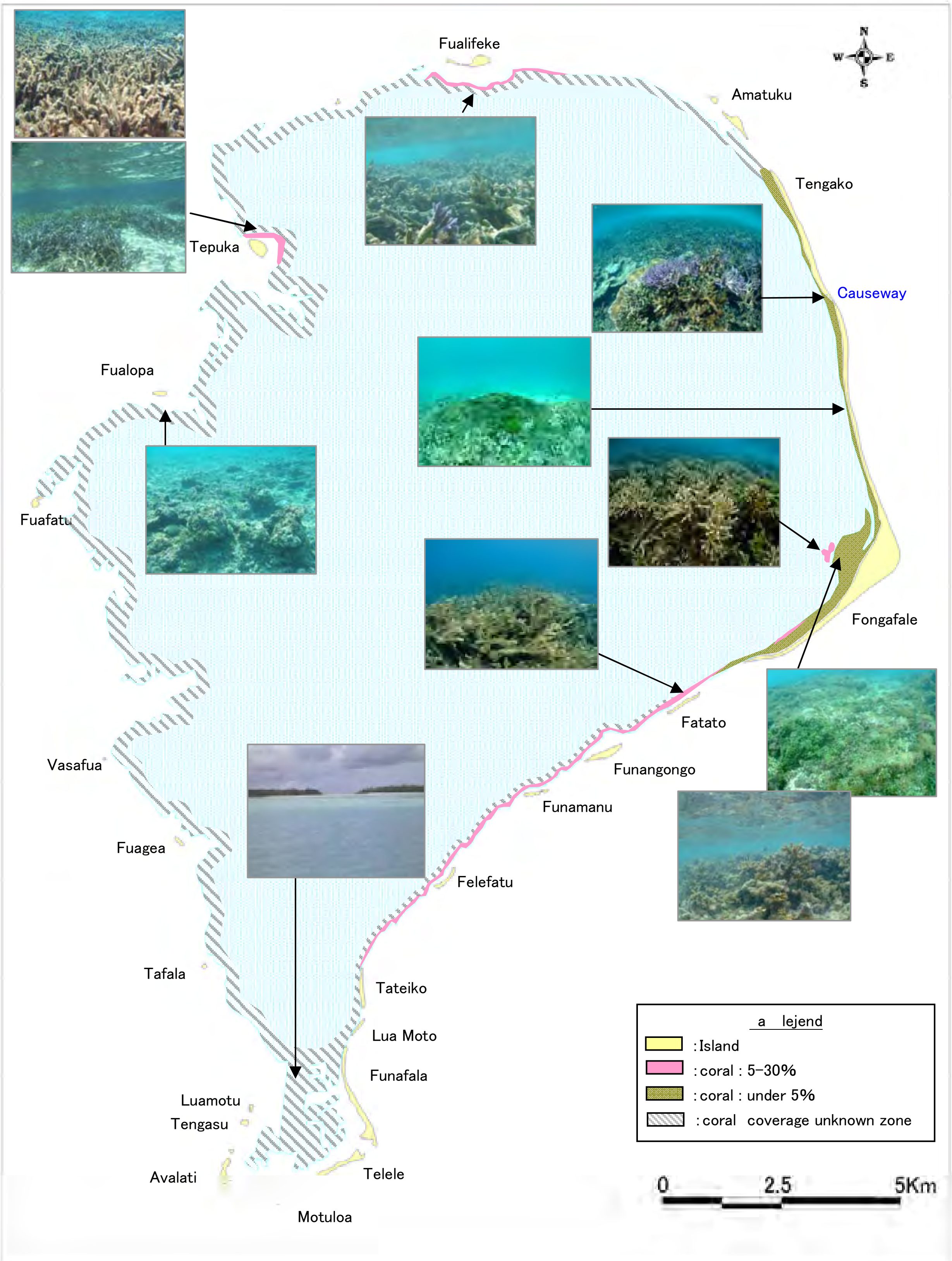
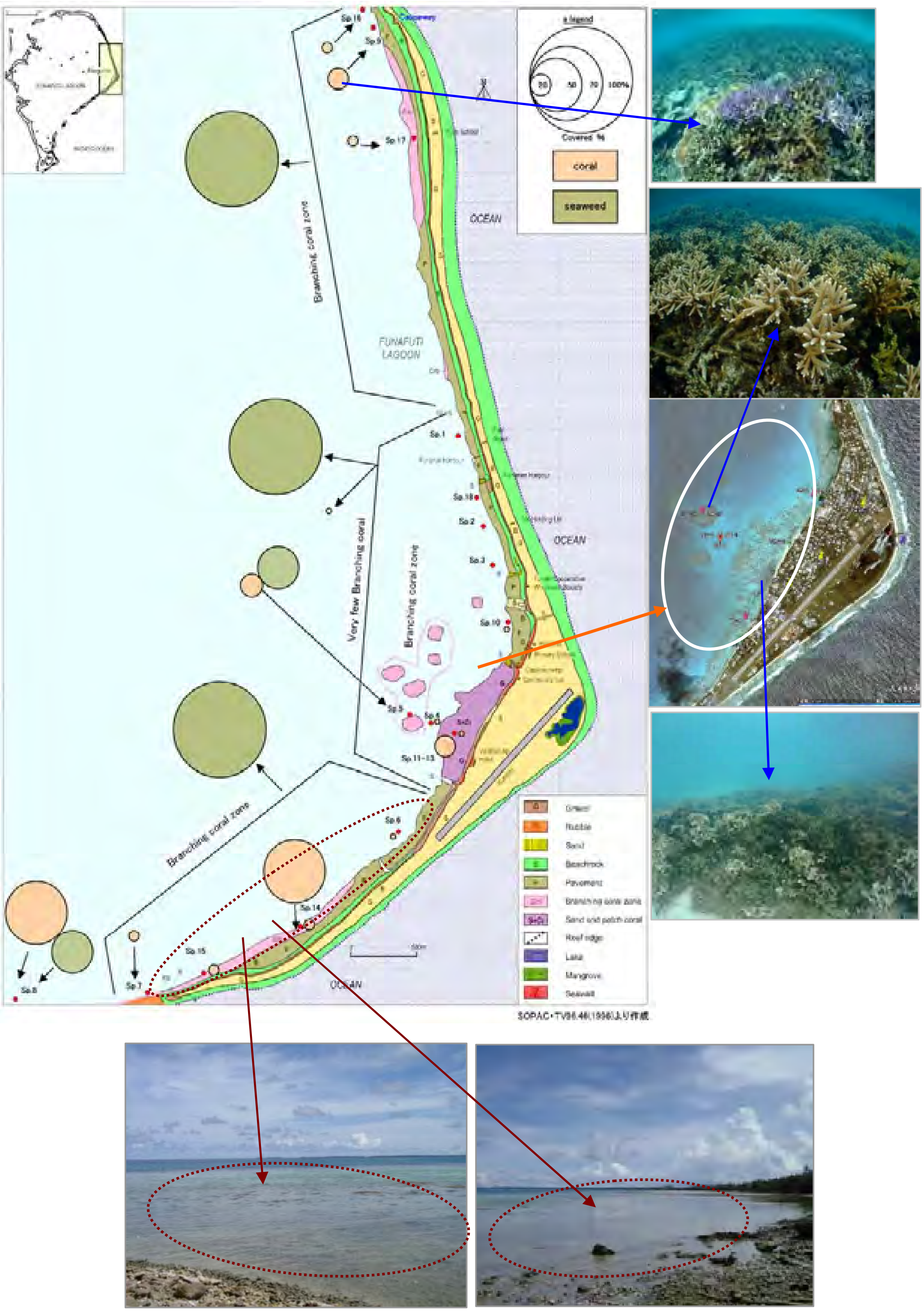


Figure 4.50 Coral Distribution Conditions (around Tuvalu Atoll)



Sargassum bed located in the south of Fongafale Islet (01.2010)

Figure 4.51 Coral Distribution Conditions (around Fongafale Islet)

CHAPTER 5 PRESENT SITUATION OF COAST

5.1 Existing Coastal Structures

5.1.1 Lagoon Side

Structures along the coast of the lagoon in Funafuti could have a great influence on transport of sand and gravel on the atoll side. A study will be conducted on the current conditions of those structures to examine their influence on coastal erosion and sedimentation. The figure below shows the locations of the major port facilities and coastal protection works constructed on Fongafale Islet and Tengako Islet, located to the north of Fongafale Islet.

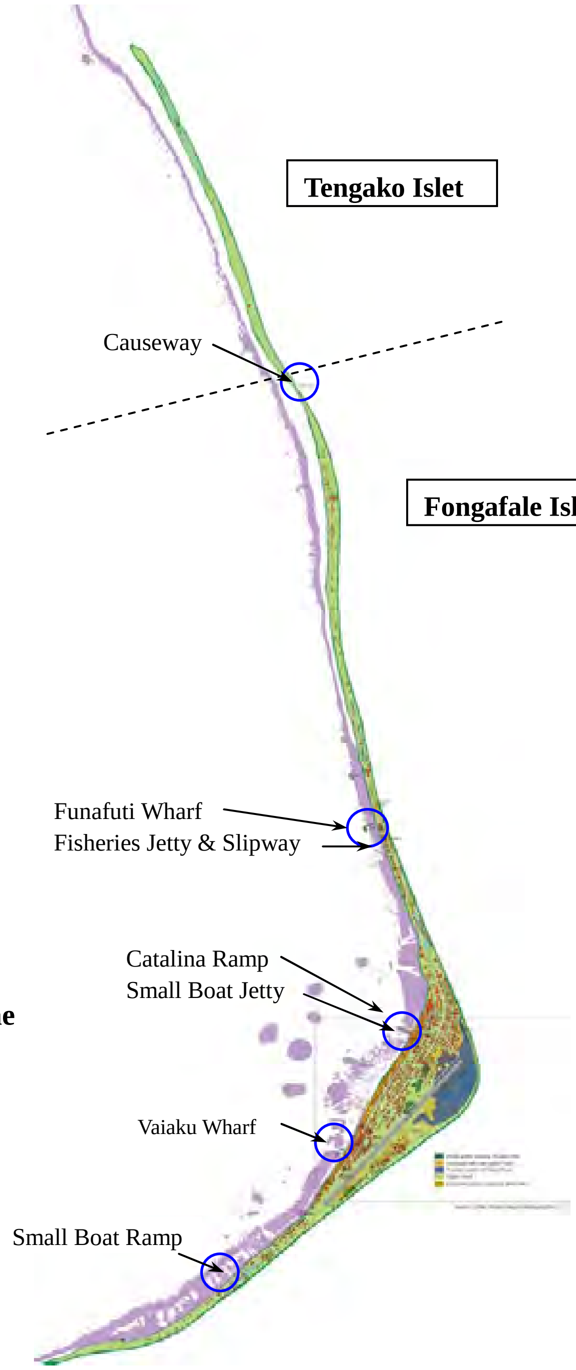


Figure 5.1 Locations of the Major Structures along the Coast of the Lagoon on Fongafale Islet

(1) Wharves and Jetties

1) In and around Funafuti Port

Port facilities in Funafuti Port were constructed with assistance from Australia in 1980, immediately after the independence of Tuvalu. They are the only port facilities in Tuvalu to which large vessels can dock.

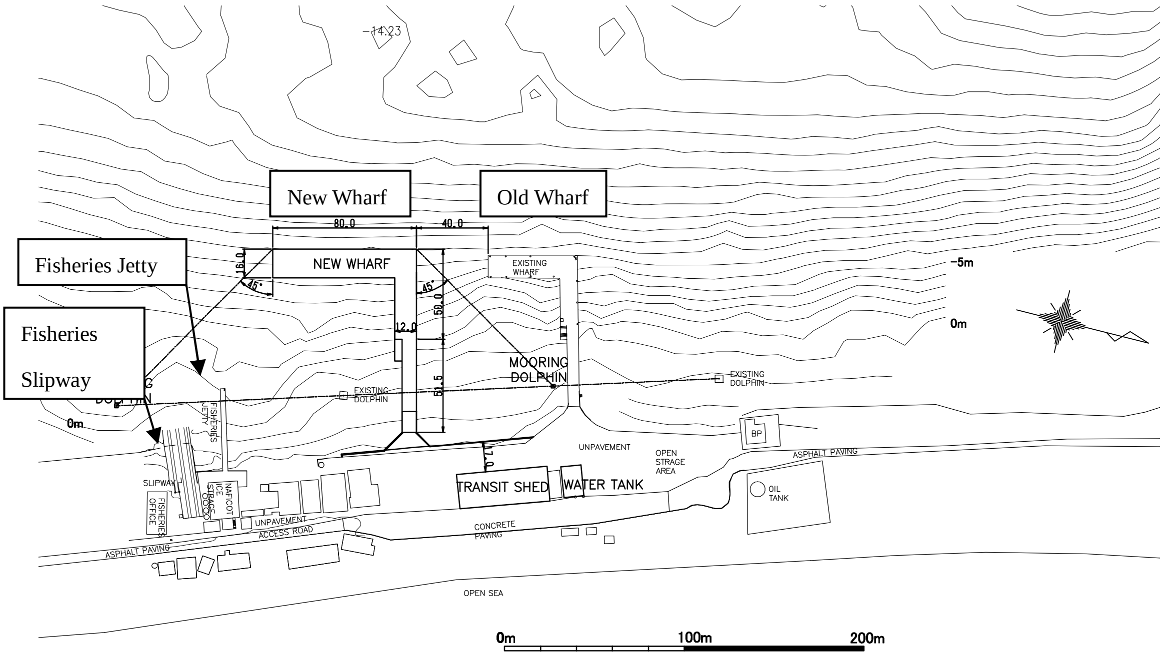


Figure 5.2 Locations of Port Facilities in Funafuti Port

a) Old Funafuti Wharf;

An L-shaped wharf on vertical steel pipe piles constructed in 1980 with assistance from Australia:

Length of the front berth; 56m, width of the berth; 8m, water depth at the berth; D.L. -8m, length of the approach jetty; *ca*. 105m from the shoreline)

b) New Funafuti Wharf (Nippon Wharf);

An L-shaped wharf on vertical steel pipe piles constructed in 2009 with grant aid from Japan

Length of the front berth; 80m, width of the berth; 16m, water depth at the berth; D.L. -9m, length of the approach jetty; *ca*. 108m from the shoreline

c) Fisheries Jetty;

A low-cost jetty with precast concrete floor slabs on steel H-piles and steel I-beams constructed in 1984 with assistance from New Zealand

The far end of the jetty was extended in 1989 with grant aid from Japan. As of 1989, length of the berth; 45m, width of the berth; 2.7m, water depth at the far end; D.L. -3m, length of the approach jetty; *ca*. 100m from the shoreline.

The far end of the jetty started collapsing in 2008 and the far half of the jetty collapsed completely when a storm hit the port in December 2009.

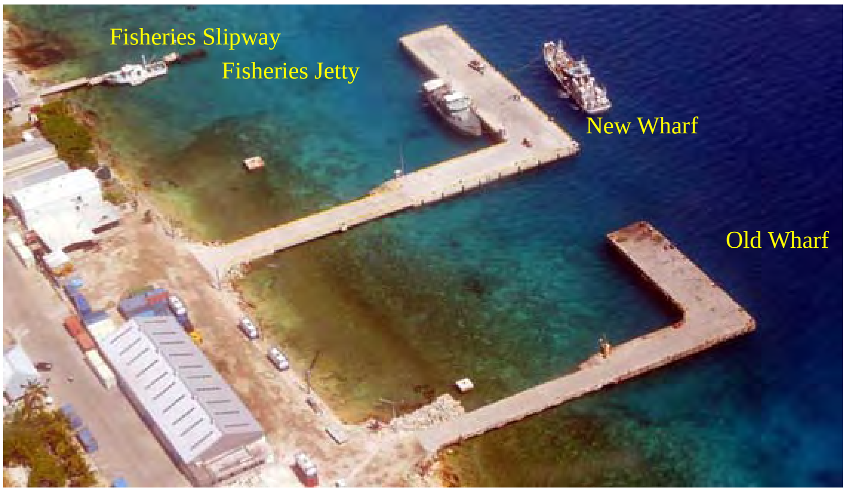


Photo 5.1 Port Facilities in Funafuti Port

d) Fisheries Slipway;

A slipway for fishing boats constructed in 1984 with assistance from New Zealand

Its far end was extended in 1989 with grant aid from Japan.

Total width of the slipway; 14.5m, total length; 50m, three pairs of hauling rails

Part of its far end collapsed in the spring of 2008 and the central part collapsed in December 2009.

Photo 5.2 Collapsed Fisheries Jetty **Photo 5.3 Slipway**

<u><Evaluation of structures and their influence on coastal erosion and sedimentation></u>

a) Old Funafuti Wharf;

b) New Funafuti Wharf (Nippon Wharf);

Both old and new commercial wharves near Funafuti Port are considered to have little influence on coastal erosion/sedimentation because they are pile jetties. However, both wharves have 10 to 15 meter-long impermeable jetties made of concrete seawalls on the shoreline ends. Because of this structure, a small deposit of gravel is found on the northwestern side at the base of the Old Wharf, while deposit of gravel is not found on the other side, the southeastern side, of the wharf. No erosion is observed on the shoreline southeast to the base of the Old Wharf because the shoreline has been protected by a vertical concrete seawall since the construction of the port in 1980 and because beach rocks cover the seabed of the shallow waters from the shoreline.

The figure below shows the results of the coastal bottom sediment survey of the area around the Old Wharf of Funafuti Port carried out by SOPAC in 1995. Concrete cubes with sides of 30cm were placed as rubble-mound seawall on the southeastern side of the base of the Old Wharf as a measure against erosion. Meanwhile, sedimentation of gravel is found on the northwestern side. The concrete blocks were relocated and the deposited gravel was used to transform the rubble-mound seawall into a temporary yard on the northeastern side of the Old Wharf from 2008 to 2009 for the construction of the New Wharf. Implementation of these measures resulted in a slight change in sedimentation. Nonetheless, little change was observed in sedimentation patterns between before the construction of the New Wharf and at the time of the survey in 1995. The asymmetry in shoreline between the northern and southern sides of the impermeable jetty at the base of the wharf indicates prevalence of southerly littoral drift at this point.

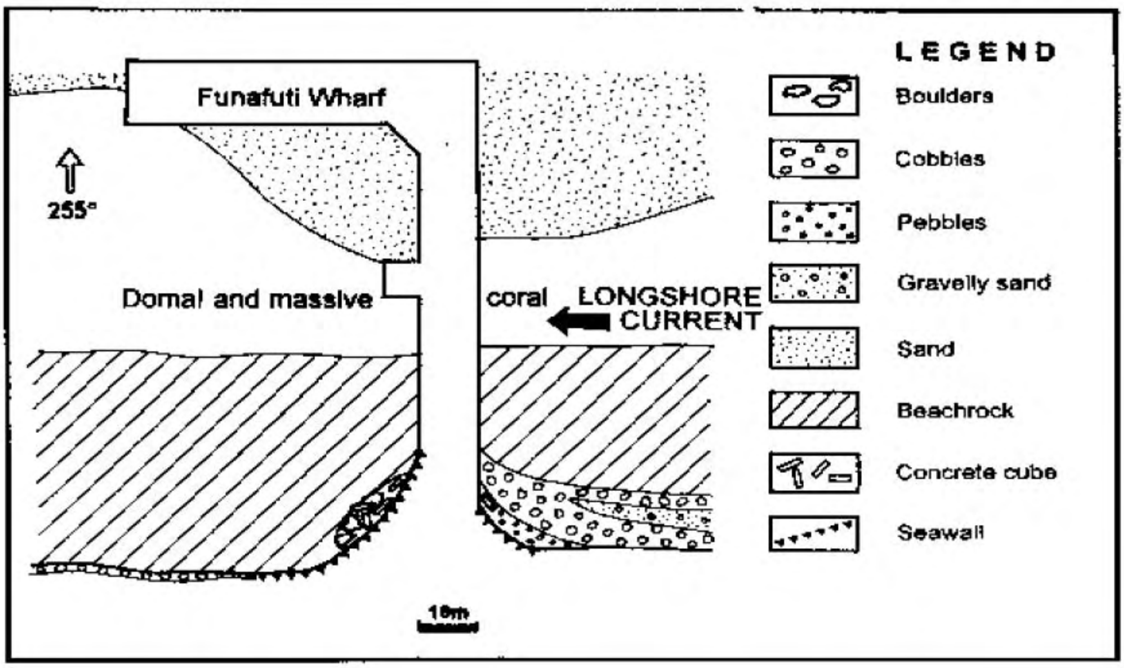


Figure 5.3 Sedimentation and Erosion around the Old Wharf of Funafuti Port

Source: SOPAC Technical Report 221 (Sept. 1995)

c) Fisheries Jetty;

d) Fisheries Slipway;

The Fisheries Jetty and the Fisheries Slipway are at the location where beach rocks were scraped so that earth could be unloaded from dredge barges to trucks during the World War II. This fact may explain why beach rocks are not exposed on the surface of the sediment and a thin layer of sand gravel covers the surface. Because the Fisheries Jetty is on piles from the base, it has little effect on erosion or sedimentation. However, the far end and the middle part of the jetty collapsed to the seabed in 2008 and December 2009, respectively. Although the collapsed structures could impede transport of sand and gravel, significant change was not observed at the time of the survey in February 2010.

The slipway was constructed by scraping beach rocks. Because it is at almost the same elevation as the beach rock shoreline nearby, no significant erosion or sedimentation is observed. However, when a tropical depression or a cyclone passes through and brings strong westerly wind and high waves, the gravel stirred up from the seabed off the far end of the slipway will be deposited on the northern side of the slipway.

2) The Central Area of Funafuti City

This is the area which can be considered as the center of the life in Funafuti as the area has many public facilities including Funafuti City Hall, shops, houses, churches, schools, pre-schools and hospitals located close to each other.

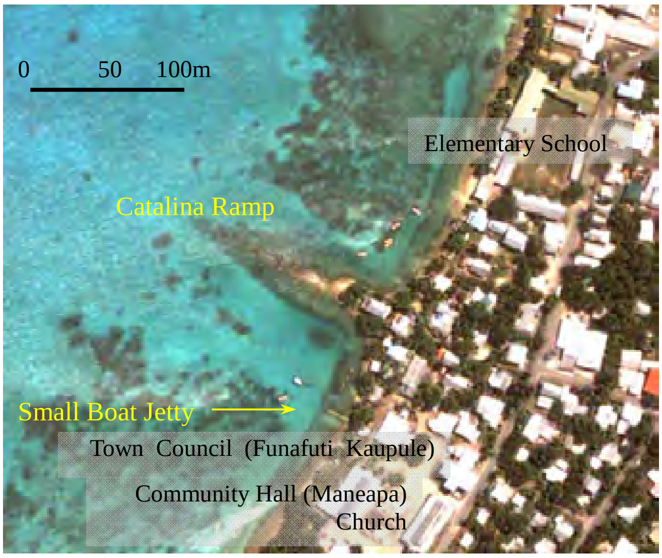


Photo 5.4 Satellite Image of the Area around Catalina Ramp

a) Catalina Ramp;

This is a jetty-type ramp to haul seaplanes constructed hastily by the American troops in 1943 during the Pacific War. Several attacks by cyclones caused cracks on its concrete floor. Earth packed inside the ramp has flowed through the cracks and the jetty has been completely

collapsed. Pieces of concrete and stone materials are scattered around the ramp.
The total length of the ramp (from the shoreline); *ca*. 130m, width; 20m, and water depth at the far end; D.L. -5m (estimates), when it was constructed.

Photo 5.5 Catalina Ramp

Photo 5.6 The Top of the Ramp

b) Small Boat Jetty;
A small-scale jetty-type wharf to the southwest of the base of Catalina Ramp constructed by laying up small concrete blocks. The total length of the jetty (from the shoreline); *ca.* 16m, width 1m, water depth at the front; *ca.* D.L. ±0.0m.

Photo 5.7 Small Boat Jetty (to the South of Catalina Ramp)

As seen in Photo 5.7 above, beach rocks in the water areas to the south and north of Catalina Ramp were dredged deep and the areas were used for docking and unloading of the US military boats. At present, although littoral drift is gradually filling the dredged places, the area is still deep enough for the use by small boats. Because public facilities including government offices, schools, churches, a meeting place, hospitals, supermarkets, and stores are located in the hinterland few minutes' walk from the jetty, small boats equipped with outboard motors owned by area residents and cutters equipped with outboard motors commuting to and from the Marine Institute in Amatuku Islet in the atoll and small islets in the atoll including Funafala Islet dock at Small Boat Jetty mentioned below and use this place as a boat basin.

Seawalls were constructed with concrete cubes with sides of 30 cm on the shorelines both to the north and to the south of Catalina Ramp around 1990. As seen in the figure below, the seawalls have collapsed gradually since then and, at present, most part of the shore is in such desperate condition with scattered concrete blocks and gravel that it is difficult to walk along the shore and, thus, people's access to the shorelines is very poor.

<Evaluation of structures and their influence on coastal erosion and sedimentation>

a) Catalina Ramp;

b) Small Boat Jetty;

Slight erosion and slight sedimentation of sand gravel are observed on the northern and southern sides of Catalina Ramp, respectively.

This observation confirms the general prevalence of northerly littoral drift on the lagoon side of the central part of Fongafale Islet. The reason for the prevalence will be explained in detail in Chapter 8, "Beach Deformation Mechanism."

Photo 5.8 Seawall on the Northern Side of Catalina Ramp

Photo 5.9 Seawall on the Southern Side of Catalina Ramp

Photo 5.10 Close-up View of Catalina Ramp

Photo 5.11 Distant View of Catalina Ramp from the North

3) Southern Part of Funafuti City

This area is the administrative center of Tuvalu with the government buildings, the police, satellite parabolic antennas, telephone switchboard facilities, internet host server facilities, radio stations, an airport, the central bank and the government-owned hotel located close to each other.

Photo 5.12 Satellite Image of the Area around Vaiaku Wharf

a) Vaiaku Wharf;

This is an impermeable jetty-type wharf for cargo unloading which was used after the Pacific War until the Old Wharf had been constructed. The far end of the jetty is slanted so that a ramp of a landing craft can be used. SOPAC implemented a pilot project of dredging sand within the lagoon from April 1992 to September 1993. The actual dredging was carried out in the dry season during the above period because the frequent westerly wind causes high waves in the rainy season. This jetty was used to unload the dredged sea bottom materials. The University of Hawaii installed a tide gauge on the northern side in the middle part of the jetty. However, the gauge is out of order. The total length of the jetty (from the shoreline); 50m, the width of the crest; 6.5m, water depth at the far end; D.L. -2m.

Photo 5.13 Vaiaku Wharf Seen from the South

Photo 5.14 Vaiaku Wharf

b) Small Hotel Jetty;

Small Hotel Jetty is a jetty-type semi-permeable wharf for small boats located *ca*. 180m to the north of the Vaiaku Wharf mentioned above in a) and to the south of Vaiaku Lagi Hotel. The total length of the jetty (from the shoreline); 22m, the width of the crest; 1.6m, water depth at the far end; D.L. *ca*. -0.5m.

Photo 5.15 Small Hotel Jetty

<Evaluation of structures and their influence on coastal erosion and sedimentation>

a) Vaiaku Wharf;

As shown in the figure below, strikingly asymmetrical sedimentation patterns can be observed between the northern and southern sides of Vaiaku Wharf.

On the northern side of the Vaiaku Wharf (photograph below left), no gravel beach exists in front of the seawall and the shoreline in front of the Government Building is curved because of erosion. On the other hand, a gravel beach in a triangular shape toward the base of the wharf has been formed on the southern side. Such asymmetry of shoreline confirms the prevalence of northerly littoral drift at this point.

Photo 5.16 The Northern Side of Vaiaku Wharf

Photo 5.17 The Southern Side of Vaiaku Wharf

The figure below shows the results of the coastal bottom sediment survey of the area around Vaiaku Wharf implemented by SOPAC in 1995. Comparison between the results of the survey in 1995 and the current conditions revealed no significant change in sedimentation patterns. The sediments composing the shoreline area, as well as the asymmetry of the shoreline mentioned above, confirm the prevalence of the northerly littoral drift at this point.

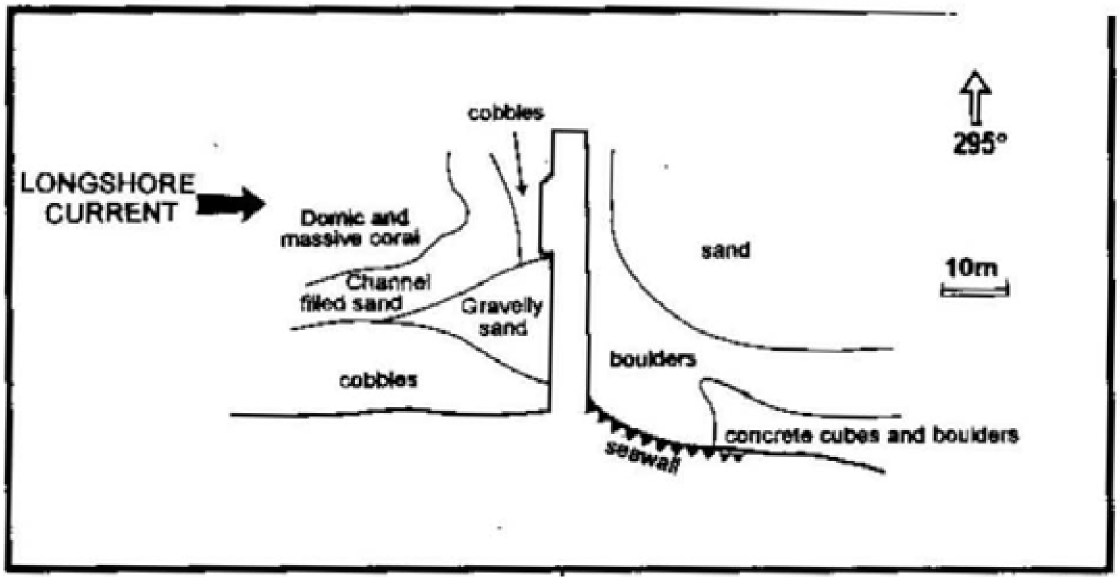


Figure 5.4 Sedimentation and Erosion around Vaiaku Wharf

Source: SOPAC Technical Report 221 (Sept. 1995)

b) Small Hotel Jetty;

Although the small jetty in front of the Hotel is not a completely impermeable jetty, there is no gravel beach in front of the seawall of the hotel on the northern side, while a gravel beach in a triangular shape toward the base of the jetty has been formed on the southern side, as seen at the above-mentioned Vaiaku Wharf.

Photo 5.18 The Northern Side of Small Hotel Jetty

Photo 5.19 The Southern Side of Small Hotel Jetty

4) Southern Part of Fongafale Islet

The official residences of the Prime Minister, other ministers and government employees are found in the hinterland of the coast to the south of Vaiaku Wharf. Privately-owned houses are found further south. As you go further south, the density of houses decreases gradually.

Small Boat Ramps;

Along this southern coastal area, there is no jetty or wharf of a scale which can be considered as a port facility. Only privately-owned small boat ramps for landing small boats are found at several locations. As the patterns of erosion and sedimentation on both southern and northern sides of these ramp structures are similar, a typical small boat ramp located at the southernmost end in Figure 7.1 is analyzed.

<Evaluation of structures and their influence on coastal erosion and sedimentation>

The length of the jetty-type ramp from the shoreline to the far end is *ca*. 15m. The gradient of the ramp is *ca*. 1/6. The ramp is of impermeable type and acts as a barrier against littoral drift toward the shoreline.

The photograph on the left in Figure 7.13 shows the northern side of the ramp. It shows exposed beach rocks, which implies that movable gravel has been exhausted. On the other hand, formation of gravel beach is clearly seen on the southern side (the photograph on the right).

This is the same characteristic observed at the impermeable jetties in the southern part of the islet mentioned above.

In other words, prevalence of northerly littoral drift in this area has been confirmed.

Photo 5.20 The Northern Side of a Small Boat Ramp

Photo 5.21 The Southern Side of the Same Boat Ramp

(2) Seawalls

Several seawalls for coastal erosion prevention have been constructed along the coast of Fongafale Islet. Some of them were constructed as public works, while others were privately constructed.

1) Seawalls constructed as public works

The concrete block seawalls constructed with concrete cubes with sides of 30 cm found along the coast near Catalina Ramp seem to have been the ones constructed as public works. However, most of them have disintegrated into disorderly rubble-mound seawalls scattered with concrete blocks and gravel. The condition of such areas is so poor that it is difficult even to walk there. Some residents along the coast recycled the disintegrated concrete blocks to construct ramps for landing boats and small jetties. Photo 5.22 shows a jetty to the south of Catalina Ramp constructed by laying up the concrete cubes, while Photo 5.23 shows a private boat landing ramp north of Catalina Ramp constructed by laying the concrete blocks.

Photo 5.22 A Jetty Constructed with Recycled Concrete Blocks

Photo 5.23 A Boat Landing Ramp

The seawalls at the side of Vaiaku Wharf and in front of the former government building and the government-owned hotel have a structure similar to a vertical concrete seawall. At many places, this structure causes scour by creating reflected waves and downward flow of water when wave run-ups fall in front of the seawall, instead of having a wave absorption effect, and, thus, makes sedimentation of gravel and sand on the foreshore difficult. Many places were observed where the seawalls were the very cause of the erosion in the surrounding area.

Photo 5.24 A Seawall Implemented as a Public Work - the Mixed Vertical/Sloping Seawall in front of Vaiaku Lagi Hotel

Photo 5.25 A seawall Implemented as a Public Work – a Vertical Seawall on the Northern Side of Vaiaku Wharf
(Remnant of part of a gabion seawall is seen.)

Most of these seawalls constructed as public works are vertical seawalls which do not have a wave absorption effect. Therefore, when a high wave hits a seawall, a large amount of sea spray is produced. Such spray washes ashore gravel and rubbish and is the main cause of salt damage to structures. Photos 5.26 and 5.27 were taken at the same locations as the photographs in the figure above at the end of January 2010 when a low pressure system went through the area at the time of a spring tide.

Photo 5.26 Wave Run-ups in front of a Vertical Seawall - the Mixed Vertical/Sloping Seawall in front of Vaiaku Lagi Hotel
(The photograph taken when a low pressure system passed through the area at the time of a spring tide.)

Photo 5.27 Wave Run-ups in front of a Vertical Seawall – A vertical Seawall on the Northern Side of Vaiaku Wharf
(The photograph taken when a low pressure system passed through the area at the time of a spring tide.)

2) Privately-Constructed Seawalls

Many of the privately-implemented seawall works have been construction of masonry, gabion or concrete seawalls by residents of coastal areas against the erosion of shorelines and impact of waves. An existing law of Tuvalu provides an owner of a coastal area with a right to own land formed on the seaward side of the original natural shoreline regardless of whether such land has been formed by natural sedimentation or artificial reclamation. Some people try to take advantage of this provision to own land by constructing seawalls on the seaward side of the original natural shorelines.

Photo 5.28 A Privately-Implemented Seawall – a Wet Masonry Seawall to the North of Vaiaku Lagi Hotel (partially collapsed)

Photo 5.29 A Privately-Implemented Seawall – a Seawall at the Coastal Area at the Southern End of Funafuti Constructed with Concrete-Filled Oil Drums

Almost all of the privately constructed seawalls are causing erosion and sedimentation in the surrounding shoreline areas by blocking littoral drift because they were constructed on the seaward side of the shorelines. In addition, most of them are structurally inappropriate: some have structurally insufficient wave tolerance. Others have cross-sections similar to a vertical seawall, which are likely to cause scour at their base, to create a large amount of sea spray when waves hit them, and/or to cause disturbance of waves by generating reflected waves. Yet others facilitate erosion of the surrounding shorelines. For these reasons, many of them have collapsed even before their construction has been completed. The condition in which people are taking their own initiatives to construct seawall structures with their haphazard reclamation/seawall plans will be a problem in formulating a coastal protection program in future.

Photo 5.30 A Privately-Implemented Seawall – The Lower and Upper Parts Constructed with Gabions and Coping Concrete, Respectively

Photo 5.31 A Privately-Implemented Seawall – Collapsed because of Inappropriate Structure

Photo 5.32 A Privately-Implemented Seawall – a Work Aimed at Land Development

Photo 5.33 A Privately-Implemented Seawall – only Gabion Work Has Been Completed

5.1.2 Ocean Side

The existing condition of coastal structures on the ocean side of Funafuti Atoll was surveyed and their impact investigated. The following map shows the position of the main coastal protection structures on the ocean side of Fongafale Islet.

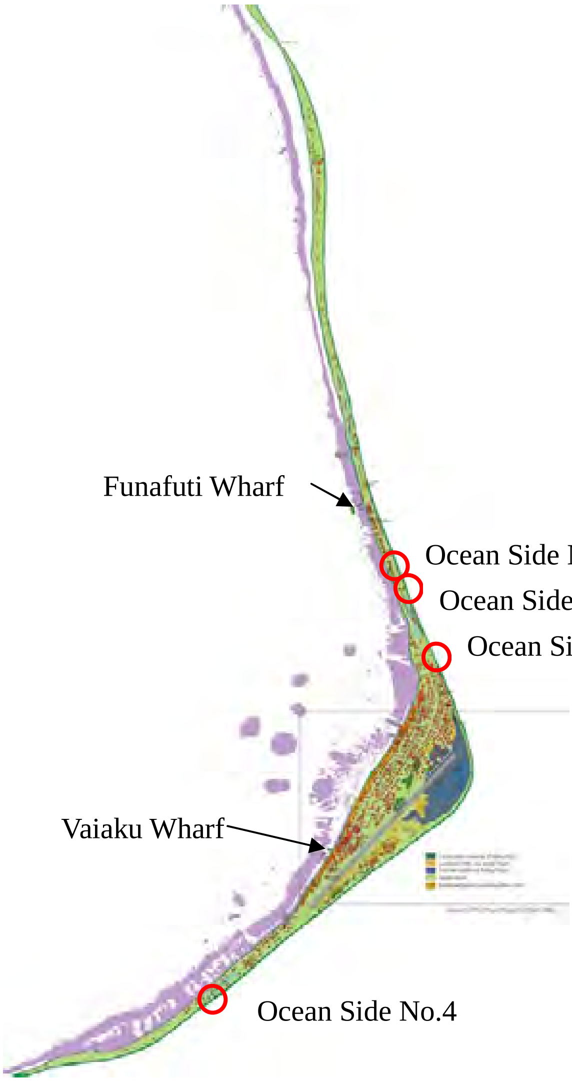


Figure 5.5 Location of Coastal Protection Structures on Fongafale's Ocean Side

(1) Seawalls

The coastal structures on the ocean side of Funafuti have been constructed privately by residents in the hinterland by stacking up rocks or concrete seawalls to increase the area of their properties or out of fear of wave runup and coastal erosion. Most of these seawalls have been constructed by leveling the storm ridge and cutting down vegetation (coconut and pandanus trees) to extend the natural shoreline seaward.

As can be seen in photos 5.34 to 5.37 there are several seawalls, both stacked rocks and concrete, along parts of the ocean coastline in Fakai Fou, north of the airstrip. In particular, along the narrow strip of coastline between the Pacific to the east and the ponds formed in borrow pits to the west—photos 5.36 and 5.37—the beachrock is exposed immediately in front of these walls, where normally a gravel slope would have formed as a result of wave action.

In the case of stacked-rock walls, this is a result of the bedrock fragments having been gathered to make the rock wall, moreover, the seawalls are jutting out seaward of the original coastline in order to increase the area of usable land. Also, most of the beach ridge is very low having been excavated.

Photo 5.35 shows the concrete seawall constructed in front of the church where all of the vegetation (coconut and pandanus trees) has been cut down. As a result, the church receives the full impact of winds from the ocean, so has had to put up tarpaulins as windbreaks.

Photo 5.34 Private Seawall of Stacked-up Beachrock Fragments

Ocean Side No.1

Photo 5.35 Concrete seawall in front of Church

Ocean Side No.3

Photo 5.36 Private Seawall of Sacked-up Beachrock Fragments

Ocean Side No.2

Photo 5.37 Private Seawall of Stacked-up Beachrock Fragments and Tyres

Ocean Side No.2

Along the ocean side coastline south of the airstrip in Kavatoetoe, photos 5.38 to 5.40, there is a 1.2 m high by 50 cm wide concrete seawall and one made of cemented rocks. Further, in this area south of the airstrip vegetation, such as pandanus and coconut tress, grow immediately behind the storm ridge, however, around these seawalls vegetation is very sparse. It is therefore apparent that the seawalls are extending past the original shoreline to increase the area of land right up to the storm ridge and that the vegetation has been cut down.

Photo 5.38 Concrete Seawall at Private Residence

Ocean Side No.4

Photo 5.39 Cemented-Rock Seawall at Private Residence

Ocean Side No.4

Photo 5.40 Concrete Seawall at Private Residence

Ocean Side No.4

5.2 Causeway, Coastal Borrow Pit, Breaching

5.2.1 Causeway

As can be seen in **Figure 5.1**, Tengako and Fongafale islets were separated by 20 to 30 meters up until World War II. During the war the US military built a temporary road running the length of both islets and connected them with land, the causeway, in order to transport earth by truck from central Tengako to make the airstrip in the south. The current concrete causeway was built at the same time the lagoon side road was paved as part of Australian aid in around 1995. It is 20 m long by 5 m wide with a crown height of D.L.+3.3 m. Riprap has been placed on the lagoon side shoreline on either side, approximately 30 m on Tengako and 200 m on Fongafale, using rocks weighing 70 to 100 kg that are thought to have been imported from somewhere besides Funafuti.

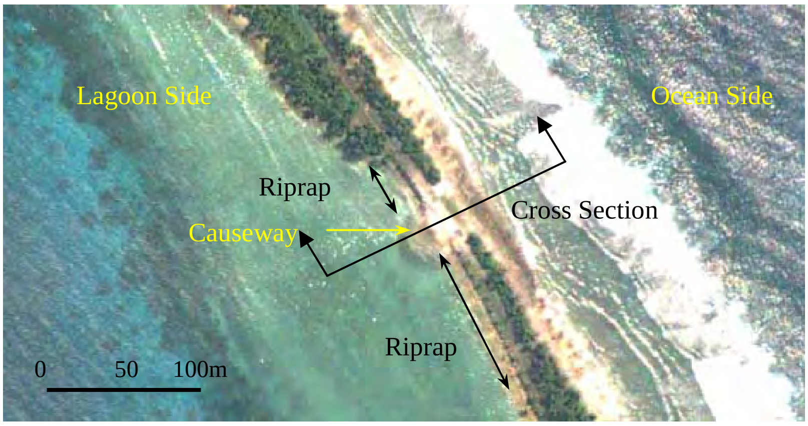


Photo 5.41 Satellite Image of the Causeway

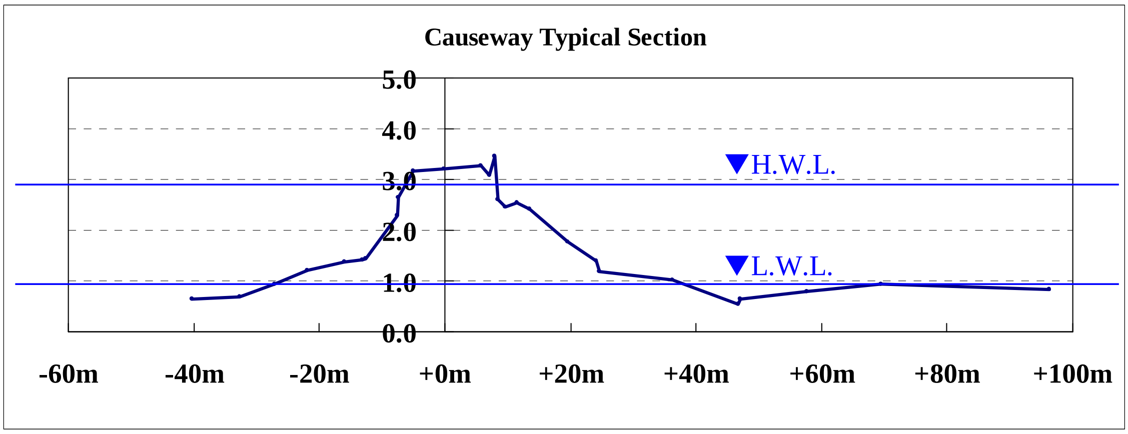


Figure 5.6 Causeway Typical Section

Coastal protection impact of excavating causeway and issues for consideration

There is a significant possibility the construction of the causeway has contributed to further erosion along the lagoon coast on Fongafale Islet by reducing the source of materials for the lagoon side longshore drift as a result of the inflow of foraminifera, sand, and gravel from the ocean being cut-off or reduced.
Removing the causeway and returning it to its original condition can be expected to be effective in increasing the amount of foraminifera, sand and gravel flowing into the lagoon, and the amount of sand deposited on the lagoon side coastline. However, in order to predict how effective this will be, it is necessary to consider a variety of factors starting with wave measurements, also how much foraminifera (sand) will flow into the lagoon from the ocean, and whether there is sufficient external force to transport the sand as longshore drift in the lagoon. It is desirable to excavate a waterway of sufficient width and depth in order to secure ample flow through the causeway into the lagoon, however, this will also mean a great deal of wave energy will be enter from the ocean, namely, this is expected to change the wave and flow dynamics within the lagoon and lead to new coastal geomorphological activity on both ends of the causeway opening. Moreover, this will also lead to not only foraminifera and sand derived from it being washed in, but also coral gravel, which may reduce the effectiveness of this measure by chocking up the waterway with gravel. Therefore, it is important to consider issues surrounding the maintenance of this waterway.

5.2.2 Coastal Borrow Pit

The beachrock in the shallows of central Fongafale was excavated in four locations—during WWII by the US military to land equipment for the construction of the airstrip—the remains of which can be seen in **Figure 5.7**. These anthropogenic seafloor depression remaining in the littoral zone, are known as coastal borrow pits, similar to those on land. The detailed bathymetric survey shows that the seabed around the borrow pits is from C.D.L.±0 m to ＋1 m, meanwhile the maximum depth of the borrow pits is below C.D.L.－3 m.

Incoming waves on the lagoon side break on the flat shallows offshore and their energy dissipates. In the deeper water of the borrow pits, however, this does not occur, meaning the waves break further up the shore. Also, wave height is increased due to this localised and complex seabed terrain combined with waves reflected from the shore. These borrow pits also generate fast outflowing currents during high seas that wash sand offshore, which has accreted in the pits during calm periods as a result of longshore drift. As such, sand naturally accumulates in the borrow pits, which is hindering the rehabilitation of the surrounding seabed height.

An effective long-term measure to promote accretion on the beach without impeding longshore drift is to refill the borrow pits, thereby restoring the seabed topography to its original flat state.

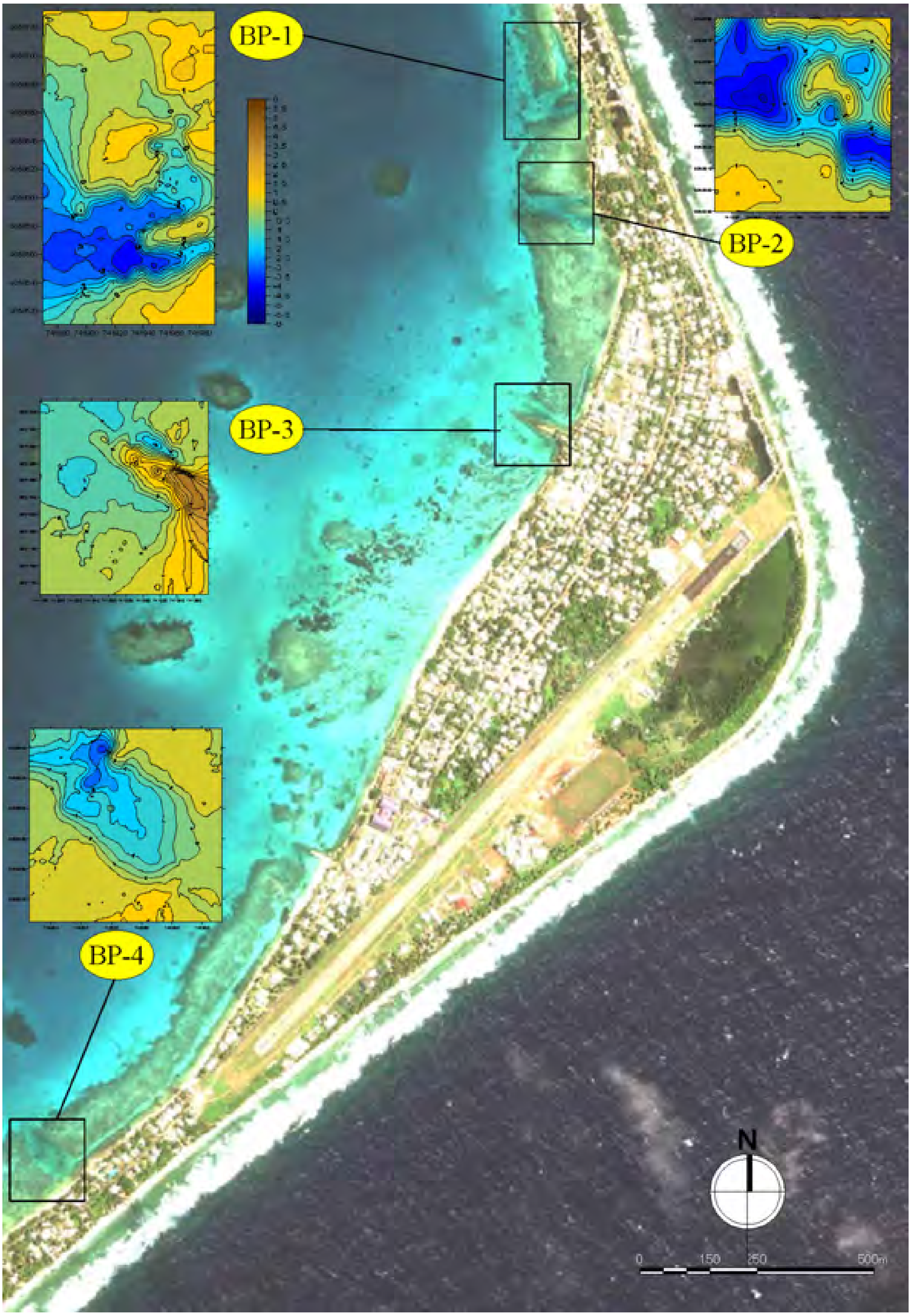
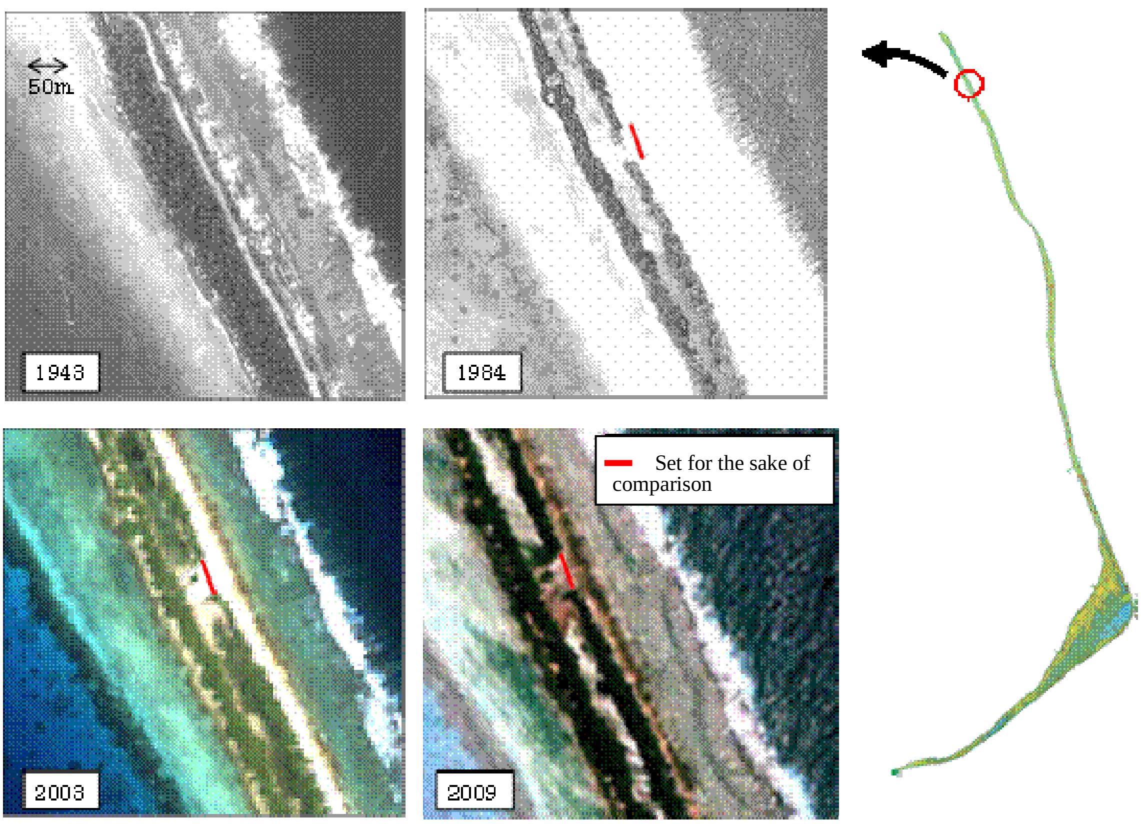


Figure 5.7 Location of Borrow Pits and Bathymetric Maps

5.2.3 Breaching

As can be seen in **Figure 5.8**, the breaching is a result of the storm ridge along the eastern coast collapsing and sand and gravel flowing into the borrow pit running along the centre of the islet, which was dug out by the US military during WWII to obtain gravel for the construction of the airstrip. This area is uninhabited; however, there is concern over the expansion of the breach, which has shown a tendency of expansion until recently, and also possible impact on the lagoon side.



Source: 1943 to 2003: EU EDF 8/9 – SOPAC Project Report 54, Reducing Vulnerability of Pacific ACP States
TUVALU TECHNICAL REPORT – COASTAL CHANGE ANALYSIS USING MULTI-TEMPORAL IMAGE COMPARISONS – FUNAFUTI ATOLL, April 2006

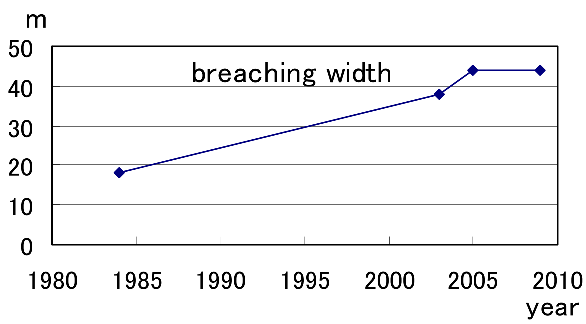


Figure 5.8 Changes in the Breaching Opening

Future trends concerning the breaching considered based on the results of the field reconnaissance:

- It is apparent that the beach ridge on the ocean side has been breached and massive amounts of sand/gravel have been washed into the long, narrow borrow pit in the middle of the islet. Breaching is when a barrier is cut and seawater and sediment is washed from the ocean into a lagoon, therefore, this case is technically not breaching. The beach ridge has collapsed, however, and the fact that large quantities of sediment has been washed into the borrow pit is very similar to breaching. As such, the observed phenomenon can be included in breaching in the wider sense of the word.
- Large quantities of sediment were washed into the pit due to the breaching, however, this resulted in an increased ground elevation in the areas of seawater intrusion. This has lead to the restoration of the beach ridge with gravel being washed in from the surrounding ocean by wave action.
- Large quantities of sediment being washed into the pit due to the breaching leads to accretion in the borrow pit and as a result the impact of wave power on the long, narrow ridge between the west coast and the borrow pit is reduced. As such, the stability of the lagoon side ridge will increase. It is reasonable to say, therefore, that there is no risk of this ridge being breached. This, however, is based on the assumption that there will be a sufficient supply of beachrock and coral fragments that form the beach ridge. If, for example, the supply is limited, then the breached opening will not be sufficiently closed and the beach ridge will not develop adequately. Under such a scenario, overtopping of the beach ridge will continue unabated, and so too will the movement of the beach ridge towards the lagoon side. If the coral dies off, the reduced supply of coral fragments will cause the beach ridge to move landward by a comparable amount.

Further, the borrow pit on Tengako Islet where the breaching has occurred is being filled in with municipal waste in a EU supported project. This project can be expected to prevent the storm ridge collapsing. For these abovementioned reasons, breaching countermeasures on Tengako Islet will not be considered.

5.3 Interview Survey

5.3.1 Justification

Information on the hinterland is crucial when proposing coastal protection measures. However, in Tuvalu, there is almost no basic information of such. For example, where houses exist in what density; positions of the important infrastructures behind what type of coastal characteristics; and what type of coastal disasters are occurring in what frequency and where.

If this kind of information is available, the mechanism of coastal disasters could be explained together with effective measures. 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.

5.3.2 Purposes

The purposes of this hinterland damage survey (the Survey) are the following three (3) particulars:

(1) To acquire information of hinterland damages and coastal disasters (the frequency and distribution) of Fongafale Islet.
(2) To acquire information of residents: community groups, years of living in the present address, etc.
(3) To let the residents know JICA's study on emergency coastal protection measures is being conducted.

5.3.3 Method of Acquiring Information and the Contents of Questionnaire

(1) The Subject Residents

One representative from every single household in Fongafale Islet was to respond to this interview survey. It was thought to be important to receive information on damages in all areas of the islet where the residents live, and to acquire individual perceptions without other people's influence. However, churches, company offices and shops, offices of the Government were excluded from the Survey due to the following reasons: the respondent may be confused whether to reply about their house or work place; their information may well be double counted; they don't know phenomenon in the evening or unusual climate. Number of households is expected to be 700 according to hearing from Council of Funafuti (Kaupule).

(2) Acquiring Geographic Coordinates

Geographic positions of respondents are essential for making distribution maps of the hinterland damages. In order to take many coordinates in a short time, three (3) handy GPS were utilized.

(3) Contents of Questionnaire

In order to avoid any ambiguity, the questionnaire was in Tuvaluan and used multiple choice answers. For those residents who request to express their own ideas, free answer is furnished at the end of the questionnaire. The contents of the questionnaire are shown in Table 5.1, and actual questionnaire used in the Survey is shown in Section 2 of PART IV in the Supporting report.

(4) Other References

For explanation of the Study to the residents, the Survey Team carried brochures of the Study (Section 2 of PART IV in the Supporting report).

Table 5.1 Contents of Questionnaire

Type of Damages	Question Number	Questions	Selection of Answers
Coastal Erosion	Q1	Do you feel "the nearest beach to your house" is smaller (or larger) than before?	* Smaller than before * Larger than before * No change
	Q2	When the change (erosion/ accretion) began?	* This year * 2-3 years ago * Around 5 years ago * Even before that
	Q3	What is YOUR house's damage by coastal erosion?	* Plants/vegetation damage * Building damage * Land loss * No damage by erosion
Salt Water Inundation	Q4	Is YOUR house or adjacent land inundated by salt water before?	* No, my house is never inundated by salt water * Yes, just once * Yes, 2-3 times * Yes, it happens almost like every year
	Q5	If you answered "Yes" for above question, what was the highest level of the water?	* Yes, water level was lower than floor of living room * Yes, the water was above the living floor level * No inundation experienced before
	Q6	Where does the saltwater coming from? (Plural answer possible)	* From the ground (through "potholes") * Waves from <u>ocean-side</u> shore as surface water * Waves from <u>lagoon-side</u> shore as surface water * I don't know
	Q7	What was the longest duration of inundation you have experienced?	* Few hours * About One day * More than two days * More than a week
	Q8	What was the damage of inundation?	* Traffic halted * Plants and/or vegetables * Building foundation

Type of Damages	Question Number	Questions	Selection of Answers
			* Furniture
High Waves	Q9	Have you ever experienced oceanic waves hit YOUR house? (Please exclude oceanic "Spray")	* No, never. * No, but salt water flew in my neighbor from the ocean side during high waves * No, but salt water flew in my neighbor from the lagoon side during high waves * Yes, high waves hit my house before/ frequently
	Q10	What was your damage from high waves? (Plural answer possible)	* Road was closed * Plants and vegetables died * YOUR house was damaged
Saltwater intrusion to ground water	Q11	Is there a well near your house? If there is, please answer following question.	* Yes, there is a well nearby my house * No, there is not a well around my house.
	Q12	(Only for answers of "Y" in "Q11") What is the well's water used for? (Plural answer possible)	* Drinking and cooking * Washing and/or bathing * Agricultural use * It's not used (abandoned)
	Q13	Is the well's water salty?	* Yes, it is salty since long time ago. * Yes, the well's water became salty recently (less than 10 years) * No, it's not salty at all.
Respondent's information	Q14	You are a	* Male * Female
	Q15	What is your age?	* 10-20 * 21-30 * 31-40 * 41-50 * 51-60 * 61 or over
	Q16	What is the name of island you were born?	* Fongafale * Funafala * Tengako * Amatuku * Other Island of Funafuti Atoll * Nanumea * Nanymaga * Niutao * Nui * Vaitupu * Nukufetau * Nukulaelae * Niulakita * I'm from other country
	Q17	How long have you been living in your present address?	* Less than 5 years * 5-10 years * More than 10 years
	Q18	Who is the landowner of land you are living on now?	* It is my land * It belongs to my parents (or close relatives) * It is not my land
	Q19	Which village are you living in now?	* Alapi * Fakai Fou * Senala * Vaiaku

Type of Damages	Question Number	Questions	Selection of Answers
			* Lofeagai * Kavatoetoe * Asagatau Paka
Free Answer	Q19	Do you have any comment on rising sea-level?	-

5.3.4 Implementation of Survey

The Survey was conducted in following steps:

(1) The purpose and method of the Survey was explained to Kaupule, and received endorsement from the Chairman. Cooperation staff of Kaupule translated the English questionnaire into Tuvaluan, together with an explanation of the Study.

(2) The Survey team explained the Survey procedure to the Islet's supreme decision making committee (Fale Kaupule), and obtained their agreement.

(3) The Survey team broadcasted implementation of the Survey through the Islet's radio station. It read the team's message eight (8) times altogether in two days.

(4) The Survey team consisted of: 10 residents, a coordinator (NGO staff), two (2) Kaupule staff, and two JICA Study Team staff; and was divided into three (3) teams. The briefing was held before conducting the Survey in following manner.

Table 5.2 Division of Survey Team

	Responsible Villages
Team A	Senala Village and Fakai Fou Village
Team B	Alapi Village and VaiakuVillage
Team C	Asagatau Paka Village, LofeagaiVillage, and Kavatoetoe Village

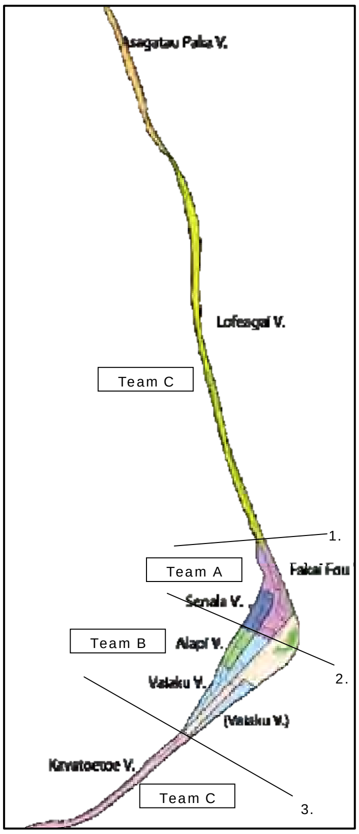


Figure 5.9 Responsible Villages

Photo 5.42 Explanation at Fale Kaupule

Photo 5.43 Briefing before Survey

Photo 5.44 Interviewing Residents

Photo 5.45 Residents Were Aware of the Survey by Radio

5.3.5 Data Processing and Summary

Geographic coordinates are given for every answer sheet; and they are plotted over a map of the Islet which shows specific coastal lines, roads, and all the buildings and structures. The map was produced by the JICA Study team by using newest satellite images.

5.3.6 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'. Invalid answers are 30, approximately. Some lost their coordinates, over rapping, or had invalid answers.

(1) Coastal Erosion

Figure 5.10 shows positions of the houses of the people who answered: neighbouring coast is eroding and their houses were damaged. The number of corresponding respondents is extremely small. Assuming the inland correspondents were errors, impact of erosion is extraordinary small in the Inlet so far.

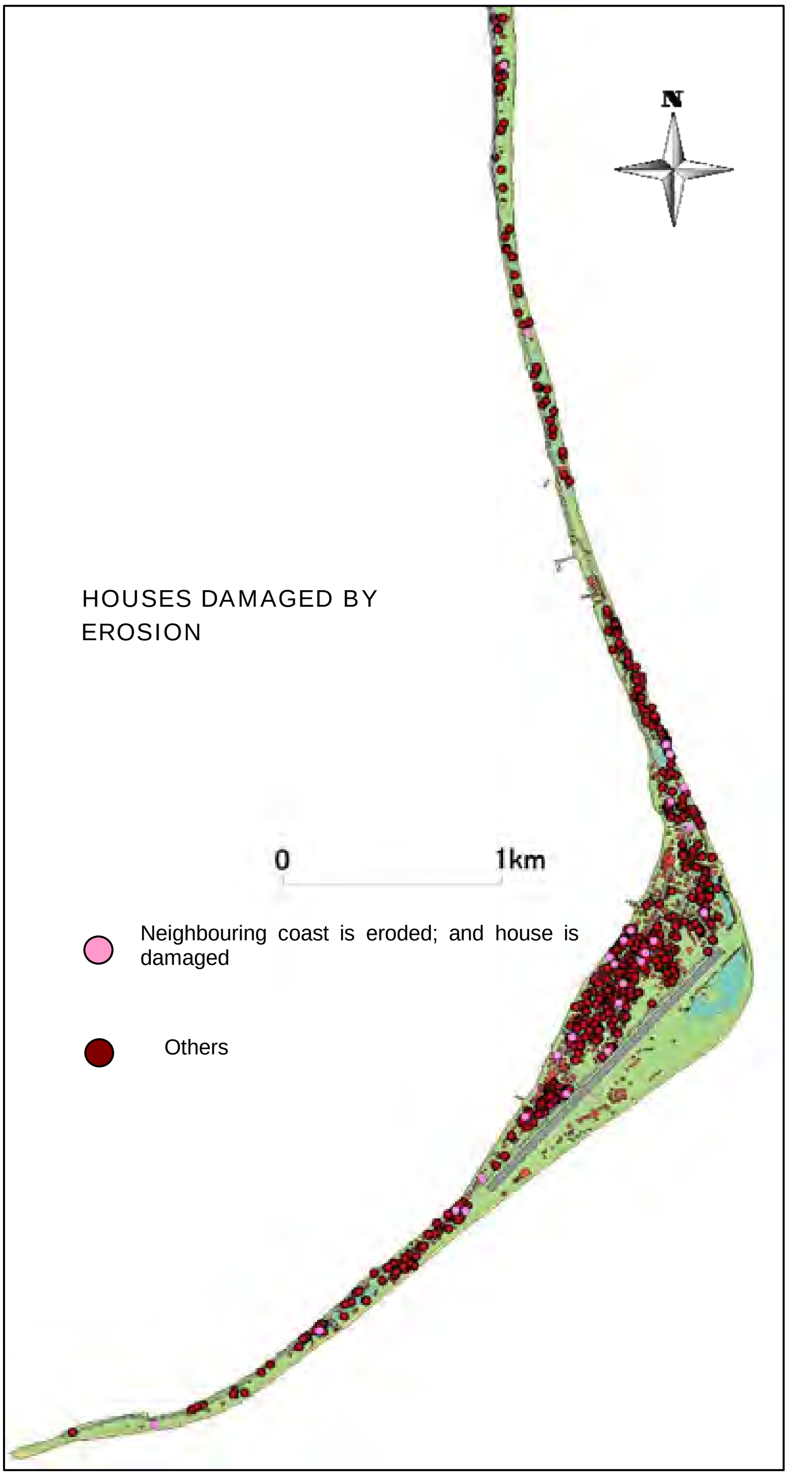


Figure 5.10 Damaged Houses by Erosion

(2) Inundation

a) Inundation Level

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

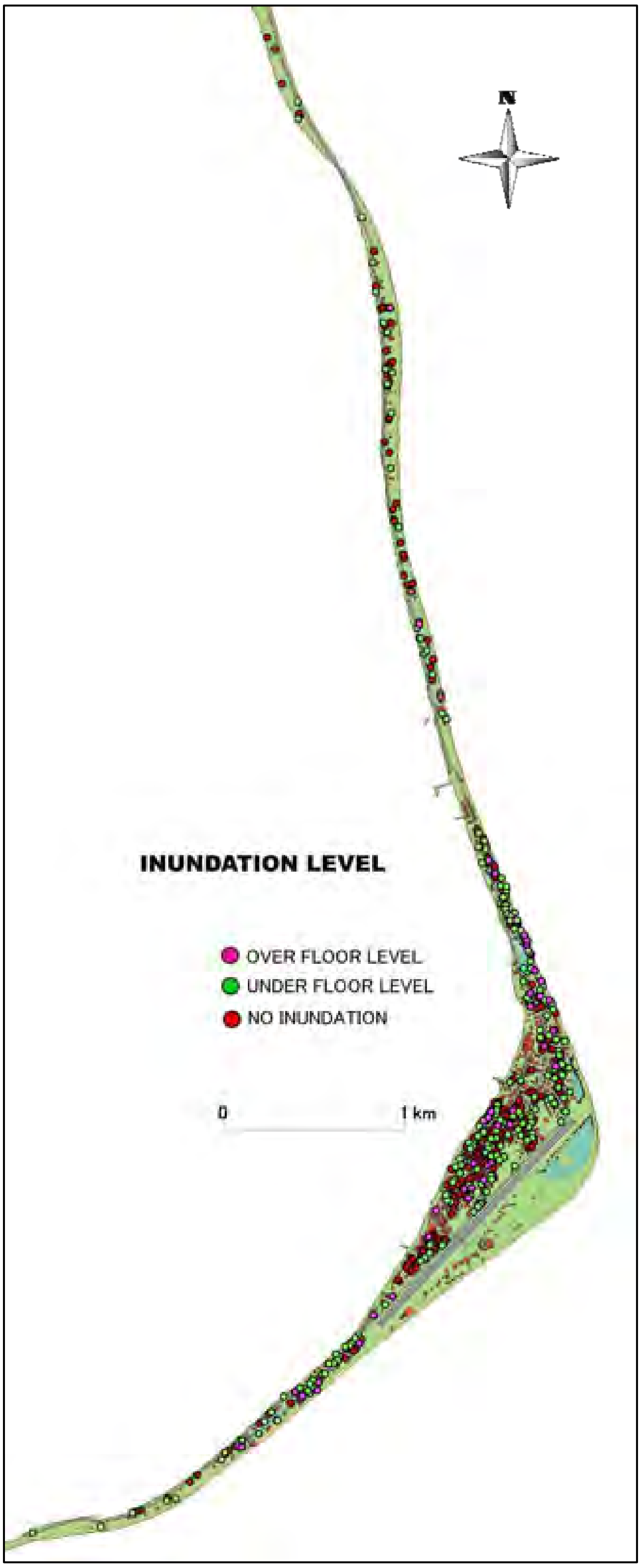


Figure 5.11 Inundation Level

b) Inundation Frequency

Except Alapi Village and the surrounding area, most of the residential area is inundated every year.

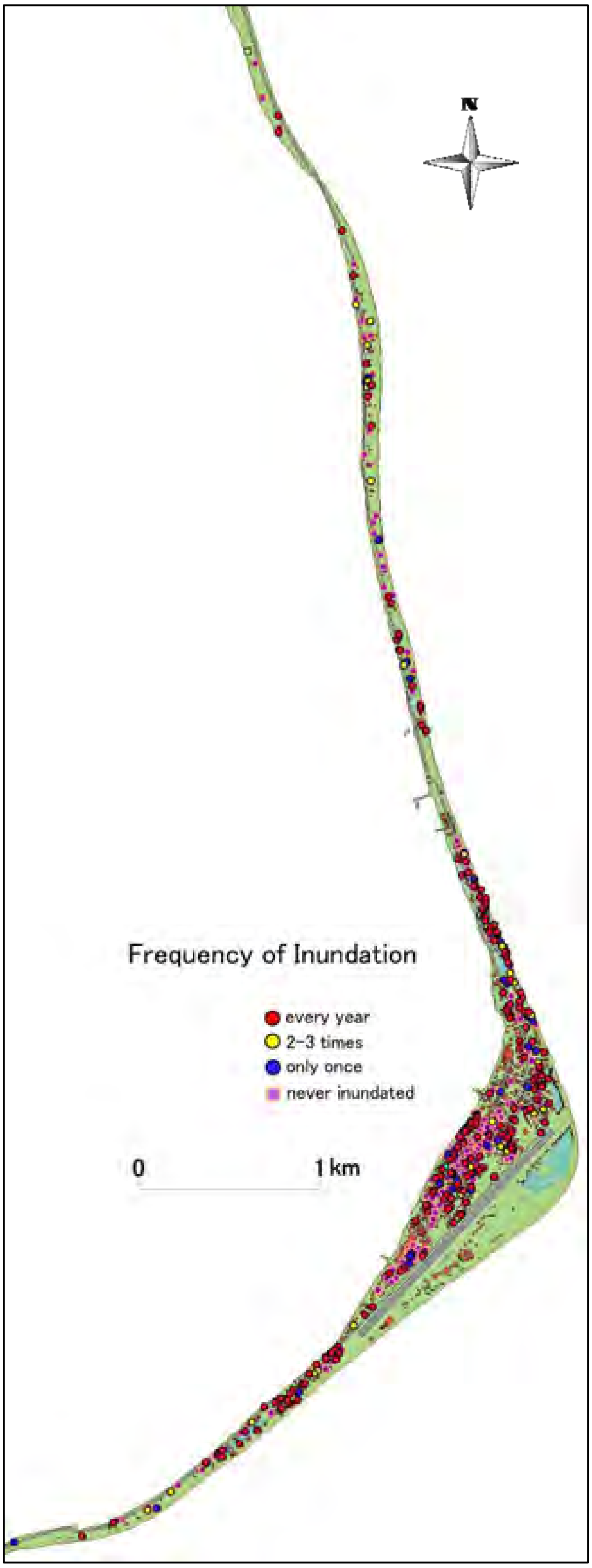


Figure 5.12 Inundation Frequency

c) Origin of Sea Water

Sea water intrude inland area through "Pot-holes" and sites of demolished borrow pits. For other areas, the water is coming from either lagoon side or ocean side over ground.

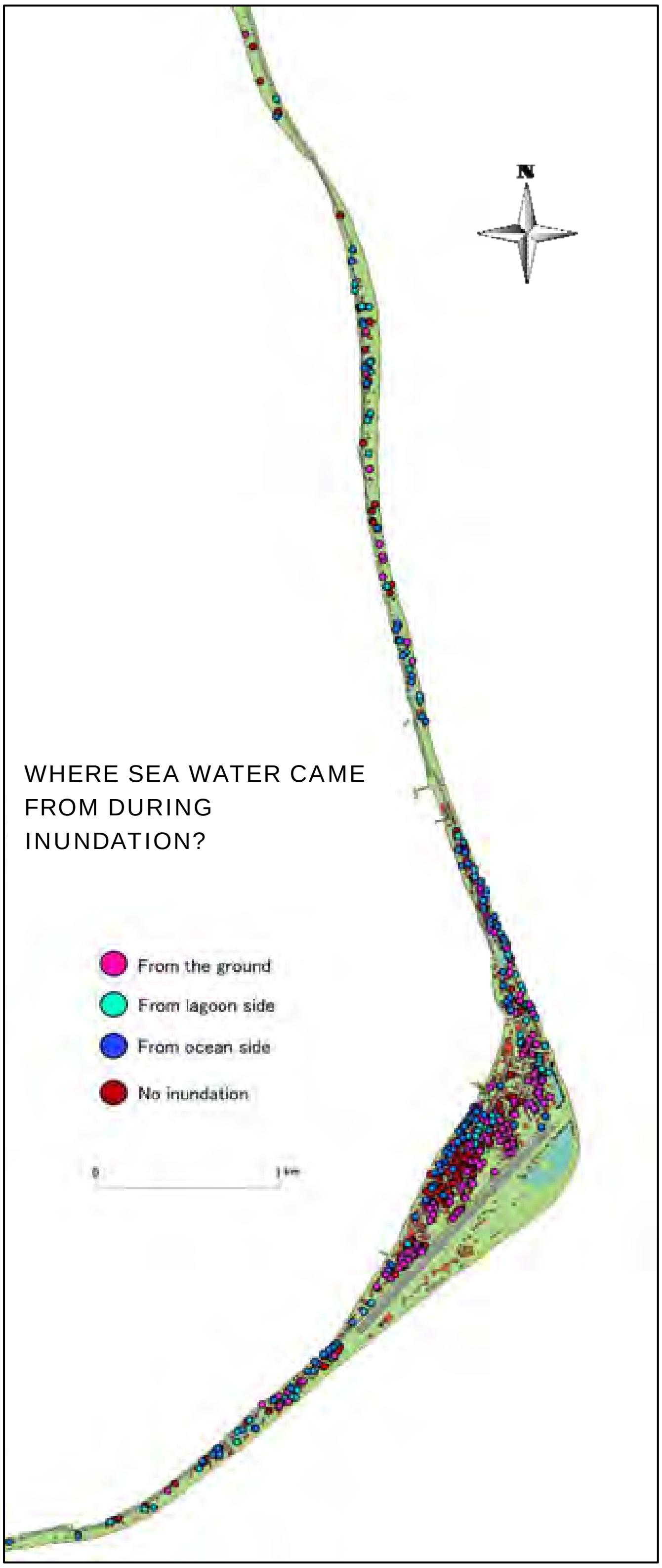


Figure 5.13 Origin of Inundation Water

(3) Over-Topping Waves

a) Distribution of Over-Topping Waves

There are two areas where over-topping of waves are concentrated: 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.

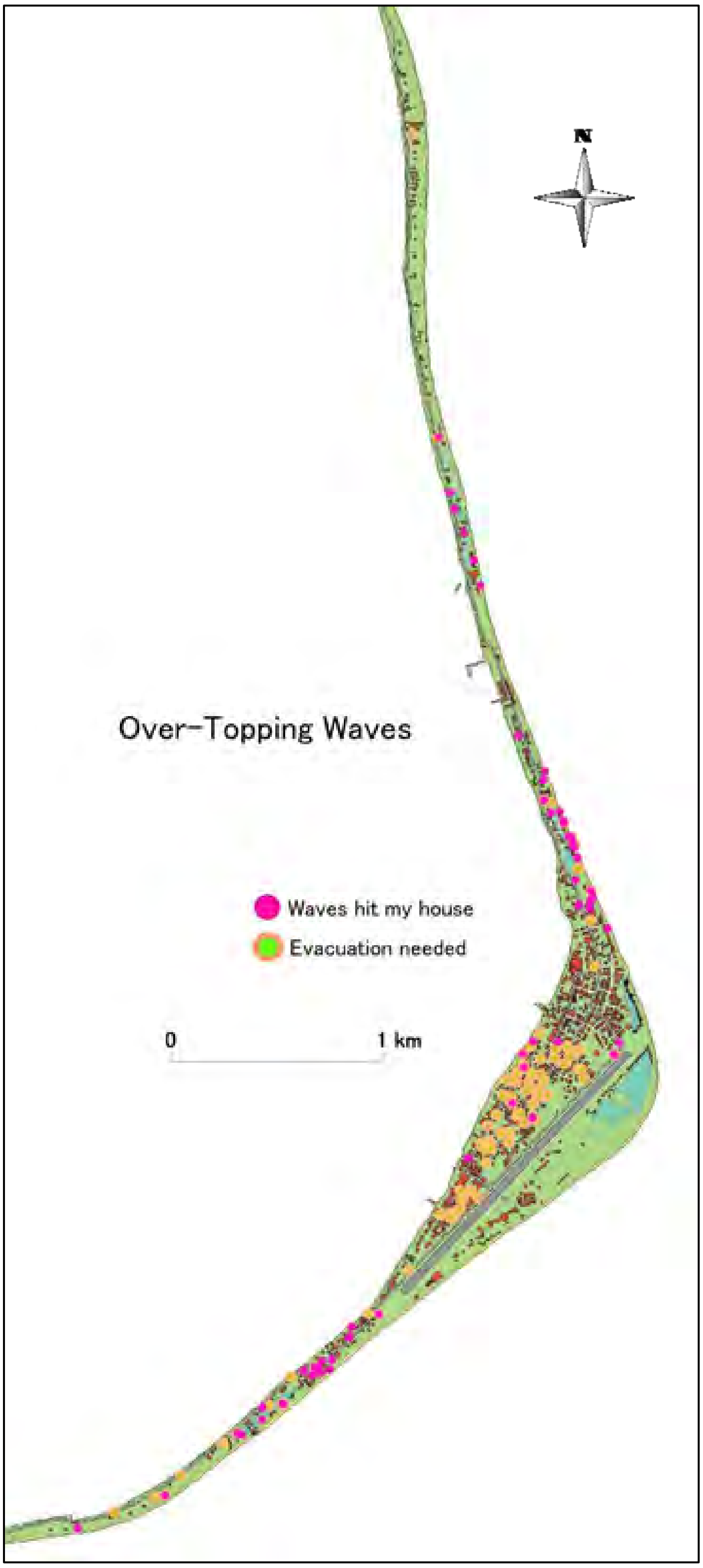


Figure 5.14 Occurrence of Over-Topping Waves

b) Damaged Houses by Over-Topping Waves

Number of houses which are damaged by over-topping waves is even smaller. The area is limited to the north or south ocean side. It should be assumed that the plots in the inland are errors.

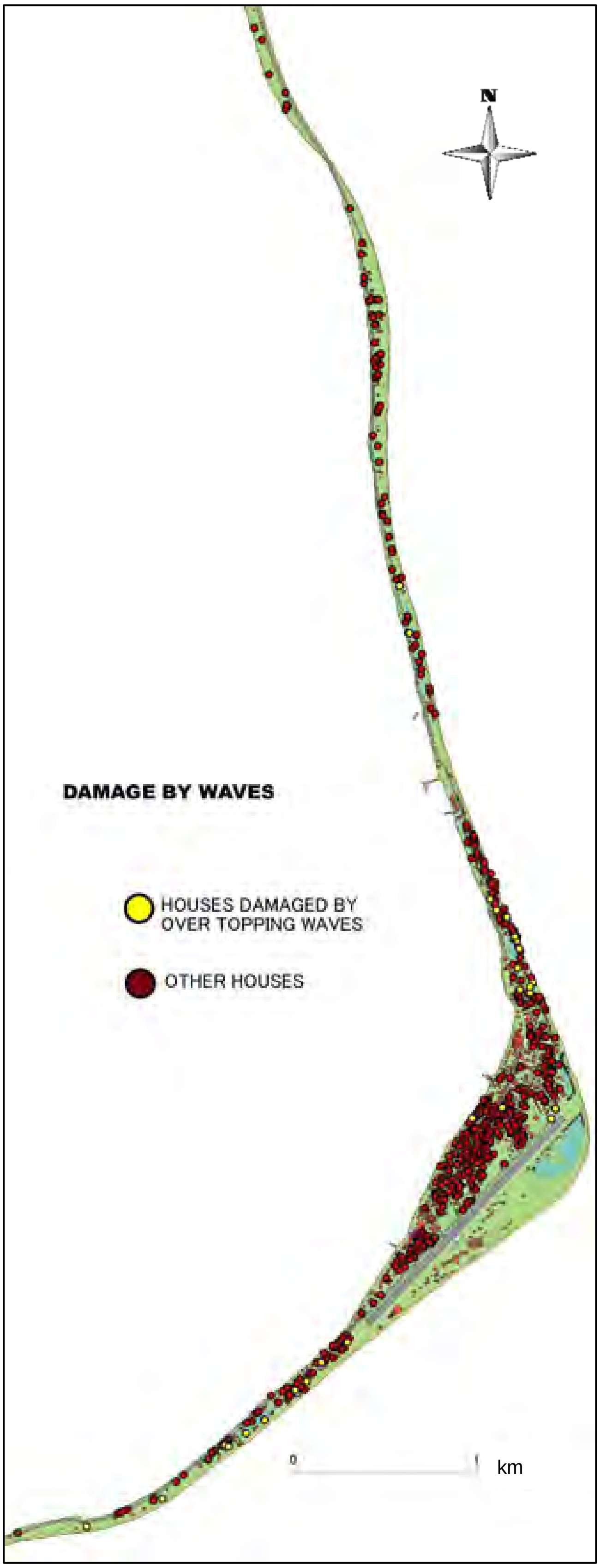


Figure 5.15 Damaged Houses by Over-Topping Waves

(4) Salt Intrusion

There are wells around taro swamp fields (*pulaka* pits) in the islet. The question was designed to reflect recent salinity intrusion; however, the questionnaire found that all the wells in the Islet are not being used for drinking or cooking. Some wells are answered as "fresh water well", but since they are either abandoned or used only for washing, accuracy of their answers is doubtful.

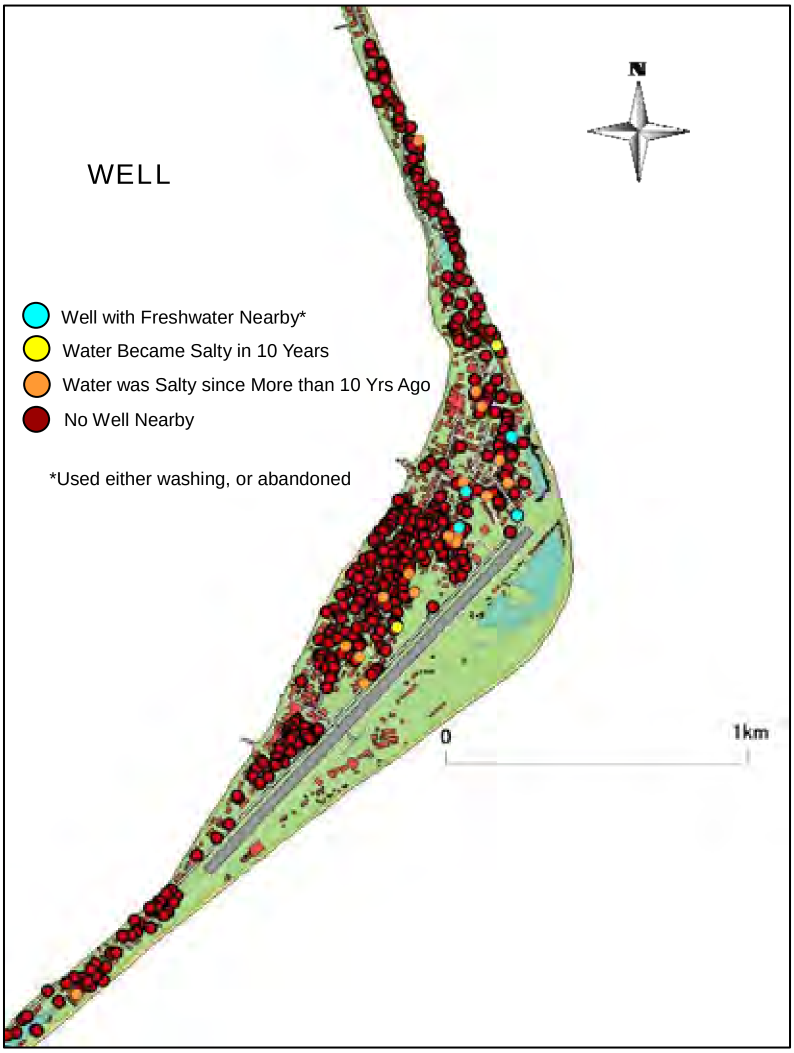


Figure 5.16 Wells and the Salinity

(5) Respondents' Characteristics

a) Years of Living

There are many residents living more than 10 years in Alapi Village; on the other hand, areas vulnerable to oceanic waves are inhabited by many new comers (less than 5 years).

It is expected that more than half of the population moved in to the present address within the last 10 years.

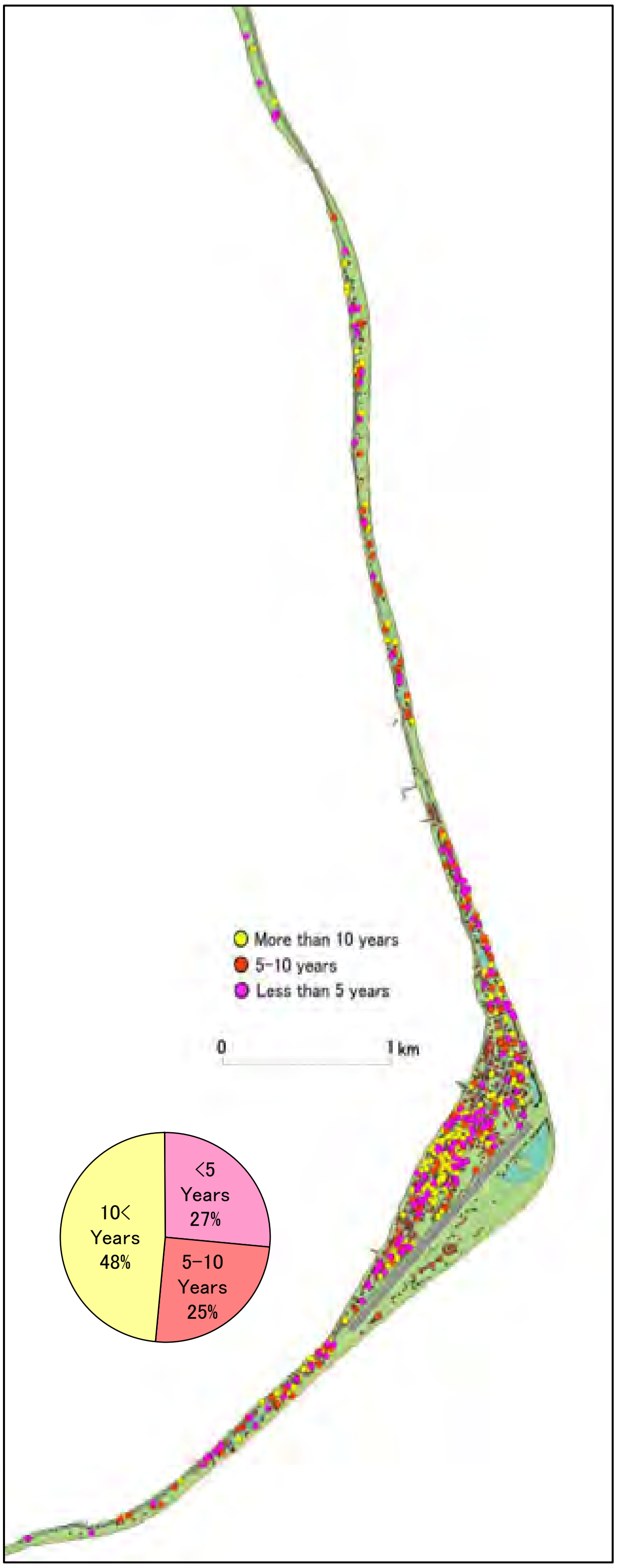


Figure 5.17 Years of Living

b) Island of Birth

Only 23% of the respondents were born in Fongafale Islet.
No respondents were born on other islets in Funafuti Atoll. There are 22% born in foreign countries.

Table 5.3 Ratio of Islanders

Island of Birth	No. of Respondents
Fongafale (Funafuti)	136
Funafala (ditto)	0
Tengako (ditto)	0
Amatuku (ditto)	0
Nanumea	78
Vaitupu	56
Nukufetau	53
Niutao	51
Namumaga	42
Nui	19
Nukulaelae	14
Niulakita	3
Foreign country	125

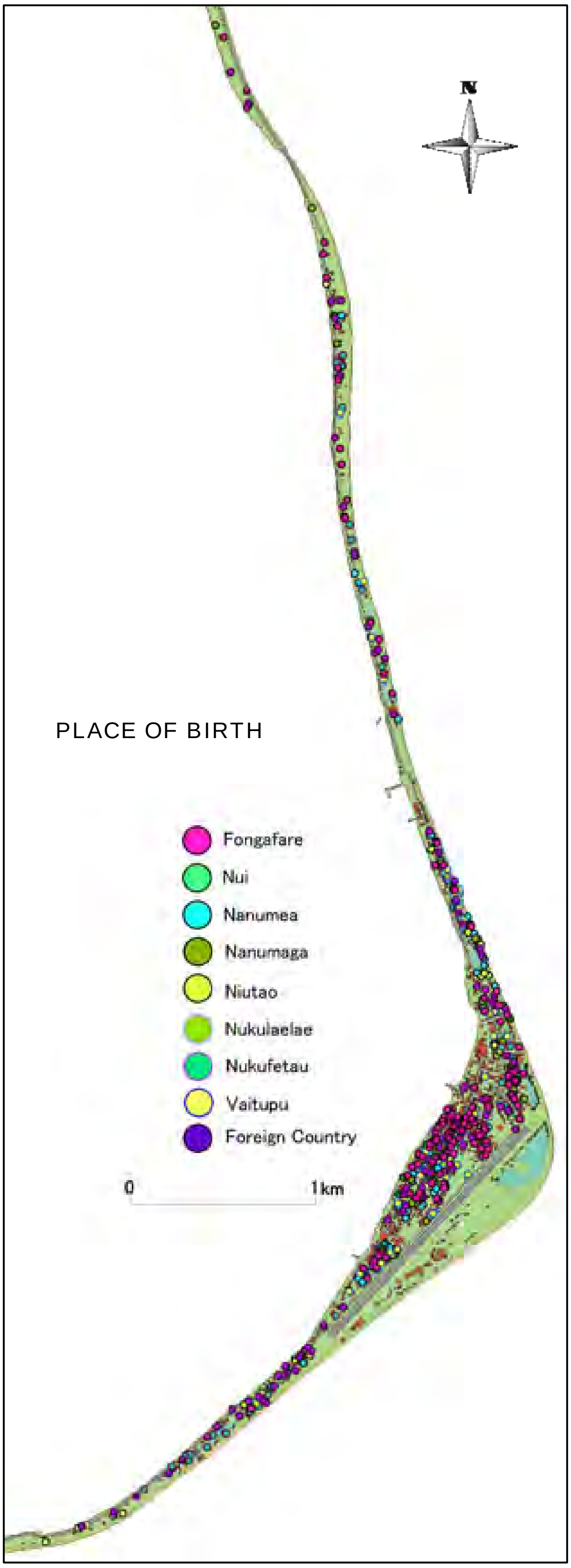


Figure 5.18 Island of Birth

(6) Free Answers

The following are the free answers for "Do you have any comment on rising sea-level?". Similar answers are merged together, and listed in sequence of frequency.

Table 5.4 Free Answers

Opinion on Sea Level Rising (SLR)	No. Opinion
We need help from the Government/Japan/other countries	103
We need evacuation/migration before SLR happens	93
We need seawall	57
Reclamation is necessary	32
I am afraid/worried of SLR	26
There is NO SLR happening yet	24
SLR is caused by climate change. Reduce COx	12
Coast is eroded. Protection is needed	11
We can't do anything. Faith is important. We will stay.	9
We need ships and life jackets	8
Plant trees, we should stop cutting trees	7
Do something to protect our island	5
We need plan before SLR happens	5
Private excavation should be prohibited	4
We need information/awareness programs	3
We have to be prepared	3
Build Breakwater	2
Flood prevention is needed	2
Land is too low to live, too small to withstand SLR	2
Sea level is rising slowly	2
We need to raise land elevation	1
Damages are bigger during beginning of year	1
High tide is causing problems	1
Fish population is decreasing.	1
There IS climate change	1

5.4 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. Several photos showing the situation at the time and handheld GPS readings of the wave overtopping sites are included in **Figure 5.19**. The red lines encircle the areas of damage as reported in the questionnaire, which mostly, besides E, correspond with the results of the fact-finding survey. The fact that E area does not show up in these results is considered to be due to the oceanographic conditions at the time of the fact-finding survey, and because the questionnaire included overtopping damage from the ocean side.

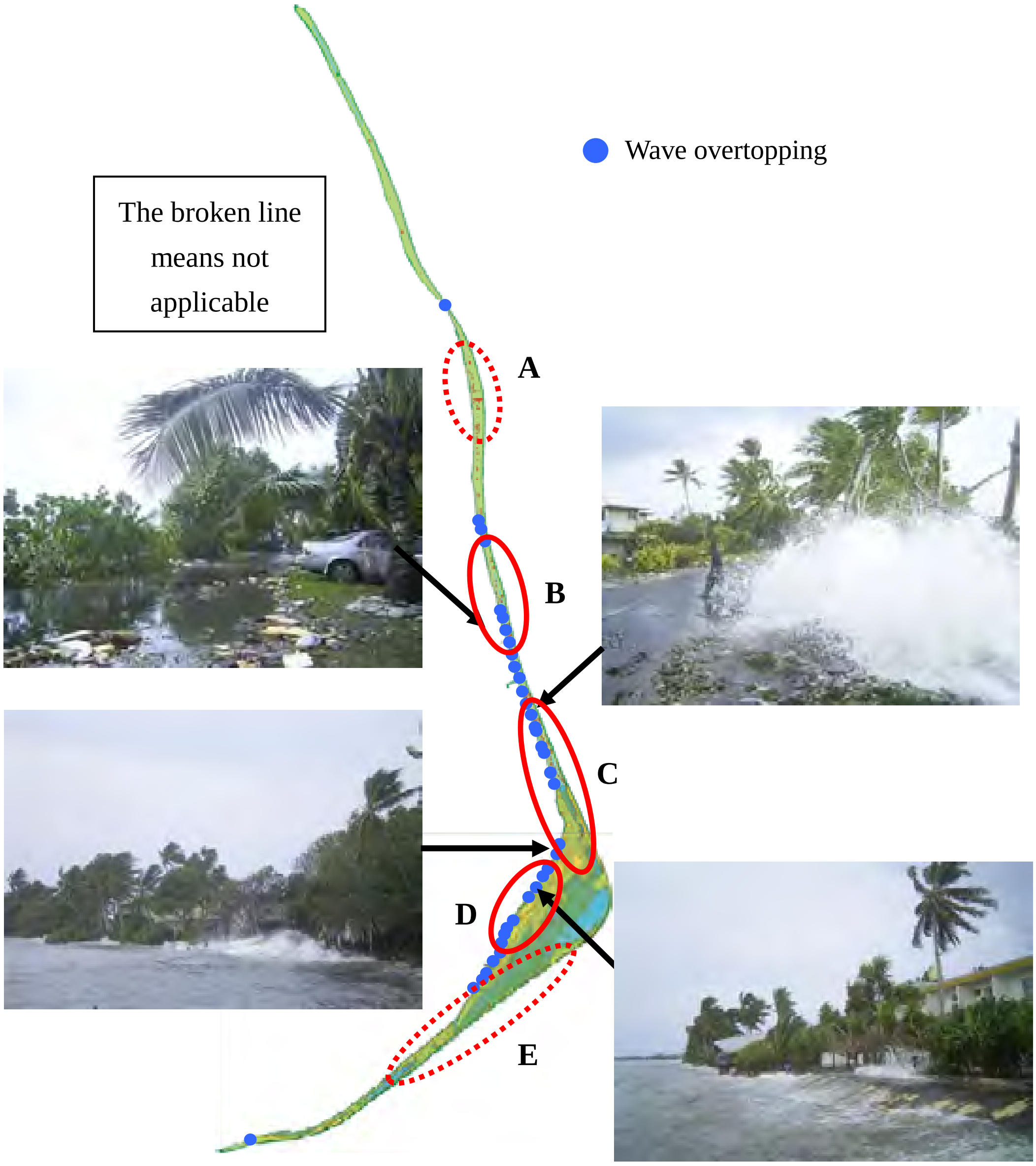


Figure 5.19 Distribution of Damage Levels Found in the Wave Overtopping Field Survey

5.5 Findings on Coastal Vulnerability

Vulnerability issues on both the ocean and lagoon sides of Tengako Islet, which lies to the north of Fongafale Islet, have been compiled based on the results of the field reconnaissance, the questionnaire and the overtopping survey.

5.5.1 Lagoon Side

On the lagoon coastline, there are sandy beaches over 200 m long in the north of Tegako Islet and in the central part of Fongafale Islet; however, the rest of the coastline consists mainly of beachrock and gravel, or gravel and scattered 30 cm concrete blocks. The height of the storm ridge on the ocean side is a little less than 5 m above chart datum level, while that on the lagoon side is a little less than 4 m above CDL.

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. These magnify wave overtopping damage by causing larger waves than in surrounding areas because of the greater depth, whereby waves reach the shore without having been depleted of energy.

The lagoon coastline has various public and private coastal structures—wharfs, jetties, seawalls and so on—however, it is evident that these structures are impacting sand and gravel movements in their vicinity. Many of the private seawalls in particular, have been constructed encroaching beyond the original shoreline. These obstruct the longshore drift and cause erosion and accretion of the surrounding shoreline. Furthermore, the majority of which are structurally unsound, with many collapsing before completion; and it is evident that private seawall and landfilling is being undertaken haphazardly.

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.

5.5.2 Ocean Side

The storm ridge is made up of gravel of coral reef origin (coral and beachrock fragments), and plays an extremely important role in protecting the islet from ocean waves. Moreover, the vegetation that grows around the storm ridge—coconut and pandanus trees—is vital in strengthening and compacting the ridge.

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 (Photo 5.46 and Photo 5.47). Further, some areas of the backshore are extremely narrow where the landward side of the storm ridge has been excavated away to increase the area of flat land (Photo 5.46). The storm ridge is vulnerable and in danger of collapsing in these areas and on Tengako Islet near the waste disposal site (Photo 5.47) and near the area of breaching.

Photo 5.46 Excavated Area behind the Storm Ridge

Photo 5.47 Coastline at Waste Disposal Site

Issues facing the 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.