CHAPTER 8 CONSENSUS BUILDING WITH LOCAL RESIDENTS

8.1 Outline of Public Hearings

8.1.1 Justification

The basic policy for the Coastal Protection and Rehabilitation Plan was drafted based on the results of baseline surveys—conducted since August 2009, and has been discussed through a series of meetings with the Project Coordination Committee (PCC). However, the Project may affect the quality of life in the local neighborhood when implemented. Decisions for all community matters that are of public interest or political importance are basically made by the community, rather than the government. Therefore, it is crucial to reach agreement with local residents on the Project and gain their cooperation for implementation. It is also desirable that the concept of the Plan—including: the need for the Project, selection process of the target area, outline of implementation, matters of concern, and resident's roles and responsibilities—should be shared with local residents in the early planning stage. Such interactive communication process with local residents will lead to a more realistic plan that reflects the community's real needs.

8.1.2 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. After the consultation process, the final report, which includes recommendations for implementation, was submitted to the Tuvalu government by January 2011.

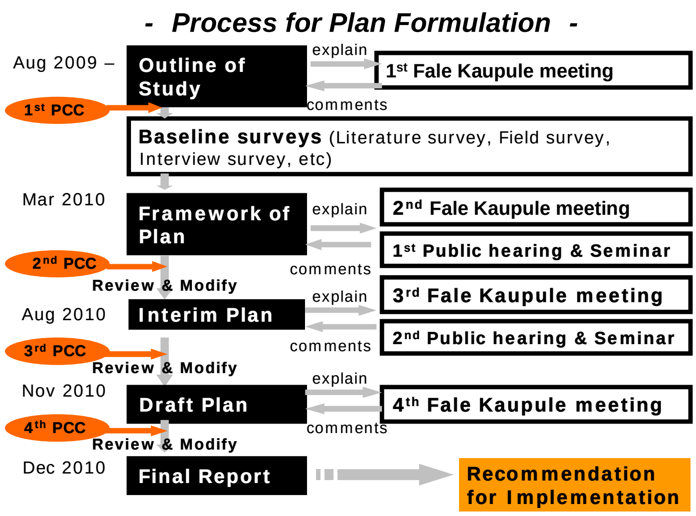


Figure 8.1 Community Involvement in the Planning Process

8.1.3 Purpose

The purposes of the public hearings are to promote community involvement in the planning process, and to reflect the views of the local community in the proposed Plan and countermeasures for coastal protection and rehabilitation.

8.1.4 Target Residents

The #1 area in the central part of Fongafale Islet, including Senala, Alapi and Vaiaku areas shown in the **Figure 8.2**, has been selected as the highest priority area according to the condition of the hinterland, disaster damage, and wave run-up. The public hearings targeted residents who live in, and fishermen who use the above mentioned locations. Considering Tuvalu's social hierarchy, Funafuti community can be divided into two groups:

- Falekaupule - has the highest authority in terms of making decisions for community matters, and
- Funafuti Island Community - composed of the residents.

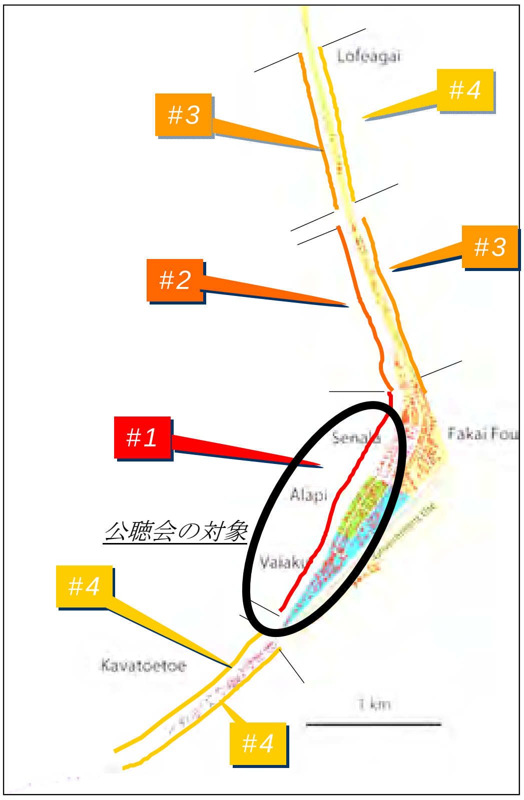


Figure 8.2 Target Area

These two groups were targeted for the public hearings. Women and youth are not allowed to speak out in general community meetings, so public hearings for women and youth were organized individually in order to make them comfortable to express their views. And, meetings for fishermen were also held separately to gain their frank opinions since the proposed countermeasure will affect their present usage of the coastal area. As a result, five public hearing meetings were organized targeting the following groups.

Table 8.1 Target Group

Target group
1. Fale Kaupule （*Matai*）
2. Women's group （who live in the Alapi, Senala, Vaiaku areas）
3. Masaua (all residents/men) （ditto）
4. Youth group （ditto）
5. Fishermen group （who use the target coastal area）

8.1.5 Implementation Procedure

(1) Invite residents

Details of the public hearings were informed to the target residents by the following methods with the assistance of Funafuti Kaupule.

1) Fale Kaupule's approval [1st and 2nd hearings]

The purpose and implementation procedure of the public hearings were explained to Fale Kauple by Funafuti Kaupule, and their approval was obtained.

2) Distribution of leaflet (in Tuvaluan language) [1st hearing only]

A leaflet explaining the justification, purpose and schedule of the public hearings was developed and translated into Tuvaluan in cooperation with the Funafuti Kaupule (Figure 3.3). It was distributed through house-to-house visits by local volunteers.

3) Cooperation of the leader of each group [1st & 2nd hearings]

A study team member visited all group leaders with Funafuti Kaupule, and determined a suitable schedule for the public hearings. In order to gain a high participation rate, the public hearing dates were set according to the schedule of their regular meetings. The leader of each group was also requested to call members up.

J·PACE
Japan - Project Against Coastal Erosion

Te iloiloga/sukesukega/akoakoga, o mea ola I tou tafa, penaa foki mo te puipuiga o te kaigina o tou tafatai, mo te fakaleiga o kogaakoga o Tuvalu kola ne fakamaseigina.

TE FAIPATIIGA MO TINO KATOA

E mankogina tou kaufakatasi mai, ke sautala tatou mo te aso a taeao!!!

A te fakapotopotoga tenei ko te J-PACE ko galue nei, kae aofaga ne latou te palani tela ka fesoasoani ki te puipuiga o tou tafatai pena foki mo te fakaleiga o kogaakoga kola ne fakamaseigina ne te natula. A te palani tenei ka fakavae tonu ki luga I ikuga o savea kola ne fai ne nisi o latou kola ne mua mai o fai I masina mo tausaga konei ko teka atu. A te palani foki tenei ia koe totino, me ka mafai o isi ne pokotiaga ki te ola lei o te olaga, tela la e manakogina malosi ko koulua ke maina kae ke fakatau galue o fesoasoani mo te fakataunuga fakalei o te atiakega tenei. A matou(J-PACE) e fiafia lasi o galue fakatasi mo koulua, I te fai se motou tusaga fesoasoani I te palaniiga mo te fakatoka o mafaufauga kola ka fakataunu manuia ei ne ia a te taumaffaiga tenei.

Schedule

Date	Time	Target group
Fri, 11 June	10:00 - 11:30	Fafine (Funafui, Vaiaku)
	19:00 - 20:30	Tino katoa (Funafuti, Vaiaku)
Tue, 15 June	19:00 - 20:30	Talavou (Funafuti, Vaiaku)
Wed, 16 June	19:00 - 20:30	Tagata faika

Fetaui I te Tausoalima FaleKaupule I taimi mo aso konei ka fakasoko atu mai lalo.

For more information:

Funafuti Kaupule
Address: Funafuti Kaupule, Senala, Funafuti
TEL: 688-20423
Responsible person: Mr. Andrew Ionatana

J-PACE
Address: c/o Fisheries Center, Teone, Funafuti
TEL: 688—20807
Responsible person: Dr. Takayoshi KURATA

Figure 8.3 Leaflet

4) Radio announcement [1st and 2nd hearings]

Radio announcement is one of the most effective information tools for Tuvalu community. The Funafuti Kaupule broadcast an invitation to residents through the Islet's radio station before, and the day of the hearings. The public hearing was informed to target residents by the following methods with the assistance of Funafuti Kaupule.

(2) Schedule

1) 1st Public hearing

Table 8.2 Schedule (1st Public Hearing)

Date	Time	Target group
Fri, 11th June, 2010	10:00 - 12:00	1. Women's group
	19:00 - 21:00	2. Residents (men)
Wed, 16th June, 2010	10:00 -12:00	3. Youth group
	19:00 - 21:00	4. Fishermen group(1)
Sun, 20th June, 2010	19:00 – 20:30	5. Fishermen group(2)

An additional public hearing targeting the fishermen group was scheduled for a Sunday due to a low participation rate on the Wednesday. Some fishermen go fishing on weeknights.

2) 2nd Public hearing

Table 8.3 Schedule (2nd Public Hearing)

Date	Time	Target group
Tue, 7th Sep, 2010	8:30 - 10:00	1. FaleKaupule
Wed, 8th Sep, 2010	16:00 - 18:00	2. Masaua (Men)
	19:30 - 21:30	3. Women's group（Vaiaku area）
Thu, 9th Sep, 2010	14:30 - 16:30	4. Women's group（Senala / Alapi areas）
	19:30 - 22:00	5. Youth group
Mon, 13th Sep, 2010	19:00 - 22:00	6. Fishermen group

The Department of Women Development of the Ministry of Home Affairs and Rural Development and Tuvalu National Council of Women, which are organizations dealing with gender matters, took part in the hearing for women's group. These two organizations also attended the second PCC meeting held in March 2010.

In addition, the Department of Land and Survey, which is a member of PCC, was also invited since the ownership of the nourished beach was one of the key issues for implementation.

(3) Outlines of presentations

Funafuti Kaupule staff cooperated by translating the presentation materials from English into Tuvaluan, and also with the actual presentation. Mrs. Peitala, who is a community worker of Funafuti Kaupule, presented for women's and youth groups; and Mr. Apinel, Mr. Kilisi and Mr. Semese, who are a Kaupule staff, did so for Fale Kaupule, Masaua (men) and fishermen group. The study team made presentation materials with script, and then gave the brief of each slide to make all presenters fully understood. The outline of each presentation is attached in Section 1 of PART V in the Supporting report. Summary of presentation used for each public hearing is as follows.

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.

Table 8.4 Outline of Presentation (1st Public Hearing)

	Items	Contents
1	Outline of the Study	Background Objective Process for plan formulation (community involvement in the planning process)
2	Summarized Report on the results of Baseline Study *(What J-PACE has found)*	Status of sea-level rising Damage caused by coastal disaster (based on the interview survey) Coastal erosion caused by sand movement
3	Basic Policy for Coastal Protection and Rehabilitation Plan and Proposed Countermeasures *(What we will do / What you will be requested)*	Select priority areas Examine an appropriate coastal protection work (Advantage and disadvantage of each work; seawall, breakwater and beach nourishment) Matters of concern (lagoon use, land owner issues, the need of monitoring and maintenance etc) Examine the monitoring and maintenance method
4	Matters to be Discussed	Current use of priority area Obstacles to be caused by implementation of the Project. Action for coastal protection in the priority area Possibility that the community can work for coastal management, especially for monitoring and maintenance work. Affairs or concerns about the Project. Activities to be implemented to the community before or during or after the Project. Others

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.

Table 8.5 Outline of Presentation (2nd Public Hearing)

	Items	Contents
1	Seminar: [Coastal disaster and its countermeasures]	Outline of the Study Summarized report on the results of baseline study Basic Policy for coastal protection and rehabilitation plan and proposed countermeasures （*Based on the presentation material used for the first public hearing）
２	Discussion： [Matters to be discussed for implementation]	Basic design of beach nourishment Ownership of the nourished beach Monitoring and maintenance system Acquirement of required amount of gravel Consideration for fishermen (ramps, etc）

(4) Feedback sheet

Some residents might not be used to speaking in public, so a feedback sheet written in Tuvaluan was distributed to participants in order to know their level of understanding and to gain their views as much as possible. The contents and results of the feedback sheet are attached in Section 1 of PART V in the Supporting report.

8.1.6 Photos

The scene of each public hearing is as follows.

1) 1st Public Hearing

1. Public Hearing for Women Group

Photo 8.1 Public hearing for women group

Photo 8.2 Discussion among participants

2. Public Hearing for Residents

Photo 8.3 Public Hearing for Residents

Photo 8.4 Priority Area was shown by Presenter (Kaupule Staff)

3. Public Hearing for Youth Group

Photo 8.5 Youths Raising Their Hands in a Show of Their Idea for the Most Appropriate Coastal Work

Photo 8.6 Participants Filling in the Feedback Sheet

4. Public Hearing for Fishermen Group

Photo 8.7 Options of Coastal Protection Works Were Shown by Presenter (Kaupule staff)

Photo 8.8 The Second Public Hearing for Fishermen

2) 2nd Public Hearing

Photo 8.9 Public Hearing for Fale Kapule

Photo 8.10 Public Hearing for Masaua（men）

Photo 8.11 Public Hearing for Women Group (Vaiaku Area)

Photo 8.12 Public Hearing for Women Group （Funafuti (Senala/ Alapi) Areas)

Photo 8.13 Public Hearing for Youth Group

Photo 8.14 Presentation Done by Funafuti Kaupule and the Study Team

Photo 8.15 Public Hearing for Fishermen Group (Discussion among Group Members)

Photo 8.16 Presentation by Participant (Fishermen)

8.2 Comments and Suggestions Given by Residents

1) 1st Public hearing

The following table shows that comments and suggestions given by residents during the first public hearing, and related plans to be reflected in the proposed coastal protection and rehabilitation plan.

Table 8.6 Comments and Suggestions Given by Residents (1st Public Hearing)

Comments and suggestions given by residents ＜target group＞	Plans to be reflected
【Considerations】 ① It will get harder for fisherman to go out fishing during the construction work. <Fishermen> ② Possibility that gravel will be washed away by waves or currents. <All groups> 【Suggestions】 ③ Need to clarify the responsible body for monitoring and maintenance <Women, Youth> ④ Possibility that Tuvalu could get continuous assistance from Japan for the monitoring and maintenance after completion of the project. <Men> ⑤ Need more awareness workshops, capacity building training for monitoring and maintenance, and radio programmmes, for the whole community to well aware of how important their coastal area to them is. <All groups> ⑥ Need to clarify the ownership of the nourished beach. <Fishermen> ⑦ There should be a law enforced so people stop misusing the beach. <All groups> ⑧ Plant trees in the coastal area <All groups> ⑨ It will hard for fisherman to get their boats from the sea to shore after the construction, so that it will be better if the Project could provide a trailer or slope to pull up boats after using. <Fishermen> ⑩ Special place for boats to be safe from the strong wind or hurricanes. <Fishermen> ⑪ Project should start immediately <All groups>	3.2.4 Construction work program （①、⑨、⑪） 3.2.5 Monitoring plan （②～⑤） 3.2.6 Environmental and Social consideration plan （①、④、⑥、⑨） 3.2.9 Maintenance and management plan （③、④、⑥、⑦、⑧） 3.2.10 Planning on Organization for Coastal Disaster Prevention and its Mandate （⑥～⑩）

（*The number attached on plans to be reflected is following the Index number of the coastal protection and rehabilitation plan which was proposed in the Interim report）

2) 2nd Public hearing

The following table shows that comments and suggestions given by residents during the second public hearing, and responses and consideration done by the study team, and related plans to be reflected in the proposed coastal protection and rehabilitation plan.

Table 8.7 Comments and Suggestions Given by Residents (2nd Public Hearing)

Comments and Suggestions ＜Target group＞	Summary	Response by the Study team	Plans to be reflected
① Ownership of the nourished beach ＜All groups＞	- J-PACE proposed that the ownership of the nourished beach should vest in the Crown as defined in the existing law. - Community suggested that the nourished beach should be owned by the Fale Kaupule. According to the Fale Kaupule Act, the ownership of crown land has already been given to the Fale Kaupule. - As a result of the discussion among Fale Kaupule, they agreed to own and call the nourished beach the community land, not to be owned by any landowners or individuals. Fale Kaupule will write a letter and submit it to the Minister for approval and to amendment into the law of Tuvalu. - Fale Kaupule has recognized that the J-PACE project has been commenced since Fale Kaupule seems have made a request for land reclamation to the Japanese government through the Tuvalu government in 2006. Fale Kaupule seems to have strong ownership of the Project. - The majority of people who live in Vaiaku area came from outer islands, so that some of them prefer that the government own the nourished beach. - Fishermen expressed a desire to leave their boats on the	- Need a follow-up. - For community-based monitoring and maintenance, it is desirable that the landownership of the nourished beach is vested with the Fale Kaupule. Government will manage to provide technical advice for the community, but it might be difficult for them to implement continuously since most of them seem to be generally away from the country on business trips. - Consensus building with Vaiaku residents is crucial for implementation.	9.6 Maintenance and Operation Plan 9.7 Monitoring Plan 9.8 Organization and System Plan 10 Environment and Social Consideration

	nourished beach.		
② By-law to be enacted ＜all groups＞	- People suggested that a by-law specified beach nourishment should be enacted to avoid beach being misused. In the by-law, the following matters should be clarified; ・ Ownership （Residents suggested that the landownership of the nourished beach should be vested with the Fale Kaupule, and Funafuti Kaupule should be responsible for the implementation of monitoring and maintenance (refer to the results of feedback sheet, which attached in Section 1 of PART Ⅳin the Supporting report.)） ・ Penalty (people who misuse the beach should incur heavy financial penalties) - By-law is normally drafted by Funafuti Kaupule, and is finalized after a series of meetings with Fale Kaupule. These procedures will take time if related to ownership. (From the interview with Funafuti Kaupule)	- By-law needs to be established from two perspectives; landowners and users. - The process of law formulation is very important. It is better to secure enough time and involve all stakeholders in the process, e.g. Tuvalu government such as the Department of Land and Survey, Fale Kaupule, Funafuti Kaupule, landowners, etc. - Law enforcement procedures should also be defined in the law. Police could be one of enforcement officers. - Should secure adequate time frame for making by-law.	9.6 Maintenance and Operation Plan 9.7 Monitoring Plan 9.8 Organization and System Plan
③ Environmental impact on the sites where acquire gravels ＜All groups＞		- The sturdy team answered as follows; ・ Three islets within the Fongafale atoll: Project will dig gravel from the southernmost point of the islets where gravel has accumulated. It is below sea level, so that land ownership should not be an issue. ・ Side of the Runway: Present land use will be	9.3 Study on the Required Volume of Beach Nourishment Materials 9.4 Assessment of impact on the ecosystem 9.5 Construction Work Program

	- Fishermen showed some concerns although this subject was not explained for fishermen due to time limit. (refer to the results of the feedback sheet, attached in Section 1 of PART Ⅳin the Supporting report.)	fully considered. The sites will be backfilled with sand after digging gravel, which give land suitable condition for runway use. ・ Lagoon: The study conducted by SOPAC has already proved that the site where the Project proposed acquiring sand has less environmental impact. - Environmental impact should be monitored during the construction work, and its results should be reported to community including fishermen.	9.7 Monitoring Plan 10 Environmental and Social Consideration
④ Environmental impact on marine ecosystem and surrounding area ＜Men＞	-	- The Study team answered that the proposed plan has been designed considering environmental impact on marine ecosystem and surrounding area. - It is desirable to monitor the impact regularly during the construction work, and report its results to the community.	9.4 Assessment of impact on the ecosystem 9.7 Monitoring Plan 10 Environmental and Social Consideration
⑤ Possibility that the gravel will be washed away. <Women, Fishermen>	- Some residents were apprehensive that the gravel would be washed away on windy days or during bad weather.	- The study team explained that gravel should not be washed offshore, and it would only move slightly if at all. - It is preferable to conduct a pilot project on a small scale in order to define the characteristic of gravel movement. Project should be implemented gradually.	9.5 Construction Work Program 9.7 Monitoring Plan 9.10 Financial Plan
⑥ Possibility that	- Some residents showed some concerns since existing	- J-PACE answered that it will be designed to withstand	9.2 Design of Coastal

materials for edge treatments will be washed away. <Fale Kaupule, Fishermen ＞	concrete structures such as Catalina ramp have collapsed.	wave energy.	Protection Facilities 9.7 Monitoring Plan
⑦ Parapet will block drainage and boat access ＜Fishermen＞	- Fishermen pointed out that the parapet would block water discharge when flooded, and become an obstacle to unloading boats for fishermen. It will be harder for fishermen to lift their boats.	- J-PACE answered that the design of parapet would be changed to one with slits and small ramps.	9.2 Design of Coastal Protection Facilities
⑧ Need ramps ＜Men, Fishermen＞	- Fishermen showed some concerns on boat access between land and sea. It will get harder for them to bring their boats and to upload some goods e.g. fish, coconuts etc, onto on the shore since it will become farther away.	- J-PACE explained as follows; • Construction ramps on the nourished beach will be restricted since ramps will disturb natural sand movements. • Edge treatment could be utilized as a ramp. • Removable ramps could be one alternative. - It will need enough space onshore for keeping boats temporarily if fishermen use edge treatments as ramps. It requires consensus with landowners.	9.2 Design of Coastal Protection Facilities 9.8 Organization and System Plan 9.9 Cost Estimation 10 Environmental and Social Consideration
⑨ Facility for boat safety ＜Fishermen＞	- Fishermen made a request for boat harbor or marina as a safe anchorage place for their boats during bad weather.	- The study team answered that it is out of the scope of the project since boat harbor is not a solution to the problems caused by beach erosion. - Boat safety seems one of the main concerns for fishermen, especially during the bad weather. Soft component measures such as appropriate warning	9.8 Organization and System Plan

		system should be strengthened.	
⑩ Coastal erosion after implementation ＜Fale Kaupule, Women＞	-	- The study team explained that there is little possibility of coastal erosion occurring since the gravel could not be washed offshore and an increase in sand supply can be expected as a result of the Forum Sand Project.	9.2 Design of Coastal Protection Facilities 9.7 Monitoring Plan
⑪ Responsibility of Fale Kaupule for monitoring and maintenance plan ＜Men＞	- Some residents suggested that Fale Kaupule should be involved in the implementation structure of monitoring and maintenance plan.	- Existing social structure for decision-making will be useful and effective to implement community-based monitoring and maintenance measures.	9.6 Maintenance and Operation Plan 9.7 Monitoring Plan 9.8 Organization and System Plan
⑫ Involvement of women and youth in the planning and implementation stages ＜Women, Youth＞	- Women and Youth are willing to take part in the Project including monitoring and maintenance.	- It is desirable to involve women and youth in the Project by providing opportunities, e.g. awareness rising through workshops and radio announcements, hiring youth as laborers for construction work, training women to educate their children, feeding workers for construction, organizing community groups as an implementation body for monitoring and maintenance.	9.6 Maintenance and Operation Plan 9.7 Monitoring Plan 9.8 Organization and System Plan 10 Environmental and Social Consideration

8.3 Ripple Effects and Conclusions

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

- It was found that most of local residents had recognized that the actual coastal disasters were caused by climate change, even it was presumed that damage, such as from storm surges, would be mainly caused by the development of human activities. The public hearings made participants understand the real cause of coastal disaster and its mechanisms for occurring.
- Initially, not few people desired to set up seawalls or breakwater. 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.
- As a part of NAPA programme, a Community Organizer who has responsibility for coordinating NAPA implementation in each outer island, has been appointed. Some outer islands had planned to implement coastal protection works. At the request of NAPA Coordinator who was also PCC member, the study team made a presentation to share the outcomes of the study.
- Both public hearings were successfully conducted through full support of Funafuti Kaupule. 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.
- The beneficiary of the Project should be given to the whole country of Tuvalu. As many participants suggested, more awareness workshops should be conducted in order to make them well aware of how important their coastal area to the community is.
- It is desirable to implement the Project immediately but surely since the more concretely the plan, the more expected residents became for implementation.

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 (**Table 7.2**), 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

While offshore drift is almost nonexistent, there is longshore drift (Kadomatsu *et al.* 1991; Tsuboka *et al.* 1992; Doshi *et al*. 2009). Namely, 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 (see Section 9.2.3) being C.D.L. +4.5m or less.

(1) Setting a representative wave

The mean energy of waves were calculated from wave data estimated with the SMB method using wind data for Funafuti port from 1999 to 2008. **Figure 9.1** shows the directional energy flux distribution of waves coming ashore in the target area. The red line on the rose diagram represents the average coastline normal vector in the target area.

Given that:

- the energy flux in the target area is larger for rainy season waves than in the dry season, and
- waves predominantly from a northerly aspect compared to the coastline.

The following equations are to find the mean wave energy to be used in the shoreline change forecast model.

Wave period formula: $$\widetilde{T} = \frac{\sum_k n_k T_k}{\sum_k n_k} \quad (1)$$

Wave height formula: $$\widetilde{T} \cdot \widetilde{H}^2 = \frac{\sum_k \sum_l (n_{kl} \cdot T_k \cdot H_l^2)}{\sum_k \sum_l n_{kl}} \quad (2)$$

Wave direction formula: $$\widetilde{T} \cdot \widetilde{H}^2 \cos\widetilde{\alpha} \cdot \sin\widetilde{\alpha} = \frac{\sum_m \sum_k \sum_l n_{klm} \cdot T_k H_l^2 \cdot \cos\alpha_m \cdot \sin\alpha_m}{\sum_k \sum_l \sum_m n_{klm}}$$

$$\widetilde{\alpha} = \frac{1}{2}\sin^{-1}\left[2\frac{\sum_m \sum_k \sum_l n_{klm} \cdot T_k H_l^2 \cdot \cos\alpha_m \cdot \sin\alpha_m}{\widetilde{T} \cdot \widetilde{H}^2 \sum_k \sum_l \sum_m n_{klm}} \right] \quad (3)$$

Where, H , T , α : Wave height, period, direction

$\widetilde{H}$ 、 $\widetilde{T}$ 、 $\widetilde{\alpha}$: Mean wave height energy, wave period, wave direction

n 、 k 、 l 、 m : Occurrence, extra letter for period level, extra letter for wave height level, extra letter for wave direction level.

Further, this is taken from the Handbook on Coastal Protection Planning (1994, March, Ministry of Environment, Rivers Department, Coastal Division), on page 41 in the chapter, Waves to be employed in planning erosion measures:

> If the daily mean effective wave height is less than approximately 30 cm, its effect on erosion is mostly negligible, therefore, it is necessary to exclude it from the data. For example, exclude the data in summer on the Japan Sea coast when the ocean is calm. If it is not excluded, then the design wave will be underestimated.

Therefore, formulae (1) to (3) were used to find the mean wave energy after making an aggregate calculation of waves 0.3 m or higher.

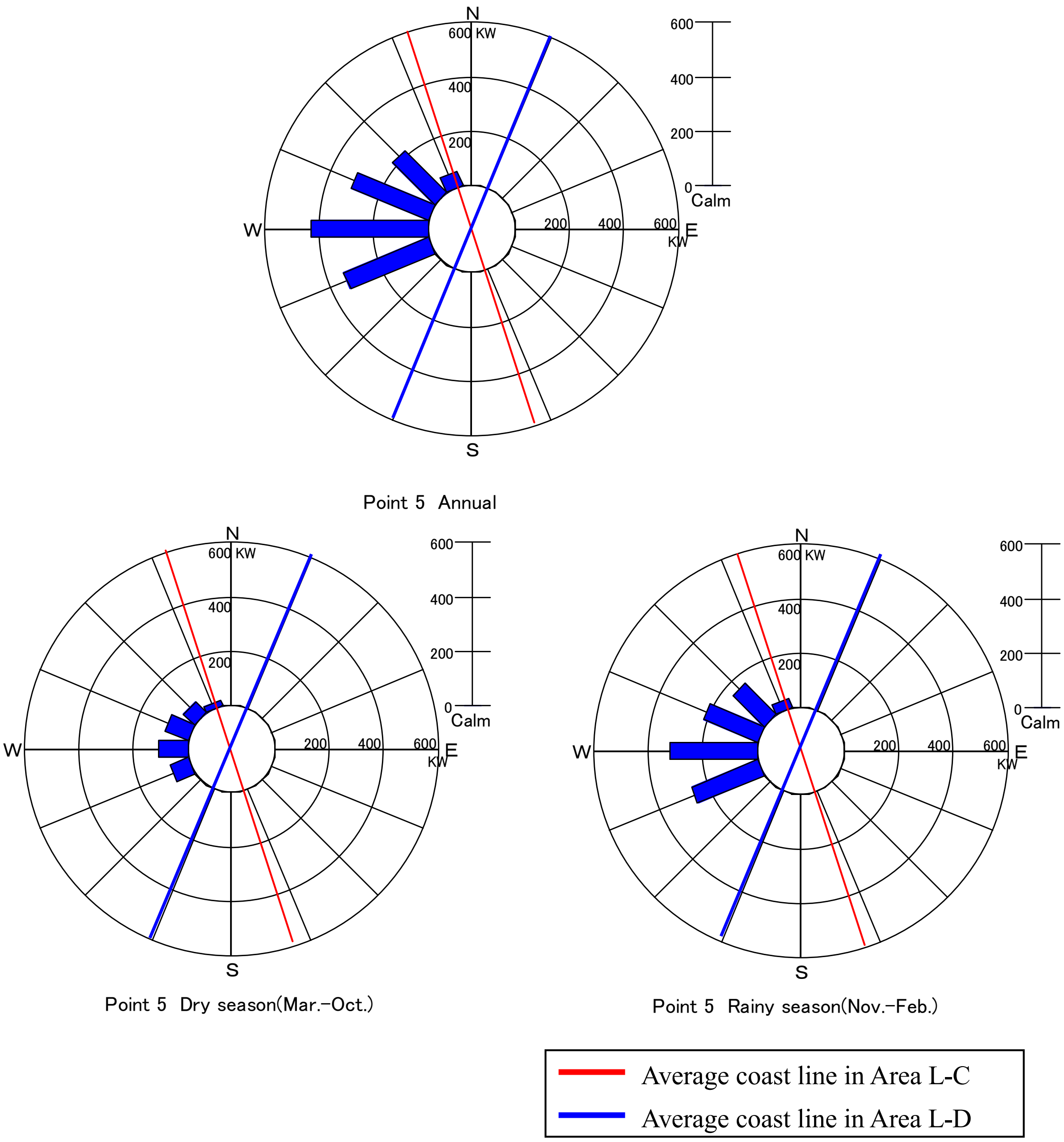


Figure 9.1 Distribution of Wave Directional Energy Flux (Target Area, 1999 to 2008)

Table 9.1 shows the results of the calculation of the mean wave energy. Active days are calculated by comparing the number of days waves 0.3 m or higher were active with the overall yearly energy. When making the calculations for shoreline change forecast model, rather than a one year calculation, mean wave energy uses 18 active days.

Table 9.1 Representative Wave (Mean Energy Wave)

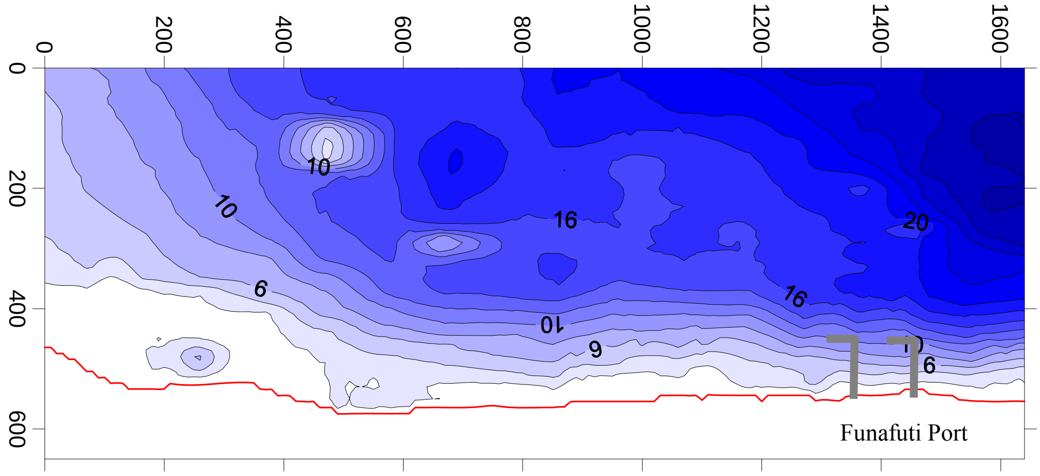
Factor	Wave height (m)	Wave period (s)	Direction (degree: °)	Active days
Mean wave energy	0.52	3.6	288.4 (Area L-C:which is 36.7° clockwise to wave action perpendicular to the mean coastline vector of the target area, 341..7° . Area L-D:which is 6° anticlockwise to wave action perpendicular to the mean coastline vector of the target area, 24.4°)	18

(2) Wave transformation calculation

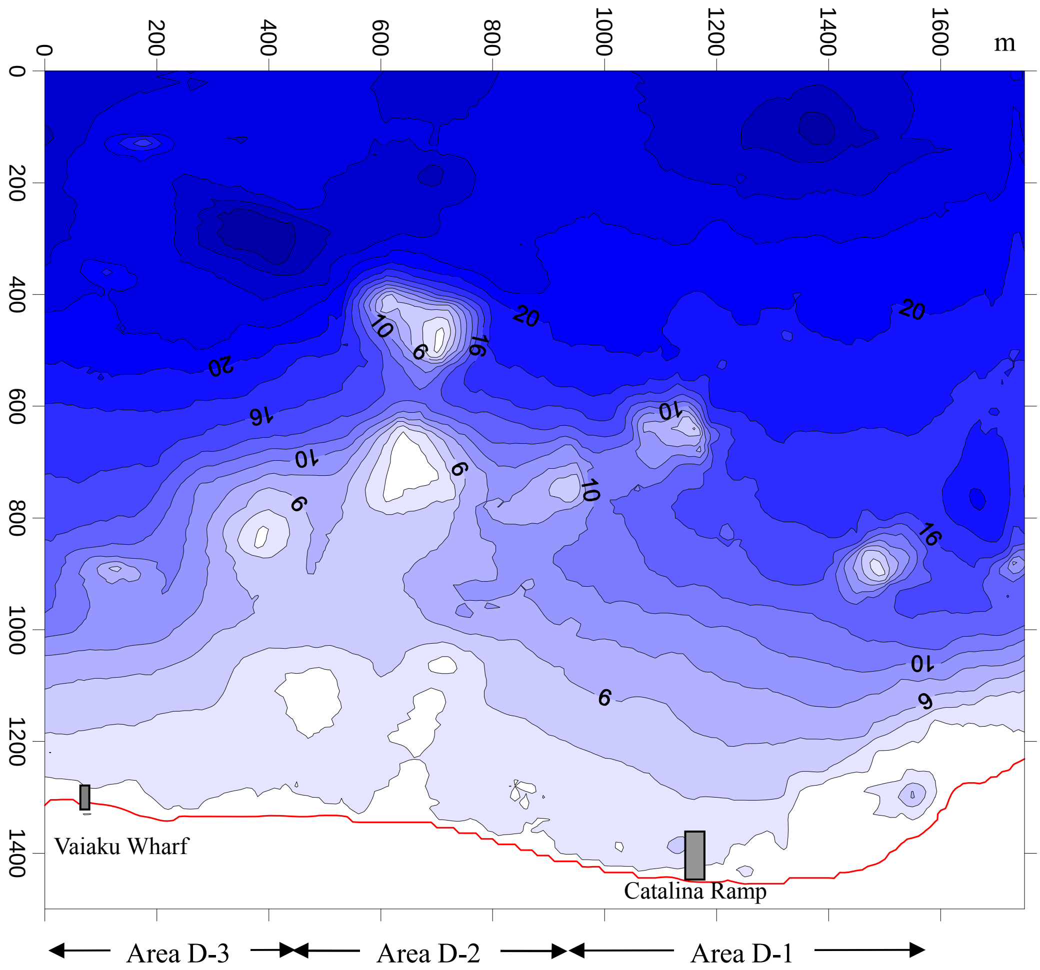
The wave place was calculated with an energy balanced equation using the set representative wave. The grid conditions set are shown in **Table 9.2**, the water depth map used in the calculations in **Figure 9.2**, and the wave vector map is shown in **Figure 9.3**.

Table 9.2 Grid Conditions

	Area L-C	Area L-D
Grid number	165 (shoreline)×66 (offshore)	176 (shoreline)×151 (offshore)
Grid spacing	10 m	10 m



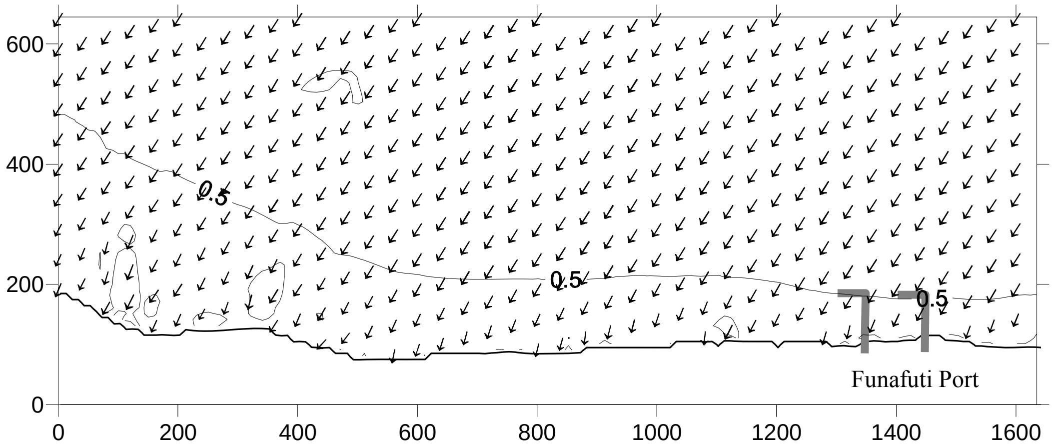
Area L-C



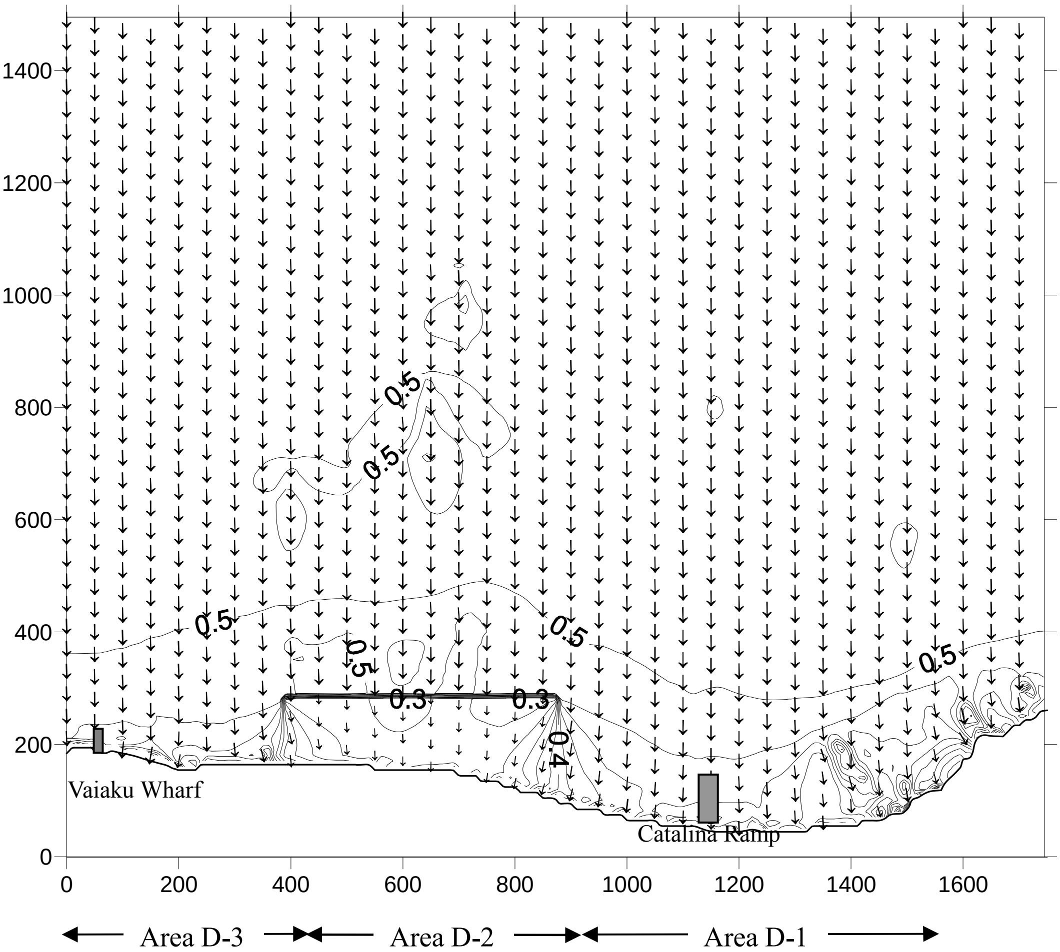
Arera L-D

Note) The red line represents the shoreline.

Figure 9.2 Water Depth Map



Area L-C



Area L-D

Note) A structure of 0.6 penetration probability taken from the simulation of the shoreline change forecast model from around mesh 400 to 900 on the horizontal axis. Because there is a wide shallow place off shore in area D-2, it is impossible to evaluate the attenuation effect of waves by an energy balanced equation.

Figure 9.3 Wave Vector Map

(3) Establishment of a shoreline change prediction model

The calculation to reproduce the current state using the shoreline change prediction model shows that since WWII when aerial photographs were first taken, there have been no prominent changes--besides those human in nature--in the geomorphology, and that even though it protrudes slightly into the lagoon, the sand beach in area2 has been maintained; this model was developed so that the coastline becomes stable. Using the calculation conditions in **Table 9.3**, calculations were made until the shoreline became stable with the current shoreline being the initial setting (blue line). The results are shown in **Figure 9.4** below.

Table 9.3 Shoreline Change Calculation Conditions

Item		Set value
Grid number		176 (shoreline)
Grid spacing		10 m
Δt		4320 sec (0.05 days)
Mean seabed gradient		1:50
Drift sand amount coefficient		*k1=0.1,k2=0.08*
Boundary condition	Left side (north)	No inflow
	Right side (south)	No inflow

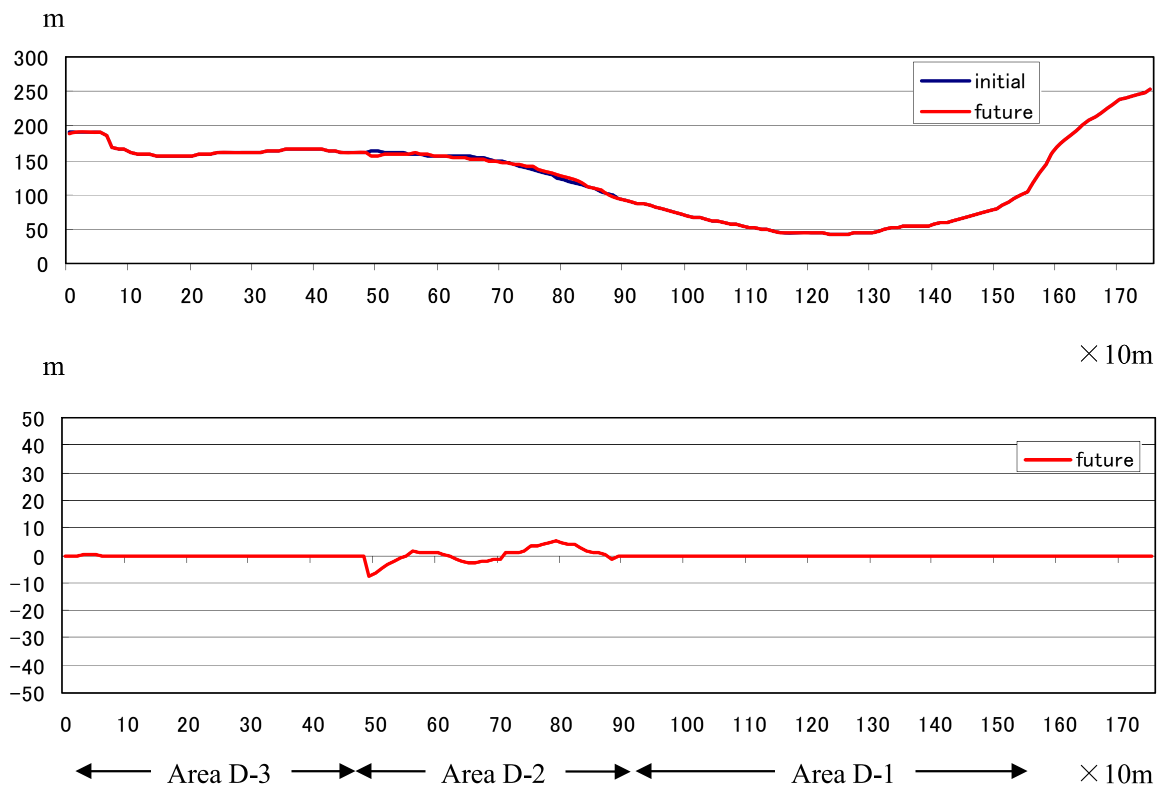


Figure 9.4 Result of Present-State Simulation

(4) L-C Area

Figure 9.5 shows the shoreline change when a berm width of 15 m is nourished. The nourished gravel is transported southward, with erosion from around 80 to 122, and accretion from 10 to 20 and 35 to 60 on the x-axis. Accordingly, the protective function of the beach will decrease north of 80, and from 10 to 20 and 35 to 60 the beach width will be excessive in this respect.

As such, the effect of implementing edge treatment to prevent longshore drift of the gravel at 55, 60, 70, 85, 100 and 115 on the x-axis is shown in **Figure 9.6**. As a result, edge treatment is expected to mitigate erosion of the nourished beach, while also curbing accretion from 10 to 20 and from 35 to 60.

Wave runup heights in the case with and without end treatment are compiled in **Table 9.4**. From these it is apparent that erosion will occur in the northern part of the nourished area—under current conditions whereby sediment supply cannot be expected—due to southward longshore drift; and the maximum wave runup height will be 4.1 m with end treatment and 5.0 m without; which exceed the current ridge heights and the nourished berm height of 4.0 m; and therefore, the wave runup height is not satisfied.

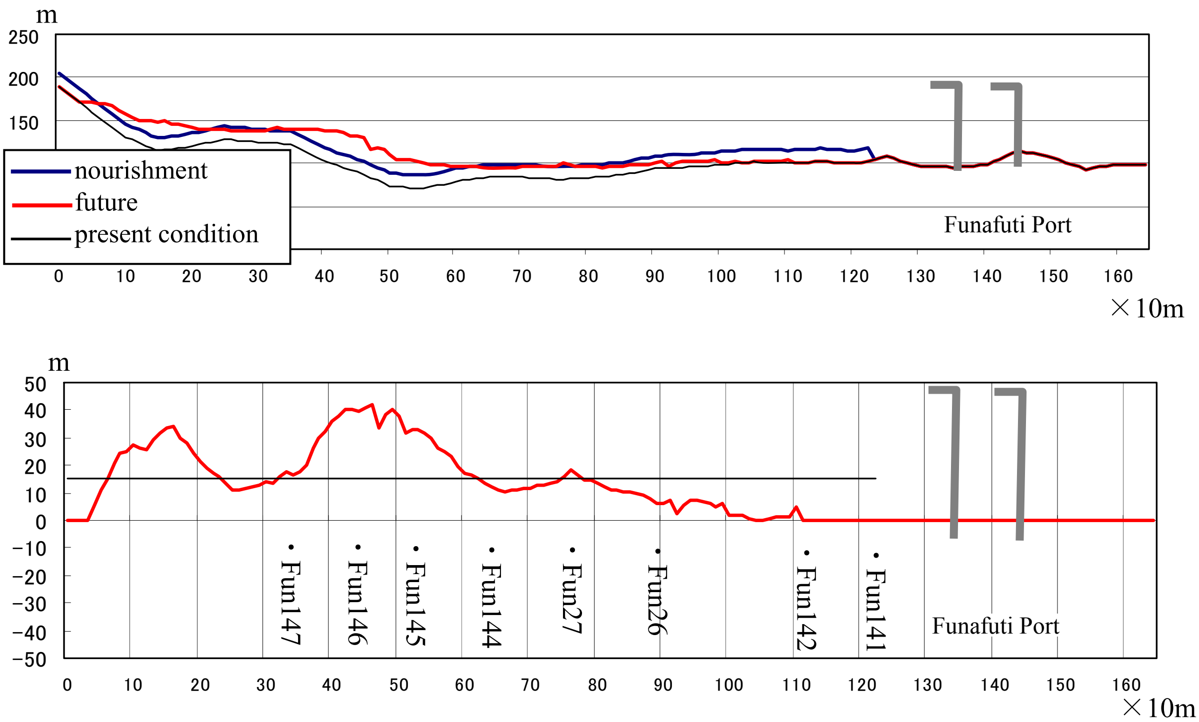


Figure 9.5 Future Prediction with 15 m Berm Works

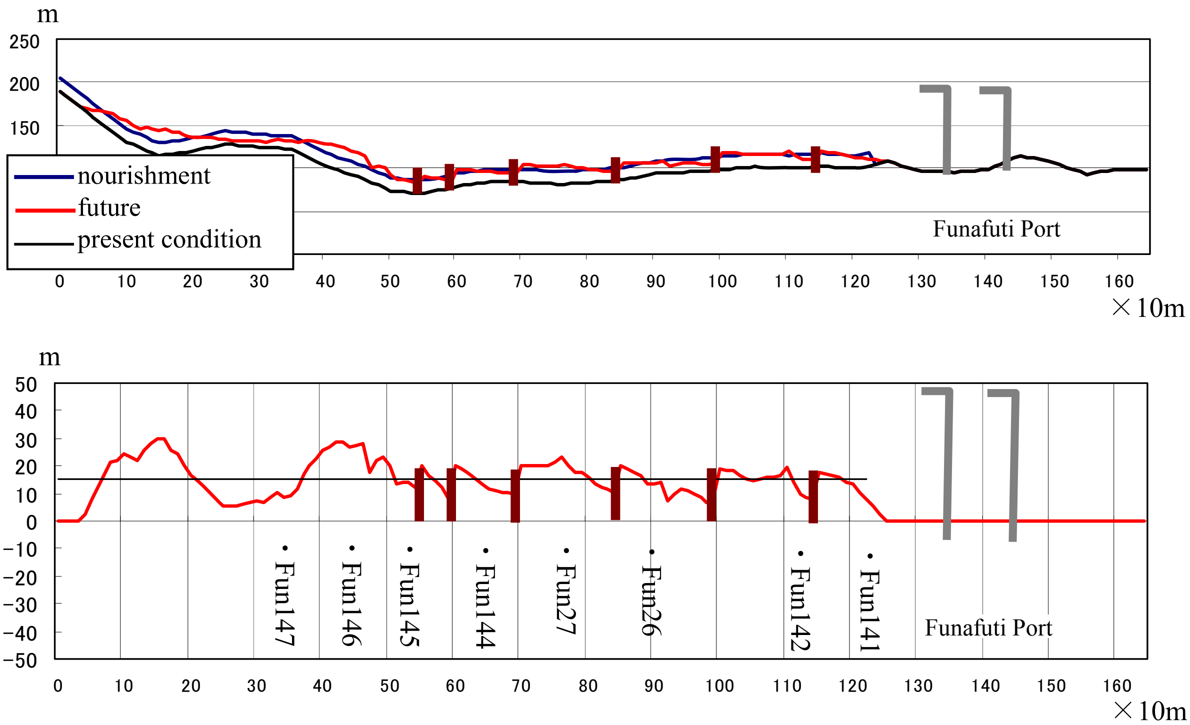


Figure 9.6 Future Prediction with 15 m Berm Works and Edge Treatment

Table 9.4 Wave Runup Height after Beach Transformation

Line	Ridge height (C.D.L.m)	Wave runup height 10-year return period wave+H.H.W.L. (C.D.L.m)						
		Current condition	Immediately after nourishment		Future Without end treatment		Future With end treatment	
			Backshore width (+current)	Runup height	Backshore width (+current)	Runup height	Backshore width (+current)	Runup height
Fun141	4.0	**4.6**	15.0	**4.0**	0.0	**4.6**	10.4	**4.1**
Fun142	4.0	**5.0**	15.0	**4.0**	0.0	**5.0**	14.0	**4.0**
Fun26	4.1	**4.8**	15.0	**4.0**	6.0	**4.4**	13.5	**4.0**
Fun27	4.1	**5.0**	15.0	**4.0**	16.4	**<4.0**	20.4	**<4.0**
Fun144	3.9	**5.1**	15.0	**<4.0**	12.3	**4.0**	13.4	**<4.0**
Fun145	4.1	**5.1**	15.0	**<4.0**	32.8	**<4.0**	14.0	**4.0**
Fun146	4.1	**5.0**	15.0	**<4.0**	39.7	**<4.0**	27.0	**<4.0**
Fun147	3.8	**4.9**	15.0	**<4.0**	16.7	**<4.0**	8.7	**4.0**

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

In order to satisfy the wave runup height in the northern part of the nourishment area, namely, to keep the runup height below the current ridge height and the nourished berm height, a berm width of 15 m after shoreline change is necessary, it is also necessary to construct approximately six edge treatment, because the difference in coastline normal and wave direction is large in this area. Furthermore, a parapet of low-crown height is to be constructed on the landward side of the nourishment in order to:

- 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 at traverse line Fun141 in the northern end where the runup is 4.1 m even with edge treatment, meaning it is insufficient by 0.1 m.
- 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.
- a potential sea level rise of 0.1 m derived from the surf beat and from the following formula; where the wave height is in *rms* notation, therefore, in order to convert it to water level (η), $\eta=\zeta rms\times4.003\times0.7$ is used.

$$\xi_{rms} = \frac{0.01Ho'}{\sqrt{\frac{Ho'}{Lo}(1+\frac{h}{Ho'})}}$$

Based on the abovementioned reasons, the berm width of the nourishment is to be 15 m (C.D.L.+4.0m) in addition to a 0.5 m parapet (crown height C.D.L.+4.5m) as shown in **Figure 9.7**, cross-section, and **Figure 9.8**, planar view.

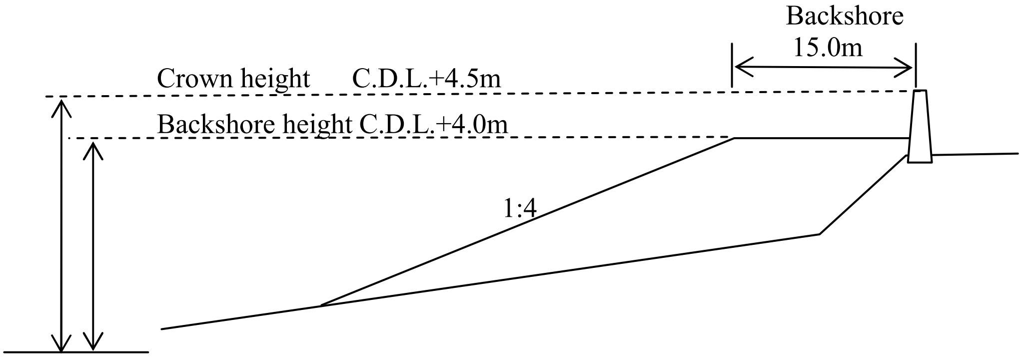


Figure 9.7 Standard Cross-Section of Area L-C

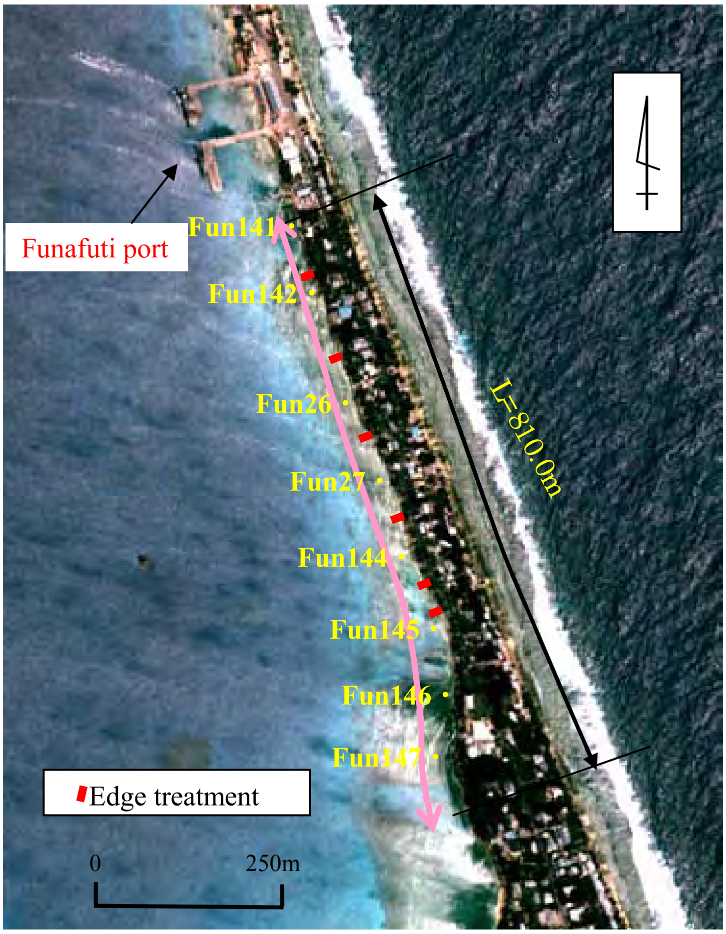


Figure 9.8 Top View of Area L-C

(5) Area D-1 in L-D Area

The shoreline change if nourishment is undertaken to form a backshore of 15 m is shown in **Figure 9.9**. The nourished gravel on the north side of the Catalina ramp will be transported to the south, trapped by the ramp and deposited close to the ramp, resulting in erosion on the northern side. On the southern side, it will be deposited on the beach currently formed in Area D-2. Therefore, the protective capacity of the coastline south of the Catalina ramp and between 140 and 155 on the X-axis will decrease, and gravel accretion will occur on the sand beach in Area D-2. The effect of edge treatment, at the southern end of the gravel nourishment area, as a measure to counter the loss of this gravel is shown in **Figure 9.10**. From these results, it can be expected that, although the shape of the nourished beach will change, the edge treatment will lessen the shoreline retreat in the nourishment area and will be effective in controlling gravel outflow from Area D-2. In **Table 9.5** the wave run-up heights with and without edge treatment are given. From these it is apparent that erosion will occur in the northern part of the nourished area—under current conditions whereby sediment supply cannot be expected—due to southward longshore drift; and the maximum wave runup height will be

4.4 m with edge treatment and 4.6 m without; which exceed the current ridge heights and the nourished berm height of 4.0 m; and therefore, the wave runup height is not satisfied. For reference, the future simulation with 20 m wide backshore nourishment and without edge treatment on the north side of the Catalina ramp is shown in **Figure 9.11** and **Table 9.6**.

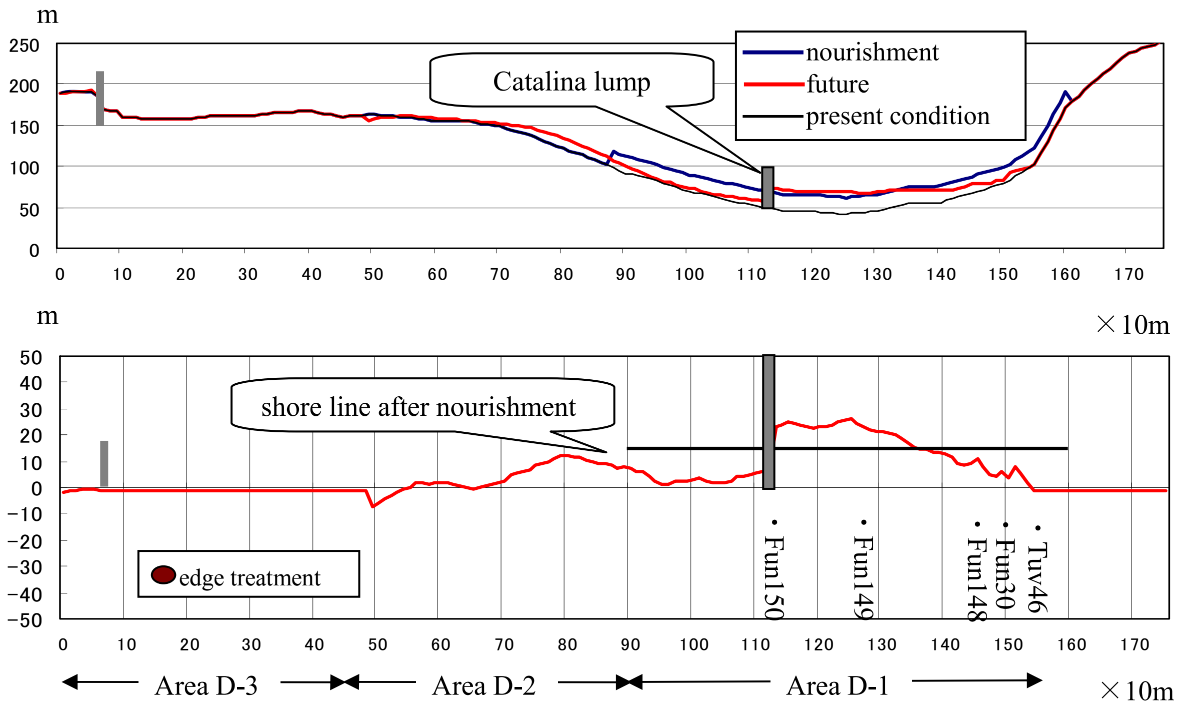


Figure 9.9 Future Simulation of 15 m Wide Backshore Nourishment

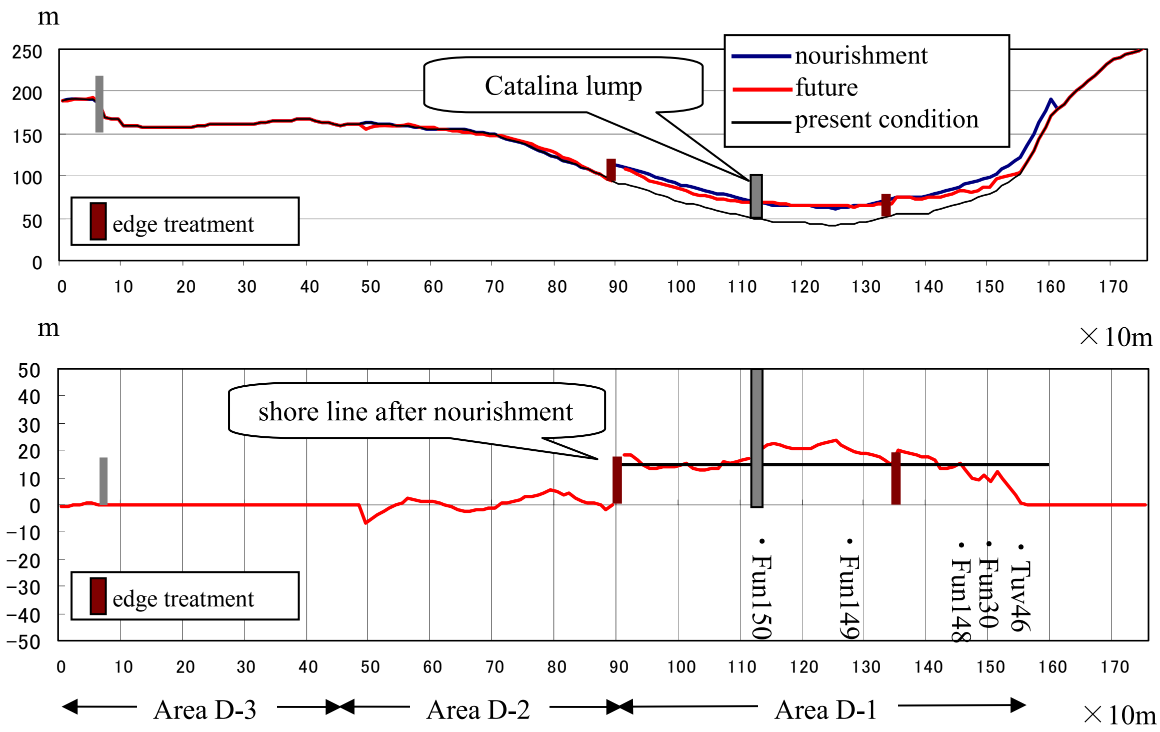


Figure 9.10 Future Simulation of 15 m Wide Backshore Nourishment + Edge Treatment

Table 9.5 Run-up Height after Change in Beach Form

Traverse line	Ridge height (C.D.L.m)	Wave run-up height 10-return year wave + H.H.W.L.						
		Current state (C.D.L.m)	Immediately after nourishment		Future: No edge treatment		Current state (C.D.L.m)	
			Backshore width* (m)	Run-up height (C.D.L.m)	Backshore width* (m)	Run-up height (C.D.L.m)	Backshore width* (m)	Run-up height (C.D.L.m)
Tuv46	3.7	**4.6**	15.0	**4.0**	0.0	**4.6**	3.6	**4.4**
Fun30	3.8	**4.3**	15.0	**4.0**	7.3	**4.2**	11.0	**4.1**
Fun148	3.7	**5.1**	15.0	**4.0**	11.8	**4.1**	15.5	**<4.0**
Fun149	4.6	**5.0**	15.0	**4.0**	27.0	**<4.0**	23.7	**<4.0**
Fun150	4.1	**4.2**	15.0	**<4.0**	24.3	**<4.0**	21.0	**<4.0**

* Backshore widths in this table are those in addition to the current shoreline.

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

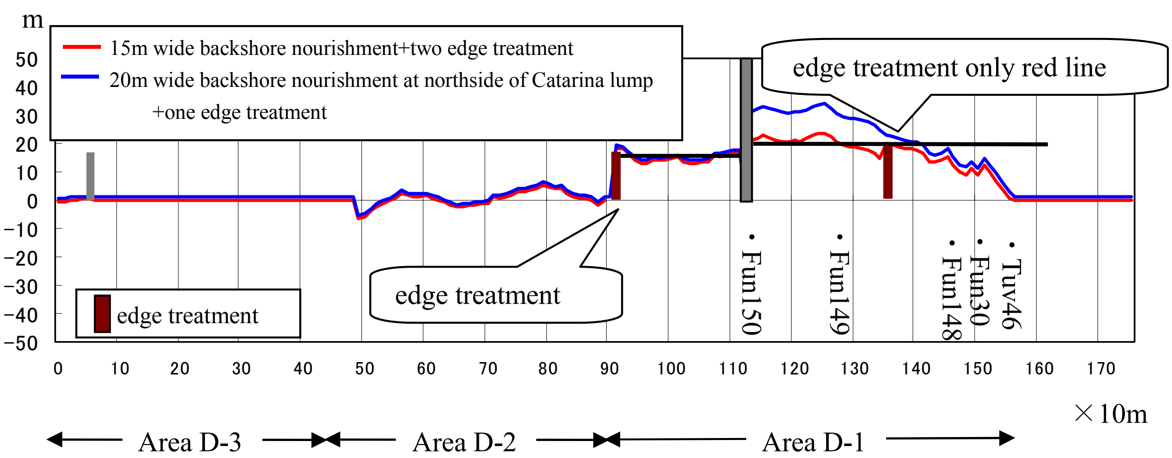


Figure 9.11 Future Simulation of 20 m Wide Backshore Nourishment at North Side of Catarina Lump

Table 9.6 Run-up Height after Change in Beach Form

Traverse line	Ridge height (C.D.L.m)	Wave run-up height 10-return year wave + H.H.W.L.				
		Current state (C.D.L. m)	15m wide Backshore Nourishment +two edge treatment		20m wide Backshore nourishment at northside Of Catarinalump +one edge processing	
			Backshore width* (m)	Run-up height (C.D.L. m)	Backshore width* (m)	Run-up height (C.D.L. m)
Tuv46	3.7	**4.6**	3.6	**4.4**	5.0	**4.4**
Fun30	3.8	**4.3**	11.0	**4.1**	12.5	**4.1**
Fun148	3.7	**5.1**	15.5	**<4.0**	17.1	**4.0**
Fun149	4.6	**5.0**	23.7	**<4.0**	32.9	**<4.0**
Fun150	4.1	**4.2**	21.0	**<4.0**	30.3	**<4.0**

* Backshore widths in this table are those in addition to the current shoreline.
**The red run-up heights are for non-satisfying, while blue are satisfying beach width run-up heights.

In order to satisfy the run-up height on the north side of the nourishment area, a 15 m wide backshore is necessary after the shape of the shoreline changes; however, the normal line of the coastline in this area is very different to the wave direction. Therefore, it would need many edge treatments towards the Catalina ramp or the nourishment with a wide backshore more than 15m. Furthermore, due to the fact that the run-up height is already satisfied near this ramp, and for 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 at traverse line FunTuv46 and Fun30 in the northern end where the runup is 4.4m and 4.1 m even with edge treatment, meaning it is insufficient by 0.4m and 0.1 m.
- 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.
- a potential sea level rise of 0.1 m derived from the surf beat and from the following formula; where the wave height is in *rms* notation, therefore, in order to convert it to

water level (η), $\eta = \zeta rms \times 4.003 \times 0.7$ is used.

$$\xi_{rms} = \frac{0.01Ho'}{\sqrt{\frac{Ho'}{Lo}(1+\frac{h}{Ho'})}}$$

Therefore:

The berm width of the nourishment is to be 15 m (C.D.L.+4.0m) in addition to a 0.5 m parapet (crown height C.D.L.+4.5m) as shown in **Figure 9.12**, cross-section, and **Figure 9.13**, planar view. Moreover, the runup height at Tuv46 is 4.4 m meaning there is only 0.1 m of leeway, however, a decision on whether to undertake heightening will be made based on monitoring because the beach is expected to recover in future.

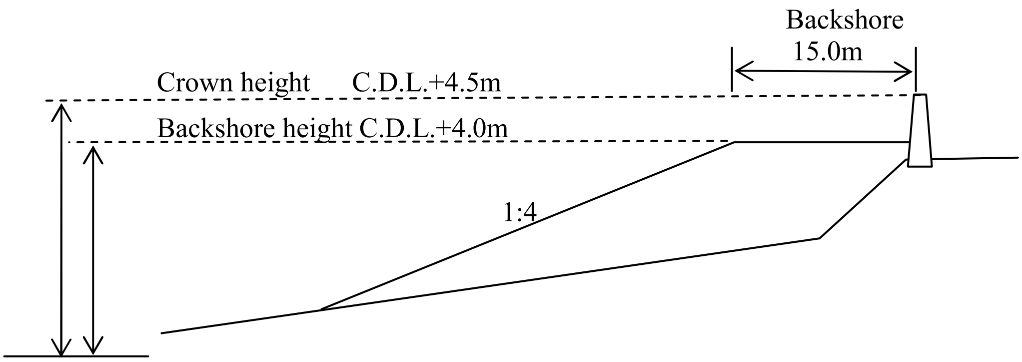


Figure 9.12 Standard Cross-Section of Area D-1

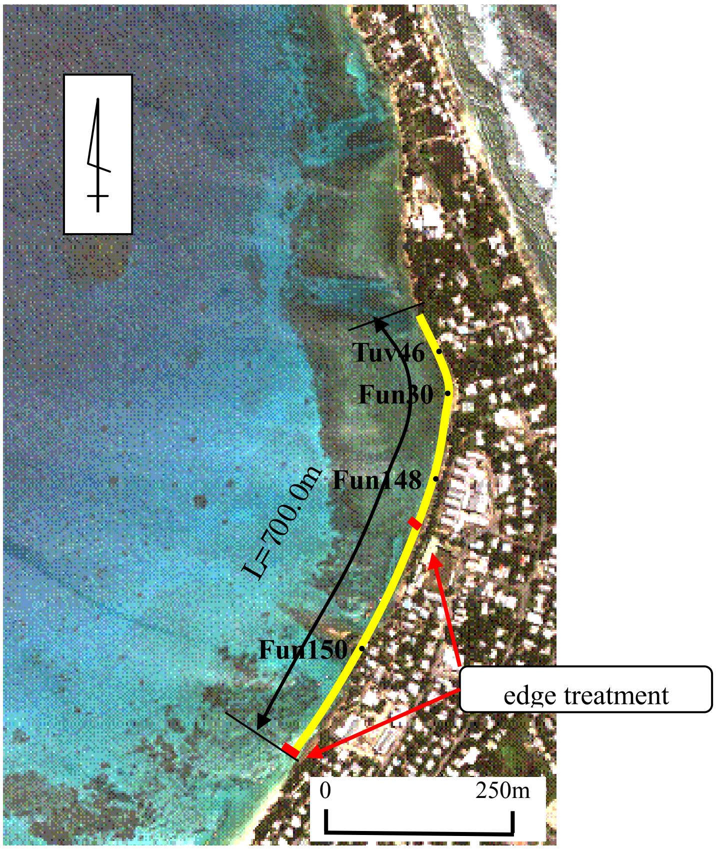


Figure 9.13 Top View of Area D-1

(6) Area D-2 in L-D Area

Due to the fact that the run-up height in area D-2 is already satisfied at present, the gravel nourishment will be implemented. (see **Figure 7.14**)

(7) Area D-3 in L-D Area

The shoreline change resultant of implementation of coral gravel nourishment of 10 m width in the backshore is shown in **Figure 9.14**. The nourishment gravel will be transported in the predominant longshore drift direction, northward, and deposited on the sand beach currently in the process of accretion. As a result, the nourished coast's protective function will be degraded, and the coral gravel will be deposited on the sandy coast.

The following figures show the effect of edge treatment on the northern end of the gravel nourishment area to prevent the loss of gravel. According to this, it can be deduced that although the shape of the nourished beach will change, the shoreline retreat will be alleviated and the northerly outflow of gravel will be controlled.

In **Table 9.7** the wave run-up heights with and without edge treatment are given. From these the maximum wave runup height will be 4.5 m with end treatment and 5.0 m without; which exceed the current ridge heights and the nourished berm height of 4.0 m; and therefore, the wave runup height is not satisfied. Therefore, the run-up heights whereby nourishment is undertaken for a 15 m wide backshore are shown in **Table 9.8.** The run-up heights at Fun155 and Fun 156 are respectively 4.3m and 4.2m, and these lines will not be satisfied by 0.3 m and 0.2m.

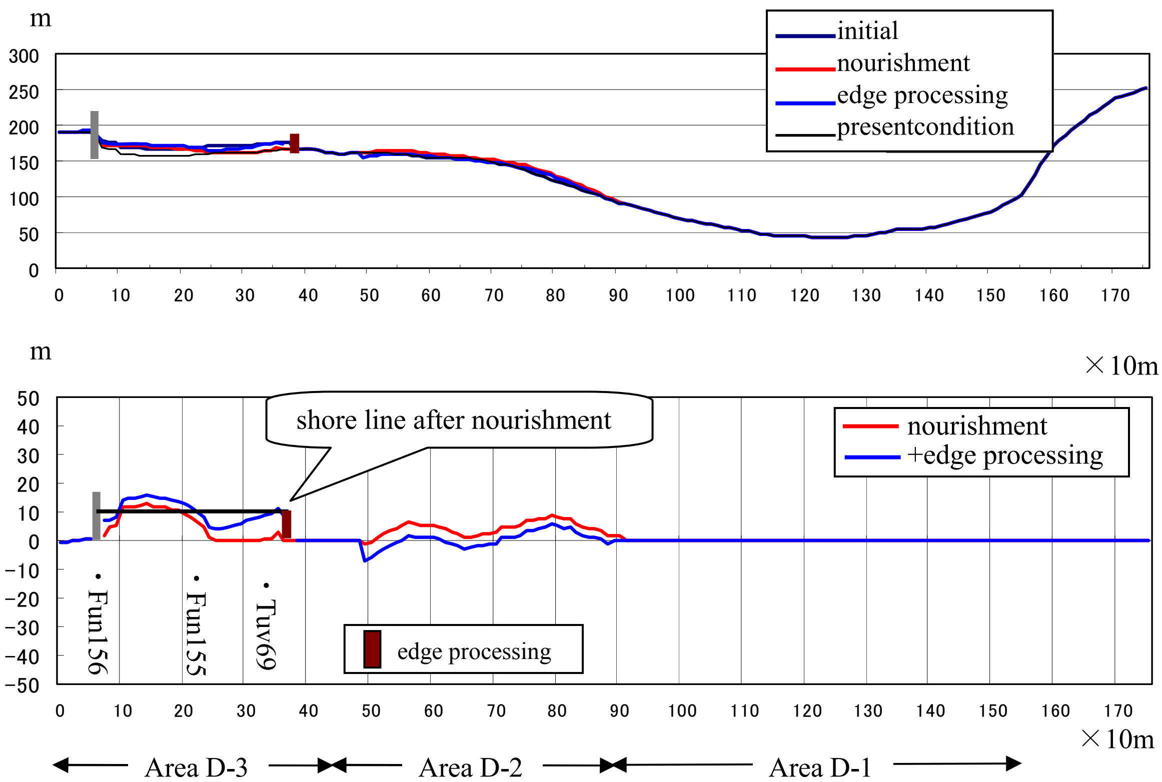


Figure 9.14 Future Simulation of 10 m Wide Backshore Nourishment

Table 9.7 Run-up Heights after Coastline Change

Traverse line	Ridge height (C.D.L.m)	Wave run-up height 10-return year wave + H.H.W.L.						
		Current state (C.D.L. m)	Immediately after nourishment		Future: No edge treatment		Future: With edge treatment	
			Backshore width* (m)	Run-up height (C.D.L. m)	Backshore width (m)	Run-up height (C.D.L. m)	Backshore width (m)	Run-up height (C.D.L. m)
Tuv69	4.8	**4.5**	10.0	**4.1**	0.0	**4.5**	8.8	**4.2**
Fun155	4.5	**4.8**	10.0	**4.1**	1.0	**4.7**	4.0	**4.5**
Fun156	4.1	**5.1**	10.0	**4.2**	1.6	**5.0**	7.0	**4.4**

* Backshore widths in this table are those in addition to the current shoreline.

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

Table 9.8 Run-up Heights with Different Width Backshores

Traverse line	Ridge height (C.D.L.m)	Wave run-up height 10-return year wave + H.H.W.L. (C.D.L.m)			
		Future: No edge treatment, 10 m backshore at time of nourishment		Future: With edge treatment, 15 m backshore at time of nourishment	
		Backshore width*	Run-up height	Backshore width	Run-up height
Tuv69	4.8	8.8	**4.2**	13.8	**4.0**
Fun155	4.5	4.0	**4.5**	9.0	**4.3**
Fun156	4.1	7.0	**4.4**	9.3	**4.2**

* Backshore widths in this table are those in addition to the current shoreline.

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

In order to satisfy the wave run-up height in the southern end of the nourishment area, the backshore width would have to be 15 m after the shoreline change; however, a backshore width of 10 m constructed in the northern end has already been shown to satisfy the wave run-up height; for this, and the following reasons, a low parapet seawall is to be constructed on the shoreward side of the nourishment area to satisfy the wave run-up height.

- 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 at traverse line Tuv69, Fun155 and Fun 156 where the runup is respectively 4.2m, 4.5m and 4.4 m even with edge treatment, and the present ridge height is respectively 4.8m, 4.5m and 4.1. Especially, to use a great deal of coral gravel to satisfy the run-up height in Fun156.
- 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,
- a potential sea level rise of 0.1 m derived from the surf beat and from the following formula; where the wave height is in *rms* notation, therefore, in order to convert it to water level (η), $\eta = \zeta rms \times 4.003 \times 0.7$ is used.

$$\xi_{rms} = \frac{0.01Ho'}{\sqrt{\frac{Ho'}{Lo}\left(1+\frac{h}{Ho'}\right)}}$$

Therefore:

The cross-sectional shape consists of 10 m backshore nourishment (backshore height CDL +4.0 m) with a parapet (crown height of CDL +4.5 m, ground level height of 0.5 m). It is desirable that the parapet is made of material such as stacked stones so that it can be easily maintained in Tuvalu. Moreover, the runup height at Fun155 and Fun156 is respectively 4.5 m and 4.4m meaning there is only 0.0m and 0.1 m for leeway, however, a decision on whether to undertake heightening will be made based on monitoring because the beach is expected to recover in future.

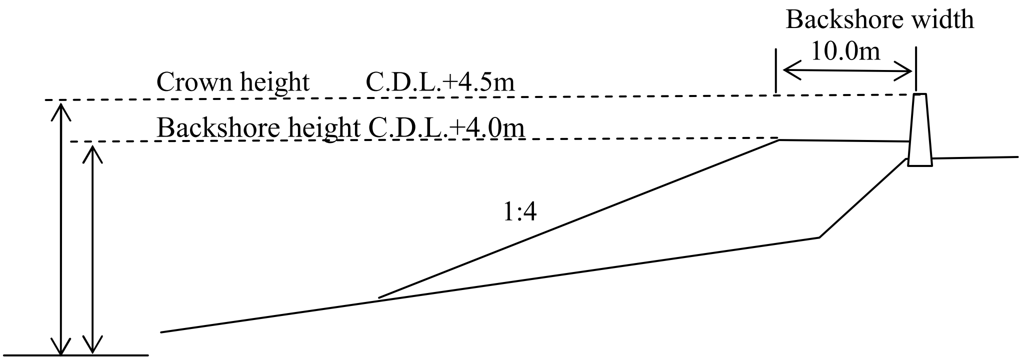


Figure 9.15 Standard Cross-Section of Area D-3

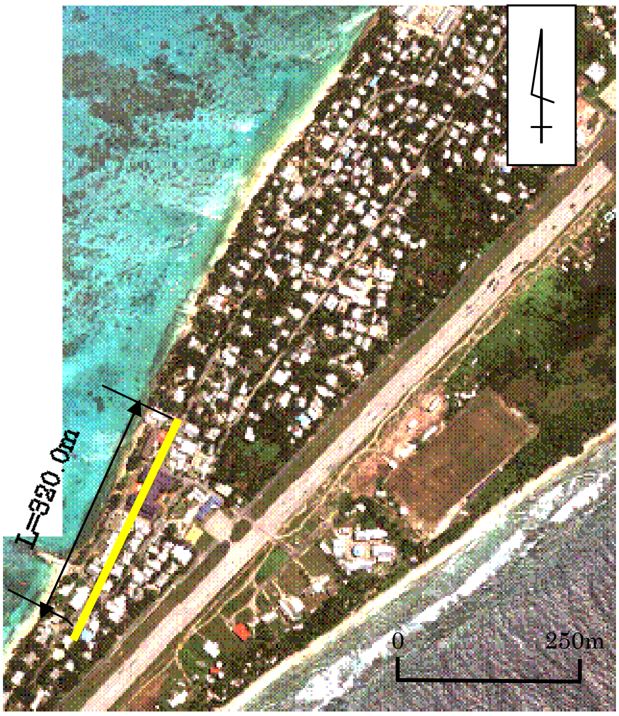


Figure 9.16 Planar View of Area D-3

Source :
Kadomatsu, T., Osugi, H., Ito, H., 1991, Field experiment of beach nourishment using gravel at Nishijima district of Toban beach, Proceedings of Coastal Engineering, Vol.38, JSCE, pp.301-305.
Tsuboka, T., Uda, T., Tani, M., Osugi, H., Ito, H., 1992, Monitoring survey of beach nourishment using gravel at Nishijima district of Toban beach, Proceedings of Coastal Engineering, Vol.39, JSCE, pp.361-365.
Tsuchiko, H., Uda, T., Matsuura, T., Abe, R., Kumada, T., Oki, Y., 2009, Field investigation of gravel layers after beach nourishment using gravel at Jinkoji coast, Proceedings of JSCE(Coastal Engineering), Vol.B2-65, No.1, pp.735-740.

9.2.2 Edge Treatment

The edge treatment is to be small groynes of stacked stones, down to the toe of the gravel nourishment in order to prevent longshore drift of the gravel. Taking advantage of the fact that the range of movement of sand is larger than that of gravel, hindrance to the movement of earth and sand expected from a future increase in supply of sand by littoral drift is to be prevented by limiting the length of a jetty to the edge of the slope of the gravel beach nourishment. 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. **Figure 9.17** shows schematic diagrams of the work on the edges of the nourishment.

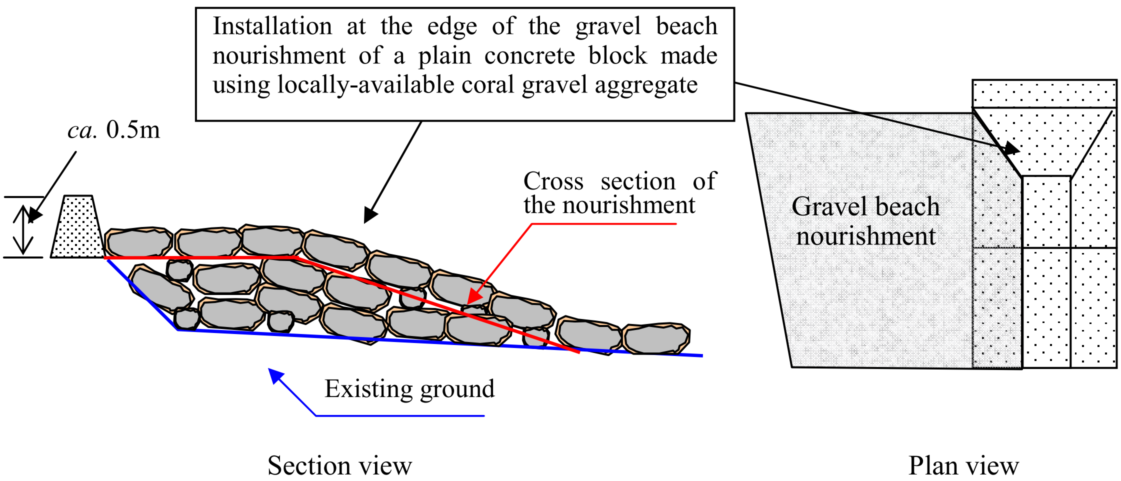


Figure 9.17 Schematic diagram of the work on the edges of the nourishment

9.2.3 Parapet

The parapet is to be constructed of stacked rocks or stacked rocks cemented with mortar, and, as shown in **Figure 9.18**, its crown width is to be 0.5 m, its slope gradient 1:1, and its ground height 0.5 m.

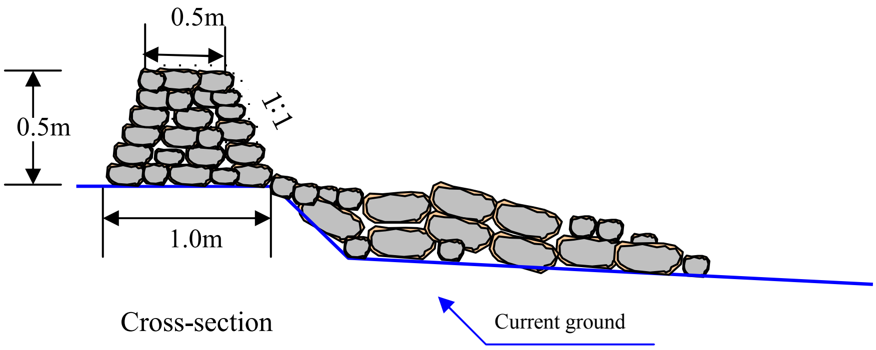


Figure 9.18 Illustration of the parapet

9.2.4 Refilling of the Borrow Pits

There are several borrow pits, where sediment was excavated during WWII by the US military, in the vicinity of the nourishment area (**Figure 5.7**). This 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. BP-3-S is omitted because the water depth is shallow.

9.2.5 Catalina Ramp Removal

The Catalina ramp is inhibiting the southerly longshore drift. **Figure 9.19** shows the shoreline change after nourishment with and without the Catalina ramp. It is estimated, based on the calculation results, that the ramp will have a minimal effect in trapping longshore drift, because the stable shape of the gravel shoreline after end treatment is mostly stable against incoming waves. Consequently, the removal of the Catalina ramp is considered to have only a minor impact on the surrounding coastline.

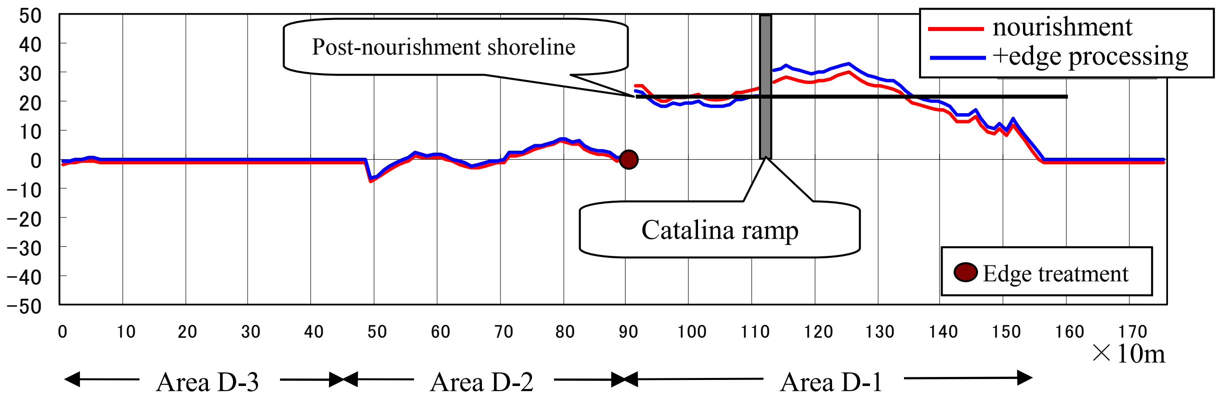


Figure 9.19 Effect of Catalina ramp

9.2.6 Removal of Vaiaku Wharf

Currently, there is a sandy beach formed on the southern side of Vaiaku wharf, therefore, it can be considered that it is inhibiting the northward longshore drift. In the field it could not be confirmed that the beach width near the wharf is gradually accreting, therefore, it is unlikely that there is a plentiful sand supply from the south. If there is insufficient sand supply to maintain the beach on the southern side after the removal of the wharf, the sediment accumulated on the southern side of the wharf will be transported northerly, and as a result there is likelihood that this beach will be eroded. Therefore, this issue of whether to remove the wharf or not will have to be considered in future, when the sand supply has become possible and after an evaluation of sand nourishment has been undertaken.

9.2.7 Planting Design on Gravel Nourishment Areas

(1) Planting overview

Planting is implemented as a part of artificial gravel nourishment to close and consolidate the gravel beach and to protect the washing of the coral gravel onto the land and the flying of wave splash during high wave conditions. 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.

(2) Planting overview

According to vegetation map (Mclean & Hosking, 1992), "*Cocos nucifera*", "*Scaevola taccada*", "*Pandanus tectorius*", and "*Pemphis acidula G.Forst*" were recorded and illustrated at the lagoon side of Fogafale in 1992. The existence of *Cocos nucifera*, *Scaevola taccada* and *Pandanus tectorius* was identified by our survey in 2010. Consequently, *Cocos nucifera*, which is a type of fast–growing and arboreal vegetation, should be selected as principal trees for this planting work. Also, *Pandanus tectorius* was verified as the function of disaster prevention during the tsunami of the Indian Ocean and *Scaevola taccada* will be also utilized as a combination species of the mixture woodland in this area.

(3) Planting procedures

1) Procedure of the work

Planting site of gravel nourishment is located along the seacoast in which is hit at all times by sea-breeze. Due to the survival rate remains unsolved, setting plot sites up are needed on the gravel nourishment areas. The growth situation is ensured after planting. If the survival rate of the seedling is high and the growth is confirmed, it will be expanded to the rest of other areas of the gravel nourishment. During the time from the seedlings and initial growth stage, wave spindrift and strong sea breeze with salt may have triggered concerns on the poor growth and low survival rates. In order to improve the chances of survival, sufficient protection measures will be considered and provided. For example, setting fences and cover sheets for whole plots areas and tree shelters and tree guards for respective saplings will be suggested as options for protection measures.

2) Implementation method

- Planting activity is conducted voluntarily by the community participation.
- Planting species are scheduled to be settled through the community participation to advance the management with considering resident's intention.
- Due to the community participation of planting activity, the related lecture regarding biological knowledge and technology of the selected planting species should be conducted to be successful for paving the way of local community involvement.
- Additionally, the resident becomes a key player in the following activities, leveling the land, setting nursery, excavating plant hole, sapling plantation, protection treatments for transplanted saplings, and survey for growth of biological integrity of sapling. Then withered saplings are removed and brand-new saplings are exchanged and a series of planting management work involving pruning and thinning should be conducted continuously.

3) Experimental site

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 : refer to the attached separate sheet). The plot site is designed for coconut as principal tree at 1.0 m intervals (refer to the attached separate sheet). Around this principal tree “*Cocos*”, *Scaevola taccada*” and “*Pandanus tectorius*” will be planted in the alternate shifts and aligned state. Experimental plot is 2m in the east to west and 10m in the south to north (**Figure 9.20**).

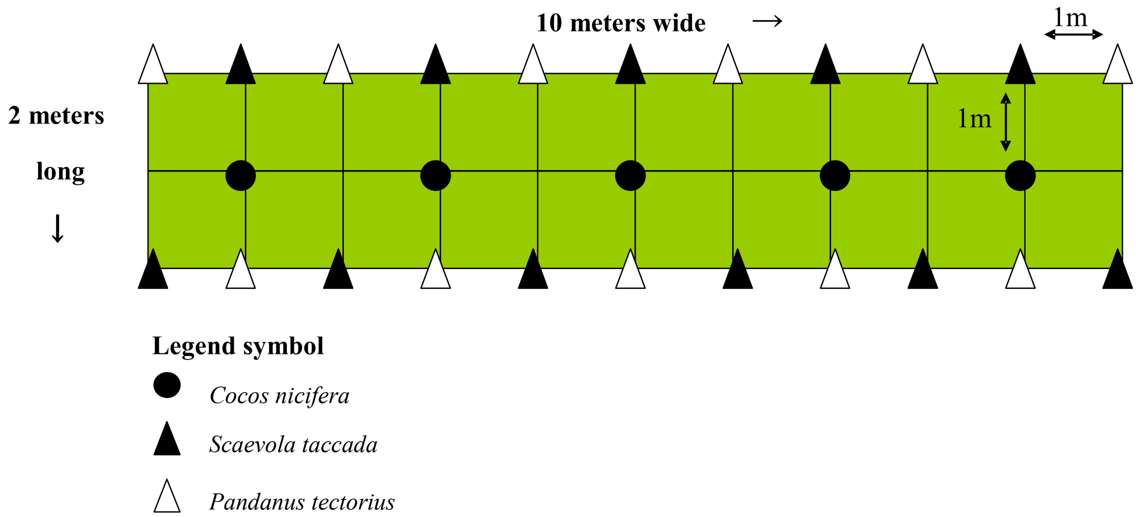


Figure 9.20 The Display of Experimental Planting Plot

4) Planting technologies

- Cutting propagation is applied.
  (Tinen, 1988), (Miyajima, 1988), (Fukushima Integrated Vegetation Center Association, 1981)
- *Cocos nucifera*: First of all, a cocoa is picked from parent tree. In order to have a high water absorption rate, stripping the skin of the bottom of the cocoa and burying the two-thirds in the ground will be practiced. Then the budding of the seedling will be generated from them. Those seedlings with budding are planted at plot on the gravel nourishment.
- *Pandanus tectorius*: The branches will be cut out of the parent plant. They will be taken root easily if the aerial root is attached to the cut-out branch. Then the head of aerial root of the plants should be buried in the soil.
- *Scaevola taccada*: Around 5cm-seedling is taken from the parent plant. 2 or 3 leaves around the ear are removed. Then it will be developed as the rooted cutting. After pouring water of the cutting sapling, the joint of the leaf trace of the branch should be buried to the ground in the soil.

5) Applied vegetative materials

Rooted cutting is come by existing plants in Tuvalu under the mutual consent of the local administration and tree owners.

6) Planting period

It takes more than 5 or 6 years to be grown as a mature tree. In order to stabilize the site ground and activate the function of disaster reduction, the planting activity would be conducted with a long-term view for 10 years.

7) Materials needed for planting construction and maintenance

- Machinery for land grading
- Support pole for planting
- Rope to bind each seeding up to the pole
- Simple fence, cover sheet, sapling shelter, and sapling guard for protecting from storm and strong sea breeze

(4) The Expected outcome of planting

- *Cocos* is classified into for arboreal vegetation category. *Pundanus* and *Scaevola* are classified into shrub category. Therefore, the multiple layers of the woodland can be formed by utilizing these plant materials and it may contribute to preserve the gravel nourishment.

- The beautiful scenery of seashore would be created due to planting at gravel nourishment.

- The development of the community ownership through the planting activity based on community participation and the advancement of environmental awareness will be promised.

Source :
(1) Chinen Masayoshi (1988), The breeding and the plantation test of *Pandanus*, Okinawa Prefectural Experimental Forestry Station
(2) R.F. McLean and P.L. Hosking (1992), Tuvalu Land Resources Survey Island Report NO.7 University of Auckland, NZ
(3) Tanaka Shigenobu, Kuribayashi Daisuke, Tokioka Toshikazu (2010), Research on Sustainable Measures for Tsunami Disaster Mitigation in Developing Countries (1)
(4) Miyajima et al. (1987), Research II on *Pandanus* , Collection of Papers for 98th Japanese Forestry Society
(5) “Fundamental knowledge for vegetation trees” (1981), Fukushima Integrated Vegetation Center Association

9.3 Study on the Required Volume of Beach Nourishment Materials

9.3.1 Procurement Circumstances of Beach Nourishment Material

Before the 1990's, Sand and coral gravel on the land and the beach have been able to be used as construction materials in Tuvalu.
At present, Funafuti Kaupule regulates the collection place and the unit price of sand and gravel , which is sold as aggregate of concrete for local small-scale construction. As for large-scale construction, however, the aggregate is supplied only importing from Fiji. The ocean transport cost pushes up the local construction price greatly. For instance, unit price of fresh concrete in the projects in 2008 – 2009 in Tuvalu tripled or more to the price in Fiji, as a result of the ocean transport cost accounting about 70 percent of the price in Tuvalu.
Moreover, severe flora and fauna quarantine is imposed in Tuvalu and the neighboring countries, that requires strict fumigation processing for aggregate, soil and sand. That cost also pushes up the price of imported aggregate.
Therefore, it is expected that the beach nourishment materials would be procured as much as possible locally in Tuvalu in order to reduce the project expense.

9.3.2 Domestic Procurement and Resource Quantity of Gravel Material

As mentioned in the Section 7.4.1 (3) beach nourishment 1) Particle Size, the beach nourishment materials required for the counter measure work were the gravels of median particle diameter d50=6.5mm or more.

(1) Gravel material of The Small Islets

Existing gravel sources under natural condition are limited to the following three places in Funafuti Atoll.

a) Central part of Fongafale and/or Tengako Island
b) Storm ridge along the beach line at the ocean side
c) Both ends of the islets in the southeast of Funafuti Atoll
(Funamanu Islet, Falefatu Islet and Mateika Islet)

Hereafter, possibility of collection of gravel is examined in the three cases above.

a) Central part of Fongafale Island
In the central part of Fongafale Island and Tengako Island, gravel piles up abundantly and forms the land.
However, it is virtually impossible to collect gravel here. Some part is inhabited by people and the land ownership would become an issue. Some part is already exploited by the U.S. military for the development of the runway in the past.

b) Storm ridge along beach line on the ocean side
In case of the gravel that forms the storm ridge on the ocean side of Fongafale Island and Tengako Island, there is an advantage of easy transportation by loading through adjoining lands to the project site.
However, collecting gravel is virtually impossible. Because removing the gravel of the storm ridge would permit the ocean waves easily overtop into the land and risk the residents' lives.
Moreover, from the east to the southeast side of Funafuti Atoll, there are gravel resources where the shingle beach is formed by the cyclone “Bebe” casting large stones and coral gravel in 1972. Those gravel and stone were generated by cyclones high wave destroying the ridge part of the coral reef on the edge.
However, it is deemed to be quite dangerous to collect gravel here by machinery or man power, because the ocean waves from the east always act on the reef rat on the ocean side.

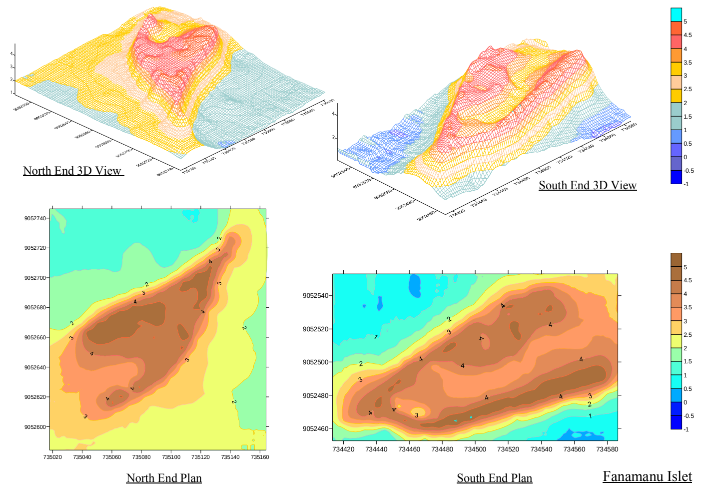
c) Both ends of the islets in the southeast of Funafuti Atoll (Funamanu Islet, Falefatu Islet and Mateika Islet)
On the other hand, both ends of some islets located from the east to the southeast of the atoll, the shingle beach where gravel piles up like a sandspit is formed, and it is deemed to be a land of gravel comparatively newly formed, because the land is not forested. To collect the gravel here, it seems that it is accessible and also possible to gather sequentially, and to send off gravel from the tip of the sandspit at low water with the machine from a calm lagoon side. However, when the temporary access (waterway, temporary jetty, and causeway, etc.) to load gravel into the transportation barge is set up, the sufficient consideration is necessary for the environmental protection because an active coral reef belt has extended to the lagoon side of these state islands.
In this Feasibility Study, after having reconnaissance all isles of Funafuti Atoll, topographic survey was carried out for estimation of quantity of gravel resources in the shingle beach at both ends of three islets which located southeast of Funafuti Atoll (Funamanu Islet, Falefatu Islet and

Mateika Islet, Refer to **Figure 9.21** and **Figure 9.22**).

For estimation of resource quantity of gravel, it is assumed that the gravel is piling up higher than the beach rock (=Mean Sea Level =C.D.L.+2.0m) and the soil volume in this part was calculated and estimated into the potential gravel volume.

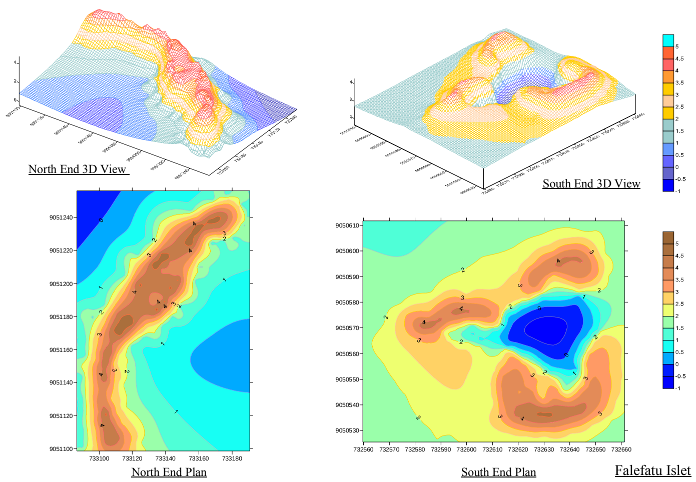
Figure 9.21 Resource Survey of Gravel as Beach Nourishment Materials around South-Eastern Islets of the Funafuti Lagoon

(1) Funamanu Islet



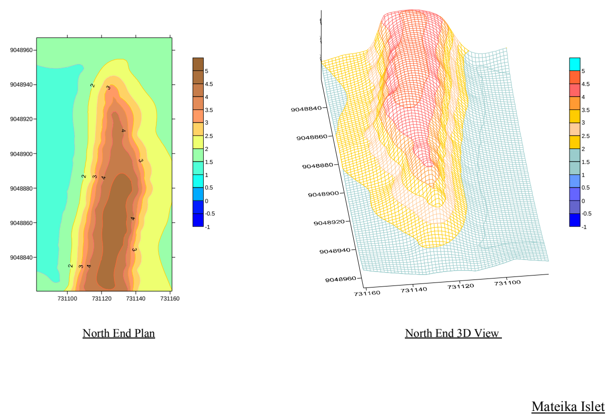
Estimated Quantity: Noth End 11,110 m3 + South End 11,946m3=Total 23,056m3

(2) Falefatou Islet



Estimated Quantity: Noth End 5,089m3 + South End 1,461m3=Total 6,550m3

(3) Mateika Islet



Note) The soil volume higher than Mean Sea Level =C.D.L+2.0m was calculated, and it made it to estimated gravel volume.

Estimated Quantity: Noth End 4,915 m3

Figure 9.22 Geographical Features on Islets in the Southeast of Funafuti Atoll and Estimated Gravel Volume

(2) Gravel Material from the Existing Runway Area

It is thought that gathering the gravel from Fongafale and/or Tengako Island or Funafuti Atoll is inexpensive method for this countermeasure works, however, gravel in the center part of the on Fongafale and Tengako Island has already been mined for developing runway during the WW2 and the mining of a new gravel material seems quite difficult.

In addition, as described in the following clause (3) Estimation of Exploitable Gravel Resource Quantity and Section 9.3.4 Examination of the Required Gravel Volume, it found exploitable gravel resource quantity is not enough for beach nourishment work. Thus it is necessary to examine not only the gravel naturally piled up gravel but also the place where the gravel can be gathered at an affordable price in Funafuti Atoll.

The gravel from the east side of the runway can be used for the countermeasure works and to be replaced with dredged sand. The dredged sand is piled up in the deep seabed of the lagoon where is deeper than the critical depth for sediment movement.

For estimation of exploitable gravel source, test pits were dug up in the east side of the existing runway safety zone every 100m along runway with 1600m long and investigations of depth and thickness of gravel layer, sand and gravel ratio and gravel size were carried out. Test pit positions are as shown in **Figure 9.23**.
As a result, about 80% to 85% in weight ratio of soil is classified as gravel that can be used as gravel materials for this gravel beach nourishment. (see **Figure 9.24** and **Figure 9.25**)

The change according to the depth was not obviously seen as the distributions of gravel sizes were almost similar in any test pit. However, as shown in **Figure 9.26**, some sandy layer were observed around the central part of the runway in the three test pits (P-10, P-10+0.5, P-10+) in total 18 test pits. Underground water was also observed in the relatively lower ground area at M.S.L.(C.D.L.+2.0m) and at high tide this underground water seems to connect and flow between the east swamp of the pulaka vegetation area in the western side of the runway.

Figure 9.23 Resource Survey of Gravel as Beach Nourishment Materials beside of the Existing Runway Area

Full view of Test Pit

Test Pit

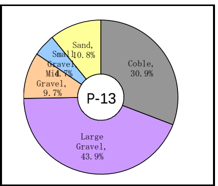
1m Quadrat 10cm mesh

After sieve sorting

Figure 9.24 Test Pit (No.P-13: at North End of the Runway)

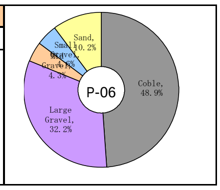
P-13

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	9.63	30.9%	Date and hour: 2010/6/26 14:14 Position: Runway East Side 1.6km from South End 742413E, 9057670N G.L. = C.D.L.+4.9 m Pit Depth = G.L. -1.5 m U/G Water = Not Observed Tide Level= C.D.L.+1.91m
Large Gravel	75～19	13.69	43.9%	
Mid Gravel	19～8	3.02	9.7%	
Small Gravel	8～2	1.46	4.7%	
Sand	<2	3.37	10.8%	
Total		31.17	100.0%	



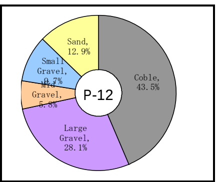
P-06

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	20.30	48.9%	Date and hour: 2010/6/26 17:39 Position: Runway East Side 0.5km from South End 741661E, 9056866N G.L. = C.D.L.+3.0 m Pit Depth = G.L. -1.0 m U/G Water = G.L. -0.7 m Tide Level= C.D.L.+2.51m
Large Gravel	75～19	13.36	32.2%	
Mid Gravel	19～8	1.77	4.3%	
Small Gravel	8～2	1.90	4.6%	
Sand	<2	4.22	10.2%	
Total		41.55	100.0%	



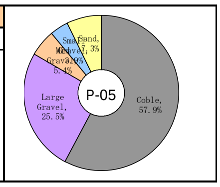
P-12

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	12.70	43.5%	Date and hour: 2010/6/26 14:45 Position: Runway East Side 1.4km from South End 742278E, 9057521N G.L. = C.D.L.+2.9 m Pit Depth = G.L. -1.0 m U/G Water = G.L. -1.0 m Tide Level= C.D.L.+2.08m
Large Gravel	75～19	8.21	28.1%	
Mid Gravel	19～8	1.68	5.8%	
Small Gravel	8～2	2.84	9.7%	
Sand	<2	3.75	12.9%	
Total		29.18	100.0%	



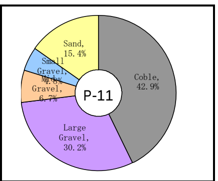
P-05

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	26.10	57.9%	Date and hour: 2010/6/26 17:46 Position: Runway East Side 0.4km from South End 741593E, 9056794N G.L. = C.D.L.+3.1 m Pit Depth = G.L. -0.5 m U/G Water = Not Observed Tide Level= C.D.L.+2.50m
Large Gravel	75～19	11.51	25.5%	
Mid Gravel	19～8	2.42	5.4%	
Small Gravel	8～2	1.76	3.9%	
Sand	<2	3.30	7.3%	
Total		45.09	100.0%	



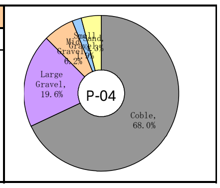
P-11

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	20.15	42.9%	Date and hour: 2010/6/26 15:07 Position: Runway East Side 1.2km from South End 742136E, 9057377N G.L. = C.D.L.+3.0 m Pit Depth = G.L. -1.0 m U/G Water = Not Observed Tide Level= C.D.L.+2.19m
Large Gravel	75～19	14.17	30.2%	
Mid Gravel	19～8	3.14	6.7%	
Small Gravel	8～2	2.27	4.8%	
Sand	<2	7.24	15.4%	
Total		46.97	100.0%	



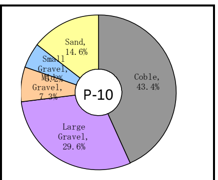
P-04

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	44.41	68.0%	Date and hour: 2010/6/25 11:25 Position: Runway East Side 0.3km from South End 741525E, 9056718N G.L. = C.D.L.+3.4 m Pit Depth = G.L. -0.8 m U/G Water = Not Observed Tide Level= C.D.L.+1.30m
Large Gravel	75～19	12.83	19.6%	
Mid Gravel	19～8	4.06	6.2%	
Small Gravel	8～2	1.22	1.9%	
Sand	<2	2.81	4.3%	
Total		65.33	100.0%	



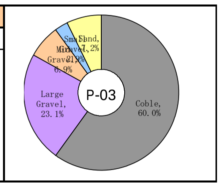
P-10

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	21.86	43.4%	Date and hour: 2010/6/26 15:40 Position: Runway East Side 1.0km from South End 742001E, 9057232N G.L. = C.D.L.+3.0 m Pit Depth = G.L. -1.0 m U/G Water = Not Observed Tide Level= C.D.L.+2.33m
Large Gravel	75～19	14.91	29.6%	
Mid Gravel	19～8	3.67	7.3%	
Small Gravel	8～2	2.62	5.2%	
Sand	<2	7.35	14.6%	
Total		50.41	100.0%	



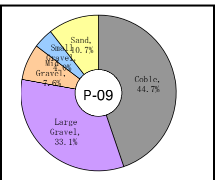
P-03

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	34.08	60.0%	Date and hour: 2010/6/25 10:30 Position: Runway East Side 0.2km from South End 741456E, 9056574N G.L. = C.D.L.+3.4 m Pit Depth = G.L. -1.0 m U/G Water = Not Observed Tide Level= C.D.L.+1.23m
Large Gravel	75～19	13.11	23.1%	
Mid Gravel	19～8	3.90	6.9%	
Small Gravel	8～2	1.64	2.9%	
Sand	<2	4.09	7.2%	
Total		56.82	100.0%	



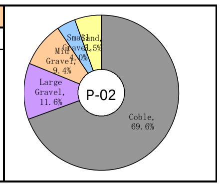
P-09

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	21.60	44.7%	Date and hour: 2010/6/26 16:04 Position: Runway East Side 0.8km from South End 741864E, 9057085N G.L. = C.D.L.+2.9 m Pit Depth = G.L. -1.2 m U/G Water = G.L. -1.0 m Tide Level= C.D.L.+2.42m
Large Gravel	75～19	15.99	33.1%	
Mid Gravel	19～8	3.67	7.6%	
Small Gravel	8～2	1.91	4.0%	
Sand	<2	5.16	10.7%	
Total		48.33	100.0%	



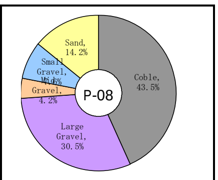
P-02

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	30.86	69.6%	Date and hour: 2010/6/25 10:58 Position: Runway East Side 0.1km from South End 741389E, 9056574N G.L. = C.D.L.+3.5 m Pit Depth = G.L. -1.2 m U/G Water = Not Observed Tide Level= C.D.L.+1.25m
Large Gravel	75～19	5.13	11.6%	
Mid Gravel	19～8	4.18	9.4%	
Small Gravel	8～2	1.78	4.0%	
Sand	<2	2.42	5.5%	
Total		44.37	100.0%	



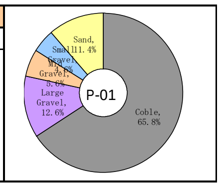
P-08

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	20.09	43.5%	Date and hour: 2010/6/26 16:46 Position: Runway East Side 0.7km from South End 741794E, 9057013N G.L. = C.D.L.+3.0 m Pit Depth = G.L. -1.0 m U/G Water = G.L. -0.9 m Tide Level= C.D.L.+2.51m
Large Gravel	75～19	14.10	30.5%	
Mid Gravel	19～8	1.94	4.2%	
Small Gravel	8～2	3.51	7.6%	
Sand	<2	6.58	14.2%	
Total		46.22	100.0%	



P-01

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	26.67	65.8%	Date and hour: 2010/6/25 9:46 Position: Runway East Side 0.0km from South End 741318E, 9056504N G.L. = C.D.L.+3.4 m Pit Depth = G.L. -1.0 m U/G Water = Not Observed Tide Level= C.D.L.+1.29m
Large Gravel	75～19	5.13	12.6%	
Mid Gravel	19～8	2.27	5.6%	
Small Gravel	8～2	1.85	4.6%	
Sand	<2	4.64	11.4%	
Total		40.56	100.0%	



P-07

Nominal Name	Size	Weight (kg)	Percentage	Remarks
Coble	300～75mm	27.80	56.4%	Date and hour: 2010/6/26 17:09 Position: Runway East Side 0.6km from South End 741729E, 9056938N G.L. = C.D.L.+3.0 m Pit Depth = G.L.-1.0 m U/G Water = G.L.-1.0 m Tide Level= C.D.L.+2.52m
Large Gravel	75～19	11.76	23.9%	
Mid Gravel	19～8	2.74	5.6%	
Small Gravel	8～2	3.00	6.1%	
Sand	<2	4.00	8.1%	
Total		49.30	100.0%	

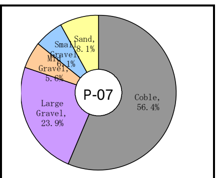


Figure 9.25 Particle Size Distribution of Test Pits at East Side Safety Zone of Runway

Geographical Information for Test Pits beside of the Existing Runway

(25th to 27th June, 2010, at Funafuti International Airport)

St.	Dist. From South End of Runway (km)	Easting	Northing	Natural Ground Level (above C.D.L.)	Depth (from N.G.L.)	Bedrock Level (above C.D.L.)	Underground Water Level (C.D.L.)	Classification	Remarks
P-13	1.600	742411.8796	9057672.1989	+4.09	-1.50	+2.59	Not observed	G	
P-12+	1.500	742343.2790	9057595.2910	+3.10	-1.10	+2.00	+2.10	G	Gravelly、Slight high U/G Water
P-12	1.400	742277.4945	9057524.0969	+2.94	-1.00	+1.94	+1.94	G	Gravelly、Slight high U/G Water
P-11+	1.300	742207.3849	9057453.0774	+2.97	-1.20	+1.77	+2.17	G	Gravelly、High U/G Water
P-11	1.200	742136.8308	9057380.3482	+2.95	-1.00	+1.95	Not observed	G	Gravelly、High U/G Water
P-10+	1.100	742067.9129	9057307.9960	+3.07	-1.25	+1.82	+1.97	S	No Gravel, High U/G water
P-10+0.5	1.050	742036.0473	9057276.0453	+3.10	-1.35	+1.75	+1.75	GS	Sand with Gravel, Low U/G water
P-10	1.000	741999.1026	9057236.3817	+3.05	-1.00	+2.05	Not observed	GS	Sand with Gravel, No U/G water
P-09+	0.900	741935.2287	9057160.3079	+2.90	-1.25	+1.65	+2.30	G	Gravelly、High U/G Water
P-09	0.800	741863.5388	9057087.6325	+2.94	-1.20	+1.74	+1.94	G	
P-08	0.700	741794.4500	9057014.7703	+2.97	-1.00	+1.97	+2.07	G	
P-07	0.600	741728.0656	9056940.8265	+3.01	-1.00	+2.01	+2.01	G	
P-06	0.500	741659.9577	9056868.6012	+2.99	-1.00	+1.99	+2.29	G	
P-05	0.400	741592.9891	9056795.6242	+3.15	-0.50	+2.65	Not observed	G	
P-04	0.300	741524.3872	9056721.0248	+3.40	-0.80	+2.60	Not observed	G	
P-03	0.200	741457.3948	9056647.7584	+3.41	-1.00	+2.41	Not observed	G	
P-02	0.100	741386.1791	9056576.9882	+3.47	-1.20	+2.27	Not observed	G	
P-01	0.000	741314.9658	9056506.3991	+3.44	-1.00	+2.44	Not observed	G	
Average				+3.16	-1.08	+2.09	+2.05		

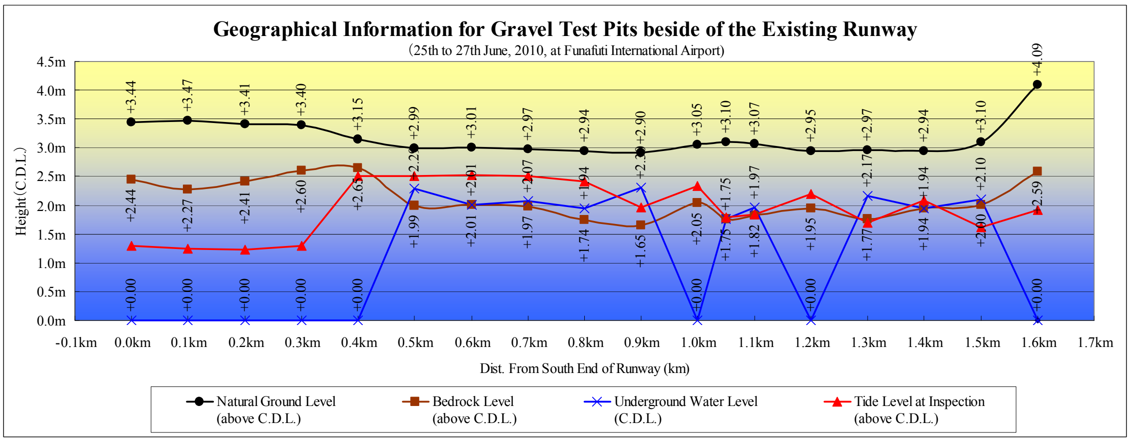


Figure 9.26 Ground Height and Underground Water Level of Test Pits

(3) Estimated Quantity of Gravel Resource

Quantity of exploitable gravel in the three islets and the gravel materials around the runway area are estimated as shown in **Table 9.9**.

Table 9.9 Exploitable Gravel Volume

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

9.3.3 Problem in Gravel Material Collection

(1) Gravel Material Collection from Islets

a) Type of Temporary Access

In case of mining the gravel materials from both ends of the islets (Funamanu Islet, Falefatu Islet and Mateka Islet) located southeast of Funafuti Atoll, it can be accessed from a calm lagoon side and gathered it onto the transportation barge, then transport to the Fongafale Island by sea.

The temporary access (waterway, Jetty, and Causeway etc.) is necessary for loading the gravel onto the barge. In this project, Causeway type is planned to which the gravel material gathered on each islet is filled up to depth to be able to access on the shallow beach flat coast the barge of beginning scattering.

Examination of the temporary access type is shown in the following Section "Construction Plan".

b) Examination of Economic Efficiency

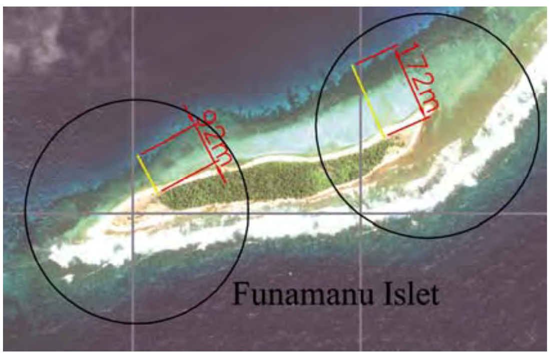
Each islet should be set up with the head of the access in about 90m to 170m offshore on the lagoon side in order to secure the depth C.D.L.-3m for access of the barge. The length of temporary causeway and the volume balance between the required gravel for the temporary causeway and the exploitable gravel necessary for each candidate gravel mining site are as shown in **Table 9.10**. Except the southern end of Funamanu Islet, it is found that the required volume for the temporary causeway is exceeding exploitable gravel volume for each mining site.

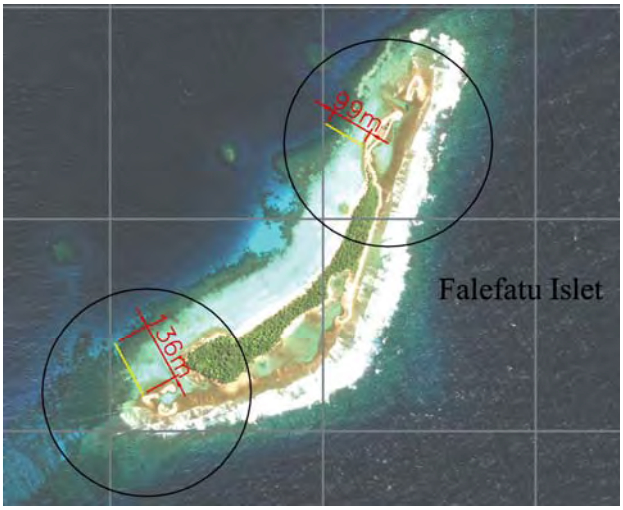
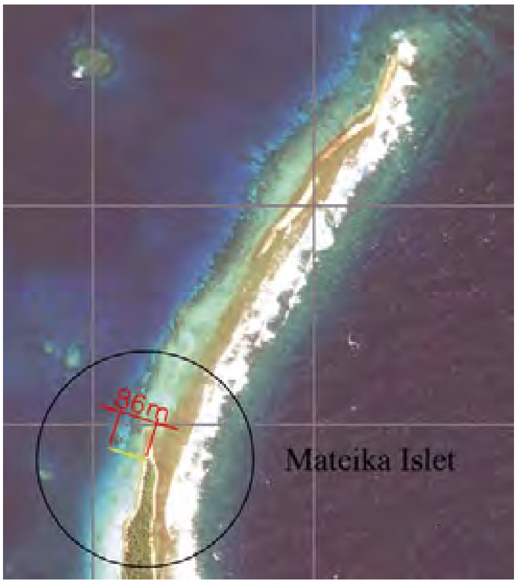
Judging from the balance between required gravel for temporary causeway and exploitable gravel, lack of gravel is acceptable up to about minus 50% of exploitable gravel volume at each gravel mining site. However, especially at the southern end of Falefatu Islet, quantity is extremely low (lack of 8,795 m3) exceeding minus 600%. Therefore, this area should be excluded from the candidate site of mining in this project.

In addition, at Mateika Islet during dry season, big ocean waves from the deep water strait between Falefatu Islet and Mateika Islet greatly affect the barge transportation between Fongafale Island and Mateika Islet.

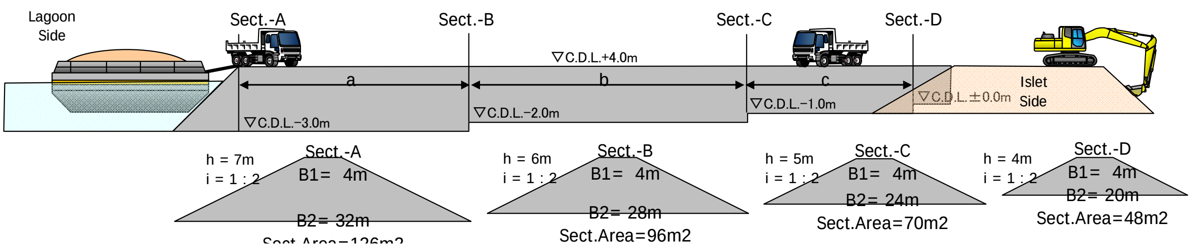
Therefore the priority of this mining site is evaluated to be the subordinate position considering the risk of barge transportation.

Table 9.10 Required Temporary Access Way to Islet and Exploitable Gravel Volume

Access Way Locations at Each Islet	Location (Length of Temp. Access way)	Uppper: Exploitable Vol. Mid. Temp.Causeay Lower: Balance
	Funamanu Is. North End (172 m)	11,110 m3 ー) 12,812 m3 ▲1,702 m3 Luck Vol / Exploitable Vol. =▲15%
	Funamanu Is. South End (92 m)	11,946 m3 ー) 7,132 m3 △4,814 m3 Luck Vol / Exploitable Vol. =△40%

	Falefatou Is. North End (99 m)	5,089 m3 −) 7,629 m3 ▲2,540 m3 Luck Vol / Exploitable Vol. =▲50%
	Falefatou Is. South End (136 m)	1,461 m3 −) 10,256 m3 ▲8,795 m3 Luck Vol / Exploitable Vol. =▲602%
	Mateika Is. North End (86 m)	4,915 m3 −) 6,706 m3 ▲1,791 m3 Luck Vol / Exploitable Vol. =▲36%

Note) The dimensions of bank body section and the amount of necessary gravel for the temporary access causeway vary in each collection place of gravel, and are assumed as follows.



Location	Distance a (m)	b (m)	c (m)	Total (m)	Volume (m3)
Funamanu N	15.0	78.5	78.5	172.0	12,812
Funamanu S	15.0	38.5	38.5	92.0	7,132
Falefatu N	15.0	42.0	42.0	99.0	7,629
Falefatu S	15.0	60.5	60.5	136.0	10,256
Mateika N	15.0	35.5	35.5	86.0	6,706

c) Impact on the coral

Impact on the coral by temporary access by the barge, counter measures

The impact on the coral ecosystem caused by the construction of causeway type access and the countermeasures to mitigate it are examined as follows.

Impact

To gather and to load the gravel from two islets (Funamanu Islet, Falefatu Islet), when the access bank body of the causeway type is developed by about 30m in base width (*Width depends on depth), physical damage may be given to the coral ecosystem living in the flat area of shallow lagoon beach.

Measures

The corals directly affected by construction of access bank should be temporarily transplanted prior to the gravel mining work. Then they will be transplanted again to the original area after completion of the work.

Figure 9.27shows the gravel collection site in the south of Funamanu Islet. Based on the coral living distribution charts prepared by the biological survey under this feasibility study, the location of temporary causeway is determined. Thus the surface area where the coral is transplanted (yellow frame) is estimated as follows.

- Coral coverage degree 50% or more 187.6 m2
- Coral coverage degree 20% to 50% 681.7 m2
- Coral coverage degree less than 1% 211.4. m2

According to habitat range of affected area and each coral coverage degree, the temporary site area to be transplanted can be estimated as at least 229.3m2,

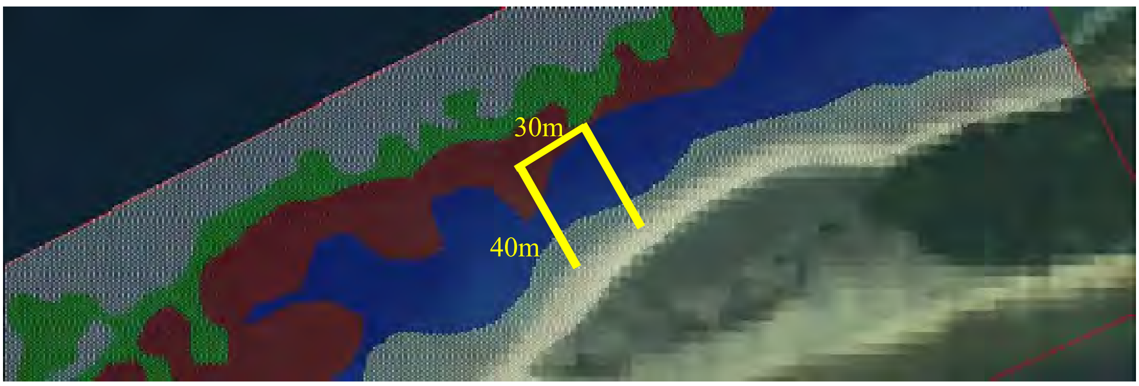


Figure 9.27 Live Coral Area around Gravel Mining Site in the South of Funamanu Islet

(Yellow frame: Coral transplant area due to construction of temporary access way)

The corals reaped for transplantation shall be temporarily accommodated in the shelves on the shallow water bottom of the lagoon. The coral is transplanted by using underwater bond by divers.

(2) Gravel Material from the Existing Runway Area

a) Base layer of Runway Area

The area around the existing runway used be covered by a kind of soft rock called "beach rock", cemented foraminifera origin sand and coral gravel piled up on the coral reef at about mean sea level in many years. Before WW2, this whole area used to be a swamp, however, this area was reclaimed during WW2 for developing a runway, using the gravel exploited from inland on Fongafale Island and Tengako Island.

The original base is composed of porous coral reef and beach locks that have cracks and voids here and there in them, and functions as an underground water conduit between the inland and the ocean.

When dredged sand including very fine sand and silt is backfilled into the estuarine basin on this porous base layer where water vain remains a lot after gravel is dug out into the safety zone at the runway, the fine soil particle is sucked out from the newly backfilled layer with the flow of underground water

Therefore there is a possibility that the underground void will be created in the future. Civil Aviation Department and the Public Works Department of the Tuvaluan Government pointed it out and requested to examine the construction method carefully enough for it.

b) Soil Characteristics of Dredging Sand

On the other hand, as a result of the laboratory soil test, the Halimeda origin sand from the lagoon bottom to be dredged in this project, was observed to be very fragile and is easy to be broken into very fine particles.

As for the particle size distribution, grading of the dredging sand is classified on the border between sand and silt, about half of which is very fine particle of the size less than 0.074mm.

The permeability of the dredged sand is 5.87×10^{-5}cm/s as of compacted sample and is 5.37×10^{-4}cm/s as of loosen sample, which is classified of the border between sand and silt.

c) Countermeasure against Sucking out of Soil particles

As countermeasures, it is effective enough to backfill the dredged sand after laying geotextile on the porous base layer in order to prevent sucking out of fine particles. According to the laboratory test, spun bond geofabric shows excellent permeability and soil particle trapping performance for this dredging sand. In case of woven textile, poor permeability was observed and took very long time to drain and poor soil particle trapping performance. Woven textile turned out to require long period to drain water and to consolidate soil, because it made very

fine soil particle clogged and worsened soil consolidation process. Some of sand particle leaked out from woven textile because it has large opening in between weaving yarns.
On the other hand, these problems did not exist and an excellent result was obtained for the spun bond geofabric.

Therefore, it is suitable to lay down spun bond geofabric over the base layer before backfilling. And according to the laboratory soil test, it is recommended to backfill with well drained dredged sand as much as possible and to compact with optimum moisture content (Wopt=31.3%).

(3) Planned Mining Volume of Gravel Material

The exploitable gravel volume is estimated on **Table 9.9** of clause 9.2.3. However, given the impact on the coral ecosystem, sea condition and cost for temporary work, the actual volume of the planned mining gravel material for this plan is estimated as shown on **Table 9.11**.

Table 9.11 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

9.3.4 Required Volume of the Gravel Material for Countermeasure Works

(1) Location of the Countermeasure Works

As shown in **Figure 9.28**, the detail topographic survey at the L-C and L-D area, the highest and the second highest priority respectively among the candidates, was conducted.

- Gravel Beach Nourishment Work: 【L-C】 and 【D-1】to【D-3】
- Coastal Borrow Pits Backfilling Work: 【BP-1】to【BP-4】

The required gravel volume was estimated according to the countermeasure work plan that is examined in the previous Section 9.2.1. In the countermeasure work plan, alignments and sections were determined based on the high resolution satellite image taken on May 5, 2010 and the detailed survey plans prepared in 2010.

For the coastal borrow pits prescribed in the Section 5.2.2, the Japanese science and technology cooperation team suggested from the long-term countermeasures point of view, that these “Coastal borrow pits” are assumed as one of the causes of inhibiting sand drifting and obstructing sand from piling up, therefore, it is recommended to restore the former beach flat landform. Thus, required volume for the borrow pit backfilling work is also estimated.

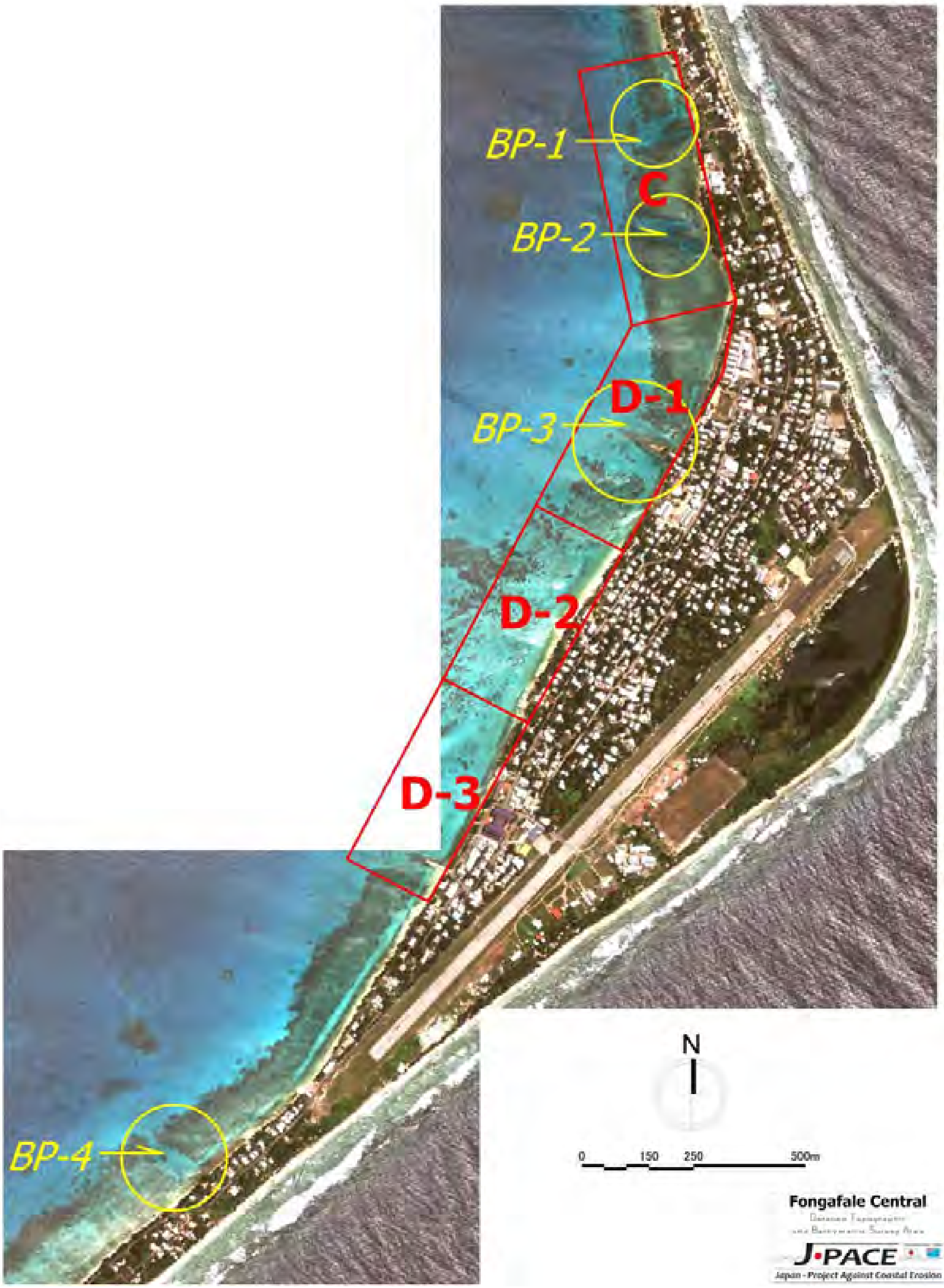


Figure 9.28 Detail Survey of Shallow Sea Area in the Target Zone for Coastal Protection Measures and Costal Borrow Pits

As a result, in case of executing the gravel beach nourishment, the parapet work, the borrow pit backfilling work and all the conceivable countermeasures, the required gravel volume is estimated as shown on **Table 9.12**.

Table 9.12 Required Volume of the Gravel Material for Countermeasure Works

Location			Required Volume (m3)
A. Countermeasure Works			
A-1. Beach Nourishment Work			
L-C-N	Back shore width=15m		13,175
L-C-S	Back shore width=15m		22,915
D-1	Back shore width=15m		31,018
D-2	*Not included in the Project		0
D-3	Back shore width=10m		21,173
		S/Total	**88,281**
A-2. Parapet Work			
L-C-N	Parapet (438mL)		263
L-C-S	Parapet (317m+300m=617mL)		814
D-1	Parapet (計 668mL=北(452m)+南(216mL)		357
D-2	*Not included in the Project		0
D-3	Parapet (計 293mL=北(116m)+南(177mL)		176
		S/Total	**1,610**
A-3. Borrow Pit Backfilling Work			
BP-1	D-1 area (North side)		15,505
BP-2	D-1 area (South side)		7,119
BP-3-N	D-1 area (Catalina Ramp North side)		1,140
		S/Total	**23,764**
		Total	**113,655**

(2) Balance of Required Volume and Exploitable Gravel Material

The balance of the required gravel volume examined in the previous Section 9.3.2 on **Table 9.9** and planned gravel mining volume is shown on **Table 9.13.**

Table 9.13 Balance of the Required Volume and Exploitable Gravel Material

Required Gravel Volume (m3)	Exploitable Gravel Volume (m3)	Balance (m3)
113,655	**58,867**	**▲54,788**

In case of executing all of the conceivable countermeasure works for the lagoon coast, the central part of Fongafale Island, high in the priority order, gravel materials of about ▲54,788m3 are still deficient.

Scope of countermeasure works and contents should be narrowed down according to the priority order. The construction method should also be re-examined from the technical point of view to reduce the required gravel amount .

Detailed examination of such construction methods is described in Section 9.5 "Construction Plan"

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 9.14**. If, however, the amount of gravel needed is expected to increase, other recommendations, from the second on, will be adopted in accordance 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 9.29** gives a plan view of the proposed works.

Table 9.14 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

Note: As for plan-3, the crown height of parapet in L-C area (C.D.L. +4.5m) was set, considering that the gravel beach nourishment work in L-C area by plan-4 will be implemented and the sand beach will be formed in future. The wave runup height in L-C area will not be satisfied only by plan-3.

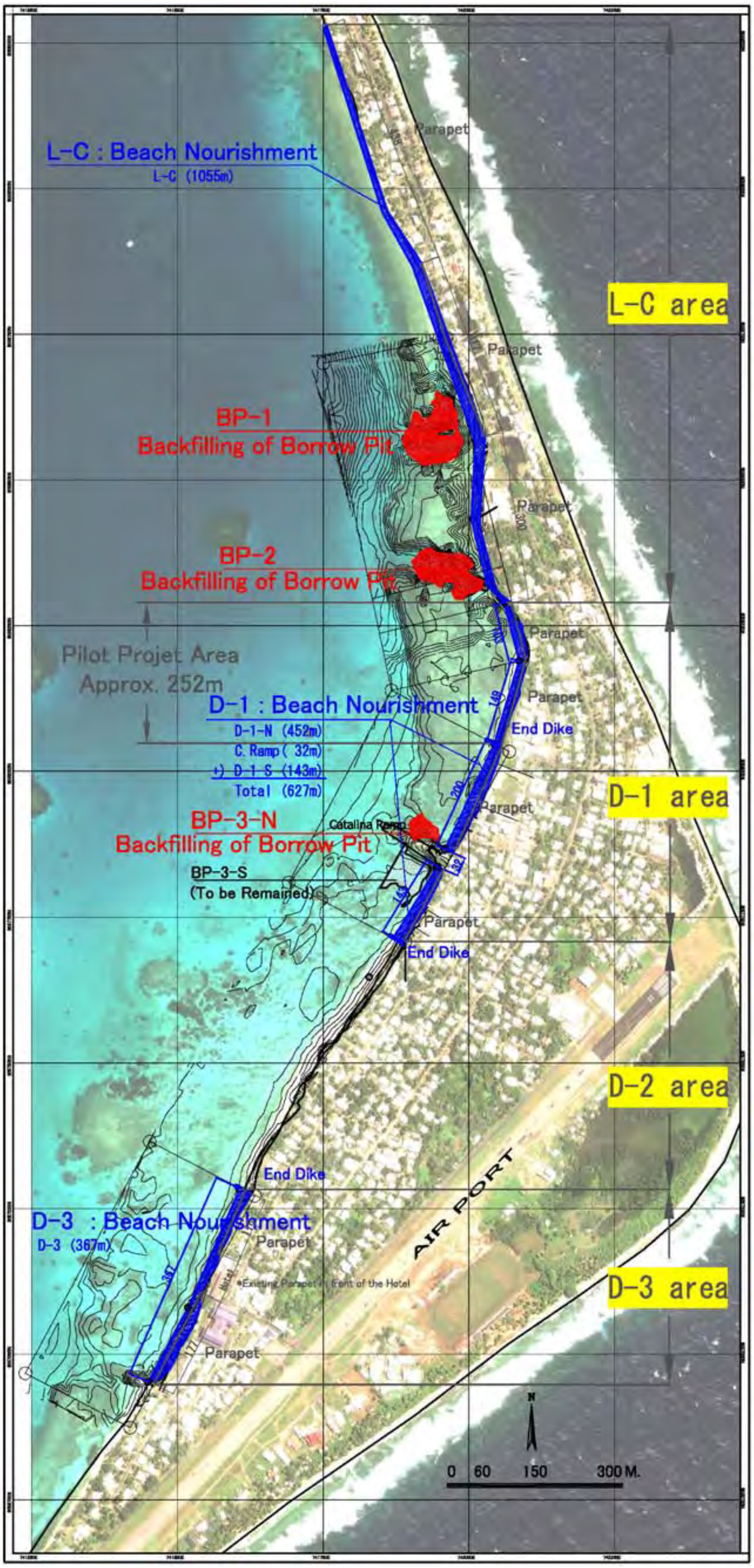


Figure 9.29 Plot Plan of Proposed Coastal Protection Measures