As shown in Fig. 5-15 a large cyclone may supply materials to the lagoon by lifting them from the offshore area. Without this action beach banks here could not form. Thus, a cyclone has two faces: eroding beaches and supplying the materials for new land.

5.4.4 Erosion vs Deposit

Beach shape may change from cyclone by cyclone. The amount of beach change is normally measured during a certain period which may be the time length of seasonal circulation. Winter in Rarotonga may be the best time to monitor the changes, since the beaches are more stable than in the summer time. If the total between erosion (-) and deposit (+) during the previous 365 days is plus, the beach observed is called a deposit beach. If minus, it is defined as an eroded beach.

However there are no data available in the island showing the past record of changes in quantitative manners. Only the available one is a map showing location of erosion.

In order to measure coastal changes, aerial photographs since the 1960's were analysed. However, a clear indication can not find out, since photographs are not in detail and do not cover the entire 31 km coastal length.

The perception study was analysed in order to know the past coastal changes in respect to the whole coastline.

Figs 5-16 and 5-17 shows the villagers response regarding coastal erosion and deposit. The responses on erosion by villagers are plotted in the figures.

According to the study, the average coastal erosion over the last five years was 1.8 meters to the entire coastline. The scale of erosion is moderate. It is reported that the beach sand erosion was 4.4 meter during the same period. Sally, the worst cyclone, caused 80 percent of the erosion in the same period. Since it is reported that the landing of the worst cyclone was made in 1987, the previous two figures should be read as erosion caused mainly by Sally.

Note : The response by villagers covers the total changes over the past 10 years. However, it is concluded that the data should read "within five years" since most of the villagers believe that erosion was caused by Cyclone Sally in Jan. 1987.

Year 1991 - Year 1987 = 5 years

The relationship between the Coastal Erosion and Beach Erosion is shown in Fig. 5-18.

Fig. 5-16 Coastal Changes by Villagers' Observation

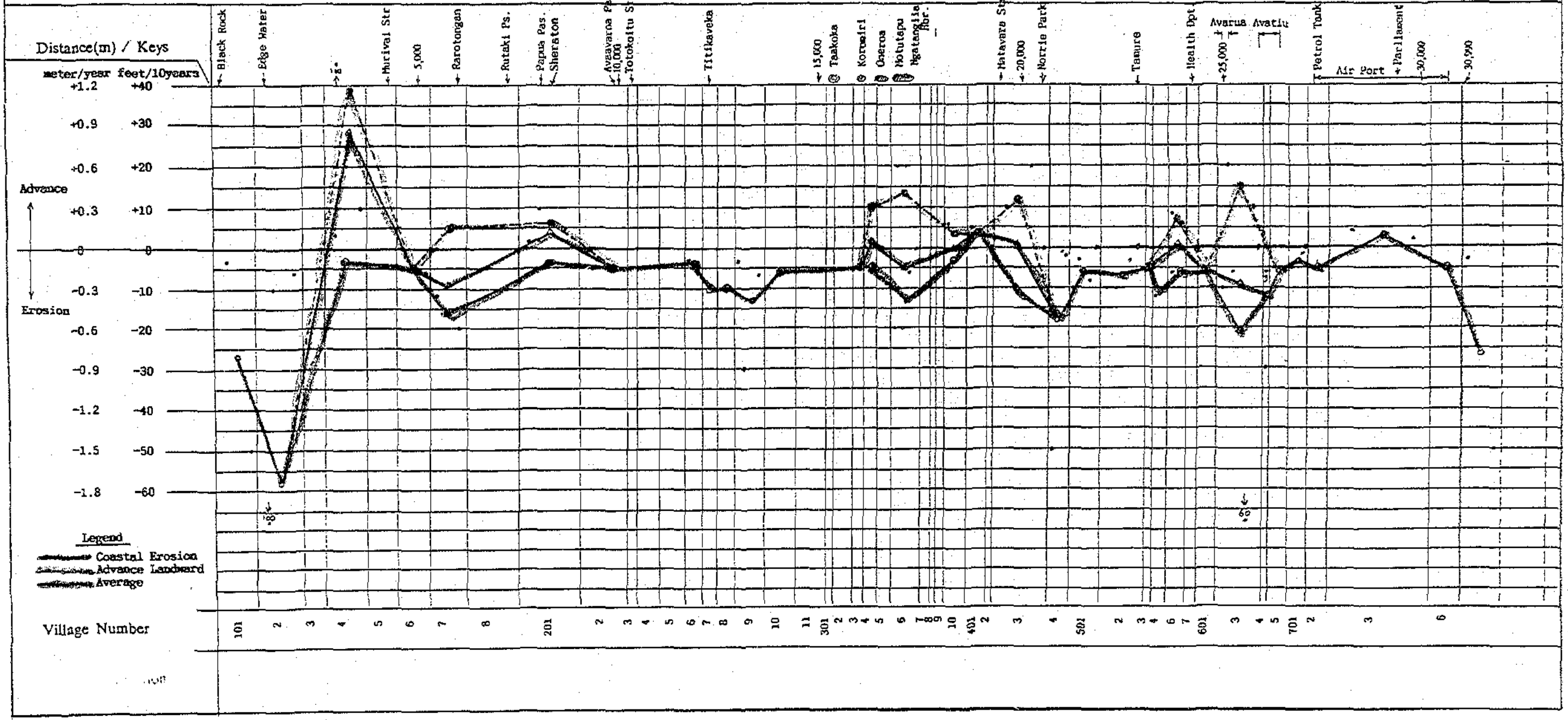


Fig. 5-17 Beach Changes by Villagers' Observation

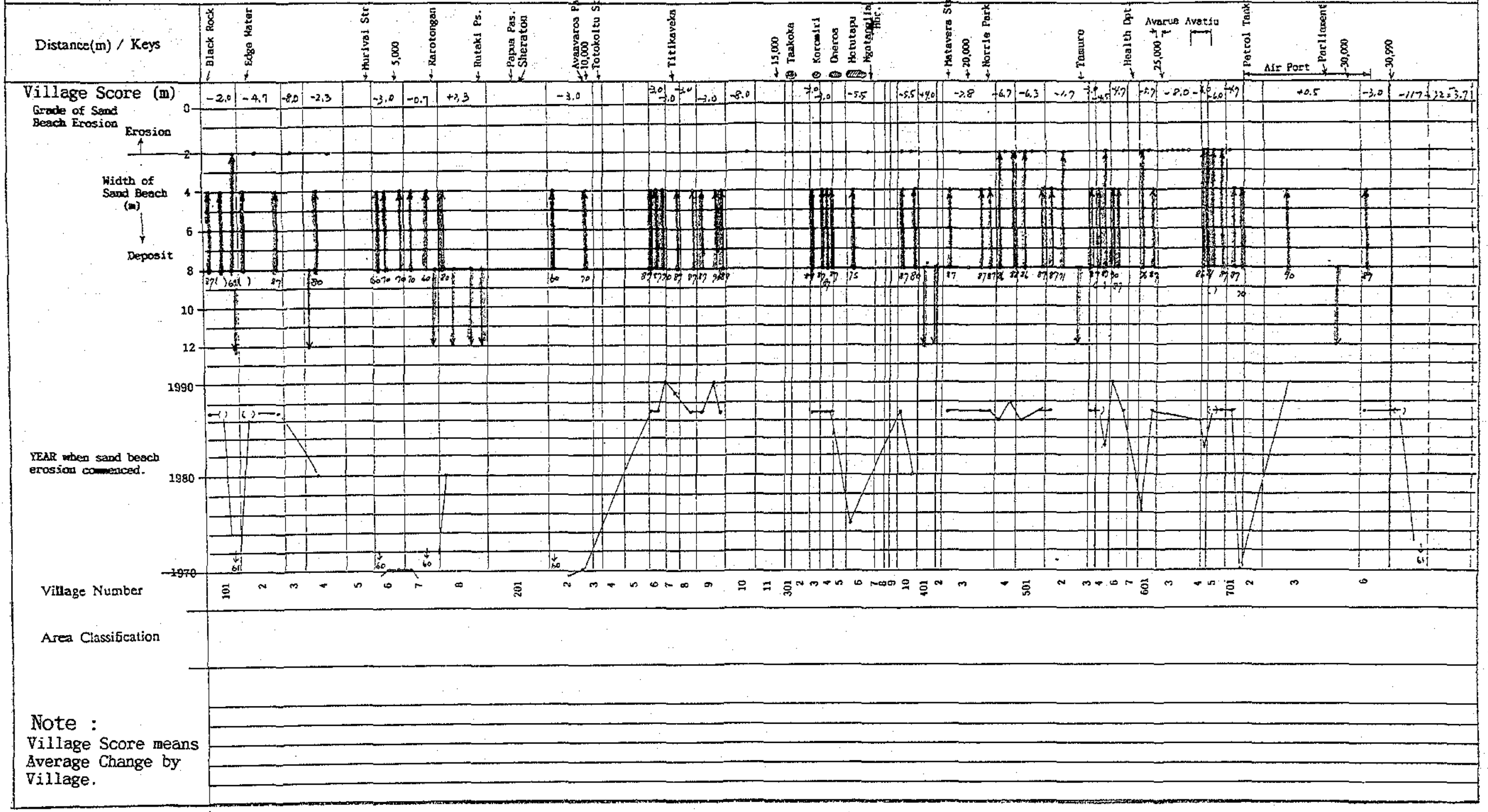
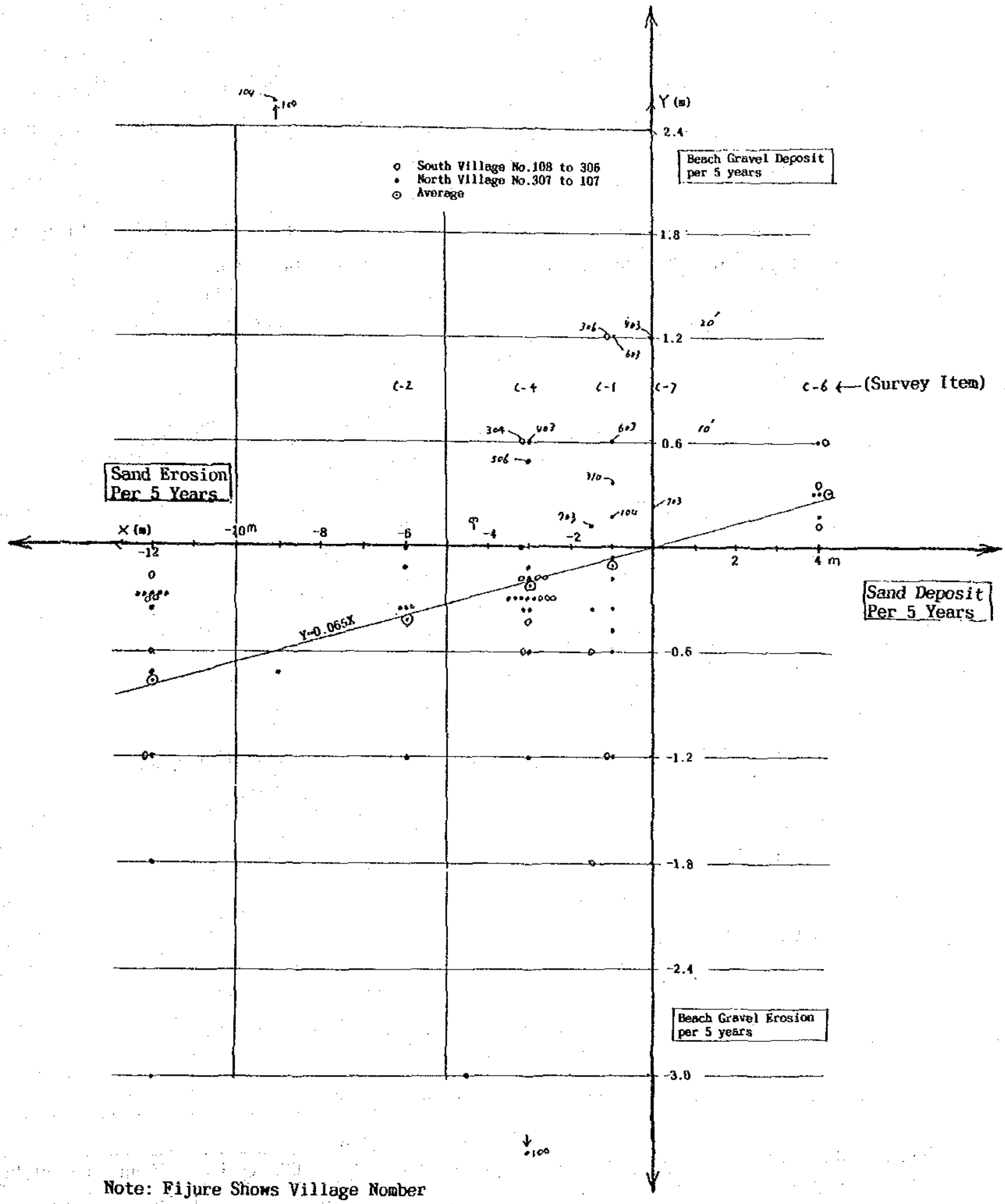


Fig. 5-18 Relationship between Coastal Changes and Beach Changes



Note: Fijure Shows Village Nomber

Fig. 5-18 Relationship between Coastal Changes and Beach Changes

5.4.5 Loss vs Gain in Micro View

The loss and gain of drifting materials can be understood by employing micro and macro view. The micro view is an observation of the loss any gain in a particular section of beach to estimate stable material size. This method focuses on material movement at beach waterfront and provide idea on material drifting normal to the beachline. Relationship between the average size of beach materials and wave are one of main study items in the coastal engineering. Followings are major findings.

This relationship will be evaluated here using Fig. 5-18A which was developed in observation of Japanese 12 stable beaches.

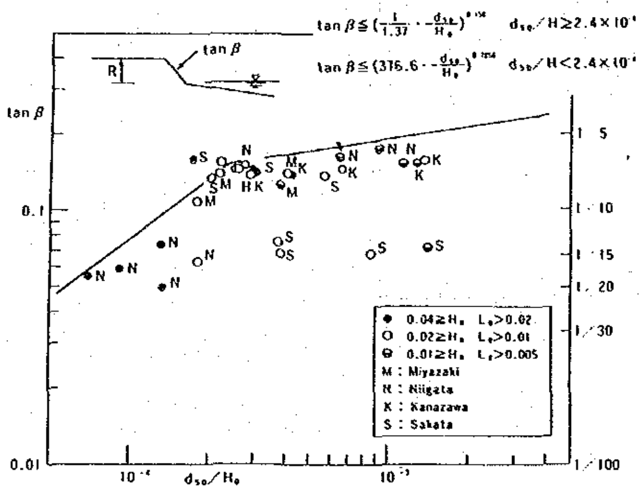


Fig. 5-18A Relationship Between Beach Slope and d50/Ho

Study Conditions:

Equivalent Offshore wave

Ho' = 4,5,6,7,8,9, m

Beach slope

tan β = 0.10, 0.20, 0.25, 0.30

Table 5-5 shows the minimum size for stable condition d_{50}.

Table 5-5 Mimimum Size d_{50}

		d50 (cm)					
tan β	d50/Ho'	Ho'=400cm	Ho'=500cm	Ho'=600cm	Ho'=700cm	Ho'=800cm	Ho'=900cm
0.1	0.0005	0.20	0.25	0.30	0.35	0.40	0.45
0.2	0.0015	0.60	0.75	0.50	1.05	1.20	1.35
0.25*	0.0050	2.00	2.50	3.00	3.50	4.00	4.50
0.3*	0.0150	6.00	7.50	9.00	10.50	12.00	13.50

Note: tan β = 0.25 and tan β = 0.30 are assumed by the study team.

5.4.6 Loss vs Gain in Macro View

The macro view is an observation of the loss and gain in a particular area where the material circulation is completed. According to the past observation, the existence of heavy return currents from the lagoon to the natural passages are assumed. This phenomenon was confirmed by the study team conducting the computer simulation analyses as described in section 5.3.7. Since material supply from the stream is so limited here that materials in lagoon are moving through the reef.

Erosion and deposit at a certain length of particular coastline, say from 500m to 1,000m, may be governed by the total balance of drifting materials, loss and gain.

1) Beach Sand

a) Gains

There are four gain sources:

- Gain from offshore nurseries over the reef front as a result of current induced by waves.
- Gain due to local production in the lagoon
- Gain from the adjacent foreshore and lagoon
- Gain at the stream mouth where fresh water and fine materials are discharged.

Of these gain sources, sand drifting from the neighboring beaches is not the basic impact because it may be lost at other areas. Sand supplied by a stream cannot be a main sources since the discharged volume seems minor and some coastal areas have no stream. Gain in-situ may be one of main sources. However, this may depend upon the ecological characteristics of lagoon, including its width. Thus, gain from the offshore sand production and deposit areas will be the most probable sources.

Fig. 5-19 Loss and Gain of Fine Particles

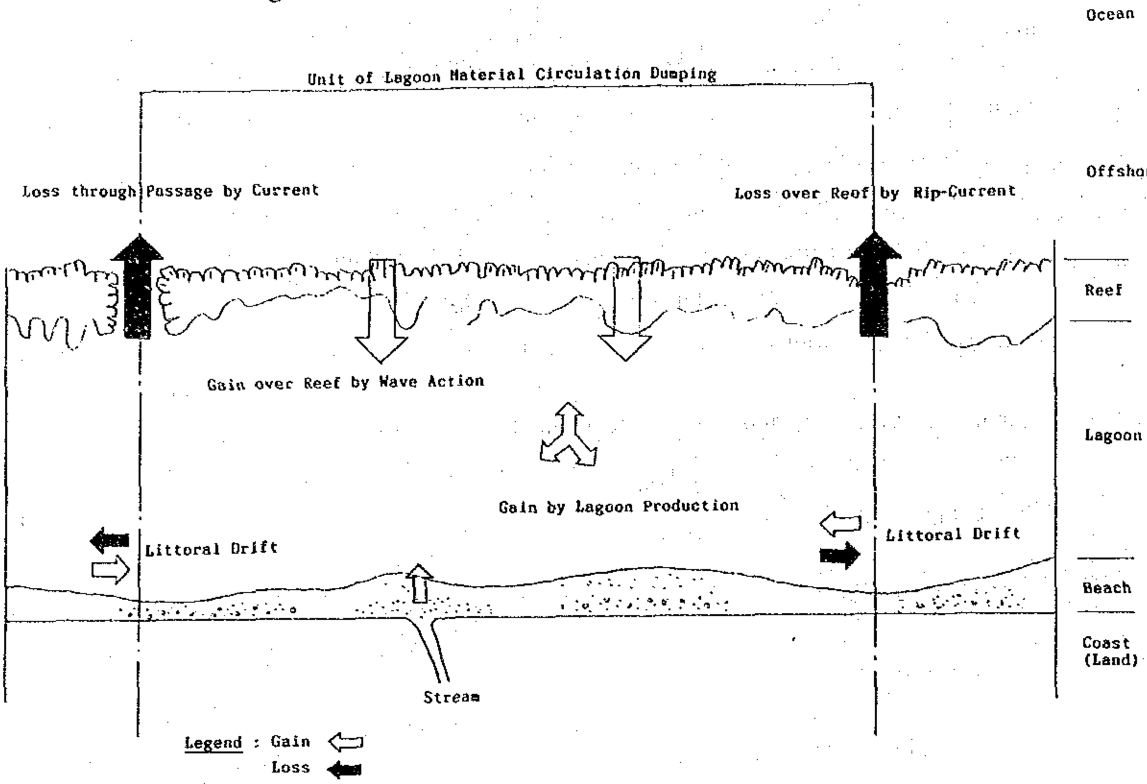
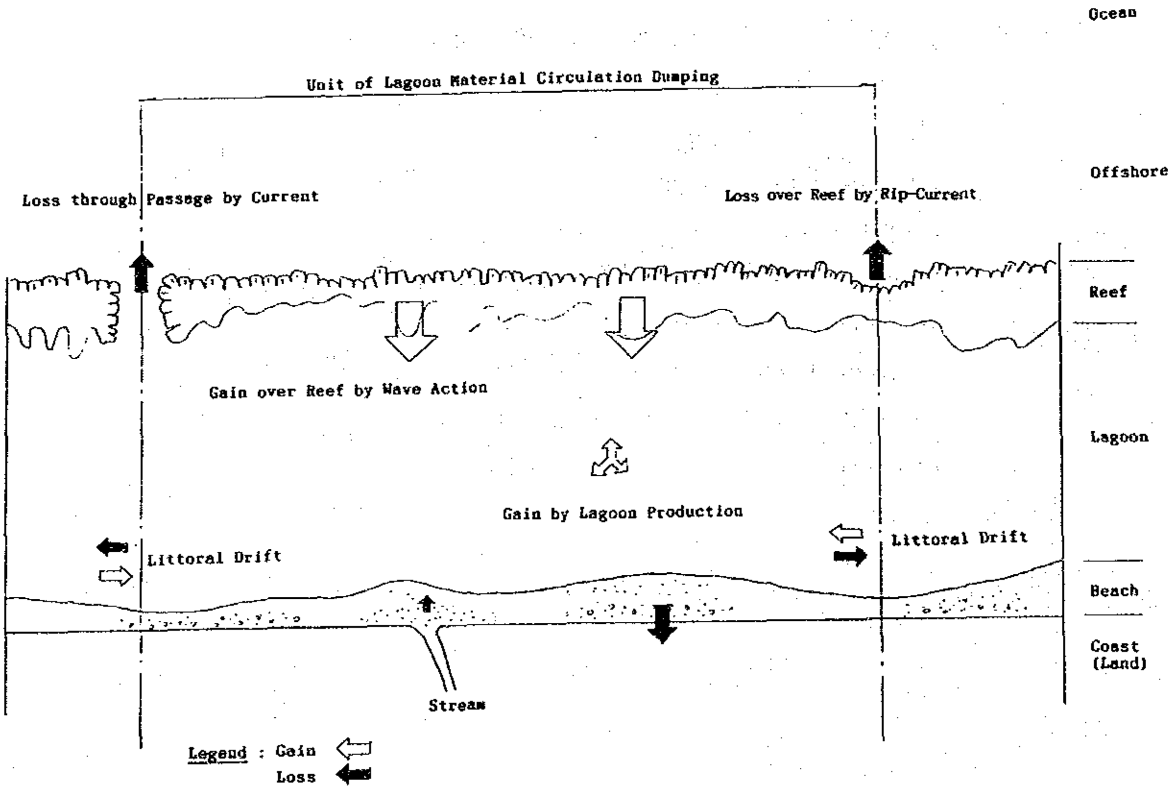


Fig. 5-20 Loss and Gain of Coarse Particles



b) Loss

There are two main reason for loss:

- Loss going to offshore through the passages by return current. This includes the rip-current which may occur where no significant natural passage exists.
- Loss by drifing to the adjacent foreshore and lagoon.

Of these two loss causes, sand drifing to nearby beaches is not a significant cause as the sand will represent a gain for those areas. It is assumed the main loss is sand drifing offshore.

2) Beach Gravel

a) Gain

The gain sources will be the same as those for beach sand. However, the gains at the lagoon and from the adjacent beach appear not to be major ones. The main gain will be from coral fragments that may be dumped into the lagoon by water bodies overtopping the reef as a result of wave action.

Due to the weight of materials, wave action is the only power that can move them. Thus the direction of drifting is the same as the wave direction, this is normally perpendicular to the shoreline. Lateral movement along the shoreline may be limited.

b) Loss

The reasons for gravel loss are the same for sand loss. However, the rate of loss and gain and will be much more conservative than for sand. There is little loss to neighboring beaches and through passages.

Some of gravels may dump on the beach bank. This action is loss to the beach but gain to the flat land.

By comparing the two materials (fine and coarse particles), the balance between gain and loss can be demonstrated as follows:

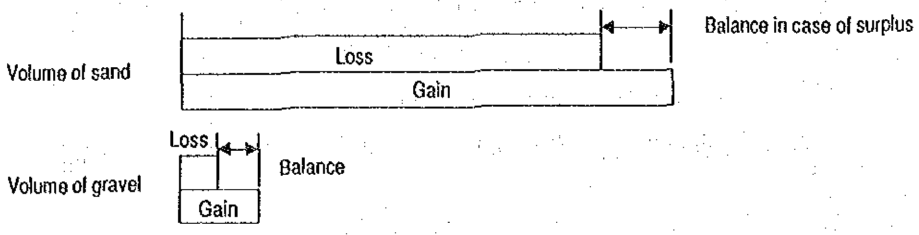


Fig. 5-19 and Fig. 5-20 show the balance and major supply sources both for sand and gravel.

5.4.7 Material Circulation Pattern in Macro View

Since the average grain size of sand and density are about 0.5 millimeter and 2.37 gr/cm^3 respectively and is lighter in weight than other coarse particles such as gravel, current forces can easily have an affect on its drifting. Main sand production may be conducted in the lagoon and at deeper water areas off the reef. The sand is transported by current circulating at certain areas.

This current is deeply related to wave energy transformation.

First, the water level in a lagoon may rise for two reasons:

a) Water body dumped into the lagoon

b) Water level rise due to a change of wave energy type, i.e., from kinetic energy to static energy.

A wave's kinetic energy at the top of reef will gradually be diminished by lagoon bed friction and by carrying the sand. The remaining energy will become static, i.e., the wave setup.

Water flows generally from a higher place to a lower place because of gravity. But in the lagoon case, there is no chance for the water to return offshore by going back over the reef because of the continuous penetration of active water bodies. The passive inner water must find other routes to escape by, such as through a natural passage or the likes. Finding a way out, they return to the offshore. This return current through the passage shows a high velocity, of about 1.5 meter per second, or three knots. Since the average velocity in the lagoon is about 0.5 meter per second, the velocity of the return current is about three times higher than those in the lagoon.

Fig. 5-21 shows this pattern at the 2,000 meter lagoon for a case when a large cyclone like Sally occurs. It also shows the current pattern where the wave penetrates at a certain angle.

In order to simplify the pattern, cases where waves penetrate perpendicular to the reef front where the lagoon width is 200 m are shown in Figs. 5-22, 5-23 and 5-24.

It is assumed that the current circulation is limited in a certain water space by two lines of return currents, namely "an Unit of Lagoon Material Circulation". This return current may take place both at the natural passage and at the natural reef where this current can pass. The main stream of this current has a channel one hundred meters wide. There are two centers of circulation which may be located at the crossing point at 200/300 meters off the reef edge and within 150 meters from the main return current center.

Fig. 5-21 Material Circulation Pattern in Macro View
Unit Length 2,000 m x Lagoon Width 200 m

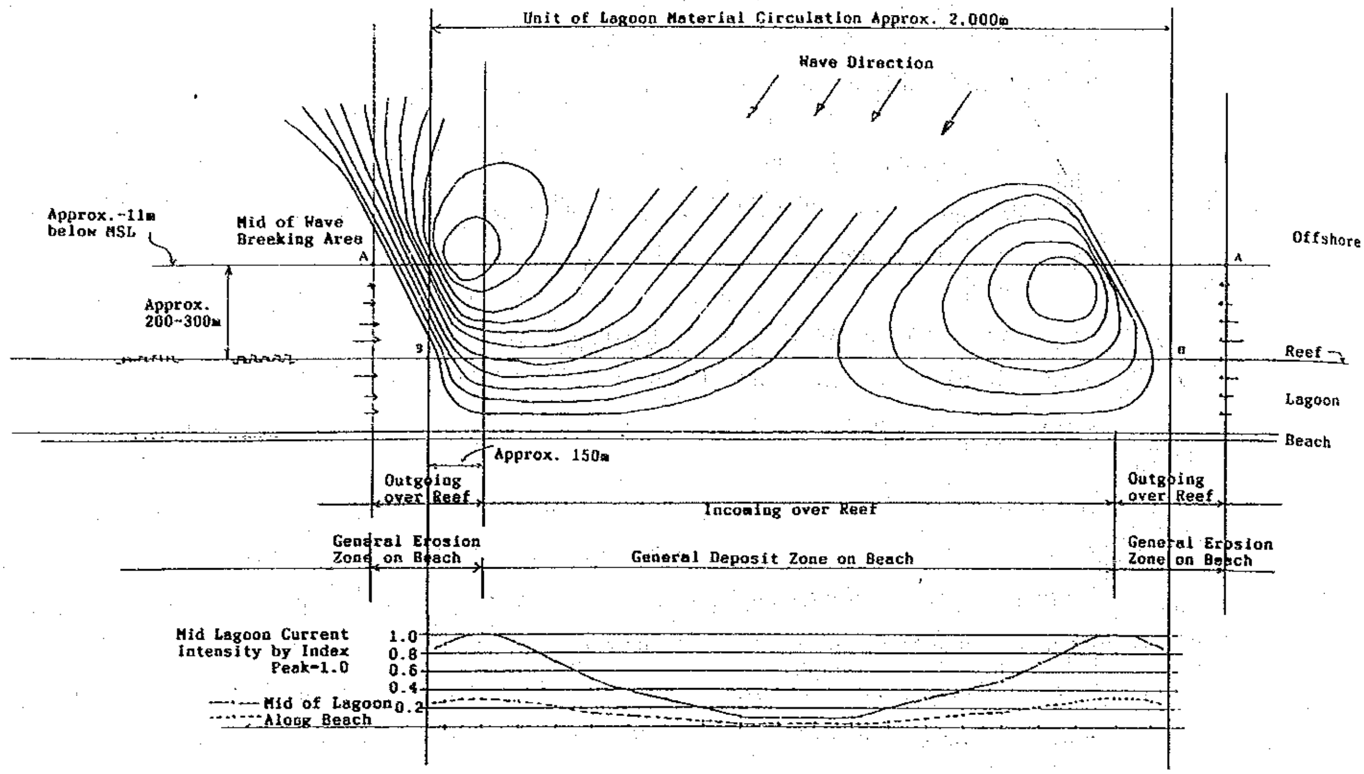


Fig. 5-22 Material Circulation Pattern in Macro View
Unit Length 1,100 m x Lagoon Width 200 m

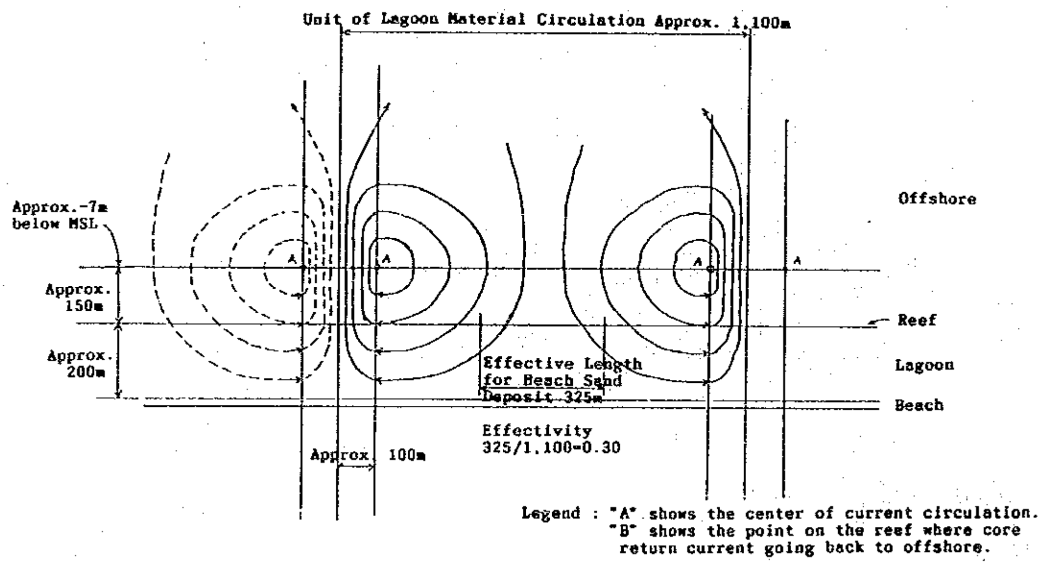


Fig. 5-23 Material Circulation Pattern in Macro View
Unit Length 2,000 m x Lagoon Width 200 m

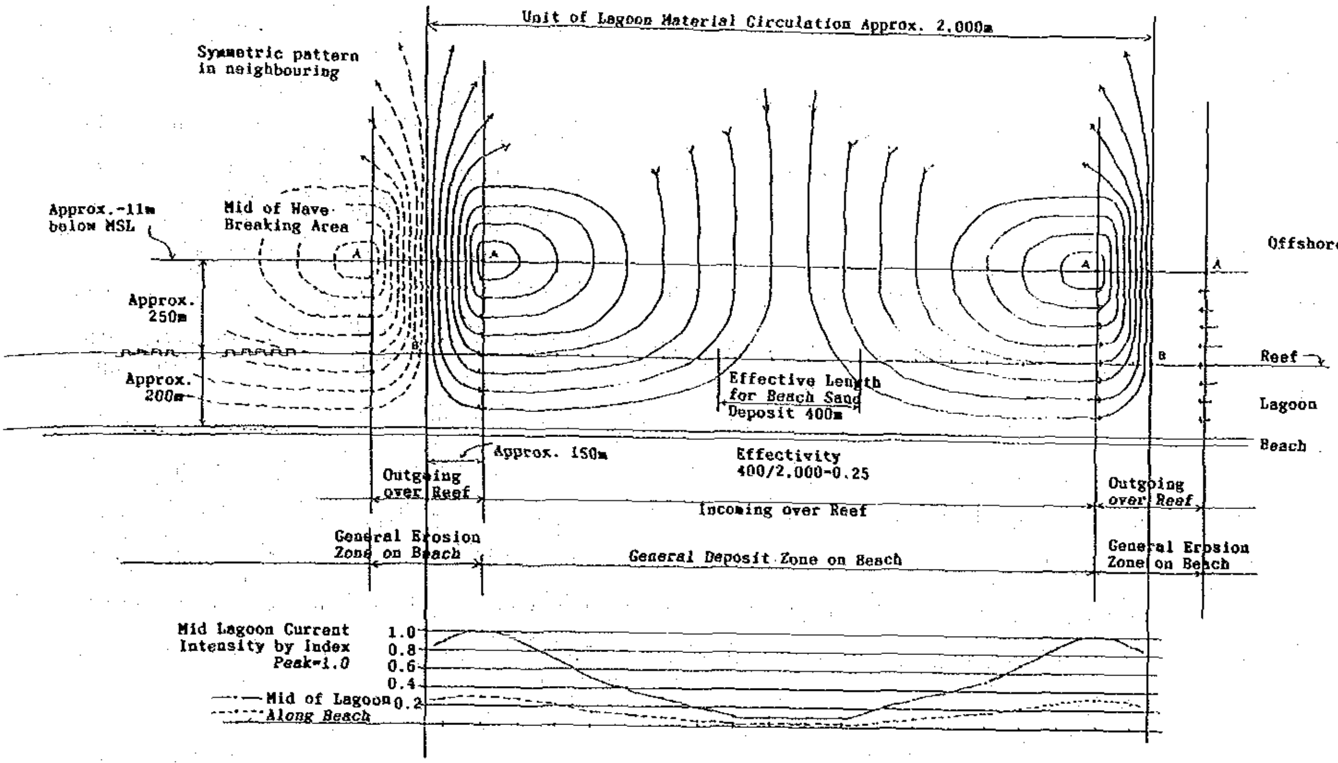
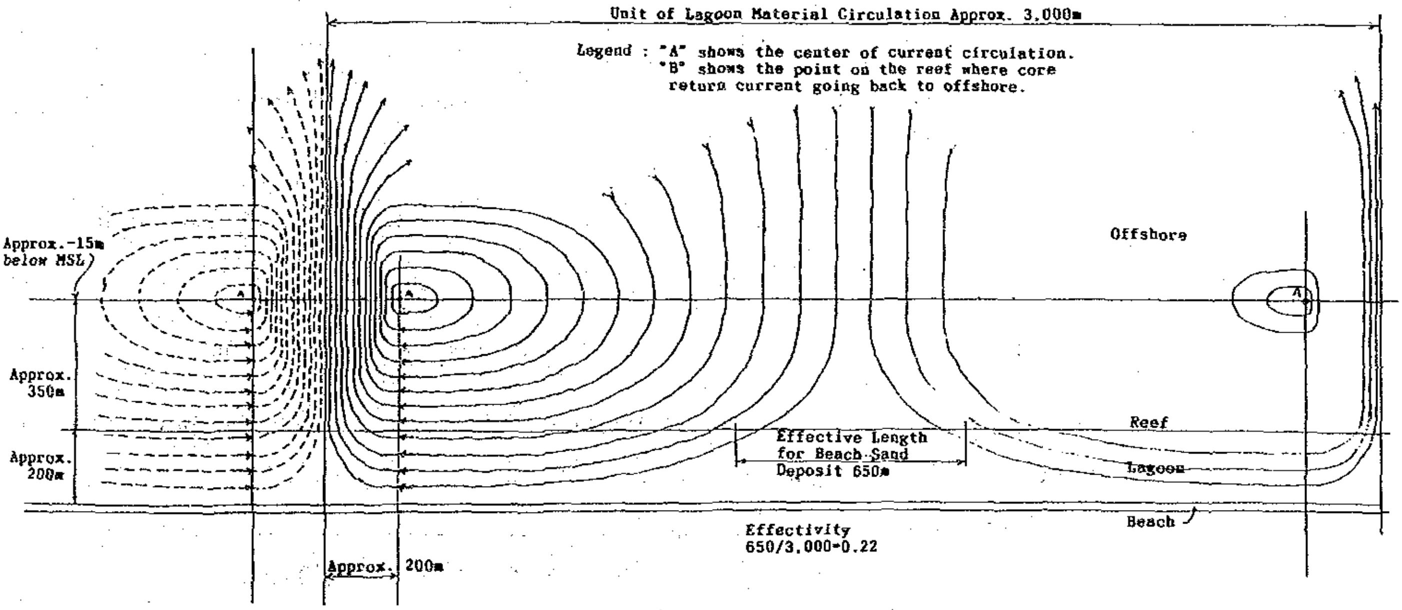


Fig. 5-24 Material Circulation Pattern in Macro View
Unit Length 3,000 m x Lagoon Width 200 m



If a wave penetrates perpendicular to the reef, circulation may not be mixed with the neighboring return current beyond the boundary. The core of circulation may be located in the middle of wave-breaking zone, where the most active places for the current to pick up sand from the coral forest and the sea bottom. The water bodies containing a rich sand content may return passing the breaking zone and reapproach the outer reef edge. These water bodies may dump in (or jump up) the lagoon. In this pattern, all the water bodies may circulate the core.

As shown in the figure given, half of the current may not land on the lagoon; thus, only the remaining half may overtop the reef and go into the lagoon.

Another pertinent fact is that most of the current in the lagoon may run parallel to the shoreline. It can be said that only ten to thirty percent of the water bodies can effectively run along the beach front. This means that the other seventy to ninety percent of water may run well off the beach; thus, very little water body has a chance to reach the beach.

The effectivity of sand drift contacting the beach front can be obtained using the following formula:

$$E = Lr \div Lu$$

Where, E : Efficiency showing a rate which may indicate how many water bodies containing sand overtopped the reef reach the beach front.

Lr : Length of the reef over which water bodies can make contact with the beach front.

Lu : Total length of unit of lagoon material circulation.

Effectivity is shown is the following Table in respect to both the variations of lagoon width and unit length.

	Effectivity by Unit Length		
Width of Lagoon	1,100 m	2,000 m	3,000 m
200 m	0.30	0.25	0.22
400 m	0.18	0.15	0.12

This table indicates that a narrow lagoon having a shorter unit length maintains a high efficiency for catching sand along the beach.

Current velocity will be maximum near the passage or at other places where the return current takes place. The minimum intensity can be observed in the middle of the two return currents. A computer analysis shows that the latter velocity is about ten percent of the former. This may be due to the fact that the rised in water level by wave setup in the middle lagoon of two passages may decrease as a result of energy reverting to kinetic energy.

According to the Conservation Department, this phenomenon is observed at the various passages where active or low erosion of beach sand has taken place. The Department also reported that the deposit at the beach has been observed near the middle of the passages.
Sand in the return current will circulate to the deeper water through the passage as far as the current force can carry them. The current velocity will then gradually decrease where the sand will settle on the seabed. If this area is in the wave-breaking zone, the sand will be lifted up again for another trip towards the reef or lagoon.

Current patterns to the lagoon of 400 m width are shown in Fig. 5-25, 5-26 and 5-27.

Based on the discussion above, possible means to catch more sand at the beach front will be as folows.

i Making width of lagoon narrow
ii Making new passage for shorter unit of lagoon material circulation

The former may increase wave kinetic energy at the beach front and construction cost is very high, thus is not practical. The latter may be carried out by means of making an artificial passage. This idea will be discussed further in subsection 7.3.4. However, more detailed study should be conducted for implementation.

Fig. 5-25 Material Circulation Pattern in Macro View
Unit Length 1,100 m x Lagoon Width 400 m

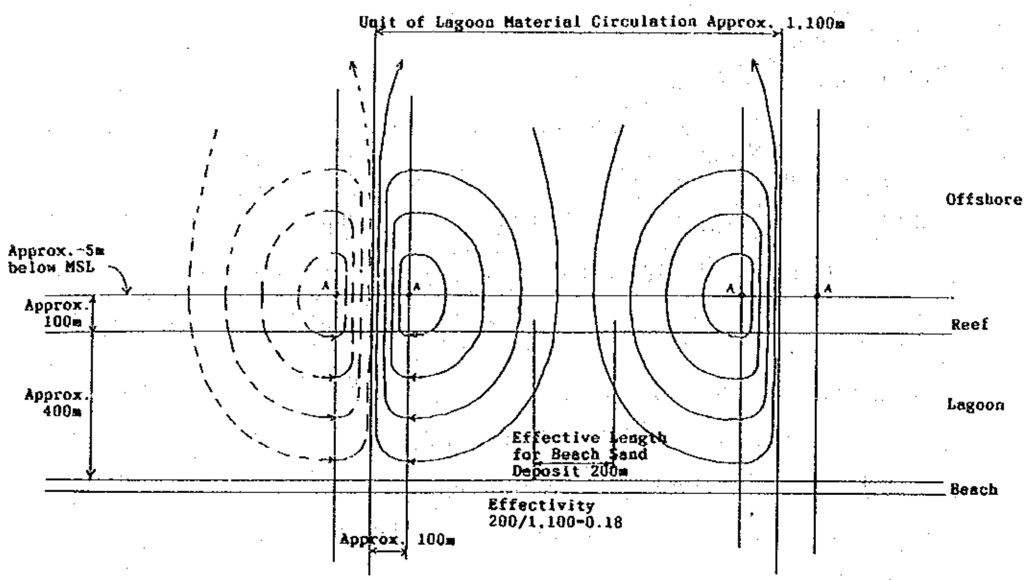


Fig. 5-26 Material Circulation Pattern in Macro View
Unit Length 2,000 m x Lagoon Width 400 m

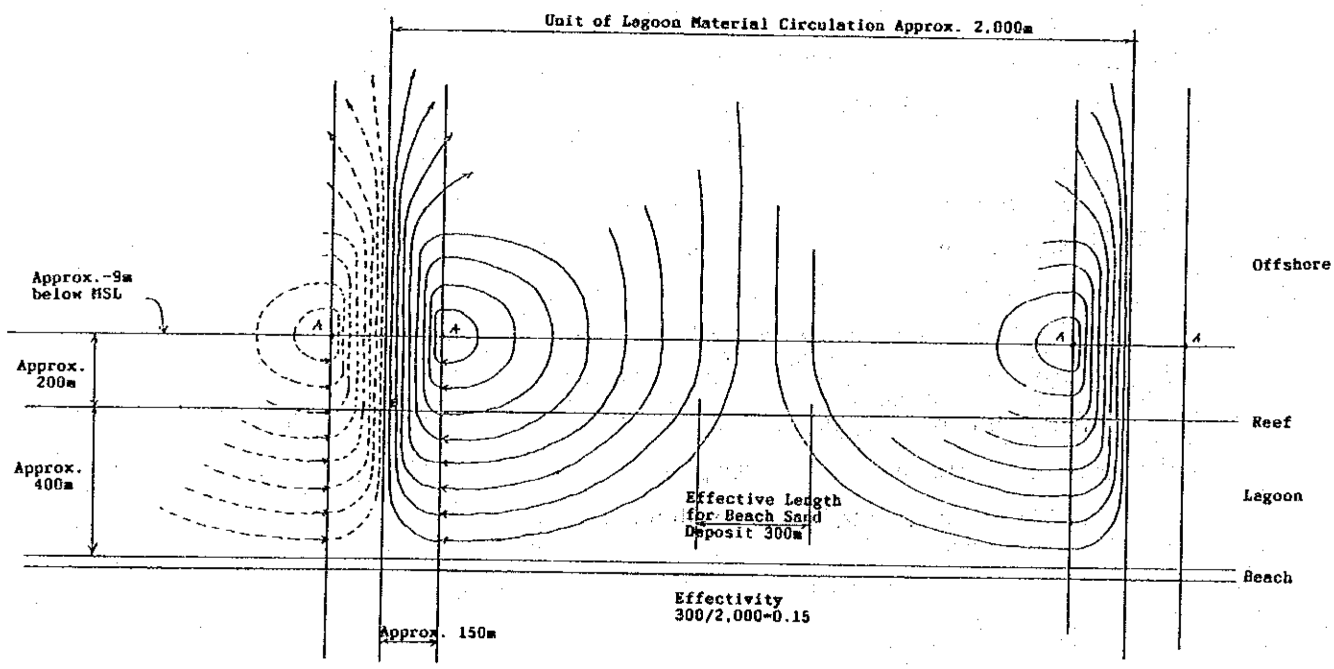
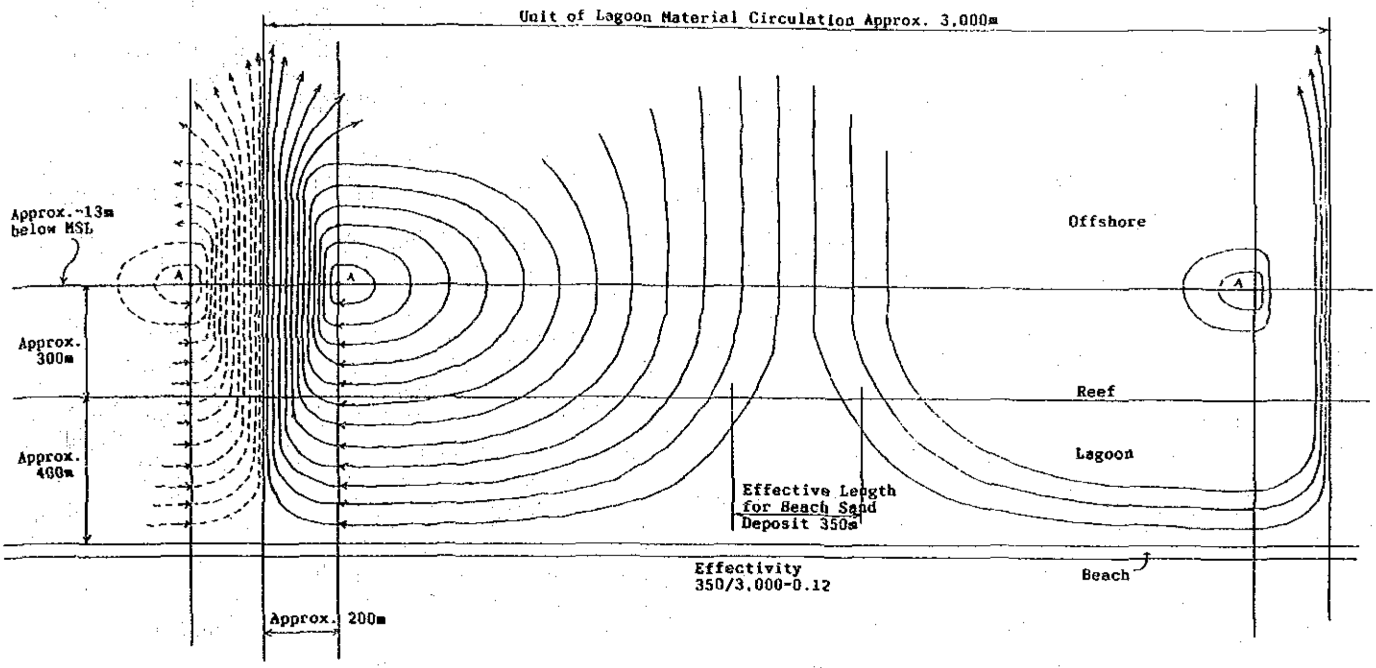


Fig. 5-27 Material Circulation Pattern in Macro View
Unit Length 3,000 m x Lagoon Width 400 m



5.5 Incremental Damage caused by Development

Cyclone Sally may have caused the largest disaster here in the last 25 years. Her return period to the island is about 30 years; thus, this scale of cyclone may occur every 30 years. However there are other small cyclone than Sally during the said period. There are 9 Sally class cyclones if all the cyclones in 30 years are counted by Sally's intensity (Refer to subsection 12.2.7). Thus disasters of 9 Sally class cyclones may occur during 30 years if proper countermeasures, including protection work, are not undertaken. It can be said that the people on this beautiful island are not protected yet from the disasters by cyclones.

In general, offshore waves and winds generated by cyclones cannot be controlled by artificial means. Thus, the island coast should be prepared to stabilize those external forces in the proper manner. This can mainly be achieved through efforts on the lagoon and coastal area.

It was observed that the people and the existing facilities here are faced with higher disaster risks than before because of recent coastal area development. This section deals with the vulnerability of the island to natural disasters due to major changes that come under the name of development.

5.5.1 Construction near the Beach

The extension of Avatiu Harbour was conducted in three steps: the first extension in 1969, the second in 1971, and the last in 1985. Land reclamation of 250 meter long was finally completed. This development could be justified as it provides the sole gate for national maritime transport. However, water bodies dumped on the lagoon between two harbours will be unfortunately forced to travel a longer distance than before. This may cause the higher wave setup at the said lagoon.

In 1971, sand reclamation on the lagoon in front of Nikao and Pokoinu Villages began to prepare the way for the extension of the airport westward. 200 meters of the western end was penetrated into the natural lagoon; thus, the remaining free lagoon was reduced to 150 meters. Due to the limited land availability suitable for the airport, this might have been inevitable.

It was observed that new houses are being built near the beach. Trees are being cut down and the surface coral fragment layers are being graded to conform to the landscaped areas. The building houses here may only have started recently, however it increases the chance of wave overtopping and direct heavy wind to their properties.

Tourism industries were responsible for building hotels, motels and restaurants. Some of these facilities face the beach for gaining a better view and for making easy access to the lagoon. Some investors have conducted land reclamation beachward to obtain more flat land.

Pleasure in lagoon here contains wind-surfing and canoe. These activities can be made in the northern east coast where lagoon depth is about 0.5 m.

5.5.2 Digging Sand

Sand digging in the marine waters has been prohibited by the government. However, it appears that the damage already done has not been fully restored.

5.5.3 Other Impacts

There is no data on the water quality in the lagoon, BOD, COD etc.

The development of the coastal area may contaminate the sea water quality by the concentration of sewage if no sewerage treatment facility is provided. If the effluent is discharged to the wetlands and swamps behind the beach bank after treatment, such sea water contamination can be minimized.

It is said that sea water pollution may affect marine ecology including coral life. If this is the case, it is assumed that not only sand and gravel sources on the seabed but also marine tourism resources have decreased.

5.6 Expectation to Coastal Protection

The total direct damage by wave of Cyclone Sally is estimated at 14 million Dollars (1992 price). It is assumed that nine Sally class cyclones will attack to the island in the next 30 years, if all the cyclone impacts are counted by an amount of disaster by Sally. Refer to subsection 12.2.7. This indicates that total direct damage by cyclone wave in 30 years amounts 130 million Dollars. This cost represents almost 200 % of the national budget at present.

The paramount purpose of coastal protection is to protect the lives of people, however reported past life loss is light. Thus, the subject of protection will focus on the mitigation of damage to both property and natural resources.

5.6.1 Mitigation of Direct Damage to Coastal On-land Facilities

The most important objective here is to eliminate damage to on-land facilities both public and private (See Subsection 5.1.3).

Total on-land facility damage by Sally was 11.1 million dollars, (80 % of the grand total 13.9 million dollars). The share of cost among the public and private sectors is 91 % and 9 % respectively.

Among the public on-land facilities, the most damage was done to civil works including bridges, culverts, foreshore protection, and stream embankments. Second was the damage done to the same works including roads and drains. Third was the damage done to the government offices and buildings.

These damage can be summarized as follows:

a) Roads and their surrounding public facilities
b) Government offices and buildings

All these facilities are so important that their damage may affect villager's life.

The most inflicted damage on private on-land facilities was done to residential houses. Second was the damage done to shops and stores. Damages to hotels, and motels, was reported as being minor.

The main cause of these damages were the rushing of waves landwards followed by the erosion of facility foundations. Coastal protection work should aim at protecting facilities by decreasing wave overtopping the existing beach tops where both public facilities and private facilities are concentrated.

5.6.2 Mitigation of Direct Damage along the Shoreline

This covers the following three categories of damage:

- Beach Erosion
- Coastal Erosion
- Failure of Reclaimed Land

Beach erosion by Sally mainly occurred when the high velocity coastal current caused sand deposits to drift offshore. Coastal erosion and the failure of reclaimed land occurred when wave running up washed away the beach slope composition. The total cost of these three disasters by Sally amounted to 2.8 million dollars and shared 20 percent of the total of damage.

Beach erosion damage should be estimated based on the changes in economic values of each beach. In some cases, beach erosion will not cause significant problems if there is no coastal erosion. For tourism industries, however, beach erosion can result in large business losses.

Thus, protection work for coast itself should aim at protection of beach slopes to prevent coastal erosion, and establish countermeasures, when required, for making littoral current moderate and minimizing sand drifting.

5.6.3 Consideration to Indirect Damage

Indirect damages may cause additional impacts to the people, industries and the natural environment.

Note: Indirect damage is an effect which can not be counted in monetary figures. Refer to subsection 5.2.4.

When planning the countermeasures for mitigating direct damages, indirect damages should also be taken into consideration. The most important aspect of mitigating indirect damages is to eliminate the adverse

effects they have on transport networks, including vehicle, air, and maritime transportation.

Damage to the beach road, Ara Tapu, should be minimized at places where no back road, Ara Metra, is provided.

The existing airport should also be well protected against wave in order to maintain air transport.

The port facilities should also be protected. Avatiu Harbour is the sole international port and domestic hub port here. The pavement, sheds, machines and other back-up port facilities should be important protection targets.

Other indirect damages may be generated by the followings.

- Damage to the water supply system
- Damage to the power supply system
- River mouse close
- Disrupt of natural environment
- others

Edge Water Hotel being built too close to the beach, urgent sea wall was constructed, Tokorau District

Chapter 6: General Policies in the Master Plan

Chapter 6 General Policies in the Master Plan

This chapter deals with the objective pertaining to coastal protection and port improvement together with the general policies in the Master Plan preparation.

6.1 Objective of the Master Plan

The latest Five Year Plan identifies five broad national development policies that include:

1) To raise the level of prosperity of the people of the Cook Islands (to stem further migration).

2) To attain of a larger measure of economic independence.

3) To ensure that economic development proceeds in a manner compatible with social, cultural and natural values.

4) The promotion of a more equitable distribution of the benefits derived by development.

5) To cooperate closely with Pacific neighbors and other nations in economic affairs and other matters of mutual interest.

These demonstrate a strong desire to construct a country in which the people here enjoy their living in harmony with others by activate economy, generating employment opportunity and industrial development.

According to the Government of Cook Island's request of 3 March 1988 for technical assistance to prepare a Master Plan Study, it is noted that the objectives of the study are as follows:

a) To provide basic reference material on the social and economic development of the Cook Islands to help the policy makers in Tokyo decide on the merits of possible future requests by the Cook Islands Government for financial assistance for the above mentioned projects.

b) To transfer technology to local officials, particularly in the areas of data gathering, data analysis and project formulation.

c) To prepare a report which the Cook Islands Government could use as documentation when seeking financial assistance for the projects; and which could be used as a procedural guide for implementing the project.

According to Appendix A-1, the Scope of Work agreed to by the both governments on 17 April, 1991, the objective of the Study is to carry out the study on coastal protection and port improvement at Rarotonga Island in the Cook Islands from technical and economic points of view.

Thus the objective of Master Plan is to provide a long-term scheme for the coastal protection and port improvement in Rarotonga Island taking the National Policies and the request by the Government of Cook Islands into consideration.

6.2 Master Plan Policies

This section deals with the general policies in the preparation of Master Plan for the coastal protection and port improvement in Rarotonga Island.

a) Preliminary Project Economy

The scale of investment cost should be evaluated by comparing it with the benefits of the project. Priority of the project components should be considered for high efficiency of investment.
Benefits of the project will be:

- Decreased disasters by cyclone,
- Maintaining the public utilities including port facilities, in an operational condition.
- Indirect damages to be reduced

b) Long-term Prospective

Long-term policies for coastal protection and port improvement should be prepared. This policy should be conducted based on both the long-term land use plan and facility layout.

c) Encouragement to the Industries

The mitigation of damage to public utilities including port, road, power supply and water supply should be conducted. Tourism industry here should encouraged by the implementation of coastal protection work and port improvements.

d) Flexibility in Land Use

Flexibility for future land use should be taken into account, since the existing available land for public use is so limited. New land should be generated by reclamation in the Avarua Coast.

e) Maintaining Life Line in Respect to Transport

Most of daily consumer goods are imported through the gate port, Avatiu Harbour. The harbour should be also maintained for a hub port to the remote islands.

f) Technical Justification

Proposed basic system in the Master Plan should be evaluated by technical consideration. Basic characteristics of tropical cyclone and its power should be taken into account. Alternative study on major facilities should be carried out.

g) Locality

Proposed system should meet with the locality including the natural condition and material available. Construction experience of similar project in the island should be taken into account.

h) Environment

Since the tourism is one of leading industries, adverse environmental effects to the industry by the project should be minimized.

i) Phasing

Staged development plan should be prepared considering the priority on project components.

6.3 Development Circumstances

Covering whole the island coastline, this project may provide here with various impacts. Since proposed works should concentrate along the coast where existing major development are made, it is essential for smooth construction works to maintain both cooperation with and understanding by villagers to the project.

Development of the coastal areas can be achieved once the general circumstances are improved. Most important step to this is letting villagers to participate the project preparation. In order to carry out this, best effort of the government to condense villagers consensus on the project should be made.

1) Disclosure of Planning Process

For the better understanding of project, basic planning process should be explained to villagers.

2) Alternatives

For the better agreement on project, the final layout together with alternatives should be provided to villagers.

3) Disclosure of Related Information

Data and information relating to the utilization of coastal areas and the possible effects of cyclones should be published and made available to the villagers and to industries.

a) Coast File

Available information should be kept on file as permanent records. A sample of this file is shown in Appendix C1. The file shall include the physical characteristic and existing land use of each section of coast. This file may provide the people with an opportunity to learn about their coast.

b) Coastal Disaster Forecast

Possible disasters by cyclone waves and surges should be shown on a map and distributed to the public.

4) Share of Responsibility

The government can not share all the responsibility for cyclone disasters. The budget is normally limited in any country, thus budget allocation to the project shall be carried out to selected projects having the highest priorities based on real demands. It is recommended that the private sector should do also its best to prevent their property from cyclone damage. The private sector should not locate their properties in the high risk area of cyclone. The government may provide estimated dangerous area with the protection work if such damage cannot be prevented through the efforts made by the private sector.

The government should locate their new property in safe places and should provide protection measures for the existing facilities located in danger zones. For the project economy, relocation of the existing facilities to the safety zones may be a possible choice.

MOW is requested to take the initiative in this matter. And, the distribution of building codes that set forth the minimum requirements for building construction in the coastal areas should continue.

5) Conservation Control

The Conservation Department should play a role in controlling the ordinary development of specified coastal areas. The monitoring of the coastal areas should be maintained. The department is requested to provide villagers with proper explanation of benefits of coastal conservation.

6) Establishment of the Project Executing Agency

Project executing agency should be established for smooth project implementation. Financial assistance should be considered by the government for better maintenance efforts, if so required.

Chapter 7: Master Plan for Coastal Protection

Chapter 7 Master Plan for Coastal Protection

This chapter deals with the preparation of Master Plan for coastal protection along with alternative studies. Protection work will be provided for coastal on-land facilities and the shoreline where required. The work will target on the mitigation of damage by waves and surges caused by cyclones.

Of the facilities to be protected, the ports should be provided with special care since they are exposed to the open sea and are the most susceptible to cyclone damage. Thus, the port layout must be studied carefully. Chapter 8 will detail the possible arrangements of the port that will harmonize with the total concept of coastal protection.

7.1 Purpose of the Protection Work

7.1.1 General Descriptions

The coastal protection work should aim mainly at:

a) Mitigating direct damage to coastal on-land facilities
b) Mitigating direct damage to the shorelines
c) Consideration to the combined direct damage brought on by the previous two items

The protection work should be conducted based on priority, the larger damage forecasted the larger the investment for the work contrarily, the less damage the lower the investment.

Other than above direct damage, consideration to the following indirect damage should be taken into account.

a) Damage to the beach road
b) Damage to the existing airport
c) Damage to the port facilities
d) Damage to the power supply system and water supply system
e) Damage by river mouse closing
f) Disruption to the natural environment
g) Other indirect damage

During the Master Plan preparation, the following considerations should be taken into account:

During the Master Plan preparation, the following considerations should be taken into account:

a) Project Economy
b) Long-term Prospective
c) Encouragement to the Industries
d) Life Line of transportation
e) Flexibility in Land Use
f) Technical Justification
g) Locality
h) Environment
i) Phased Development
j) Others

7.1.2 Suggestion by Villagers

According to the perception study on the cyclone disasters, people here are aware of the major reasons for coastal damage. The countermeasures they recommend are shown in Fig. 7-1a and should be kept in mind by the planners.

Table below shows the causes of coastal disaster which villagers believe.

Order	Causes *	Supporting Rate (%)
(i)	No coastal protection works	31.2
(ii)	Beach eroded naturally	24.0
(iii)	Don't know	15.2
(iv)	Building house close to the beach	12.8
(v)	Digging the beach sand	8.8
(vi)	Just a nature in Rarotonga	8.0
(vii)	Others	0.0
	Total	100.0 %

Notes
1. Cause of coastal disaster by cyclone wave.
2. Villager are provided with 6 typical answers for their free selection.
3. There are many villagers who put a whiten note on the questionnaire that tree cut by villagers revenge their masters.

As seen in the table, "No protection works" as cause of disasters got the first place by 31.2 % support. This suggests that villagers expect basically the coastal protection works by their government. While total supports for the items second and the sixth is 32.0 % in which villagers show their feeling that they are not surprised by coastal disasters. The fourth is that they built their home close to the beach. This is supported by 12.8 %. Cause of beach sand digging is the fifth one which is rather low order than expected.

Next table indicates the coastal protection countermeasures proposed by villagers.

Order	Proposed Countermeasures	Supporting Rate (%)
(i)	Planting trees along the beach	25.1
(ii)	Provide protection works	25.1
(iii)	Stop digging up beach sand	20.2
(iv)	Build concrete house	10.0
(v)	House relocation to other site	9.5
(vi)	Provide stormwater drainage	8.7
(vii)	Don't know	1.0
(viii)	Others	0.4
	Total	100.0%

Note: Countermeasures here are for cyclone wave, not for wind forces.

There are active measures and passive measures. Among them, active ones are items (i) and (ii) which gain support by 50.2 %. Thus passive ones are 49.8 % support. Among the active ones, "planting trees along the beach bank" get the first place that suggests villagers are aware of the effect of plant against disasters. Trees will also provide villagers with good barrier against cyclone gales. Provision of coastal protection works is also ranked at the first place.

Highest support on the passive ones is given to "stop digging up beach sand". This may suggest they are afraid of affect of sand digging. A 29.5 % support rate is given to the countermeasures on their houses, 9.5 % of which wants to relocate their house to other safety area. Remaining 10 % support rate is given by villagers who want to stay there by strengthening their house.

Following can be said when damage causes one superimposed on the countermeasures proposed.

(i) They strongly desire provision of coastal protection works by the central government.

(ii) Many villagers want to plant trees along the beach bank.

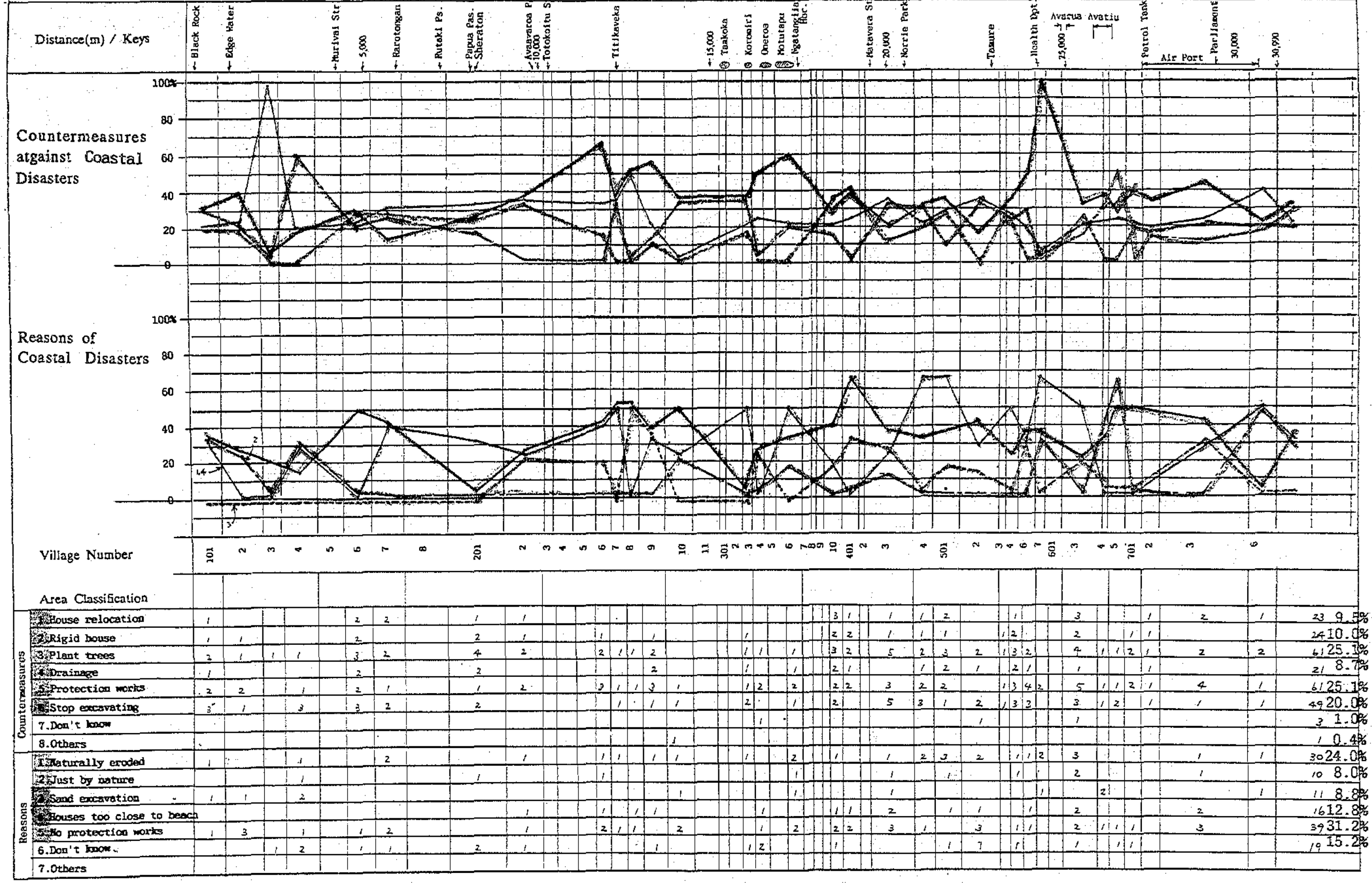
(iii) "Digging sand" is not main cause but they want to stop it.

(iv) They are feeling that they built house too close to the beach, however majority of them want to stay there.

After all, village interviewees made a frank response on the questionnaire. The study team highly appreciates their kind assistance to the study.

Appendix C-4 shows the results of Perception Study.

Fig. 7-1-a Villagers' Perception : Reasons of Disaster and Its Countermeasures



7.1.3 Methodology of Master Plan Preparation

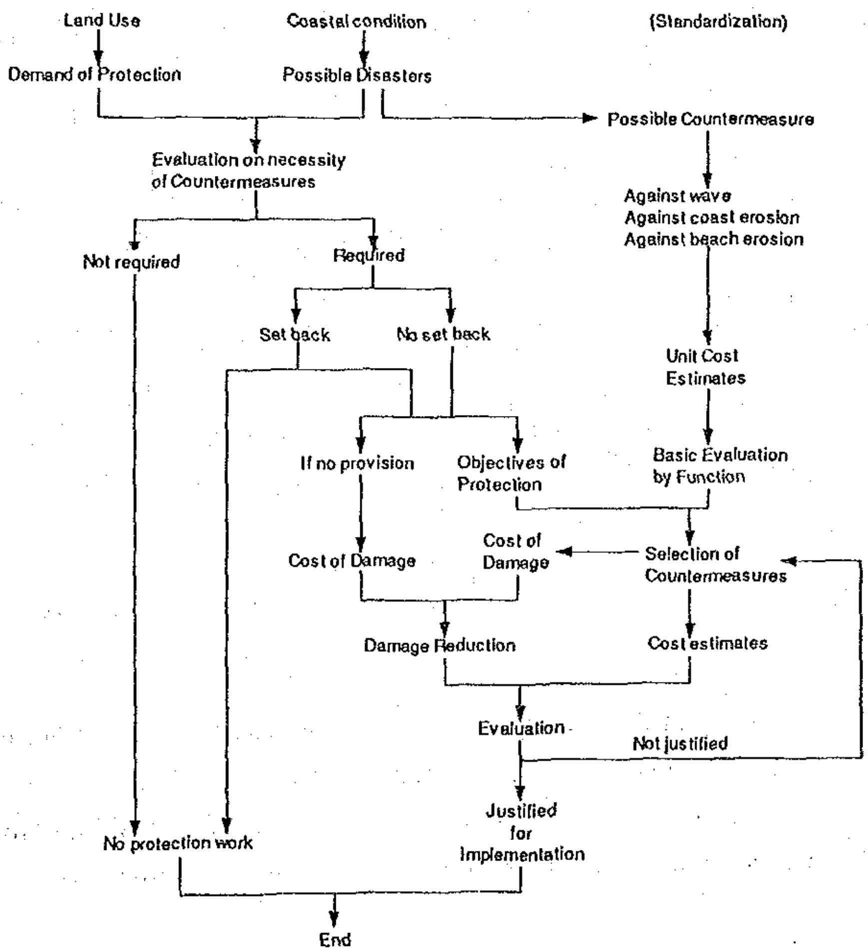
1) Basic Method

Coastal protection Master Plan should be an integrated plan which shows the guidelines for the long period, say 10 ~ 20 years. Thus, the plan should meet the following requirements.

(i) Showing the plan to meet the locality

(ii) The plan, as a whole, should be based on the system of acceptable planning concepts.

When an implementation of Master Plan is carried out, detailed study should be conducted with not only the field investigation but also detailed design based on the proposed concepts. Basic methodology between the Master Plan and the detailed design design is the same as follows.



However, the basic method employed here is modified one for simplification. The following are modified parts.

(i) "Set back" of the existing on-land facility is not considered.

(ii) Damage by Sally was adopted as unit damage. A total damage reduction during the project life, 30 years, is estimated as follows.

$$Dr = Ud \cdot Nr$$
$$= Ud \ (No - Np)$$

where,

Dr : Damage reduction by the project (Dollars)
Ud : Unit damage by Sally (Dollars)
Nr : Number of reduced model cyclone for 30 years by project effect
No : Number model cyclone for 30 years without the project
Np : Number of model cyclone for 30 years with the project
(Note : Model cyclone is Sally)

For the Master Plan preparation, following figures are used.

$$Dr = Ud \cdot Nr$$
$$= 13.9 \text{ million dollars} \times 2$$
$$= 27.8 \text{ million dollars}$$

Refer to subsections 5.2.3 and 12.2.7.

2) Minimum Coastal Unit

Accuracy in respect of the plan will rise if its study is made dividing the coast by shorter unit length as possible. In this study, a coast of 200 meter long that is named as "Coast Unit" was fixed as the minimum coastal unit. Technical study is carried out for this unit.

Appendix C-1 "Coast File" shows characteristics of each Coast Unit. There are 172 units in total coast length of 31 km.

If required data is not available, study result were complied for longer coastal length than this unit, namely from hundred meters to thousands meters of coast. This unit can be utilized as recording format of data collected in future. Refer to both Fig. 4-2 and Appendix C-1.

7.2 Possible Type of Protection System

There are two basic coastal protection systems, namely, soft countermeasures and hard countermeasures. The former represents a disaster protection system not requiring construction, while the latter a protection by civil work.

1) The Soft Countermeasures

a) National Consensus

Without clear information and a future plan, protection work will not be supported by the taxpayers. As discussed in Chapter 6, the preparation of a "Coast File" will provide people with more knowledge about coasts where they live. The "Coastal Disaster Forecast" will provide people with data concerning the possibilities of cyclone disasters. This information will enforce their decision-making concerning investments along the beaches. Disclosure of coastal protection Master Plan will be most important one in order to create the national consensus.

b) Enforcement of Regulations

MOW and the Conservation Department among others may be the governmental agencies that will manage coastal area development by the private sectors. If any private coastal development is assumed to be prone to cyclone damage, the responsible agencies should provide advice for modifying the safety plan. If any development is assumed to add to the damage cyclones caused to the surroundings, the agencies should take appropriate action to change such development.

In this respect, the limiting of private rights in the coastal area may be included in the regulations if supported by the people.

Sand digging in the coastal area is prohibited to prevent the beach from heavy erosion. This measure should be enforced continuously until the beach erosion is recovered. The cutting down of existing trees on the beach bank should be an item to discuss in the future.

It is reported that the Conservation Department currently prepares regulations on effluent standard of domestic sewege in the coastal bank. This should be carried out for better environmental condition.

c) Share of Responsibility

If villager builds his house in the dangerous coastal area even though he knows this, it is difficult to justify to spend national budget for protection of the house. Discussion of responsibility sharing between the private sector and the government in respect to coastal protection may be necessary.

d) Incentive

An incentive provision for developers may be necessary if they take the necessary action to protect the coastal area from the cyclone disasters.

2) The Hard Countermeasures

The hard countermeasures is the actual work in si-tu of the coastal protection measures, the main objective of this study.

The countermeasures include both the Micro Concept and Macro Concept. The former takes in the countermeasures that may be performed along the shoreline. The latter takes in the various methods that may be conducted on-land or at the lagoon seaward.

a) Micro concept

- Provision of coastal defense work including detached breakwater
- Nourishment of sand

b) Macro concept

- Provision of the on land buffer zone
- Relocation of existing facilities to safe areas
- To increase numbers of plant in the coastal bank
- Provision of artificial passages for the control of littoral currents. (Note: An artificial passage should be studied further.)

Application of these systems depends upon the existing locality both of land use and possible type of coastal disaster at the site to be protected.

7.3 Standardization of the Hard Countermeasures

This section deals with the standardization of work here for wave protection and erosion protection. The former will be provided at places where wave excessive overtopping is expected. The latter will be provided at places where excessive coastal and/or beach erosions may occur.

7.3.1 Classification of Land Use

In respect to the protection demands, the existing land is classified by its utilizing intensity. Based on the results of the field survey and the data/information collected on the island, the following items were evaluated place by place:

- Existing coastal profiles
- Utilization of hinterland at present
- Past cyclone damage records mainly by Sally
- Past tendencies of coastal changes, erosion or deposit

To standardize the site, 172 coast units in the entire 31km long shoreline were classified into several zones. Detailed descriptions are given in subsection 4.3.3. Classified land use zones are as follows.

a) Land Use Zone One

Established urban area

b) Land Use Zone Two

Rural area where the beach road runs within 30 meter from the beach top: Rural area "A".

c) Land Use Zone Three

Tourism development areas

d) Land Use Zone Four

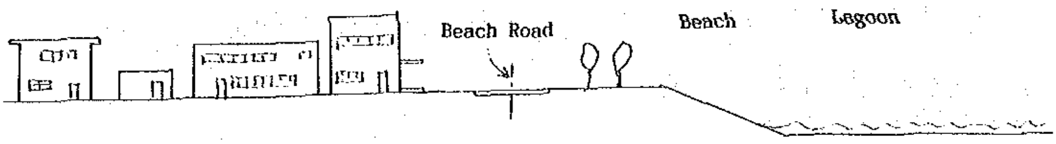
Rural area where the beach road runs through a deeper area that is more than 30 meters from the beach top: Rural area "B".

e) Land Use Zone Five

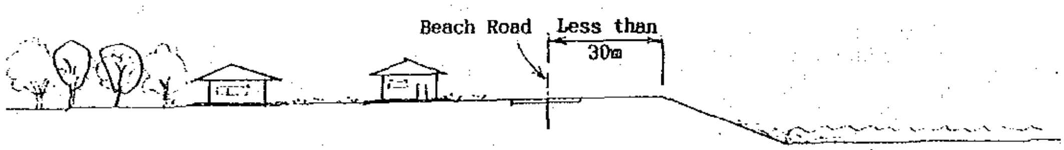
Natural areas having very little artificial development

Fig. 7-1-b Land Use Classification

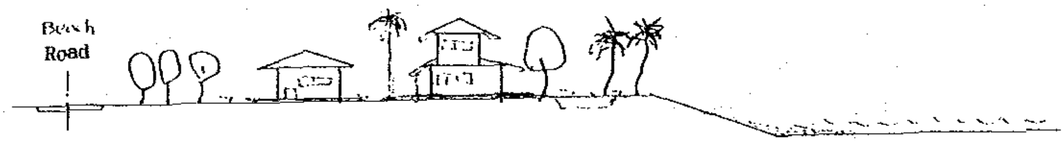
Zone One: Established Urban Area



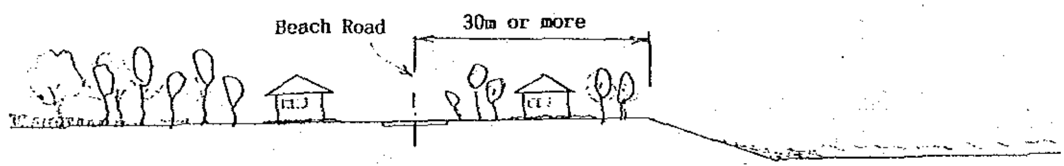
Zone Two: Rural Area "A"



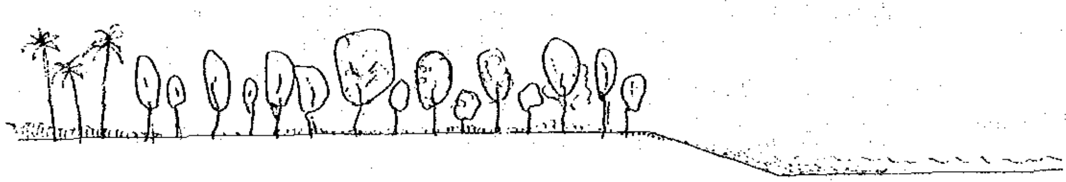
Zone Three: Tourism Area



Zone Four: Rural Area "B"



Zone Five: Nature Area



7.3.2 Classification of Disasters

The hard countermeasures applied per each coast unit should meet the various requirements in terms of protection. In order to standardize, the types of coastal damage in 172 coast units were classified into several grades.

Classification	Grade of Disaster				
	I	II	III	IV	V
"W"	O	O	O		
"EN"	O			O	
"EB"		O			O

Notes:

"W" Shows damage by wave overtopping above beach top. The entire coast was also affected by the wave set-up during cyclones.

"EN" Erosion of both fine particles and coarse particles including coral rock fragments and reclaimed earth.

"EB" Erosion of fine particles, i.e., sand.

a) Grade I for W-EN

The areas most affected by cyclones by means of:

- Wave run-up under the surging of tide.
- Both erosion of fine particles and coarse particles

b) Grade II for W-EB

The areas affected by cyclones by means of:

- Wave run-up under the surging of tide.
- Erosion of fine particles only.

c) Grade III for W

Wave run-up under the surging of tide but causing no significant beach erosion.

d) Grade III for EN

Beach erosion of coarse materials and fine particles, but no significant wave run-up.

e) Grade V for EB

Beach erosion of fine particles only.

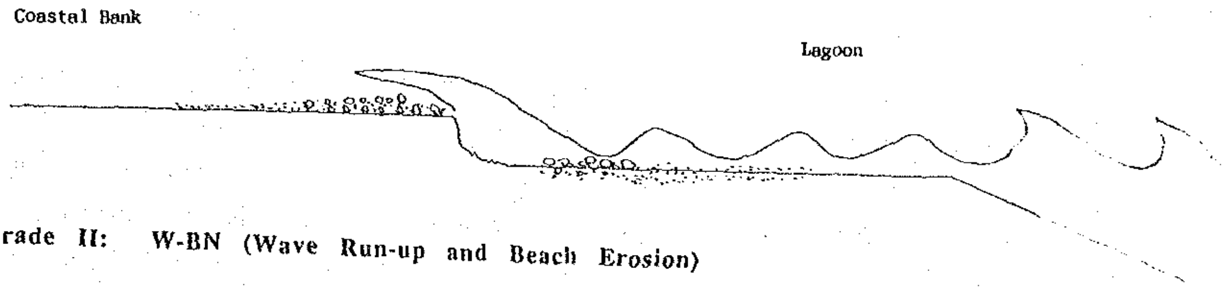
Fig. 7-1-c shows the typical sections of disaster classification.

Disaster classification has been conducted for 47 villagers, by taking into consideration the perception study to villagers, the damage record map prepared by the Conservation Department, and field observations by the study team. For wave damage estimation, wave overtopping height at each 200 meters of coast unit has been researched by the study team as showing in Fig. 5-6 and 7-15.

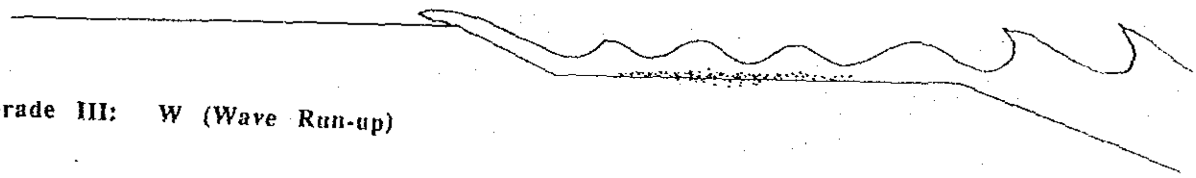
Fig. 7-15 is also a summary of disaster classifications by village, together with land classifications.

Fig. 7-1-c Disaster Classification

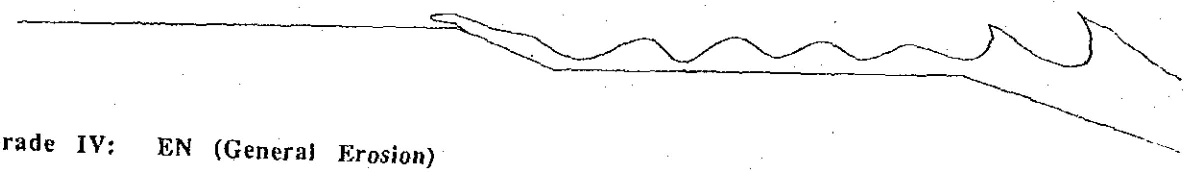
Grade I: W-EN (Wave Run-up and General Erosion)



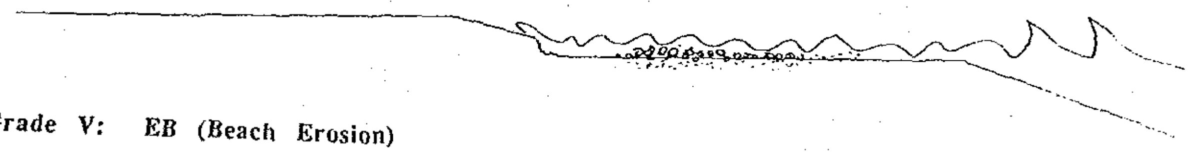
Grade II: W-BN (Wave Run-up and Beach Erosion)



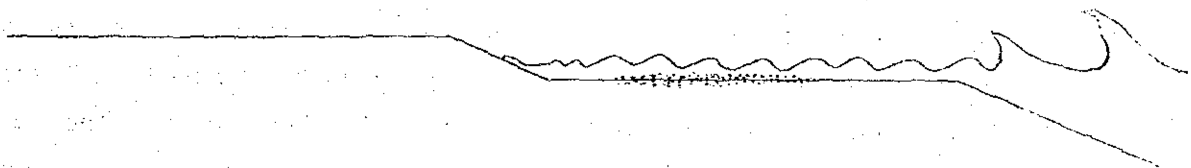
Grade III: W (Wave Run-up)



Grade IV: EN (General Erosion)



Grade V: EB (Beach Erosion)

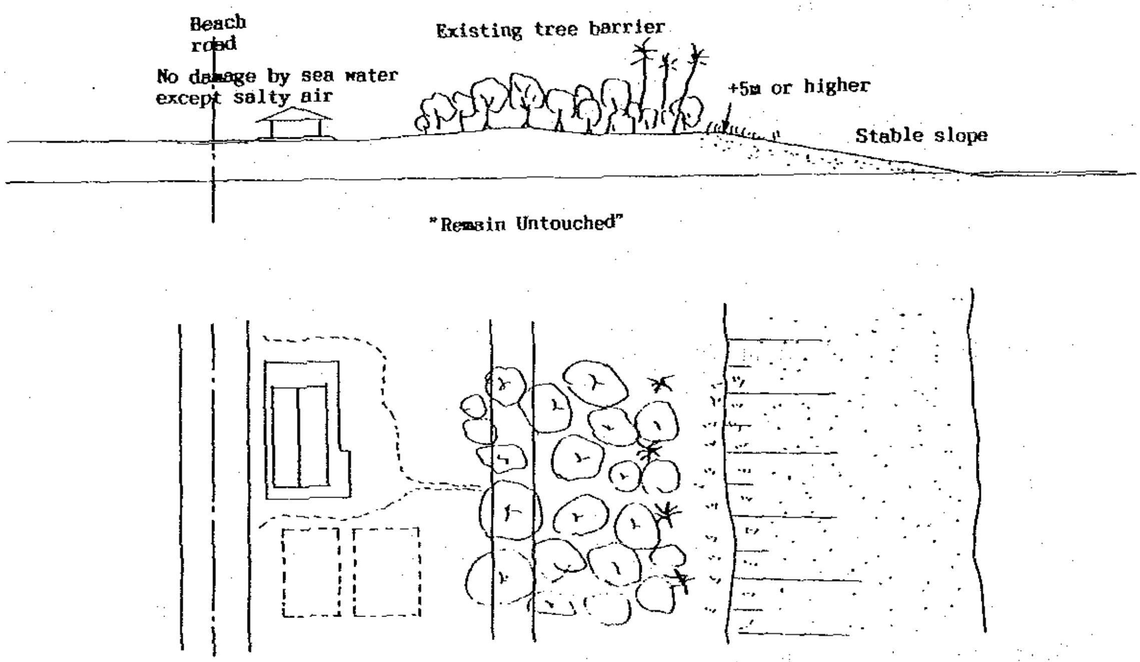


7.3.3 Preliminary Discussion in the Island

When the study team made its first visit to the site in mid-October 1991, a kickoff meeting relating to the government responsibility on coastal protection was held.

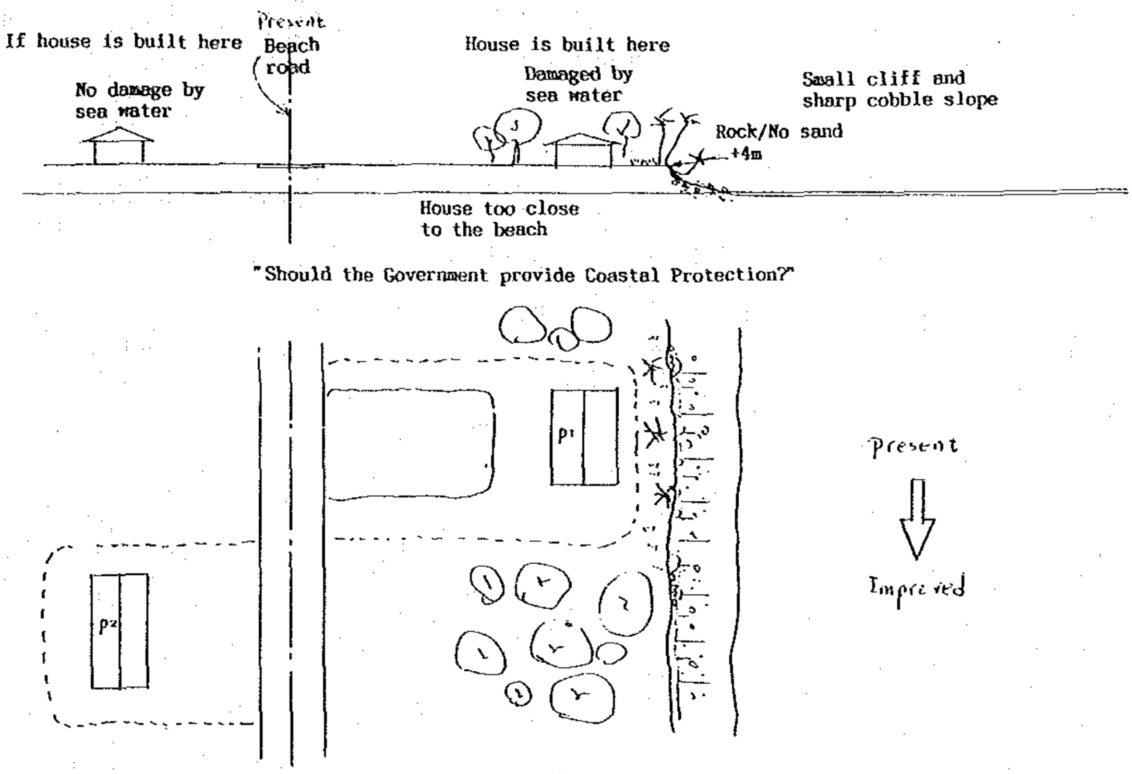
The team presented the Committee members with a sketch showing a typical profile having no wave and surge disasters (See Fig. 7-2 Sketch "A" for "Ideal Section"). This situation was observed at many places on the island. All participants agreed that this was the ideal protection from cyclone disaster and should remain and be maintained as is. This may be good not only for mitigating cyclone disasters but for maintaining a better environment.

Fig. 7-2 Sketch "A" Ideal Section



Then the team presented another sketch showing a typical section, a type which has recently been increasing (See Fig. 7-3 Sketch "B" for "Questionable Section"). A question to the Committee was "should the government provide this with coastal protection?". Sketch "B" shows a house built within 30 meters from the High Water Mark. The beach is eroded and trees are about to fall on the beach. The team, unfortunately, received no response to the question. If the house was built at point P_2 not point P_1, house has no damage and protected by natural barriers of trees.

Fig. 7-3 Sketch "B" Inappropriate Section



Discussion continues further. The study team asked whether or not the Sketches "C" and "D" were practical for use here. Both Sketches show the relocation of existing facilities well behind the beach bank and planting is taking place. The study team asked if the public sector could relocate the beach road landward and if they would accept the idea of constructing dikes on their property for establishing plantations.

All of these matters should be discussed for the purpose of improving the living environment on the island.

Fig. 7-4 Sketch "C" Planting with Dike

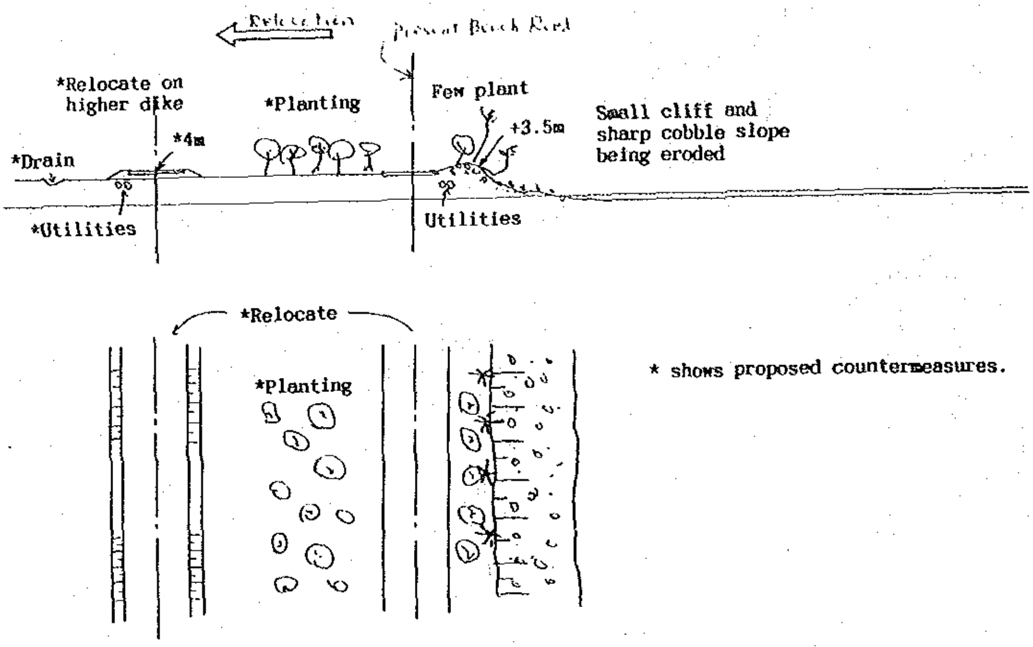
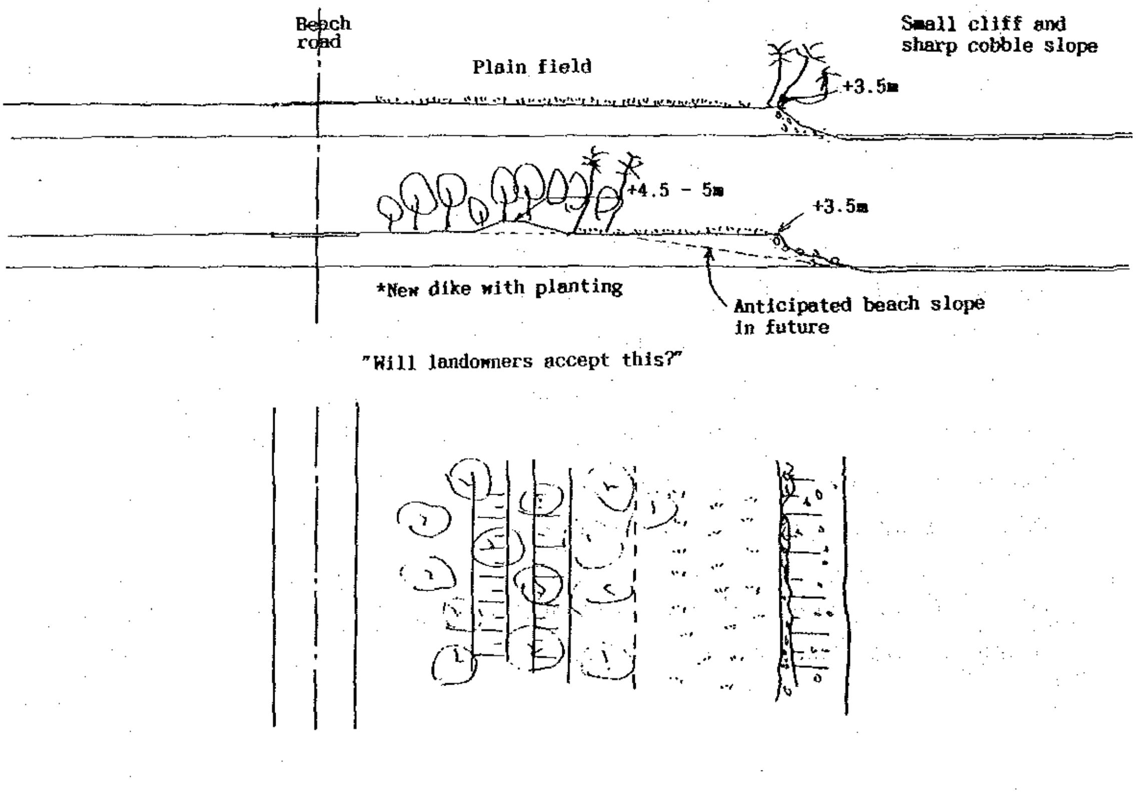


Fig. 7-5 Sketch "D" Planting with Dike



7.3.4 Standardization of Countermeasures

In this subsection possible protection measures and their standardization will be discussed.

Fourteen alternatives were selected as the basic countermeasures by considering the general characteristics of disaster and the coastal condition here. There are seven alternatives for coastal defense work in the micro concept. These are the most popular structures for mitigating possible coastal disasters.

Sand nourishment has also been selected as one of the alternatives in the micro concept.

Five alternatives were chosen for the macro concept which may apply for improving the existing surrounding conditions to encourage defense work.

a) Micro Concepts

<u>Coastal Defence Works</u>

MIC-1; Gravity Seawall

MIC-2; Rock mound Seawall

MIC-3; Stepped Slope

MIC-4; Flexible Hollow Slope

MIC-5; Flexible Gabion Slope

MIC-6; Groin

MIC-7; Lagoon Breakwater including artificial reef

Note: Foot protection by rock or deformed concrete block will be provided where necessary.

<u>Sand Nourishment</u>

MIC-8; Beach Nourishment

MIC-9; Trap Nourishment

b) Macro Concepts

<u>On-land Works</u>

MAC-1; On-land Buffer Zone

MAC-2; Existing Facility Relocation

MAC-3; Plantation with Dike

Work near the reef

MAC-4; Artificial Passage "I"

MAC-5; Artificial Passage "Y"

Note: Application of an artificial passage should be conducted after technical study. Please refer to subsection 5.4.7.

The general arrangement and characteristics of these countermeasures are summarized in Table 7-1. Other details together with the plan and section are shown in Figs. 7-6 to 7-10.

As seen in Table 7-1 fourteen alternatives were evaluated by the eight basic characteristics and functions the protection works aim at. Such functions include the following;

1) Structural stability

If a structure requires no maintenance work, it is stable. If a large amount of maintenance cost is expected, it is not stable.

2) Wave over-topping

The capability of providing wave over-topping protection or reducing wave over-topping should be evaluated.

3) Coastal erosion

Capability to reduce coastal erosion.
(Note, Coastal erosion is defined here as the erosion of beach slopes consisting of coarse particles and coral rock fragments. Beach erosion means the erosion of fine beach particles such as sand.)

4) Beach erosion

Capability to reduce beach erosion.

5) Accessibility to shoreline

Access to beaches by local people and tourists is an important function. Access by vehicles is not taken into consideration.

6) Scenery

It is assumed that natural scenery is the best. Thus, it is generally not suitable to artificially modify coastal scenery.

7) Wind

Coastal defense work aims basically at the mitigation of disasters by waves and surges caused by cyclones. Wind is also one of the items to be discussed, as it is reported that more than 80% of cyclone damage is caused by wind forces. Thus, it will be noted that any alternative that will provide the coastal area with effective protection against wind forces will be considered.

8) Economy

Economy is also an important item to be considered.

9) Others

The environmental effect may be evaluated and could include the effects on water quality and marine life. Due to lack of information they are not discussed here.

Table 7-1 Summary of Protection Concepts

Type of Protection Works	Function and Evaluation								Remarks
	1. Stable	2. Wave	3. Coast E.	4. Beach E.	5. Access	6. Scenery	7. Wind	8. U. Cost	
a) Micro Concepts									
Coastal Defense Works									
MIC-1; Gravity Seawall	B	B	B	N	P	P	-	5,000	Con. block if required
MIC-2; Rock mound Seawall	G	G	G	N	P	F	-	3,500	
MIC-3; Stepped Slope	G	F	G	F	G	F	-	4,000	
MIC-4; Flexible Hollow Slope	G	F	G	F	F	F	-	2,000	
MIC-5; Flexible Gabion Slope	G	F	F	G	F	F	-	700	
MIC-6; Groin	F	P	F	G	B	F	-	1,200	
MIC-7; Lagoon Breakwater	F	F	F	G	B	F	-	1,200	
Sand Nourishment									
MIC-8; Beach Nourishment	P	P	F	G	B	B	-	500	Cost for ten years
MIC-9; Trap Nourishment	P	P	F	G	B	B	-	400	"
b) Macro Concepts									
On-land Works									
MAC-1; On-land Buffer Zone	B	G	F	-	G	F	F	2,000	For 25 meter wide
MAC-2; Facility Relocation	B	G	F	-	G	G	G	2,500	Beach road 7m wide
MAC-3; Plantation with Dike	B	G	F	-	F	G	G	400	For 20 meter wide
Work near the reef									
MAC-4; Artificial Passage "I"	F	F	F	G	B	B	-	4,000	100m x 30m x 4m
MAC-5; Artificial Passage "Y"	F	N	F	G	B	B	-	8,000	200m x 30m x 4m

Notes 1. Marks,
B: Best, G: Good, F: Fair, P: Poor, N: not Suitable, -: Not applicable
2. Unit cost is estimated cost per shoreline meter, in dollars as 1992 price.
3. "Stable" means grade of structural stability against cyclone wave and surge.

Fig. 7-6 List of Protection Concepts with Characteristics (1/5)

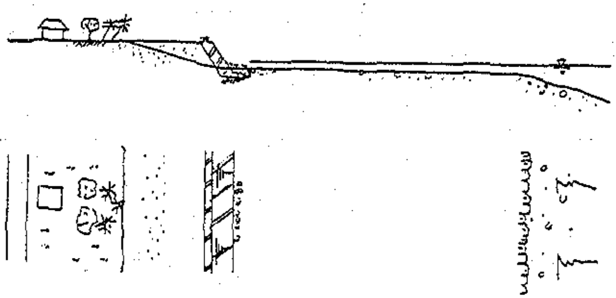
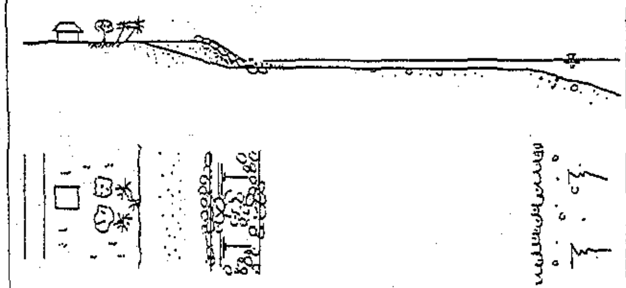
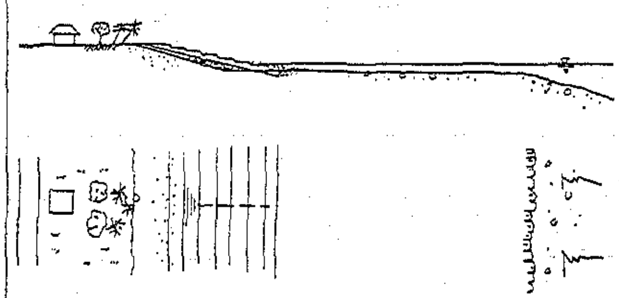
Mark	Name	Type of Concepts: Section / Plan	Type of Concepts: General Characteristics	Effective to: Wave Run-up "W"	Effective to: Coastal Erosion "EN"	Effective to: Beach Erosion "EB"	Unit Cost per meter (NZ$)
MIC-1	Gravity Seawall		**Basic structural type** is a heavily reinforced concrete wall thus stable. Top of wall will be adequate height to cope with wave run-up. When necessary, deformed concrete block will be placed in front of wall. General earth can be retained behind thus suitable to land reclamation. **Wave run-up** can be prevented, if the wall top is enough height. **Coastal erosion** will be perfectly prevented. **Beach erosion** in front of the wall will not be protected and will be accelerated due to the wave back washing. **Accessibility to shoreline** is very poor. **Scenery** of wall itself is poor due to heavy artificial works. View to the offshore may be improved. **Wind** intensity will not be reduced. **Others,** cost is the most expensive	○	○	—	5,000
MIC-2	Rock Mound Seawall		**Basic structural type** is a rock riprapping type with parapet wall at the top thus stable. Top of wall will be adequate height to cope with wave run-up. General earth can be retained with filter rock layer under the surface armour rock. **Wave run-up** can be prevented, if the wall top is enough height. **Coastal erosion** will be perfectly prevented. **Beach erosion** in front of the wall may not be protected. **Accessibility to shoreline** is generally poor. **Scenery** of wall itself is fair due to adoption of natural materials. **Wind** intensity will not be affected. **Others,** cost is expensive	○	○	—	3,500
MIC-3	Stepped Slope		**Basic structural type** is reinforced concrete of a flight of moderate steps in gradient of one to three. Top of wall will normally be same level with beach bank. No parapet wall will normally be provided. **Wave run-up** can be prevented, if the wall top is enough height. However the wall height may be limited in order to accessibility. **Coastal erosion** will be prevented. **Beach erosion** in front of the wall may not be protected, however sand may partly be trapped at toe of wall due to low wash back current by moderate slope. **Accessibility to shoreline** is good. Steps may be place where the tourists take rest. **Scenery** of wall itself is fair. **Wind** intensity will not be affected. **Others,** cost is moderate or expensive	—	○	—	4,000

Fig. 7-7 List of Protection Concepts with Characteristics (2/5)

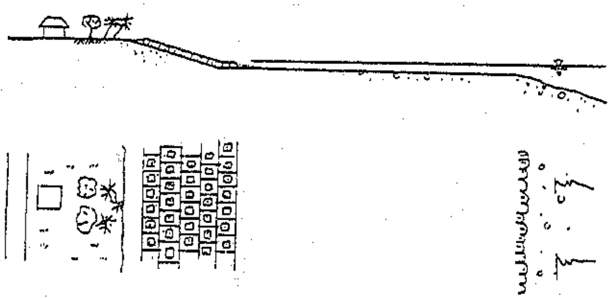
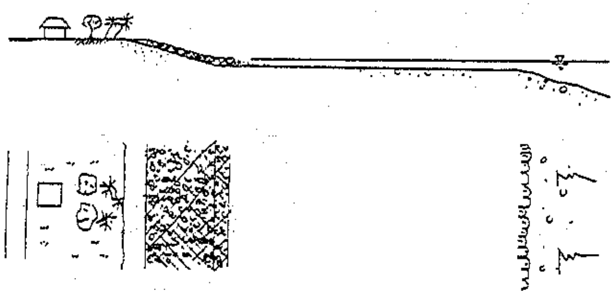
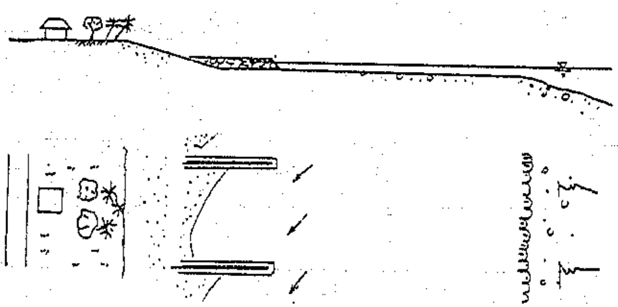
Mark	Name	Type of Concepts: Section / Plan	Type of Concepts: General Characteristics	Effective to: Wave Run-up "W"	Effective to: Coastal Erosion "EN"	Effective to: Beach Erosion "EB"	Unit Cost per meter (NZ$)
MIC-4	Flexible Hollow Slope		**Basic structural type** is combination of precast reinforced concrete blocks which may shape hollow type or skeleton. Center space of block should be filled by rock. This structure can follow the settlement of foundation. **Wave run-up** can not be prevented because limit of top height. This is structurally weak against large waves. **Coastal erosion** will be prevented, if this structure is maintained during cyclone. **Beach erosion** in front of the wall may not be protected, if slope gradient is steep. If the gradient is moderate than one to three, sand may partly be trapped at toe of wall. **Accessibility to shoreline** is not good but possible. **Scenery** of wall itself is fair. **Wind** intensity will not be affected. **Others,** cost is moderate	—	○	—	2,000
MIC-5	Flexible Gabion Slope		**Basic structural type** is an aggregated rock or gravel in the wire net. This will be laid down on the natural slope, and will becomes attached to the foundation. The top height of wall is limited structurally. Slope will be one to four or moderate. **Wave run-up** can not be reduced because limit of top height. **Coastal erosion** will be prevented as far as this slope is maintained during cyclone. **Beach erosion** may be protected in some degree, due to reduction of back wash energy. Sand can easily penetrate into the structure thus, smooth connection to sand beach is expected. **Accessibility to shoreline** is not good but possible. **Scenery** of wall itself is good. **Wind** intensity will not be affected. **Others,** cost is reasonably low, however maintenance should be made.	—	○	○	700
MIC-6	Groin		**Basic structural type** is rock or concrete block or piles or any structure which can form a low dike. This will be laid on the lagoon bed papendicular to the beach, to cut the littoral current and to retain sand its leeward. **Wave run-up** can not be affected. **Coastal erosion** will be reduced in certain degree. **Beach erosion** will be reduced and sand beach restoration is expected, if it laid properly. **Accessibility to shoreline** is the best. **Scenery** of wall itself is fair. Ocean view will not be affected. **Wind** intensity will not be affected. **Others,** cost is reasonably low.	—	—	○	1,200

Fig. 7-8 List of Protection Concepts with Characteristics (3/5)

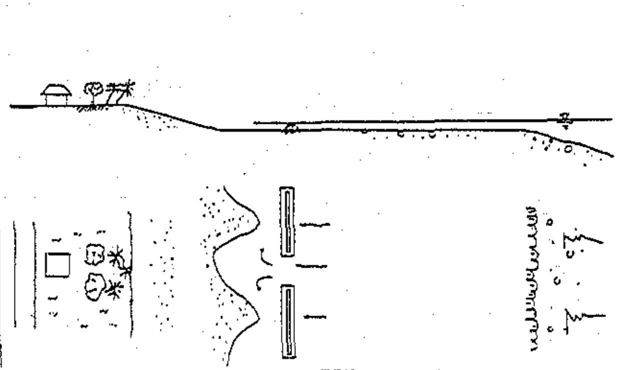
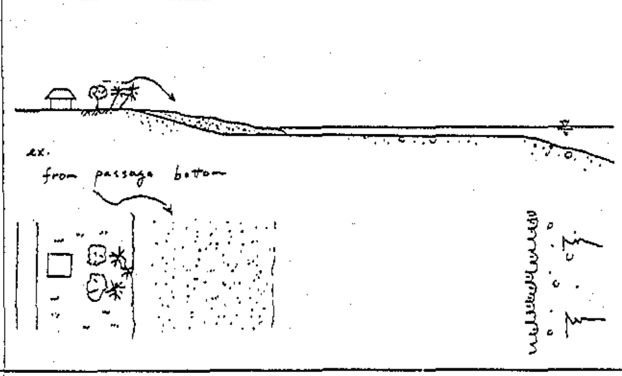
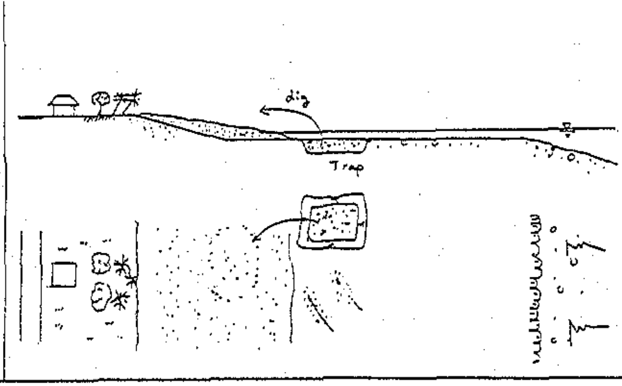
Mark	Name	Type of Concepts: Section / Plan	Type of Concepts: General Characteristics	Effective to: Wave Run-up "W"	Effective to: Coastal Erosion "EN"	Effective to: Beach Erosion "EB"	Unit Cost per meter (NZ$)
MIC-7	Lagoon Breakwater		**Basic structural type** is rock or concrete block or the like. This will be laid on the lagoon parallel to the beach. Top of this will be +1.0 to +1.5 meter above MSL. **Wave run-up** can be slighty affected. **Coastal erosion** can be slightly affected. **Beach erosion** may be partly reduced. In some case sand accumulation can be expected. **Accessibility to shoreline** is the best. **Scenery** of wall itself is fair. **Wind** intensity will not be affected. **Others,** cost is moderate or expensive.	○	○	○	1,200
MIC-8	Beach Nourishment		**Basic structural type** This is not structure but artificial sand supply to eroded areas. Size of sand will be ones which are available in the island. Generally coarse mountains or river sand is better to stabilize the beach shape. **Wave run-up** will be slighty affected in certain degree as far as sand stays the place. **Coastal erosion** will not be slightly affected. **Beach erosion** will be reduced as far as sand supplied is staying at the place nourished. Nourished sand may drift to other beach nearby making advance of beachline seaward. **Accessibility to shoreline** is the best. **Scenery** is the best, nothing to compare. **Wind** intensity will not be affected. **Others,** cost is moderate, if sand is available.	—	—	○	500
MIC-9	Trap Nourishment		**Basic structural type** This is not structure but artificially supply of sand to eroded areas. Natural sand will be caught at the sand traps which are holes dug in shallow lagoon. Deposited sand there will be removed to beaches when the sea is calm. **Wave run-up** will be slightly affected as far as sand stays the removed beach front. **Coastal erosion** will not be affected. **Beach erosion** will be reduced as far as sand nourished is staying at the place. Such sand may drift by down current to adjacent beach offsetting imbance of supply. **Accessibility to shoreline** is the best. **Scenery** is the best, nothing to compare. **Wind** intensity will not be affected. **Others,** cost is reasonably low, if sand is easily trapped.	—	—	○	400

Fig. 7-9 List of Protection Concepts with Characteristics (4/5)

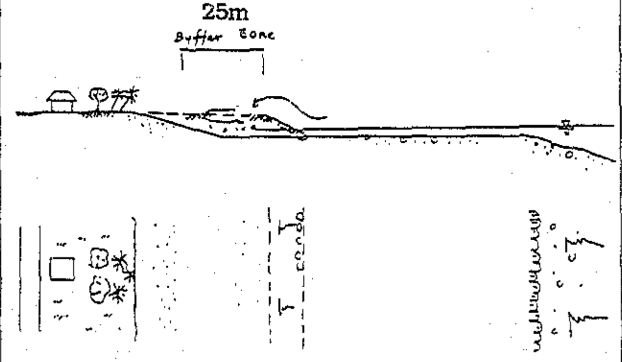
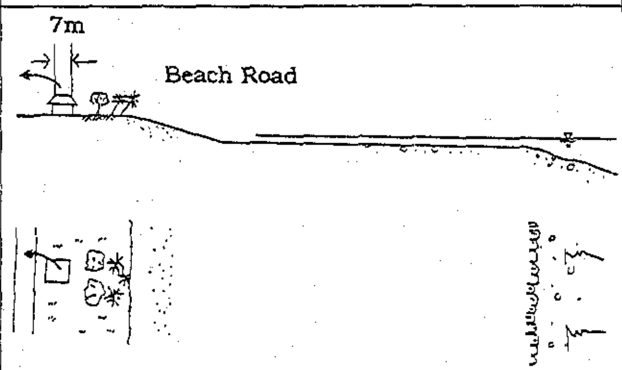
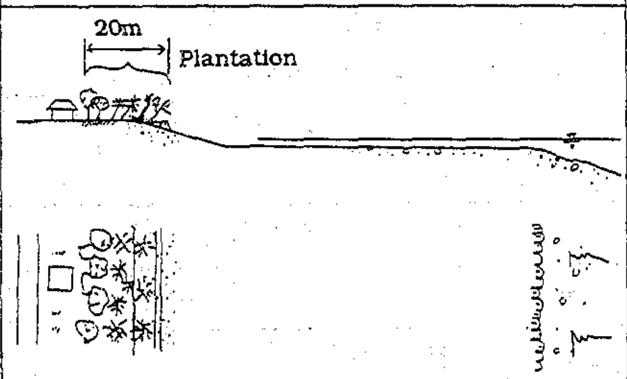
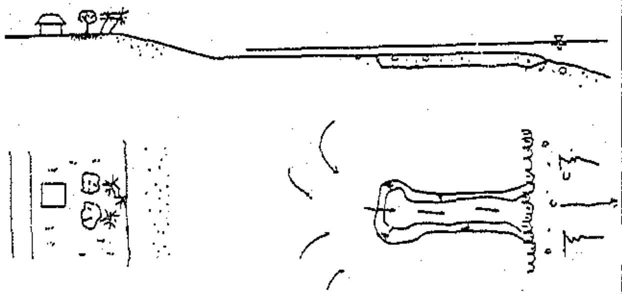
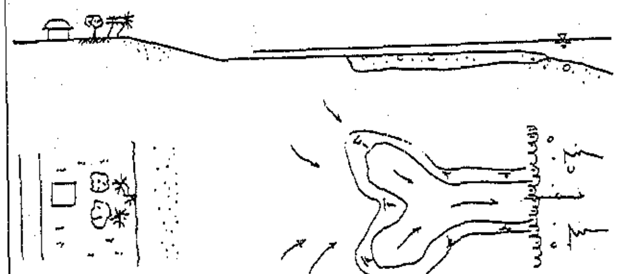
Mark	Name	Type of Concepts: Section / Plan	Type of Concepts: General Characteristics	Effective to: Wave Run-up "W"	Effective to: Coastal Erosion "EN"	Effective to: Beach Erosion "EB"	Unit Cost per meter (NZ$)
MAC-1	On-land Buffer Zone		**Basic structural type** is reclaimed land by general earth covered by gravel or pavement. Some time land will be covered by green for parks during the normal condition. Overtopped water bodies may touchdown and stabilize before arriving the existing public properties. **Wave run-up** can not be affected but water bodies after run-up can be affected by the ground friction. **Coastal erosion** will not be affected. **Beach erosion** will not be affected. **Accessibility to shoreline** will not be changed as far as no steep slope facility like MIC-1 or 2 are provided. **Scenery** will be good if the reclaimed area is provided with the proper landscaping. **Wind** intensity will be slightly affected due to more friction of the ground. **Others,** cost depend on the size of buffer zone, however generally expensive.	○	—	—	2,000
MAC-2	Facility Location		**Basic structural type** This is not structure, but relocation or set-back of the existing facilities to landward enough to escape the cyclone disasters. Facilities may include public ones like the beach road and governmental office and buildings or private facilities. **Wave run-up** will not be affected, however damage to the facilities will be minimized. **Coastal erosion** will not be affected. **Beach erosion** will not be affected. **Accessibility to shoreline** will be good. **Scenery** will be good if the vacant land is provided with trees. **Wind** intensity will be slightly affected if air buffer like trees are planted. **Others,** cost depend on the type of facility to be relocated and replaced.	○	—	—	2,500
MAC-3	Plantation with Dike		**Basic structural type** is combination of trees and low dike along the beach bank. **Wave run-up** will be affected although it may depend on the size of forest and scale of dike. **Coastal erosion** will slightly be affected. Roots may add to the coastal bank with cohesion. **Beach erosion** will not be affected. **Accessibility to shoreline** will not be affected if narrow path is prepared. **Scenery** will generally be good. Ocean view will be affected. **Wind** intensity will be affected by air buffer of forest. **Others,** cost is reasonably low, if land is available and private sector can cooperate with this.	○	—	—	400

Fig. 7-10 List of Protection Concepts with Characteristics (5/5)

Mark	Name	Type of Concepts: Section / Plan	Type of Concepts: General Characteristics	Effective to: Wave Run-up "W"	Effective to: Coastal Erosion "EN"	Effective to: Beach Erosion "EB"	Unit Cost per meter (NZ$)
MAC-4	Artificial Passage "I" Shaped	Size 100 m x 30 m x -4 m 	**Basic structural type** is provision of new passage through the reef, in order to increase number of return current groups. This work may decrease velocity of littoral current and stabilize the beach sand. This will be a line perpendicular to reef. **Wave run-up** will slightly be affected due to reduction of water setup. **Coastal erosion** will be reduced. **Beach erosion** will be reduced and the beach front may advance reefward in some case. **Accessibility to shoreline** will not be affected, thus good. **Scenery** will not be affected, thus good. **Wind** intensity will not be affected. **Others.** cost is reasonably low. Note: This should be evaluated by model test.	—	—	○	4,000
MAC-5	Artificial Passage "Y" Shaped	Size 200 m x 30 m x -4 m 	**Basic structural type** is same with MAC-5. However the shape is like letter "Y", one enetrance channel on the reef but two branched foreshore. **Wave run-up** will slightly be affected due to reduction of water set up. **Coastal erosion** will be reduced. **Beach erosion** will be reduced and the beach front may advance reefward in some case. **Accessibility to shoreline** will not be affected. If wider Channel is provided, small boat can be berthed here in the normal condition. Thus good. **Scenery** will not be affected. Thus good. **Wind** intensity will not be affected. **Others.** cost is reasonably low or moderate. Note: This should be evaluated by model test.	—	—	○	8,000

7.3.5 Application of Basic Protection Concept

Fourteen alternatives can either be applied independently or for combined use. The selection of alternatives and its combination is related to the objectives of the work and the characteristics of each coast.

1) Independent use

Seawall will be constructed independently. Gabion, groin and lagoon breakwater can be used under combination with other method.

2) Combination among same concept

For example, the combination of MIC-7 "Langoon breakwater" and MIC-8 "Sand Nourishment". Another example is the combination of MIC-2 "Regular Seawall" and MIC-6 "Groin".

3) Combination between different concept

For example, MIC-1 "Heavy Seawall" and MAC-1 "On-land Buffer Zone". Another example is the combination of MIC-5 "Flexible Gabion Slope" and "MAX-3 Plantation with Dike". An important aspect is the necessity of cooperation by the private sector, especially land owners.

Section 7.5 will provide more detailed study on system application to the actual coast.

7.4 Typical Application Scheme

This section deals with typical application of protection concepts to five land use classification. This arrangement may provide planner with reference guidelines, though application can not be fixed since each coast has its own characteristics. The "Natural Area" was excluded from the study.

7.4.1 Methodology

The required coastal protection measures at the particular coast will depend on the demand of protection based on the land use of its hinterland. Then, it will be evaluated whether or not the present coastal conditions provide its hinterland with enough protection. If any area is unprotected, it will be a target for being provided with suitable countermeasures. Refer to subsection 7.1.3.

Before the selection of the best countermeasures is made, it is recommended that the possibility of modification of land use by means of setting facilities far enough behind to maintain safety is confirmed. If this is possible, the necessity of protection will be reconsidered based on the new facility location.

If no damage is anticipated even after the setting back of facilities, no protection work may basically be provided.

When countermeasures to be provided are identified, the required functions of such work should be clarified. Possible countermeasure will be provided using one or a combination of alternatives against various disasters including;

a) Wave over-topping under wave set-up
b) Erosion of a coastal bank consisting of coarse particles like coral rocks and artificially reclaimed earth.
c) Erosion of beach slopes consisting of fine particles such as sand.

Appropriate countermeasures will be selected from the various countermeasure alternatives as shown in subsection 7.3.4.

Adaptability of these coastal protection work should be evaluated by making a cost comparison between the prevented damage and the required protection cost. Environmental aspects should be also considered.

7.4.2 Modelling and General Application

Application of countermeasure at the particular site should be decided upon by considering its locality and future prospects. (Note: Future prospects are incorporated only for port improvements.)

This subsection deals with the modelling study for possible application of alternatives based on the general classification of land use and the demand for protection (or type of disasters expected). Area zoning is classified into five divisions and disaster types are categorized into five grades as shown in subsections 7.3.1 and 7.3.2.

Table 7-2 shows the possible standardized application of countermeasure alternatives. Proposed standardized applications by each classification are as follows.

Zone One : Established Urban Area

a) Grade I, Grade II and Grade III

Combination of MIC-1 Gravity seawall and macro concept including MAC-1 Buffer Zone and MAC-3 Plantation.

b) Grade IV

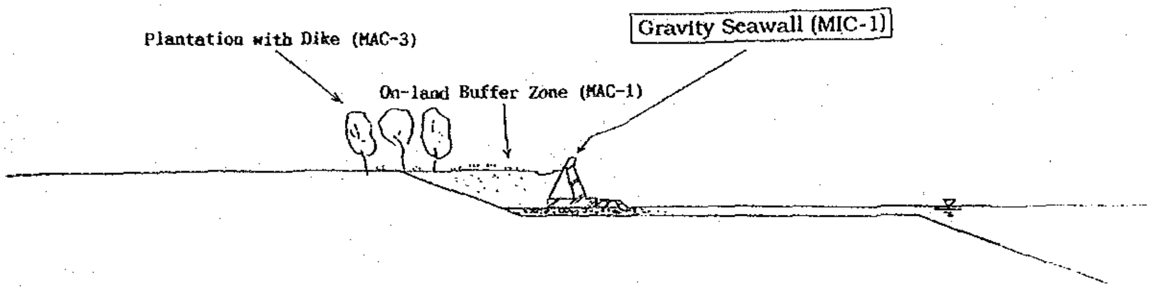
MIC-4 Flexible Hollow Slope and MIC-7 Lagoon Breakwater

c) Grade V

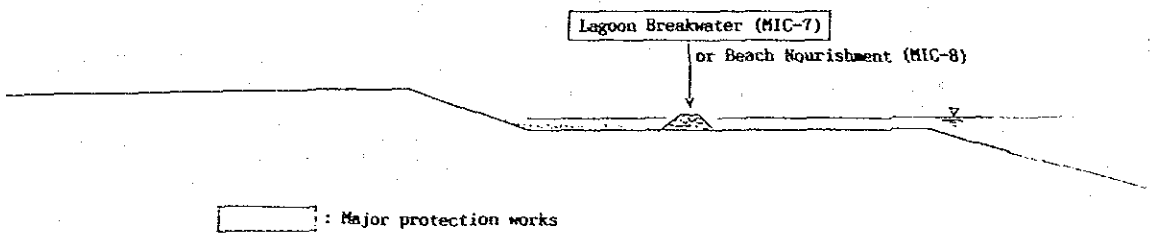
MIC-7 Lagoon Breakwater or MIC-8 Beach Nourishment.

Fig. 7-11 Typical Profiles for Zone One: Urban Area

Disaster Grade : I (Wave Over-topping and Coastal Erosion)



Disaster Grade : V (Beach Erosion)



Zone Two : Dense Rural Area "A"

a) Grade I, Grade II and Grad III

Combination of MIC-2 Rock Mound Seawall and macro concept including MAC-2 Existing Facility Relocation and MAC-3 plantation

b) Grade IV

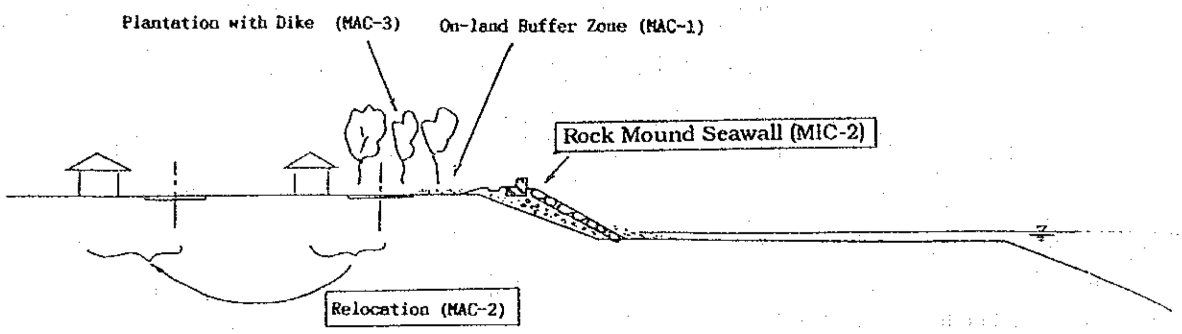
MIC-4 Flexible Hollow Slope

c) Grade V

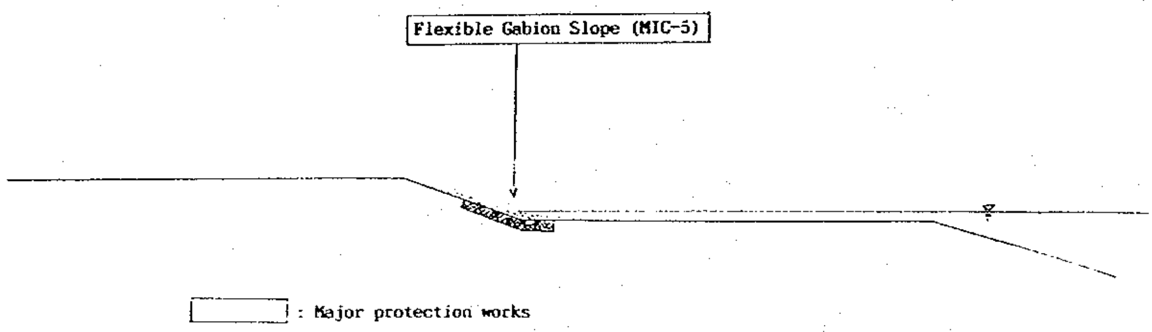
MIC-5 Flexible Gabion Slope

Fig. 7-12 Typical Profiles for Zone Two: Rural Area "A"

Disaster Grade : I



Disaster Grade : V



Zone Three : Tourism Development Area

a) Grade I and Grade II

Combination of MIC-2 Rock Mound Seawall, MIC-6 Groin and MIC-8 Beach Nourishment and macro concept including MAC-4 Artificail Passage in "I" shape or MAC-5 Artificial Passage in "Y" shape

b) Grade III

Combination of MIC-2 Rock Mound Seawall and MIC-6 Groin

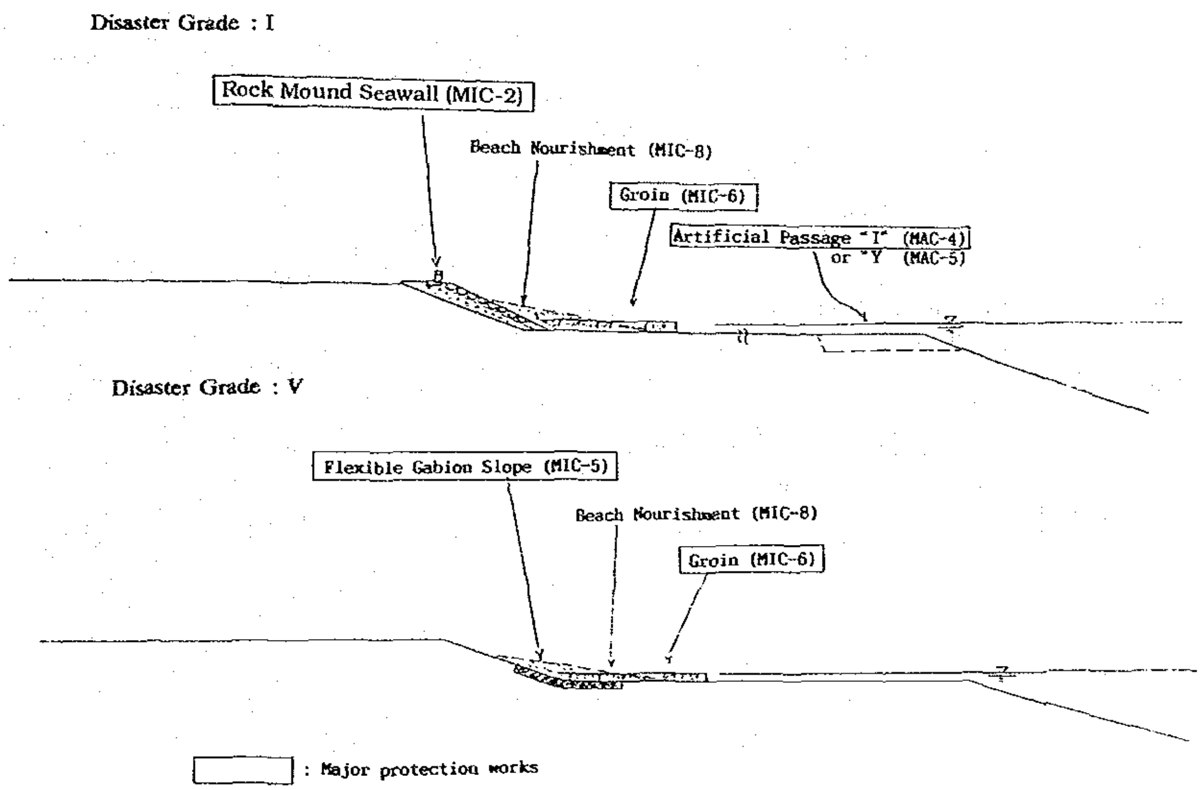
c) Grade IV

MIC-4 Flexible Hollow Slope and MIC-6 Groin and macro concept including MAC-4 or MAC-5 Artificial Passage.

d) Grade V

Combination of MIC-5 Flexible Gabion Slope, MIC-6 Groin and MIC-8 Beach Nourishment.

Fig. 7-13 Typical Profiles for Zone Three: Tourism Area



Zone Four : Rural Area "B"

a) Grade I, Grade II and Grade III

Combination of MIC-2 Rock Mound seawall and macro concept including MAC-3 Plantation.

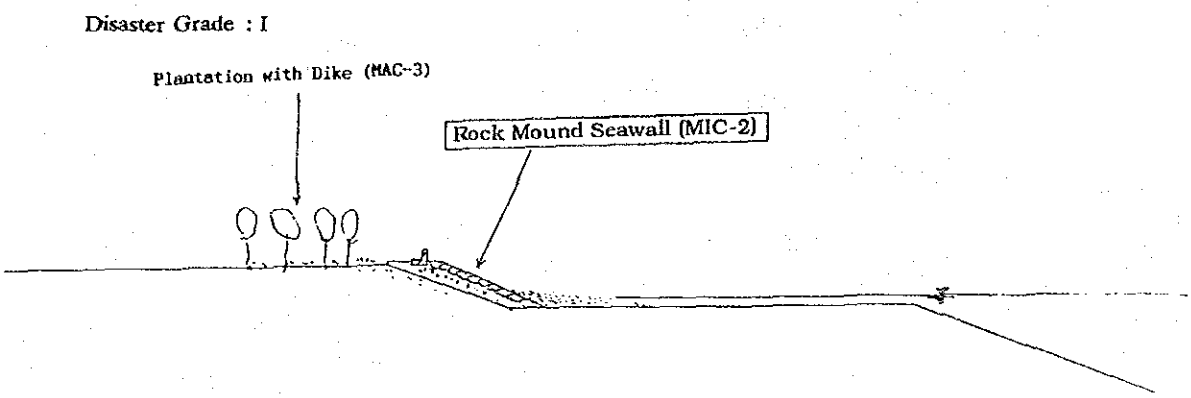
b) Grade IV

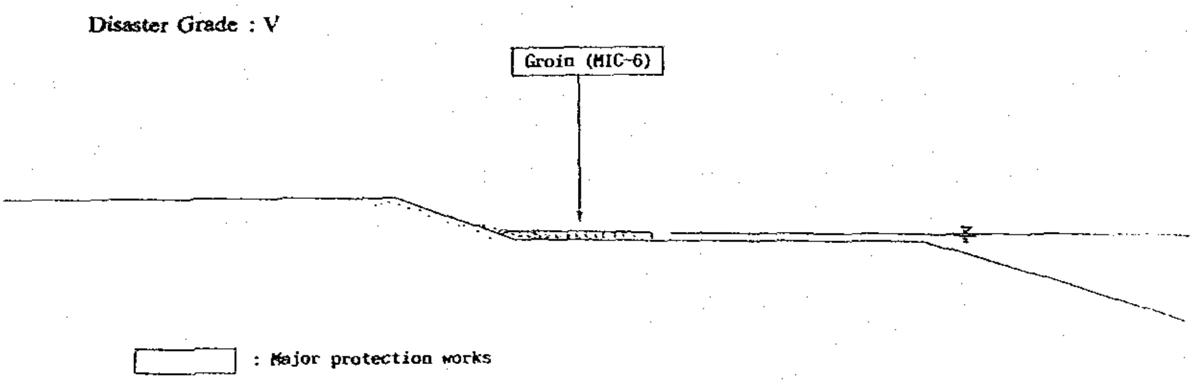
Combination of MIC-4 Flexible Hollow Slope and MIC-6 Groin

c) Grade V

MIC-6 Groin

Fig. 7-14 Typical Profiles for Zone Four: Rural Area "B"





Zone Five : Natural Area

Leave it as is, thus no provision

Table 7-2 Application of Countermeasure Alternatives

COUNTER MEASURE ALTERNATIVES									AREA ZONING ⇨ ONE URBAN					TWO RURAL "A"					THREE TOURISM					FOUR RURAL "B"					FIVE NATURE				
TYPE OF DISASTER ⇨								GRADE ⇨	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
W								WAVE OVER-TOP	○	○	○			○	○	○			○	○	○			○	○	○			○	○	○		
EN								COAST EROSION	○			○		○			○		○			○		○			○		○			○	
EB								BEACH EROSION	○	○		○	○	○	○		○	○	○	○		○	○	○	○		○	○	○	○			○
FUNCTION ⇨	1 ST	2 W	3 C.E	4 B.E	5 AC	6 SE	7 WD	8 U.C																									
MICRO CONCEPT — COASTAL DEFENSE WORKS																																	
MIC-1 GRAVITY SEAWALL	B	B	B	N	P	P	-		**(WC)**	**(WC)**	**(WC)**			(WC)	(WC)	(WC)			(WC)	(WC)	(WC)			(WC)	(WC)	(WC)			(WC)	(WC)	(WC)		
MIC-2 ROCK MOUND SEAWALL	G	G	G	N	P	F	-		(WC)	(WC)	(WC)			**(WC)**	**(WC)**	**(WC)**			**(WC)**	**(WC)**	**(WC)**			**(WC)**	**(WC)**	**(WC)**			(WC)	(WC)	(WC)		
MIC-3 STEPPED SLOPE	G	F	G	F	G	F	-		(C)			(C)		(C)			(C)		(C)			**(C)**		(C)			(C)		(C)			(C)	
MIC-4 Fix. HOLLOW Sl.	G	F	G	F	F	F	-		(C)			**(C)**		(C)			**(C)**		(C)			((C))		(C)			**(C)**		(C)			(C)	
MIC-5 Fix. GABION Sl.	G	F	F	G	F	F	-		B	B		B	B	(B)	(B)		((B))	**(B)**	(B)	(B)		(B)	**(B)**	B	B		B	B	B	B		B	B
MIC-6 GROIN	F	P	F	G	B	F	-		B	B		B	B	B	B		B	B	**(B)**	**(B)**	**(·)**	**(B)**	**(B)**	(B)	(B)		**(B)**	**(B)**	B	B		B	B
MIC-7 LG. BREAKWATER	F	F	F	G	B	F	-		(B)	(B)		**(B)**	**(B)**	B	B		B	B	B	B		B	B	B	B		B	B	B	B		B	B
SAND NOURISHMENT																																	
MIC-8 BEACH NOURISH.	P	P	F	G	B	B	-		(B)	(B)		((B))	((B))	B	B			B	**(B)**	**(B)**		**(B)**	**(B)**	B	B		B	B	B	B		B	B
MIC-9 TRAP NOURISH.	P	P	F	G	B	B	-		B	B		B	B	B	B		B	B	(B)	(B)		(B)	(B)	B	B		B	B	B	B		B	B
MACRO CONCEPT — MAC-1 BUFFER ZONE	B	G	F	-	G	F	F		**(W)**	**(W)**	**(W)**			(W)	(W)	(W)			(W)	(W)	(W)			(W)	(W)	(W)			(W)	(W)	(W)		
MAC-2 RELOCATION	B	G	F	-	G	G	G		(W)	(W)	(W)			**(W)**	**(W)**	**(W)**			(W)	(W)	(W)			(W)	(W)	(W)			(W)	(W)	(W)		
MAC-3 PLANTATION	B	G	F	-	F	G	G		**(W)**	**(W)**	**(W)**			**(W)**	**(W)**	**(W)**			(W)	(W)	(W)			**(W)**	**(W)**	**(W)**			(W)	(W)	(W)		
MAC-4 ART. PASS. I	F	N	F	G	B	B	-		(B)	(B)		(B)	(B)	(B)	(B)			(B)	**(B)**	((B))		**(B)**	((B))	(B)	(B)		(B)	(B)	B	B		B	B
MAC-5 ART. PASS. Y	F	N	F	G	B	B	-		B	B		B	B	B	B		B	B	((B))	((B))		((B))	((B))	B	B		B	B	B	B		B	B

Notes 1. Marks, W: Wave Run-up, C: Coastal Erosion, B: Beach Erosion,
○: Applicable, ◎: Suitable ones **○**: Selected ones
2. Marks in Function see Table 7-1.
3. Marks, Function evaluation, B: Best, G: Good, F = Fair, P = poor, N = No good.

(In the table: (X) = mark in thin circle, ((X)) = mark in double circle, **(X)** = mark in bold circle.)

7.5 Application of System to Site

This section deals with the actual application of various coastal protection countermeasures to the site, namely 172 coast units under 47 villages.

Each coast unit of the 31 kilometer coastal area has its own particular characteristics. Countermeasure applying to each unit should meet these local condition. As discussed in Section 7.3, an area can be classified from two overall viewpoints: land use of hinterland and estimated disaster grade. The higher the land use intensity with larger disaster forecasted, the more investment required for coastal protection. Contrarily, the lower land use requirement with few disasters expected, the less investment.

7.5.1 Classification of 31 Km Coastal Line by Land Use

Since a land use development plan for the island in the year 2010 has not yet been provided, this classification has been conducted based on existing land use. Subsection 4.3.3 shows the breakdown of five zones. A summary of the total area by the length of beach road is as follows:

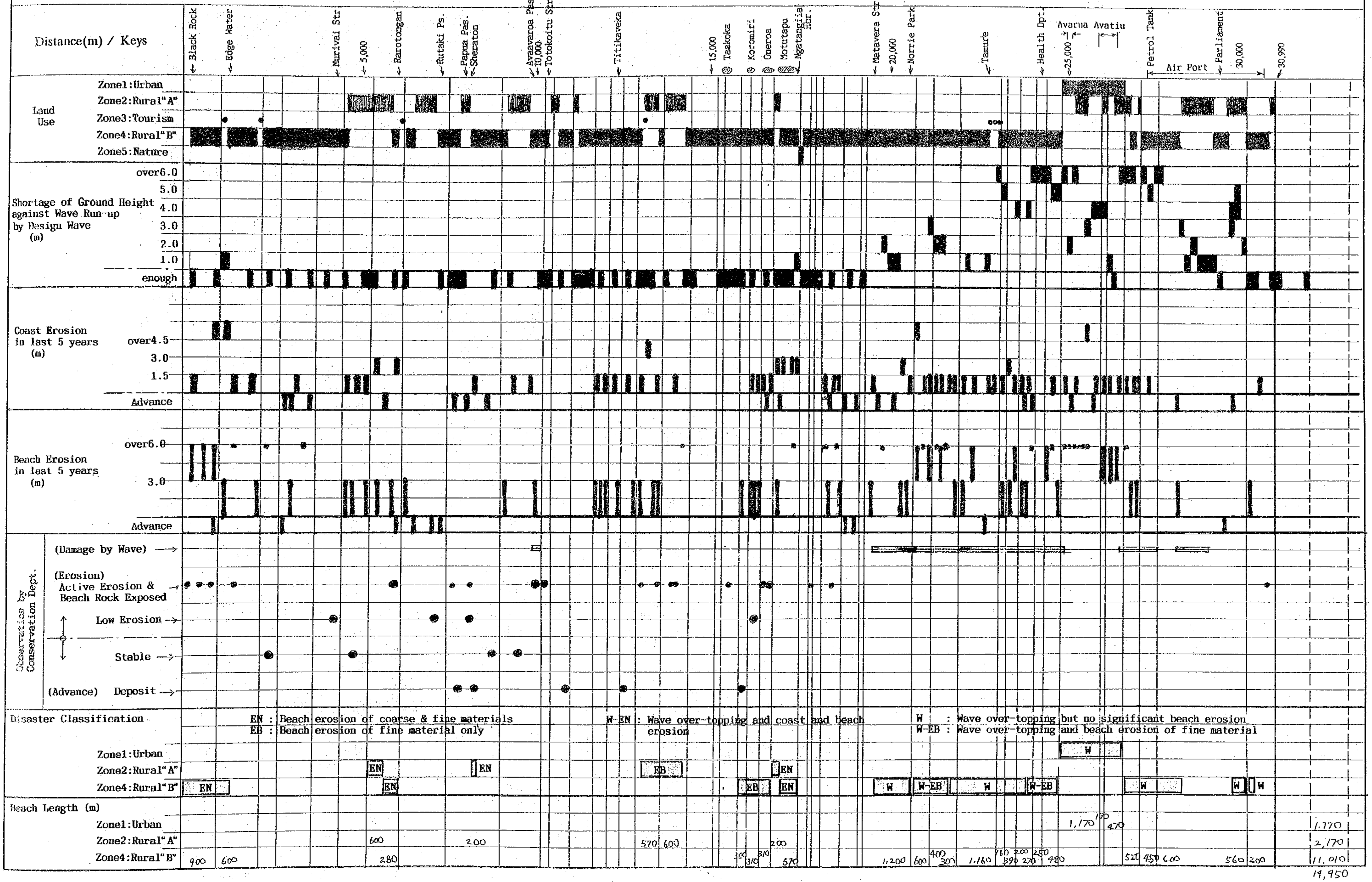
Zone		Area	Length	Share (%)
- Land use zone one	:	Established urban areas	1,770 m	(5.7)
- Land use zone two	:	Rural areas "A"	6,420 m	(20.7)
- Land use zone three	:	Tourism development Area	1,000 m	(3.2)
- Land use zone four	:	Rural areas "B"	21,600 m	(69.7)
- Land use zone five	:	Natural areas	200 m	(0.7)
		Total length	30,990 m	(100)

Source: Study team

This indicates that the majority of area belongs to rural zones, sharing 90.4 percent. Among this, area sharing 20.7% has the beach road within 30 m from the shoreline and has potential for further development. Established urban areas share 5.7 % of total areas and are located concentrately along the Avarua area of island northern coast. There are few empty area remaining there.

Fig. 7-15 shows the dominant land use classification village by village.

Fig. 7–15 Classification of Disaster and Countermeasures by Village



7.5.2 Classification of 31 Km Coastal Line by Disaster Grade

Cyclone disasters are caused by not only waves and surges but also coastal erosion and beach erosion. In order to identify the dominant disaster grade by village, the following three data sources were studied:

i) Cyclone Sally damage map prepared by the Conservation Department.
ii) Perception of villagers concerning damage by waves and surges by Sally
iii) Wave run-up and over-topping calculation against design wave conducted by the study team.

Most of these data is damage assumed to have been caused by Cyclone Sally. A summary of this data is also shown in Fig. 7-15.

A summary of estimated disaster grades by the existing land use is shown in the following Table.

Table 7-3 Summary of Countermeasures

unit : Length of Beach in meter

Disaster Grade	Present Land Use Classification						Shared (%)	
	Urban	Rural "A"	Tourism	Rural "B"	Nature	Total	Affected	Total
I Wave over-topping and coastal erosion	1,770	-	-	-	-	1,770	11.8	5.7
II Wave over-topping and beach erosion	-	-	-	2,000	-	2,000	13.4	6.5
III Wave over-topping	-	-	-	5,740	-	5,740	38.4	18.5
IV Coastal erosion	-	1,000	400	1,850	100	3,350	22.4	10.8
V Beach erosion	-	1,170	200	720	-	2,090	14.0	6.7
Subtotal	1,770	2,170	600	10,310	100	14,950	100%	-
No damage	-	4,250	400	11,290	100	16,040	-	51.8
Total	1,770	6,420	1,000	21,600	200	30,990	-	100%

Locations of identified disaster grades are shown in Fig. 7-15 and Table 7-4.

According to the table above, all the existing urban area is identified as dangerous area. Reason of this may be attributed that the urban area has been developed along the coastline. About 34 % of the rural "A" and 48 % of the rural "B" are categorized as dangerous areas. A total coastal length of dangerous rural areas is 12.5 km long sharing 83 % of a total dangerous area in 15.0 km long.

Particular in wave over-topping data indicate as follows:

(i) Over-topping is concentrated in the island northern coast.

(ii) Over-topping is observed all the coastlines between village Matavera/Tupara and Village Kaikaveka. Wave over-topping heights vary 1 m to over 6 m averaging about 4 m.

(iii) Over-topping is observed at three coasts except the northern coast.
- Northern end of Village Tokerau/Inava ---------------- 1 m
- Near the Ngarangii Passage at Village Avarua ---------- 1 m
- West of the existing airport ---------------------------- 1~5 m

(iv) Damage records of wave action by Conservation Department well meet with the severe wave over-topping coast estimated by the study team.

Based on these data and their evaluation, coasts to be provided with wave over-topping countermeasures should be selected. It is proposed that criteria for selection is the coast which wave cover-topping height is over than 2 m.

As shown in the Table and Figure, the countermeasures against wave over-topping, the most serious disaster to coastal areas are proposed along the following areas.

Coastlines of Wave Over-topping more than 2 meters

a) Shoreline between the northeast corner at Village Matavera/Tupapa to the East end of the airport (8,750 meter long)

b) West of the airport (760 meter long)

Affected coast by erosion can be summarized as follows:

(i) According to the perception study on cyclone damage, erosions here happen over all the coasts. However, these data should carefully be read because villagers are not always technical persons.

(ii) According to the damage records by the Conservation Department, erosion is observed all the coastline except northern one. Even in the same village, both erosion and deposit were observed. This may indicate that coastal change is depend also on the local condition.

Based on these data and their evaluation, coasts to be provided with erosion countermeasures should be selected. It is proposed that following condition will be selection criteria.

(i) Coasts recorded as "Active Erosion" and "Exposed Beach Rock" by the Conservation Department.

(ii) Coasts of coastal erosion more than 1.5 m per 5 years or coasts of beach erosion more than 3.0 m per 5 years in the perception study.

Coastline with Active Erosion Observed by Conservation Dep. or Villagers

Countermeasures against erosion is proposed at the following five coastal groups:

a) Northwest shoreline 1,500 meters at Villages Pokoinu I.R. and Tokerau/Inave against coastal erosion. This area is immediately South of the Black Rock where the lagoon width is the narrowest and is exposed to the northern direction from which larger waves approach.

b) Southwest corner (880 meters) at Village Aroa against coastal erosion.

c) Southwest shoreline (200 meters) at Village Vaimaanga against coastal erosion. This area faces Papua Passage.

d) Southeast corner (1,170 meters) at Villages Akapuao and Tikioki against beach erosion.

e) East coast (1,690 meters in total) at Villages Areite, Nukupure, Aroko and Avana. The shoreline (920 meters) at first three villages of requires countermeasures against beach erosion. The remaining 770 m at Avana coast requires countermeasures against coastal erosion.

Table 7-4 List of Coasts to be protected

No.	Village	Coast Unit* (200 m each)	Length (m)	Land Use		Disaster Grade
101	Pokoinu I.R.	1011 - 1015	900	Rural "B"	III	Coastal Erosion
102	Tokerau/Inave	1012 - 1023	600	"	"	"
-	-	-	-	-	-	-
107	Aroa	1071 - 1073	600	Rural "A"	IV	Coastal Erosion
"	"	1074 - 1075	280	Rural "B"	"	"
-	-	-	-	-	-	-
201	Vaimaanga	2014	200	Rural "A"	IV	Coastal Erosion
-	-	-	-	-	-	-
209	Akapuao	2092 - 2094	570	Rural "A"	V	Beach Erosion
210	Tikioki	2101 - 2103	600	"	"	"
-	-	-	-	-	-	-
303	Areite	3031 - 3032	300	Rural "B"	V	Beach Erosion
304	Nukupure	3041 - 3042	310	"	"	"
305	Aroko	3051 - 3052	310	"	"	"
306	Avana	3061	200	Rural "A"	IV	Coastal Erosion
"	"	3062 - 3064	570	Rural "B"	"	"
-	-	-	-	-	-	-
403	Matevera/Tupapa	4032 - 4037	1200	Rural "B"	III	Wave Over-topping
404	Titama	4041 - 4043	600	"	II	Wave Over-topping and Beach Erosion
501	Araitetonga	5011 - 5012	400	"	"	"
"	"	5013 - 5014	300	"	III	Wave Over-topping
502	Kiikii	5021 - 5026	1,160	"	"	"
503	Punataia	5031	160	"	"	"
504	Tapae	5041 - 5042	390	"	"	"
506	Pue	5061	200	"	"	"
"	"	5062 - 5063	270	"	II	Wave Over-topping and Beach Erosion
507	Vaikai	5071 - 5072	250	"	"	"
601	Ngatipa	6011 - 6013	480	"	"	"
603	Avarua	6031 - 6036	1,170	Urban	III	Wave Over-topping
604	Ruatonga	6041	130	"	"	"
605	Avatiu	6051 - 6053	470	"	"	"
701	Atupa	7011 - 7013	520	Rural "B"	"	"
702	Kaikaveka	7021 - 7023	450	"	"	"
703	"Airport"	7031 - 7033	600	"	"	"
-	-	-	-	-	-	-
703	"Airport"	70311 - 70313	560	Rural "B"	III	Wave Over-topping
706	Pokoinu	7061	200	"	"	"
	Total		14,950 m			

Note, For the Coast Units, see Appendix C-1. "Coastal File"

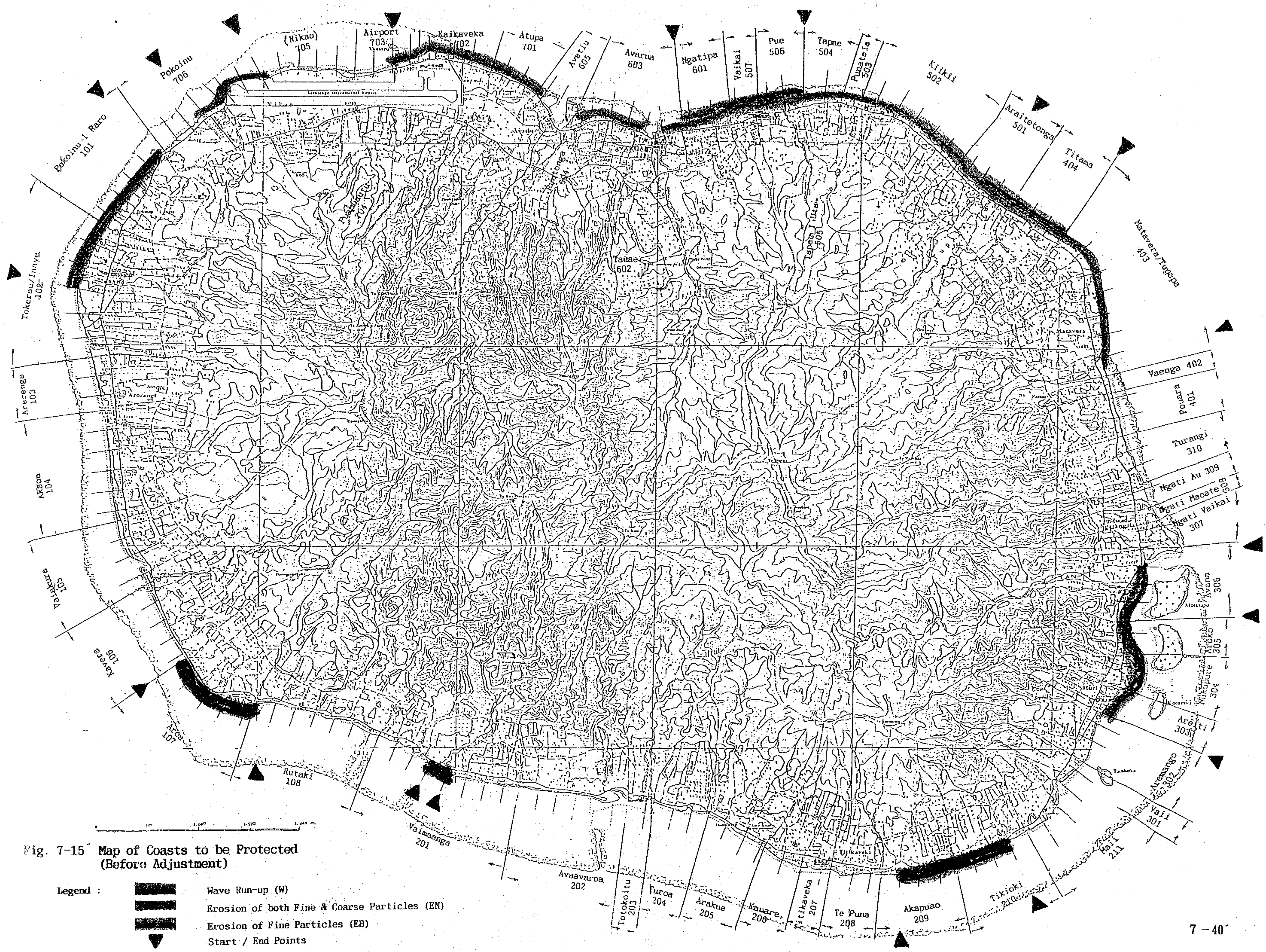


Fig. 7-15 Map of Coasts to be Protected (Before Adjustment)

Legend :

- Wave Run-up (W)
- Erosion of both Fine & Coarse Particles (EN)
- Erosion of Fine Particles (EB)
- Start / End Points

7.6 Countermeasures at Northern Coast.

This section deals with the basic countermeasures of northern coast protection in the Rarotonga Island. This area seems high disaster potential and large amount of damage by cyclone. Thus, it is recommended that this area should be provided with an urgent protection as defined the "Short-term Development Plan". For this purpose, the basic protection concepts of urbanized areas especially Avarua Coast.

7.6.1 Proposed Protection Areas

The main protection target at the northern coast is the mitigation of cyclone disasters by wave over-topping beyond the beach top.

As shown in Fig. 5-6, the grade of overtopping height differs depending upon place. Blue line in the figure shows the lack of existing beach top height, that means a gap between the beach top of and the top of overtopping water bodies.

Required countermeasures will basically be provided at the coasts where overtopping of more than two meters is expected by the design waves namely equivalent significant offshore waves caused by Cyclone Sally. Proposed protection study areas are as follows:

1) Village Matevera/Tupapa to the middle of Village Pue (4,410 m)

   The lack of height is generally about two meters, but partly six meters. There is practically few erosion.

2) From the middle of Village Pue to Village Ngatipa (1,000 m)

   The lack of height is generally about five meters, but partly seven meters. The largest gap can be seen at the coast behind the Health Department at Village Vaikai.

3) Avarua - Ruatonga - Avatiu Coast (1,770 m)

   This area belongs to the developed urban zones having the highest concentration of facilities such as shopping centers, restaurants, banks, government offices and the two existing harbours, Avatiu and Avarua.

   The lack of height is about four meters, but partly six meters at the Avarua East. The areas covered by the existing breakwater may be overtopped by two meters. A lack of height in the Avarua Coast (700 m) between the existing two harbours is about 3.5 meters.

4) Villages Atupa, Kaikaveka and the first 600 m of the "Airport" Area. (1,570 m)

The lack of height here is about six meters. This area includes the fuel storage yard which directly faces the lagoon.

In the West beyond this coast, the width of lagoon becomes larger where wave overtopping is about one meter.

5) West end of "Airport" and Village Pokoinu (760 m)

In this area, the level of beach road is low as MSL +2.5 m in order to maintain a structural clearance subject to airport construction limit. Wave overtopping here is about four meters.

Note: The allowable over-topping limit height here is two meters. In the detailed design stage, this limit should be decided by the land use scheduled and structural condition of seawall.

Fore the time being, allowable limit height is proposed as follows:

(i) Durable seawall in the ordinary area
Limit height = 4 m

(iii) Average seawall in the urbanized area
Limit height = 2 m

See more disucussion in subsection 12.2.3.

These five selected areas can be divided into two groups in respect to the coastline configuration.

(i) Areas where coastline runs straightly and rather simple line.

- Matevera/Tupapa to Pue Coast,	4,410 m
- Pue to Ngatipa coast,	1,000 m
- Atupa, Kaikaveka and airport area,	1,570 m

Normal line of coastal protection work may run along the existing coastline.

(ii) Areas where coastline curves.

- Avarua - Ruatonga - Avatiu coast,	1,770 m
- Airport west and Pokoinu coast,	760 m

These coastlines curve, in and out, by means of passages, breakwaters and reclaimed works on lagoon. Avarua - Ruatonga - Avatiu coast contains two harbours and runs in front of valuable facilities on beach bank. It is assumed that wave and current during cyclone may be so complicate that simulation study is required.

Above : Entrance of existing Avarua Harbour and the reef towards east

Below : Avarua Lagoon between Avarua Harbour and Avatiu Harbour