APPENDIX F REUSE AND DISPOSAL OF EFFLUENT AND SLUDGE

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APPENDIX F REUSE AND DISPOSAL OF EFFLUENT AND SLUDGE

1. Introduction

As a result of introduction of sewage treatment for Port Moresby Sewerage System, a large amount of treated sewage and sludge will be generated continuously. The estimated amount of the effluent and sludge at year of 2015 are summarized below.

Table F.1 The Estimated Amount of the Effluent and Sludge on Eight STPs in 2015

Zone	STP	Effluent m^3/day	Sludge tonDS/year
Inland Area	Waigani	86,700	< 100
	Morata	15,200	< 20
	Gerehu	18,000	< 20
	Bomana	39,900	< 40
Coastal Area	Paga Point	15,900	302
	Kila Kila	31,600	599
	Vetorogo	13,100	< 20
	Dogra Kohu	18,200	< 20
Total		238,600	

Reuse/disposal of the treatment products, especially sludge, may be a key issue for the sustainable operation/maintenance of the sewerage system. It is the best solution to build in natural recycling system. Accordingly, the reuse of effluent and sludge is studied in the following section.

2. Reuse of Effluent from Sewage Treatment Plant

2.1 Options of Effluent Reuse

Continued population growth, contamination of both surface and groundwaters, uneven distribution of sources, and periodic droughts have forced water agencies to search for innovative sources of water supply. Use of highly treated wastewater effluent, now discharged to the environment from municipal wastewater treatment plants, is receiving more attention as a reliable source of water in some developed countries.

Port Moresby city is located in Tropical Savanna Zone and the operation of the water supply in the city is comparatively adequate at present. However, a drought and an increase of water demand in the future will easily cause water shortage in the city. From this viewpoint, the reuse of sewage treatment plant effluent can be one of measures against water shortage.

As for the reuse of sewage treatment plant effluent in Port Moresby city, options are required to examine, in consideration of the following elements.

- Locations (Inland area and Coastal area)

- Applications
- Required water quality for each applications
- Methods of sewage treatment

The followings are the options for Inland and Coastal areas:

2.1.1. Inland Area

(1) Green Belt

The government areas presently without particular use, is located on the north of the runway extension of Port Moresby International Airport and between Morata and Moitaka. This area with a width of 1 km and a length of 3 km can be utilized for a forest by planting the trees such as eucalyptus etc. This can eventually be converted into a park and as a place of the relaxation of the people of Port Moresby, when this part of the city is developed into a suburban area.

Water supply to this area will be done by pumping the effluent from Waigani sewage treatment plant to an artificial pond in the southeast end of the area. Water is distributed to this whole area, through the channels that are encircled and stretched in a grid state in this area from an artificial pond. In the early stage of forest plantation, it will need manual sprinkle by getting water from the channel.

(2) Garden Watering

Many government offices, a university, green areas, a golf course and other open spaces are located in Waigani (Inland area) and most of these facilities require sprinkling to their yards and green areas.

The water supply is done by sending effluent with pumps from Waigani sewage treatment plant to a concrete reservoir exclusively for this at a high place in this area. Water is supplied by gravity flow from the tank to the yard of the facilities in the area.

(3) Toilet Flushing/Car Washing

This option is to reuse sewage treatment plant effluent to toilet flushing and car washing at the above mentioned facilities or buildings in Waigani area.

The water supply is done by the same method as garden watering. In this case, it needs to consider not to cause misconnection of piping, because two pipelines, one for tap water and another for reuse water, should be installed in buildings.

2.1.2. Coastal Area

(1) Garden Watering

There are numerous green areas such as Sea Park and Ela Beach in Town area, especially near Paga Point in Coastal Area. They are always a lot of people enjoying sports or relaxation. The effluent of Paga Point sewage treatment plant can be utilized for sprinkling of trees growing in these areas.

The water supply is done by sending effluent with pumps from Paga Point sewage treatment plant to a concrete reservoir exclusively for this at a high place in this area.

(2) Toilet Flushing/Car Washing

Sewage treatment plant effluent can be utilized to the toilet flushing and car washing in some buildings, mainly in government offices, also located in Town of Coastal area.

The water supply is done by sending effluent with pumps from Paga Point sewage treatment plant to a concrete reservoir exclusively for this purpose at a high place in this area. Misconnection of two pipings should be prevented.

2.2 Required Water Quality for Each Applications

There are many standards and technical papers on the reuse of sewage treatment plant effluent in developed countries and most of them indicate similar figures for reuse water quality. "Draft Guidelines for Sewerage Systems – Use of Reclaimed Water " by National Health and Medical Research Council Of Australia and New Zealand is referred to in this report.

2.2.1. Green Belt (A)

Type of reuse:
- Municipal with controlled public access
- Irrigation open spaces, parks, sports grounds

Level of treatment:
- Secondary
- Pathogen reduction

Reclaimed water quality
- <1000 thermotolerant coliforms / 100 ml

2.2.2. Garden Watering (B)

Type of reuse:
- Municipal with uncontrolled public access
- Irrigation open spaces, parks, sports grounds

Level of treatment:
- Secondary + Filtration
- Pathogen reduction

Reclaimed water quality
- pH 6.5 – 8.0
- < 2 NTU
- 1 mg/L Cl_2 residual or equivalent level of pathogen reduction
- < 10 thermotolerant coliforms / 100 ml

2.2.3. Toilet Flushing/Car Washing (C)

Type of reuse:
- Residential
- Garden watering, toilet flushing, car washing, path/wall washing

Level of treatment:

Secondary + Filtration
Pathogen reduction

Reclaimed water quality

pH 6.5 – 8.0
< 2 NTU
1 mg/L Cl_2 residual after 30 min or equivalent indicator organism reduction < 10 thermotolerant coliforms / 100 ml

2.3 Treatment Facilities for Reuse

2.3.1. Inland Area

At the three sewage treatment plants, secondary treatment is applied, consisting of anaerobic ponds and facultative ponds. Additional treatment facilities, a disinfection tank and a filter, are required for effluent reuse. Reuse water for Green Belt (A) and Garden Watering (B) is taken after a disinfection tank, while the water for Toilet Flushing/Car Washing (C) is taken after a filter.

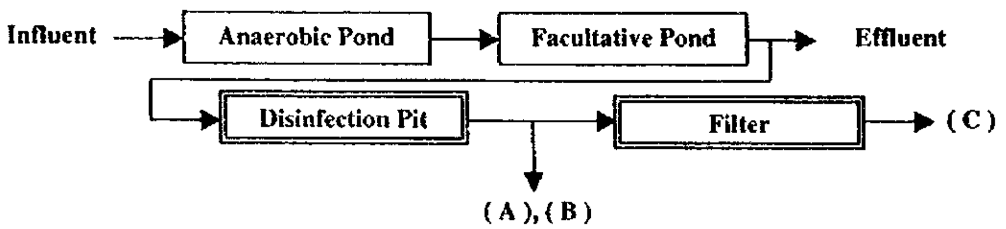

Figure F.1 Flow Seet (1)

Pumping facilities are also needed to transfer the water to distribution points, such as pond or reservoirs.

2.3.2. Coastal Area

Only primary treatment (sedimentation basin) with disinfection is applied for two treatment plant in Coastal Area. Additional treatment facilities, chemical dosing facilities and a filter are required for effluent reuse. Reuse water for Garden Watering (B) is treated by a sedimentation basin with chemical dosing, followed by a disinfection pit, while the water for Toilet Flushing/Car Washing (C) is additionally treated by a filter following to a sedimentation basin.

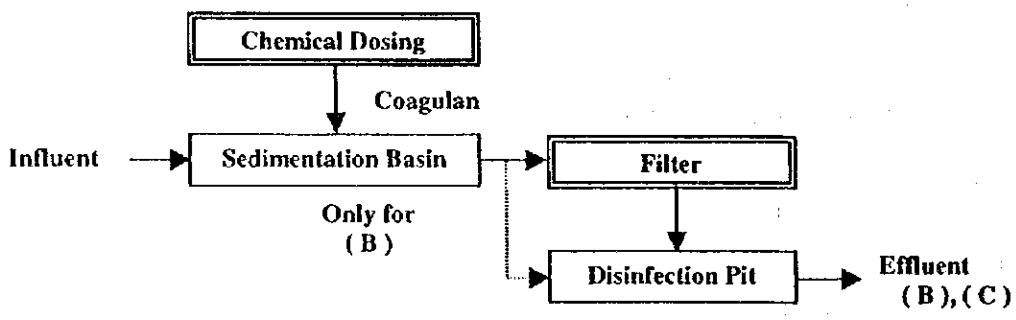

Figure F.2 Flow Seet (2)

Pumping facilities are also needed to transfer the water to distribution points such as ponds or reservoirs.

2.4 Cost for Effluent Reuse System

In "Managing Wastewater in Coastal Urban Areas : National Research Council, USA", it indicates referential figures for costs (capital cost, and operation and maintenance cost) for the above mentioned additional treatment facilities. These table are applied in this section for rough cost estimate.

Table F.2 Cost for Effluent Reuse System

	Disinfection	Chemical Dosing	Filtration
Capital Cost ($/MG)*	-	90 - 155	140 - 270
O & M Cost ($/MG)	-	45 - 110	60 - 80
Total Cost ($/MG)	-	135 - 265	200 - 350
Capital Cost (Kina/m^3)	0.18	0.12 - 0.20	0.18 - 0.36
O & M Cost (Kina/m^3)	0.04	0.02 - 0.05	0.03 - 0.04
Total Cost (Kina/m^3)	0.22	0.14 - 0.25	0.21 - 0.39

* Capital Cost ($/MG) assumptions used in computing these costs include an 8 % interest rate for a 20 MGD (76000 m^3/day) facility with a design period of 20 years. Land costs are not included.

Capital Cost ($/MG) is based on large size of facility, therefore Capital Cost (Kina/m^3) is estimated three times of Capital Cost ($/MG) because capacity of effluent reuse is estimated only size of 1000 m^3/day.

Distribution system consists of pumping stations, transfer piping, a reservoir etc. Capital cost and O & M cost of each option are estimated as follows:,

Table F.3 Capital Cost and O/M Cost of Each Options (1)

Area	Inland Area			Coastal Area	
Option	A	B	C	B	C
Capital Cost (Kina/m^3)	0.26	0.25	0.25	0.11	0.17
O & M Cost (Kina/m^3)	0.07	0.13	0.13	0.01	0.07
Total Cost (Kina/m^3)	0.33	0.38	0.38	0.12	0.23

Additional costs for each options are calculated as follows:

Table F.4 Capital Cost and O/M Cost of Each Options (2)

Area	Option	Additional Treatment	Cost (Kina/m^3)
Inland	A: Green Belt	Disinfection	0.55
	B: Garden Watering	Disinfection	0.60
	C: Toilet/Car Washing	Disinfection + Filtration	0.81 - 0.99
Coastal	B: Garden Watering	Disinfection + Chemical Dosing	0.48 - 0.60
	C: Toilet/Car Washing	Disinfection + Chemical Dosing + Filtration	0.81 - 1.10

The above cost does not include distribution system such as channels in green belt, sprinklers for garden watering and duplicate piping for reuse water in the buildings.

Meanwhile, the present water tariff of Eda Ranu is as follows:

Table F.5 Water Tariff of EDA RANU 1997

	Residential	Non-Commercial Government	Commercial/ Industrial
First 50 m^3	K 0.30 per 1 m^3	K 0.50 per 1 m^3	K 0.50 per 1 m^3
Next 100 m^3	K 0.75 per 1 m^3	K 0.85 per 1 m^3	K 0.85 per 1 m^3
Next 200 m^3	K 1.05 per 1 m^3	K 1.05 per 1 m^3	K 1.05 per 1 m^3
Minimum Charge per month	K 50.00	K 50.00	K 50.00

In terms of cost per m^3, both water supply and reuse water supply are similar. Further, detailed cost comparison are required for promotion of reuse water supply.

2.5 Comments on Effluent Reuse System

In general, reuse-water supply cost is much higher than water supply, considering the bad quality of raw water (sewage), additional treatment required, size of facilities for treatment and distribution etc.

In Inland Area, sewage is treated by stabilization pond, and treated water quality is comparatively good and easily applied for forestry and garden watering. However, the location for reuse is far from treatment plants and therefore, higher transportation cost is required. While, in Coastal Area, especially Paga Point, there are many facilities where reuse water can be utilized, but sewage is only treated by sedimentation basins and additional treatment needs higher cost. Moreover, treatment plant in Paga Point has difficulty of land availability for the additional treatment.

However, the facts that Port Moresby city is located in Tropical Savanna Zone having less rainfall and limited water source, requires conservation of the present water source and multiple usage of water. The responsible authority for water resources should accelerate reuse of effluent of sewage treatment plant as a new water source.

3. Reuse of Sludge from Sewage Treatment Plant

3.1 Possible areas for sludge reuse

(1) Sludge use in forestry

The use of sludge in forested areas is subject to be considered on application rates, method of application, nitrogen requirements etc.

It is recommended that annual sludge application rates to nature forests be limited to 200 t DS/ha to prevent possible damaging effects to tree root systems and to minimize the risk of pollution to water by runoff since forest land is often on steep slopes in water catchment areas.

Contamination of water supplies by nitrates can be prevented by limiting sludge application rates according to the nitrogen needs of the trees. A typical application rate of 40 t/ha in a single application every 5 years is quoted by the U.S. EPA.

Acid soils, which may cause increase metal mobility is another area which should be investigated in this reuse option.

(2) Sludge for turf production
Liquid, dewatered, dried or composted sludge may be used in turf production. If liquid sludge is to be used, it is recommended that it should be injected or ploughed into the soil prior to planting of turf. If dewartered or dried sludge is surface applied to establish turf, public access should be limited for 3 months.

(3) Sludge use in parks and public recreational areas
Sludge may be used as a substitute for conventional inorganic fertilizer and as a soil conditioner in the maintenance of parkland vegetation - lawns, trees and shrubs, golf courses, sports fields etc., or in the reclamation of land for park establishment.
Surface application of liquid sludge is not recommended (except for land reclamation prior to park establishment) to reduce odors, to avoid sludge sticking to the surface of turf, particularly close cut, veil maintained turf such as golf courses, and to lessen public concerns relating to the use of sludge in public areas.
Dewatered or air dried sludge may be used but it is recommen9ed.that.it should be evenly mixed with sand or soil and applied in thin layers and the sludge/soil mixture covered over by a minimum 50mm thick layer of topsoil. Public access should be restricted until a vegetative cover is established.
Where sludge is to be used on sports fields where contact sports are played, it is recommended that either the soil cover is increased to 125mm or heat dried sludge is used or a minimum 3 month period is allowed before contact sports are played.

(4) Sludge use on highways, construction site landscaping
The construction of highways, shopping malls, large buildings etc. can create large areas of marginal, eroded or generally poor quality soil. Liquid, dewatered, dried or composted sludge may be used in landscaping these areas by mixing in with the soil prior to planting to provide a soil environment suitable for vegetative growth.

3.2 Sludge reuse in agriculture

Agricultural land is defined here as land used for planting food crops, for direct or indirect human consumption or for animal feed intended for for human consumption. It includes land used as pastures for animal grazing.

(1) Application methods
Spreading of sludge prior to crop planting is recommended because of the problem of adherence of sludge to plant surface if it is applied during growth. This is also a problem for pasture land, where sludge may adhere to grass and be ingested directly by grazing animals.
Sludge should not be applied during excessively wet weather conditions to prevent hydraulic overloading of the soil which may lead to excessive runoff from the site.

(2) Application rates
The application rate to crops is dependent on several factors including crop type, soil characteristics, site location, yield requirements, available nitrogen in the soil and contaminant levels in the soil and sludge. The relationship between the Annual Pollutant Loading Rate (APLR) and the Annual Whole Sludge Application Rate (AWSAR) is given by the equation:

APLR = C x 0.001 x AWSAR

Where APLR = Annual Pollutant Loading Rate (kg/ha/year)

C = Pollutant concentration in sewage sludge (mg/kg DS)

AWSAR = Annual Whole Sludge Application Rate (ton/ha/year)

Table below outlines a method for approximating Annual Application rates based on the heavy metal content of any given sludge.

Table F.6 Annual Application rates on the Heavy Metal Content of Sludge

(Unit: mg/kg DRY WEIGHT)

AWSAR	5 t/ha	10 t/ha	20 t/ha	30 t/ha	40 t/ha	50 t/ha
Cadmium	50	25	12.5	8.3	6.3	5
Chromium	3000	1500	750	500	375	300
Copper	4000	2000	1000	667	500	400
Mercury	120	60	30	20	15	12
Manganese	2000	1000	500	333	250	200
Nickel	800	400	200	133	100	80
Lead	3000	1500	750	500	375	300
Selenium	1000	500	250	167	125	100
Zinc	10000	5000	2500	1667	1250	1000

Note: Limiting value of AWSAR suggested by US EPA.

(3) Crops

Food crops whose harvested parts are above ground and touch the sludge or soil-sludge mixture should not be grown for 6 months after application.

Food crops whose harvested parts are above ground and do not touch the sludge may be grown at any time but any dropped fruit should not be harvested for human consumption.

Food crops whose harvested parts are below the surface should not be grown for 4 years after land application, or 6 months if it can be demonstrated at that time that there are no viable helminth eggs in the soil.

Feed crops (for animal consumption) grown on land to which sludge has been applied should not be harvested for 1 month after application. This period of exposure to environmental conditions before harvesting allows wind action and rainfall to reduce the amount of sludge adhering to crops and to further attenuate pathogens.

Tobacco should not be grown on land receiving sludge because of excessive cadmium accumulation by this crop and the potential for increased exposure to cadmiun in cigarette smoke.

(4) Farm management

Pigs and poultry should be excluded from any pastures to which sludge has been added.

Where sludge is applied to pastures for grazing animals, it is recommended that the sludge be injected or ploughed in and a minimum 4 week no-grazing period should be observed.

Livestock should not be grazed on excessively short pastures nor during muddy conditions to prevent ingestion of large amounts of sludge amended soil.

(5) Soil

Soil pH should be 6.5 or greater at the time of sludge application. Depending on circumstances, acid soil will probably require working to lower soil metal limits because of increased metal mobility and hence potential toxicity.

The concentration of heavy metals, plant available nitrogen and phosphorus, and pesticides in the soil should be measured before sludge is applied to agricultural land. If contamination with one of the metals contained in following table is found then the concentration of these must be considered in determining the permissible metal loading.

(6) Sludge sampling and analysis
Sludge should be sampled after processing, but before delivery to the user i.e. it should be representative of the sludge delivered to the user. Sludge analysis should be carried out at least every 12 months. Where changes occur in the characteristics of the wastewater being treated or if there is a change in the treatment process being used, then the frequency of analysis should be increased. Sludge should be analyzed for the pollutants listed in following table.

(7) Metal pollutants
Sludge for use in agriculture or in sludge (or sludge products) which is commercially marketed/retailed as potting mix or fertilizer etc. should meet the following criteria for metal concentrations and loading rates contained in below table.

Table F.7 Criteria for Metal Concentrations and Loading Rate

Pollutant	Cmax (mg/kgDS)	Max. APLR (kg/ha)	Max. CLR (kg/ha)
Cadmium	8 - 20	0.25	2.5
Chromium	500	15	75
Copper	1200	20	100
Mercury	10	0.6	3
Manganese	500	10	50
Nickel	100	4	20
Lead	500	15	75
Selenium	25	5	25
Zinc	1800	50	250

Note: Cmax means maxim metal concentrations in sludge or sludge products.
APLR means maximum annual loading of metals in sludge or sludge products.
CLR means maximum cumulative loading of metals in sludge or sludge products.

3.3 Examination result of sludge characteristics

Sludge characteristics examination was carried out at the existing STP's during the field study in PNG. The results in regard to metal concentration are summarized below:

Table F.8 Examination Result of Sludge Characteristics

(Unit: mg/kgDS)

Pollutant	Waigani STP	Morata STP	Gerehu STP
Cadmium (Cd)	2.2 - 5.0 (4.3)	3.0 - 4.6 (3.9)	2.5 - 9.2 (5.7)
Copper (Cu)	162 - 650 (449)	236 - 330 (276)	35 - 300 (193)
Mercury (Hg)	0.6 - 5.2 (2.9)	0.4 - 0.6 (0.5)	1.0 - 6.7 (3.9)
Nickel (Ni)	10 - 60 (31)	10 - 79 (48)	13 - 70 (36)
Lead (Pb)	43 - 339 (132)	129 - 150 (137)	33 - 170 (116)
Zinc (Zn)	362 - 2385 (1446)	1090 - 1494 (1252)	180 - 2800 (1307)

Note: Numbers in ( ) means average.

The original data were measured in unit of mg/L, however, the stated figures above are converted in unit of mg/kgDS. As shown in the table, the average of each item does not exceed objective level, and maximum numbers, except Zinc, which is in a satisfactory range.

3.4 Comments on Sludge Reuse System

Treatment/disposal of the sludge that is generated constant and permanent, as a consequence of sewage treatment (=sedimentation) at Paga STP and Kila kila STP, is a significant challenge for Port Moresby sewerage system.

It is considered that reuse of the sludge is a radical problem-solving method in relation to the above mentioned challenge.
Through the reuse of treated sludge, prevention of excessive load on waste-disposal dumping site, recovering worthy resources in fertilizer form and coming on the market can be achieved.
It is obvious that recycling sludge is an ideal system to mitigate an environmental impact as well as to contribute building an economical sewerage and agricultural system.

Sludge reuse for agriculture land is regarded as a optimum manner among a multitude of sludge reuse methods due to its superiority over stability, permanence and great demend.

Future measures to be conducted related to agricultural utilization of sludge are as follows:

1) To clarify the agricultural land and the demanded amount of the sludge in reference to the Annual Whole Sludge Application Rate (AWSAR), it is shown in "3.2 Sludge reuse in agriculture".
2) To establish a monitoring system of industrial wastewater and to develop a system for supervisory functions and accomplishment of adequate measures. Because the metal concentrations of the sludge is a crucial factor for agricultural reuse.
3) To study the countermeasures in case of the demands fall short of sludge products, such as storage the dried sludge and landfill into the existing solid waste dumping site.

APPENDIX G CORAL REEF ASSESSMENT

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1. INTRODUCTION

This report provides the result of a rapid ecological survey of the Walter and Joyce Bay areas of Port Moresby Harbor (Figs. G.1 and G.2). The purpose of the survey is to assess the state of the coral reef and the marine environment and evaluate the possible impacts of the construction of a sewage system in Port Moresby on the ecosystem. The two bays are in the vicinity of an inlet, which is the main shipping passage to the Fairfax Harbor. There is a wide range of ecological zones of considerable nature conservation and traditional resource use importance. These have been subjected to increasing environmental stress due to industrial and commercial development and increased usage associated increasing population pressure in the city.

Papua New Guinea (PNG) lies within the zone of maximum global coral reef diversity (Veron, 1986; Sekhran and Miller, 1994). This situation is similar for the mangroves. Of the 54 mangrove species in existence globally, 33 are found in the Pacific Region and 31 of these occur in PNG (Bleakley, 1996). Therefore every attempt must be made in the sustainable use and conservation of such resources along with developmental activities. In addition to their importance in biodiversity, PNG'S coral reefs and the related ecosystems are of great social and economic significance. Literature search shows very little information on the biotic and abiotic components of PNG reefs. An assessment of the status of the coral reefs in PNG by Huber (1994) reveals that they are very poorly known and studied, although they are recognized as having high biodiversity and global significance.

2. OBJECTIVES

1) Provide a general qualitative description of the biotic and abiotic environments Joyce Bay and Walter Bay.
2) Identify sensitive important areas or marine habitats.
3) Identify possible routes of the proposed sewage pipeline routes with minimal destructive impacts to the coral reef communities.
4) Establish permanent sampling sites for the long-term assessment of the health of the reef communities and other related habitats.
5) Identify other issues that need to be addressed in the mitigation of negative impacts of the proposed sewage system on the marine environment.

3. METHODS

For the purpose of this study, the survey site is divided into three sectors A, B, and C (Fig. G.2). Fieldwork was done over a 12-day period between 19th December 1997 and 4th February 1998. Details of the sampling program are given in Appendix I. An 8-meter dinghy and a 5-GT support vessel TV Scomber were used. Four SCUBA divers and two-support personnel made up the team. The techniques for data collection included, casual visual observations both in and out of water, SCUBA, snorkeling, viewing through glass-bottom boxes while motoring slowly over the reef flats, inter-tidal zone and the sea grass beds. The positions of all survey sites were fixed using portable Global Positioning System (GPS) equipment.

The Manta Tow technique was employed along the approximately 18 kilometers of coastline of the three sectors, with a 2-minute-timed series at the various routes along the intertidal zone, reef slope and edge, across the bay, and around the three small rocky islands of Lade Kone, Daunagena and Manubada. The intertidal zone is approximately 50 meters from the shoreline. A total of 11 transects were made. Figures G.3 to G.5 show the Manta Tow transects in each of the 3 sectors.

Coral percentage cover estimates were made using the Line Intersect Transect (LIT) technique. Seven representative permanent recoverable stations were established for the long term monitoring of coral health (Fig. G.6). Star pickets were hammered into the substrate at the survey. In each of the 7 LIT stations, 5 replicates of 20 meters in length were made giving a total of 100m of reef length per station. At least 45 minutes of bottom dive time at each site were devoted in doing the 5 x 20-meter transect. Benthic life forms, sketches of reef features and notes on environmental conditions were recorded on underwater paper.

Survey techniques used in this study were adopted from the manual "ASEAN – Australia Marine Science Project: Living Coastal Resources" (English et at, 1994). Techniques of Manta Tow and of the assessment of coral predator crown-of-thorns (Acanthaster planci) were adopted from Bass and Miller (1996). Identifications of corals, fishes, marine algae and sea grasses were made with the help of field guides and species identification books [Brouns (1986), Heijs (1985), Johnstone, (1979) for seagrasses; Veron (1986), Allen and Steene (1994) for corals; Colin and Arneson (1995) for marine invertebrates; Randall et al. (1992), Allen and Swainston (1993) for fishes].

The software ARMDES: AIMS Reef Monitoring Data Entry System (Bainbridge, 1995) was used in processing the collected data on the coral reef survey.

4. GENERAL DESCRIPTION OF THE STUDY SITE

The study area is in the western sector of the Papuan coastal lagoon and lies within the Port Moresby Harbor. It covers Walter Bay and Joyce Bay (Fig. G.1). It is separated from the open sea by a discontinuous coral line barrier reef, which occurs on the edge of the narrow continental shelf approximately 3-km offshore (Moore, 1982a). There are two major inlets. To the northwest is the Port Moresby Harbor, the Port to the capital city of Papua New Guinea. The other is Bootless Inlet to the east. The Bays are protected from the open sea by a discontinuous barrier reef.

Coral reefs in the study site can generally be grouped into 3 categories: 1) the narrow discontinuous fringing reefs, 2) the patch reefs, and 3) the offshore barrier reefs which are either exposed and submerged. The reef slopes ranged from shallow (0 – 20°) to moderate (21 - 45°). Sectors A and B are generally shallow and Sector C is relatively steeper. Between the reef and the intertidal zone, seagrass beds are extensive. Water depths in the lagoon do not exceed 50 meters.

The landforms consist of a series of low hills with slopes ranging from 45 - 90°. The coastal plain is narrow. But in Pyramid Point, the eastern-most point in the survey site, the coastline of rocky hills drop straight into the sea. The hills are mainly open savanna. The vegetation is dominated by eucalyptus trees (Eucalyptus sp.). Precipitation is distinct. The wet season is November – April; and May – August the dry season. During the wet season, the northwest winds predominant while during the dry season the southeast trade winds prevail. The region lies in the rain shadow of the Owen Stanley Mountains, which restricts the annual precipitation (Moore, 1982b). No rivers or creeks flow into the harbor and the lagoon.

5. TYPES OF HABITAT

Moving seawards from the high water mark, the following types of habitat can be encountered: the shoreline, the intertidal zone, the seagrass beds, the shallow submerged reef, the reef slope, and the basin floor. The outer reefs and mangrove habitats are also briefly described here.

Coral growth was observed down to 6 meters depth in Sectors A and B. In Sector C, coral growth was observed down to 10 meters depth. Coral growth sharply declines in the sandy/silty basin floor.

The coral reefs contain a diverse range of species and a genetic pool of marine flora and fauna. These include fishes, crustaceans (crabs), seagrasses, algae, soft corals, molluscs, echinoderms (sea urchins), polychaetes (sea worms). Table G.1 lists the marine organisms observed during the sampling period, and their distribution in the survey site. Huber (1992) has done a similar preliminary marine environmental investigation in the western portion of the Port Moresby Harbor and found a similar marine biodiversity.

The Shoreline. The shoreline is made of one or the combination of rocks, rocky cliff, boulders, sand, and coral rubbles. A small strand of mangroves can also be found. Generally, the shoreline is rocky except on Ela Beach and some parts of Joyce Bay where shore is sandy. A total of approximately 18-km cover the survey area.

Intertidal Zone. The intertidal zone is the portion of the beach that is submerged during high tide and exposed during low tide. The intertidal zone of the survey site has a sandy/silly substrate. The zone is generally covered by a mixture of species seagrasses Syringodium sp. and Thalassia sp. At Pyramid Point, however, single species of seagrass (Syringodium sp.) predominates. The seagrass beds are hosts to a number of juvenile invertebrates such as shrimps and crabs. Some areas have coral rubble covered by algal assemblages. The width of the zone ranges from 1 to 3 meters. This zone has been highly degraded due to prolonged exposure at low tides and overharvesting of the resources they contain.

Seagrass Beds. Seagrass beds extend beyond the intertidal zone. Thalassia hemprichii, Enhalus acoroides, Halophila ovalis, Syringodium isoetifolium and Halodule sp. prevails. On areas with hard substrate (coral rubble and boulders) and some sandy areas, brown algae Padina minor, Sargassum sp., Turbinaria sp. and coralline algae dominate. The seagrass beds were seen to contain schools of juvenile fishes. This suggest that they are the nursery grounds for the nearby reef fishes. This observation is consistent with that of Kawanamo (1997) who identified 47 species of juvenile coral-reef associated fishes in the seagrass beds and mangroves of Motupore Island.

Submerged Reef Flat. The depth of the submerged reef flat does not exceed 4 meters. A wide range of organisms inhabit this area, including snails (gastropods), sea urchins (echinoids), sea cucumbers (holothurians) and sea stars (echinoderms) among which Choriaster granulatus was common. The sea urchin Diadema setosum occurred in large aggregations, and seemed to graze on the rubble and boulders.

Reef slope. The inclination of the reef slopes varies from shallow (0-20°) to moderate (21 - 45°). The edge of the reef slope is broken and undefined. The seaward, windward side of Manubada Island has a steeper slope of more than 45°. Areas of rubble sand, algal assemblages, and live coral make up the slope. Coral growth occurs down to less than 10 meters depth.

Basin Floor. The basin floor has a depth of more than 10 meters. The substrate is composed of sand and silt, and support an array of polychaetes (sea worms), crustaceans (crabs), and holoturians (sea cucumber), the latter being the most abundant.

Outer Reefs. The waters of the offshore reefs of Clarke Patches, Sinavi, Lark Patches, Nateara and the sunken barrier are well mixed due to their exposure to the open oceanic waters. However, the waters in the 2 bay areas are not always mixed and flushed. Water movement is dependent on the tidal regime (Moore 1982a). The reefs are relatively undisturbed and it appears that the fishing pressure is relatively low.

Mangroves. Only a small patch of red Rhizophora sp. and black Avicenia sp. mangroves exist between the Joyce Bay Outfall and Pari village. The mangrove strand seems to be highly degraded, probably due to removal for house building and firewood.

6. HYDROLOGY

Oceanographic studies, specifically the circulation patterns have been studied by Moore (1981; 1982a; 1982b) in a bigger area that covers the survey site. The following are some of the findings from Moore's studies:

- Water movement is predominantly tide-driven.
- The tides of the region are of mixed amplitude and predominantly semi-diurnal. The tidal range is about 3.0m with a mean spring tidal range of 1.7 meters. When tidal range is wide (i.e. during spring tides), the lagoon is highly flushed.
- The theoretical flushing time for the harbor is 5-14 days depending on the prevailing tidal range --- shorter flushing time during spring tides than during neap tides.
- Mass water movement in the harbor is considered to be in gyre, moving in an anti-clock wise flow. A single circulation pattern appears to exist throughout the annual cycle, regardless of the prevailing dominant wind direction. This is also true for the outer lagoon

in which the dominant flow direction is from west to east, towards Pyramid Point and Bootless Inlet (Figs. G.1, and G.7-G.9).

- The surface current has a mean depth of 1.5 meters. (We note, however, that we experienced the tide currents at depths 10-15 meters while SCUBA diving during the sampling period near the Paga Outfall and the proposed outfall location.)

- The harbor waters lie above the permanent thermocline and spatial temperature gradients and diurnal variations are minimal (≤ 1.01°C). The water is always warm (26°C - 30°C) and temperature variations are responses to slight seasonal fluctuation in the atmospheric temperature.

- The surface harbor waters approximate a homohaline condition and show seasonal variation of approximately 30 – 35 ‰ salinity, depending on precipitation and fresh-water runoff.

- During the dry season, the waters develop a vertical homohalinity and become vertically stratified during the wet season. These changes are also influenced by tides entering the lagoon.

7. RESULTS

The common coral families throughout the Bays are the branching and tabulate corals (Acroporidae), branching corals (Pocilloporidae, and Milliporidae), brain or massive corals (Poritidae), and soft corals (Alcyoniidae). The corals on the fringing reefs are distributed in a patchy manner. Staghorn corals (branching Acropora) are the most common. It constitute 16% of the corals in Sectors A and B; and 20% at Sector C (Table G.2).

There is an increasing trend on the coral percentage cover and on the number of families (species richness) towards the east. Percentage cover of live corals in Sectors A, B, and C are 22, 22, and 43 %, respectively (Table G.3). Figures G.10 – G.16 give the percentages of hard coral cover and other benthic forms in each seven LIT sites. The three common coral families Acroporidae, Posilloporidae, and Alcyoniidae were encountered in Sectors A and B. In Sector C, six common families were encountered: Acroporidae, Posilloporidae, Favidae, Fungiidae, Dendrophyllidae, and Milliporidae. The Walter Bay at Sector B showed intermediate levels of coral percentage cover and species richness. The levels increase going east towards Pyramid Point at Sector C.

Figures G.17 – G.19 give the results of the Manta Tow survey along the along eleven transects in the 3 Sectors. The percentage cover on live, dead, and soft corals are presented in detail. Table G.4 summarizes these results. They also show a trend of increasing live coral percentage cover towards Pyramid Point. The trend corresponds to the increasing distance from the city center of Port Moresby. This high diversity and percentage cover towards the Pyramid Point can also be attributed to the favorable flushing and circulation condition from the open sea. Coral growth was observed at the slopes at Pyramid Point down to 10 meters depth. At Walter Bay, coral growth was observed down to only 6 meters depth. Corals can grow only in clear waters. Thus, the maximum depth at which corals can form is an indication of the "pristineness" of the waters. The dominance of fire coral Milliporidae at the shallow sandy slope Sector B is unusual. This needs further investigation for scientific interest

An array of benthic organisms was encountered. The common groups are sea urchins (Echinoderms), sea cucumbers (Holothurians), sea worms (Polychaetes), starfish (Asteria), and featherstars (Comasterids). The sea urchin Diadema setusom was the most abundant. Large aggregations of sea urchins were found in throughout the survey site. Large aggregation of sea cucumbers were also found in Sector B. Cone shells (Conidae) were encountered more frequently in Sector A. Sea slugs (Nudibranchs), sea squirts (Ascidians), and sponges were relatively less common.

Coral predators crown-of-thorns (Acanthaster planci), and gastropods (Culcita sp. and Drupella sp.) were rare, except on the leeward side of Manubada Island where crown-of-thorns appears to be causing significant predation, leaving colonies of dead corals. Large aggregations of the sea urchin Diadema setosum residing at the intertidal zones of sector A and C are probably due to the removal of the fishes that feed on the sea urchin.

The macro algae funnel weed Padina sp. and Sargassum sp. are abundant in the Walter Bay, becoming less common towards Pyramid Point. The brown algae turbin weed (Turbinaria sp.) is abundant on hard substrate at Pyramid Point on reef tops. The green algae Caulerpa serrulata, Caulerpa racemosa occur together with Halimeda macroloba and Halimeda annulata, suggesting strong association of Caulerpas and Halimedas. The brown algae spikewood Actinotrichia fragilis and Dictyota sp. are more abundant at Sector C than in other sectors. A red filamentous algae, probably Lyngbya bouillonii was found growing on dead staghorn corals. Seagrass species Thalassia hemprichii, Enhalus acoroides, Halophila ovalis, Syringodium isoetifolium and Halodule sp. are common. Halophila ovalis is found mainly on sandy substrates in the patch reefs areas. Enhalus acoroides was generally associated with Thalassia hemprechii in Sectors B and C.

A more detailed description of the survey area is given in Appendix II.

Anthropogenic stresses were also observed. They are more concentrated nearer to the shoreline. Fishing, disposal of solid waste such as food wrapping plastics, and raw effluents from the surrounding villages and settlements were some of the stresses. The offshore reefs appear to display less impact and fish populations comprising of larger individuals were observed at this area. This observation is consistent with the observations during fishing experiments at the nearby Horseshoe Reef conducted between 1996 and 1997 (H. Nagaleta, pers. comm.). During the sampling period, there is no clear evidence on the use of dynamites for harvesting reef fishes, although there are anecdotal reports about this illegal and destructive fishing operation on the neighboring reefs just outside the survey site.

Another unusual stress to coral communities in Sector A & B is the large accumulations of the brown algae Padina sp. on sandy patches and shallow coral habitats. It is not clear whether these accumulations are natural occurrence or tied to anthropogenic factors. The discharge in the bays could be one possibility. Overfishing herbivore fish that feed on the algae is another possibility. The algal accumulations needed regular monitoring, as they can be used as environmental indicator species, suggesting overfishing of herbivore fish and eutrophication.

8. DISCUSSIONS

Literature review by Carpenter and Maragos (1989) indicated that some ecosystems like the mangrove swamps could assimilate low to moderate levels of sewage with few obvious effects, while coral reef ecosystems appear less adaptive to such disturbance. This is because coral reefs do not benefit from increased nutrient supply from the sewage. Corals have evolved functional processes in recycling nutrients. Additional nutrients only encourage the growth of other organisms such as the micro and macro algae, which out-competes the corals and lead to them being wiped out from probable effects such as increased sedimentation, competition from sponges, turnicates, other suspension feeders. In other words, coral reefs ecosystems are much more sensitive than mangroves to environmental disturbance.

Apart from the probable shift in the community structure that the sewage discharge can cause, sewage discharge contains pathogenic organisms that are a health risk. To avoid this, sewage should be treated and the effluents to be discharged offshore. In this case it would be outside the lagoon further from the edge of the barrier reef. Also a marine monitoring scheme to evaluate the water quality should be an integral part of the waste management plan.

The case study in the Kaneohe Bay, Oahu, Hawaii has shown such consequences. Kaneohe Bay has restricted circulation. The water resident time is in duration of weeks. Discharges caused eutrophication, stimulating massive phytoplankton growth that lead to the complete replacement of the original normal reef biological community. This further contributed to the decline of the recreational use and aesthetic values. Public outcry for the relocation of the outfall to a well-flushed, open- sea condition was strong. Within 6 years after the sewage relocation from the bay, complete coral recovery took. place (Henderson, 1992).

Sewage discharge outside the bay did not seem to have caused any problems due to rapid dilution and mixing of the sewage with open waters. An additional factor that helped promote dilution and reduce sewage effects at the surface was the placing of the outfall at more than 30 meters depth. From this case study, it is hoped that the diversion of the Paga and Badili outfalls will prevent or at least reduce coral reef degradation. However, the main Port Moresby Harbor receives raw sewage from eight different outfalls, as well as discharges from the large villages and settlement along the coast. All these discharges depend on the same current circulation pattern for their flushing. Very little improvement will take place, unless all the localized sewage discharges are connected to the main city system. The outfall performance can not be accurately determined until all other sources are centralized. Engineering consultation with standards of performance from other countries with similar hydrographic setting is to be consulted before construction. The incoming surface tidal may have some impacts to the coastal communities if the sewage is not treated.

The Current Uses of the Area and The Impacts

During the survey, the team confirmed the sources of anthropogenic stress on the marine environment. Unless this issue is also addressed, the effectiveness of any carefully-planned waste disposal scheme in mitigating adverse effects on the marine environment would be minimal

Fishing. The two bays and the reefs are the fishing grounds for the local population. There is considerable fishing within the bays and the adjacent reefs. Line fishing, gill nets and spear fishing are the main fishing methods. In the survey done by Federizon and Anas (1997) at the fishmarket of Koki, where most if not all of the fish for sale were caught within 50 kilometers from the city center, they were able to identify 5 fishing spots within the survey site. More than 40 fish species were identified from the site, about half of them as coral reef-associated fish species (Table G.5). More than 50 boats were sighted fishing at the lagoon throughout the study period. Line fishing is the prevalent gear at the Joyce Bay and at the outfall at 3-Km-Paga. The intertidal zones at the three Sectors seem overfished, especially along the Ela Beach area where large numbers of people forage on during low tides gleaning for seashells and other aquatic resources.

Disposal Practices. Observations indicate that the Bays are already severely polluted due to inadequate sewage system and improper solid waste disposals. Human feces and garbage from stilt households, and the existing untreated outfalls of the city are responsible for the contamination of the beaches and the shore waters. This imposes a risk of ciguatera (fish food poisoning), considering that the main supply of fish at the fishmarket comes from the survey site and the environs. Recent newspaper accounts corroborate this risk (Appendix III). Bacteriological analyses done by the National Capital District Commission (NCDC) Health Division on the surrounding sea indicate record high levels of fecal contamination. This contamination has also been observed to persist all year round and is most likely aggravated by current weather conditions. The wind is blowing in from the sea and the tidal movement is not strong enough to flush out the wastes.

Recreational uses. The city residents heavily use the sandy beach on the windward side of Manubada as a picnic place. The shore waters are used for yachting and canoe racing. The popular Ela Beach (at Sector A) and the adjacent area were highly contaminated with human feces in the months of December 1997 and January 1998. The NCDC issued a strong warning to the city residents to keep off the beaches and refrain from fishing during that time. The issue made headlines in the national newspapers.

Transportation. Ocean liners and container ships anchor in the Walter Bay. Anchor-damage may be minimal but increased shipping activities bring in other risks such as the discharge of oil and rubbish. There is already heavy boating in the waterways by fishers bringing their catch for sale at Koki Fishmarket. Boating in the waterways is now a hazard due to the numerous solids wastes, especially food wrapping plastics. This has been common sight throughout the lagoon. During the survey, one of the plastics got into the propeller of the dinghy and blocked the cooling system, thereby damaging the engine of the outboard motor.

Local And Public Opinion On The Construction Of The Proposed Sewage Outfall

We interviewed coastal villagers, a dive operator and a resort operator. It is not surprising that they oppose the proposed sewage scheme, for fear of the adverse impacts on their livelihood and business. They contend that the fish catch and the aesthetic values will decrease. They would rather opt that: 1) the sewage out fall to be placed beyond the proposed site (at the edge of the barrier) in open oceanic waters, and 2) the pipelines be rerouted to

avoid passing through the coral patches that exist between the shore and the fringing reef. Such opinions
expressed by the different stakeholders typify a "not-in-my-backyard" attitude.

9. CONCLUSIONS

Potential Impacts of the Proposed Joyce Bay Outfall

There will be some disturbance to the coral, fish and benthic communities during construction, regardless of the route of the pipelines. The extent of the disturbance is unknown because specific roles of many component species in the marine community are not yet well-understood. It is however, well-known the coral reefs provide sanctuary of many fish species of high economic value. Any disturbance will have differential effects on the component species. In worst ecological scenario, there will be a shift in the biodiversity of the marine community towards undesirable species composition.

The risk of an adverse impact would however be greatly minimized if the outfall is located well beyond the outer reef where water circulation is strong, and the effluents are treated. Benefits can be derived by drawing on the lessons from the case of the Hawaiian sewage system.

The results of rapid ecological survey results show that the ecosystems in the Walter and Joyce Bay areas are heavily polluted because of improper waste disposal practices and increasing industrial and economic activities. Despite the anthropogenic stresses, the marine environment still maintains a moderate level of biodiversity.

The release of pathogenic organisms from the sewage discharge has health risks. Low rates of dilution and flushing by the water circulation regime can deplete oxygen levels to the point of killing fish. It can raise nutrient levels, causing undesirable plant growth that may foul the water or smother reefs (Gangaiya, 1994).

The net effect on the near-shore communities will be the reduction in the level of contamination, if and when the entire localized sewage disposal are connected to the proposed system. The proposed distance and depth of the outfall from the shore would help reduce the present level of stress. Acceptability of the discharge again depends upon the assimilative capacity and flushing of the receiving waters.

Recommendations

In order to prevent further degradation of the marine environment and recover the ecological and aesthetic values of the area, the following recommendations are put forward.

1) To minimize the risk of destructive impact to the coral communities, the pipe route should be diverted towards Vabukori village and along the reef edge to CM1. In this case, the pipes will pass through a minimal amount of coral patches that exist between the shoreline and the fringing reef (Fig. G.20).

2) The outfall to be placed beyond the ocean edge of the barrier reef where the water circulation and flushing rates are high.

3) Sewage should be completely treated on land before being pumped into the sea.

4) Operations of the proposed sewage system should be coupled with a long-term monitoring of the water quality of the marine waters and the biotic environment to be able to detect early signals of environmental degradation. The permanent sites for long-term monitoring are identified and indicated in Figure G.6.

5) Further oceanographic studies on the location of the outfall is required to determine the exact water movements, flushing time, and circulation.

6) Issues concerning the sources of anthropogenic stress should be addressed.

7) A massive educational campaign on the proper methods of waste disposal should be instituted, including a campaign to prohibit improper practices of residents on waste disposal (e.g. disposal of plastics).

It should be noted the above recommendations are tied to each other. A disregard of one recommendation would render the other recommendations useless in the pursuit of marine environmental protection.

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Table G.1 The list of coomon marine organisms encountered during the survey.

SECTOR	SITE NAME	MOST COMMON CORAL FAMILIES	OTHER COMMON BENTHICS
A	Paga Short overflow	-Alcyoniidae, (Sinularia sp.), -Acroporidae	-Seagrass (Syringodium isoctifolium)
A	Arakuti Reef Ela Beach	-Acroporidae, -Pocilloporidae	-Coneshell (Conidae) -Brown Algae Padina minor and Sargassum sp. -Seagrass (Halophila ovalis)
B	Badili outfall	None	-Sea Urchin (Diadema setosum) -Seagrass (Enhalus sp)
B	Duagena Island	-Pocilloporidae, -Acroporidae -Milleporidae	-Brown algae (Padina minor, Padina gymnospora) -Sea cucumber (Holothuria fuscogila and Thelenota ananas)
B	Manubada Island	-Milleporidae -Acroporidae	-Coraline Algae
C	Joyce Bay Outfall	None	-Seagrass (Enhalus acoroides)
C	Joyce Bay/Vabukori village	-Milleporidae -Poritidae	-Sea cucumber (Holothuria fuscogila)
C	Joyce Bay	-Milleporidae -Poritidae	-Coraline algae
C	Joyce Bay/Pari village	-Acroporidae -Faviidae -Fungiidae -Dendrophyllidae -Pocilloporidae	-Green algae (Halimeda sp., Dictyota sp.,and Caulerpa sp.), -Sea slugs (Nudibranchs), -Sea squirts (Ascidians), -Sponges -Featherstars
C	Joyce Bay (Pyramid Point)	-Acroporida -Faviidae -Fungiidae -Pocilloporidae	Green algae (Halimeda sp., Dictyota sp.,and Caulerpa sp.), -Sea slugs (Nudibranchs), -Sea squirts (Ascidians), -Sponges -Featherstars

Table G.2 Mean Percentage Cover of Acropora and Non-acropora corals, coraline Algae, Macro and Turf Algae at the LIT stations. Standard errors are in brackets.

Sector	Site ID	LIT Station	Site Name	Acropora corals	Non Acropora corals	Coraline Algae	Macro Algae	Turf Algae
A	PGWB0001	1	Arakuti reef Ela beach	16.45 (7)	5.7 (3.5)	×	×	×
A	PGWB0002	2	Manubada Island	13.56 (1)	18 (4)	×	×	×
B	PGWB0003	3	Manubada Island	2.15 (1)	11.66 (2.5)	8 (5.5)	×	×
B	PDJB0004	4	Vabakori Village	2.2 (7)	21 (3)	3 (3.5)	×	×
C	PGJB0005	5	Joyce Bay Site 2	5.9 (4.5)	17.25 (7)	×	×	×
C	PGJB0006	6	Pari Village	11.5 (3)	31.27 (4)	2.1 (1)	×	×
C	PGJB0007	7	Pyramid Point	20.21 (7)	22.83 (4)	1.3 (1)	×	×

Table G.3 Percentage cover of hard corals, algae and abiotic forms at the LIT stations. Standard errors are given in brackets.

Sector	Site ID	LIT Station	Site Name	Hard Coral	Algae	Abiotic	Other
A	PGWB0001	1	Arakuti reef Ela beach	22.15 (7)	18.00 (5)	58.35 (11)	1.5 (1)
A	PGWB0002	2	Manubada Island	31.84 (5)	39.95 (4)	18.66 (5)	9.55 (5)
B	PGWB0003	3	Manubada Island	13.81 (3)	46.94 (7)	21.7 (9)	17.55 (5)
B	PDJB0004	4	Vabakori Village	23.54 (3)	7.6 (3)	67 (3)	1.6 (2)
C	PGJB0005	5	Joyce Bay Site 2	23.1 (6)	32.9 (4)	34.3 (10)	9.8 (2)
C	PGJB0006	6	Pari Village	42.77 (4)	36.44 (5)	15.44 (5)	5.35 (2)
C	PGJB0007	7	Pyramid Point	43.04 (5)	45.18 (4)	0.1 (0.1)	11.69 (1)

Table G.4 Medians of Live, Dead, and Soft corals from eleven Manta Tow transects.

Sector	Route	Site ID	Location	Number of Tows	Medians		
					Live corals	Dead corals	Soft corals
A	A	PDWB0001	ELA beach Inter tidal	19	2	0	2.5
A	B	PGWB0002	Ela beach Arakuti	26	3	1	1
B	C	PGWB0003	Koki-Kabutu Inter tidal	29	1	0	1
B	D	PGWB0004	Koki-Vabukori edge/slope	25	1	0	1.5
B	E	PGWB0005	Around Kone lade Island	4	2	0	1
B	F	PGWB0006	Around Duagena Island	8	1	1	1
B	G	PGWB0007	Around Manubada Island	28	1	0	0
C	H	PGJB0008	Joyce Bay-Pyramid inter tidal	32	0	0	0
C	I	PGJB0009	Joyce Bay-Pyramid edge/slope	50	3	1	1
C	J	PGJB0010	Joyce Bay middle inter tidal (Sabama)	12	1	0	1
C	K	PGJB0011	Joyce Bay back reef (Pari)	12	1.5	0	1

Table G.5 List of commercially important fish species found in the survey site (from Federizon and Anas, 1997).

Family	Genus	Species	Common Name	Fishing gear
Balistidae	*Abalistes*	*stellatus*	triggerfish	handline
Acanthuridae	*Acanthurus*	*nigricauda*	surgeonfish	spear
Scaridae	*Bolbometopon*	*muricatum*	parrotfish	troll-line
Carangidae	*Carangoides*	*ferdau*	jacks	spear
Carangidae	*Carangoides*	*fulvoguttatus*	jacks	gillnet
Carangidae	*Caranx*	*lugubris*	jacks	handline
Carangidae	*Caranx*	*melampygus*	jacks	gillnet
Carangidae	*Caranx*	*tille*	jacks	handline
Carcharhinidae	*Carcharinus*	*sp.*	shark	gillnet
Serranidae	*Cephalopholis*	*sonnerati*	sea bass	handline
Labridae	*Cheilinus*	*chlorourus*	wrass	spear
Chirocentridae	*Chirocentrus*	*dorad*	wolf herring	gillnet
Serranidae	*Epinephelus*	*corallicola*	sea bass	spear
Scombridae	*Euthynnus*	*affinis*	tuna	gillnet
Scombridae	*Katsuwonus*	*pelamis*	tuna	spear
Leiognathidae	*Leiognathus*	*equula*	slipmuth	gillnet
Lethrinidae	*Lethrinus*	*erythropteus*	bream	spear
Lethrinidae	*Lethrinus*	*olivaceus*	bream	gillnet
Lutjanidae	*Lutjanus*	*gibbus*	snapper	handline
Lutjanidae	*Lutjanus*	*kasmira*	snapper	handline
Lutjanidae	*Lutjanus*	*rivulatus*	snapper	handline
Lutjanidae	*Lutjanus*	*semicinctus*	snapper	spear
Lutjanidae	*Lutjanus argenti-*	*maculatus*	snapper	handline
Megalopidae	*Megalops*	*cyprinoides*	tarpon	gillnet
Holocentridae	*Myripristis*	*violacea*	squirrefish	handline
Acanthuridae	*Naso*	*unicornis*	surgeonfish	spear
Mullidae	*Parupeneus*	*indicus*	goatfish	spear
Polynemidae	*Polydactylus*	*plebius*	threadfin	gillnet
Priacanthidae	*Priacanthus*	*hamrur*	bigeye	handline
Scombridae	*Rastrelliger*	*kanagurta*	mackerel	handline
Holocentridae	*Sargocentron*	*spiniferum*	squirrelfish	handline
Scaridae	*Scarus*	*forsteni*	parrotfish	spear
Scaridae	*Scarus*	*rivulatus*	parrotfish	spear
Scombridae	*Scomberomorus*	*commerson*	spanish mackerel	gillnet
Siganidae	*Siganus*	*argenteus*	rabbitfish	spear
Siganidae	*Siganus*	*doliatus*	rabbitfish	spear
Sphyraenidae	*Sphyraena*	*qenie*	barracuda	handline
Sphyrnidae	*Sphyrna*	*lewini*	shark	gillnet
Scomberidae	*Thunnus*	*albacares*	tuna	troll-line
Scomberidae	*Thunnus*	*albacares*	tuna	troll-line
Hemigaleidae	*Triaenodon*	*obesus*	shark	gillnet
Belonidae	*Tylosurus*	*crocodilus*	needlefish	spear
Mugilidae	*Valamugil*	*seheli*	mullet	gillnet

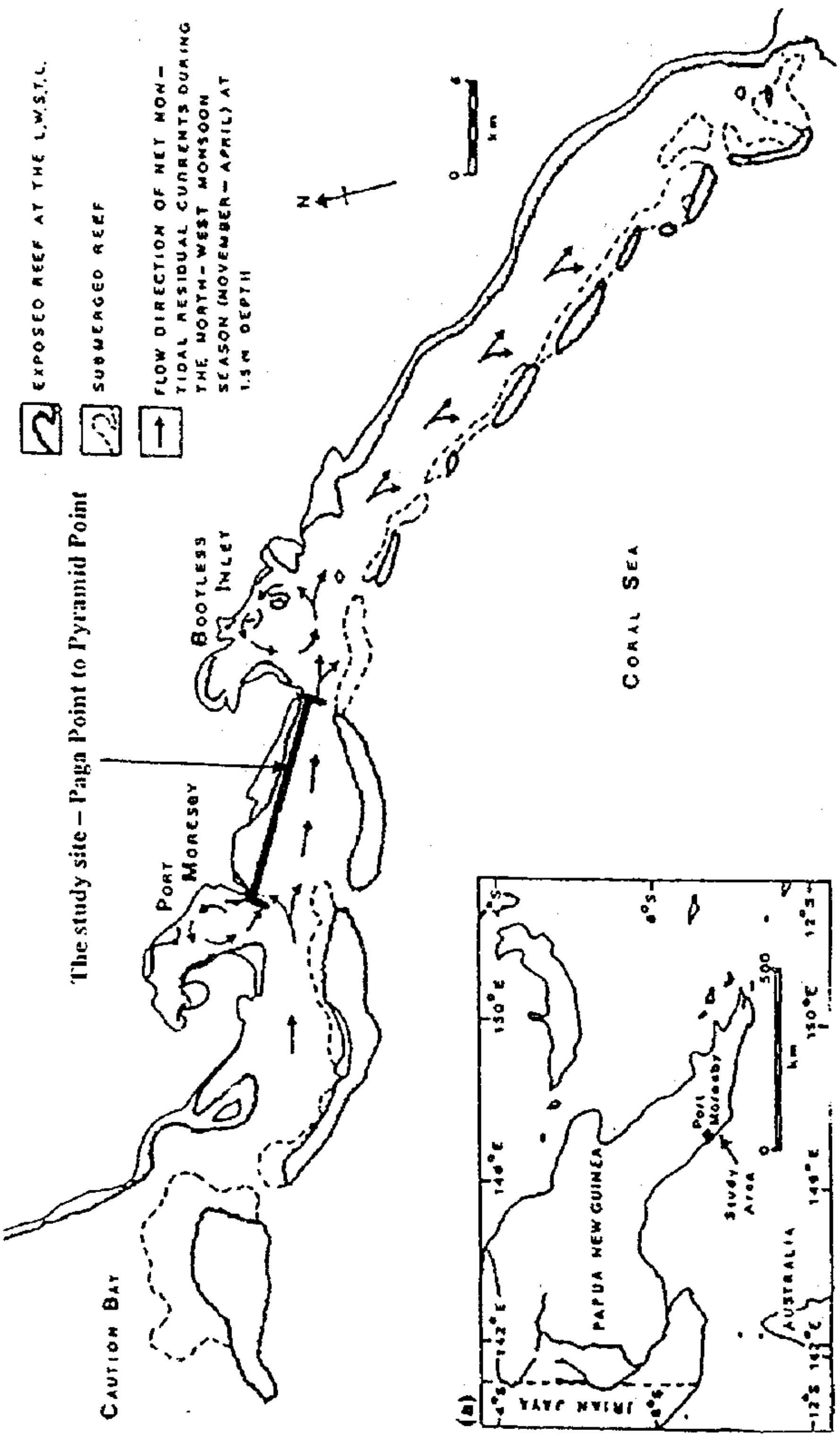


Figure G.1 Location of the Study Site with the Surface Dominant Current Flow Directions During North-Westerly Monsoon Winds (November - April) (From Moore, 1982 a)

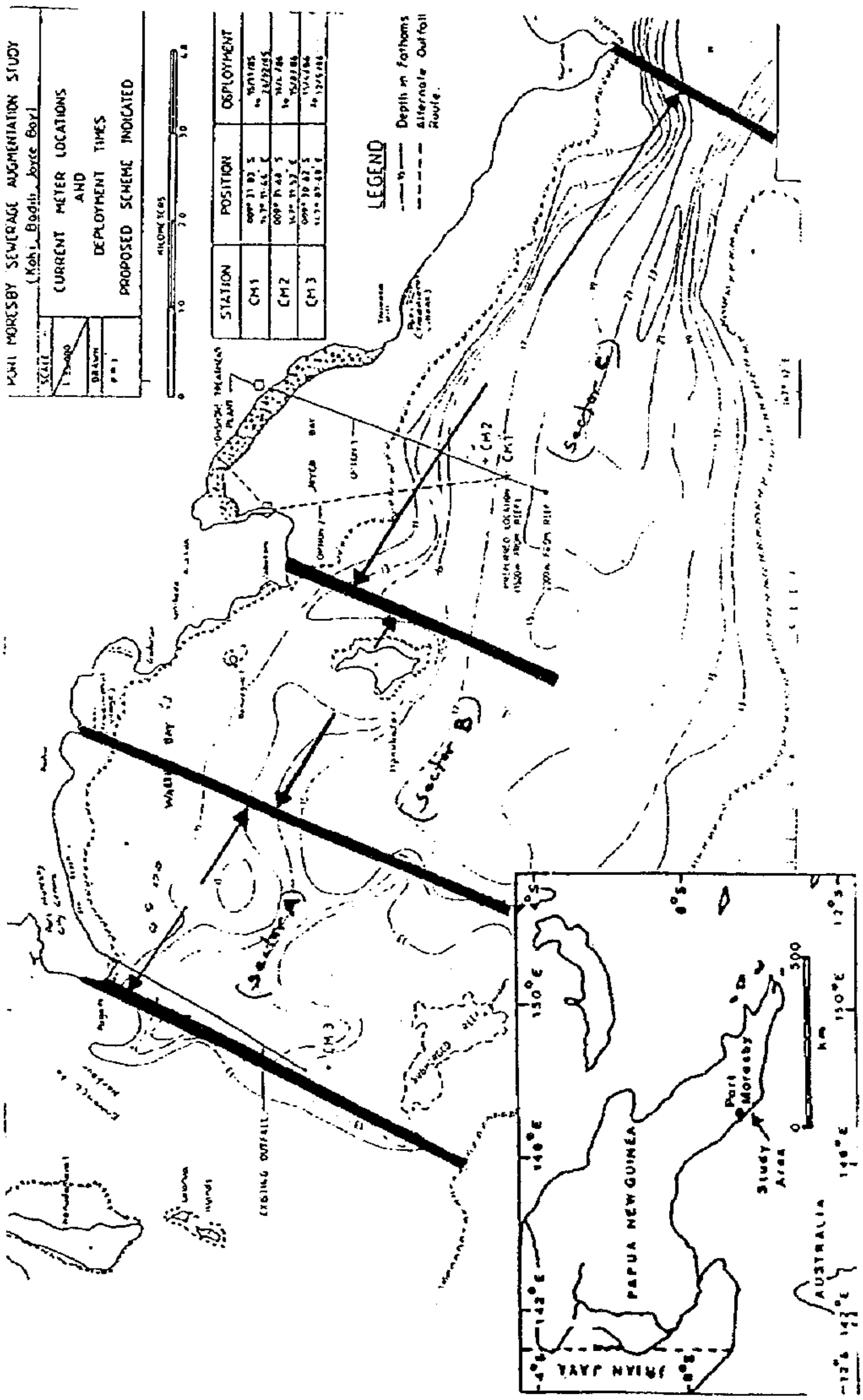


Figure G.2 The Survey Site Joyce and Walter Bays, Showing the Three Sectors A, B, and C

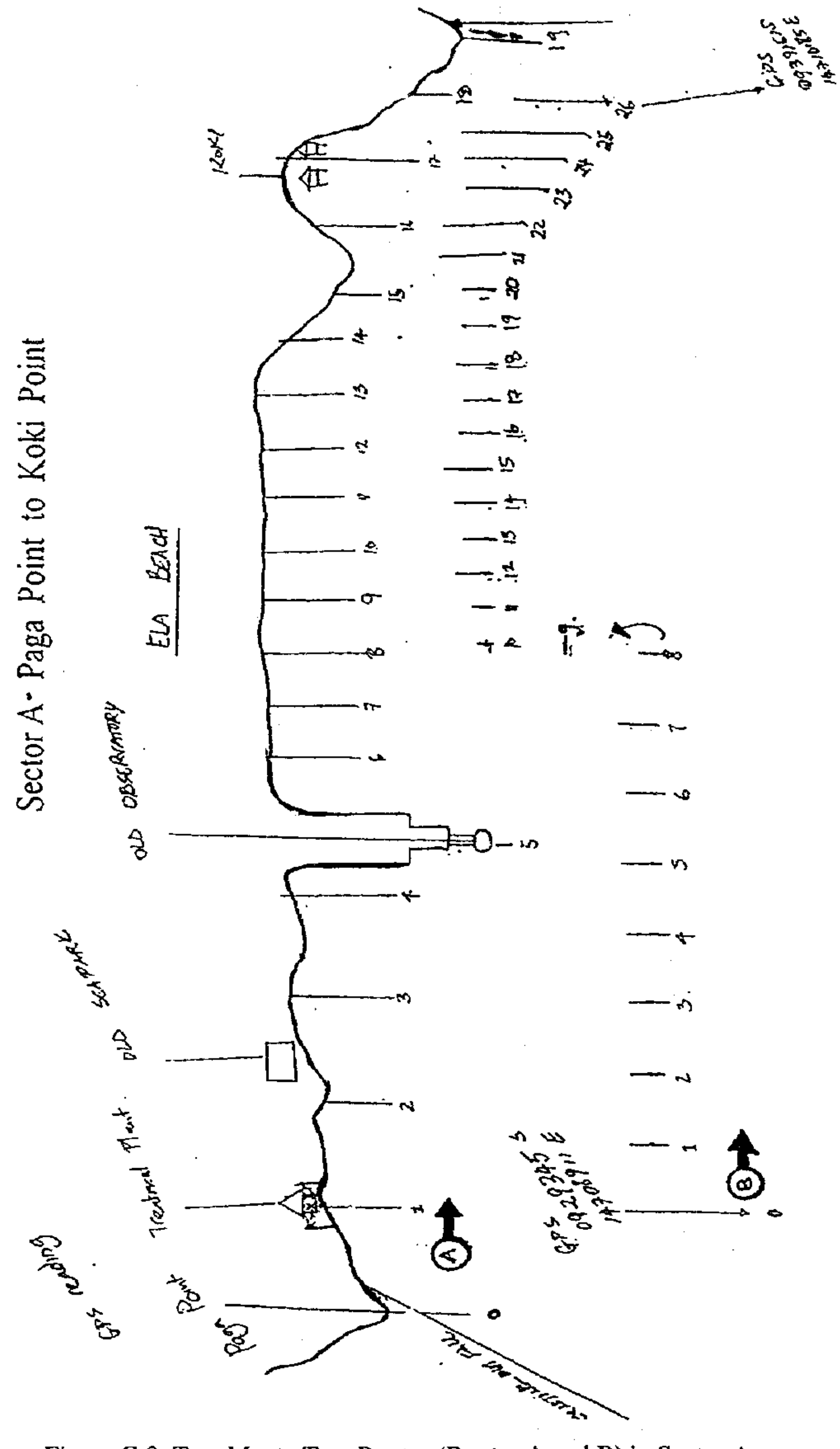


Figure G.3 Two Manta Tow Routes (Routes A and B) in Sector A

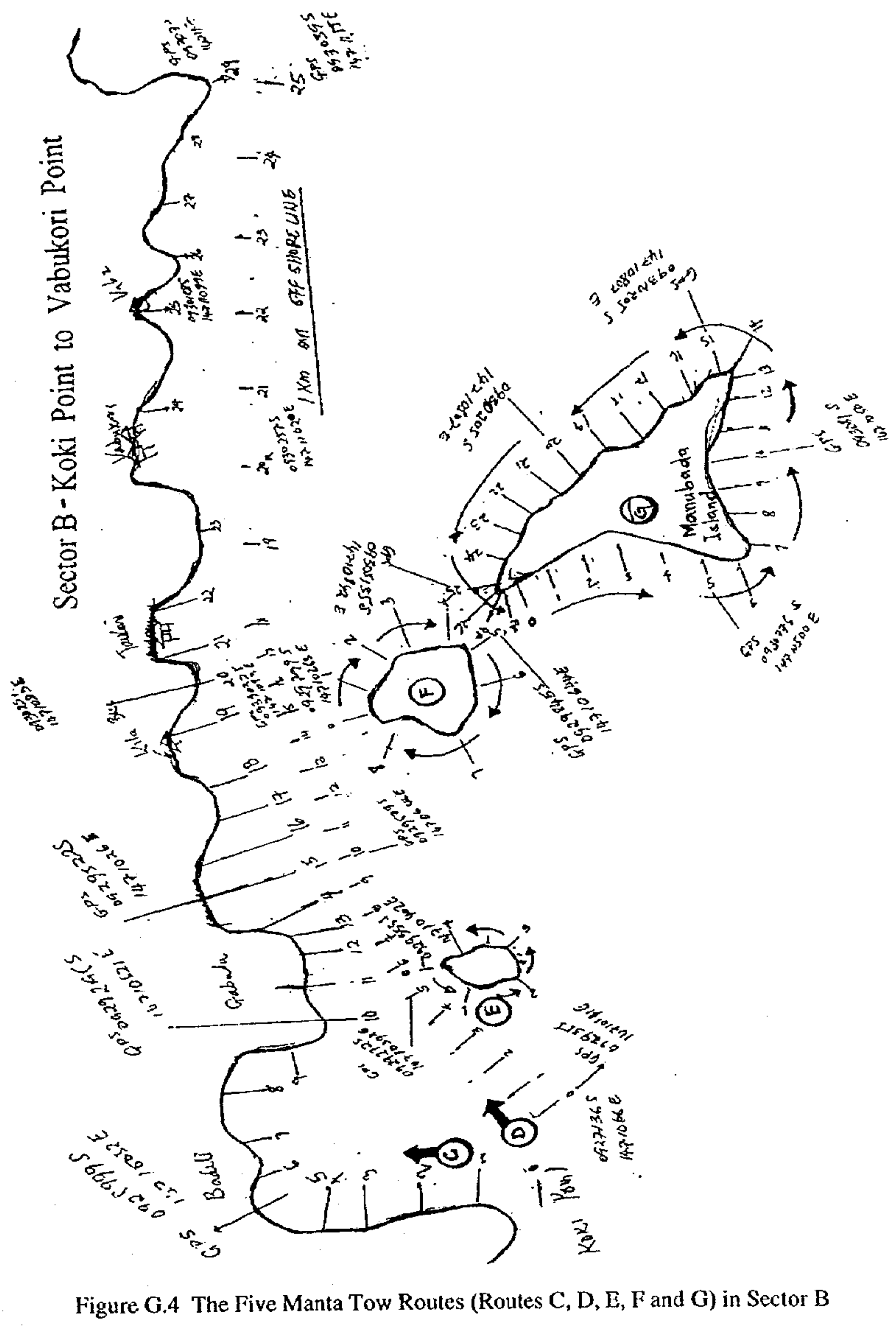


Figure G.4 The Five Manta Tow Routes (Routes C, D, E, F and G) in Sector B

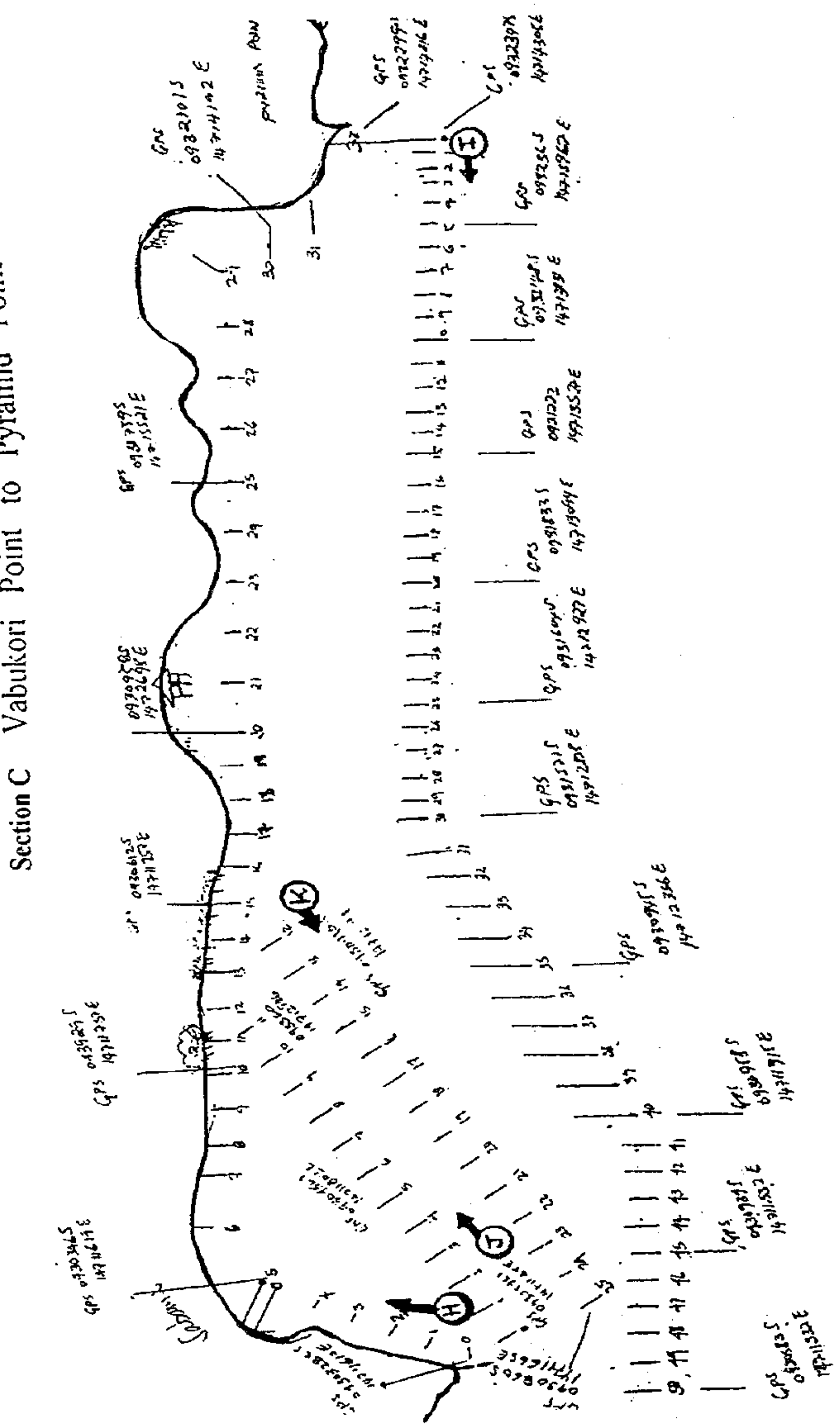


Figure G.5 Four Manta Tow Routes (Route H, I, J, and K) in Sector C

Site No.	GPS Locations
1	09 29 23 s & 147 00 21 e
2	09 25 52 s & 147 10 37 e
3	09 30 50 s & 147 10 51 e
4	09 30 47 s & 147 10 52 e
5	09 30 24 s & 147 11 14 e
6	09 30 56 s & 147 11 39 e
7	09 31 33 s & 147 12 44 e
8	09 32 06 s &147 13 50 e

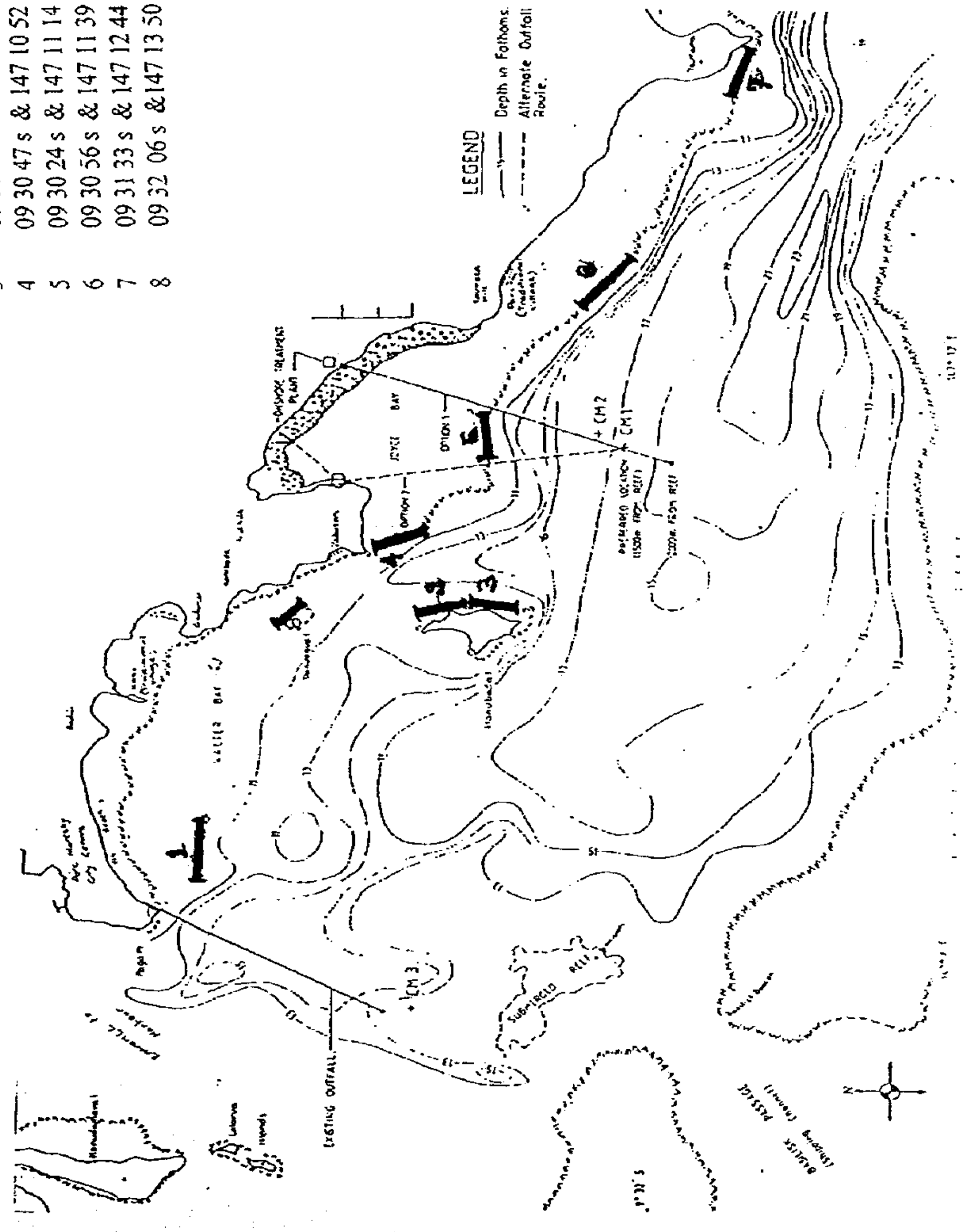


Figure G.6 The Line Intersect Transects (LIT) Stations, or the Seven Identified Stations for Long Term Monitoring of Coral Health

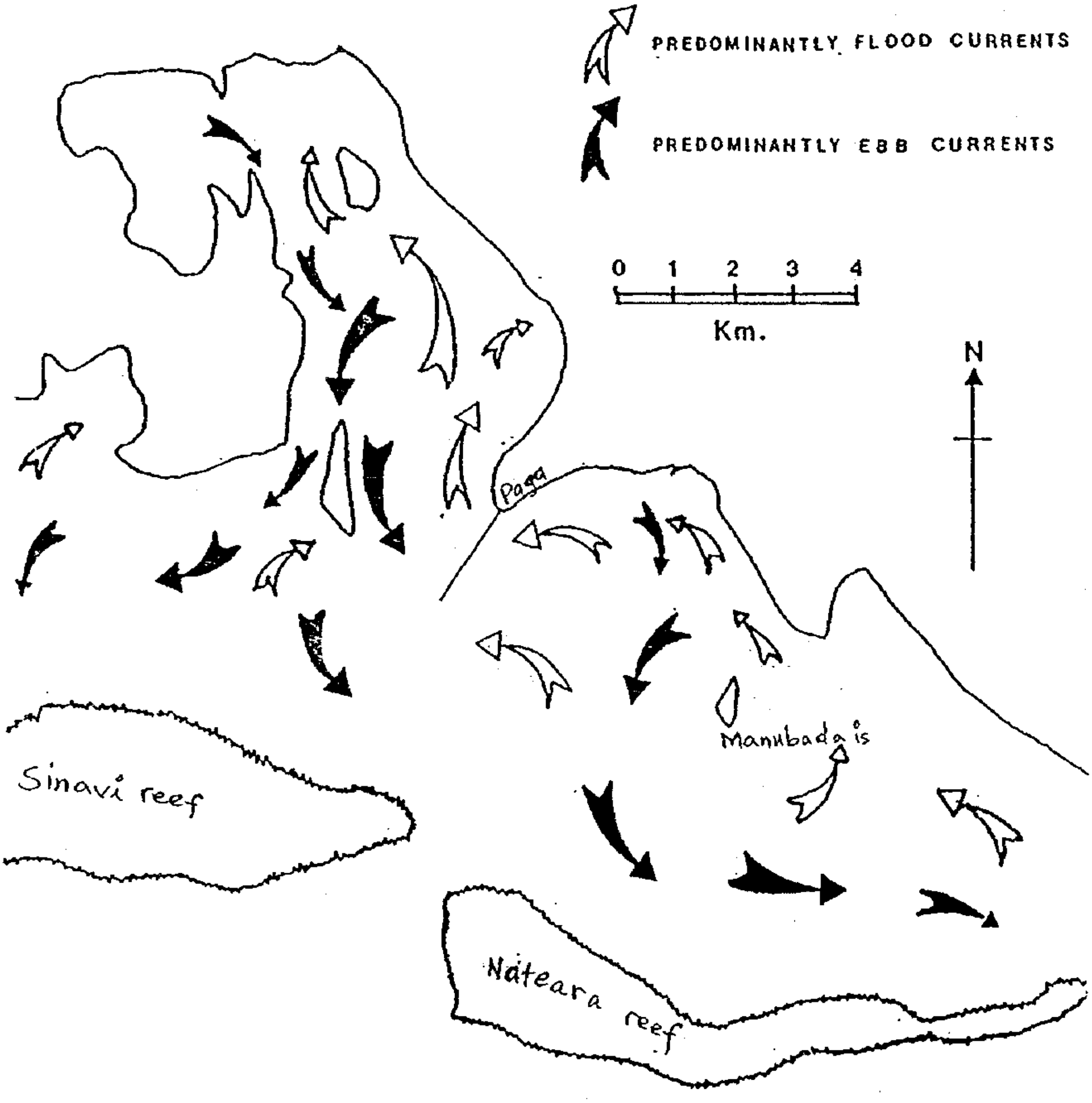


Figure G.7 Surface Current Flow Regime within Port Moresby Harbor and the Adjacent Outer Lagoon. Arrows are not Indicative of the Current Speed. Flood Currents Tend to be Deep Ones and Ebb Currents Tend to be Surface Ones (From Moore, 1982a)

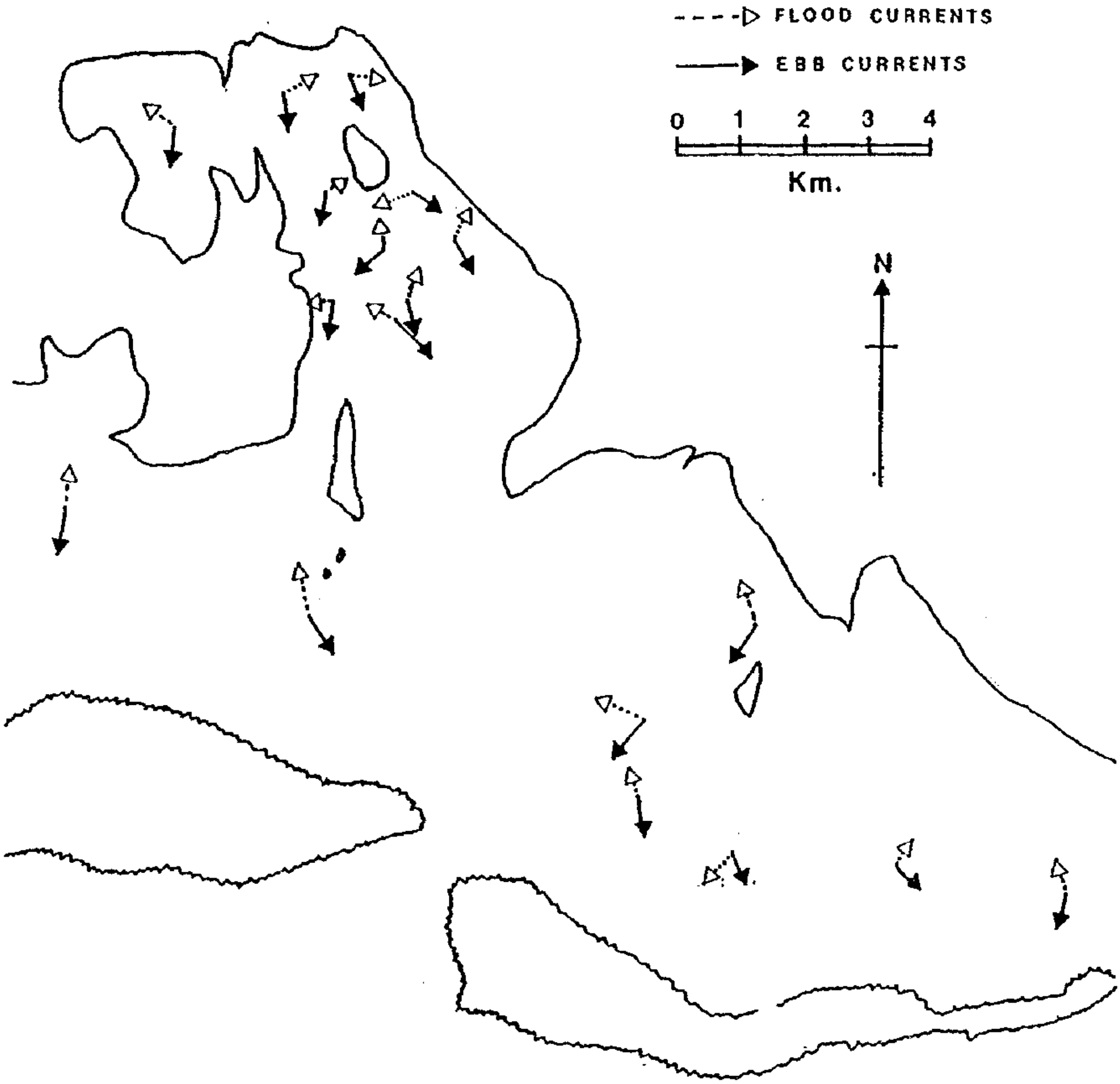


Figure G.8 Mean Surface (1.5 m depth) Current Flow Direction During Flood and Ebb Tidal Periods, Under Wet Season Wind Conditions (From Moore, 1982a)

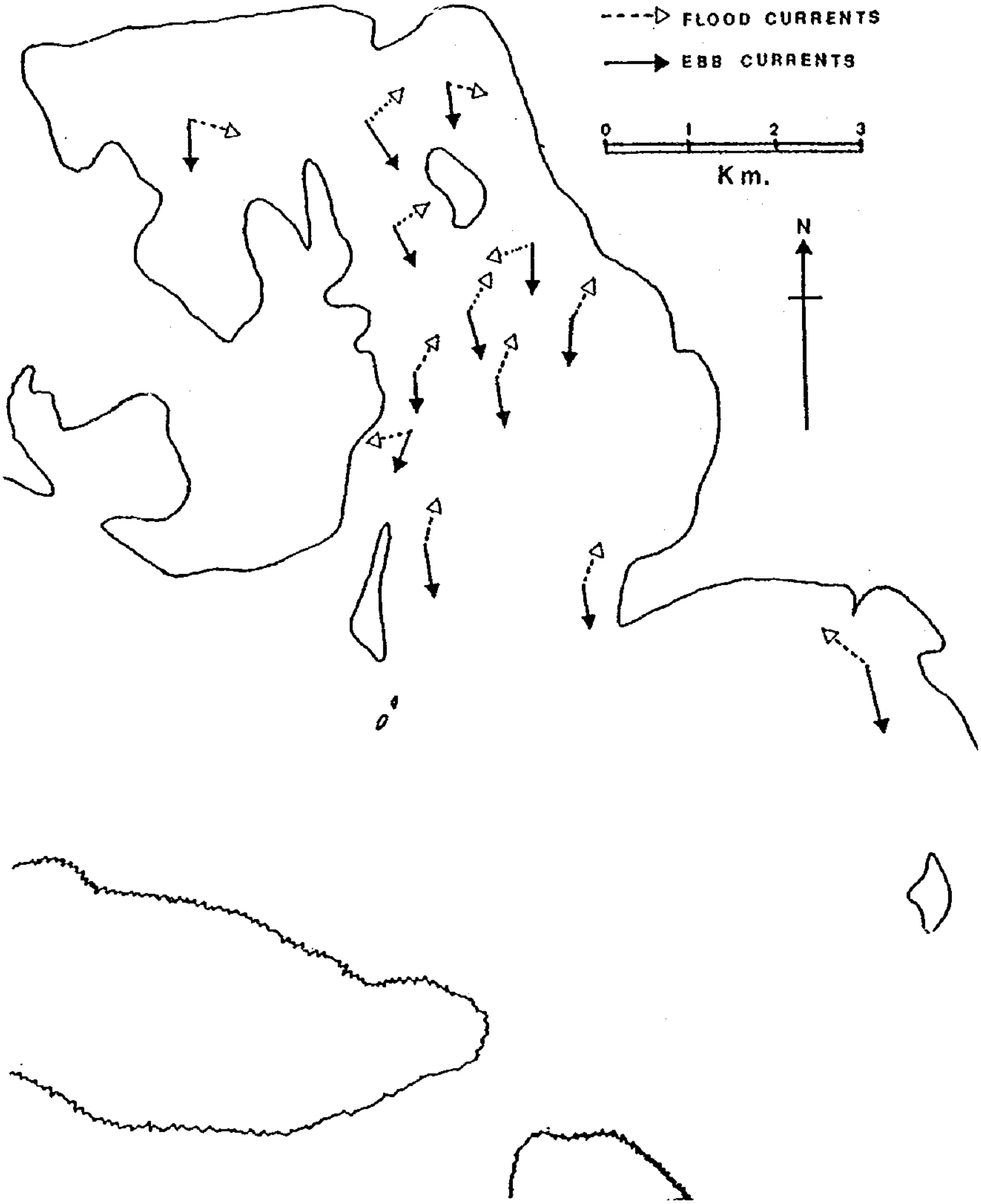
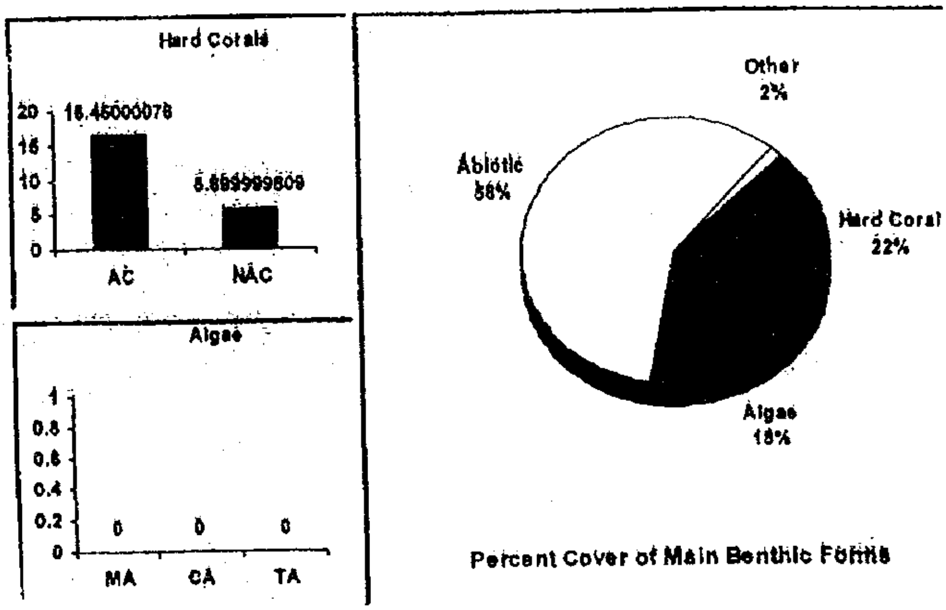


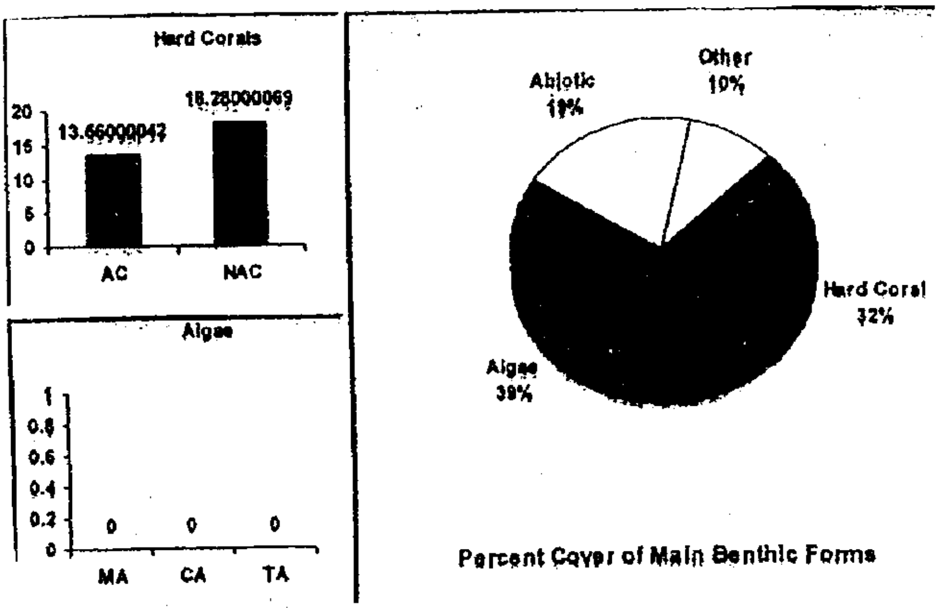
Figure G.9 Mean Surface (1.5 m depth) Current Flow Direction During Flood and Ebb Tidal Periods, Under Dry Season Wind Conditions (From Moore, 1982a)



Percent Cover of Benthic Forms for Sample Id: PGWB0001

AC = % Cover of Acroporian Corals, NAC = % Cover of Non-Acroporian Corals
MA = % Cover of Macro Algae, CA = % Cover of Coraline Algae, TA = % Cover of Turf Algae

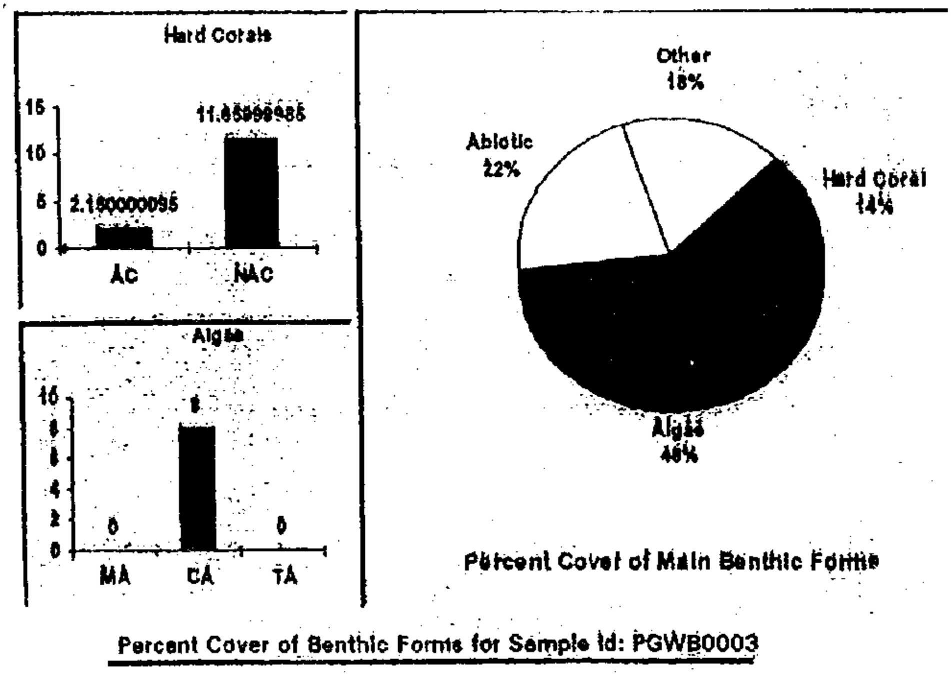
Figure G.10 Percentage Cover of Hard Corals and Benthic Forms in LIT Station 1 (Sector A)



Percent Cover of Benthic Forms for Sample Id: PGWB0002

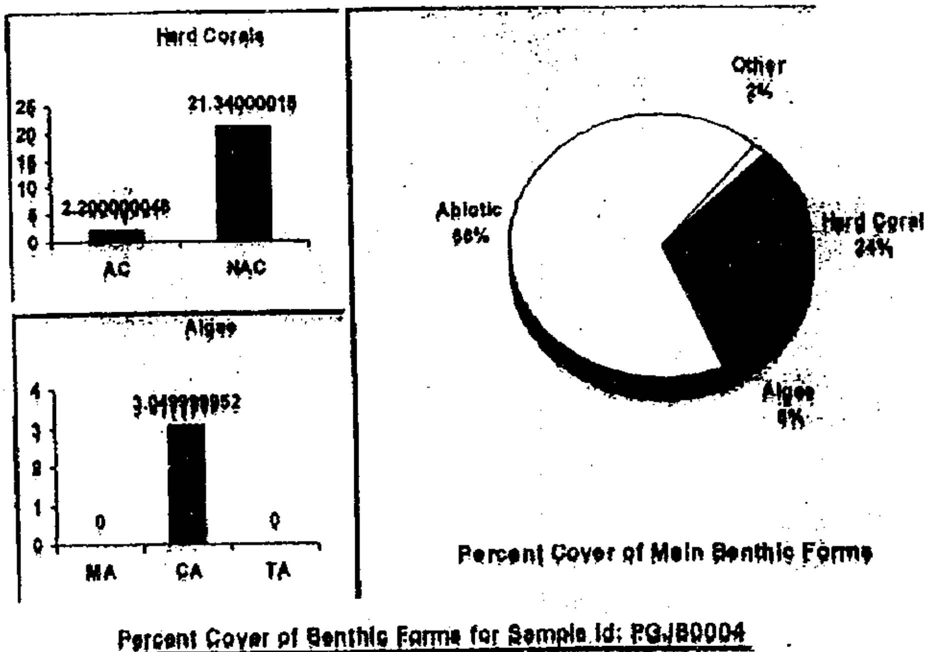
AC = % Cover of Acroporian Corals, NAC = % Cover of Non-Acroporian Corals
MA = % Cover of Macro Algae, CA = % Cover of Coraline Algae, TA = % Cover of Turf Algae

Figure G.11 Percentage Cover of Hard Corals and Benthic Forms in LIT Station 2 (Sector B)



AC = % Cover of Acroporian Corals, NAC = % Cover of Non-Acroporian Corals
MA = % Cover of Macro Algae, CA = % Cover of Coraline Algae, TA = % Cover of Turf Algae.

Figure G.12 Percentage Cover of Hard Corals and Benthic Forms in LIT Station 3 (Sector B)



AC = % Cover of Acroporian Corals, NAC = % Cover of Non-Acroporian Corals
MA = % Cover of Macro Algae, CA = % Cover of Coraline Algae, TA = % Cover of Turf Algae.

Figure G.13 Percentage Cover of Hard Corals and Benthic Forms in LIT Station 4 (Sector C)

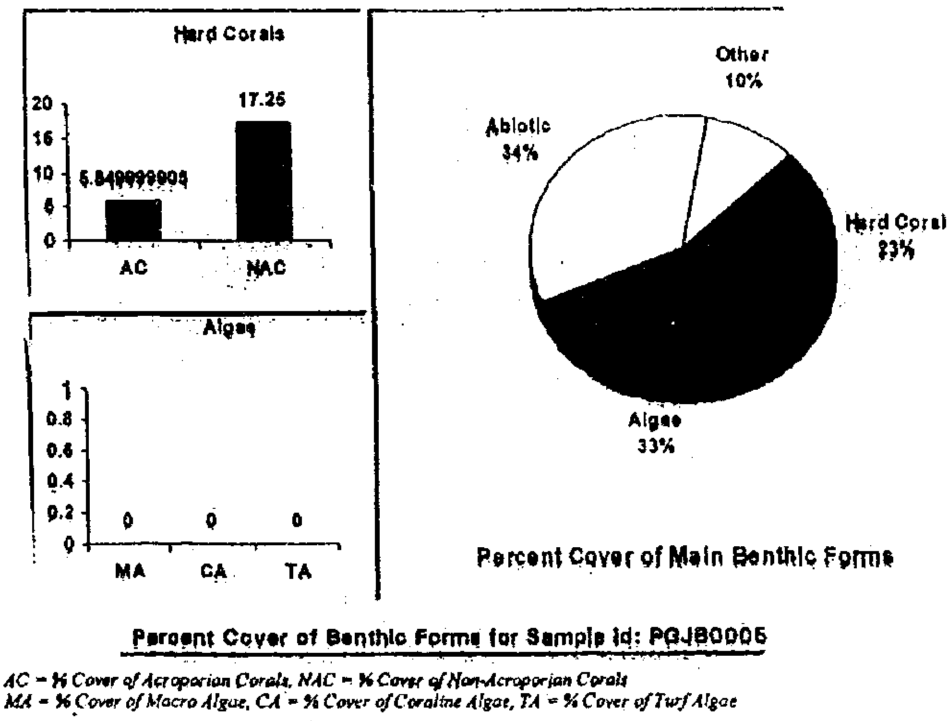


Figure G.14 Percentage Cover of Hard Corals and Benthic Forms in LIT Station 5 (Sector C)

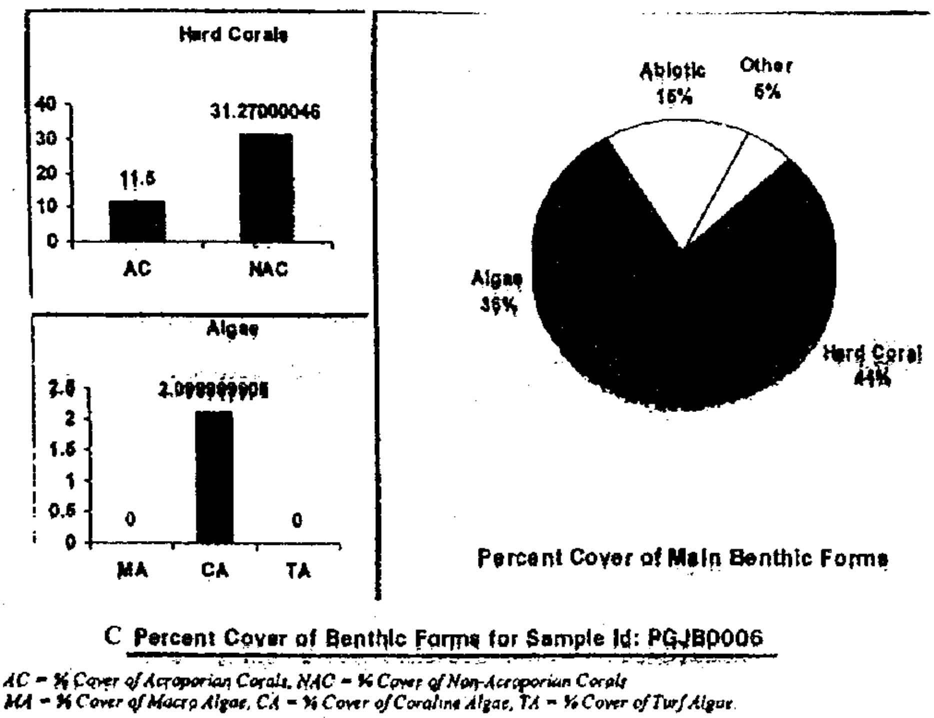


Figure G.15 Percentage Cover of Hard Corals and Benthic Forms in LIT Station 6 (Sector C)

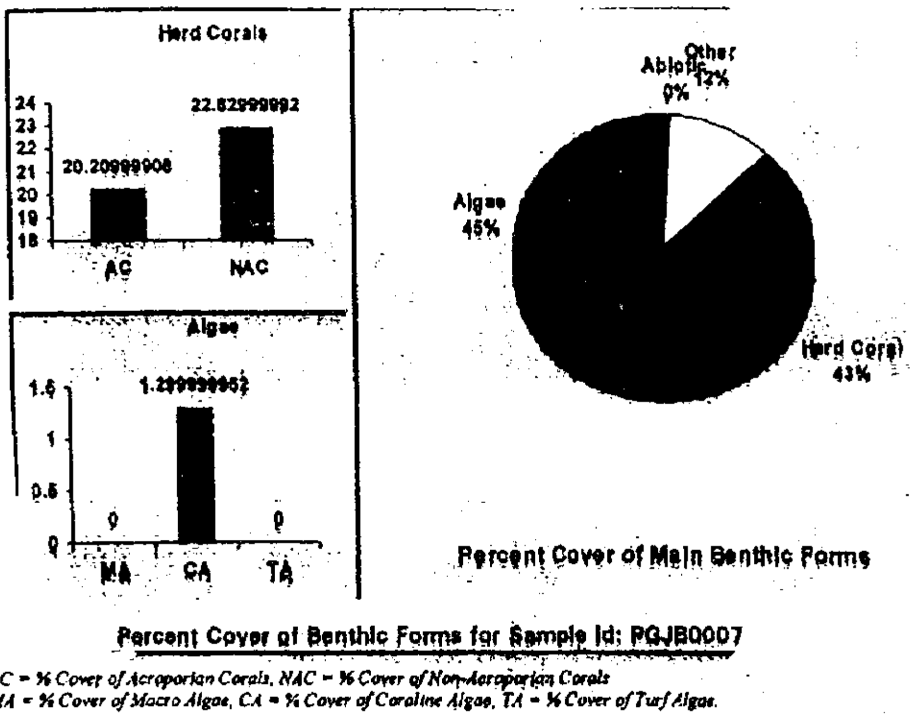
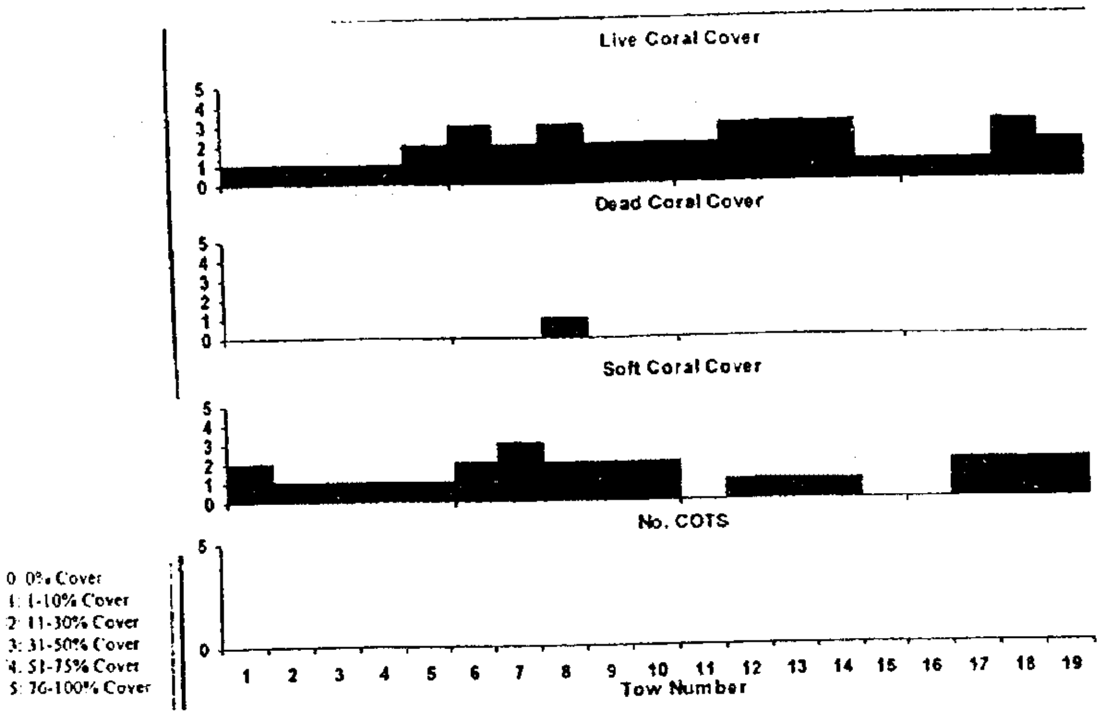


Figure 16. Percentage Cover of Hard Corals and Benthic Forms in LIT Station 7 (Sector C)

Route A Section (A) Sample ID PGWB1001



Route B Sector (A) Sample ID PGWB1002

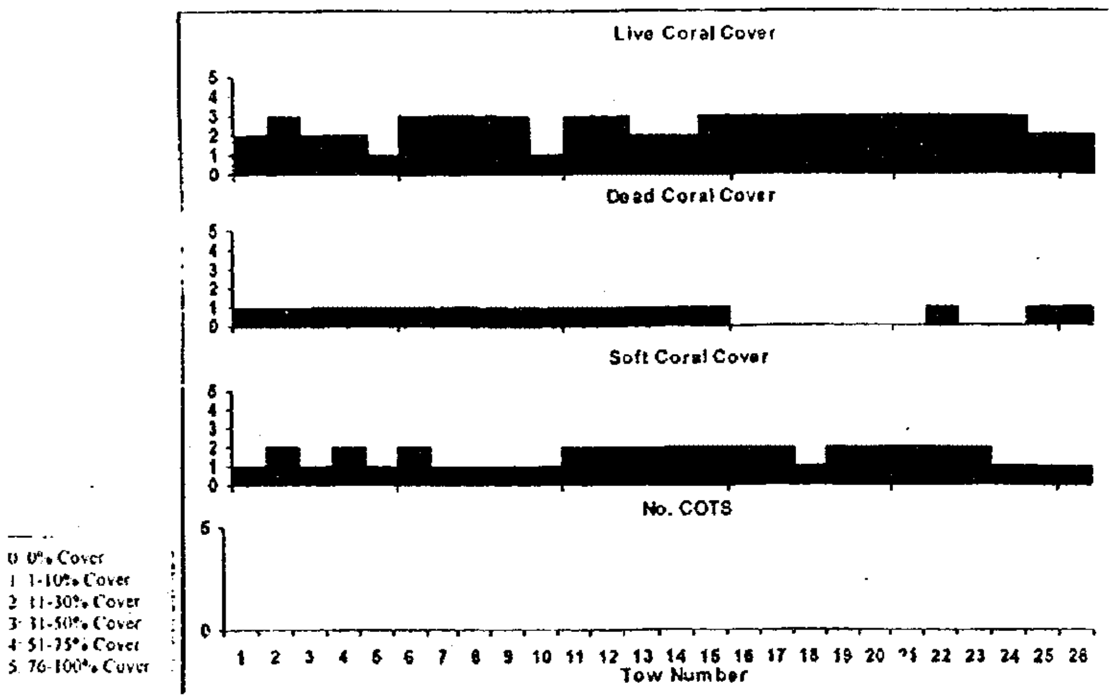
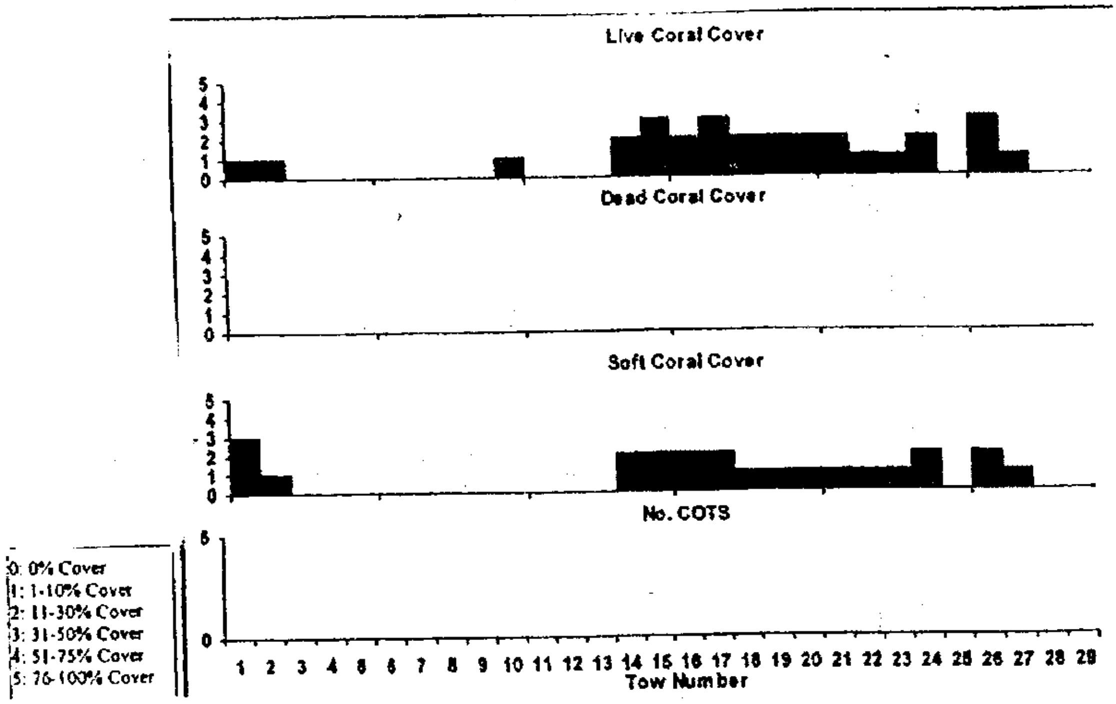


Figure G.17 Percentage Cover of Live, Dead, and Soft Corals and Crown-of-Thorns (COT) in Manta Tow Routes A and B at Sector A

Route C Sector (B) Sample ID PGWB 1003



Route D Sector (B) Sample ID PG WB1004

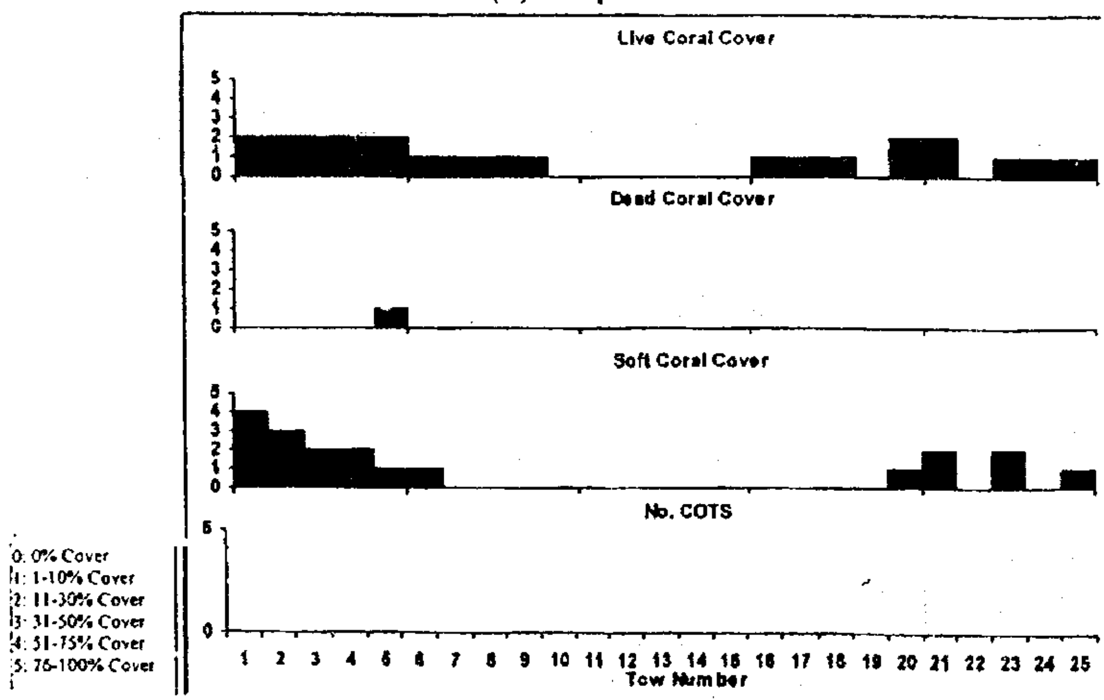
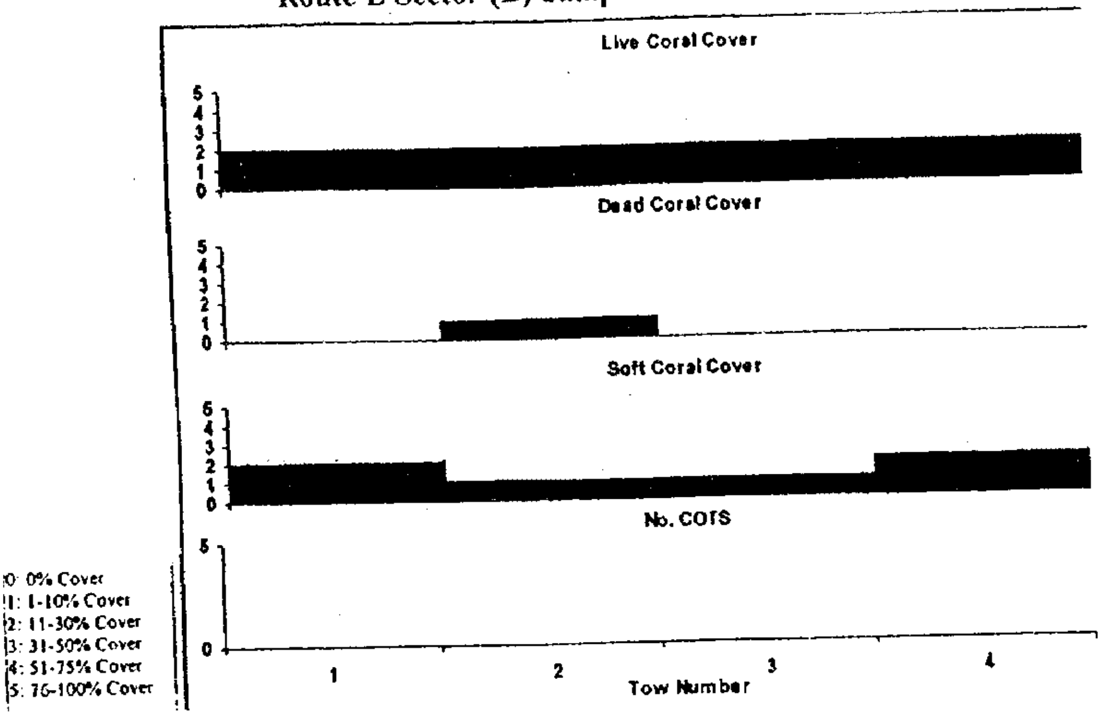


Figure G.18a Percentage Cover of Live, Dead, and Soft Corals and Crown-of-Thorns (COT) in Manta Tow Routes C, and D at Sector B

Route E Sector (B) Sample ID PGWB 1005



Route F Sector (B) Sample ID PGWB 1006

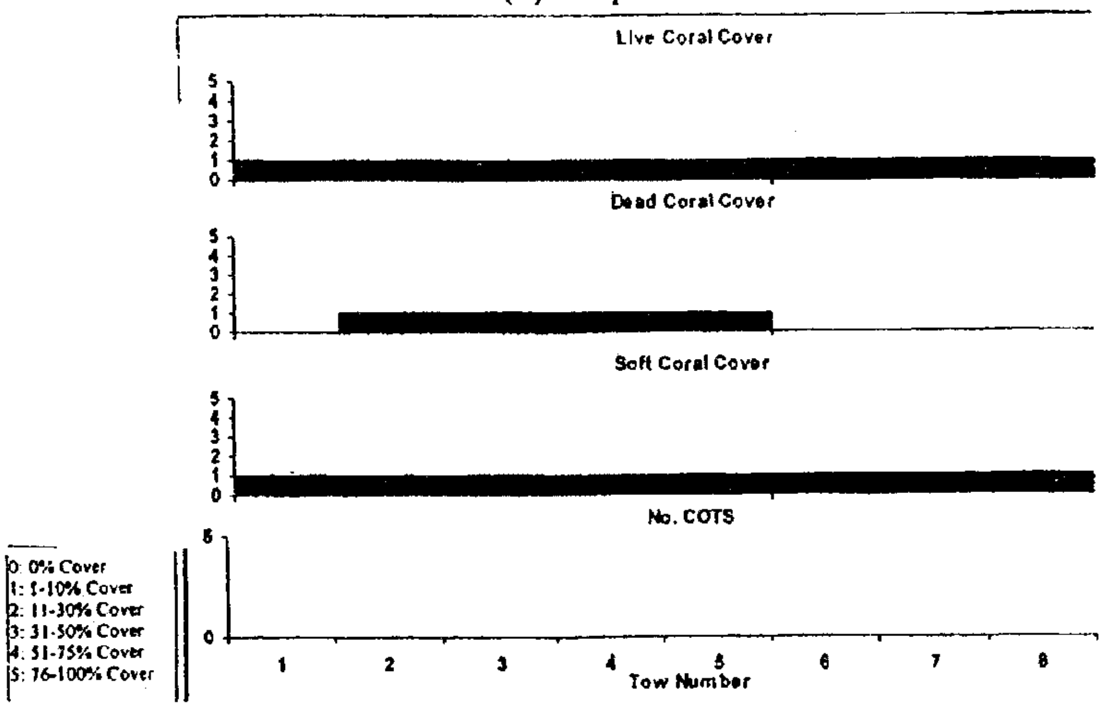


Figure G.18b Percentage Cover of Live, Dead, and Soft Corals and Crown-of-Thorns (COT) in Manta Tow Routes E and F at Sector B

Route G sector (B) Sample ID PGWB 1007

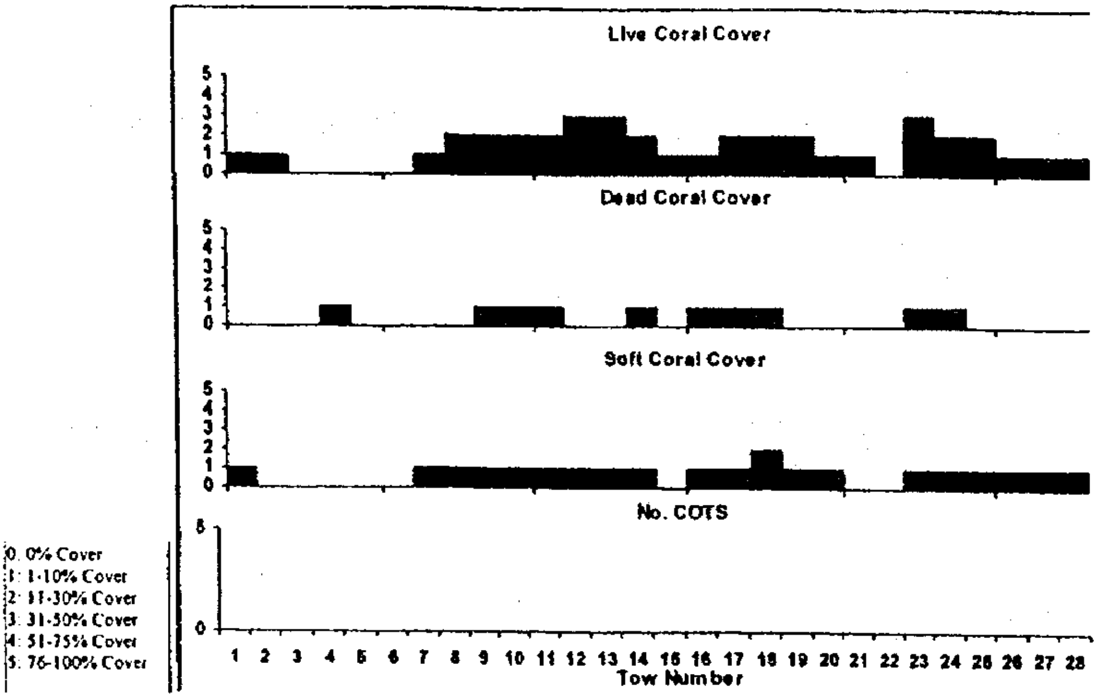
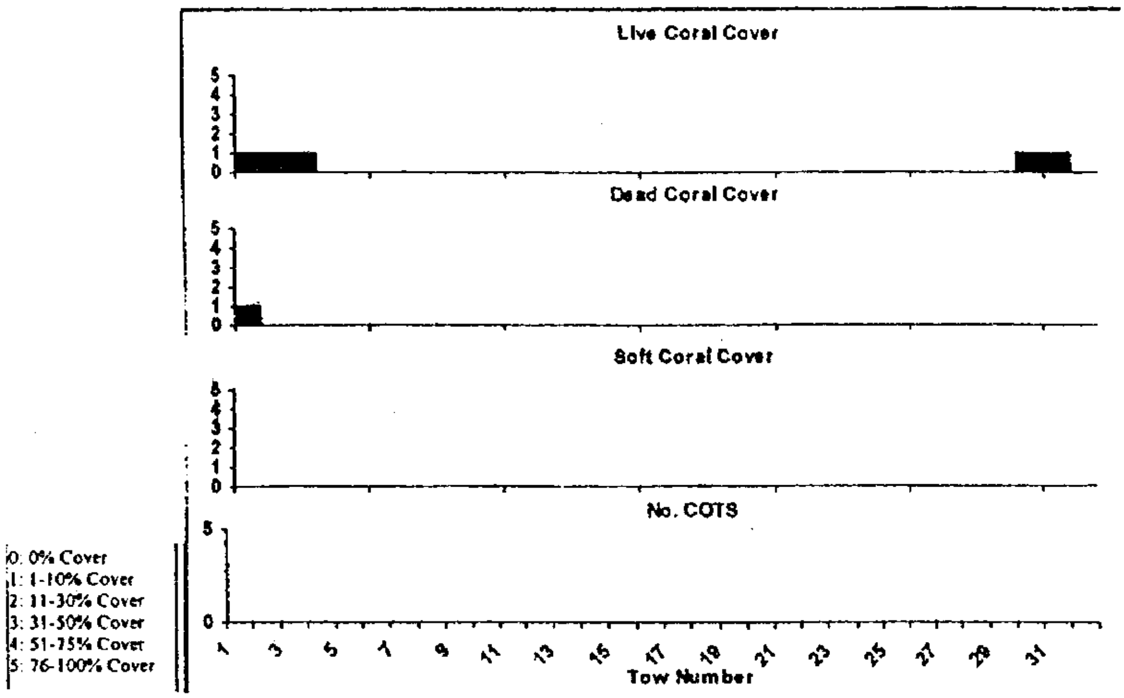


Figure G.18c Percentage Cover of Live, Dead, and Soft Corals and Crown-of-Thorns (COT) in Manta Tow Route G at Sector B

Route H Sector (C) Sample ID PGJB 1008



Route I Sector (C) Sample ID PGJB 1009

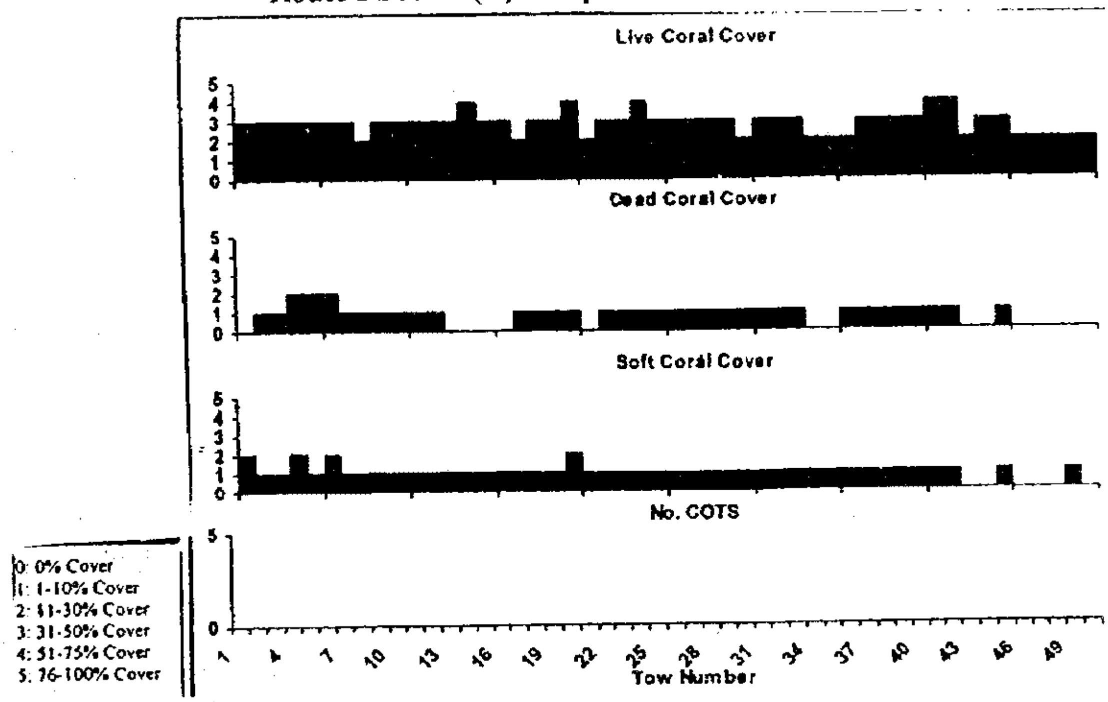


Figure G.19a Percentage Cover of Live, Dead, and Soft Corals and Crown-of-Thorns (COT) in Manta Tow Routes H and I at Sector C

Route J Sector (C) Sample ID PGJB 1010

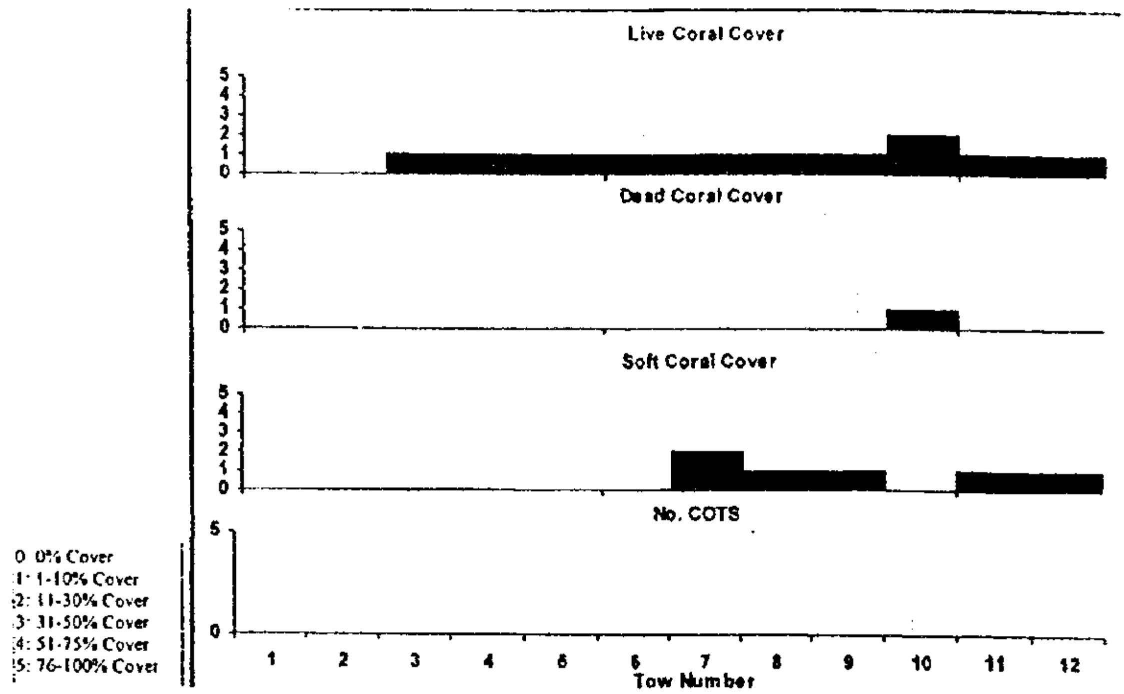


Figure 19: Manta Tow Routes I and J

Route K Sector (C) Sample ID PGJB 1011

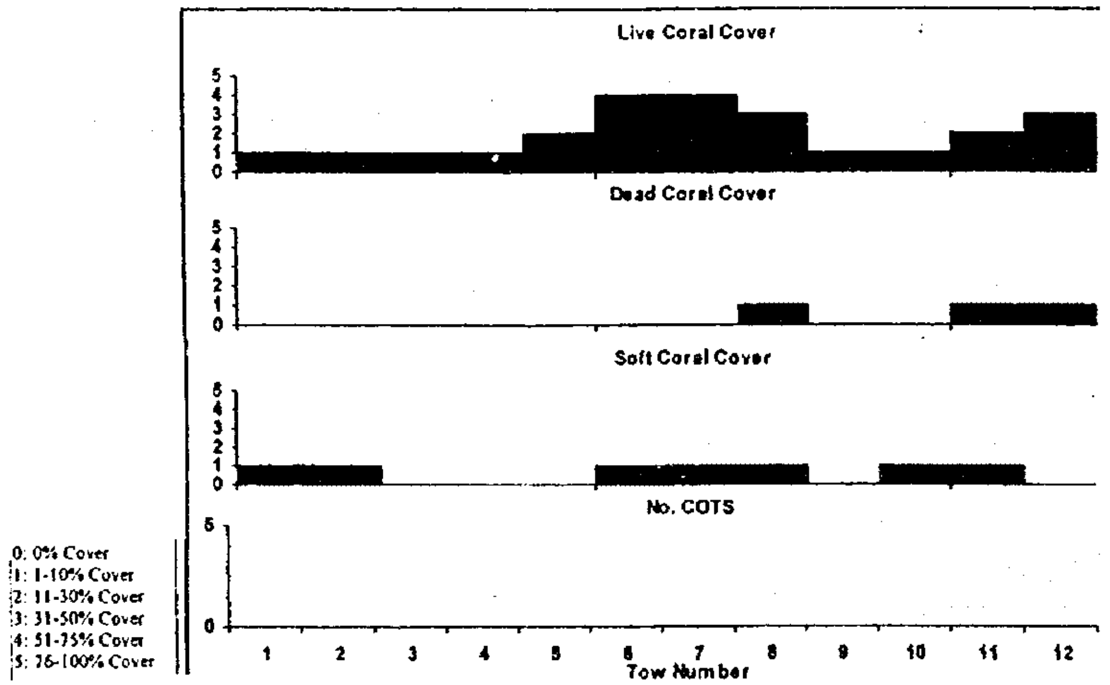


Figure G.19b Percentage Cover of Live, Dead, and Soft Corals and Crown-of-Thorns (COT) in Manta Tow Routes J and K at Sector C

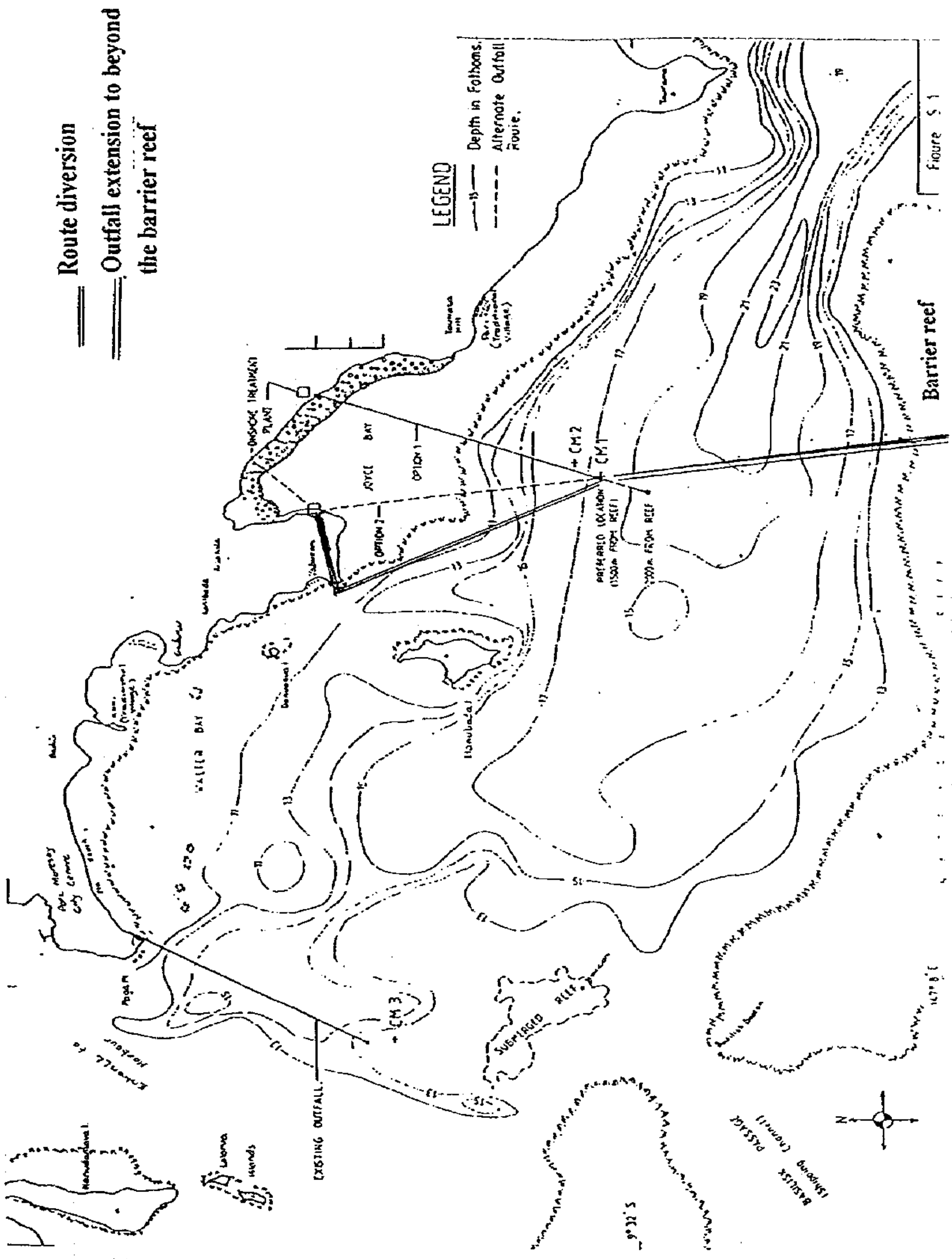


Figure G.20 The Recommended Pipeline Route and the Extended Outfall Location

11. THE SAMPLING PROGRAM

Days & Date	Activity	Sector	Personnel	Logistics/Equipment
Day 1, December 19, 1997	GPS location of all sectors and sites	A,B C	Tom, Joe, Cassy, Dede, Rod, Henry and JICA Team	Matsuoka, GPS, Maps, Charts
Day 2 20 December	Manta Tow	A	Tom, Joe, Cassy, Sae, Rod	Matsuoka, GPS, Manta Tow Board, Snorkelling gear
Day 3 21 December	Manta Tow	B	Tom, Joe, Cassy, Dede, Henry, Rod	As above
Day 4 22 December	Manta Tow	C	Tom, Joe, Cassy, Sae, Rod Dede	As above
Day 5 23 December	Manta Tow	B	Tom, Joe, Cassy, Henry, Sae	As above
Day 6 & 7 – 24/ 26, December 1997	Line Intersect Transect (LIT)	A	Tom, Joe, Cassy, Rod, Henry, Dede	Scomber, Diving Gear, Compressor, food, GPS, LIT gear
Day 8 27 December	LIT	B	Tom, Joe, Cassy, Rod, Henry, Sae	As above
Day 9 &10 28 &29 December	LIT	C	Tom, Joe, Cassy, Rod, Henry, Dede	As above
Day 11 & 12 30 &31 December	LIT	B	Tom, Joe, Cassy, Rod, Henry, Sae	As above
2 – 8 January 1998	Bad weather – No sampling	Bad weather No sampling	Bad weather – No sampling	Computers, Printers and scanners
Days 13 – 26 Jan 2-14	Report Writing,			
January 15	Submission on draft report.			
February 2,3,and 4	Diving –LIT and Manta Tow	A - C	Paga 3km and the proposed Joyce Bay Outfall	Scomber, Diving Gear, Compressor, food, GPS, LIT gear
February 5 – 16 1998	Report Writing.			

12. DETAILED DESCRIPTION OF THE SURVEY SITE

Sector A

Location: Paga Point shallow shore Overflow.
Method of Observation: On-board casual observations and snorkeling.

Fringing reefs are narrow with a shallow slope (0 - 20°). The shoreline is rocky with an outcrop and a boulder zone. Substrate is well mixed with rubble and sand. Sandy patches have sea grasses with Syringodium isoetifolium as the common species. The macro algae seaweed Padina minor, Sargassum sp and the soft coral Sinularia sp grow abundantly over the sewage pipes and the nearby areas. Massive coral Porites and some tabulate coral Acropora were sighted. Live coral cover is between 5 and 10 percent. Small school of fishes, mostly sand perch and lizard fish, were sighted in the vicinity of the 50m overflow. The shoreline becomes increasingly near the overflow.

Location: Arakuti reef top (LIT #1).
Method of Observation: SCUBA

The reef is discontinuous with sandy areas separating the coral patches and homogenous strands of branching (staghorn) corals Acropora and Pocillopora. These two genuses are the dominant hard corals. The seagrasses Halophila ovalis and Syringodium isoetifolium occupy much of sandy substrates. The seaweed Padina minor is also present. At depth range of 4 – 5 meters, scars of recently dead coral are visible. The edible coneshell Conidae is common in the mid reef and sandy areas. The LIT at the mid reeftop shows 58% abiotic (sand). Hard coral 22%, and algae 18%. A school of dolphins was sighted. Fish abundance is low. Damselfishes Pomacentridae is the most abundant. Other fish families encountered include the Pomacanthidae (angelfishes), Chaetodontidae (butterflyfishes), Mullidae (goatfishes), Nemipteridae (coral breams), Caesionidae (fusiliers) and Apogonidae (cardinalfishes). A medium size giant clam (Tridacna gigas) was seen.

Location: Intertidal zone from Paga Point to Koki Point.
Method of Observation: Manta Tow

There are numerous aggregations of the sea urchin Diadema setosum. The seagrasses Enhalus acoroides, Halophila ovalis, and Thalassia hemprechii commonly occupy the sandy substrate. The macro algae Colpomenia sinuosa also occupies a good portion of the substrate. Scattered rubble zones with live coral cover less than 10%. The site generally appears to be very highly degraded and polluted. The waters around Koki are turbid at most times. Fish life was rarely encountered. Individuals of the fish family Balistidae were seen.

Location: 3-kilometer outfall.
Method of Observation: SCUBA

From interviews we gathered that the outfall was commissioned in 1982. No pipe specification is available. The diffuser is situated approximately 2.7 kms from Paga Point, discharging at a depth of 27m. The pumping station is equipped with only a coarse screen; therefore no allowance is made for the removal of pathogenic organisms.

There is no coral growth in the 100m radius at the diffusion area. Coral growth appeared landward more than 100m from the diffusion point. A school of bump head parrotfish Bolbometopon muricatum, some individuals reaching approximately 100 cm, was seen. The substrate is sandy. A strong surface current in the first 5 - 6m of the water column exists. This may be related to the incoming tidal current. Five fishing boats were anchored at the outfall. The depression at the outfall suggests that the sewerage is being pressurized before the effluents are release. Schools of fishes that were seen include: fusiliers (Caesionidae), jacks Carangidae, Sweetlips Haemulidae and the orange striped Emperor Lethrinus obsoletus.

Sector B

Location: Badilli outfall.
Method of Observation: glass box viewing

The outfall is about 70 meters from the shoreline. The water is turbid, greasy and seems to be stagnant. Hardly any life appeared at the immediate vicinity. The depth is approximately 1 meter. The substrate is sandy and sillty. The outfall is within the inter tidal zone and is most probably exposed at low tides.

Location: Intertidal zone from Koki Point to Joyce Bay Point.
Method of Observation: Manta Tow

The site is exposed at very at low tides. The depth range from 1-3m. Turbid waters become clearer seaward. Coral growth is minimal, with soft corals Sinularia sp being the most conspicuous. Sea grasses and coral patches occupy most of the sandy substrate. The hard and branching coral family Pocilloporidae is predominant. The macro algae Padina sp is common. Seagrasses abound, comprising the species Syringodium isoetifolium, Enhalus acoroides Halophila ovalis, and Thalassia hemprechii.

Location: Reef edge Koki Point to Joyce Bay Point.
Method of Observation: Manta Tow

The depth ranges from 2 to 4m. Seagrasses and coral patches occupy the sandy substrate. The common seagrass species Syringodium isoetifolium, Enhalus acoroides Halophila ovalis, and Thalassia hemprechii. Coral growth is restricted, with the soft corals Sinularia sp being the most common at Koki point. Isolated branching Acropora colonies dwell amongst the extensive sea grass bed towards the Joyce point. Gillnet fishing is employed.

Location: Around Lade Kone Island

Method of Observation: Manta Tow

This smallest among the three islands. Around the rocky island, the slope is broken. The depth ranges from 2 – 5 m. Coral patches are separated by sand and rubble. The sandy areas have some seagrasses. Branching soft corals are common. Colonies of massive/boulder corals Porites are the dominant hard coral.

Location: Seaward side of Dauna gena Island.
Method of Observation: SCUBA (visual search for at least 100m by three divers at 2-3 m apart along the shallow slope).

The depth is between 4 – 6 m. The substrate is sandy. There are isolated staghorn Acropora, and Pocillopora verrucosa strands. Fire coral Millepora sp makes up about 2% of the substrate at the depth of seven meters. Numerous kinds of feather stars Comasteridae occupy the coral branches. The narrow reef quickly slopes beyond 10m to the sandy and silty basin. At one spot, there is a sudden drop in the slope. Here schools of fusiliers Caesionidae and emperors Lethrinidae were seen. Fish life is moderate, mainly the damsels and wrasses. A good number of the large sea cucumber Thelenota anax is present. A Second World War vintage single-engine plane wreck was discovered.

Location: Around Dauna Gena Island.
Methods of Observation: Manta Tow

There are isolated isolated colonies hard corals, mainly Acropora, Pocillopora and Millepora. Sand make up 80% of the substrate. The side facing the coast line is covered almost entirely of seagrasses and occasional heads of the massive /boulder coral Porites. The beach is white sand.

Location: Manubada Island leeward side.
Method of Observation: SCUBA

There is a narrow (50-70 m) fringing reef situated on the eastern (leeward side) of the island, facing the proposed Joyce Bay outfall. The depth at the reef top is 1 - 2m. The narrow reef slopes quickly into the sandy substrate with occasional coral colonies. The slope is shallow, with coral growth restricted to less than 7m. Tabulate acroporas represent the major component of the corals. Four large crown-of-thorns starfish (Acanthaster planci) prey on the corals. Plenty of predation scars were observed. About 20% of the corals Acropiridae and Pocilloridae have been killed by the crown-of-thorns.

Two LITs were established at the base of the slope at the depth of 6m.

Location: Around Manubada Island
Method of Observation: Manta Tow

The slope varies from shallow (0 - 20°) at the landward/leeward side to moderate and steep (30 – 60°) at the seaward/windward side. Coral growth is restricted down to 7m on the shallow slope of the leeward/landward side. A large rubble area was encountered at the southern end of the leeward side, most probably a result of blast fishing.

Sector C

Location: Intertidal zone from Joyce Bay to Pyramid Point.
Method of Observation: Manta Tow

The intertidal zone has less than 10% cover live coral, randomly distributed. The substrate is sandy/silty with isolated boulders covered by algae and seagrasses. The seastars Protoreaster nodosus and Choriaster granulatus live in the seagrasses. Fish life is moderate. Many fisheres were observedat the time of the survey. Seagrasses Halophila ovalis, and Thalassia hemprechii are distributed all along the coastline. Syringodium isoetifolium is most abundant towards the Pyramid Point

Location: Joyce Bay outfall.
Method of Observation: Glass box viewing

The water is turbid, stagnant and warm. No faunal benthos was observed at the immediate outfall. Patches of seagrass Enhalus acoroides occurs a few meters away from the outfall. A school of juvenile mullets Mugilidae appeared. Women fishing and children swimming near the outfall were observed.

Location: Reef edge and slope from Joyce Bay to Pyramid Point.
Method of Observation: Manta Tow

The reef edge/slope is broken separated by sandy patches acting as spur and groove. The slope varies considerably from shallow to steep (46 - 75°). The branching coral Acropora was the dominant hard coral. The seaweed Padina sp, Turbinaria sp, and Sargassum sp dominate some parts of the reef crest. Some dead corals, especially branches from strands of Acropora were observed. Generally the diversity of the benthic organisms and fishes increases eastward from Joyce Bay to Pyramid Point. This correlates to the structural complexity of the reef. The depth of the water column varied along the reef edge relating to the underwater topography.

Location: Intertidal zone at the middle of Joyce Bay.
Method of Observation: Manta Tow

The inter tidal zone has less than 10% coverage of live coral. The substrate is sandy/silty, with isolated boulders covered by algae and seagrasses. The seagrass Enhalus acoroides is dominant. Other seagrass species Syringodium isoetifolium, Halophila ovalis, and Thalassia hemprechii also occurred. No fish were observed although a large numbers of women were seen line fishing. The sea urchin Tripneustes gratilla and the sea stars Protoreaster nodosus and Choriaster granulatus are common amongst the sea grass beds.

Location: Across the back reef of Joyce Bay.
Method of Observation: Manta Tow

The substrate is sandy/silty, with isolated boulders covered by algae and seagrasses. The seagrass Enhalus acoroides is dominant. Other seagrass species Syringodium isoetifolium, Halophila ovalis, and Thalassia hemprechii also occurred. No fish were observed although a large numbers of women were seen line fishing. The sea urchin Tripneustes gratilla and the sea stars Protoreaster nodosus and Choriaster granulatus are common amongst the sea grass beds.

Location: Joyce Bay 1 (LIT)
Method of Observation: SCUBA

The gradient of the sandy slope nearshore is 0 - 20° becoming steeper (21-45°) 30 meters seaward. Fish life is low to moderate. The sea cucumber Holothuria fuscogilva and Thelenota anax are common. Fire coral Millipora sp is abundant. The branching coral Acropora is also present.

Location: Joyce Bay 2 (LIT).
Method of Observation: SCUBA

The reef front has a shallow slope (0 – 20°). The substrate is made up of 36% coraline algae, 15% sand, and 44% hard corals. Fish abundance is low to moderate. Angelfishes (Pomacanthidae), damselfishes (Pomacentridae) and wrasses (Labridae) were observed.

Location: Joyce Bay/Pari Village (LIT)
Method of Observation: SCUBA

The reef front has a shallow slope (0 – 20°). The dominant benthic life is the hard corals comprising 44% (Arcopora 11.5%, and non-acropora coral (32.5%). Sandy patches are present. The green algae Halimeda sp is abundant (36%). Fish life is moderate.

Location: Pyramid Point (LIT).
Method of Observation: SCUBA

The reef front has a shallow slope (0 – 20°). The site has the greatest aesthetic value among the other locations. Biodiversity is high. Two large giant clamshell Tridacna gigas were seen at the depth of 5m. The dominant benthic form is the green algae Halimeda sp. An array of coral groups is found: the branching Acropora, the massive brain coral Faviidae, the soldiery corals Fungiidae, the massive Mussidae, Poritidae and the fire coral Millepora. Live coral cover is 43%. Fish are abundant, fishing activity is dense.

Location: The proposed Joyce Bay out fall.

Method of Observation: SCUBA

The depth of the water column was 34m. The substrate is very fine silt and mud. Polychaete worms and crustaceans were discovered on close examination of the substrate. Schools of juvenile jack Carangidae and of silversides Gerreidae were present throughout the water column.

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PART I WAIGANI SWAMP

1. Introduction

1.1 Outline of Waigani swamp

Figure H.1.1 indicates the catchment area of the Waigani swamp.
Each catchment area is measured by the Study Team as enumerated in Table H.1.1.

Table H.1.1 Catchment area of Waigani swamp

Area	Area (km^2)
No. 1	55.4
No. 2	9.7
No. 3	11.7
No. 4	11.5
Total	88.3

An aerial photograph and a cross section diagram are shown in Figure H.1.2 and Figure H.1.3.

Based on the survey result (cross section diagram), mean depth of the swamp is calculated as shown below.

Table H.1.2 Survey result of Waigani swamp

Section No.		Area (m^2)	Length (m)	Depth		
				Average (m)	Maximum(m)	Ave./Max.
Cross section	No. 1	1,347,980	1,220	1.162	1.521	76%
	No. 2	384,040	1,140	0.640	0.922	69%
	Average					73%
Long section	No. 3	1,199,380	1,680	0.706	1.464	48%

The average/maximum ratio is regarded as 70% in reference to the cross section survey. The maximum depth can be estimated as 1.0 m to 1.5 m.
It is determined that 0.7 m is adopted for the mean depth of the swamp in this Study.

The swamp feature is summarized as follows :

1) Water surface area : 2,600,000 m^2 (Measured by Study team)
2) Mean depth of the swamp : 0.7 m (Based on survey result)
3) Swamp volume : 1,820,000 m^3

1.2 Water quality examination result

Water quality examinations were conducted by the Study Team in September and December in 1997. Results on the water quality examination related to Waigani swamp are summarized as follows:

Table H.1.3 Water quality examination result

Item	Sampling Point	Flow (m^3/sec)	COD Concentration (mg/L)	COD Load (kg/day)
Influent	Waigani STP Outlet	0.275	109.0	2,585
	Morata STP Outlet	0.029	64.0	158
	Gerehu STP Outlet	0.034	132.0	391
	Jacksons Creek Outlet	0	-	-
	Total	0.338	107.5	3,134
Swamp	Waigani Swamp Ave.	-	65.8	-
Effluent	Zooland Creek Inlet	0.157	72.0	974

1.3 Objectives

The objectives of the Study are to:

- Identify the pollutant load balance related to the Waigani swamp
- Establish a water quality simulation model
- Estimate the water quality of the swamp and its effluent during rainy season and in future
- Clarify the efficiency of the sewage treatment

Taking into account the above objectives, the cases to be studied are classified as indicated in Table H.1.4.

Table H.1.4 Study cases

	Existing (1997)		Future (2015)	
	Dry season	Rainy season	Dry season	Rainy season
With sewage treatment	O	O	O	O
Without sewage treatment	O	O	O	O

2. Estimation of present condition

2.1 Analysis of existing condition with sewage treatment

1) Analysis method

Generaly, December, the month when the survey was conducted, is characterized as rainy season in Port Moresby. However, there has been no significant rainfall since April due to the global-wide abnormal weather in 1997. The data listed in Table H.1.2 and Table H.1.3, therefore, should be categorized as dry seasonal hydrological data.

The analysis was drawn up with the following conditions:

- No effluent coming from the creeks to the swamp due to the creeks dried up condition.
- Effluent flow is relatively less than the total amount of STP influent due to infiltration and evaporation.
- No leakage of pollutant substance in filtration
- COD concentration of the STP effluent is reduced due to natural purification.
- Existing effluent water quality is determined refers to examination result (Table H.1.3).
- Retention time is defined as the swamp volume over the total amount of STP influent.

2) Analysis during dry season

(1) Loss of effluent flow (by filtration/evaporation)

$$Q' = Q_{in} - Q_{out} = 0.338\ m^3/sec - 0.157\ m^3/sec = 0.181\ m^3/sec$$

(2) Retention time of the swamp

$$T_0 = V / (Q_{in} + Q_{out}) / 2 = 1{,}820{,}000\ m^3 / (0.338\ m^3/sec + 0.157\ m^3/sec) / 2$$
$$= 7{,}353{,}535\ sec = 85.1\ day$$

(3) COD natural purification efficiency (λ)

λ of the linear equation of $dC / dt = - \lambda C$ is acquired as below.

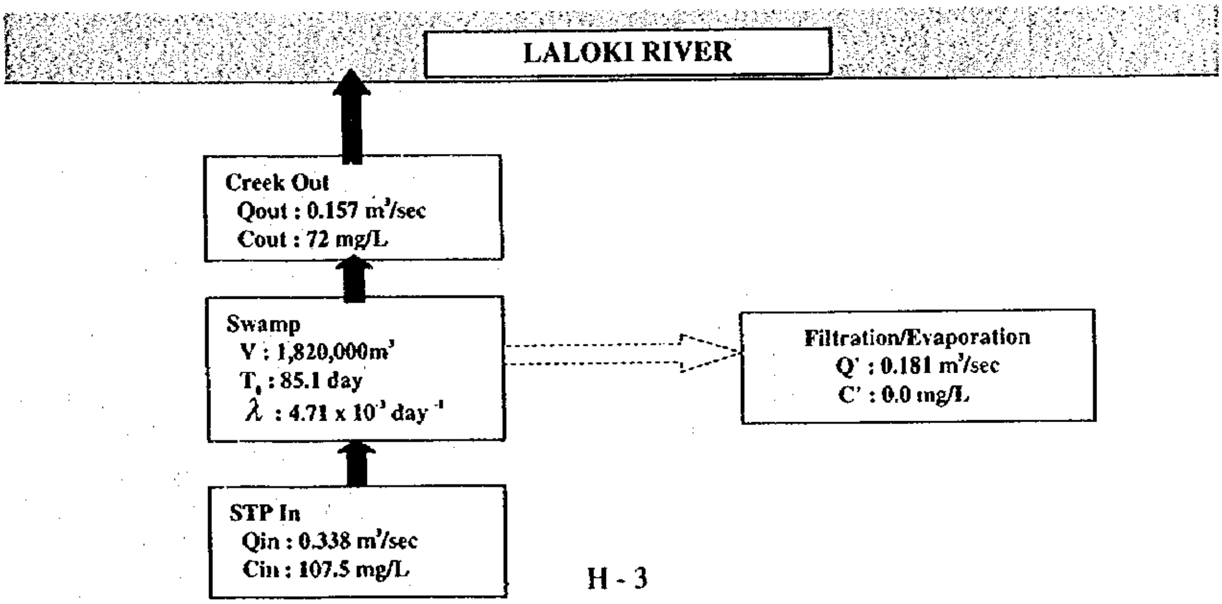
$$\lambda = - Ln (C_t / C_0) / t$$
$$= - Ln (C_{out} / C_{in}) / T_0$$
$$= - Ln (72\ mg/L / 107.5\ mg/L) / 85.1\ day = 4.71 \times 10^{-3}\ day^{-1}$$

(4) COD concentration of swamp effluent (C)

C_t of the equation of $dC / dt = - \lambda C$ is acquired as below.

$$C_t = C_0 \exp (- \lambda t)$$
$$= 107.5\ mg/L \times \exp (-4.71 \times 10^{-3}\ day^{-1} \times 85.1\ day)$$
$$= 107.5\ mg/L \times 0.670 = 72\ mg/L$$

(5) Mass balance chart during dry season



3) Estimates during rainy season

(1) Basis of estimate

The analysis was based on the following swamp condition during rainy days.

a. Influent flow and pollutant load

Influent flow is obtained by multiplying monthly rainfall with discharge efficiency.

Monthly rainfall:	232 mm per month (March) is adopted as a yearly maximum rainfall based on the meteorological data during 1961 to 1990 in Port Moresby.
Discharging efficiency:	0.7 is adopted in reference to Civil Design Manual of Japan.
Catchment area:	88.3 km^2 (Table H.1.1)
Natural pollutant load:	62.9 $kg/km^2/day$ is adopted derived from the influent of the creeks.
Influent flow:	$88.3 \times 10^6 \times 0.232 \times 0.7 / 31 = 462{,}578\ m^3/day = 5.354\ m^3/sec$
Influent load:	$62.9 \times 88.3 = 5{,}554$ kg/day
Influent COD concentration:	$5{,}554 / 462{,}578 \times 1{,}000 = 12.0$ mg/L

b. Retention time of the swamp

$$T_0 = 1{,}820{,}000 / 462{,}578 = 3.93 \text{ day}$$

c. Loss of effluent flow is not considered due to rainy season.

(2) COD concentration of swamp effluent (C)

C_t of the equation of $dC / dt = -\lambda C$ is acquired as below.

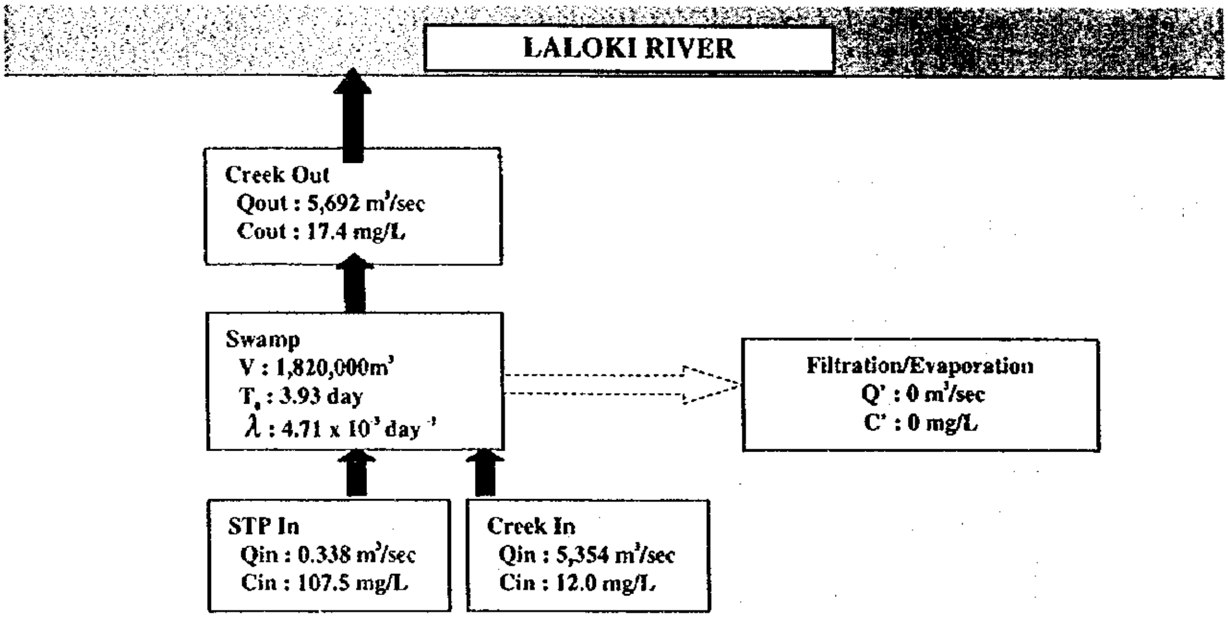
$$C_t = C_0 \exp(-\lambda t)$$

$$C_0 = (0.338 \times 107.5 + 5.354 \times 12.0) / 5.692 = 17.7 \text{ mg/L}$$

$$C_t = 17.7 \times \exp(-4.71 \times 10^{-3} \times 3.93)$$

$$= 17.7 \times 0.982 = 17.4 \text{ mg/L}$$

(3) Mass balance chart during rainy season



2.2 Estimates of existing condition without sewage treatment

1) Basis of estimates

The analysis was drawn up with the following conditions:

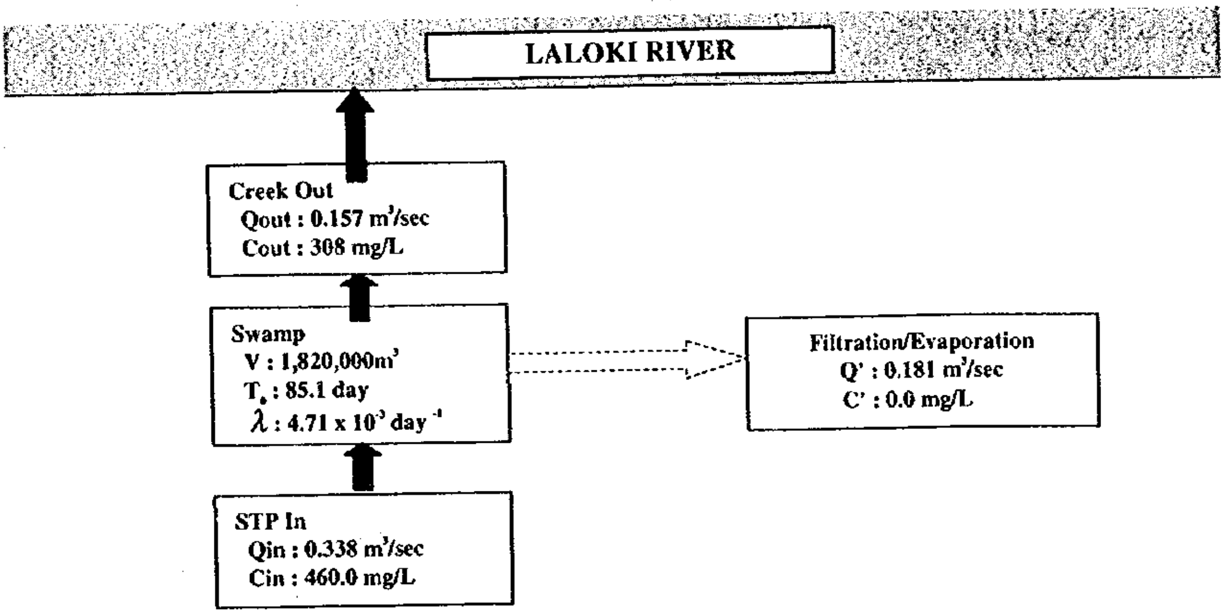
- COD concentration of untreated sewage is 460 mg/L; 170 mg/L (BOD concentration) x 2.7 (COD/BOD ratio)
- Sewage is discharged to the swamp of the same COD concentration level.

2) Estimation during dry season

(1) COD concentration of swamp effluent (C)

$$C_t = C_0 \exp(-\lambda t)$$
$$= 460.0 \times \exp(-4.71 \times 10^{-3} \times 85.1)$$
$$= 460.0 \times 0.670 = 308.2 \text{ mg/L}$$

(2) Mass balance chart during dry season

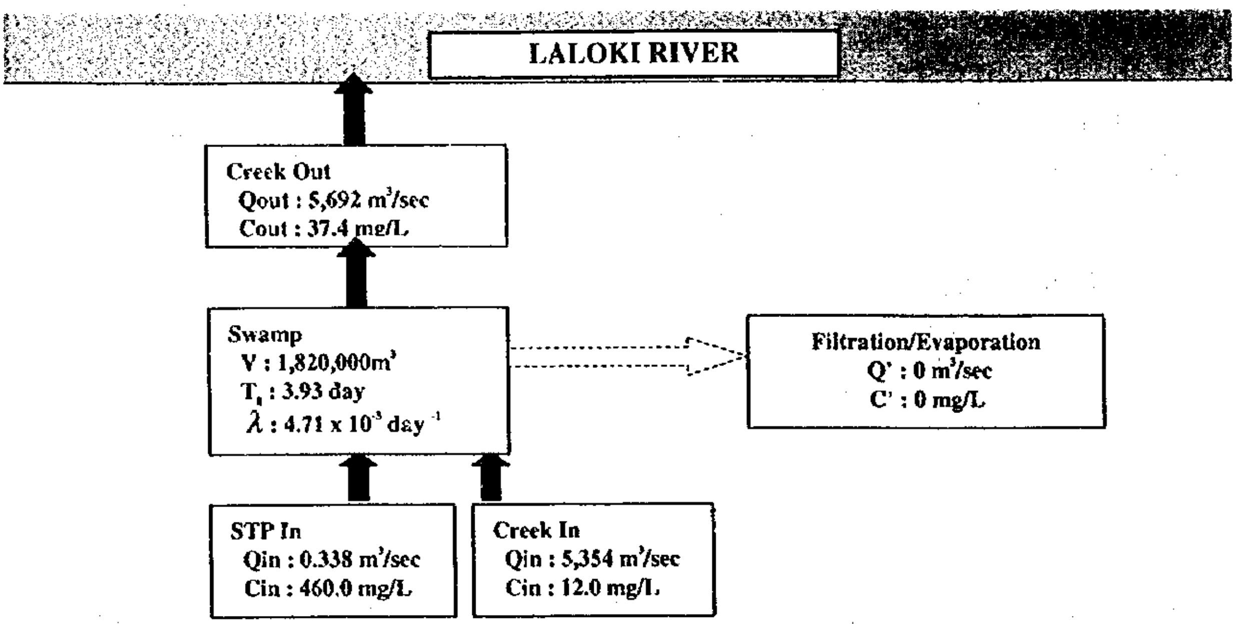


3) Estimation during rainy season

(1) COD concentration of swamp effluent (C)

$$C_t = C_0 \exp(-\lambda t)$$
$$C_0 = (0.338 \times 460.0 + 5.354 \times 12.0) / 5.692 = 38.6 \text{ mg/L}$$
$$C_t = 38.6 \times \exp(-4.71 \times 10^{-3} \times 3.93)$$
$$= 38.6 \times 0.983 = 37.9 \text{ mg/L}$$

(2) Mass balance chart during rainy season



3. Predicted Water Quality

3.1 Estimation of future condition with sewage treatment

1) Sewage flow in the future

The proposed total sewage flow for the year 2015 is as follows.

a. Waigani STP	: 86,700 m^3/day = 1.003 m^3/sec
b. Morata STP	: 15,200 m^3/day = 0.176 m^3/sec
c. Gerehu STP	: 18,000 m^3/day = 0.208 m^3/sec
Total	: 119,900 m^3/day = 1.388 m^3/sec

Proposed effluent water quality (COD) is estimated as 54 mg/L, 30mg/L (BOD concentration) x 2.7 (COD/BOD ratio), on condition that the adequate STP function shall be ensured.

2) Estimates during dry season

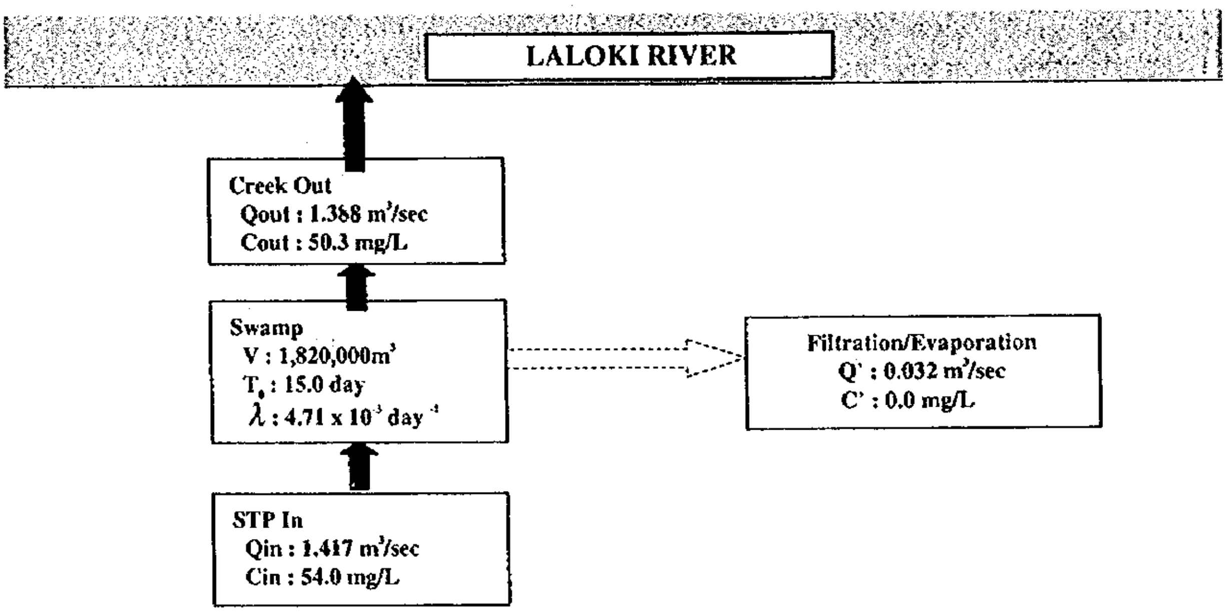
(1) Retention time of the swamp

$$T_0 = 1{,}820{,}000 / (1.417 + 1.385) / 2$$
$$= 1{,}299{,}072 \text{ sec} = 15.0 \text{ day}$$

(2) COD concentration of swamp effluent (C)

$$C_t = C_0 \exp(-\lambda t)$$
$$= 54.0 \times \exp(-4.71 \times 10^{-3} \times 15.0)$$
$$= 54.0 \times 0.932 = 50.3 \text{ mg/L}$$

(3) Mass balance chart during dry season



3) Estimates during rainy season

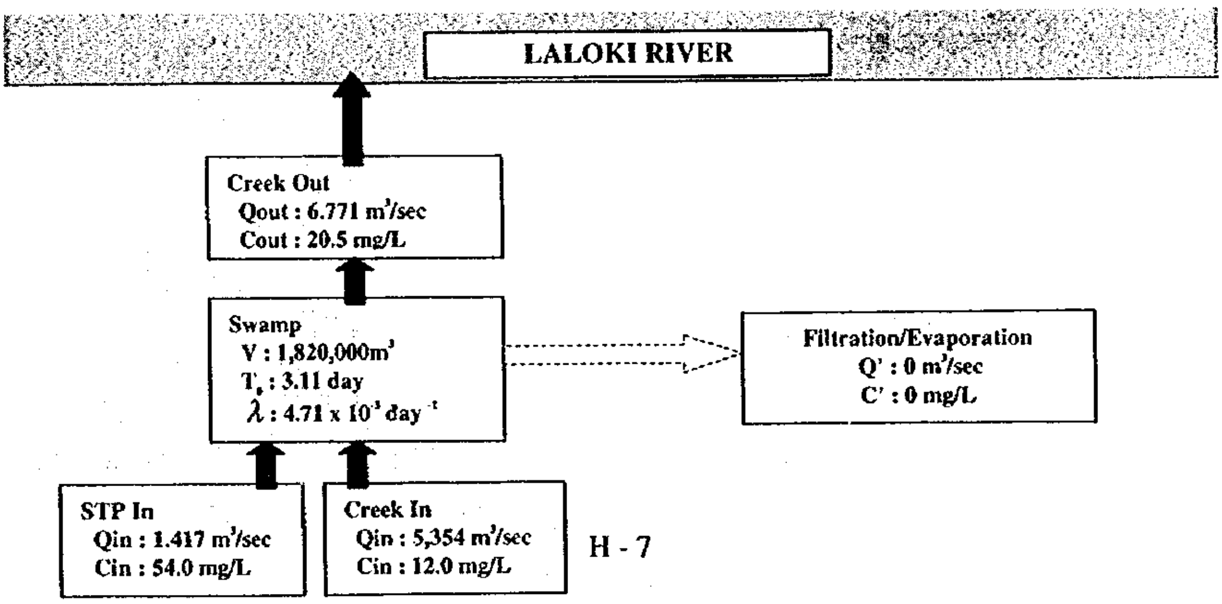
(1) Retention time of the swamp

$$T_0 = 1{,}820{,}000 / (1.417 + 5.354)$$
$$= 268{,}793 \text{ sec} = 3.11 \text{ day}$$

(2) COD concentration of swamp effluent (C)

$$C_t = C_0 \exp(-\lambda t)$$
$$C_0 = (1.417 \times 54.0 + 5.354 \times 12.0) / 6.771 = 20.8 \text{ mg/L}$$
$$C_t = 20.8 \times \exp(-4.71 \times 10^{-3} \times 3.11)$$
$$= 20.8 \times 0.985 = 20.5 \text{ mg/L}$$

(3) Mass balance chart during rainy season



3.2 Estimates of future condition without sewage treatment

1) Basis of estimates

Untreated sewage flow and its quality in year 2015 are as follows.

a. Sewage flow : 119,900 m^3/day = 1.388 m^3/sec
b. COD concentration : 460 mg/L
= 170mg/L (BOD) x 2.7 (COD/BOD ratio)

2) Estimates during dry season

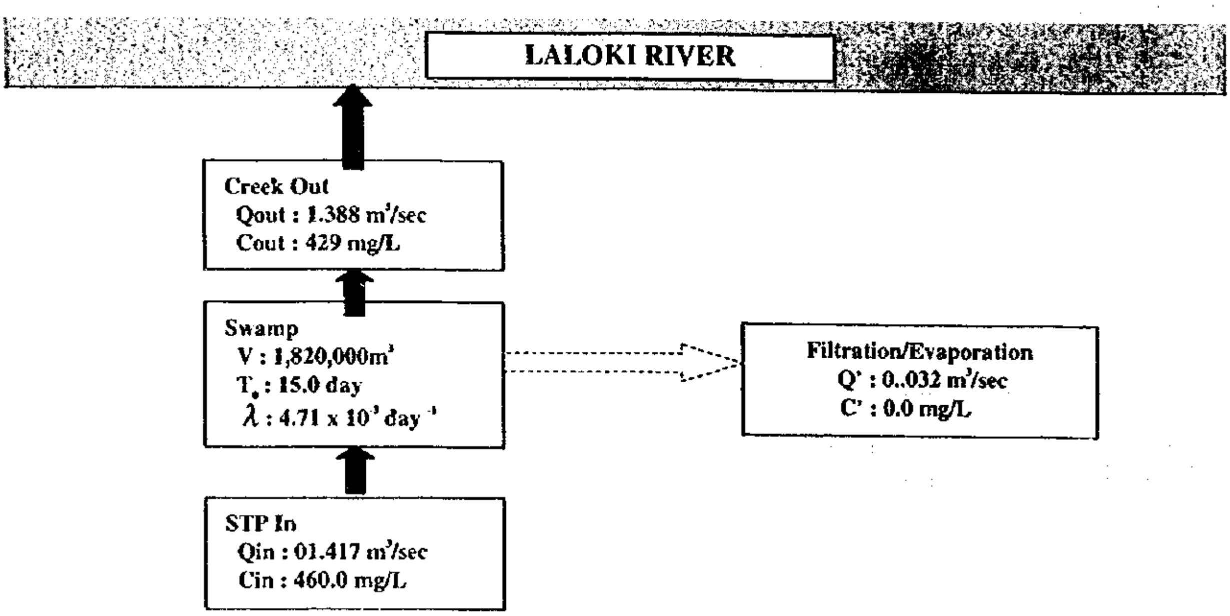
(1) Retention time of the swamp

$$T_0 = 1,820,000 / (1.417 + 1.385) / 2$$
$$= 1,299,072 \text{ sec} = 15.0 \text{ day}$$

(2) COD concentration of swamp effluent (C)

$$C_t = C_0 \exp(-\lambda t)$$
$$= 460 \times \exp(-4.71 \times 10^{-3} \times 15.0)$$
$$= 460 \times 0.932 = 428.7 \text{ mg/L}$$

(3) Mass balance chart during dry season



3) Estimates during rainy season

(1) Retention time of the swamp

$$T_0 = 1,820,000 / (1.417 + 5.354)$$
$$= 268,793 \text{ sec} = 3.11 \text{ day}$$

(2) COD concentration of swamp effluent (C)

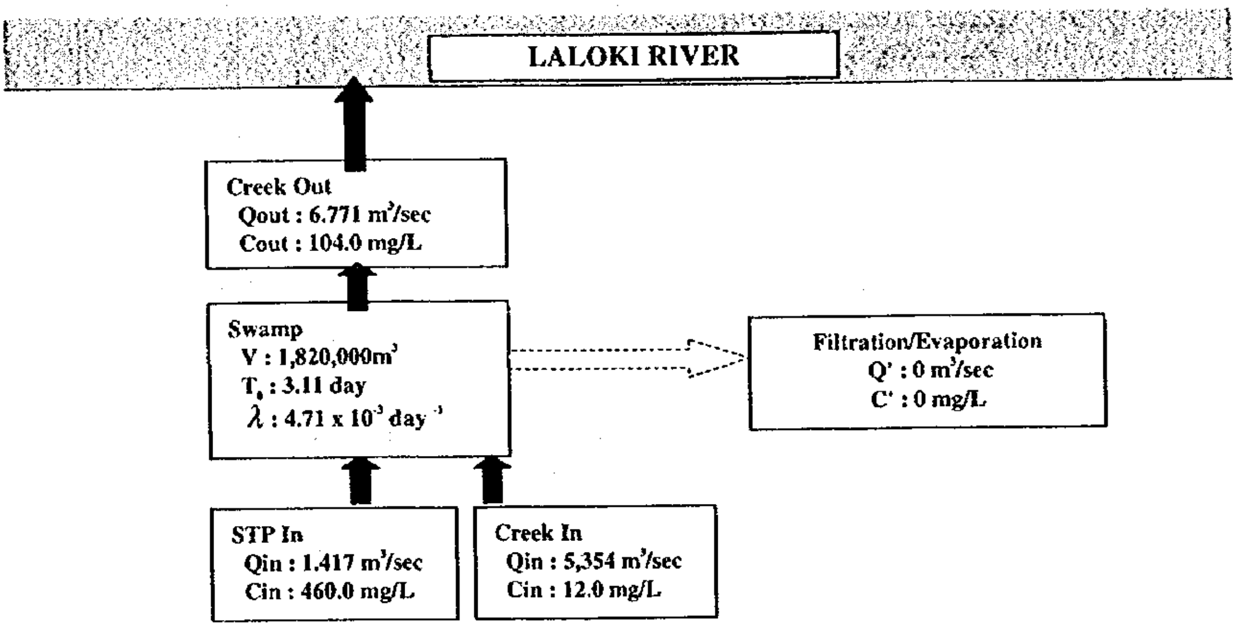
$$C_t = C_0 \exp(-\lambda t)$$

$C_0 = (1.417 \times 460 + 5.354 \times 12.0) / 6.771 = 105.8$ mg/L

$C_t = 105.8 \times \exp(-4.71 \times 10^{-3} \times 3.11)$

$= 105.8 \times 0.985 = 104.2$ mg/L

(3) Mass balance chart during rainy season



4. Comments on assessment result

The results are summarized as follows.

Table H.1.5 Evaluation of treatment effectiveness for aqua environment condition

		Existing (1997)		Future (2015)	
		Dry season	Rainy season	Dry season	Rainy season
Laloki River	COD (mg/L)	61	-	61	-
(Before junction)	Flow (m^3/sec)	5.156	-	5.156	-
Waigani swamp	COD (mg/L)	72	17	50	21
Effluent	Flow (m^3/sec)	0.157	5.692	1.385	6.771
Laloki River	COD (mg/L)	61.3	-	58.7	-
(Behind junction)	Flow (m^3/sec)	5.313	-	6.541	-
COD increase rate of the Laloki River	(%)	0.5	-	- 3.8	-

Table H.1.6 Water quality estimates of the Laloki River with no sewage treatment

		Existing (1997)		Future (2015)	
		Dry season	Rainy season	Dry season	Rainy season
Laloki River	COD (mg/L)	61	-	61	-
(Before junction)	Flow (m^3/sec)	5.156	-	5.156	-
Waigani swamp	COD (mg/L)	308	38	429	104
Effluent	Flow (m^3/sec)	0.157	5.692	1.385	6.771
Laloki River	COD (mg/L)	68.3	-	138.9	-
(Behind junction)	Flow (m^3/sec)	5.313	-	6.541	-
COD increase rate of the Laloki River	(%)	12.0	-	127.7	-

The results presented in the above tables indicated the following:

- Waigani swamp effluent has not affected water quality of the Laloki River (behind junction) at present.
- Adequate expansion/improvement of the STPs will contribute to improve the water quality of the Laloki River (behind junction) in the future.
- In case of no sewage treatment, Waigani swamp effluent worsen the water quality of the Laloki River (behind junction) both at present and in the future.

PART II COASTAL WATER

1. Introduction

This study is to assess the predictive impact by sewage discharge upon the completion of Port Moresby sewerage system development in 2015. Vertical and horizontal diffusion prediction model is applied for examination of dilution of sewage; complete mixing box model is applied for prediction of charge of water quality in long term.

2. Conditions of prediction

1) Sewage quality
Quality of treated sewage by sedimentation is as follows:

Table H.2.1 Sewage Quality

	Raw Sewage *1	Removal(%)	Treated Sewage
COD-Mn*2(mg/L)	85	40	51
T-N (mg/L)	46.8	20	37.44
T-P (mg/L)	5.2	30	3.64
Coliform(MPN/100mL)	2.4×10^9	90	2.4×10^8

*1 Planned raw sewage
BOD 170 mg/L
SS 200 mg/L
COD-Mn 85 mg/L

*2 COD-Mn is chemical oxygen demand using KM_nO_4, instead of $K_2Cr_2O_7$ for COD-Cr or Standard Methods 5220 of AWWA. COD-Mn is commonly applied to evaluated organic contaminant for seawater in Japan. In this study, raw sewage, 170 mg/L of BOD is estimated 85 mg/L of COD-Mn.

2) Sewage discharge
Amount of treated sewage discharge is estimated as follows.

Table H.2.2 Sewage Discharge

(Unit: m^3/day)

Year	Page Point STP	KilaKila STP
1995	7,816	0
1998	8,692	0
2002	9,859	25,488
2005	13,958	27,740
2015	15,900	31,600

3. Present Water Quality

Locations of water sampling is shown in Figure H.2.1. Sampling point 01 is the existing discharge point for Page STP and 02 is proposed point for Kila Kila STP, while, 001 is outside of Papuan Lagoon.

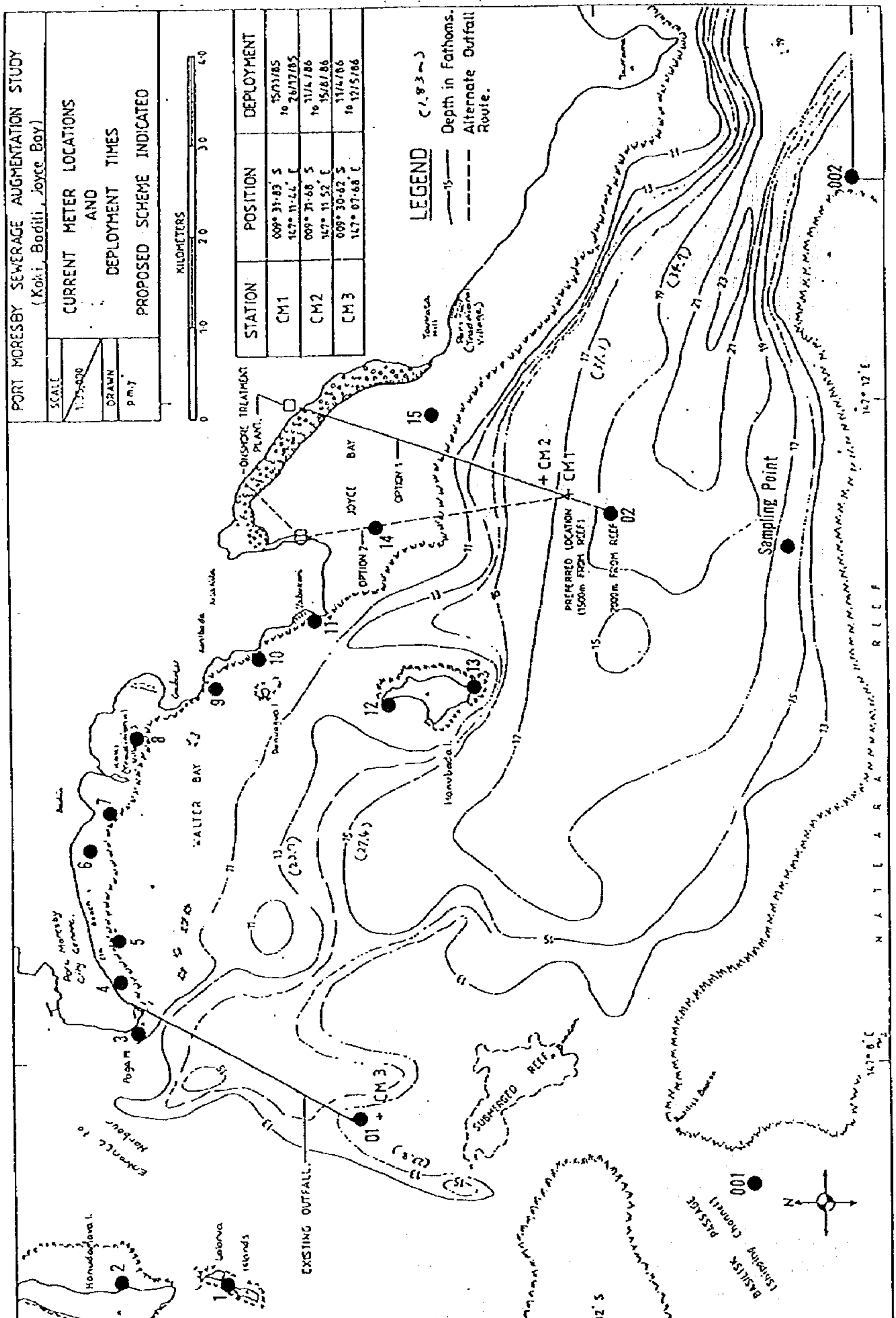


Figure H.1 Water Sampling Point

Table H.2.3 Sea Water Quality

Sampling Point	Salinity (Parts per thousand)	COD-Mn (mg/L)	T-N (mg/L)	T-P (mg/L)
01	34.38	1.3	0.13	0.009
02	34.58	1.4	0.25	0.009
001	34.44	1.3	0.09	0.008

001 shows lower value than others and it is considered that no contamination is caused by pollutants from ground and typical ocean seawater , since it is located coral sea.

4. Recommended water quality standard

Basically, "Recreational & Aesthetics users in Marine and Fresh Waters" in "Recommended Water Quality Standards for Papua New Guinea" will be applied, but for more detailed evaluation of the prediction, the following Japanese standard is applied.

Coastal water --Category A (Fishery class 1 and bathing)

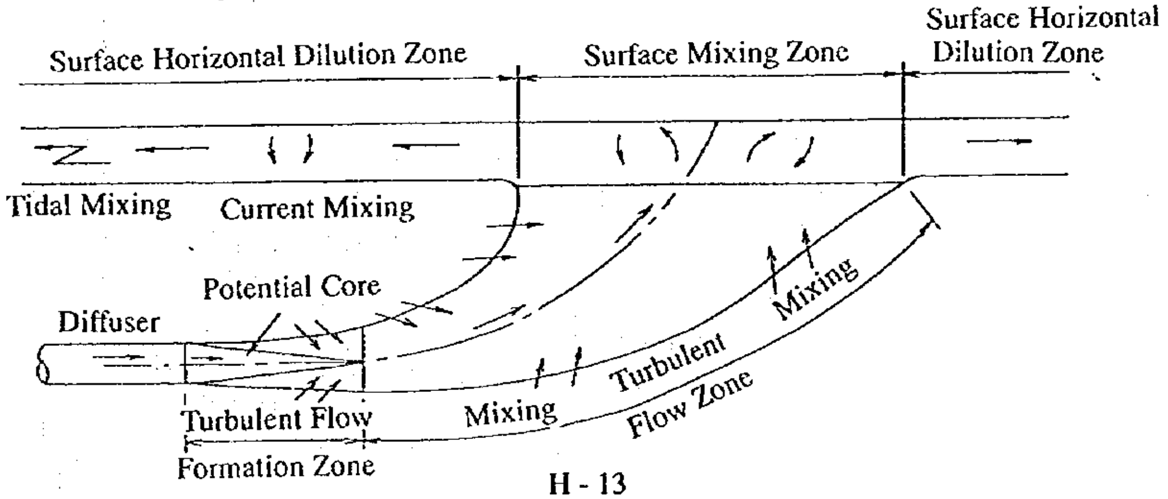
Table H.2.4 Water Quality Standard

Item	Standard
pH	7.8-8.3
COD-Mn	< 2.0 mt/L
DO	> 7.5 mg/L
Coliform	< 1000 MPN/100 mL
T-N	< 0.3 mg/L
T-P	< 0.03 mt/L

5. Diffusion Prediction

1) Concept of Prediction

Treated sewage after primary treatment or sedimentation, is proposed to discharge at the bottom of Papuan Lagoon. Diffusion of treated sewage in seawater is illustrated below. The sewage discharged approx. 1.0 m/s in a confined jet from the ports of diffuser pipe, is rapidly dispersed by clear seawater and floated up to the surface of the sea. Then, it is horizontally flowed in tongue-shape and diffused by current and turbulence at the surface.



This diffusion prediction is processed in the following manor.

(1) Vertical diffusion prediction (Initial Dilution)
The diffusion procedure of low density liquid, like treated sewage discharged in seawater moves into three dimension and requires detailed prediction by model test. In this study, however, "Three dimension, density confined jet model by numerical integral method" by Dr. Katayama et al will be applied.

(2) Horizontal Diffusion prediction (Subsequent Diffusion)
If sewage is deluded up to recommended standard no more prediction is required, however, the item like Coliforms is necessary to examine up to high dilution zone. In this zone, Fuick's diffusion formula is applied, as well as figure of microbial die-off in marine water by Feachem etal.

2) Vertical Diffusion Prediction

In this prediction, diffusion during floatation from the bottom to surface is examined.

(1) Conditions
Conditions of the vertical diffusion prediction are as follows

Table H.2.5 Vertical Diffusion Prediction

Item		Paga (01)	Kila Kila (02)
Flow (m^3/day)		15,900	31,600
COD_{Mn} (mg/L)		51	
T-N (mg/L)		37.44	
T-P (mg/L)		3.64	
Coliform (/100mL)		2.4×10^3	
Depth of diffuser pipe		24	35
No. of diffuser ports		15	30
Flow per port		0.0123	0.0244
Diameter of port		0.125	0.177
Initial discharge velocity		1.0	1.0
Discharge Water	Temperature (℃)	29.0	*1
	Salinity	0.0	
	Density (g/cm^3)	0.99595	*2
Seawater	Temperature (℃)	29.0	*3
	Salinity	34.5	*3
	Density (g/cm^3)	1.02169	*2
	Current	10	*4
	COD_{Mn} (mg/L)	1.4	*5
	T-N (mg/L)	0.19	*5
	T-P (mg/L)	0.009	*5
	Coliform (/100mL)	0.0	

*1: Same temperature as seawater is applied
*2: Value calculated by using UNESCO formula
*3: Value obtained by water quality survey
*4: Referring to "Environmental plan-Joyce Bay sewage out fall study (1988)"
*5: Average value of 01 and 02

(2) Results

a. Diffusion

Vertical and horizontal dilution trends of discharged treated sewage are illustrated in Figure H.2.2 for Paga and Figure H.2.3 for Kila Kila. In these figures, floating points of the treated sewage are approx. 25m down stream at Paga and approx. 40m at Kila Kila, respectively.

b. Dilution

Diluting condition at floating points are:

Table H.2.6 Diluting Condition at Paga & Kila Kila

Item	Paga (01)	Kila Kila (02)
Floating point (down stream)m	25	30
Dilution ratio	299	290
COD_{Mn} (mg/L)	1.6	1.6
T-N (mg/L)	0.32	0.32
T-P (mg/L)	0.021	0.022
Coliform (/100mL)	8.0×10^5	8.0×10^5

The results of the prediction are summarized as follows

(Paga)

At flouting point of Paga, T-N and Coliforms exceed the recommended standard. T-N, however, exceeds only 0.02 mg/L and it can be easily diluted by current and turbulent at surface. Therefore, the further study only for Coliforms will be continue in the next stage.

(Kila Kila)

This is similar dilution characteristic to Paga's. Since flow of each nozzle is about double, but the depth of the diffuser pipe is 10m deeper, almost same dilution ratio is obtained in this point.

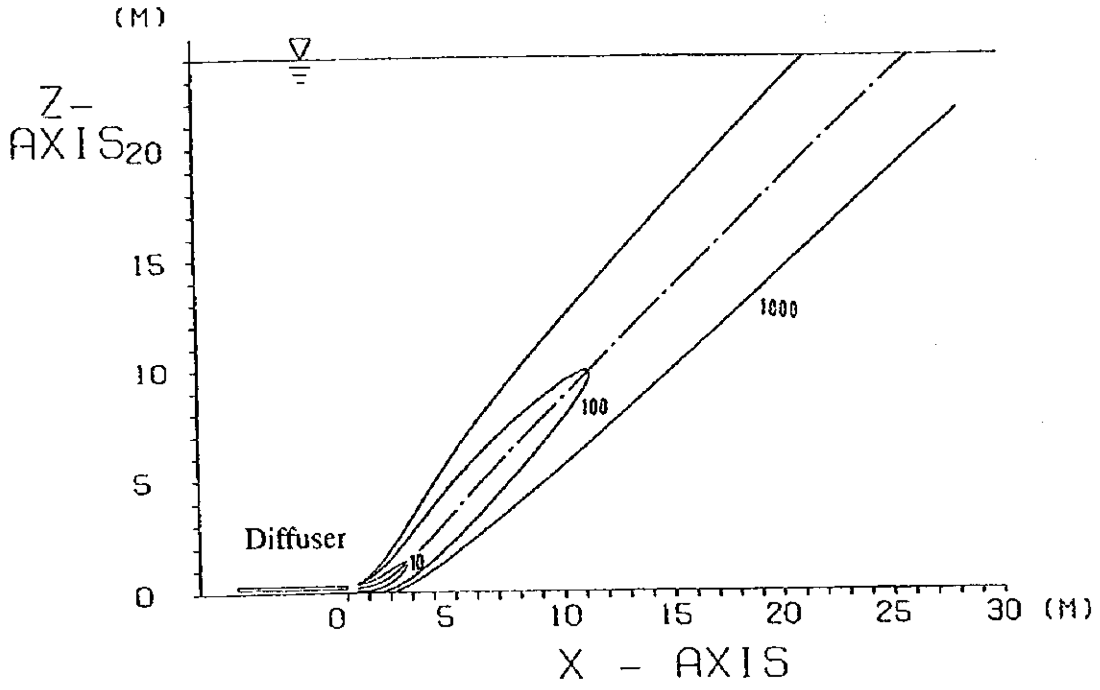


Figure H.2 (1) Paga — Vertical Distribution of Dilution

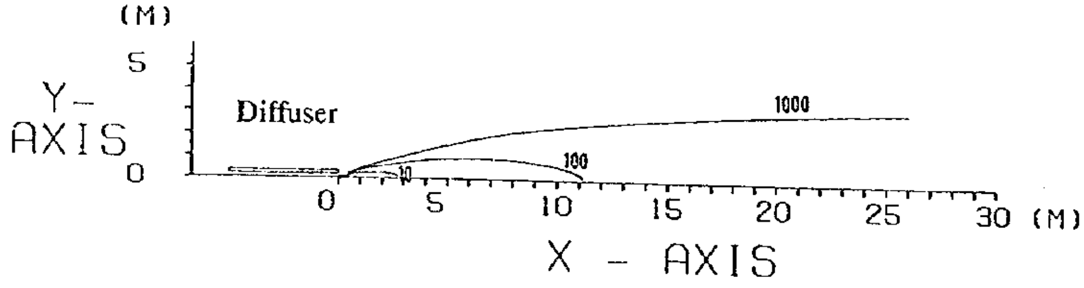


Figure H.2 (2) Paga — Horizontal Distribution of Dilution

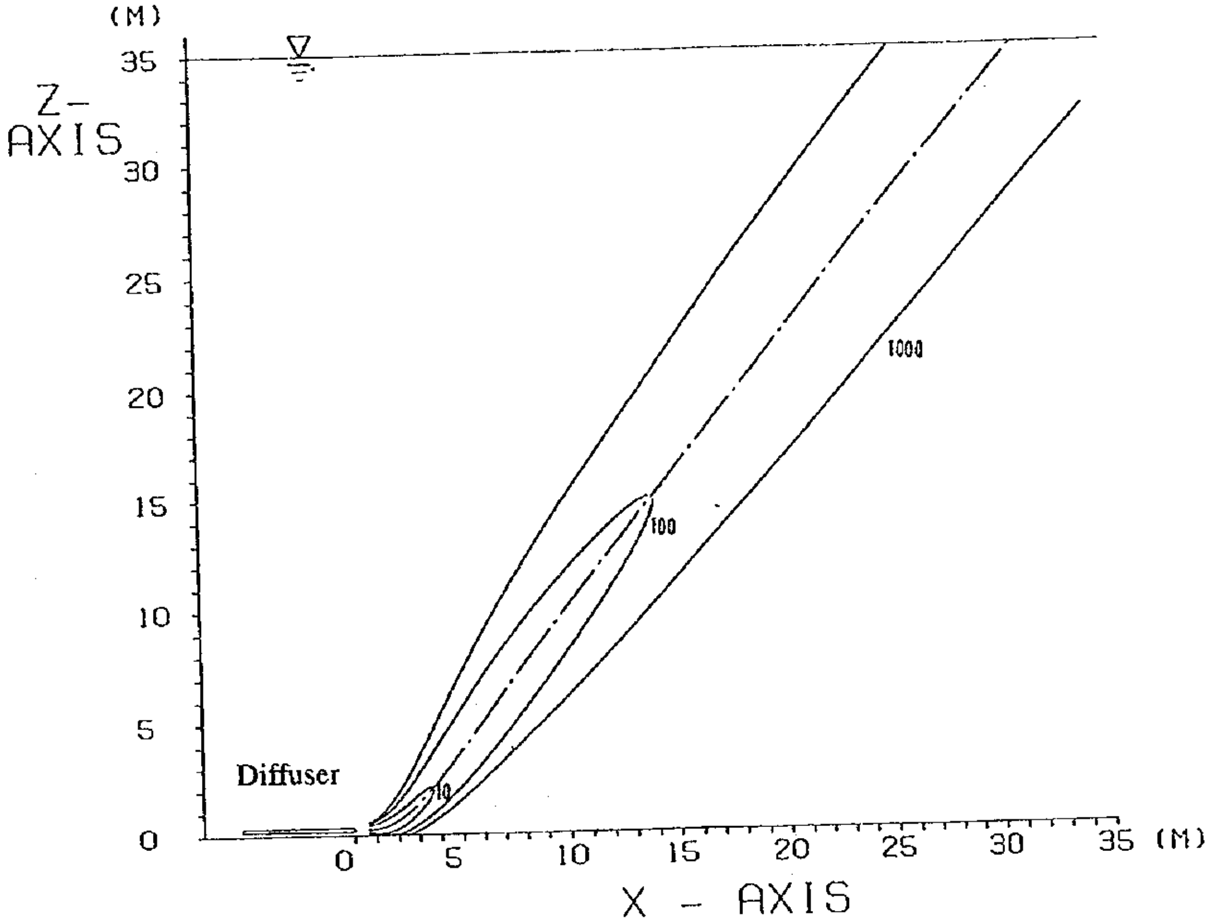


Figure H.3 (1) Kila Kila—Vertical Distribution of Dilution

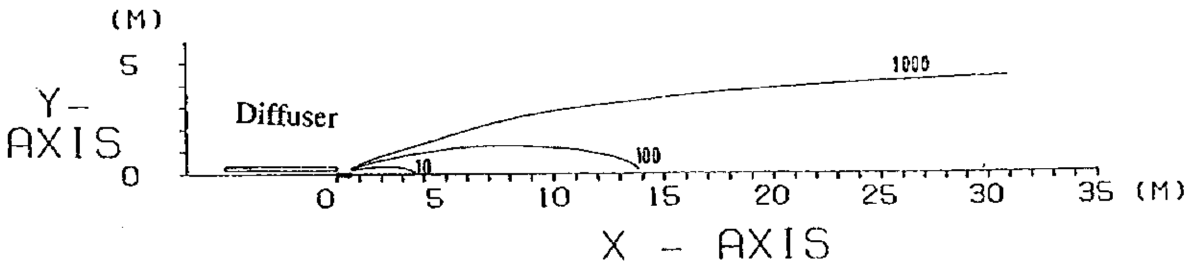


Figure H.3 (2) Kila Kila—Horizontal Distribution of Dilution

3) Horizontal Diffusion Prediction (Subsequent Dilution)

Since vertical diffusion or initial dilution could not make Coliforms (approx. 8.0×10^5 MPN/100mL) within recommended water standard, further diffusion by horizontal diffusion (Subsequent Dilution) will be examined on Coliforms.

(1) Conditions

Condition of this prediction is as follows.

Table H.2.7 Horizontal Diffusion Predicition

Item		Paga (01)	Kila Kila(02)
Floating Point	Dilution Ratio	299	290
	Coliforms /100mL	8.0×10^5	8.3×10^5
Theoretical Discharge Condition *1	Flow (m^3/s) *2	3.67	7.07
	Thickness of Diffusion *3	3.0	4.0
Field Condition	Flow (m/s) *4	0.1	
	Thickness of Diffusion *5	1.0	
Coliforms die-off	Coliforms die-off *6	$\log^{10}$(die-off)=-3x(days)	

*1: Theoretical discharge point is set at floating point
*2: (Flow of treated sewage) times (Dilution ratio at floating point)
*3: Same as thickness obtained by vertical diffusion
*4: Referring to "Environmental Plan-Joyce Bey Sewage Out fall Study (1988)"
*5: Determined by the flow of Papuan Lagoon
*6: Microbial die-off in marine waters (Feachemetal-1983)
(refer to the following table)

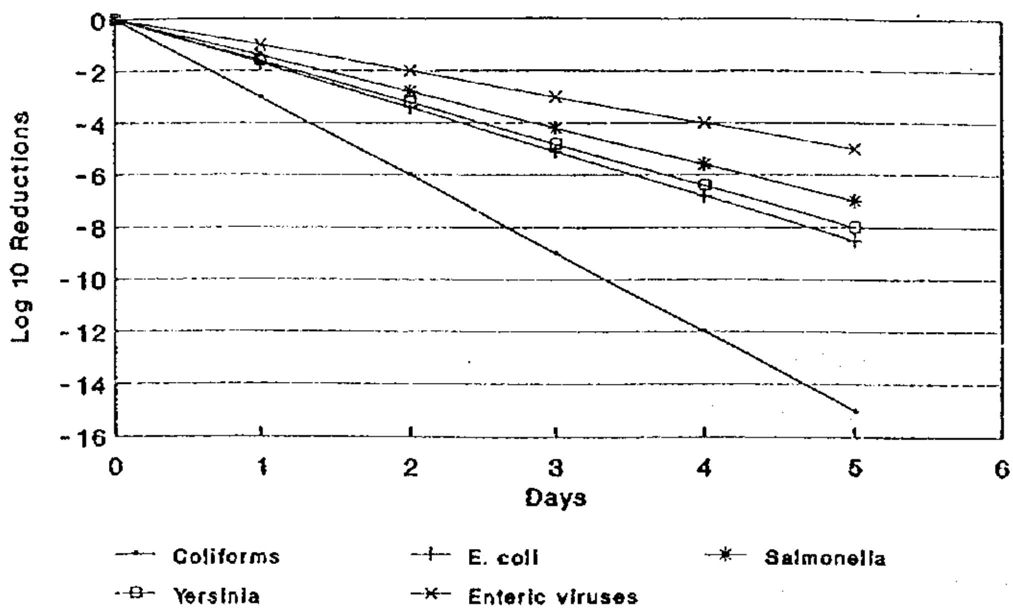


Figure H.4 Microbial die-off in marine waters (Feachem et al. 1983, Garcia-Lara et al. 1991).

(2) Results

Trends of coliforms and dilution ratio is calculated in the following table.

Table H.2.8 (1) Dilution Ratio and Coliforms Die-off by horizontal Diffusion (Paga)

Distance (m)	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000
Dilution Ratio	0.048	0.034	0.028	0.024	0.022	0.020	0.018	0.017
Days	0.058	0.116	0.174	0.231	0.289	0.347	0.405	0.463
Die-off ratio	0.670	0.450	0.301	0.202	0.136	0.091	0.061	0.041
Coliform (/100mL)	26,107	12,409	6,799	4,950	2,369	1,450	900	565

Table H.2.8 (2) Dilution Ratio and Coliforms Die-off by horizontal Diffusion (Kila Kila)

Distance (m)	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000
Dilution Ratio	0.070	0.050	0.041	0.035	0.032	0.029	0.027	0.025
Days	0.058	0.116	0.174	0.231	0.289	0.347	0.405	0.462
Die-off ratio	0.670	0.450	0.301	0.202	0.136	0.091	0.061	0.041
Coliform (/100mL)	38,936	18,505	10,138	5,889	3,541	2,162	1,342	842

Coliforms will be within the standard (1000 MPN/100 mL) after flowing of approx. 3.5km down stream from Paga outfall and approx. 4.0km of Kila Kila outfall.

6. Complete Mixing Box Model Prediction in Papuan Lagoon

1) Concept of Complete Mixing Bow Model

The Papuan Lagoon where Paga and Kila Kila outfalls are located in the center can be classified as a closed water body surrounding by reefs and islands. Changes of water quality in the lagoon is caused by the exchanges of water between inner lagoon and coral sea and the exchanges discharge pollutant from the lagoon to coral sea. These exchanges are caused by tides and turbulent of wave breaking on reefs.

In this study, this lagoon is divided into three box models with complete mixing condition, considering the effect of the above mentioned water exchanges between the boxes.

2) Formula of the Box Models

Complete mixing box models are shown in the following formula.

(Box 1) $$(C_1^{n+1} - C_1^n) \times \frac{V_1}{\Delta t} = Q_1 C_2^n - (1-\alpha_1) Q_1 C_2^n - \alpha_1 Q_1 C_1^n$$

(Box 2) $$(C_2^{n+1} - C_2^n) \times \frac{V_2}{\Delta t} = Q_2 C_3^n - (1-\alpha_2) Q_2 C_3^n - \alpha_2 Q_2 C_2^n$$

$$- Q_1 C_2^n + (1-\alpha_1) Q_1 C_2^n + \alpha_1 Q_1 C_1^n$$

$$+ Q_{IN1} C_{IN1} - Q_{IN1} C_2$$

(Box 3) $$(C_3^{n+1} - C_3^n) \times \frac{V_3}{\Delta t} = Q_3 C_0^n - (1-\alpha_3) Q_3 C_0^n - \alpha_3 Q_3 C_3^n$$

$$- Q_2 C_3^n + (1-\alpha_2) Q_2 C_3^n + \alpha_2 Q_2 C_2^n$$

$$+ Q_{IN1} C_2 + Q_{IN2} C_{IN2} - (Q_{IN1} + Q_{IN2}) C_3^n$$

where,
Q: Amount of Water Exchange
V: Capacity of Box
A: Surface of Box
C: Water quality in Box
α : Exchange ratio
Δ H: Difference of tidal level
Q_{IN}: Flow of treated sewage
C_{IN}: Concentration of treated sewage

3) Conditions

Table H.2.9 Condition of Papuan Lagoon

Item			Box 1	Box 2	Box 3
Surface (×106 m2)		*1	20.37	33.9	31.62
Ave. depth (m)		*1	15	23	30
Volume ($\times 10^6 m^2$)		*2	305.6	779.7	948.6
Difference of tidal level (m)		*3	1.2	1.2	1.2
Exchange Ratio		*4	0.05	0.1	0.1
Initial water quality	T-N	*5	0.09	0.09	0.09
(mg/L)	T-P		0.008	0.008	0.008
Coral Sea water quality	T-N	*5	0.09		
(mg/L)	T-P		0.008		
Quality of treated sewage	T-N		37.44		
(mg/L)	T-P		3.64		
Flow of treated sewage		*6	Paga	Kila Kila	
(m^3/day)	1995		7,816	0	
	1998		8,692	0	
	2002		9,859	25,477	
	2005		13,958	27,740	
	2015		15,900	31,600	

*1: Royal Australian Navy 81996) cha. No. Aus621
*2: Surface×Av. Depth
*3: 0.6×2 (tidal component×2) source; Schsiderski (1979)
*4: Determined by shape of seabed
*5: Determined by water survey result at 001
*6: Flow is set at Jan. 1 of the year

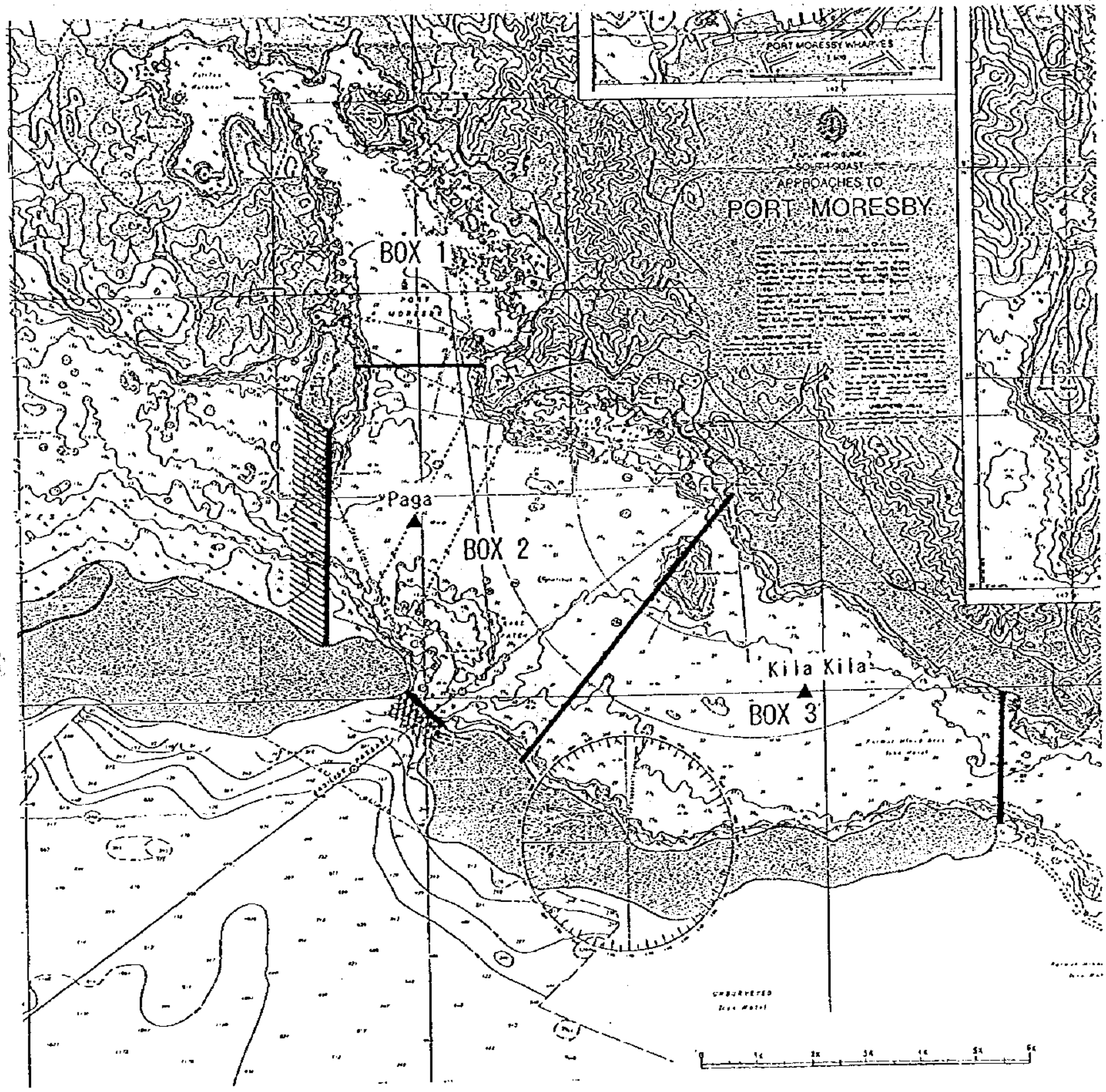


Figure H.5 Box Division in Papuan Lagoon

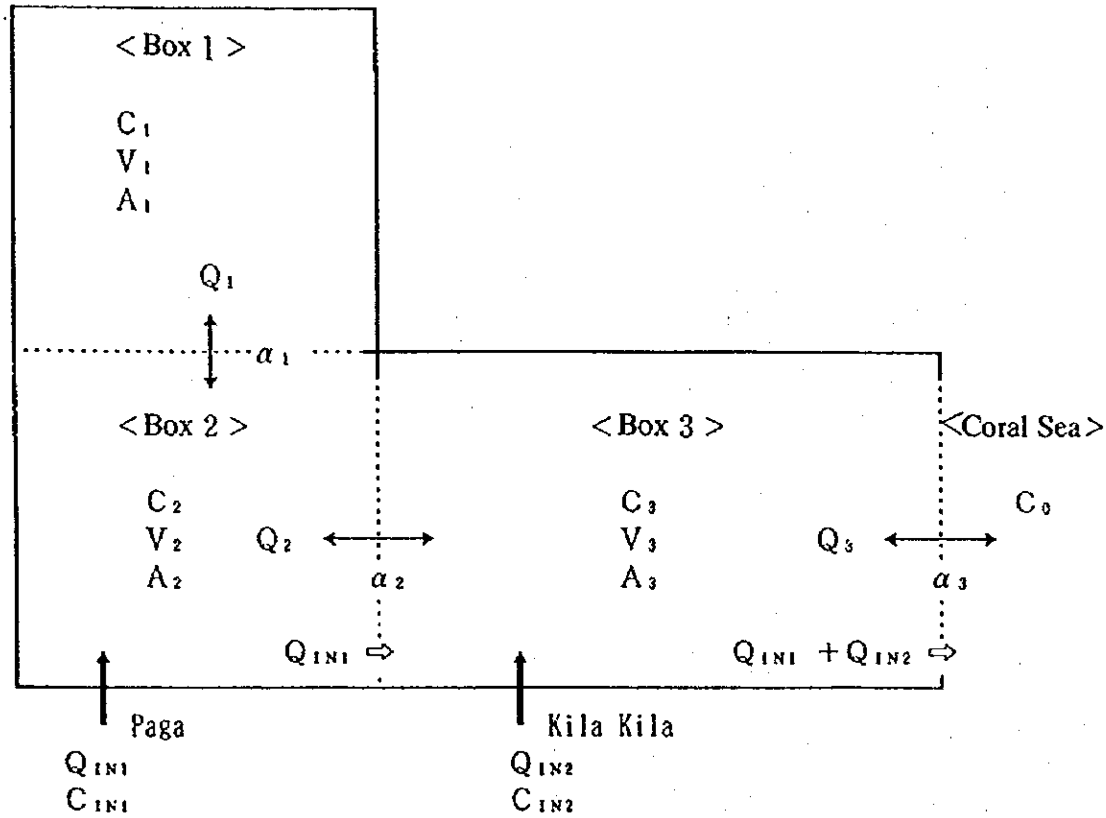


Figure H.6 Illustration of Box Model

4) Results

As shown in the conditions Paga STP started from 1995 with 7,816 m3/day and Kila Kila from 2020 with 25,477m^3/day, according to project implementation schedule. The following table shows the water quality (T-N and T-P) in the year of 2015.

Table H.2.10 Sea Water Quality in 2015

	Standard	Box 1	Box 2	Box 3
T-N (mg/L)	0.3	0.22	0.22	0.18
T-P (mg/L)	0.3	0.020	0.021	0.016

Annual changes of treated sewage flow, T-N and T-P is shown in Figure J.2.7 to J.2.9.

The results of this study are summarized as follows.

- At the year of 2015, T-N will be 0.18 to 0.22 mg/L and T-P will be 0.016 to 0.021 mg/L, and the value is less than the standard.
- Water exchange amount (water exchange flow × exchange ratio) of Box 3 is 2.06×10^7 m^3/day and it is 434 times larger than sewage flow (15,900 + 31,600 = 47,500 m3/day). It makes proper exchange between inner lagoon and coral sea and reduces pollutants in the inner lagoon.
- This box model is established with the one dimension, however, actual water exchange volume will be much more than this model.

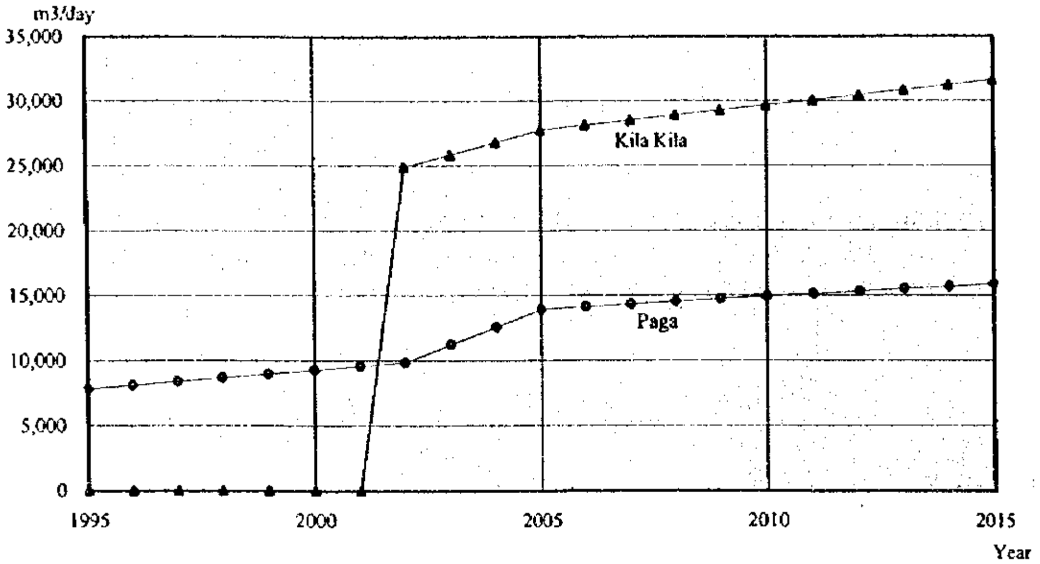


Figure H.7 Change of Treated Sewage Flow

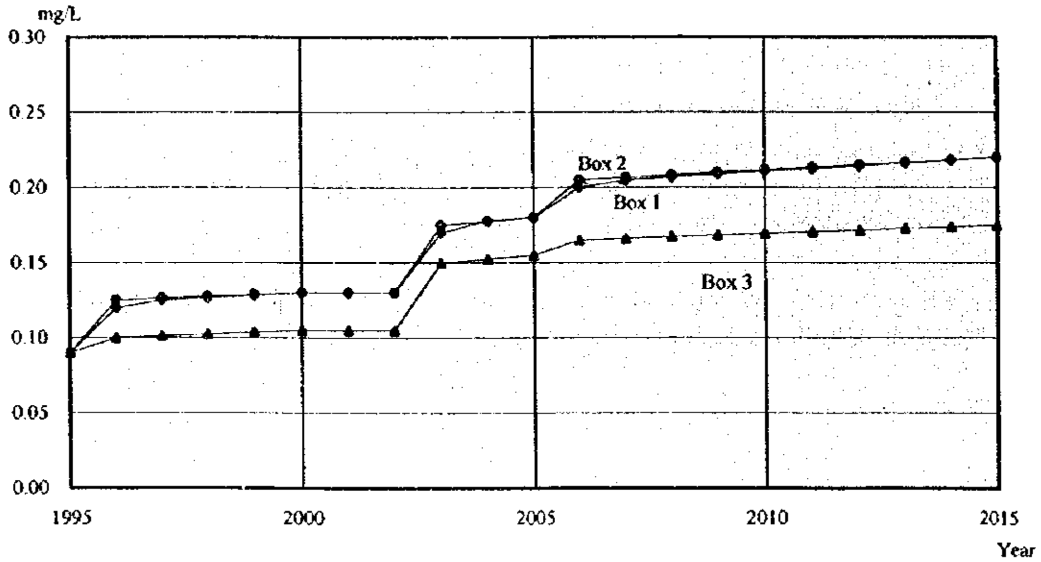


Figure H.8 Change of T-N

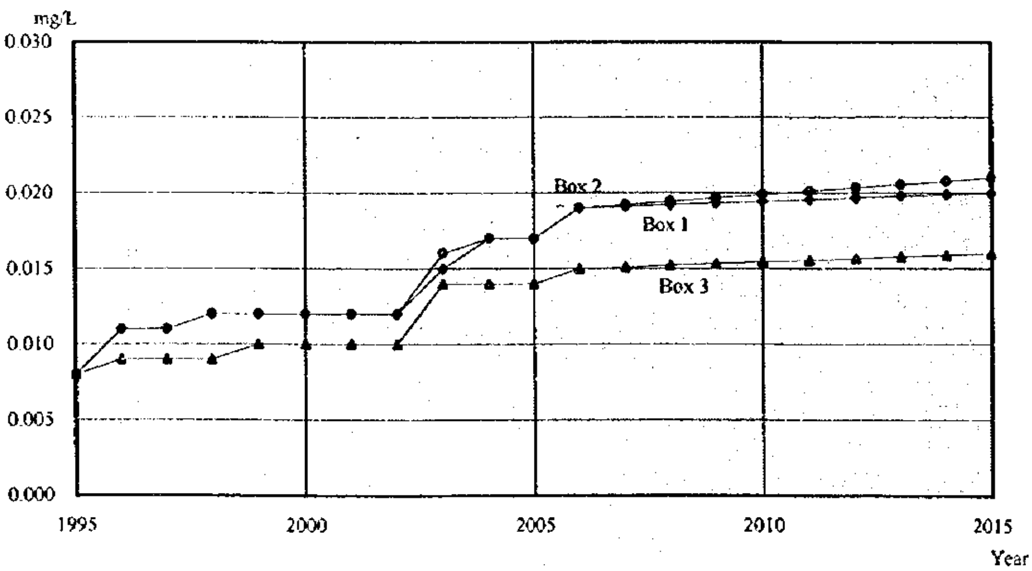


Figure H.9 Change of T-N