CRUISE REPORT 100
of PE/CK.4
10 May 1985

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BASELINE STUDY FOR COASTAL MANAGENENT
COASTAL ENGINEERING STUDY AT NGATANGIIA HARBOUR AND MURI BAY, RAROTONGA, COOK ISLANDS

CRUISE CK -84-1
21 MAY TO 12 JUNE 1984

by

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PREPARED FOR:

COMMITTEE FOR CO-ORDINATION
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EXECUTIVE SUMMARY

An analysis was made of the sedimentation and erosion problems at Ngatangiia Harbour and Muri Bay. The primary cause of the two problems appears to be the development in the watershed areas tributary to the harbour area during the present century. The filling of the harbour may have contributed to a reduction in the hydraulic flow through Muri Bay and a slight increase in the water level in the lagoon. This in turn appears to have contributed to a more aggressive wave action on the beach area near the Sailing Club and may be cause for the erosion there

The following action is recommended for melioration of the two problems. First the harbour should be dredged to remove the terrestrial sediments. Second the channel that formerly drained Muri Bay should be reestablished, and third some type of erosion control and sediment traps should be employed in the watershed.

Before the channel to Muri Bay can be opened it will be necessary to do further study in the hydraulic control area near the large fish trap in order to specify what action is to be taken

INTRODUCTION AND BACKGROUND

This cruise was undertaken as a part of the CCOP/SOPAC Work Programme, CCSP/CK.4, study of Sediments and Sedimentary Processes of the beach, lagoon and adjacent offshore areas of Rarotonga and other islands to assist with Coastal Management programmes.

Rarotonga has a tropical climate. Summer is November through March and winter is April through October. Southeast trade winds occur during the winter season. Winds are generally 6 to 14 knots. Calm occurs about 18 percent of the time, and winds in excess of 37 knots can be expected once a year. Temperature varies from 21 deg to 27 deg Celsius. The central area is mountainous with peaks to 653 meters in elevation. A 0.75 Km wide 32 Km long terrace of 3 to 50 meters in elevation surrounds the mango shaped island. The average annual rainfall on the east end of the island is 1840 mm which increased to a maximum of 4000 mm near the center of the island and decreases to 2000 mm along the northwest terrace. The New Zealand Meteorological Service reports a mean rainfall of 2028 mm +/- 394 mm at Lat 21 11 S and Long 159 48 W at elevation of 7 m. The maximum rainfall of 249 mm occurred in January and the minimum of 97 mm occurred in July (Coulter and Hessell 1980).

The Ngatangiia Harbour is located 21 deg 14.3 min S 159 deg 43.5 min W on the east end of Rarotonga~ and is protected by Motutapu and Oneroa, Fig 1. In the past it would accommodate larger ships; however, in recent times the deposition of river transported sediments have filled much of the harbour. It now required dredging so small pleasure boats could be launched. Fishing in the general harbour area, reported as once being excellent is npw very poor.

The recent history of Ngatangiia Harbour was described by Kirk (1980) in his sedimentation study of the harbour and by Dahl (1980> in his report on Marine Surveys of Rarotonga and Aitutaki. They indicated that schooners anchored in the harbour during the last century. In 1969 or 1970 significant grading for a banana plantation occurred. Recently land owners have cut trees lining the Avana Stream bank and continue to plow the steep farmed land up and down the grade. A road has been constructed into the watershed area. Hence erosion has been accelerated. Significant storms have occurred in 1967, 1978, and 1983. At present small craft cannot enter the harbour half of the year. It would be desirable to have a minimum depth of 2 m so the harbour could be utilized as a harbour of refuge during major storm conditions.

Muri Bay is located ~1 deq 15.3 min S 159 deg 43.8 min W or about one km south of Ngatangiia Harbour. The beach along the west shore of the lagoon has experienced a significant amount of sand erosion the past few years and this loss of beach sand is of concern.

CRUISE OBJECTIVES

The present study was conducted to develop baseline data on the harbour and lagoon areas. There is a need to provide a data base for control and design parameters for dredging control, shoreline protection, and restoration of the local fishery.

PERSONNEL PARTICIPATING

Ralf Carter, Marine Scientist assisted by Jan-Erik Steen, Marine Scientist both from the CCOP/SOPAC Staff in Fiji conducted the study. They had the support and assistance of the Prime Minister's Department and the Ministry of Internal Affairs. Individuals giving direct assistance or participating in the study included:

Mr. Stuart G. Kingan, Scientific Research Officer
Mr. Tony Utonga, Secretary, Internal Affairs
Mr. Mike Mitchel, Solicitor General
Mr. O. Peyrous, Registered Surveyor
Mr. R. P. Brill, Senior Surveyor

Mr. D. E. Dorrell, Governing Director, Marine Construction
Mr. Vaitoti Tupa, Conservation Officer. Internal Affairs Mr. Rongo Short, Surveyor
Mr. Tere Okirua, Assistant
Mr. Aturangi Hosking, Draughtsman
Mr. Paul Frost,Officer in Charge Meteorological Office
Mr. Ken Brown, Director Water Supply, Ministry Works Mr. John Short, Contractor
Mr. Justin De Silva. Surveyor (PWD) Mr. Altan Raymond Watters, Marine Zoo
Mr. Gerald McCormack, Education Department Mr. Jason Brown, Reporter

METHODS, EQUIPMENT, AND FACILITIES

A bathometric survey was conducted at Muri Bay. The survey department provided the horizontal and vertical control for the survey at Muri Beach.

Origins - The origins of bearings and coordinates for these traverses are from the Main Road Control survey from S.D. 314. Thus coordinates are in terms of Rarotongan Initial C.B. 1 with a false origin of +20,000 mN & +50,000 mE added to all values to make all coordinates positive and unambiguous. The origin of levels is BM 6 No.2 and is terms of Mean Sea Level May 1951.

The Survey - This consists of a series of "open" traverses run from the control marks in the north through to various old survey marks in the south. Thus checks on bearings and positions have been made by coordinate closes through old work to the S.D. 314 control traverse and subsequent surveys.

Levels have been run from BM 6 No. 2 to the reference marks placed on the concrete ramp at the Marine Zoo, a couple of hundred meters away. Both the marked beach mark placed by R. Short and the position indicated by R. Carter have been tied in.

Accuracy - Because of reliance on various old surveys and the time constraint on the amount of survey control able to be established, horizontal accuracy of survey marks is somewhat less then normal - say +/- 0.25 m. Vertical accuracy of the Benchmarks on the Marine Zoo ramp should be okay to +/- 0.02 m.

Bathometric Survey - Two flags were placed in line on the beach for each traverse. A third offset flag was placed for sextant cut-in angles made from the survey boat. A fathometer was employed to determine and record the water depth. A recording tide gauge was located in the lagoon to measure the surface water level during the survey. Transits perpendicular to the control lines were located at 25, 50 and 100 m intervals depending upon the uniformity of the lagoon bottom.

A steel bar was employed to probe the lagoon bottom in the vicinity of the old rock fish traps to determine the nature of the sediment and extent of cementation. Sand samples were collected from selected beach stations.

The following equipment was provided by CCOP/SOPAC:

- Sextant
- Compass
- Hand Level and Rod
- Tools, Sampling Equipment and Miscellaneous Items

The facilities and equipment supplied by the Cook Island Government were:

- Equipment Storage Facilities
- Ground Transportation, Truck and Automobile
- Various Maps, Charts, Photos, etc.
- Numerous Reports and Records
- Surveyors and Survey Equipment

PHYSICAL ENVIRONMENT

Tropical Cyclones and Winds

Data complied by Kree (1976) and Revell (1981) indicated that during the 40 year period, 1939 - 1979 the South Pacific Ocean averaged 9.1. tropical cyclones per season. The coefficient of variation for the average was 32 percent. The peak occurrence of storms is between January and February. Analysis of the 91. South Pacific cyclones reported between 1969 and 1979 show the geometric: mean wind speed to be 54.5 +/- 1.3 knots and the average maximum wind speed for the 50 years recurrence interval (R) was found to fit the relationship:

$$S^{C} = A + B \quad \text{LOG} \quad R$$

where c was found to be 1.899061.288. A was 1.420.203803. B was 2046.050482 and S is in knots. The value of "A" was found to vary with both latitude and longitude of a location and its value for Rarotonqa was estimated to be 1.452.060679.

Analysis of the above 91. Tropical cyclones show the Southern Cook Islands to experience 0.49 cyclones per year or 1.0 severe cyclone, in excess of 88 knots in a 50 year period. Hence, the 50 year design cyclone for the Southern Cook Islands is expected to have a sustained wind speed of 88 knots. The wind speed for storms having other recurrence intervals is:

years	knots	years	knots
1	46.2	30	83.6
5	66.3	35	85.0
10	73.5	40	86.1
15	77.4	45	87.1
20	80.0	50	88.0
25	82.0	100	93.6

Wind in excess of 20 knots, exclusive of cyclones and observed at the Rarotonga airport, can be expected to have the following annual frequency:

Knots	frequency	Knots	frequency
22	88	37	1.0
24	39	38	.8
26	20	40	.5
28	11	42	.3
30	6	44	.2
32	3	46	.15
34	2	48	.11
37	1.2	50	.08

The Southern Cook Islands experienced 5 notable storms between 1905 and 1939 and 14 storms between 1940 and 1979. These data suggest that a serious storm can be expected every 5 to 6 years.

Storm Surge

The cyclone that occurred in 1967, a 20 to 25 year storm produced a storm surge that raised the level of the sea water to 1.94 m above mean sea level. The wind setup would be less then 0.01 m due to the very steep approach to the island; hence, the wave setup would be on the order of one meter as the tide would account for 0.5 m and the barometric change 0.4 m.

The depth of water at the reef is a major controlling factor in determining the size of ocean wave to reach the beach. Wave setup can increase the depth of water significantly.

Seas, Swell

The recurrence of tropical storm produced seas* at the reef are:

years	H	T	L	years	H	T	L
5	4.68	8.2	106	30	6.68	9.8	148
10	5.37	8.8	120	35	6.92	9.9	154
15	5.80	9.1	129	40	7.14	10.1	159
20	6.13	9.4	137	45	7.36	10.3	164
25	6.42	9.6	142	50	7.58	10.4	169

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* H is the significant wave height (m), T is period (sec) and L is wave length (m). There is little available swell information for the Cook Islands. However. During the winter months swells producing 4 m high breakers on the reef and having periods of 10 to 15 seconds. This condition appears to happen frequently. The swell does not impact the beach to the same extent as local storms that produce the same wave height due to the greater depth of water at the reef associated with the storm. The swell is a more regular wave then that of the storm and as a result of the regularity it is

more efficient than the random wave in raising the wave setup water level that produces the sea return current in the lagoon. Hence, strong, along shore currents can be associated with the swell.

An analysis of the upper-level, 900mb or .9 km high wind frequencies which were reduced to 10 meter elevation was made using:

$$U_z/U_s = \text{In}\ (Z/Z_o)/\ \text{In}\ (10/Z_o) \qquad 2$$

where Z_o is .2 to .5 cm over water at 10 m height for light winds and .6 cm for stronger winds, U_z is the wind speed at 900 m, Z is 900 m and U_s is the wind speed at 10 meter elevation (Handbook of Ocean and Underwater Engineering page 12-12). Wind data for Rarotonga from 1958 to 1979 and the trade wind generated waves over a .5 nautical mile of 2.0 m average depth water are:

knots	2.43	4.86	10.90	16.94	22.98	29.08	35.12	sum
N	7	21	49	19	4	1	0	102
NE	12	29	91	34	5	1	0	173
E	10	33	147	96	12	2	0	300
SE	15	34	81	26	4	1	0	160
S	7	18	27	3	0			55
SW	10	15	26	5	1	0		58
W	7	12	32	13	3	1	0	68
NW	10	16	35	16	4	1	0	83
sum	78	178	488	212	34	7	1	calm 2

The above winds generate the following waves over the reef flat:

Wave							
P, (sec)	.56	.83	1.26	1.55	1.79	2.00	2.18
H, (m)	0.02	0.05	0.12	0.19	0.26	0.33	0.40

These smaller wind waves that are generated in the lagoon can under certain conditions errode away the beachsand and/or transport it along the beach.

Secondary Reef Waves

Another type of wave would be generated when large seas or swell break upon the reef. Roberts (1980) has shown that between 68 and 92 percent of the wave energy is 10Et by breaking at the reef during high tide and 77 to 97 percent can be lost during low tide. However, such waves do cause secondary waves to form over the reef. Ttle secondary waves tend to transport sand to the beach and as they are generally parallel with the beach do not transport much sand along it.

Homes (1979) used an equation developed by Dexter (1973) for the estimation of secondary reef waves over the Tarawa reef, a somewhat broader reef that has a seaward sloping top that cause the approaching wave to break before reaching the reef crest rather than breaking over it. This conditions appears to exist at Rarotonga, and the modified equation 3 was used for the estimation of the secondary waves given in this report. This equation assumes no secondary wave when the depth of water over the reef becomes zero. lhe modified equation for d/Ho > .325 is:

$$H = Ho^{2} \times \tfrac{3}{4} \times 1/d \times (c/8(1-\exp- (d/Ho \times 1/c)))^{2/3}$$

where c = 5.573705, and d, H, and Ho are mean water depth at the reef crest, H is the wave formed on the reef and Ho is the wave near the breakpoint respectively. This equation predicts that the secondary wave will increase in a linear relationship with the depth of water over the reef up to a maximum wave height. Where after it will decrease in height with the depth of water over the reef for a given wave height of the approaching wave. The equation for d/Ho < or = .325 is:

$$H = 0.8215\, d \quad 3b$$

Reef Current

The water introduced over the reef rim can raise the level of the water in the lagoon shoreward of the reef above that of the water outside of the reef. This difference in water level will cause a current to develop from the lagoon back to the ocean. If the channel is restricted, the speed of the current can become significant during times of large swell or seas. Using the hydraulic model data developed by Seelig (1982) for the condition of irregular waves and a 2 metre depth of water over the reef rim, the increased depth, h of water in the Muri Lagoon due to wave pumping was calculated. The deep water wave heights and periods given above in the sea and swell

Rainfall

The average annual rainfall for the various areas of Rarotonga are shown in Figure 2. The watershed tributary to Ngatangita Harbour was taken as 2500 mm per year. The annual rainfall for Rarotonga since 1930 was reviewed and the recurrence period given in Figure 3 was prepared for the entire watershed. Rainfall-duration-intensity curves were prepared from New Zealand Met data and are given in Figure 4. This information was utilized to estimate the storm water discharge from the Avana Streen in the following section.

Ngatangiia Harbour Watershed

Two streams enter the harbour area, the Turangi and the Avana. A third stream enters from the Muri area in the upper reach of the harbor across from Oneroa Motu. The individual watersheds have the following characteristics and if in a natural condition could be expected to contribute the indicated amount of sediments to the harbor basin:

	Turangi	Avana	Muri
Length, (m)	3,760	6,760	1,575
Height, (m)	600	653	199
Area (ha)	210	400	55
Erosion, (cum/yr)	73	140	19

If we assume a sediment bulk weight of 1,1220 kg/cum and an erosion rate of 0.35 cum/ha-yr, the amount expected from a brush and tree covered steep slope in 3,000 mm rainfall area, then the total annual sediment contribution to the harbor would be on the order of 233 cum/yr. kirk (1980) reported 250,000 cum of gravel deposit in the harbor area. This value includes an unknown proportion of material of volcanic origin. It would appear that much of this sediment has been deposited within the past 80 years. The Avana Stream delta system has been changed significantly since 1948 and a banana plantation scheme and other construction has occurred in the late 60ies and early 70ties. Several hurricanes have also impacted the area, 1963, 1967, 1868 and 1983 and they generally produce some level of flooding due to the associated heavy rainfall. It would appear that the erosion over the past 80 years and particularly the past 20 years has contributed as much deposition in the harbor as would occur in some 1,000 years under natural conditions.

A storm flow analysis was made on the Avana watershed using a Manning's coefficient of 0.05 for mountain streams, a time of concentration of 45 minutes, and a hydraulic radius of 1.25. The following discharge estimates for several rainfall recurrences intensities were made:

Rainfall Recurrence (yrs)	Peak Discharge (cum/s)
2	19.8
5	25.8
10	29.1
20	33.0
50	39.6

The average discharge velocity in the stream was estimated for the 10 year rainfall and found to be 3.3 mps. This is sufficient velocity to transport a significant quantity of sediment.

Beach Rock and Lagoon Sediment Cementation

The several features of the reef at Ngatangiia includes the "algae ridge" c algae have been described by Lewis etal (1979). The molluscs and algae covered subtidal cemented hard ground is a feature that is given further consideration here. This hard ground is found on either side of the entrance into Ngatangiia Harbor and to the east of Oneroa and Koromiri Motus. Kirk (1980) referred to it as the hard coral basement and/or hardpan. It can be broken by hand with a steel bar. It is 15 to 20 cm in thickness. It has been attacked by boring organisms, and in the area of the large fish trap east of the passage between Motutapu and Oreroa was found to be under layered by a sticky red brown clay material some 15 cm in thickness overlaying sand and coral rubble. When disturbed this clay material produced a significant amount of dense turbidity in the water

The reef mote bottom was probed with a bar between the mainland, passed the fish trap and over to the northwest point of Oneroa. A solid hard ground layer was found except for a 10 m wide band near and parallel with Oneroa. The aerial photos show this to be the location of a former water channel draining the Muni Lagoon area. It is now filled with unconsolidated coral rubble, carbonate sands, and sediments.

This channel is believed to be the deep water often referred to by "old-timers" of the area. They remember the time when it was not possible to walk across the mote to the motus, and the strong currents would carry them to the north when they crossed.

The hard ground underlies the large fish trap cited above. Inside the "v" of the trap the cemented layer is 0.6 m below the top of the rock wall. On the down stream side outside the rock wall it is some 1.3m below the top of the rock wall. The cemented layer extends out some 1.5 m from the base of the fish trap wall at this level where it rises up to the same level as inside of the trap. Bathurst (1971) indicates that the growth of a hard layer can occur in less than 1,000 years. Beach rock is known to be a contemporary process as shown by inclusion in the rock of man-made articles some dated as recent as seven to eight years old (Emery etal 1954). It would appear that cementation at the base of the fish trap may have occurred prior to the last century but continued up to recent times in the area some few meters from the actual wall. The hydraulic head loss through the large fish trap was approximately 15 cm during low tide 15/2/85.

A profile of the cemented layer through the center of the mote area above or south of the fish trap is shown in Figure 5. It would appear that the rim, shown at A2 in the figure, is the hydraulic control point across the mote for the return flow of wave pumped water across the reef in Muri Lagoon.

Wetlands Impact on Fishery

One of the objectives of this study is to determine ways to improve fishing in Ngatangiia Harbour and Muri Lagoon. Older residents of the area indicate that fishing was much better in the past. There is little documentation to indicate the cause for this reduction in productivity other than the recent shoaling within the system. It would appear that changes and development within the watershed has accelerated the natural aging process in the harbor and has contributed to a reduction in fish production.

It is quite possible that dredging of the harbor and removal of the sediments accumulation of the past 20 or so years may do little to improve fishing in the area. The wetland/estuarine relationship are important for mitigation of the negative impacts from increased nutrients and suspended solids that will accompany watershed development. A review of the harbour and lagoon system shows an absence of the usual mangrove/marsh habitat in this area. Due to the increased impact from the watershed such a buffer system may now be essential for improvement of the fishery.

Tidal wetlands can regulate nutrients in the lagoon system. Spartina, Rhizophors, Zostera and Thalassia (cord grass, mangrove, eelgrass and turtle grass) are a few of the plants that remove nitrogen from the water before it is used by the algae and they return it as ammonia to the sediments as they decay. In the cationic form nitrogen is adsorbed onto the clays where it is either returned to the atmosphere by defitrification or reused by the higher plants. Phosphate is also returned to the sediments by the decay of these plants. It is also stored by the sediments and will be recycled as needed by the higher plants. The algae blooms that may reduce the ultra-transparency of the water and impact the growth of coral are thus controlled to some extent by the above nutrient cycle; hence, the vital roll of the marsh and mangrove in maintaining a good water quality in the lagoon.

Another function of the mangrove is to aid in physical deposition of suspended solids. This function also improves the transparency of the water and thus improves the filter feeders efficiency. The habitat encourage insect growth for small fish food, mollusks that aid in nutrient recycling, crustaceans which are a major food source for larger fish and many small bait type fish that attract the transient fish desired for the fishery. The transient marine species are attracted to the lagoon/mangrove/marsh area by the abundance of food, availability of shelter, and/or proximity to fresh water (Bartlett and Klemas 1980). On a regional basis the proportion of estuarine dependent fish is often correlated with the quantity of tidal wetlands.

It would appear that some of the shallow margin of the harbour and lagoon system should be converted to mangrove in order to improve the fish productivity of the area.

Suspended Solids Turbidity

Dredging increases the turbidity of the water and the fine material that settles can remain in the general area for years. This material is a poor substrait for regeneration of coral, and it may be resuspended many times to further damage existing coral by increased turbidity within the water column. It can also settle onto the coral. In sufficient quantity it can kill the coral.

Suspended solids impact coral in several ways. The increased turbidity slows the rate of the coral growth. Smothering can kill the coral outright. Toxic materials associated with the fine sediments can also kill the coral. Some 70 percent of reef coral species may die in 24 hours if covered with 10 cm fines. A resuspension rate of 39 mg/sq cm/day can reduce the number of species by half and a resuspension rate of 53 mg/sq cm/day can reduce the area covered by live coral by half (Randall and Birkeland 1978). A resuspension rate of 100 mg/sq cm/day can half the growth rate of Montastrea annularis (Risk 1983). An area of coral killed from smothering may take many years to recover. The older and larger coral as well as that living on the outer reef areas are most likely to be killed if covered by sediments. A large 1 meter size coral head will be 100 years old or so as growth in clear water will approach 10 mm per year. Replacement will be slow. Resuspension of fines can prevent coral larvae from becoming established except on surfaces located 50 cm or more above the bottom (Risk 1983).

SITE OBSERVATIONS

Lagoon Water Level

Water level elevations in the lagoon were measured from 7/610/6 with an Aanderaa water level recorder. Measurements of 40 see average values were made at 5 minute intervals. The instrument was located about 50 metres east of the Marine Zoo in Murl Lagoon.

The amplitude of the tidal range inside the lagoon was approximately 40 percent that predicted for the harbour. Ocean waves pausing water over the reef maintained the low water level at that of the rim level (0.06 m above msl) of the outlet control section north of the lagoon. Channel friction restricted the inflow during flood tide so that high tide level for the ocean was never attained within the lagoon during the tidal cycle.

The flood period was shorter than the ebb period by one hour. This shift is results from the mean water level inside the lagoon being higher than the mean tide level in the ocean.

Bathometric Survey

The results of the bathometric survey of the lagoon are given in the Appendix and are shown in Figure 6 and Figure 7.

The results of a previous bathometric survey of the harbour are given in the South Pacific Marine Geological Notes, Vol 2 No 9 (Gauss 1982)

The contours indicate that at least some of the sand that has been removed from the beach near the sailing club has shoaled just off the beach in Muri lagoon. Transport to the north does not appear to have been excessive.

Hydraulic Control Section

Immediately south of the existing large fish trap at Oneroa Motu a 135 m reach of mote rises from 0.3 m below msl to 0.06 above msl.fhis section of lagoon is 320 m in width. The minimum water level in Muri Lagoon appears to be controlled by the rim at the upper end of this section. A rating curve was developed for this control section using Manning's friction factor of 0.022 for sand and gravel (English units). Assuming steady state flow in the channel then:

Depth of Channel (m)	Velocity (mps)	Flow (cu m/sec)
.05	0.27	1.44
.1	0.40	5.41
.2	0.60	20.27
.3	0.76	43.91
.33	0.80	52.65

The full 320 m width is wetted with a water depth of 0.33 m. Assuming 2/3 of the maximum (62.8 cu m/s) harbor discharge observed by Kirk (1980) would pass through this control section then the depth of water in the control section would be 0.292 m at the time of Kirk's observations. The velocity would be 0.75 m/s and the flow would be 42 cu m/s. The entrance losses at the rim would be on the order of 0.04 m; hence, the water level in the lagoon would have been approximately 0.06 + 0.04 + 0.292 = 0.4 m above msl at the time of Kirk's current measurements provided the channel remained unchanged since 1980.

The change in water level within the lagoon during the June study was 0.426 m. Low water was 0.051 m above msl and high water was 0.477 m above msl. The 9 hour discharge through this section was estimated using a maximum channel depth of .292 m. the observed tide changes, and the above rating curve. It was assumed that during the nine hours as observed by Kirk (1980) the flow was always out at the control section due to wave pumping across the reef. The calculated value was 665,993 cu m/9 hrs for the lagoon discharge. Assuming that this would be 2/3 of the total harbor discharge then the total discharge would be 999,000 cu m/tide cycle. This value compares quite well with Kirk's observed discharge value of 960,000 cu m/tidal cycle.

The flood tide appears to drown the control section at high water and the direction of flow may reverse for an hour or so.

Apparently there is sufficient friction along the mote out to the harbour entrance to prevent the last 0.12 m of ocean tide from entering the lagoon during the tidal cycle.

It will be necessary to lower the control rim to increase the hydraulic exchange through the control section. It would appear that the construction of a 50 m wide channel 0.4 m in depth on a 0.003 slope would transport water away from the lagoon at a velocity of 1.34 mps or just under scour velocity. The discharge rate from the lagoon would be 27 cu m/s with a channel depth of 0.4 m.

Lowering the water level within the lagoon should increase the flow of ocean water through the lagoon/harbor system from wave pumping. A reduction in the depth of water within the lagoon could be offset by pumping some of the sand shoaled in the lagoon back onto the beach. Lowering the depth would also shorten the effective wave generating fetch and average depth of the lagoon so wind generated wave action that erodes the beach would be reduced. The increased depth by reclamation of some of lagoon sand would have little significant impact on wave action as compared with the general lowering of the overall water level elsewhere in the lagoon.

DISCUSSION

It is the opinion of the investigator that while the sediments that have been deposited during the past 80 years or so can be safely dredged from the harbour area, it is also his opinion that the cemented material of the algae flats and the hard ground that cover a significant portion of the area above the harbour and near the harbour entrance cannot be disturbed without causing serious adverse environmental impact. Most certain none of the hurricane debris found seaward of the Motus should be mined. The biological sand that forms the beaches on the landward side of the Motus should not be mined.

Some coral damage can be anticipated from turbidity produced during dredging, and a considerable effort should be expended to minimize the amount of turbidity that remains in the harbor area.

Dredging of harbour area will expose new areas to wave action. At sometime in the future it may be necessary to construct a seawall along the west side of the dredged area to protect the shore against wave damage. Larger ocean waves will now have sufficient water depth to reach this area through the harbour entrance. The larger waves can be expected to occur every 5 or- 6 years.

The erosion from the watershed will continue to fill the harbour area during flood times and maintenance dredging will be required unless sediment traps are constructed in the streams. A vigorous erosion control program should be implemented in the watershed. A significant quantity of sediment must enter the harbour with each of the predicted 10 year flood discharges. The heavy bed load is transported mainly during the high discharge periods.

It is suggested that mangroves be developed in the areas where streams enter the harbour. Several species should be introduced. This type of development should aid to improve fishing.

An area south of the large fish trap has been identified as the hydraulic control section for impoundment of water in Murl Bay. This area need to have a detailed topographic survey before appropriate modification and restoration of the old drainage channel can be specified. Lowering the water level in the bay will increase the flow of new ocean water that is pumped over the reef by wave action. This passage of high quality water through the harbour on its way back to the ocean will increase the productivity 0+ the reef forming organisms in the area and improve the food chain to attract more fish into the area.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are tentative and are based upon the above report.

1.-It is necessary to dredge the terrestrial sediments deposited in Ngatangiia Harbour in order to provide a small craft anchorage.

2.-More study of the hydraulic control section is justified as it appears critical to flushing of Muri Bay.

3.-Some of the sand eroded from the Sailing Club beach was deposited in the near shore area in front of the Sailing Club. This sand could be safely dredged and used to resupply the beach area.

4.-No mining of sand should be permitted from the Sailing Club beach area.

5-The storm surges at Rarotonga associated with the tropical cyclones are primarily the result of change in barometric pressure and wave setup. The latter may account for 2/3 of the surge height and a 20 year storm could result in 1.4 m rise in sea level during the storm. A 40 year tropical cyclone should produce a 1.8 m rise in sea water level at Rarotonga.

b.-The 40 year tropical cyclone should result in 7.14 m high seas having 10.1 see period. This wave could produce a 1.9 m-secondary wave over the reef.

7.-A stream discharge of 29.1comes with a velocity of 3.3 mps can be expected to occur every 10 years or- so in the Avana Watershed.

8.-Dredging can proceed at this time if it is confined to the terrestrial deposits that are located at the entrance of Avana Stream and in the channel toward the harbour entrance.

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A. The views expressed in this report are those of the author and do not necessarily reflect those of th- ...

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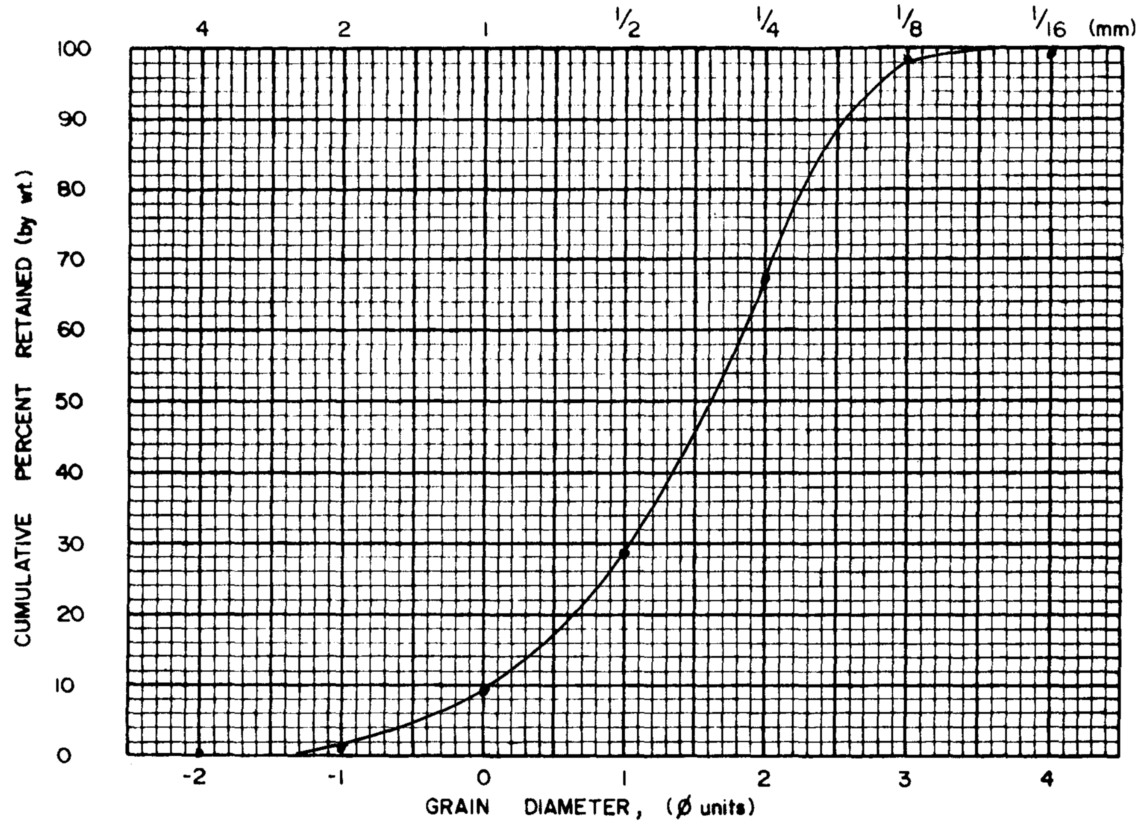


SAMPLE NO 8 LOCATION Muri Bay, Rarotonga

DESCRIPTION Beach sand from mtl @ Sailing Club 10/6/84

DESCRIPTIVE PARAMETERS:

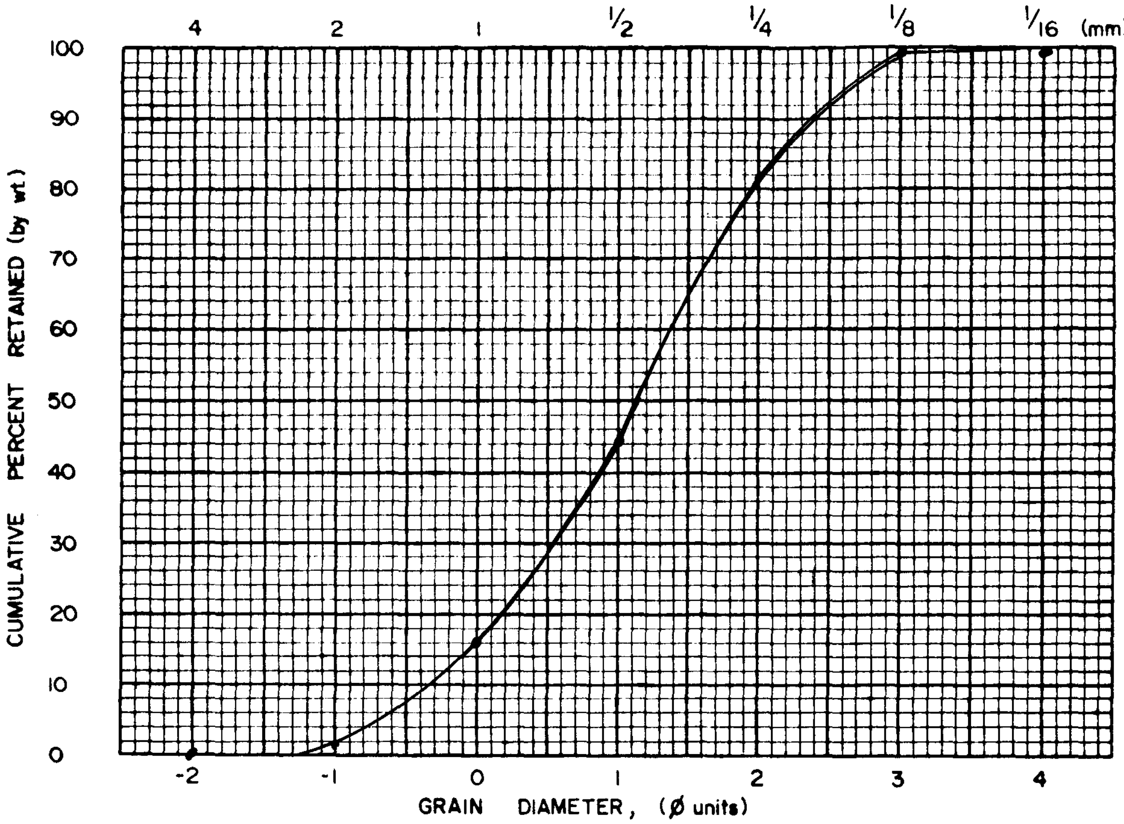
Phi median diam, $Md\phi = \phi 50$	1.61
Phi mean diam, $M\phi = \frac{1}{2}(\phi 16 + \phi 84)$	1.40
Sorting, $\sigma\phi = \frac{1}{2}(\phi 84 - \phi 16)$	0.97
Skewness, $\alpha\phi = \frac{M\phi - Md\phi}{\sigma\phi}$	-0.22

COMMENTS:

Calculated by Ralf Carter

Date 24/8/84

22.3.83



SAMPLE NO 7 LOCATION Muri Bay, Rarotonga

DESCRIPTION Beach sand collected MTL @ Marine Zoo 10/6/84

DESCRIPTIVE PARAMETERS:

Phi median diam, $Md\phi = \phi 50$ 1.13

Phi mean diam, $M\phi = \frac{1}{2}(\phi 16 + \phi 84)$ 1.06

Sorting, $\sigma\phi = \frac{1}{2}(\phi 84 - \phi 16)$ 1.06

Skewness, $\alpha\phi = \frac{M\phi - Md\phi}{\sigma\phi}$ -0.06

COMMENTS:

Calculated by Ralf Carter

Date 24/8/84

22.3.83

APPENDIX

Profile Tabulation Muri Lagoon Site

Position: Cross Section A1		Position: Cross Section A2	
Date: 8.6.84 Time: 18:00		Date: 7.6.84 Time: 16.40	
Dist. E-W (m)	Reduced to M.S.L. (m)	Dist. E-W (m)	Reduced to M.S.L. (m)
236	-0.19	200	0.02
222	-0.09	192	0.07
200	0.11	179	0.12
187	0.06	145	0.02
168	0.01	130	-0.08
156	0.06	117	-0.08
145	0.01	109	-0.08
130	0.06	97	-0.08
115	0.06	90	-0.03
98	0.06	83	-0.03
85	-0.09	76	-0.03
65	-0.09	67	-0.03
43	-0.09	58	-0.08
		52	-0.08
		49	-0.08
		40	-0.08
		37	-0.08

Position: Cross Section A3		Position: Cross Section A4	
Date: 7.6.84 Time: 16:25		Date: 7.6.84 Time: 16:10	
Dist. E-W (m)	Reduced to M.S.L. (m)	Dist. E-W (m)	Reduced to M.S.L. (m)
205	-0.18	164	0.12
196	-0.01	130	0.22
188	0.02	103	0.22
180	0.12	94	0.22
173	0.17	80	0.22
166	0.17	69	0.22
160	0.12	56	0.12
148	0.22	39	0.12
115	0.02	30	0.12
104	0.02	14	0.12
93	0.02		
84	0.12		
73	0.17		
63	0.22		
51	-0.01		
34	-0.01		
21	-0.18		

Note. Profiles labelled as per Fig.
E-W means from east towards west

APPENDIX

Profile Tabulation Muri Lagoon Site

Position: Cross Section B1		Position: Cross Section B2	
Date: 7.6.84 Time: 16:00		Date: 7.6.84 Time: 15:55	
Dist. E-W (m)	Reduced to M.S.L. (m)	Dist. E-W (m)	Reduced to M.S.L. (m)
118	0.52	130	0.37
93	0.42	112	0.32
69	0.42	98	0.32
54	0.42	87	0.18
39	0.42	71	0.18
25	0.22	62	0.08
10	0.22	45	0.08

Position: Cross Section B3		Position: Cross Section B4	
Date: 8.6.84 Time: 12:10		Date: 8.6.84 Time: 12:15	
Dist. E-W (m)	Reduced to M.S.L. (m)	Dist. E-W (m)	Reduced to M.S.L. (m)
130	0.47	148	0.59
125	0.42	143	0.59
120	0.37	138	0.39
116	0.27	128	0.19
107	0.37	119	0.29
100	0.42	111	0.44
93	0.42	104	0.49
87	0.37	90	0.59
80	0.37	84	0.59
75	0.37	73	0.59
63	0.37	63	0.59
55	0.37	53	0.59
42	0.37	45	0.59
35	0.47	38	0.49
27	0.37	31	0.44
20	0.37	25	0.29
		18	0.09

Note. Profiles labelled as per Fig.
E-W means from east towards west

APPENDIX

Profile Tabulation Muri Lagoon Site

Position: Cross Section B5 Date: 8.6.84 Time: 12:20		Position: Cross Section B6 Date: 8.6.84 Time: 12:35	
Dist. E-W (m)	Reduced to M.S.L. (m)	Dist. E-W (m)	Reduced to M.S.L. (m)
226	0.43	371	0.26
208	0.38	353	0.36
193	0.28	337	0.36
179	0.38	308	0.41
166	0.28	282	0.36
154	0.18	259	0.16
134	0.33	240	0.06
121	0.48	222	0.06
109	0.48	206	0.06
94	0.48	192	0.06
81	0.48	179	0.06
72	0.58	167	0.16
61	0.58	155	0.26
51	0.58	140	0.26
48	0.58	126	0.31
41	0.38	109	0.31
		94	0.36
		80	0.36
		67	0.36
		55	0.36
		43	0.36
		32	0.16

Note. Profiles labelled as per Fig.
E-W means from east towards west

APPENDIX

Profile Tabulation Muri Lagoon Site

Position: Cross Section C1 Date: 7.6.84 Time: 13:00		Position: Cross Section C2 Date: 7.6.84 Time: 13:25	
Dist. E-W (m)	Reduced to M.S.L. (m)	Dist. E-W (m)	Reduced to M.S.L. (m)
418	0.26	137	0.85
358	0.36	130	0.80
286	0.36	118	1.00
238	0.46	107	0.95
204	0.46	98	0.85
178	0.56	87	0.75
158	0.26	77	0.65
142	0.06	69	0.45
138	0.36	62	0.35
129	0.76	56	0.35
118	0.66	50	0.35
100	0.56	42	0.25
93	0.56	35	0.25
82	0.36		
73	0.36		
65	0.36		
59	0.36		
54	0.36		
47	0.36		
40	0.26		
34	0.26		
30	0.26		

Position: Cross Section C3 Date: 8.6.84 Time: 13:55		Position: Cross Section C4 Date: 8.6.84 Time: 14:25	
Dist. E-W (m)	Reduced to M.S.L. (m)	Dist. E-W (m)	Reduced to M.S.L. (m)
172	0.70	250	0.50
166	0.70	217	0.60
159	0.70	195	0.60
145	0.70	169	0.60
134	0.70	139	0.40
123	0.70	122	0.40
114	0.70	106	0.50
106	0.65	86	0.60
98	0.65	72	0.60
91	0.75		
85	0.75		
79	0.70		
74	0.70		
67	0.60		
52	0.50		
43	0.40		
35	0.35		

Note. Profiles labelled as per Fig.
E-W means from east towards west

APPENDIX

Profile Tabulation Muri Lagoon Site

Position: Cross Section C5

Date: 8.6.84 Time: 14:30

Dist. E-W (m)	Reduced to M.S.L. (m)
466	0.89
393	0.84
361	0.79
320	0.74
297	0.69
275	0.69
238	0.69
215	0.69
193	0.69
174	0.59
151	0.59
135	0.49
111	0.49
85	0.49
61	0.29
39	0.29

Position: Cross Section C6

Date: 8.6.84 Time: 14:55

Dist. E-W (m)	Reduced to M.S.L. (m)
462	0.90
436	0.80
412	0.81
353	0.80
322	0.70
294	0.70
240	0.60
222	0.60
206	0.50
185	0.60
173	0.60
155	0.60
135	0.60
117	0.50
101	0.50
83	0.30
67	0.20
43	0.20
16	0.10

Position: Cross Section C7

Date: 8.6.84 Time: 15:10

Dist. E-W (m)	Reduced to M.S.L. (m)
566	1.03
514	1.03
401	0.83
373	0.93
308	0.93
275	0.73
225	0.73
188	0.68
148	0.63
133	0.58
107	0.53
81	0.53
67	0.48
51	0.43
34	0.38
18	0.33

Position: Cross Section C8

Date: 8.6.84 Time: 15:20

Dist. E-W (m)	Reduced to M.S.L. (m)
437	0.93
356	0.88
316	0.88
235	0.78
200	0.58
174	0.58
154	0.58
137	0.48
118	0.48
103	0.48
83	0.43
71	0.43
58	0.43
36	0.43
22	0.43

Note. Profiles labelled as per Fig.
E-W means from east towards west

APPENDIX

Profile Tabulation Muri Lagoon Site

Position: Cross Section D1		Position: Cross Section D2	
Date: 8.6.84 Time: 16:05		Date: 8.6.84 Time: 16:15	
Dist. E-W (m)	Reduced to M.S.L. (m)	Dist. E-W (m)	Reduced to M.S.L. (m)
575	1.19	591	1.20
476	1.04	471	1.10
407	1.04	433	1.10
356	0.89	401	1.10
316	0.89	349	0.90
284	0.64	308	0.75
257	0.89	275	0.70
217	0.79	248	0.70
187	0.69	196	0.70
164	0.69	173	0.70
145	0.59	154	0.70
118	0.79	138	0.70
77	0.59	119	0.70
69	0.54	97	0.70
43	0.39	75	0.60
25	0.34	53	0.40
		49	0.10

Position: Cross Section D3		Position: Cross Section D4	
Date: 8.6.84 Time: 16:25		Date: 8.6.84 Time: 16:35	
Dist. E-W (m)	Reduced to M.S.L. (m)	Dist. E-W (m)	Reduced to M.S.L. (m)
524	1.13	678	0.90
471	1.14	607	1.05
429	0.93	539	0.95
376	0.73	499	0.90
346	0.73	464	0.90
308	0.63	417	0.90
275	0.63	389	0.85
238	0.63	362	0.65
207	0.63	315	0.65
180	0.53	273	0.35
156	0.48	236	0.35
135	0.43	186	0.45
111	0.43	156	0.15
85	0.43	113	0.05
57	0.23	75	0.05
35	0.13	42	0.04

Note. Profiles labelled as per Fig.
E-W means from east towards west

APPENDIX

Profile Tabulation Muri Lagoon Site

Position: Cross Section D5 Date: 8.6.84 Time: 16:45		Position: Cross Section D6 Date: 8.6.84 Time: 17:00	
Dist. E-W (m)	Reduced to M.S.L. (m)	Dist. E-W (m)	Reduced to M.S.L. (m)
617	0.85	539	1.37
364	0.75	462	1.17
339	0.65	430	1.07
304	0.45	399	0.97
281	0.45	371	0.87
260	0.45	343	0.47
239	0.35	318	0.42
209	0.35	281	0.37
191	0.15	245	0.27
155	0.15	210	0.17
120	0.05	189	0.22
112	0.05	168	0.22
96	0.05	138	0.22
79	0.05	116	0.32
55	0.05	79	0.32
31	0.05	60	0.37
		54	0.27
		19	0.17
		8	0.17

Position: Cross Section D7 Date: 8.6.84 Time: 17:15		Position: Cross Section Date: Time:	
Dist. E-W (m)	Reduced to M.S.L. (m)	Dist. E-W (m)	Reduced to M.S.L. (m)
130	0.66		
103	0.66		
88	0.36		
45	0.16		
34	0.06		
23	0.06		
13	-0.04		

Note. Profiles labelled as per Fig.
E-W means from east towards west

NR/SOPAC/TECHSEC-301 24 May 1985

Mr S.G. Kingan
Scientific Research Officer
Prime Minister's Department
P PO Box 66
RAROTONGA
Cook Islands

Dear Mr Kingan,

I enclose herewith for your information and records a copy each of the following Cruise Reports issued by this office since the 13th CCOP/SOPAC session.

Cruise Report No. 90	Baseline Study for Coastal Management Reef, Beach, and Lagoon Near Rarotongan Hotel, Rarotonga, Cook Islands
Cruise Report No. 100	Baseline Study for Coastal Management Coastal Engineering study at Ngatangiia Harbour and Muri Bay, Rarotonga, Cook Islands

Very truly yours,

Cruz A. Matos
Project Manager
RAS/81/102

Encls: as stated
MRA/mra

INSTITUTE OF GEOLOGY
OF FOREIGN COUNTRIES

ВНИИЗАРУБЕЖГЕОЛОГИЯ

VNIIzarubezhgeologia
Department of Information
Streletskaya, 6,
Moscow, 127018
USSR

26 July, 1985
86-10/687

Dear Mr Matos,

This is to acknowledge with thanks receipt of your letters NR/SOPAC/TECHSEC-301 of 31 May 1985 and NR/SOPAC/TECHSEC-381 of 4 June 1985 with enclosed Cruise Reports Nos. 90, 96 and 100, and Technical Reports Nos. 39 and 49.

I wish to express my gratitude to you for sending me the information and data contained in these reports which will be used in our work.

With best regards,

Sincerely yours,

Yu.Ya.Kouznetsov
Director

Mr Cruz A. Matos
Project Manager
UN Offshore Mineral Prospecting
c/o Mineral Resources Department
Private Mail Bag
Suva
Fiji

NR/SOPAC/TECHSEC-301 31 May 1985

Distribution as per listing

I enclose herewith for your information and records one copy each of the following Cruise and Technical Reports issued by this office since the 13th CCOP/SOPAC Session.

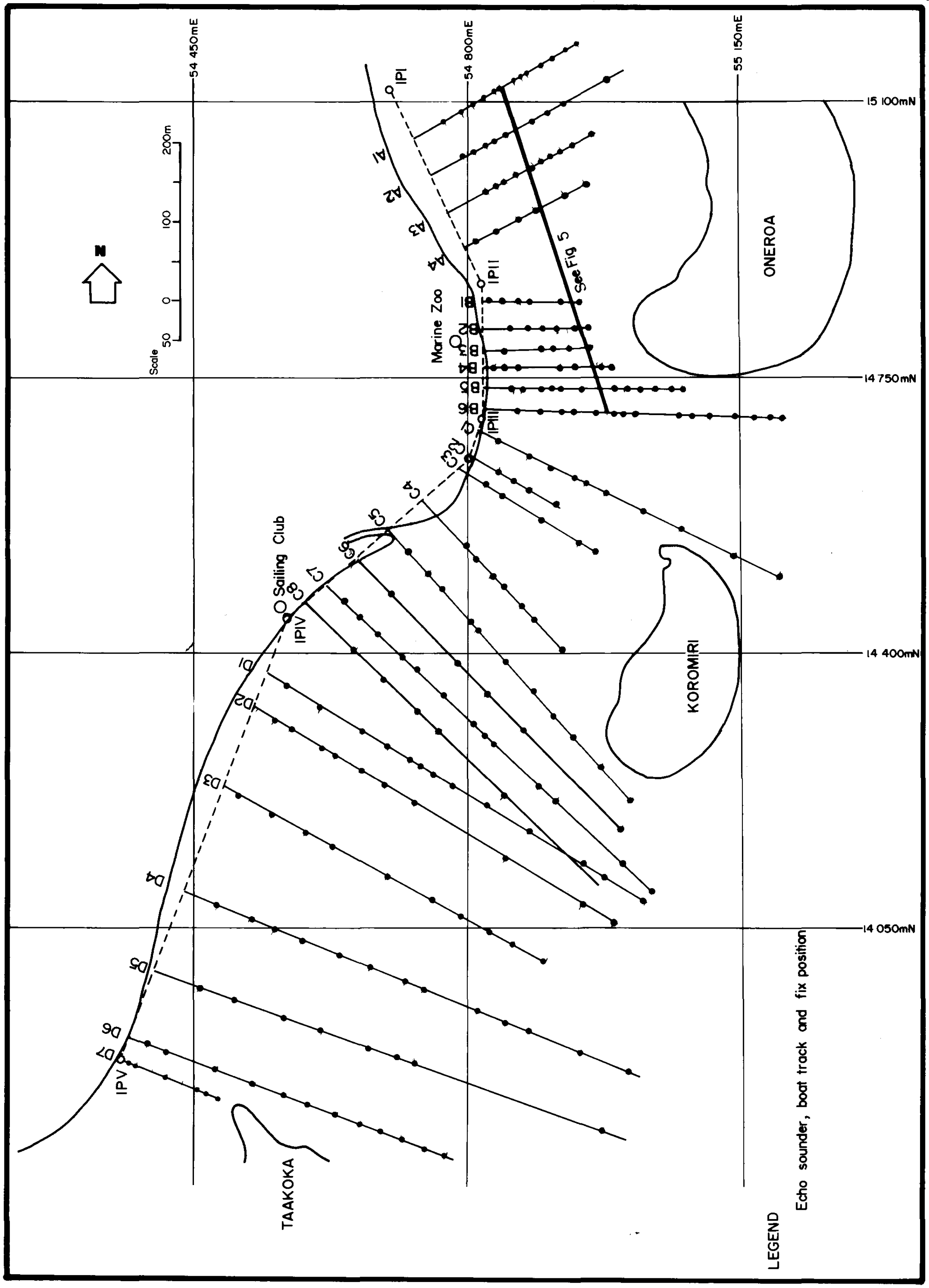
Cruise Report No. 90	Baseline Study for Coastal Management Reef, Beach, and Lagoon near Rarotonga Hotel, Rarotonga, Cook Islands
Cruise Report No. 100	Baseline Study for Coastal Management Coastal Engineering Study at Ngatangiia Harbour and Muri Bay, Rarotonga, Cook Islands
Technical Report No. 39	Structure and Sedimentation in an Active Caledra, Rabaul, Papua New Guinea
Technical Report No. 49	Initial Planning Report - Proposed Seamount Baseline Programme Mariana Archipelago North of Guam

Very truly yours,

Cruz A. Matos
Project Manager
RAS/81/102

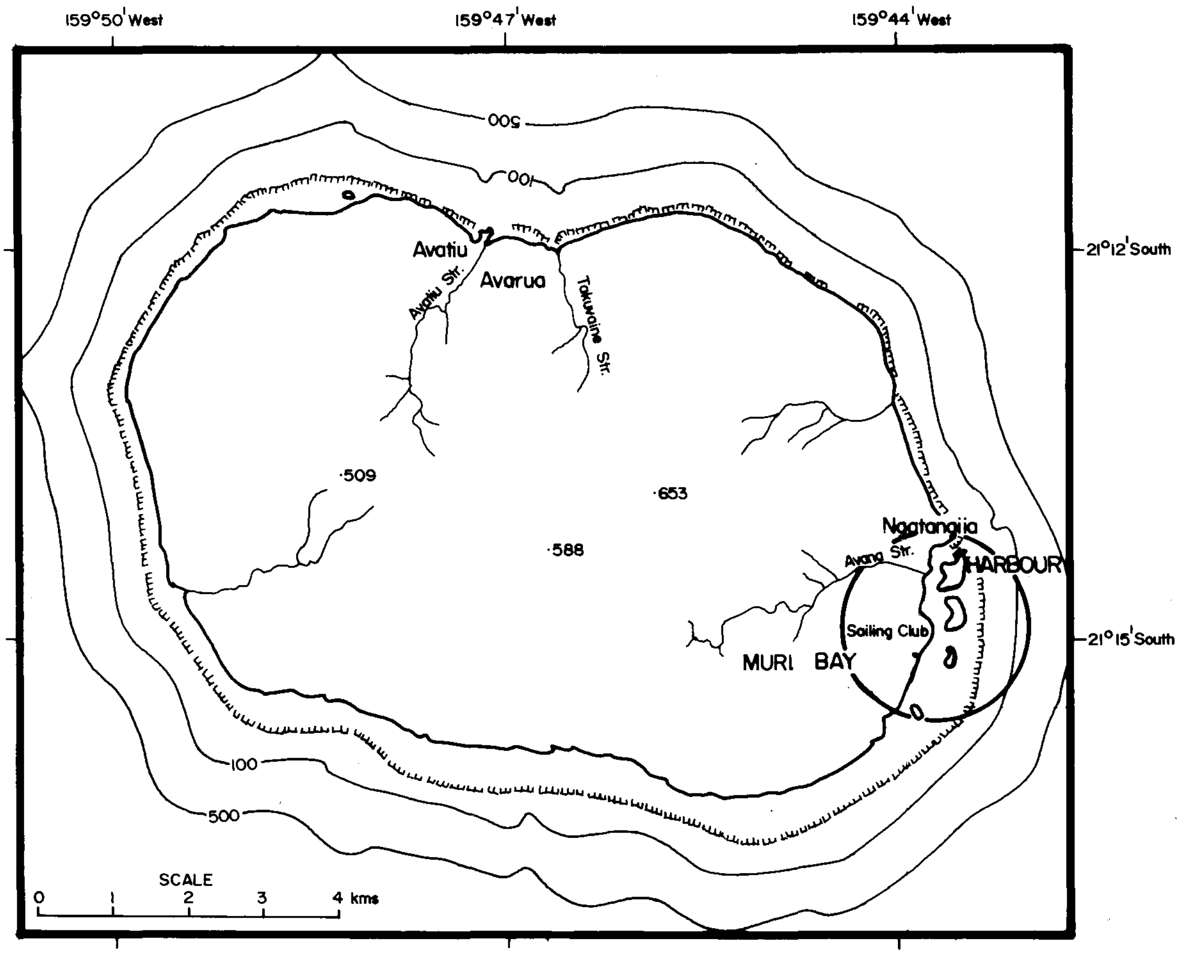
Encls: as stated
MRA/mra

FIGURE 6.



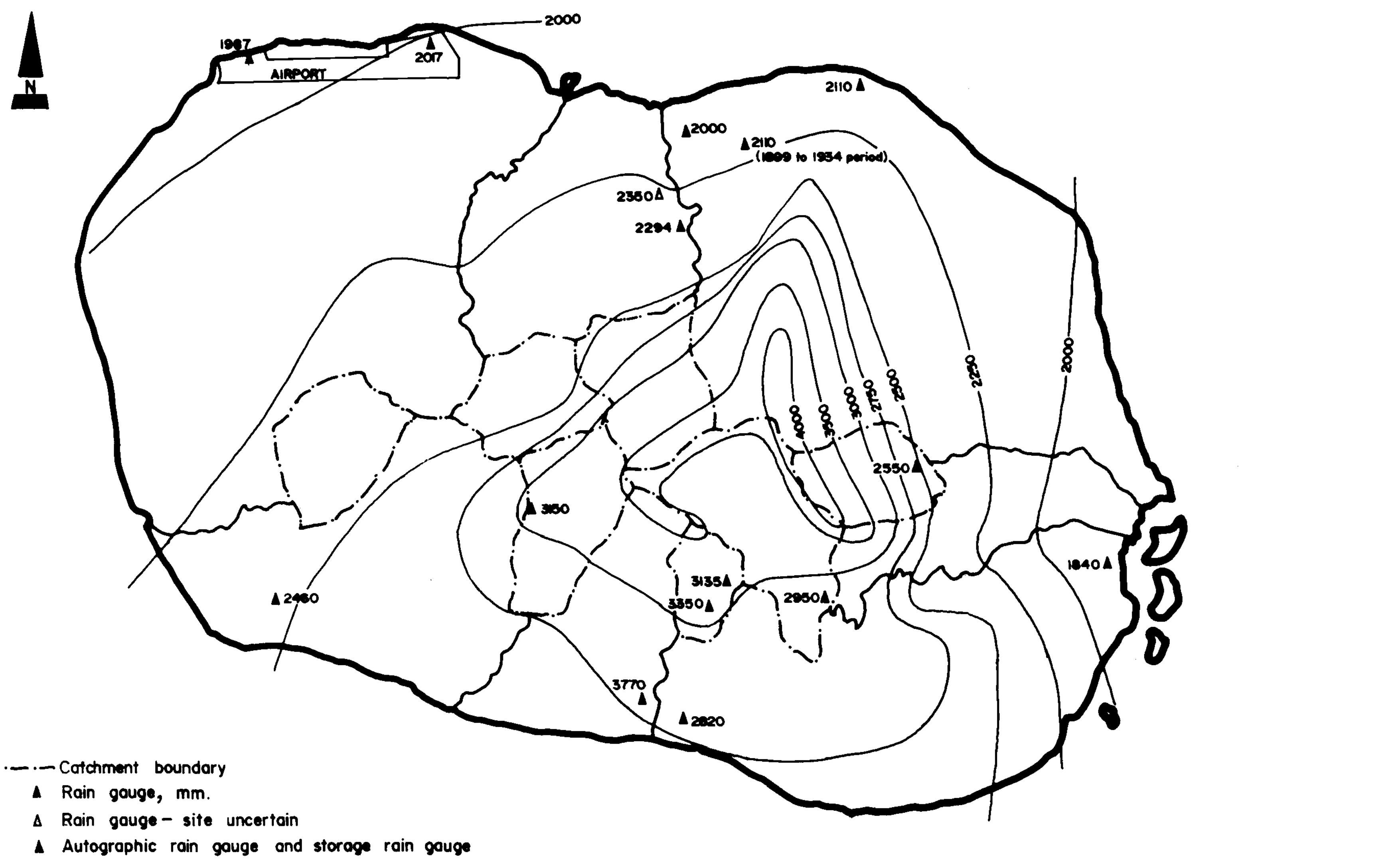
54 450mE
54 800mE
55 150mE
15 100mN
14 750mN
14 400mN
14 050mN
Scale
50
0
100
200m
N
IPI
A1
A2
A3
A4
IPII
See Fig 5
ONEROA
Marine Zoo
B1
B2
B3
B4
B5
B6
IPIII
C1
C2
C3
C4
C5
C6
C7
C8
Sailing Club
IPIV
KOROMIRI
D1
D2
D3
D4
D5
D6
D7
IPV
TAAKOKA
LEGEND
Echo sounder, boat track and fix position

FIGURE 1.



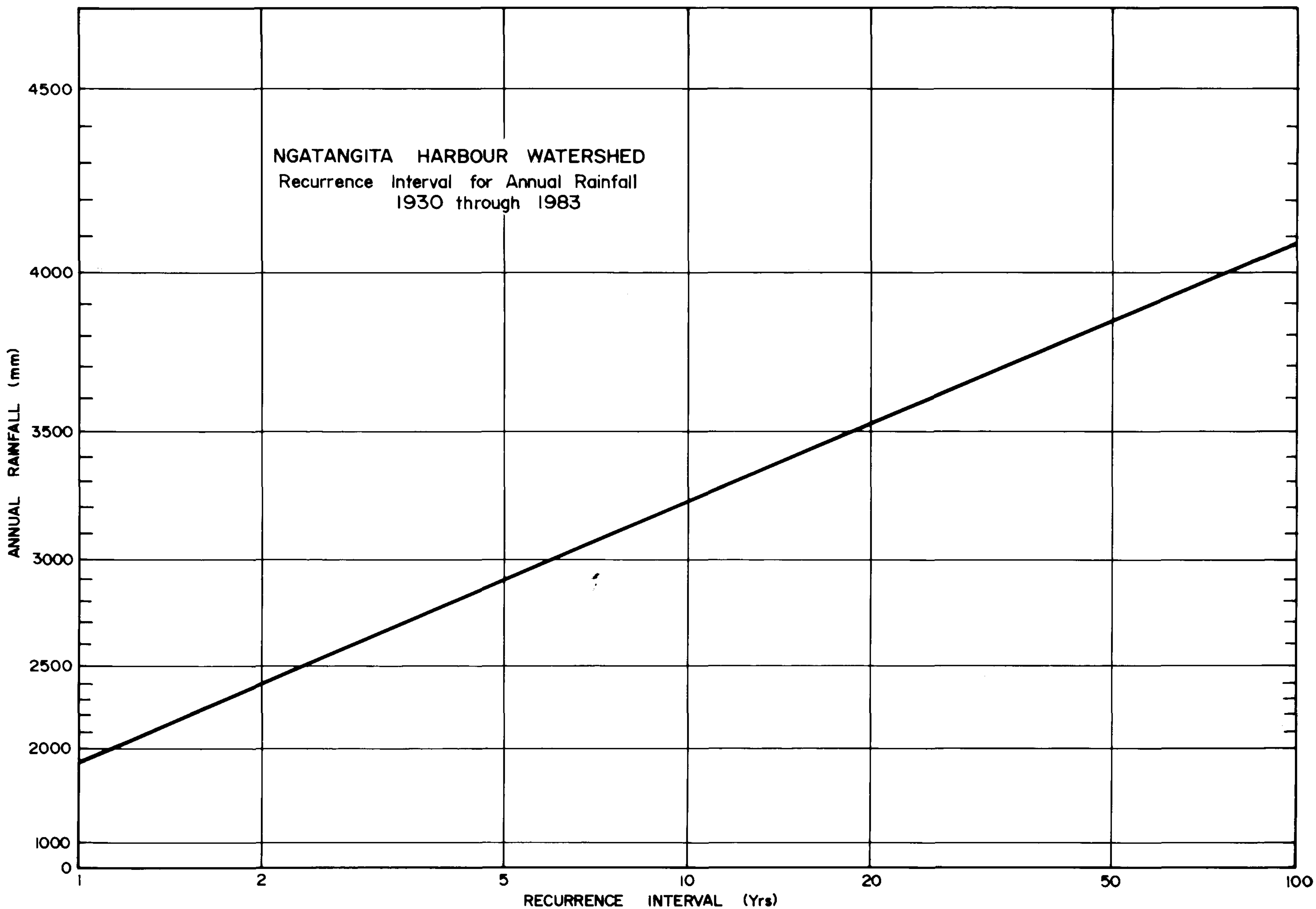
RAROTONGA STUDY AREA

FIGURE 2.



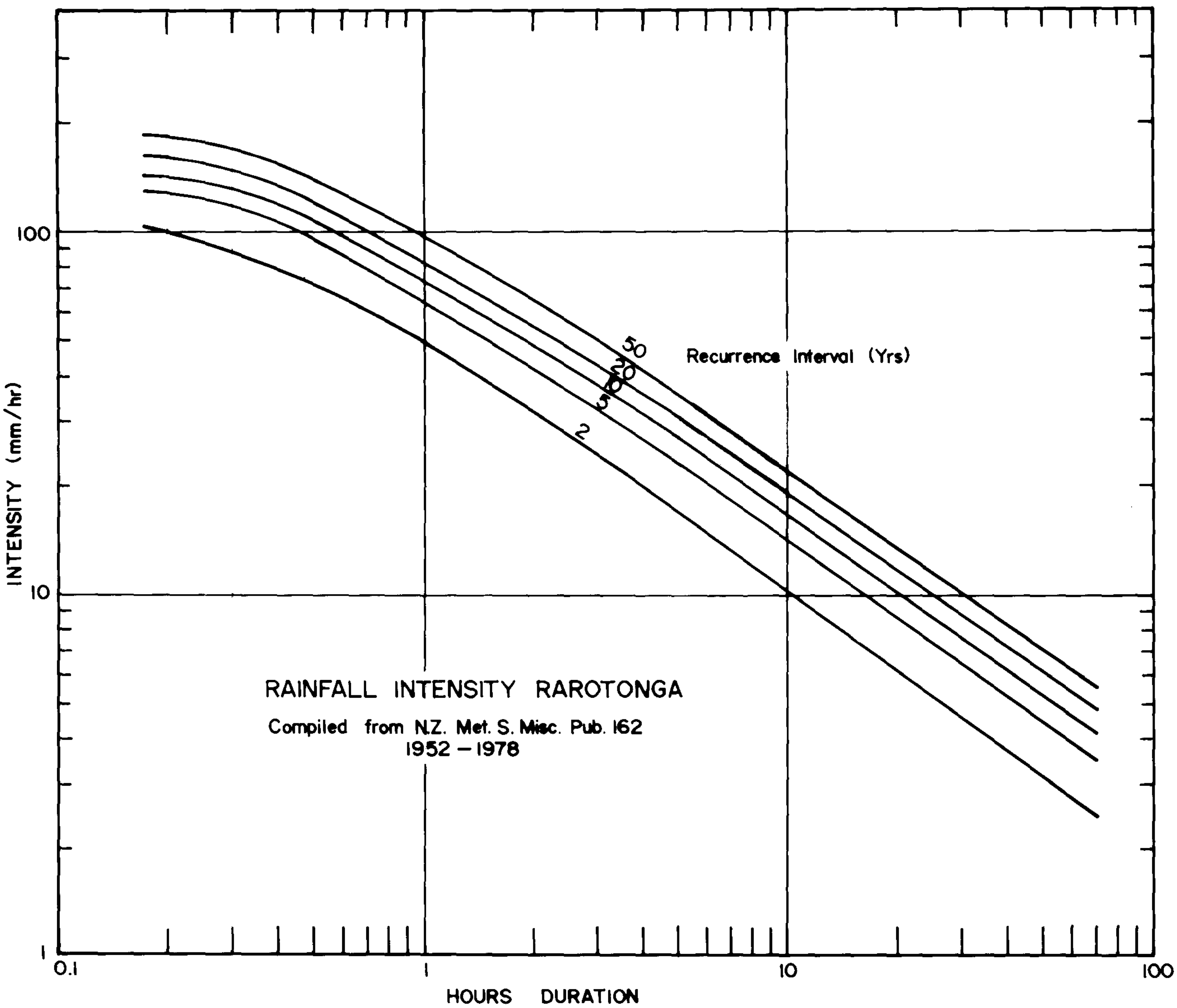
RAROTONGA, COOK ISLANDS RAINFALL

FIGURE 3.



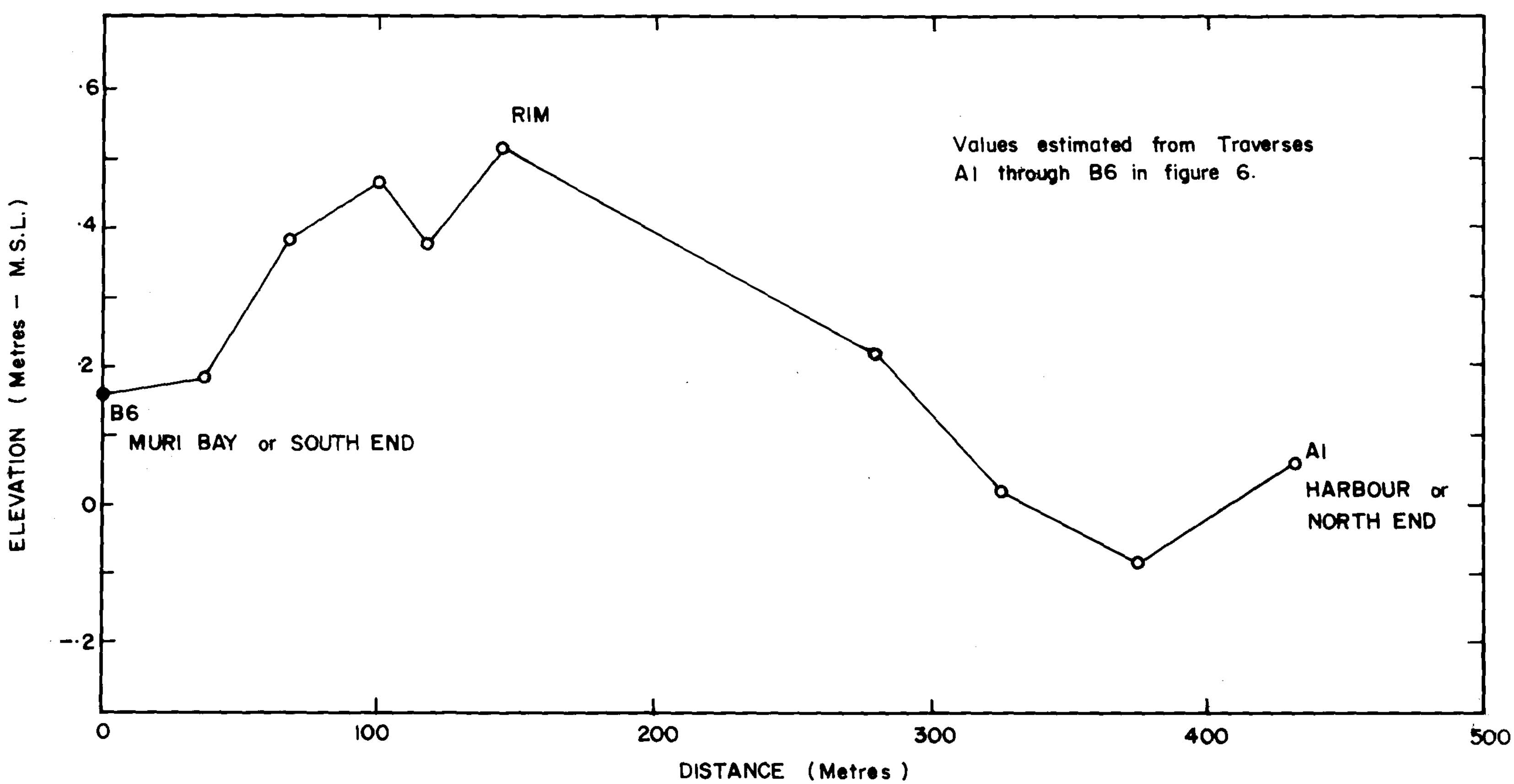
NGATANGITA HARBOUR WATERSHED
Recurrence Interval for Annual Rainfall
1930 through 1983
ANNUAL RAINFALL (mm)
4500
4000
3500
3000
2500
2000
1000
0
1
2
5
10
20
50
100
RECURRENCE INTERVAL (Yrs)

FIGURE 4.

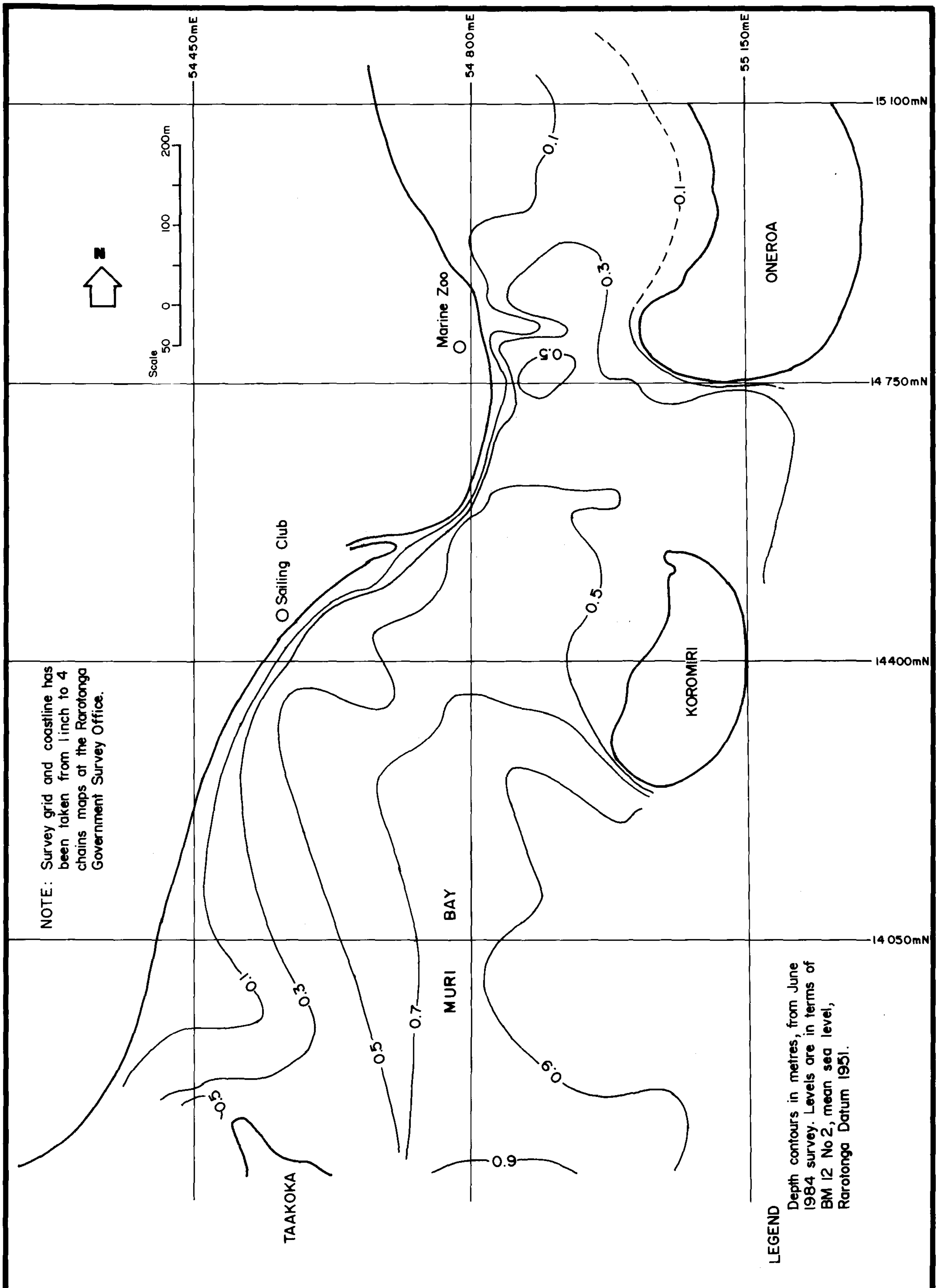


RAINFALL INTENSITY RAROTONGA
Compiled from N.Z. Met. S. Misc. Pub. 162
1952 – 1978
Recurrence Interval (Yrs)
50
20
10
5
2
INTENSITY (mm/hr)
100
10
1
0.1
1
10
100
HOURS DURATION

FIGURE 5.



PROFILE THROUGH THE HYDRAULIC CONTROL SECTION AT MURI BAY



BATHYMETRIC CHART ON MURI BAY