COASTAL EROSION PROBLEMS IN THE GILBERT ISLANDS GROUP REPUBLIC OF KIRIBATI

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SUMMARY

At the request of the Government of the Republic of Kiribati, a reconnaissance survey of coastal erosion sites was conducted on atolls in the Central and Southern Group of the Gilbert Islands (Figure 1) from 10-19 August 1992. The survey team was lead by a SOPAC coastal geologist (Rick Gillie) with assistance from the Ministry of Environment and Natural Resources Development (Naomi Biribo) and the Lands and Survey Division, Ministry of Home Affairs and Decentralization (Amberoti Nikora).

The primary objective of the survey was to define the extent and severity of coastal erosion in the Gilbert Islands. During 10 days of survey work five atolls were visited (Tabiteuea, Onotoa, onouti, Abemama and Kuria). Tabiteuea Atoll is divided into Tabiteuea North and Tabiteuea South n the basis of local government. A total of 15 sites with a history of coastal erosion problems were surveyed. Survey methods included the use of existing maps (1:25,000), inspection of vertical aerial photos from 1969 and 1984, interviews of local people for historical information and t e establishment of a beach profile monitoring station. Ground and oblique aerial photographs were aIso obtained. A literature search for any previous coastal studies on the atolls was also made.

The general findings indicate that at the sites visited where coastal erosion is a problem, causes of erosion fall into two main categories: natural and man-made causes. Natural causes include locations with a high variability of shoreline position such as depositional spit complexes at the south end of atolls, along lagoon shorelines and where the shoreline forms the sides of inter-islet channels. Periods of the year or in years with higher than average sea level and westerly winds caused by seasonal and inter-annual variations in climatic and oceanographic factors can also result in cycles of erosion on an otherwise stable lagoon shoreline.

Man-made causes include the deleterious effects of causeway construction across inter-islet channels which have cut off the supply of sand from the ocean reef to the lagoon and re-aligned the adjacent lagoon shoreline. Other man-made causes include the disruption of sediment transport budgets (local erosion and deposition changes) by harbour and associated mole construction, dredging of lagoon sediments and the creation of borrow pits near to shore and land reclamation activities.

Another major conclusion is that previous attempts at foreshore protection have been largely unsuccessful. Most coastal erosion sites possessed one or two generations of seawalls which had not only failed structurally but also not halted the erosion. Therefore, it is recommended that a complete review of the policy and design of seawall construction be undertaken. Earlier work in South Tarawa by SOPAC and researchers from the UK and Australia have made similar conclusions and recommendations.

The reconnaissance survey of known sites of erosion has been useful in determining the nature and extent of coastal erosion where it is presently a problem. However, generalizatiions regarding the overall extent and severity of coastal erosion in the atoll islands of the Gilbert Group cannot be made from this study alone.

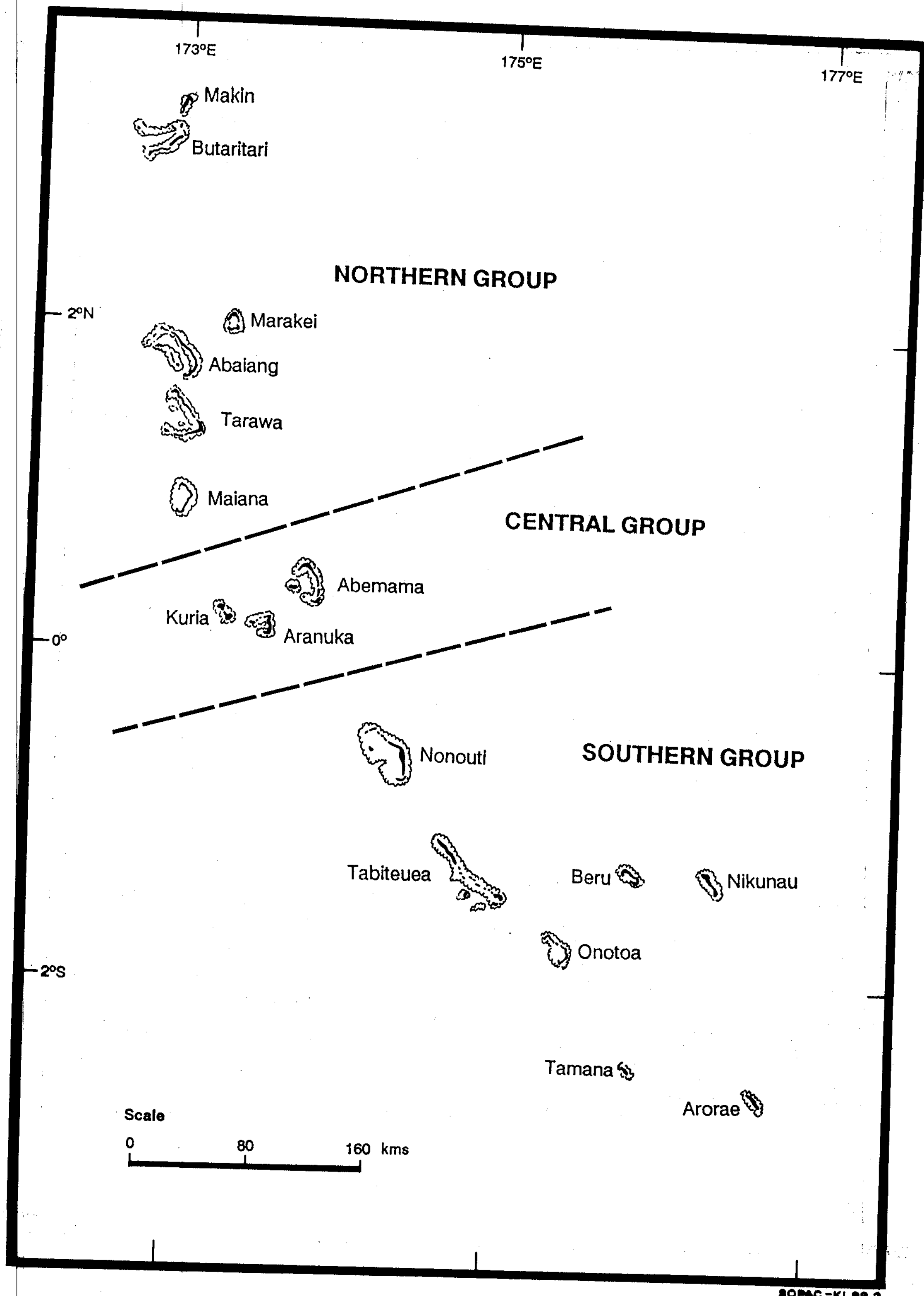


Figure 1. Location of atolls visited in the Central and Southern Group of the Gilbert Islands, Kiribati.

INTRODUCTION

One of the problems facing the small, narrow and *low* lying *coral* atoll islands of Kiribati is coastal erosion. This problem is worst in South Tarawa where high population densities and scarce land have *resulted* in over crowding and over exploitation of the physical resources of the coastal zone. *Coastal* erosion problems are also common to a lesser extent on all of the less densely populated islands in the Gilbert Group (Figure 1). *Coastal* erosion in some cases has resulted in the loss of houses, roads, coconut trees and highly valued land. In many cases foreshore protection Projects to stop the erosion have been of little value and most seawalls do not *last* long enough to justify their cost of construction. In the last year, during the session of Parliament, it was made clear that the problem of coastal erosion was affecting all islands in the Gilbert Group and that people were demanding assistance to curb the destruction of erosion to their shoreline and villages (T. luta, written comm. 1991).

As a result of the concern in Kiribati, SOPAC was approached to undertake a study of coastal erosion of all the islands in the Gilbert Group. SOPAC was directed to look into the causes of erosion on an island by island basis and then to recommend actions to remedy the problem" SOPAC was also asked to look into cheaper and more practical methods of controlling coastal erosion than the expensive construction of seawalls. Possible methods include reopening channels closed by causeways, relocation of roads and planting mangroves to stabilize the *tidal* flat area. All of this work was deemed necessary before embarking on further attempts to control the problem.

Because of the large amount of time and *personnel* resources that would be required to undertake a study of coastal erosion of all the islands in the Gilbert Group, it was decided to conduct a reconnaissance survey of sites on the outer islands where erosion has been recognized as problem. The study was commenced with an initial two week survey in which it was possible to is it five of the fifteen outer islands in the Gilbert Group (Figure 1).
The sites to be visited were selected by the Public Works Division of the Ministry of Works an Energy, Kiribati. The sites were known to have a history of erosion and in many cases had received government assistance for foreshore protection projects in the past. While conducting the survey the team was also directed to additional sites on the islands where erosion had taken place in t e recent past.

The survey was conducted from 10-19 August by: Dr Rick Gillie (SOPAC Coastal Geologist), Ms Naomi Biribo (Minerals Officer, Ministry of Environment and Natural Resources Development) and Mr Amberoti Nikora (Surveyor, Lands and Survey Division, Ministry of Home Affairs and Decentralization). Assistance was also provided by others as identified in the Acknowledgements. A SOPAC preliminary report was prepared immediately following the survey (Gillie 1992b) which documents the field activities.

This project was conducted as part of the Coastal Program for Kiribati: Project KI.4. Data collected during the field survey is archived at SOPAC as Survey No. KI.92.02. The beach profile survey data is also archived at the Lands and Survey Division, Tarawa as Survey Report No. 77/ 92.

OBJECTIVES

The objectives of the reconnaissance survey of coastal erosion sites in the Gilbert Island Group were to:

1. Define the extent, severity and causes of coastal erosion at various sites in the islands;

2. Determine the relative amount of erosion at each site in terms of its severity and the amenities affected; and

3 Make recommendations regarding the action, if any, to be taken in order to deal with the erosion problem.

The plan of work called for a SOPAC coastal scientist, with the assistance of Kiribati government staff, to visit all islands in the Gilbert Group, spending one to two days at each locality where erosion has been identified as a problem.

The request for this work was originally received from the Kiribati government in late '1991 and was not included in the work plan for the 1992 survey year. However, because of the importance of the request, priority was given to at least completing an initial phase of work on the project as soon as possible.

REVIEW OF LITERATURE

A search of the literature on the Gilbert Island Group with respect to published and unpublished research on geology, coastal evolution and coastal processes was conducted in the initial and final stages of the study. The search uncovered a number of relevant studies from which the significant results are summarised below. In general the studies can be classified under the following major

1. Geologic origin and tectonics.

2. Reef growth and atoll evolution in the last 100,000 years.

3. Islet formation and evolution on atoll rims from the late-Holocene (4,000 years BP) to the present.

4. Coastal processes, coastal erosion and coastal engineering studies conducted in the recent past. A majority of these have been conducted by SOPAC on South Tarawa.

5. Climatology, meteorology and oceanography.

6. Climate change, sea level rise and the possible impacts on atolls.

Geologic Origin and Tectonics

The 16 islands of the Gilbert Group are composed of 11 atoll reefs and five table reefs. The atoll islands comprise an annular ring of coral reef with a central lagoon which is open to the ocean via passages and or submerged reef. The extent of lagoon enclosure varies from almost total enclosure f the lagoon as at Marakei Atoll, to no constriction as at Nonouti and Tabiteuea. The table reef lands do not have lagoons or the lagoons have been filled so that most of the reef platform is covered with land with a fringing reef.

The islands of the Gilbert Group have developed on a northwest trending series of slowly subsiding, mid-oceanic volcanoes on the western edge of the Central Pacific Basin. Based upon magnetic anomalies, the age of the oceanic crust is Early Cretaceous (126 mal near Tabiteuea and Beru and Late Jurassic (139 mal further northwest near Butaritari (Circum-Pacific Tectonic Map of t e Pacific, in prep). Subsequent to crustal formation and ocean floor spreading, volcanoes formed o the seabed. No atolls in Kiribati have been drilled to determine the depth or age of their volcanic cores. However, the nearest atolls to Tarawa that have been drilled are Funafuti in Tuvalu, where t e drill hole was still in limestone at a depth of 330 m (Hinde 1904), and Eniwetok in the Marshall Is ands, where basalt was reached after penetrating 1300 m of limestone (Ladd et al 1953). The period of volcanic activity in Kiribati is believed to have occurred between 50 and 10 ma (L. Kroenke, pers comm 1992).

Concepts regarding the present tectonic situation in the Gilbert Group are under review. An earthquake swarm in 1981-1983 near Arorae was identified by Lay and Okal (1983). This and other seismicity and seafloor information in the Western Pacific was compiled as evidence to postulate the formation of a new trench in the Western Pacific which runs just southwest of the southern Gilbert Group (Kroenke and Walker 1986). What effect this is presently having on rates of subsidence or uplift within the group is not known.

Long term rates of subsidence for the Gilbert Group can be estimated from other mid-ocean atolls. Subsidence rates range between 0.03 and 0.06 m/ka for Bikini, Eniwetok and Midway (Paulay and McEdward, 1990). In the central Pacific during the Cenozoic the average rate of sinking has been about 0.02 m/ka with a possible increase to about twice this value in the last five million years (Schofield, 1977a). Therefore, the rate of subsidence in the Gilbert Group is probably in the order of 0.05 m/ka or 0.05 mm/a. By comparison, the rate of global sea level rise is estimated to be 1- mm/a (Wyrtki 1990) or 20 times greater than the rate of subsidence. Therefore, on this basis the islands of the Gilbert Group can be considered as relatively stable.

Atoll Evolution and Reef Growth

The coral islands of the Gilbert Group have formed and evolved over millions of years on gradually siding volcanic basements. Over the same period the atolls have been affected by large changes in ea level, in particular those associated with glaciation during the Quaternary Era (the Ice Ages of last 2 ma). The atolls would have been emerged above the sea and eroded by solution during sea levels of glacial periods. Conversely, during the high sea levels of interglacials, reef growth would have re-established on the atoll surface. Approximately 12,000 years ago, during the last interglacial, sea level was near the present level. In the intervening glacial period sea level fell more than 00 m, and the atolls were exposed as limestone islands and would have appeared much the same as Banaba Island and Nauru Island are today. The limestone underwent solution which lowered its surface elevation, and along with gradual subsidence, combined to create a total lowering of the surface by 10-20 m (Woodroffe and McLean 1992).

Beginning about 15,000 years ago, global sea level rose rapidly from more than '100 m below present. Drill cores to a depth of 30 m have been obtained from Tarawa (Marshall and Jacobsen 985) In general the drillholes passed down through similar lithological sequences from (i) surfical conglomerate rock andlor (ii) unconsolidated sediments, to (iii) corals, to (iv) leached limestone. The upper three lithologies were all dated as less than 8,000 years old (Holocene) while the leached limestone was 125,000 years old, indicating that the foundation of the Holocene reef deposits are carbonates of the last inter-glacial. Approximately 20 samples from depths of 4-14 m were radiocarbon dated between 8,000 and 6,000 years BP and it is therefore evident that Holocene reef growth on Tarawa began about 8,000 years before present. Vertical rates of reef accretion derived from this study were 5-8 m/ka.

Based on this data and other studies McLean (1989) proposes a three stage model for the Holocene evolution of the atolls. The first phase from about 8,000 to 6,000 BP was a phase of rapid vertical reef growth as the reefs strived to "catch up" with a rapidly rising sea level. The phase from abut 6,000 to 3,500 years BP was a phase of reef flat formation as reefs caught up with sea level and consolidated. The third phase, perhaps starting around 3,500 years a ago an continuing to the present is a phase of reef islet formation. Therefore, the atoll rim islets which form the inhabited land area in the Gilbert Group are geologically very young.

Islet Formation and Evolution

According to McLean (1992), there is considerable evidence that the sea stood 1-2 m above its present level with respect to many of the coral atolls of the Pacific and Indian Oceans about 4,0003 000 ears ago and that in the last few thousand years sea level has fallen relative to those islands. In this respect, cemented coral conglomerates (cay rock or conglomerate) on the reef flats and islands of atolls, and above the present limit to coral growth, have been radiometrically dated on many atoll islands, including Kiribati and Tuvalu (Schofield 1977a, 1977b).

A cording to Richmond (1992) two necessary conditions for the formation of atoll islets are (i) a reef platform near present sea level and (ii) the accumulation of material above the high water level. The conglomerate rock formations at elevations of less than 2 m above present sea level represent the initial stage or nuclei of islet formation. Once formed, the higher level conglomerate deposit provided the foundation of islets. These probably resulted from storms depositing material above he normal high tide. Falling sea levels in the last 4,000 years may have also assisted their formation. Richmond (1992) further distinguishes at least four major types of islets, based upon morphology, sediment and rock characteristics, and position on the atoll rim. These types are summarized in Table 1.

Table 1. Four types of islets on atoll rims from Richmond (1992). Proposed equilibrium conditions are presented based upon inferred pattern of changes over the last 100 years.

ISLET TYPE / EQUILIBRIUM CONDITIONS	CHARACTERISTICS
I Analogous to Sand Cays. Area of island envisioned to fluctuate about a mean value where there is no discernible long term trend.	Composed of mostly sand, roughly symmetrical in shape, contain concentrically developed beach ridges. Occur primarily adjacent to reef passages on the leeward rim and, more rarely, atop lagoon patch reefs. Islet shape responds rapidly to changes in incident waves and currents.
II U-shaped to Boomerang-shaped. Long term stability and are perhaps slowly growing in size. Characterized by short term fluctuations in area superimposed upon a longer term trend of slow growth.	Develop on high energy, convex seaward bends of the atoll rim. They are asymmetrical in texture and morphology, varying from coarse and steep seaward margins to finer and flatter lagoon coasts. They are formed by a combination of wave convergence at the oceanside reef bend and longshore transport culminating in deposition at the lagoonside concave bend.
III Elongated, Gently Curved to Sinuous-shaped. Very dynamic and depend upon catastrophic events to resupply sediment to their oceanside shorelines. Pulses of sediment interrupt a longer term trend of lagoonward islet migration.	Are composed primarily of several parallel ridges which are often separated by a central depression. Develop through amalgamation of storm ridges where the original ridge structure is preserved.
IV Diverse Complex Forms. As for Type III.	Developed around cemented rubble and reef flat deposits. They exhibit a wide variety of shapes and commonly exist in chains of small islets separated by inter-islet channels. Oceanside shorelines are typically fronted by conglomerates overlain by gravel ridges.

Contemporary Coastal Processes and Engineering

According to Woodroffe and Mclean (1992) "There is almost no information on the natural dynamics of the shorelines of atolls. Kiribati lies in a part of the Pacific affected by El Nino, which accounts for major variations in climatic factors and water levels. There is no information on rates o sediment production, patterns of sediment movement, or rates of sediment deposition". This statement largely ignores the large amount of valuable research which has been conducted by on coastal processes in Kiribati, mostly on South Tarawa in the last ten years. PAC has produced over 20 reports on coastal studies in South Tarawa which have identified sources and amounts of sediment production, historical shoreline changes, beach dynamics through profile monitoring, the effect of engineering structures on coastal processes, coastal mapping and coastal management: Burne (1983), Byrne (1991), Carter (1981), Gauss 1988), Gillie (1991, 1992a, 1992b, 1992c), Gillie and Woodward (1992), Harper (1 B87, 1988, 1989 , 1989b), Howorth (1982, 1983a, 1983b, 1985, 1991), Howorth, Cowan and Carter 1988), Howorth and Radke (1991), Howorth and Richmond (1988), Richmond (1990), Sherwood et al (992). In addition, SOPAC has also conducted a limited amount of work on coastal processes in the outer islands of the Gilbert Group (Harper 1989; Holden 1991, Holden 1992; Richmond 1990, 1991).

Major reviews of coastal protection, causeway construction practices and the effect on natural coastal processes in Gilbert Islands have been reported in AIDAB (1988), Colman (1989), Gilmour and Colman (1990), Holmes (1979), Hydraulics Research Station (1976). One of the major conclusions of these reviews is that many coastal protection projects have not only failed to resolve the particular problem that prompted the works but have also led to a deterioration of the situation and undesirable secondary effects. There has been a relatively high rate of failure of previous costal projects. In this regard, it is clear that a more comprehensive approach to coastal management strategies is warranted. The aim of a more comprehensive approach is to provide a greater understanding and prediction of the natural processes of sediment and water movement and the impact of engineering works on the coastal zone. There has also been a growing appreciation of alternatives to seawall construction as a first resort or response to coastal erosion. Alternatives include relocation away from the shoreline and improved land use planning and management to avoid potential problem areas (See Appendix 5).

Climatology, Meteorology and Oceanography

T e mo t recent and complete description of the climate and weather of the Gilbert Group is contained in Burgess (1987). Although the Gilbert Group has a maritime equatorial climate with little variation in temperature throughout the year, there are marked seasonal (inter-annual) and year to year intra-annual) variations in rainfall, wind speed and direction, wave climate and sea level which have implications for coastal processes.

There are two seasons, namely wet and dry. The former is well known in Kiribati as "Te Au Meang" and the latter as "Te Au Maiaki" (Tebano 1985). Te Au Meang refers to a prevailing north to northeast wind which normally brings a lot of rain and unsettled weather over the period November-April. TeAu Maiaki refers to south to southeast winds which are characterised by fine and settled weather.

Winds

In general, moderate winds between the northeast and southeast prevail throughout the year. Winds a e usually light to moderate and gales are rare. However, on most of the islands 60-80 percent of strong winds or greater (over 21 knots) are between northwest and southwest. Westerly winds are also usually associated with squally showery conditions. Tropical cyclones rarely form within 5 degrees of the equator as the Coriolis force is close to zero. For this reason there are no records of tropical cyclones having occurred in Kiribati, apart from an event recorded in late 1927 or 1928 when a "cyclone" is reported to have done considerable damage to the two most northern island of Butaritari and Makin (Sachet 1957). Gale force west to north-west winds also occur when cyclonic systems are developing beyond 5 degrees to the north or south of the equator. Thus, although winds from an easterly quarter prevail, winds from a westerly quarter probably play significant role in coastal processes within the lagoon environment, since westerly winds are onshore with respect to most lagoon beaches on atoll islets.

El Nino/Southern Oscillation

Perhaps the most significant feature of the climate and weather of the Gilbert Group is the EI Nino Southern Oscillation (ENSO) phenomena which varies in period and intensity every few years. Because of the annual wet and dry season cycle described above, there are no local names in the Gilbert Islands for ENSO phenomena, which are considered to be more prolonged or extreme variations of the annual cycle. The terms "EI Nino and La Nina" are used in the following as globally recognised terms for the two alternating extremes in ENSO phenomena.

During "EI Nino" episodes the Gilbert Group experiences a greater variation of wind patterns, the tradewinds are diminished and there are periods of strong westerlies. There is also heavier than normal rainfall. Conversely, the climatic phase between EI Nino, known as "La Nina", is characterised by persistent easterly winds and much lower than normal rainfall, sometimes resulting in severe drought. For example, Onotoa Atoll has an average annual rainfall of 1250 mm (50 inches) During EI Nino periods the annual rainfall can reach 3,000 mm. Conversely, during 1950 w en a strong EI Nina event occurred, Onotoa Atoll received only 150 mm of rainfall, with no rainfall over the first six months (Cloud 1952).

There were ENSO events in 1972 (moderate), 1977/78 (moderate), 1982/83 (strong), 1987 (moderate) and in 1991/92 (moderate). The terms moderate and strong refer to the values of the Southern Oscillation Index (SOl). Actual EN SO characteristics such as wind strength and direction, rainfall, sea surface temperatures and sea level deviations can vary within similar SOl values. Pacific atmospheric and oceanic conditions indicate that the 1991/92 EI Nino was essentially over by July 1992 (NIWAR, 1992).

Tides and Sea Level

Tidal variation is reported for the reference station at Tarawa. Mean sea level is 1.00 m above chart datum. The mean neap tide range is 1.2 m and the mean spring tide range is 1.8 m (Hydrographer of the Navy, UK 1992). The maximum recorded levels vary from -0.3 to + 2.45 m (Hydraulic Research Station 1976), but it is not known what these extreme levels were associated with. There are also large fluctuations in sea level from year to year. All tide stations in Kiribati show a strong seasonal cycle in water level of the order of 10-20 cm related to the location and strength of the trade wind system (McLean 1989). There is also a strong fluctuation in water level associated with the IENSO phenomena. During the 1982/83 EN SO event the monthly mean sea level was 28 cm above the long term mean in 1982, but 21 cm below mean in late 1983. With the passage of the most recent, moderate ENSO event 11991/92) the mean monthly sea level has varied from + 27 cm to -1 0 cm relative to the mean value (IGOSS 1992).

Waves

High areas in this region are very rare, as winds seldom exceed gale force. Most waves in the open sea come from directions between northeast and southeast in association with the trade winds. However, the situation is not this simple. Cloud (1952) reported that during a extended survey (late June, July and August) on Onotoa in 1951 there was a "marked swell from the south which produced strong surf on exposed lee reefs that face the south". Similar conditions were also observed during the period of this study (August 1992). Persistent southerly swell was observed on the south and west sides of the atolls. Conversely, seas on the windward side of the atolls were composed of very low, locally generated seas. Thus, swell waves from more distant sources, such as the South and North Pacific mid-latitude storm belts, may also reach the area. It is also very likely that waves from cyclones passing to the north (Marshall Islands) and south (between the Solomon Islands and Tuvalu) will cause large swell waves to reach the area.

Within the lagoon of each atoll the wave climate varies considerably. The effect of the leeward reef rim on swell waves passing over it is essentially that of a submerged breakwater. This effect varies with water depth over the reef. Within the lagoon wave refraction is significant. During the survey, long period, low amplitude ocean swell was observed on lagoon beaches. However, of more importance to lagoon beach changes are waves generated by strong westerly winds within the lagoon. Again, the effect of this will vary considerably from site to site, since fetch lengths are so variable. Waves generated within the lagoon would be short period, but because of oblique angles of approach to the shoreline may cause greater longshore sediment transport and predominantly determine patterns of coastal erosion and accretion. In this respect, the strong westerly winds and higher than normal sea levels which characterise the early phase of El Nino events have been associated with periods of coastal erosion on the lagoon beaches of South Tarawa (Howorth 1991).

Climate Change, Sea level Rise and Impacts

There have been several studies of the impact of climate change and sea level rise in Kiribati (Nunn 1988; McLean 1989; Sullivan and Gibson 1991; Woodroffe and McLean 1992). The studies by McLean 1(1989) and Woodroffe and McLean (1992) are the most relevant to this study because they are the most detailed and deal with an assessment of the vulnerability of coasts to sea level rise. In particular, the following points are made in the executive summary of the report by Woodroffe and McLean (1992):

(i) Pacific Ocean water level trends reconstructed from tide gauges, and from large intertidal corals (microatolls) in Kiribati, do not indicate a trend of rising sea level as rapid as the global average, and do not yet show any identifiable acceleration;

(ii) there are pronounced seasonal and inter-annual variations in mean sea level in Kiribati related in particular to El Nino, suggesting that the Islands have a certain resilience to changes in water level, but also making determination of net change more difficult

(iii) the majority of the islands of Kiribati are probably subsiding at an imperceptibly slow rate *(<:W.2* mm/yr). (This report suggests that subsidence is about 0.05 mm/yr).

(iv) the reef islands of Kiribati are geologically very young, and appear to have developed in the last 3,000-4,000 years during a period when relative sea level has fallen from a level around 1 metre above present;

(v) there are a range of coastal types, representing various sediment sizes, morphology and states of lithification, each of which exhibits a different degree of vulnerability both to present erosional and accretional forces and to accelerated sea level rise;

(vi) coastal vegetation communities, particularly mangroves, offer a protection to the coast, and decrease shoreline erodibility;

(vi) the shorelines of reef islands (islets) in Kiribati are naturally dynamic; sediment is continuing to be produced; beaches both accrete and erode; and there are seasonal and year to year shifts in the patterns of sediment movement. There are also important coastal rock types, conglomerate and beachrock.

FIELD ACTIVITIES AND METHODS

Field Activities

The greatest difficulty and cost in conducting the field survey program was transport between the islands. While on the island additional difficulties were experience with travel by truck or tractor and trailer. Scheduled passenger air services are available throughout the Gilbert Group from Air Tungaru. However, there are flights to most islands only on one or two days a week. Since most islands only required a one or two day visit, scheduled flights did not permit an efficient use of available field time. An alternative plan to use a combination of Air Tungaru's scheduled air service, scheduled flight diversions and the Kiribati fisheries research vessel proved to be unfeasible when the possibility of flight diversions was cancelled by Air Tungaru during the week previous to the survey. The only practical option in the time available was to charter an aircraft for the survey. When future surveys are planned, expected field time, mode of transport between islands and overall costs need to be given serious consideration. In addition, if a charter aircraft is used in the future, the opportunity of using the SOPAC aerial camera in conjunction with the survey should be considered.

Analysis of Maps and Air Photographs

Very little information was available on the coastal erosion sites prior to the visit to Kiribati. It is extremely fortunate that a very good series of maps is available for conducting field work in Kiribati. Detailed topographic maps were prepared by the Directorate of Overseas Survey in the late 1970's, based on photographic interpretation of aerial photographs taken by various sources: US Navy 945, 1964, ect.), RNZAF (1964), Department of Lands and Survey Fiji (1969). Topographic maps at a scale of 1:25,000 are available for all islands in the Gilbert Group. These were published in 1979-1980 and are based on 1: 1 0,000 aerial photography flown in 1968/1969. Maps of the sites of interest were obtained from the Lands and Survey Division on arriving in Kiribati. These were examined for pertinent information and taken into the field.

Aerial photographs of the Gilbert Islands are housed with the National Archives of Kiribati. All of the Gilbert Group was photographed at a scale of 1: 1 0,000 in 1968/1969 by the Department of Lands and Survey, Fiji. The 1968/1969 air photo survey provides the best set of air photos available for coastal work in the Gilbert Group of Kiribati. The coverage is complete for, all the atolls at a seal of 1: 1 0,000 and was used to prepare the set of orthophoto maps mentioned above. At present, SOPAC only has air photos from this survey for South Tarawa.The negatives and track lines for his survey are now housed with the Ordnance Survey International in the United Kingdom. A more recent Survey of portions of the islands was conducted at a similar scale in 1984 by the Australia Department of Defence (1986). A search made for photographs at the National Archives revealed that 1969 photographs were available for Abemama, Nonouti, Tabiteuea North, and Tabiteuea South. No photographs of sites on Kuria and Onotoa were found in the 1969 survey file. Fortunately, some photographs from the 1984 survey were available for Kuria and Onotoa.

Since the e air photographs are the only ones that Kiribati has, photocopies were made from the originals use duril1lg the field work. In principle, analysis of coastal changes between 1969 and 1984 is possible from the sets of air photos. In some cases, WWII photography may also be available from the U.S. Navy. However, it is expected to be some time before these air photos can be procured and analyzed by SOPAC.

If it had been possible, the SOPAC air photo camera system could have been taken along on the survey. This would have provided coverage at a scale of 1 :3,000.

Site Inspections

The study f each site visited used the following methods:

(1) notes were made from visual observations of the condition of the shoreline and its relationship to adjacent sections of shoreline and any causeway and foreshore protection activities in the

vicinity. Indications of the nature of erosion, such as exposed beachrock and erosion scarps were noted;

(2) a number of beach *level* photographs were taken of the shoreline conditions in order to illustrate and document the sites;

(3) when possibl!3, oblique aerial photographs were taken from the survey aircraft;

Beach profiles were established at most of the sites of erosion that were investigated. This was done to provide (i) a typical profile section of the shoreline and (ii) a means of monitoring changes in the shoreline in the future (Appendices 2 and 3). A simple method of measuring the beach profile was use (Emery 1961).

Beach profile data has been referenced to an approximate mean sea level elevation from reference to the water *level* at the time of the *survey* and subsequent reduction using tide tables. When the tide was too low to reach the water *level* the *elevation* of mean sea level was estimated. Documentation of the beach profile *locations* and sketches of the location of the benchmarks were made by Amberoti Nikora, Lands and *Surveys* Division. The originals of this information are archived *w*ith the Lands and Survey Division, Tarawa as Survey Report No. 77/92.

Interviews

An attempt was also made to obtain background information from the *local* inhabitants on *observed* coastal changes in the past, dates when shore protection was emplaced and the source of shore protection materials. A standard coastal erosion interview sheet was used. This included the recording information by the survey team on the nature of the shoreline, the presence of any man made structures, and specific measurements of foreshore characteristics. Interviewing of elderly persons was confined to someone born in the village or who had lived there since the time they were young. Information was also obtained on drinking water quality, fishing activities, coral reef se an historical changes in the reef, identifiable weather changes (storminess, rainfall, temperature), identifiable coastal changes and any observed sea level changes.

RESULTS

The results f the reconnaissance survey of coastal erosion sites on outer islands in the Gilbert Group are presented below. During 10 days of *survey* work six atolls were visited (Tabiteuea North, Tabiteuea South, Onotoa, Nonouti, Abemama and Kuria) and 15 sites with a history of coastal erosion problems were surveyed.

Each coastal erosion site is defined in terms of its location, a description of the site characteristics and their nature of the coastal erosion problem. Recommended action to be taken for each site is then presented. A summary of map sheet and site coordinate data is presented in Appendix 1. Appendices 2 and 3 contain, respectively, beach profile data and descriptions of beach profile bench marks. Appendix 4 contains information on relative foreshore protection construction costs. Appendix 5 presents a review of the possible coastal protection alternatives which are considered for outer islands in the Gilbert Group.

Tabiteuea North: Eita District

Site Description and Erosion Problem

The site is erosion is located along the *lagoon* (western) shore of Anikai Island which forms the northernmost island of Tabiteuea North (Figure 2). Two sites were surveyed and profiled within the district of Eita. Between the two sites a 1.5 km *length* of *lagoon* beach displays erosion indicators such as fallen coconut trees and an active scarp at the back of the beach (Figures 3 and 4). Housing density along the *lagoon* shoreline is *relatively* low with most of the houses *situated* between he beach and the road which is located about 60 m *inland* from the beach.

In general the lagoon beach is composed of sand. There is also an abundance of sand on the reef *flat* adjacent to the beach. Beachrock was not observed exposed on the surface of the beach. However, some conglomerate platform rock is exposed near the northern end of the study site. The site is exposed to waves from the west which may be generated within the lagoon or propagate over the leeward (west) reef rim at high tide. At the time of the survey the *local* seas were calm. A long period, low swell with a wave height of about 0.2 m approached the beach across the lagoon from the open ocean. There were no apparent indicators of net longshore sediment transport direction. At the government rest house at Bakokia, about 2 km south of the study site, there was an equal amount of shoreline accretion on both the north and south sides of the seawall enclosing a section of reclaimed land.

The first site visited, Eita-1, is just north of the maneaba at Tarawa. The site is about 100 m north of the TBZ16 bench mark (Figure 2). At this location the beach has a pronounced erosional scar (Figure 3 and 4) and hundreds of coconut trees have been lost to erosion (Appendix 2, Profile Eita-1) Clean sand which has been deposited on the backshore above the erosion scarp, indicates that inundation of the, backshore and sediment deposition takes place during periods of higher water.

The second site visited, Eita-2, is located 1.5 km further north of Eita-1 and represents the northern extent of the length of eroding beach (Figure 5 and 6). At this point the lagoon shoreline assumes a more northerly alignment. A discontinuous conglomerate rock platform is present at or above the high tide level. At the time of the visit sand accretion was occurring below the erosion scarp (Figure 5; Appendix 2, Profile Eita-2).

According to local island sources the erosion at Eita was identified in the 1986 island Development plan and is considered to have started in the 1970 s. (In this respect, the survey party was accompanied by the Island Council President who was elected in 1987.) The local people are calling the erosion problem "severe" and many small traditional houses have been relocated back

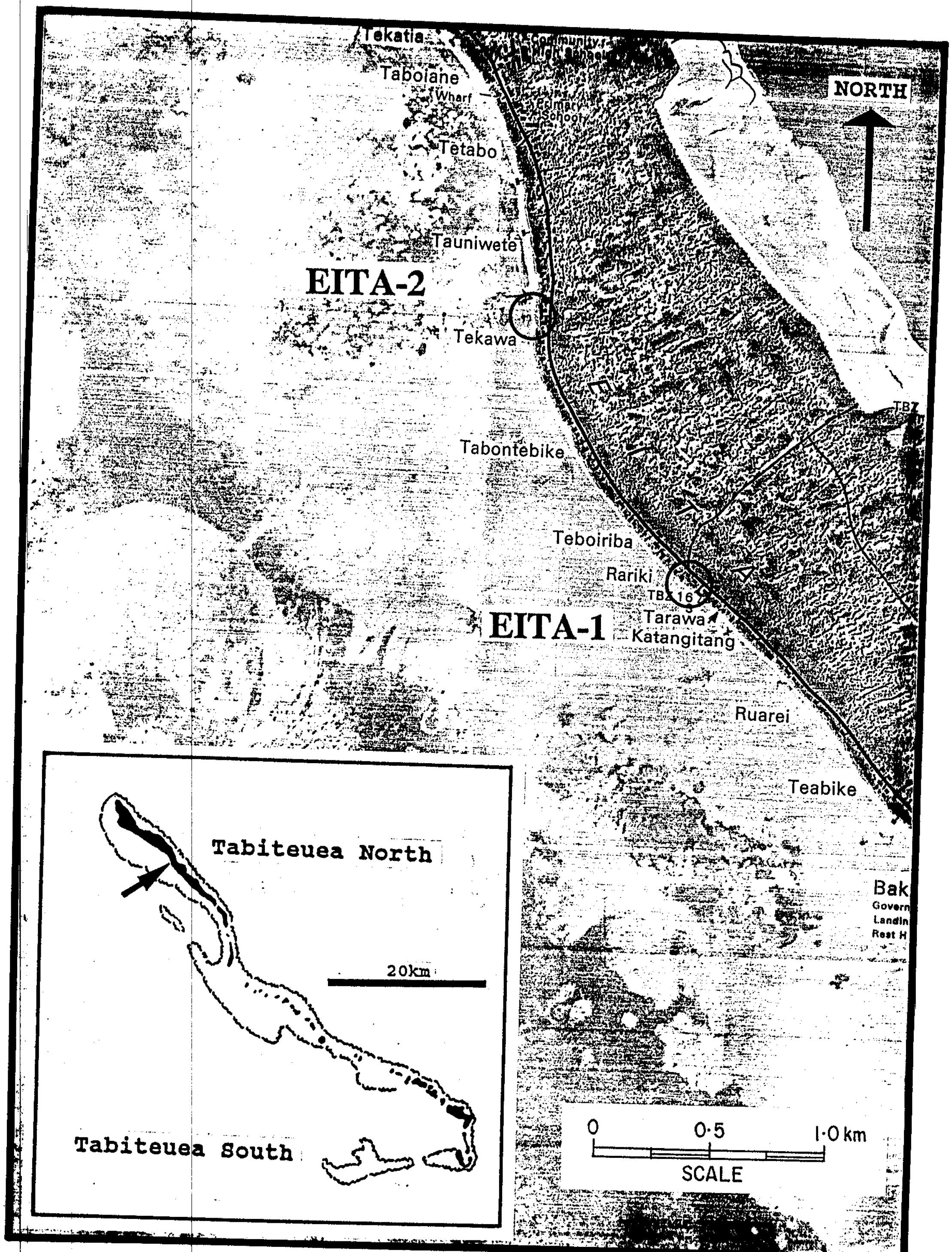


Figure 2. Map showing location of two beach profile sites along lagoon shoreline of Eita District, Tabiteuea North.

Figure 3. Eita District, Tabiteuea North. View north of beach profile location Eita-1. Note coastal erosion as indicated by beach scarp, fallen coconut trees and remains of coral boulder seawall in the foreground. Seawall foreshore protection makes up less than 5 % of the shoreline in this area.

Figure 4. Eita District, Tabiteuea North. View south past location of beach profile Eita-1. Coastal erosion extends north from this point along the lagoon shoreline for approximately 1.5 km.

Figure 5. Eita District, Tabiteuea North. View south in front of beach profile Eita-2. This point marks the end of approximately 1.5 km of active erosion along the lagoon shoreline.

Figure 6. Eita District, Tabiteuea North. View south approximately 30 m south of Figure 5. Note evidence of erosion as indicated by beach erosion scarp, fallen coconut trees and remains of seawall on beach.

from the eroding shoreline. Although it was not possible to obtain an exact measurement of the amount of erosion that has occurred, local sources estimated it at about 10 metres. Local attempts at foreshore protection have been made in t .e form of loose coral boulder seawalls (Figure 3) and 10 fences which amounts to about five percent of the shoreline length.

The nature of shoreline erosion appears to be due to natural causes (possible realignment) sin e there is no man-made impact on the shoreline in the form of beach mining, causeways, extensive seawalls or land reclamation which could account for this amount erosion over a 1.5 km length of shoreline. In this respect, the interview conducted for local information revealed that most of the erosion was associated with annual westerly conditions, usually from December to February. At his time of year strong to gale force westerly winds and seas along with higher than normal sea levels produce beach erosion events. It was also felt by the person interviewed that the frequency of each erosion events associated with westerly conditions was now greater than in the past.

Recommendations

It is clear from the information obtained from local sources that the erosion problem is regarded as "se ere". Hundreds of coconut trees have been lost to erosion and many traditional houses have had to be relocated inland. The shoreline may have retreated as much as 1 0 m over a distance of 1.5 km. This may have taken place over the last two decades and may have increased in magnitude in the last decade.

However, it is not clear how long this phase of erosion is expected to occur or whether it will be relatively short term and reverse to a phase of accretion in the next decade. In this respect, the lack of exposed beachrock and the abundance of reef flat sand adjacent to the beach indicates that the present erosion may only be a relatively short term phase in a longer term pattern of stability or acceretion. Analysis of shoreline changes from available and suitable WWII, 1968/69 and 1984 air photos may shed light on the longer term history of the shoreline.

Any effort given to the construction of foreshore protection along a 1.5 km length of shoreline would be extremely costly. Previous attempts at low cost foreshore protection, as shown in Figure 6, have only provided a temporary solution. If the nature of the erosion is long term, then any effort given to low cost (less than $ *200/m)* foreshore protection would be ill advised since any scheme would be doomed to failure. If the nature of the erosion is short term andlor cyclical, then the erosion problem will diminish or stabilize in the future. It is therefore recommended that re-location of existing buildings be continued as an appropriate response to the erosion problem. It is also recommended that the possibility of further coastal erosion be taken into consideration in the planning process for siting any permanent buildings in this area.

Tabiteuea South: Nikutiri Island

Site Description and Erosion Problem

The site of the erosion problem is located on the lagoon shoreline on the northwest corner of Nikutiri Island (Figure 7). At this location erosion of the lagoon beach is undercutting the main road.

An erosion scarp extends along the shore for about 300 m to the southeast.

The cause of the coastal erosion appear to be man-made and is related to the construction of the causeway to the north of Nikutiri Island (Figure 9). The causeway was originally constructed in the late 1950 s using manual labour to move and place coral boulder material from the ocean reef forming a solid structure. The causeway was upgraded in the 1980's with additional boulders and concrete. As a result, the causeway reduced water flow in the inter-islet channel, intercepting the sediment transport pathway from the ocean to the lagoon. Shoreline sediment has also been redistributed from the lagoon beaches to beside the causeway. As a result, accretion has occurred adjacent to the causeway on both the ocean to the lagoon sides. In particular, the accretion on the lagoon side has amounted to about 100 m beside the causeway and island shoreline. The wedge- shaped area of accretion is vegetated with coconut trees which become progressively shorter, and the therefore younger, towards the present shoreline (Figure 9).

Numerous coconut trees have been lost where the shoreline is eroding and according to local island sources the amount of lateral erosion has been up to 30 m at the site (Figure 8). The erosion where the road is undermined appears to be continuing but there are indications of the erosion diminishing gradually to the south. The extent of the erosion at the site may have been magnified by increased magnitude and frequency of westerlies in recent years. A beach profile was established at the road exposure to provide, (i) a typical profile section of the shoreline and (ii) a me ns of monitoring the situation in the future (Appendices 2 and 3).

Recommendations

Because there is no evidence that the shoreline has stabilized at this site, further erosion may continue in response to causeway construction. Thus the success of a low cost foreshore protection project, which would be required to protect about 100 m of shoreline, would be in doubt. Alternatively, the road at this location could be easily relocated inland, since there were no local houses or inhabitants in the area at the time of the survey. Compensation for the loss of land and coconut trees for the relocation of the road would need to be considered.

Tabiteuea South: Aranuka Island

Site Description and Erosion Problem

Aranuka Island is located immediately southeast of Nikutiri Island (Figure 7 and 10). Aranuka Island is joined by causeways to the islands to the north and south. The site of erosion extends along the entire length of the lagoon shoreline for a distance of about 200 m (Figure 11).

The beach is backed by a small erosion scarp (30 cm high) and beach rock is exposed over a shoreline distance of 150 m occurring about 30 m off the beach (Figure 12). According to local island sources the estimate of lateral erosion of the shoreline amounts to about 40 m, which is consistent with the lateral extent of exposed beach rock.

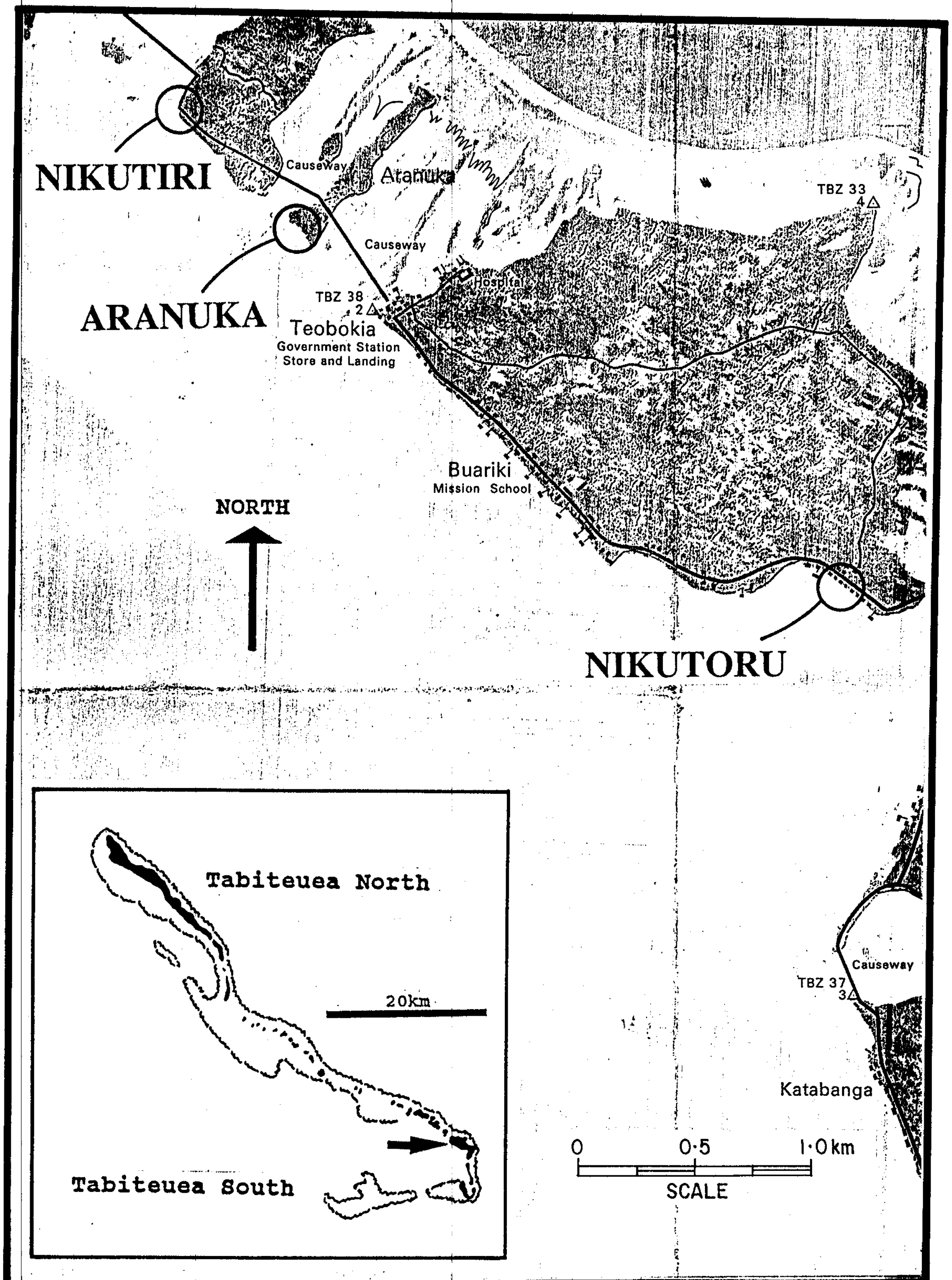


Figure 7. Map showing location of three survey sites (Nikutiri, Aranuka and Nikutoru) on lagoon shoreline, Tabiteuea South.

Figure 8. Nikutiri Island, Tabiteuea South. View north along lagoon shoreline at beach profile site showing erosion as indicated by beach scarp and fallen coconut trees. Erosion is also undermining the road. Causeway shown in Figure 9 is visible in the distance.

Figure 9. Nikutiri Island, Tabiteuea South. View south to Nikutiri Island from causeway. Accretion has occurred adjacent to the causeway on both the ocean (left) and lagoon (right) sides of the shoreline. Erosion site is located 200 m southwest of photo.

Figure 10. Aranuka Island, Tabiteuea South. View northeast to lagoon shoreline on Nikutiri Island (left) and Aranuka Island (right). Causeways joining islands have caused redistribution of lagoon shoreline sediments, specifically as erosion of island lagoon beaches and formation of lagoon spits across inter-islet channels. Note that the channel between Aranuka and Nikutiri is almost closed by spit growth.

Figure 11. Aranuka Island, Tabiteuea South. View southeast along lagoon shoreline in vicinity of beach profile. Erosion indicated by erosion scarp and exposure of tree roots. In addition, beach rock exposure is visible in lower right corner of photo.

Figure 12. Aranuka Island, Tabiteuea South. View north along beach rock exposed on lagoon shoreline south of beach profile. According to local island sources the beachrock marks the position of the shoreline approximately 20 years ago.

Figure 13. Maneaba at Nikutoru, Tabiteuea South. View northwest along lagoon shoreline beach illustrating local foreshore protection and/or land reclamation methods and the proximity of buildings to the shoreline.

The causeways were built in the early 1960 s using manual labour and local materials. Erosion of the lagoon beach on Aranuka was noticed shortly after. In addition to the lagoon beach erosion, spits have formed at both the north and south ends of the island in response to inter-islet channel closure by causeway construction. On the north end, spit growth has almost totally closed the inlet opening (Figure 10).

The erosion of the lagoon shoreline appears to have occurred in response to the following sequence of events. Prior to causeway construction flow through the inter-islet channels was predominantly from the ocean to the reef. This flow would have transported sand into the lagoon and onto sand flats (Figure 10). The sand would then have been moved onto the lagoon beaches by "constructive wave action" (low westerly swell and prevailing easterly winds which are offshore on lagoon beaches). The 1969 air photo and map (Figure 7) depicts Aranuka with a beach plan shape which is concave to the lagoon in response to sand accumulation. As a result of channel closure from causeway construction, the supply of sand from the ocean is cut off and current flow is reduced through the lagoon channel opening. Longshore sediment transport along the lagoon shoreline is then able to redistribute sand into the channel openings and form curved sand spits. As a result, the lagoon shoreline recedes and is straightened or assumes a plan shape which is convex to the lagoon. With the passage of time spit growth may completely close off the channel opening. As shown in Figure 10, this will occur more quickly with small openings. In addition to the physical changes in the shoreline and sedimentation patterns, water circulation, water quality and biological changes also may result.

Recommendations

In addition to the loss, or redistribution, of land and the loss of coconut trees, a few traditional houses have been relocated. Otherwise no houses or roads are affected by the erosion. It would not appear that the cost of the land to be protected would be justified by the expenditure on low cost foreshore protection, which in any case would not be advisable in light of a possible continuing re-adjustment of the shoreline to the construction of the causeways. Therefore no action is recommended.

Tabiteuea South: Maneaba at Nikutoru Village

Site Description and Erosion Problem

This erosion site is located on the lagoon shore of Buariki Island, the largest on Tabiteuea South (Figure 7). The specific area of concern is located in front of the maneaba in the centre of the village of Nikutoru.

The shoreline at the site is composed of a low sandy beach which is overwashed by waves during periods of strong westerly winds and high sea levels. The crest of beach is about 1 m above normal high water. The proximity of the maneaba and other buildings to the shoreline result in flooding during these events (Figure 14). This occurred most recently in November and December of 1991.

According to local sources the erosion has been occurring since the 1970's. Previously a co-op store located between the maneaba and the shoreline had to be re-located. Some small traditional houses have also been removed. The estimate of lateral erosion is 15 m. The local explanation for the problem is that erosion started after the construction in the mid-1960's of a causeway south of the village. However, the distance of 2 km between the causeway and site of erosion makes a connection between the two unlikely. Existing coastal protection along the shoreline is locally designed and consists of a combination of coral boulder seawalls and vertical log walls (Figure 13 and 14).

Recommendations

The President of the Tabiteuea Island Council has requested immediate action to protect the site of the maneaba from flooding events and further coastal erosion. In order to protect the shoreline from further coastal erosion a properly designed seawall would need to extend further north and south along the shoreline than the immediate site of the maneaba, since it was clear that the erosion also

Figure 14. Maneaba at Nikutoru, Tabiteuea South. View southeast along crest of beach (coincides with location of coconut tree). During the combination of strong westerly wind and high tides waves wash up to reach the wall of the maneaba on the left.

extended further along the shoreline. However, this is an expensive option. A more appropriate action might be to protect the maneaba from occasional flooding with the construction of a low seawall around the seaward perimeter of the maneaba corresponding to the edge of the existing fence (Figure 14). The seawall should be buried in the beach to prevent it becoming undermined and should be placed well back of the beach and not extend onto the active beach face. Seawalls which extend onto the beach face usually only worsen existing erosion problems. The seawall is intended to protect the maneaba from occasional flooding associated with extreme events and its construction should not be used as a means to "reclaim" land.

Tabiteuea South: School at Tewai Island

Site Description and Erosion Problem

The coastal erosion problem is located at the site of the school on the western end of Tewai Island (Figure 15). This area represents the northernmost extent of the existing causeway and road system on Tabiteuea South. The high population density village of Tewai is located on a smaller island in the lagoon. The school at the site conducts classes 1 to 9 and there are presently 79 students, according to the principal. The school is approximately 40 years old having been built in the 1950 s.

The school is located on a point of land which is bounded by a channel shoreline on the north and lagoon shoreline on the south. It is thus at the terminus of the channel and lagoon beach sediment transport systems. The 1969 air photo and 1:25,000 map show an area of unvegetated sand accumulation on the north side of the point in the approximate location of the school. However, when the site was visited during this study the area of sand was no longer present at this location. Instead, an approximately equivalent area of sand had formed on the south or lagoon side of the point. Thus it would appear that a major shift in the sediment deposition pattern had taken place. It is not unusual for this shift to occur where large deposits of sediment occur at the terminus of transport pathways such as sand spits. Thus the erosion problem is probably due to natural fluctuations in the sediment transport system.

As a result, lateral erosion of approximately 30 m has occurred along 100 m of the channel shoreline adjacent to the school. Evidence for this is also visible in the form of beach rock exposed up to 40 to 50 m from the present shoreline on the lower foreshore of the channel. Erosion was first noticed in the 1960 s. A seawall was built in 1982 but has now collapsed completely (Figure 16 and 17). In addition, a small seawall and groyne has been built about 100 m east of the school site. This has trapped sand on the ocean side, indicating an ocean to lagoon transport direction within the channels.

Recommendations

Considering the proximity of the school to the eroding shoreline it is recommended that a seawall be constructed at the back of the beach. A low sloping seawall which is partly buried and does not

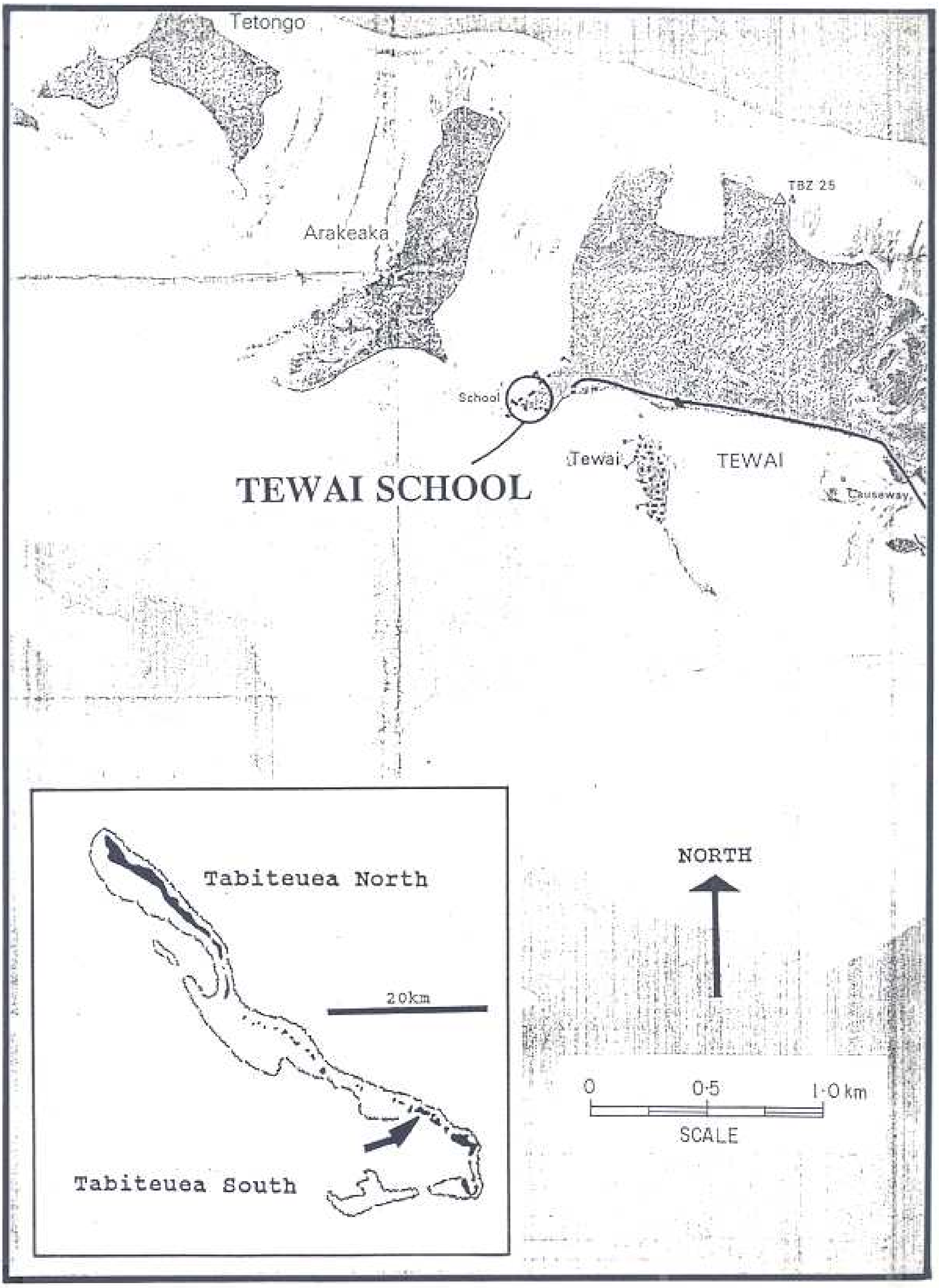


Figure 15. Map showing location of survey site at Tewai School on Tewai Island, Tabiteuea South.

Figure 16. School at Tewai, Tabiteuea South. View northeast along lagoon/channel shoreline showing location of erosion and remains of rubble seawall in front of school. According to local island sources erosion has amounted to about 30 m.

Figure 17. School at Tewai, Tabiteuea South. View southwest along inter-island channel shoreline showing condition of eastern end of seawall and proximity of school building to the shoreline.

extend onto the existing foreshore will provide protection should further erosion take place. Use of concrete is recommended. A vertical seawall in the position of the present beach face is not recommended since this will only worsen the coastal erosion problem and expose the seawall to possible structural failure.

With regard to the accumulation of sand on the south side of the school point, this area should not be exploited for easily obtained supplies of sand since it is part of a larger volume of sand that is mobile around the point. Thus,it is very likely that the sand at this location may at some point in time return to the other side of the point to form a beach in front of the school.

Onotoa: Tabuarorae Village

Site Description and Erosion Problem

Tabuarorae Village is located at the southern end of Onotoa Atoll (Figure 18). Although the village has a population of about 300, which is 15 % of the total of Onotoa, it is relatively isolated from the rest of the atoll (AIDAB, 1988). To conduct the survey the village was reached from the government station at Buraitan after a two hour journey by farm tractor and trailer along the road and lagoon beach. Access to the site was only possible at low tide across a tidal channel.

The site is close to the edge of the leeward reef rim on the southwest side of the atoll. Although the reef acts as a submerged breakwater, during times of higher sea levels the site is exposed to waves from the open ocean. Low swell may approach the site from southwest through to northwest directions. Beaches along the village are predominantly sandy with minor gravel. The adjacent reef flat has a thin veneer of mixed sand and gravel (Figure 19). Cloud (1952) has mapped the generalized geology and marine environments of Onotoa Atoll. It is interesting to note that ocean reef on the southwest corner of Onotoa is classified as "dead reef surface, generally with gravel veneer". This suggests that the supply of carbonate material from the reef at this location may be relatively small at present and may have been greater in the past.

The most prominent coastal feature in the vicinity of the village is a large spit complex which projects to the northeast away from the general east to west trend of the main island. This indicates that the predominant direction of sediment transport near the site is west to east (Figure 18) in response to the exposure to ocean waves from the west.

The shoreline at the village site has experienced dramatic changes over the last 40 years as indicated by comparison of aerial photographs taken in 1943 and 1984. In 1943 the spit on the north shore of the island enclosed the village at its western end. By 1984 the west half of the spit had vanished and the whole spit complex had migrated about 300-400 m to the east. This resulted in the exposure and erosion of the village shoreline which was previously sheltered by the spit. According to local village sources, a seawall was constructed in the 1940 s and over the years has been rebuilt. With continued shoreline recession the seawall has been moved back at least 20 m. In addition, two gabion basket groynes were built opposite the corners of the KPC maneaba in about 1986 in an apparent attempt to trap sand (Figure 20 and 21). The gabion groynes appear to have been partly successful in producing the desired effect, at least on the upper foreshore. However, they are in need of maintenance. Also significant is the accretion of sand at the proximal (base) end

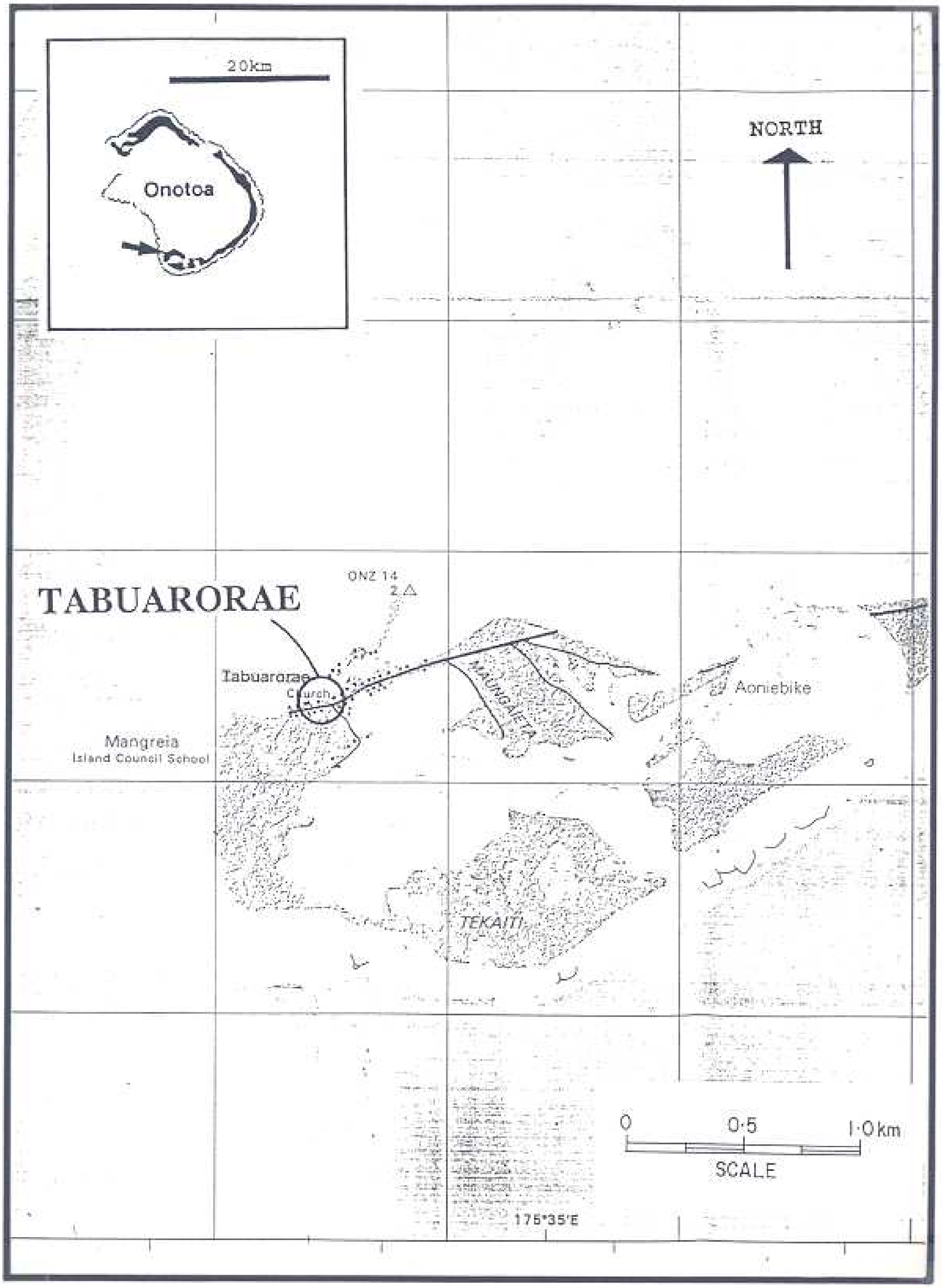


Figure 18. Map showing location of survey site at Tabuarorae Village on the south end of Onotoa.

Figure 19. Tabuarorae Village, Onotoa. View east along lagoon shoreline of village showing narrow sandy beach and gravel veneer on reef flat. Most of the shoreline is protected with seawalls. The proximal portion of the rapidly evolving sand spit complex is visible at the extreme left end of the beach.

Figure 20. Tabuarorae Village, Onotoa. View southeast from reef flat. Photo shows seawall in front of maneaba and west of two gabion basket groynes. The beach profile runs down the beach to the right of gabion basket.

Figure 21. Onotoa, Tabuarorae Village. View southeast from reef flat showing east gabion basket groyne and extensive seawall construction. Photo taken approximately 40 m west of Figure 20.

Figure 22. Tabuarorae Village, Onotoa. View east showing large area of accreting shoreline located at end of seawall shown in Figure 21. Area of accretion represents the proximal end of sandy spit complex extending further east.

of the spit (Figure 22). This indicates that a substantial amount at sand is bypassing the groynes and accumulating at the base of the spit. As a result, sand is accumulating in the corner and protecting a section of shoreline previously exposed to erosion, as indicated by the seawall at this location.

The cause of the erosion along the shoreline of the village is directly associated with the migration of the large sand spit. When visiting the site the village elders produced a set of mounted historical air photos (1943, 1984) which have been presented to them by the Australian engineering firm of Kinhill Riedel and Bryne. Apparently, a brief study has been done by the firm for Kiribati and they concluded that the cause of the erosion was natural (F. Kotvojs, pers. comm, 1992). Spit migration is a natural process and fluctuations in sediment supply to the spit can be expected over time as source materials and wave condition's change.

Recommendations

Due to the dramatic change in shoreline conditions that has taken place at this site and the desire of the village of Tabuarorae to protect their substantial investment (churches, maneaba, etc), the historical response to the erosion problem has been the construction of seawalls. Because the conditions causing the erosion (spit migration) have not stabilized or abated, it is likely that the need for protection will continue. If further foreshore protection work at this site is to be considered than the fact that the site may be exposed to higher than normal wave conditions needs to be included in the design of any structures. Given that a historical pattern of longshore sediment transport is a feature of this location it is also appropriate that properly designed and constructed sediment accretion devices (groynes) could play a role in future foreshore protection planning. Most importantly, it should be clearly recognized that it is highly likely that the site will continue to be threatened by coastal erosion, with or without further foreshore protection. Therefore, implementation of future land use planning should include this fact. In particular, future construction of important buildings, roads and other village utilities should be sited further inland away from the threatened shoreline.

Nonouti: Temotu Island, Site 1, Tebakauto Village

Site Description and Erosion Problem

Tebakauto Village is located on Temotu at the southern end of Nonouti Atoll (Figure 23). The village is sited behind a mixed sand and gravel beach adjacent to the ocean reef flat, which at this location is about 500 m wide. The shoreline faces southwest.

At the location of the village the shoreline protrudes outward onto the ocean reef flat in association with a gravel and boulder bar or narrow, low platform which runs perpendicular to the shoreline across the reef. The gravel bar acts as a groyne and induces the accumulation of beach sediments on both sides (Figure 24).

According to local sources the beach in front of the village, which is southeast of the gravel

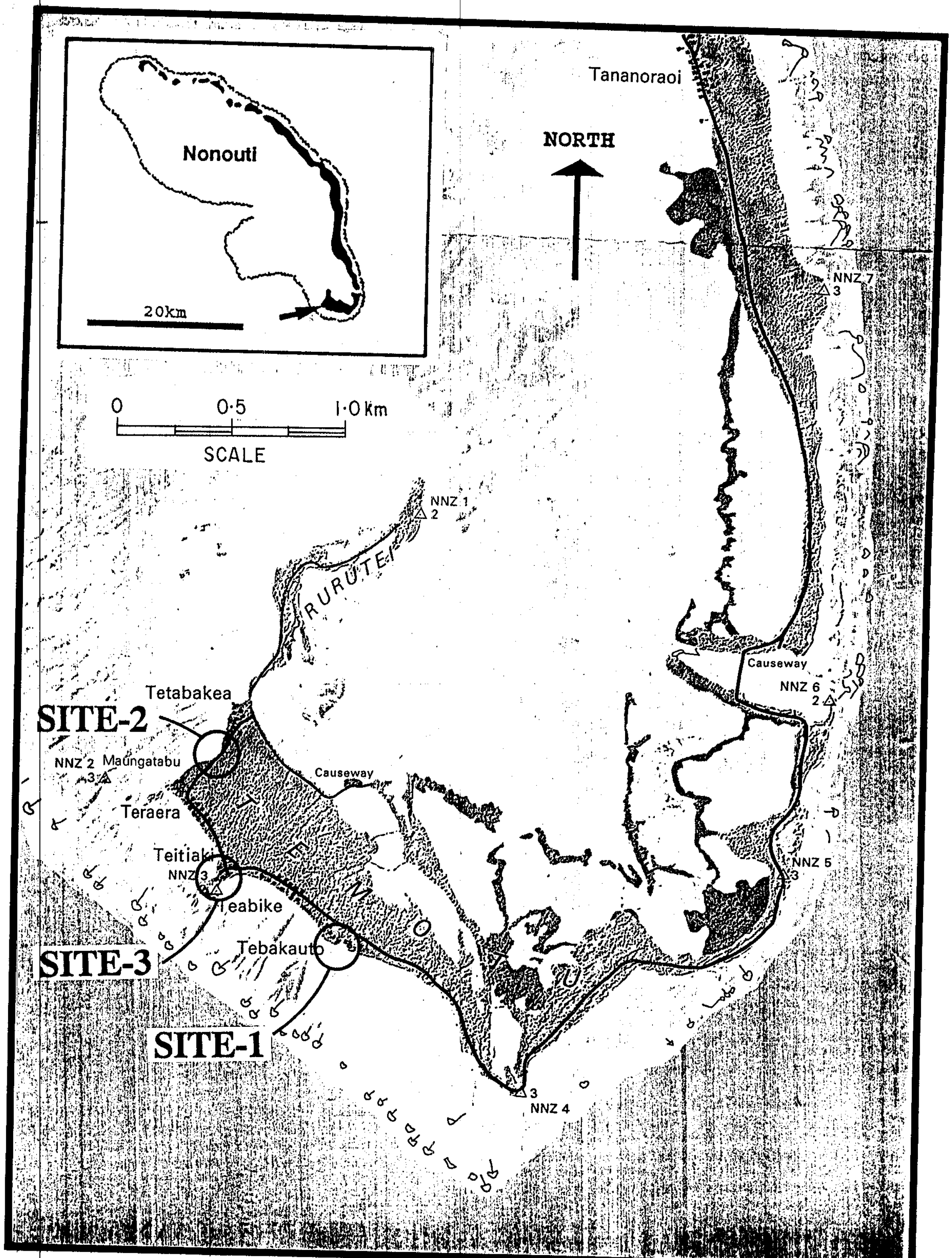


Figure 23. Map showing location of survey sites at Tebakauto (site 1), Tetabakea (site 2) and Teitiaki (site 3) on the island of Temotu, Nonouti.

Figure 24. Tebakauto Village (Site 1), Temotu Island, Nonouti. View southeast along ocean reef shoreline. Photo taken from location of raised boulder/gravel platform running perpendicular to shoreline across ocean reef.

Figure 25. Tebakauto Village (Site 1), Temotu Island, Nonouti. View southeast approximately 50 m east of Figure 24 showing remains of seawall built circa 1983 according to local sources.

platform, has eroded about 10-15 m over the last two decades. At the time of the visit there was evidence of erosion extending along the shoreline of the village for about 100 m southeast from the gravel platform. The shoreline further east and to the west showed no sign of erosion. In addition, the locals also thought that the gravel platform had also been eroded, being lower than before.

In response to the erosion, houses were relocated further away from the beach and new houses were set-back from the shoreline. We were also informed that the backshore is subject to occasional wave incursion and flooding. The remains of a government funded seawall which was built circa 1983 was present on the beach. The location of the remains of the seawall near the high tide line on the beach face indicates that there has been negligible erosion of the shoreline since the seawall was constructed.

There was no evidence for any beach sand mining or other man-induced changes to the shoreline. Therefore, the cause of the erosion appears to be natural and may be associated with changes in a groyne effect of the gravel platform or other natural causes.

Recommendations

The local people are requesting funding to rebuild and extend the seawall along the front of their village. The present erosion problem is confined to a small area, although it is likely that a greater length of the shoreline will experience similar fluctuations in position over time. In this respect, there was no physical evidence observed to indicate that the erosion problem is a long term one.

Given the failure of the previously built seawall, it is clear that a similarly designed and constructed seawall would have a limited life. A seawall is only likely to provide a temporary solution and if built on the beach face may actually make things worse by inducing erosion. If any foreshore protection activity is contemplated for this site, then consideration should be given to a low, partly buried seawall placed 3-5 m landward of the existing beach. This would be low cost, have a longer life, provide protection in the event of further erosion or wave incursion and not impact the natural beach processes. Over time it is expected that the natural coastal processes will restore the beach to a stable condition.

Nonouti: Temotu Island, Site 2, Tetabakea

Site Description and Erosion Problem

Tetabakea is a small village located on Temotu at the southern end of Nonouti Atoll (Figure 23). The shoreline on this part of Temotu faces the northwest and is adjacent to the ocean reef which is about 1 km wide. Just south of the village the shoreline beside the road was reported to have suffered erosion.

According to local sources approximately 5-6 m of land has been lost beside the road. It was not clear over what period of time this had taken place. There was also evidence of a limited amount of erosion extending north and south of this point over a total length of about 100 m of shoreline. A flat conglomerate platform is exposed to the south of the site while a narrow beach fronts the shoreline to the north (Figure 26). Foreshore protection of a local design has been placed along the shoreline to control the problem. This is composed of disc-shaped coral boulders which are stacked with the long axis vertical (Figure 27).

Recommendations

Although the existing erosion problem is relatively minor in severity and extent along the shoreline, because the road is affected the local people have requested immediate action. The local response of building a small seawall appears to have controlled, at least temporarily, the erosion. The local people have asked for further assistance to maintain and possibly extend the existing seawall. In this case funds for the hire of local labour and a truck to transport coral boulders from the ocean side reef are being requested.

The type of seawall present at the site has a limited life and is really only suitable for sites with low wave exposure. In addition, the practice of collecting coral boulders from the ocean side reef needs to be examined, as this may be creating a problem in that area.

Two possible options are recommended. The first option is relocation of the road inland about 5-10 m at this point. Unoccupied land is present for this action. Alternatively, the second option is extending the existing seawall using concrete to prolong the life of the structure.

Nonouti: Temotu Island, Site 3, Teitiaki

Site Description and Erosion Problem

The third site on Temotu Island which the survey team was requested to examine is the shoreline at the village of Teitiaki which is located on the southwest side (Figure 23). This site is composed of a small peninsula or headland with a sandy beach on the west side (Figure 28) and a gravel beach on the east side (Figure 29).

The base of the headland is composed of a conglomerate platform and covered with coral rubble ranging from gravel to boulder size. According to local sources approximately 5-6 m of erosion has occurred since the late 1970s. At the time of the visit only a minor amount of erosion was observed. No permanent buildings or roads were being threatened. The outer part of the headland because of its low elevation and exposure appears to be vulnerable to wave inundation. Despite this, cultivation of coconut trees had recently commenced here.

Recommendations

Because of the minor nature of the erosion at this site no action is recommended at this time. Furthermore, because of the high vulnerability of the headland to periodic wave inundation, no intended use or development of this area which might ultimately require foreshore protection,

Figure 26. Tetabakea (Site 2), Temotu Island, Nonouti. View northeast along ocean shoreline showing narrow mixed sand and gravel beach and erosion below road.

Figure 27. Tetabakea (Site 2), Temotu Island, Nonouti. Beach below road showing traditional seawall constructed of disc-shaped coral boulders. The boulders are stacked vertically. This type of seawall is only suitable for sites of low wave exposure.

Figure 28. Teitiaki (Site 3), Temotu Island, Nonouti. View northeast along sand beach on west side of headland. The beach is relatively sheltered due to the effect of a natural breakwater (a conglomerate platform) to the left of the photo. A negligible amount of erosion was observed.

Figure 29. Teitiaki (Site 3), Temotu Island, Nonouti. View northeast along gravel beach on east side of headland. Minor erosion was confined to the corner of the bay.

should be planned. The land should remain undeveloped or used for low intensity agriculture for example, rather than be used for permanent structures associated with high intensity use.

Nonouti: Rotima Island, Site 1, Airfield Road

Site Description and Erosion Problem

This site is located on Rotima in the middle of Nonouti Atoll (Figure 30). The study site extends along the lagoon beach in front of the road south of the airfield (Figure 31).

Coastal erosion in front of the road starts about 30 m south from the site of the airfield terminal (a concrete block building which was under construction at the time of the visit) and extends further south for about 300-400 m (Figure 34). To the north the erosion is limited by a conglomerate platform outcrop. According to local information, there had been little erosion before the construction of the airfield in the 1970s. The airfield runway was built in part using reef flat sediment from borrow pits about 1 m in depth located directly opposite the lagoon beach. Although the borrow pits are now infilled (probably from sediment eroded from the beach), their location is visible as shallow, shore-parallel depressions approximately 40 m from the present beach (Figure 33).

Shoreline erosion apparently increased at the site after airfield construction and subsequently, a seawall was built in an attempt to prevent further erosion. The seawall is now in ruins along its entire 300 m length (Figure 33). The seawall was constructed from loose coral boulders which had been collected by hand from the ocean beach and reef flat. The local agriculture tractor and trailer had been used to transport the coral boulders to the site. During construction of the seawall, all the coral boulders were placed by hand and no concrete was used. The local people were paid to work on the seawall and each person was required to construct a 2 m long portion of the seawall.

The shoreline has continued to erode up to 5 m inland of the ruins of the seawall and is now undermining the road (Figure 34). A beach profile was established to monitor the situation (Appendices 2 and 3). As a result of the erosion, the road is now impassable to the few carrier trucks on the island and most vehicles are instead using the side of the airfield runway as an alternative route.

Recommendations

Since the erosion problem extends over 300-400 m of shoreline, the cost of even low cost (less than \$ 200/m) foreshore protection would be very high (in the order of \$ 80,000, see Appendix 4). As indicated by the failure of the existing seawall, any low cost protection would have a very limited lifetime. Conversely, high cost protection would have a lower risk of failure, but the total cost may not be justified given the value of the road being protected.

The most practical option is to abandon the location of the present road and re-route traffic inland on the side of the airfield runway. In this respect, most vehicular traffic has already chosen this option. Possible conflicts with aircraft landings and take-offs, which are limited to a couple of hours each week, would need to be resolved.

Nonouti: Rotima Island, Site 2, West end of Airfield

Site Description and Erosion Problem

This site is located on Rotima on the lagoon shoreline at the west end of the airfield (Figures 30 and 32). Erosion is occurring on the south side of the airfield at the east end of a gabion basket seawall and is undermining the existing road (Figures 35 and 36).

Prior to construction of the runway a prominent conglomerate platform extended onto the lagoon shoreline. It is apparent from the beach accretion on the north side of the platform that longshore sediment transport is predominantly directed southward (Figure 32). Construction of the airfield extended onto the lagoon reef flat north of the platform and beach accretion has continued to occur at this location.

Conversely, on the south side of the airfield it would appear that some land reclamation was required and subsequently erosion of the reclaimed land developed. This may have been partly due to the interception of sand supplied from the north. Subsequently, this length of shore was protected by a gabion basket seawall (Figure 35), believed to have been built in 1990 according to local sources. The gabion basket seawall is still largely intact, but the basket wire is now rusted and broken. About 1% of the seawall has structurally failed and another 10% is near failing, mostly because of rusting of the wire or slumping of the basket because of an inadequate foundation. In addition, the construction of the seawall may have simply transferred the locus of erosion to the southeast, since the erosion problem is worse immediately adjacent to the east end of the seawall (Figure 36).

The extent of the present erosion is limited to about 50 m of shoreline and is undermining the road over a length of less than 20 m. A beach profile was established on the beach just south of the road exposure to provide, (i) a typical profile section of the shoreline and (ii) a means of monitoring the situation in the future (Appendices 2 and 3).

Recommendations

One possible course of action would be to extend the gabion basket seawall further along the shoreline. However, this may not prevent further erosion and may also just transfer the problem further along to the end of the seawall extension.

Although the road is being undermined, it is not presently used by traffic which is taking a detour along the side of the runway. In this respect, the present response of the traffic to the two sites of erosion north and south of the airport are related. As suggested for the site south of the airport, it is recommended that consideration be given to rerouting traffic alongside the airfield.

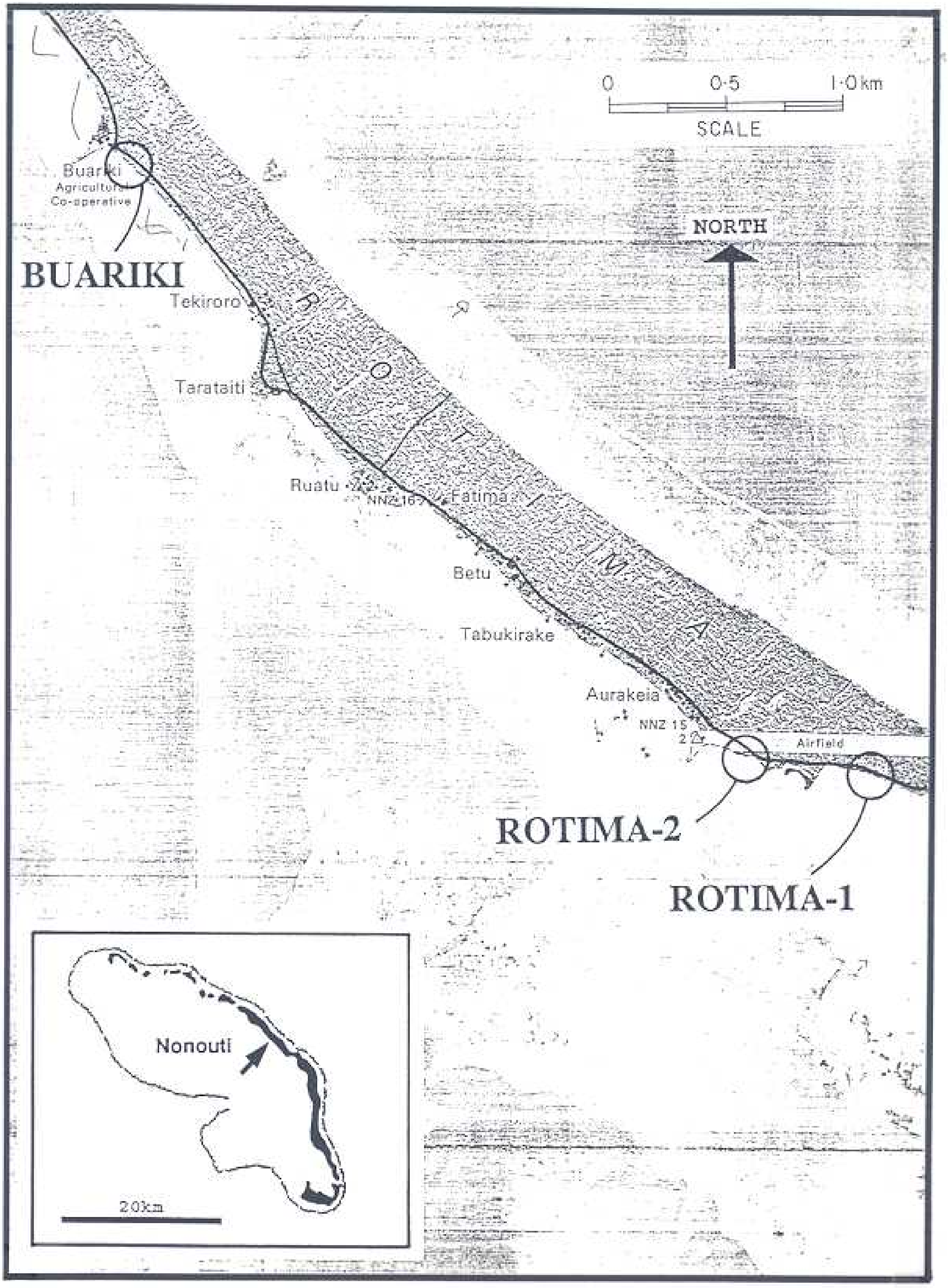


Figure 30. Map showing location of survey sites at airfield (Rotima-1, Rotima-2) and Buariki, Nonouti.

Figure 31. Rotima Island (Site 1: airfield road), Nonouti. Oblique aerial view northeast towards lagoon shoreline and airfield. Road along shoreline in middle of photo is being undermined by coastal erosion.

Figure 32. Rotima Island (Site 2: west end of airfield), Nonouti. View northeast of lagoon shoreline. Airfield shoreline reclamation with gabion basket seawall extends east (right) of conglomerate platform in centre of photo.

Figure 33. Rotima Island (Site 1: airfield road), Nonouti. View northwest along lagoon shoreline. Coastal erosion indicated by exposed roots of coconut trees, encroachment of beach on road and remains of seawall constructed at original position of shoreline.

Figure 34. Rotima Island (Site 1: airfield road), Nonouti. View southeast showing erosion of airfield road approximately 30 m south of terminal under construction on date of survey.

Figure 35. Rotima Island (Site 2: west end of airfield), Nonouti. View southeast along gabion basket seawall constructed to protect land reclaimed for airfield. According to local island sources the seawall was built in 1990.

Figure 36. Rotima Island (Site 2: west end of airfield), Nonouti. View northwest at east end of gabion basket seawall shown in Figure 35. Erosion of shoreline is undermining existing road.

Nonouti: Buariki Village

Site Description and Erosion Problem

Buariki is located in the district of Rotima on the lagoon shoreline of Nonouti Atoll approximately 3.5 km north of the airfield (Figure 30). This location was previously the site of a small village and agricultural co-operative, but it is now essentially unoccupied.

At the site, a large conglomerate platform projects perpendicular to the shoreline for 200 m onto the reef flat. The platform has the same effect as a groyne, which is to impede the longshore transport of sand caused by waves and currents. The resulting effect is that the beach may expand on either or both sides of the groyne, depending on the relative rates of long term longshore transport directions.

The "groyne effect" of the platform on the shoreline at Buariki is visible on both the 1969 aerial photograph and 1:25,000 map. Both shorelines adjacent to the northwest and southeast sides of the platform show beach accumulation, with the accumulation on the northwest side being greater. Thus, it is inferred that there is longshore sediment transport at this location in both directions (northwest and southeast) and that the net direction appears to be from the northwest.

At the time of the site inspection the shoreline on the southeast side was severely eroded (Figure 37), whilst the shoreline on the northwest side consisted of a suite of prograded beach ridges across a wide backshore and with no signs of recent erosion. Of interest was the high shell content in the sediment of the beach to the northwest which suggests a local rather than distant source. The reef flat adjacent to the eroding southeast shoreline was sediment poor with only a thin veneer of sand. In many places on the reef flat there was no sediment cover and dead coral in growth position was exposed. This surface is inferred to be the original reef top environment prior to islet formation circa 3,000-4,000 years before present.

According to local island sources, the erosion of the road adjacent to the southeast shoreline became severe just two years ago and was associated with a period of westerly winds and waves. Prior to that, erosion was apparent but not severe. Concrete filled sand bags were used to build a seawall which is now in ruins (Figure 37). In response to the road becoming undermined a new road has recently been located 10-20 m inland (Figure 38).

Recommendations

During our site visit the survey team was told that it was on the initiative of the Roman Catholic Association that the road was relocated. In this regard bags and cement had originally been provided by the government of Kiribati in Tarawa for further seawall construction. However, the alternative response of road relocation was chosen by the local body and the materials were used for this purpose (Figure 38). In light of the failure of the former concrete filled sandbag seawall, this action would appear to be justified.

In this case, road relocation is the recommended action to have been taken. However, it is not clear from the available data what the rate of erosion is at the site or whether the shoreline will

Figure 37. Buariki Village, Nonouti. View southeast along lagoon shoreline. Erosion indicated by beach scarp undermining road and remains of seawall constructed from concrete filled sandbags. Reef is covered by thin veneer of sand.

Figure 38. Buariki Village, Nonouti. View southwest along line of beach profile at site. Middle of photo shows new location of road, approximately 20 back of beach.

erode further. Air photo analysis to determine historical shoreline changes and monitoring of the beach profile is recommended.

Abemama: Tanimainiku

Site Description and Erosion Problem

Tanimainiku is located on the lagoon shoreline on the northern part of Abemama Atoll (Figure 39). In addition to the nearby villages, the main features at the site are a large mole and channel extending across the reef flat, a small boat basin and landing, a few store houses and an ice plant (Figure 40). Inter-island shipping vessels anchor in the deeper waters of the lagoon and small boats transport goods to and from the landing.

The site, along with the airfield to the north, was part of a large American base built during WWII. The channel and mole were built at that time. Although the channel and small harbour provide a valuable transportation amenity for the atoll, an undesirable side effect of its construction has been the erosion of the shoreline to the northwest. The mole has acted as a large groyne which has interrupted the longshore transport of sediment. As a result the beach has expanded on the southeast side and retreated on the northwest side. This indicates that the net direction of longshore transport is to the northwest at this site (Figure 40).

The length of actively eroding shoreline extends for about 400 m, over a distance of about 200-600 m north of the mole/channel. The 200 m of shoreline immediately north of the mole shows evidence of previous erosion in the form of a small scarp at the back of the beach. However, presently this section of beach is accreting. For the 200-600 m section further north there is active erosion with either a beach scarp, seawall in ruins, or a partly intact gabion basket seawall. Erosion is undermining the road and larger vehicles, such as the Island Council truck, must use the ocean side road as an alternative route to the north.

The road along the shoreline was originally built by the American forces during WWII. According to local island sources the erosion problem first became serious in 1969 and the road was relocated inland. It is also obvious from the site inspection that two generations of seawalls have been built and have failed (Figures 41, 42 and 43). The first seawall was built in the 1970 s by hand using coral boulders from the ocean reef flat (Figure 43). The second seawall was built in the late 1980 s and was of the rock filled wire basket or gabion type. The gabion basket originally extended over the entire length of erosion but most is now destroyed (Figure 41). The total amount of lateral shoreline retreat has been estimated as 30 m by the local people. Assuming that 30 m of erosion has taken place then the average rate since 1945 is about 0.6 m/year. This seems reasonable and could be verified by comparison of 1945, 1969 and photos from other dates. Unfortunately, the area does not appear to have been covered in the 1984 air photo survey (Department of Defence Australia, 1986), and other surveys since 1969 have not been identified.

The Island Council has previously requested assistance for a further seawall construction project from the government in Tarawa, but this has not been approved. The Island Council indicated that they do not want the road relocated inland again because of the loss of private land. In this respect, they indicated they would prefer further seawall construction rather than

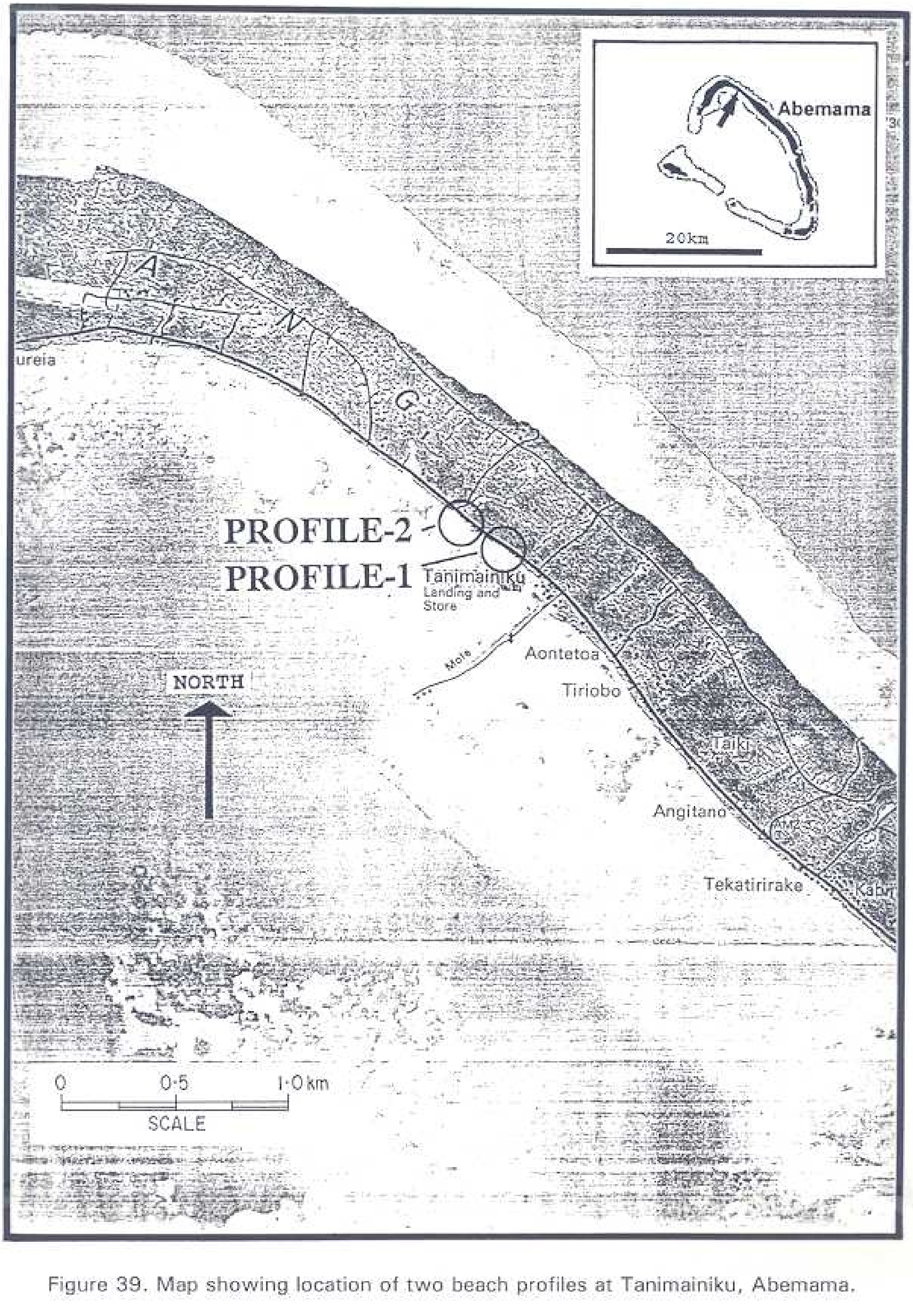


Figure 39. Map showing location of two beach profiles at Tanimainiku, Abemama.

Figure 40. Tanimainiku, Abemama. Oblique aerial view to the southeast showing pronounced shoreline accretion on southeast side of coral rubble mole indicating net longshore transport to the northwest. As a consequence, shoreline erosion has occurred for approximately 300-500 m to the northwest.

Figure 41. Tanimainiku (Beach Profile: 1), Abemama. View southeast along lagoon shoreline at location of beach profile. Note erosion of shoreline behind existing seawall position (right of photo centre).

Figure 42. Tanimainiku (Beach Profile: 2), Abemama. View southeast past location of beach profile. Note severe erosion of road and remains of coral rubble seawall on beach.

Figure 43. Tanimainiku (Beach Profile: 2), Abemama. View northwest past location of beach profile. Note severe erosion of road and remains of seawall constructed from coral rubble and boulders including whole micro-atolls.

compensation for the loss of land as a result of road relocation. The matter of compensation for the loss of presently eroded land was not discussed.

Recommendations

From the available site observations and oral history at Tanimainiku it is apparent that shoreline erosion has taken place over more than two decades (since at least 1969) and probably soon after construction of the channel and mole in WWII. It does not appear that the shoreline erosion has stabilized. Therefore the erosion can be considered to be long term and continued erosion can probably be expected. In order to quantify the exact amount and rate of erosion, air photos from 1945 and 1969 need to be compared with more recent map, airphoto or ground measurements. The two beach profile stations installed during this survey will provide a means for monitoring the present rate of shoreline erosion. It is recommended that the beach profiles be re-surveyed regularly, once a year if possible.

The history of failure of the previously constructed seawalls indicates the inability of local seawall design and construction practices to provide an effective means of foreshore protection at this location where coastal erosion is long term rather than cyclical. Therefore, for these reasons, further seawall construction is not recommended. Furthermore, if previous designs costing $ 200 per linear metre have failed in a relatively short period of time, the rationale for spending as much as $ 500 per metre for more substantial designs should be carefully examined before proceeding. In this regard, the cost to protect 400 m of shoreline at this site would amount to $ 200,000. Road relocation, for up to 1,000 m of road would probably cost less than $10,000, exclusive of land and coconut tree compensation claims (see Appendix 4). For these reasons, road relocation is the recommended action to be taken at this site. It is also recommended that further use and possible upgrading of the existing ocean side road should be considered as an alternative.

Kuria: Taubukintekira (East of Airfield)

Site Description and Erosion Problem

This site is located at the most eastern point of the island of Kuria (Figure 44). The airfield, which is visible in Figure 45, was constructed in 1978 and is not shown on the earlier map (Figure 44).

Unlike most islands in the Gilbert Group which are atolls, Kuria comprises two reef-top or table reef islands (Buariki and Oneaka) with no central lagoon. Therefore all of the shoreline on Kuria is adjacent to the ocean reef and exposed to the waves from the open ocean. In this regard, the southwest facing shorelines are on the leeward side of the island and the windward shorelines (northeast and southeast sides) are exposed to the prevailing easterly winds and waves. Therefore, the site at Taubukintekira is generally exposed to onshore conditions.

During the site visit the following features were noticed. A conglomerate platform extending from low tide to above high tide level is exposed over most the shoreline at the site and forms the base of the point. The conglomerate is composed of well cemented coral rubble and boulders. The

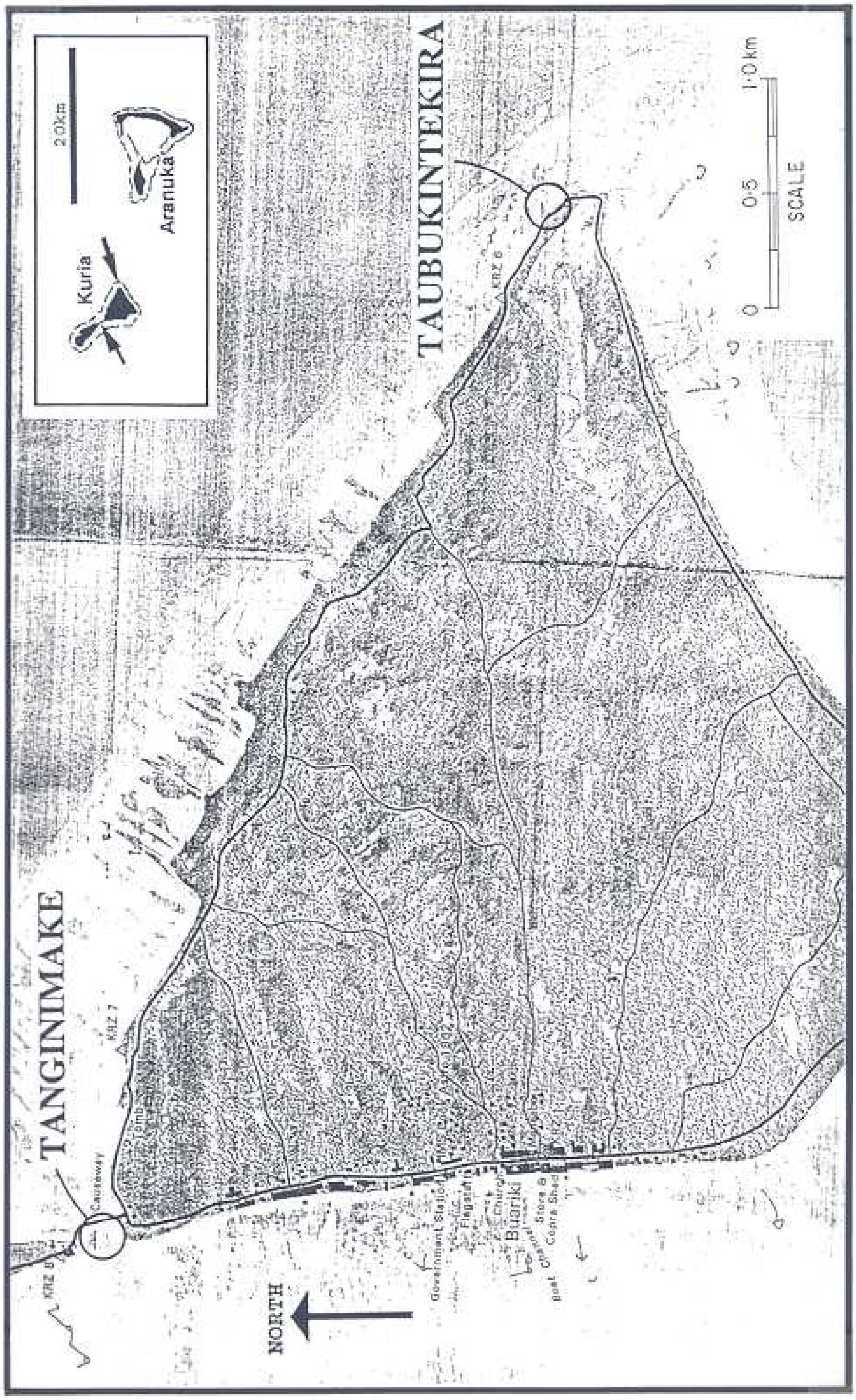


Figure 44. Map showing location of survey sites at Taubukintekira (east of airfield), and at Tanginimake (causeway), Kuria.

modern beach is composed of unconsolidated coral rubble and boulders with a negligible amount of sand at the point (Figure 47). Beach sand content increases progressively away from the point (Figure 48). In this regard, we were informed that near the point there has never been any sand beaches, just coarse coral material.

According to local island sources, erosion on the northeast facing shoreline east of the point was first noticed or became a problem about 20 years ago. A narrow road runs around the point and about 4 m of erosion was reported to have occurred there. The amount of erosion apparently increases to the west and about 10 m was reported to have occurred near the site of the beach profile (Figure 48; Appendices 2 and 3). A gabion basket seawall was built about 1974 (?) and was apparently destroyed within three years. In 1988 a vertical seawall composed of cemented coral boulders was built for a distance of about 150 along the shoreline. Portions of this seawall are still intact although much of it has been destroyed (Figure 47). Local materials (coral rubble and boulders) for both seawalls were taken from the beach and oceanside inner reef flat. Construction materials to build the airport were taken from borrow pits in the centre of Buariki, the larger of the two islands. No materials were taken from the beaches or ocean reef. We were also told that the local explanation for coastal erosion at the site was due to construction of the causeway in the 1960 s. This explanation appears unlikely because of the distance between the two sites (2-3 km) and the fact that the causeway is downdrift, not updrift, of the east point.

The site of erosion is very exposed to waves from the prevailing easterly winds. In general, the location of the point acts to deflect these currents (and the sediment they carry) to the southeast and northwest away from the point. Thus, only the coarser material, boulders, remain at the site. The loose coral material forming the beach and the underlying conglomerate in effect forms a relatively efficient and durable form of natural foreshore protection. Thus, although it may occasionally be overtopped by waves, the ridge of material along the shore should remain intact. If further erosion takes place, the mobile ridge of material will migrate landward with more or less the same elevation and shape.

The land and amenities threatened by the erosion at present include the narrow road along the shoreline, the lagoon pond behind the point and land adjacent to the shoreline. Occasional overtopping of the road by wave action takes place. The location and elevation of the road suggests that it is actually built upon the storm berm deposit and therefore it is expected to be overtopped by waves periodically. Seawater flooding of the lagoon also occurs. The lagoon had in the past been utilized for fish ponds but this activity has been abandoned because of the dominance of tilapia, considered to be an undesirable species. The present erosion does not extend along the shoreline as far as the airfield. Therefore the airfield is not under threat from coastal erosion at present and it is not likely to be in the future because it is located well inland from the adjacent stable shoreline.

Recommendations

According to local island sources an "Australian engineer" has visited the site and suggested that a sloping seawall composed of cemented coral boulders would provide suitable foreshore protection. This may be the case, but the likely cost of such a structure (in the order of $ 200-300/m)

Figure 45. Taubukintekira (east of airfield), Kuria. View northwest along the northeast facing shore of Buariki Island. Area of erosion extends for about 500-600 m along north shore from point of land in the foreground (left centre of photo).

Figure 46. Taubukintekira (east of airfield), Kuria. View south showing area of erosion along shoreline. Erosion appears to be natural and is due to exposure to ocean waves and currents which transport sand and gravel to the northwest and southeast away from the point.

Figure 47. Taubukintekira (east of airfield), Kuria. View northwest near "east point" showing cemented coral rubble seawall. Seawall rests on a foundation of coral rubble overlying conglomerate platform.

Figure 48. Taubukintekira (east of airfield), Kuria. View southeast in vicinity of beach profile. Coral rubble and sand beach overly a conglomerate platform which acts as a natural groyne. Note erosion scarp beneath scrub at back of beach.

extending over 500 m of shoreline needs to be taken into consideration and weighed against the cost of the amenities which would be protected.

It is recommended that no foreshore protection be considered for this site at this time.

Kuria: Tanginimake (Causeway)

Site Description and Erosion Problem

This site is located between the two main islands of Kuria, Buariki and Oneaka (Figure 44). The site was originally an open channel between the two reef-top islands. During the site visit the survey team was guided by Mr Robati Murdoch, who is the Member of Parliament for Kuria.

According to local sources, construction of a causeway between the two islands took place over a period of five or six years in the 1960 s. The AIDAB (1988) report states that the causeway was completed in the late 1970 s. The apparent conflict in this information may be due to the fact that the causeway probably had two phases of construction: a local one and an aid assisted one. The first phase of causeway construction was a local community initiative and used local labour with little use of machinery. The second phase may have used concrete to strengthen the causeway.

Prior to construction, the open channel between the two islands was filled with strong currents during rising and falling phases of the tide. In particular, with the prevailing easterly wind and wave regime, westward flowing currents through the channel were especially strong. Thus, as a result of the current regime, transport of coastal sediment would also have been predominantly westward. The result of this transport regime is evident on the 1977 orthophoto map (based on 1969 air photos), the 1984 air photos and oblique aerial photos taken during the present survey (Figure 49). Basically, before causeway construction the pattern of sediment accumulation on the west side of the island resembled a tidal delta with submerged sand bars on either side of a wide central channel. Coastal sediment distribution occurred in equilibrium with this pattern with beaches north and south of the channel receiving the benefits of this prevailing supply of sediment. After causeway construction, the supply of sediment from the east was cut off. However, because strong currents were no longer present the location of the previous channel (now the causeway) became the locus of sediment accumulation, at the expense of the adjacent beaches.

The 1977 orthophoto map (which is based upon 1969 photography) shows the causeway as it appeared soon after construction. By 1984, aerial photos indicate that extensive areas of shoreline accretion had occurred on the east, and to a greater extent, on the west side of the causeway. Accretion has continued to occur to the present day (Figures 49, 50 and 51).

In general, the site of the causeway does not have a coastal erosion problem. There has been substantial accretion on both sides of the causeway (especially on the western side) since completion. According to the AIDAB (1988) report "this has been accompanied by erosion of the eastern foreshore on both islands". However, during the survey team's site visit and interviews there was no mention of erosion on the eastern foreshore and none was observed (see Figure 49 and 50). In contrast, on the west side of Buariki, approximately 300 m south of the causeway (Figure 52), there is a 100 m length of shoreline which has eroded by 20-40 m according to local

Figure 49. Tanginimake (causeway), Kuria. Oblique aerial view south over site of causeway. Original line of causeway indicated by road on left side. Since causeway completion extensive coastal accretion has occurred on both sides, especially to the west(right) side.

Figure 50. Tanginimake (causeway), Kuria. View south along east side of island immediately to north of causeway. This section of shoreline has experienced significant accretion since causeway construction as indicated by the wide beach.

Figure 51. Tanginimake (causeway), Kuria. View south along west side of island immediately north of the causeway. Photo shows extensive area of coastal accretion (progradation of over 40 m) resulting from causeway construction.

Figure 52. Tanginimake (causeway), Kuria. View north along west side of island approximately 300 m to the south of causeway. This is the only length of beach in the vicinity of the causeway which appears to have suffered any erosion.

sources. A claim for compensation of the lost land has been made by the owner, Mr Murdoch, but the case has not been resolved and no compensation has been received. Conversely, the area of accretion beside the causeway is being claimed by the land owner adjacent to the north side of the causeway.

It is also claimed that fishing is now poorer since causeway construction, especially on the western side. Thus, the main interest of the local people in the site is to request that the passage between the islands be re-opened. This would entail essentially re-building the causeway with an open or bridge section. On these matters the AIDAB (1988) report recommends:

(i) “changing the hydraulic behaviour by means of a bridge would not reverse the coastal changes that have occurred";

(ii) “ the issue of ownership of the newly created land and compensation for lost land should be a matter for the Kiribati Government";

(iii) "it would be useful to have an expert report from the Fisheries Division on the real extent of the problem, whether a bridge would reverse the problem and whether a culvert and channel would provide sufficient flow;

(iv) "in the meantime it is recommended that no action be taken by Australia".

Recommendations

Given the information known at this time it is considered that no action be taken at this time and that the recommendations of the AIDAB (1988) report referred to above be investigated and resolved.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

1. The primary objective of the survey was to define the extent and severity of coastal erosion in the outer Islands of the Gilbert Group. During 10 days of survey work six atolls were visited (Tabiteuea North, Tabiteuea South, Onotoa, Nonouti, Abemama and Kuria) and 15 sites with a history of coastal erosion problems were surveyed. The survey results are summarised in Table 2 which provides a list of islands visited, sites surveyed, summary of coastal erosion problem and the recommended action to be taken.

2. The results of the survey indicate that at the sites visited where coastal erosion is a problem, the causes of the erosion fall into two main categories: natural and man-made or man-induced causes.

3. Natural causes are evident at locations with a high variability of shoreline position such as depositional spit complexes at the south end of atolls, along lagoon shorelines and at the sides of inter-islet channels. Periods of time with higher than average sea level and westerly winds caused by seasonal and inter-annual variations in climatic and oceanographic factors can also result in cycles of erosion and/or accretion on an otherwise stable lagoon shoreline. Basically, these cycles of erosion and accretion are times when the shoreline is re-aligned in response to varying coastal processes.

4. Man-made causes include the deleterious effects of causeway construction across inter-islet channels. This effectively cuts off the supply of sand from the ocean reef to the lagoon and causes the re-alignment of the adjacent lagoon shoreline. Other man-made causes of coastal erosion include the disruption of sediment transport budgets by harbour and associated mole construction, dredging of lagoon sediments and the creation of borrow pits near to the shore, and land reclamation activities.

5. The majority of the erosion sites that were visited are located on the lagoon shoreline of atolls. This is probably a reflection of two factors. First, it has been established on South Tarawa that lagoon beaches tend to be more dynamic than ocean beaches (Harper 1989b). This is because lagoon beaches experience a greater temporal variation in the magnitude and direction of waves than ocean beaches. Second, the settlement pattern on most atolls tends to be concentrated along the lagoon shorelines. These settlements are ultimately impacted by the dynamic lagoon shoreline.

6. It is clear that previous attempts at foreshore protection have been largely unsuccessful. Most coastal erosion sites visited have had one or two generations of seawalls which had failed totally. Failed seawall types included traditional loose coral boulders stacked as a vertical wall, cemented coral boulders as a vertical wall, rock fill gabion wire baskets and grout filled sandbags. Earlier work in South Tarawa by SOPAC and overseas researchers from the UK and Australia have made similar conclusions. It is therefore recommended that a complete review of the policy, design and construction of foreshore protection be undertaken.

7. Shore protection on outer islands is relative costly in terms of other development needs. It is clear from the history of previous foreshore protection projects on outer islands that this provides only a temporary solution to erosion problems. This is either because the nature of the erosion is long term and chronic or the locally designed and built foreshore protection experiences structural failure soon after completion. As discussed in Appendix 5, more consideration needs to be given to the cost effectiveness and advantages of setback and/or relocation as a viable alternative to coastal protection. This will require education, government regulations and enforcement.

8. The possible risk of coastal erosion at all sites visited in the Gilbert Islands needs to be taken into consideration in the future planning and siting of villages, permanent buildings and other valuable land use activities.

9. The reconnaissance survey of known sites of erosion has been useful in determining the nature and extent of coastal erosion where it has presently become a problem. However, generalisations regarding the overall extent and severity of coastal erosion in the atoll islands of the Gilbert Group cannot be made from this study.

   Therefore it is recommended that a wider ranging geographic study of coastal erosion and mapping be conducted in the Gilbert Islands. To implement this recommendation the techniques which would need to employed to conduct this type of study would include: analysis of aerial photographs for historical shoreline changes, use of contemporary aerial photography and low angle aerial video surveys and detailed ground surveys. Analysis of historical air photos (from WWI/, 1969, 1984, and more recent if available) is required to document the longer term nature and ratj9s of shoreline change.

10. An attempt should be made to continue monitoring the beach profiles established during this survey in order to document the present rate of erosion. Beach profiles should be re-surveyed once a year if possible. It would be desirable, but not absolutely necessary, to conduct the re-survey during the same season each year.

Table 2. List of islands visited, sites surveyed, summary of coastal erosion problems and recommended action to be taken. See text of report for further explanation of summary of erosion problem and consideration of recommendationed action.

ISLAND / SITE SURVEYED	SUMMARY OF COASTAL EROSION PROBLEM	RECOMMENDED ACTION
TABITEUEA NORTH		
Eita District	Erosion along 1.5 km of lagoon beach. Erosion has been occurring for last 10 years and appears due to natural causes. Hundreds of coconut trees have been lost to erosion and traditional houses have been relocated inland.	It is recommended that no foreshore protection be considered for this site. Relocation of existing buildings should be continued as the most appropriate response to the erosion problem. The possibility of further erosion should be considered when siting permanent buildings.
TABITEUEA SOUTH		
Nikutiri Island	Erosion on lagoon beach is undercutting local road. Erosion probably caused by causeway to the north believed to have constructed in late 1950's and rebuilt with concrete in 1980's.	It is recommended that no foreshore protection be considered for this site. Further erosion may occur at the site. The road should be relocated inland a minimum of 10 m.
Aranuka Island	Erosion on lagoon beach extends entire length of shoreline (approx. 200 m). Erosion first observed after construction of causeways to the north and south in the early 1960's.	It is recommended that no foreshore protection be considered for this site. The possibility of further erosion at this site should be taken in consideration when planning future land use.
School at Tewai Island	Erosion on lagoon beach and channel passage beside school. Erosion first noticed in 1960's and since then a maximum of 30 m of lateral erosion has occurred. A seawall made of loose coral boulders was built in 1982 but is now in ruins.	It is recommended that foreshore protection is warranted at this site, because of the value of the school building and its proximity to the eroding shoreline.
Maneaba at Nikutoru Village	According to local information, erosion along lagoon shoreline was first noticed in 1975 and has amounted to about 15 m of lateral erosion. Maneaba exposed to occasional wave inundation.	Recommend construction of a low seawall around seaward perimeter of maneaba (see text for details). Otherwise, no coastal protection is recommended and the possibility of further erosion at this site should be taken into consideration.
ONOTOA		
Tabuarorae Village	Erosion of shoreline was induced by migration of a beach spit complex to the northeast by about 300-400 m between 1950 and today. Existing foreshore protection includes seawalls of different ages and gabion basket groynes built about 1986.	It should be recognized that it is likely that the site will continue to be threatened by coastal erosion, with or without further foreshore protection. Implementation of land use planning should include the threat of further coastal erosion.

NONOUTI		
Tebakauto Village, Temotu Island Site 1	Erosion along 100 m of ocean beach shoreline has occurred for last 10-15 years according to locals. Government built (PWD) seawall in 1983 is now in ruins.	It is recommended that no foreshore protection be considered for this site. There was no physical evidence to indicate that the nature of the erosion is long term.
Tetabakea, Temotu Island Site 2	Erosion of oceanside beach for approximately 100 m beside road south of village. Locals estimate 5-6 m of lateral erosion has occurred beside road.	It is recommended that no major foreshore protection be considered for this site, apart from possibly extending the existing seawall and using concrte to prolong the life of the structure. Alternatively, relocation of road inland 5-10 m is recommended.
Teitiaki, Temotu Island Site 3	Locals claim 5-6 m of lateral erosion since late 1970's extending over 20-30 m of shoreline at the base of either side of headland.	It is recommended that no foreshore protection be considered for this site. Land use planning should be applied to avoid future problems.
Airfield Road, Rotima Island Site 1	Erosion extends south approximately 300-400 m from site of airfield terminal (under construction) along road frontage on lagoon shoreline. Borrow pits located directly off shoreline probably contributed to erosion. Seawall in ruins extends along entire length of road frontage.	It is recommended that no foreshore protection be considered for this site. The best alternative is to abandon the location of the present road and re-route traffic along the side of the airfield.
West end of Airfield, Rotima Island Site 2	Runway extension into lagoon caused erosion on shoreline to the southeast which subsequently required gabion basket seawall to be built in 1990. Local erosion occurring at end of seawall.	As for above. It is recommended that no foreshore protection be planned for this site. The best alternative is to abandon the location of the present road and re-route traffic along the side of the airfield.
Buariki Village	Severe erosion on southeast side of rock platform which acts as a natural groyne with accretion on the northwest side. Erosion has required section of road to be relocated 10-20 m inland from lagoon shoreline. Previously built seawall in ruins.	It is recommended that no foreshore protection be considered for this site. Road relocation has already taken place and is the recommended action to have taken.
ABEMAMA		
Tanimainiku	Erosion of shoreline along lagoon beach to north of the harbour and mole (breakwater) originally constructed by American troops in WWII. Erosion starts about 200 m north of harbour and continues for a further 400 m along road frontage. Road has already been relocated once and two generations of seawalls have been built (both have failed). Long term erosion has been caused by construction of harbour and mole.	It is recommended that no foreshore protection be considered for this site. As an alternative it is recommended that the road is relocated inland or that traffic is re-routed to the ocean side road.

KURIA		
Taubukintekira (East of Airfield)	Erosion extends for about 500-600 m along north side of point at extreme east end of island. Erosion was first noticed about 20 years ago and has resulted in 4 m of shoreline recession. Previously built seawalls (gabion basket in 1974 and cemented rock in 1988) have failed to stop erosion. Erosion is natural and due to the location and exposure of the site to the open ocean.	It is recommended that no foreshore protection be considered for this site.
Tanginimake (Causeway)	Beaches have accreted on both sides of the causeway since construction in the mid-1960's. Lateral accretion on west side amounts to 40 m. Some erosion has occurred to the south of the causeway on the west side. Locals want opening built through causeway to reverse alleged decline in fishing.	Until it can be established that the causeway has adversely affected fishing, no construction action is recommended.

REFERENCES

AIDAB, 1988: North Tarawa and outer islands causeways proposal. Prepared for the Government of Kiribati and the Australian International Development Assistance Bureau, 176 p.

Burgess, S.M. 1987: The climate and weather of Western Kiribati, New Zealand Meteorological Service Misc. Pub 188(7).

Burne, R.V. 1983: Origin and transportation of beach sand Betio-Bairiki, Tarawa, Kiribati _ July 1983. CCOP/SOPAC Cruise Report 81 (Draft).

Byrne, G. 1991: Sediment movement on Tarawa, Kiribati. Proceedings Workshop on Coastal Processes in the South Pacific Nations, Lae, PNG, 1987. CCOP/SOPAC Tech. Bull. 7: 155-159.

Carter, R. 1983: Coastal erosion in Kiribati 10-13 Jan 1983. CCOP/SOPAC Technical Report 76: 25 pages.

Cloud, P.E. 1952: Preliminary report on geology and marine environments of Onotoa Atoll, Gilbert Islands. Atoll Res. Bull., 12: 1-73.

Colman, R. 1989: The hydrodynamics and sediment transport of atoll lagoon channels: a pilot investigation into the effects of construction of road links between the islets of North Tarawa, Kiribati. Report prepared to AIDAB, Victoria Institute of Marine Sciences, 70 pp.

Department of Defense, Australia, 1986. The results of (air photo) surveys carried out by the Australian Government on behalf of the Republic of Kiribati. Department of Defence, Army Office, Canberra, ACT, Australia.

Department of lands and Surveys, Fiji, 1968/1969: Air photo flight coverage diagrams for the Gilbert Group, Republic of Kiribati.

Emery, K.O. 1961: A simple method of measuring beach profiles. Limnology and Oceanography 6: 90 -93.

Gauss, G.A. 1982: Nearshore surveys, Tarawa, Kiribati, 5 November - 23 December, 1981. CCOP/SOPAC Technical Report 63:

Gillie, R.D. 1991: Beach profile surveys on Betio and Bairiki and along the Nippon Causeway, South Tarawa, Republic of Kiribati, January, 1991. SOPAC Preliminary Report 37: 22 pages.

Gillie, R.D. 1992a: Air photo and coastal surveys, South Tarawa, Kiribati, May 1992. SOPAC Preliminary Report 48: 19 pages.

Gillie, R.D. 1992b: Reconnaissance survey of coastal erosion sites in the Gilbert Islands Group, R public of Kiribati. SOPAC Preliminary Report 52: 18 pages.

Gillie, R.D. 1992c: Air photo survey, South Tarawa, Kiribati, May 1992. SOPAC Miscellaneous Report 136: 33 pages.

Gillie, R.D. and P. Woodward 1992: Preliminary coastal morphology maps, Tarawa, Kiribati, 1988. S PAC Miscellaneous Report 128: 10 pages, 5 map sheets.

Gilmour, A.J. and Colman, R. 1990: A pilot environmental study of the Outer Island Development Program, Republic of Kiribati. Consultants report by Graduate School of the Environment, Macquarie University, Australia. 151 pages.

Harper, J.R. 1987: Initial survey of the Betio/Bairiki causeway, Tarawa, Republic of Kiribati. COP/SOPAC Technical Report 82: 34 pages.

Harper, J.R. 1988: Follow-up survey of the Betio-Bairiki causeway, Tarawa, Republic of Kiribati. COP/SOPAC Technical Report 86: 58 pages.

Harper, J.R. 1989a: Reconnaissance survey of coastal erosion sites on Abaiang Atoll, Republic of Kiribati, 3-4 April, 1989. SOPAC Technical Report 92: 52 pages.

Harper, J.R. 1989b: Evaluation of beach profile data from Betio and Bairiki, Republic of Kiribati. COP/SOPAC Technical Report 94: 136 pages.

Hinde, G.J. 1904: Report on the materials from the borings at the Funafuti atoll. In: The atoll of Funafuti. The Royal Society London, pp 186.-361.

Holden, B. 1992: Coastal protection Tebunginako Village, Abaiang, Kiribati. SOPAC Technical Report 136: 47 pages.

Holmes, O.W. 1979: Gilbert Islands: Land reclamation and sea defenses on Tarawa Atoll. Report No OD 18. Hydraulics Research Station, Wallingford, Oxfordshire, England.

Howorth, R. 1982: Coastal erosion in Kiribati: visit to South Tarawa, 22 Jan - 10 Feb 1982. COP/SOPAC Technical Report 22: 13 pages.

Howorth, R. 1983a: Coastal erosion in Kiribati: second visit to South Tarawa, 10-16 June, 1982. COP/SOPAC Technical Report 25: 5 pages.

Howorth, R. 1983b: Coastal erosion in Kiribati: visit to South Tarawa, 23 Aug-8 Sept, 1983. CCOP/SOPAC Technical Report 31: 22 pages.

Howorth, R. 1985: Atlas of beach profiles monitored on Betio-Bairiki, Tarawa Atoll, Kiribati: January 1982 to July 1985. CCOP/SOPAC Technical Report 50: 45 pages.

Howorth, R. 1991: Beach profile monitoring programmes in Kiribati and Tuvalu (abstract). In: Workshop on Coastal Processes in the South Pacific Island Nations, Lae, Papua New Guinea, 1-8 October 1987. SOPAC Technical Bulletin 7: 201.

Howorth, R., Cowan, H. and R. Carter 1986: Coastal erosion potential South Tarawa, Kiribati. South Pacific Marine Geology Notes, 3(3): 29-32.

Howorth, R. and Radke, B. 1991: Investigation of historical evidence of shoreline changes: Betio, Tarawa Atoll, Kiribati, and Fongafale, Funafuti Atoll, Tuvalu. Proceedings Workshop on Coastal Processes in the South Pacific Nations, Lae, PNG, 1987. CCOP/SOPAC Technical Bulletin 7: 91 - 98

Howorth, R. and B.M. Richmond 1988: CCOP/SOPAC Coastal Mapping Workshop, 7-15 July, 88, Kiribati. CCOP/SOPAC Training Report 18: 6 pages.

Hydraulics Research Station, 1976: Gilbert Islands: Land reclamation,. causeway construction and sea defenses. Report No. EX 727. Hydraulics Research Station, Wallingford, Oxfordshire, England.

Hyrographer of the Navy, UK 1992: Admiralty Tide Tables and Tidal Stream Tables, Vol 3, Pacific Ocean and Adjacent Seas ..

IGOSS, 1992: Monthly mean sea level data in the Pacific Ocean. IGOSS Sea Level Program in the Pacific, Department of Oceanography, University of Hawaii.

Kroenke, L.W. and D.A. Walker, 1986: Evidence for the formation of a New Trench in the Western Pacific. EOS, Transactions, American Geophysical Union, 67(12): 145-146.

Ladd H.S., Ingerson E., Townsend R.D., Russell M., and H.K. Stephenson, 1953: Drilling on Eniwetok atoll, Marshall Islands. Bull. Am. Assoc. Petrol. Geol. 37: pp 2257-2280.

Lay , T. and E. Okal, 1983: The Gilbert Islands (Republic of Kiribati) earthquake swarm of 1981-983. Phys. Earth Planet. Inter., 33: p. 284.

Marshall, J.F. and G. Jacobson 1985: Holocene growth of a mid-Pacific atoll: Tarawa, Kiribati. Coral Reefs 4: 11-17.

McLean, R.F. 1989: Kiribati and Sea Level Rise. Commonwealth Secretariat, Expert Group on Climatic Change and Sea Level Rise. 87 pages.

McLean, R.F. 1991: Weather and climate interactions with coastal environmental systems in the outh Pacific. In Proceedings of the Conference: South Pacific Environments: Interactions with eather and Climate. Organised by Environmental Science, University of Auckland, Auckland, New Zealand, pages 49-55.

Nunn, P. 1988: Potential impacts of projected sea level rise on Pacific Island States (Cook Islands, Fiji, Kiribati, Tonga and Western Samoa): a preliminary report. Potential impacts of greenhouse gas generated c1imati change and projected sea level rise on Pacific Island states of the SPREP region, pp. 53-81.

NIWAR 1992: South Pacific Climate Monitor, July 1992. Published by National Institute of Water and Atmospheric Research, Wellington, New Zealand. 6 pages.

Paulay G. and L.R. McEdward, 1990: A simulation model of island reef morphology: the effects of s a level fluctuations, growth, subsidence and erosion. Coral Reefs, 9: pp 51-62.

Richmond, B, 1990: Nearshore sediment distribution, South Tarawa, Kiribati. CCOP/SOPAC Technical Report 91:

Richmond, B. 1991: Reconnaissance geology of the Gilbert Group, Western Kiribati. SOPAC Technical Report 77 (Draft).

Richmond, B. 1992: Holocene Geomorphology and Reef History of Islands in the South and Central Pacific. Unpub. Ph.D. Thesis, University of California at Santa Cruz. 298 pages.

Sachet, M.H. 1957: Climate and meteorology of the Gilbert Islands. Atoll Res. Bull., 60.

Schofield, J.C. 1977a: Late Holocene sea level, Gilbert and Ellice Islands, West Central Pacific ocean. New Zealand Jour. Geol. and Geophys., 20:503-529.

Schofield, J.C. 1977b: Effect of Late Holocene sea level fall on atoll development. New Zealand Jour. Geol. and Geophys., 20:531-536.

Sherwood, A., Gillie, R. and T. Teuea 1992: Planning seminar on increasing public awareness of coastal processes and coastal management in Kiribati, 4-6 August 1992. SOPAC Trip Report 132: 11 pages, appendices.

Tebano, T. 1985: Atoll environment in Kiribati: a geography book on Kiribati. Atoll Research and Development Unit, University of the South Pacific, Tarawa, Kiribati. 30 pages.

DP, 1991: Kuria Island Development Plan (1991-1995), Prepared by the people of Kuria with Technical assistance from the Integrated Atoll Development Project, RAS/88/014.

Woodroffe, C.D. and R. F. McLean 1990: Microatolls and recent sea level change on coral atolls. Nature, 344: 531-534.

Woodroffe, C.D. and R. F. McLean 1992: Kiribati vulnerability to accelerated sea-level rise: a preliminary study. Based upon research and field visit funded by Department of Arts, Sports, Environment and Territories, Government of Australia. 82 pages.

Wyrtki, K. 1990: Sea level rise: the facts and the future. Pacific Science 44: 1-16.

APPENDIX 1

SUMMARY OF MAP SHIEET AND COORDINATE DATA FOR EACH SURVEY SITE

Table A1. Summary of map sheet and coordinate data.

ISLAND / SHEET	SITE / VILLAGE	COORDINATES
TABITEUEA-1 (Edition 1 - DOS 1980)	Eita District	13500 E 169500 N
TABITEUEA-4 (Edition 1 - DOS 1980)	School at Tewai Island	44100 E 140700 N
	Nikutiri Island	47800 E 138300 N
	Aranuka Island	48400 E 137900 N
	Maneaba at Nikutoru	50800 E 136500 N
ONOTOA (Edition 2 - DOS 1980)	Tabuarorae	12700 E 135500 N
NONOUTI-2 (Edition 1 - DOS 1982)	Buariki Village	27300 E 133000 N
	Airfield at Rotima Island	30000 E 130300 N
	Temotu Island	34000 E 112000 N
ABEMAMA-1 (Edition 1 - DOS 1979)	Tanimainiku	20000 E 153300 N
KURIA (Edition 1 - DOS 1977)	Taubukintekira (east of airfield)	21400 E 123700 N
	Tanginimake (causeway)	16800 E 125500 N

APPENDIX 2

BEACH PROFILE DATA

Table A2. List of beach profile sites.

ISLAND	SITE/VILLAGE	PROFILE NAME	DATE
Tabiteuea North	Eita District	Eita - 1 Eita - 2	10/08/92 10/08/92
Tabiteuea South	Nikutiri Island Aranuka Island School at Tewai Island Nikutoru Maneaba	Nikutiri Aranuka Tewai Nikutora	11/08/92 11/08/92 12/08/92 12/08/92
Onotoa	Tabuarorae Village	Tabuarorae	13/08/92
Nonouti	Temotu Island Site 2, Tetabakea Rotima Island Site 1, Road Rotima Island Site 2, Airfield Buariki Village	Tetabakea Rotima - 1 Rotima - 2 Buariki	14/08/92 15/08/92 15/08/92 15/08/92
Abemama	Tanimainiku	Tanimainiku - 1 Tanimainiku - 2	17/08/92 17/08/92
Kuria	Taubukintekira	Taubukintekira	18/08/92

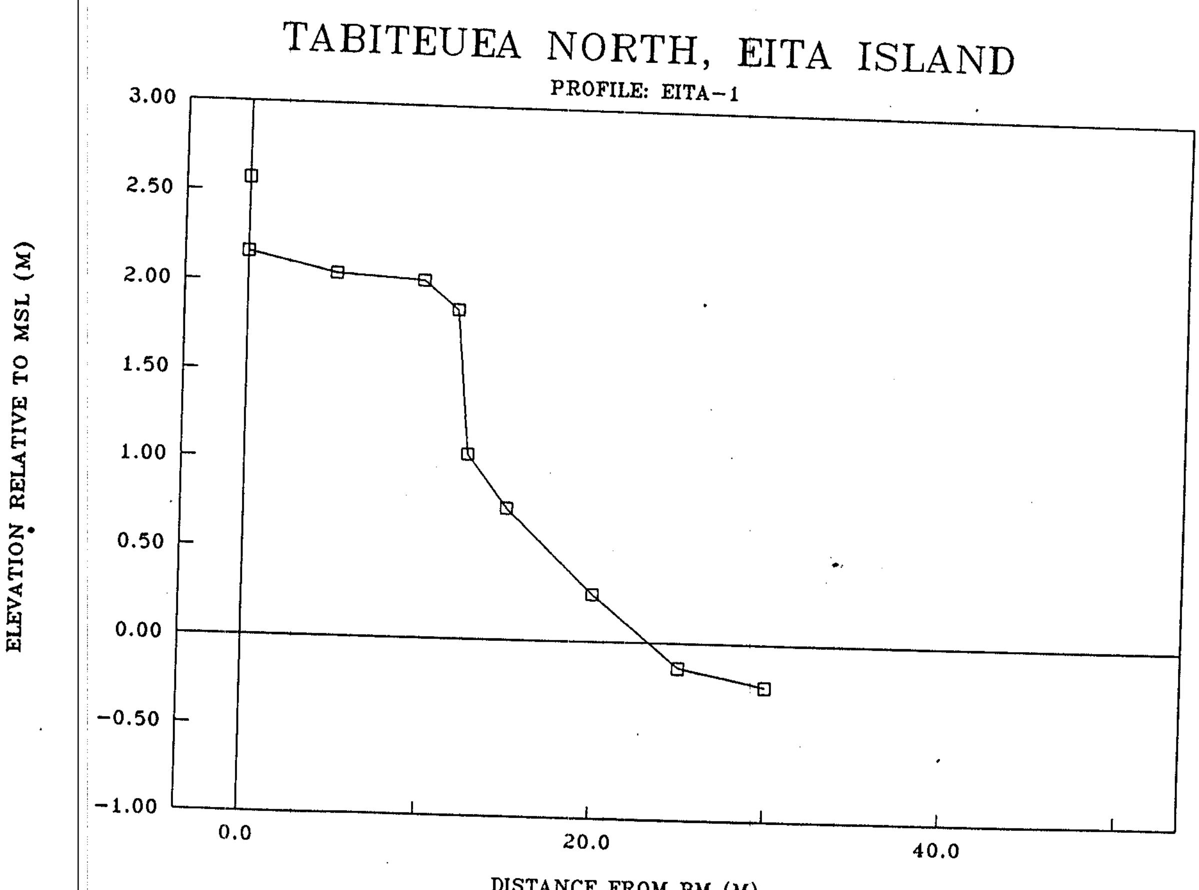
ISLAND: TABITEUEA NORTH
SITE: EITA ISLAND
PROFILE: EITA-1
DATE: 10/08/92

COPY

BEARING = 214 MN

ELEVATION CORRECTION TO MSL = 2.16

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.41	2.57	BM, NAIL IN TREE
0.0	0.00	2.16	GROUND LEVEL BESIDE TREE
5.0	-0.11	2.05	GROUND SURFACE, FLAT
10.0	-0.14	2.02	GROUND
12.0	-0.30	1.86	TOP OF EROSION SCARP
12.7	-1.12	1.04	BOTTOM OF SCARP/TOP OF BEACH
15.0	-1.42	0.74	BEACH
20.0	-1.89	0.27	BEACH (WATER LEVEL AT 14:45)
25.0	-2.30	-0.14	BEACH BELOW WATER LEVEL
30.0	-2.40	-0.24	BEACH



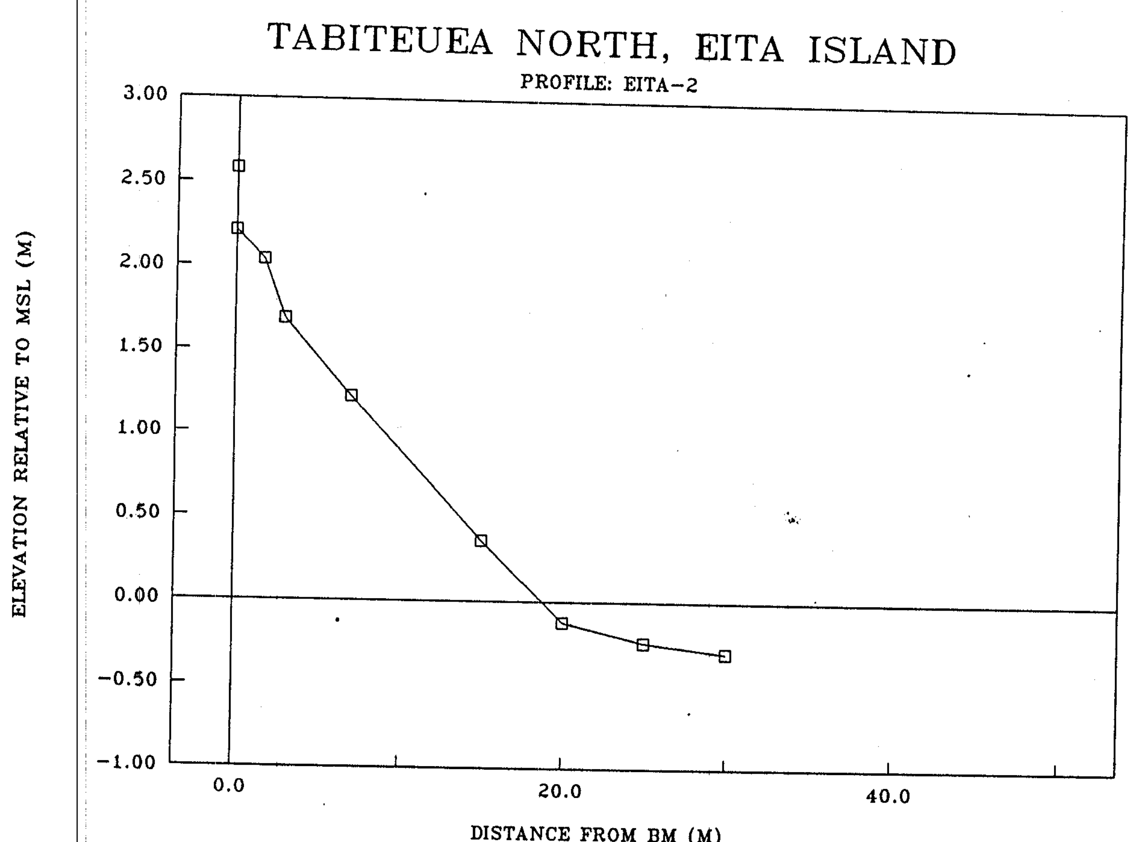
ISLAND: TABITEUEA NORTH
SITE: EITA ISLAND
PROFILE: EITA-2
DATE: 10/08/92

COPY

BEARING = SEAWARD

ELEVATION CORRECTION TO MSL = 2.21

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.37	2.58	BM, NAIL IN TREE
0.0	0.00	2.21	GROUND LEVEL BESIDE TREE
1.7	-0.17	2.04	TOP OF BEACH
3.0	-0.52	1.69	BEACH
7.0	-0.99	1.22	BEACH
15.0	-1.85	0.36	BEACH (WATER LEVEL AT 15:50)
20.0	-2.33	-0.12	BEACH
25.0	-2.45	-0.24	BEACH
30.0	-2.51	-0.30	BEACH



ISLAND: TABITEUEA SOUTH
SITE: NIKUTIRI ISLAND
PROFILE: NIKUTIRI
DATE: 11/08/92

BEARING = 243 MN

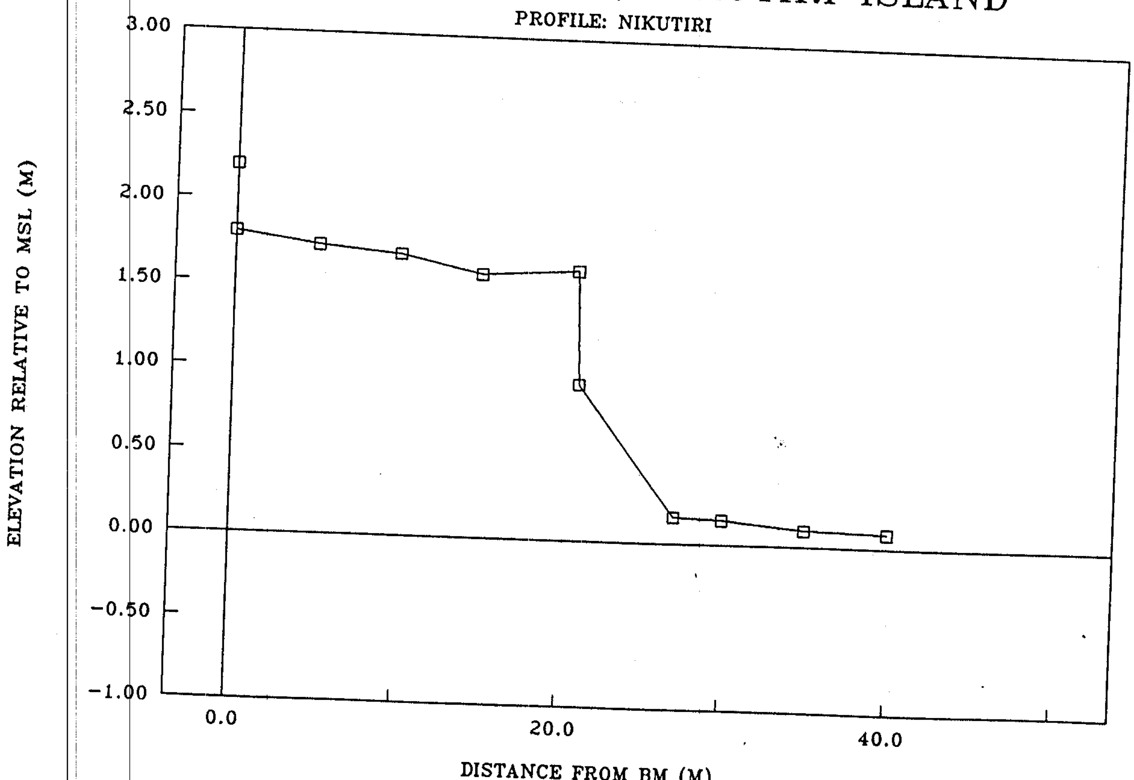
ELEVATION CORRECTION TO MSL = 1.8

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.40	2.20	BM, NAIL IN TREE
0.0	0.00	1.80	GROUND LEVEL BESIDE TREE
5.0	-0.07	1.73	GROUND, COCONUT TREES
10.0	-0.11	1.69	GROUND, COCONUT TREES
15.0	-0.22	1.58	MIDDLE OF ROAD
20.8	-0.18	1.62	TOP OF EROSION SCARP
21.0	-0.86	0.94	BOTTOM OF SCARP / TOP OF BEACH
27.0	-1.64	0.16	BOTTOM OF BEACH
30.0	-1.65	0.15	TIDAL FLAT WITH GRAVEL AND SAND
35.0	-1.70	0.10	REEF FLAT
40.0	-1.71	0.09	REEF FLAT

NOTE: WATER LEVEL AT 13:20 APPROX 0.1-0.2 M BELOW LAST SURVEY POINT

TABITEUEA SOUTH, NIKUTIRI ISLAND

PROFILE: NIKUTIRI

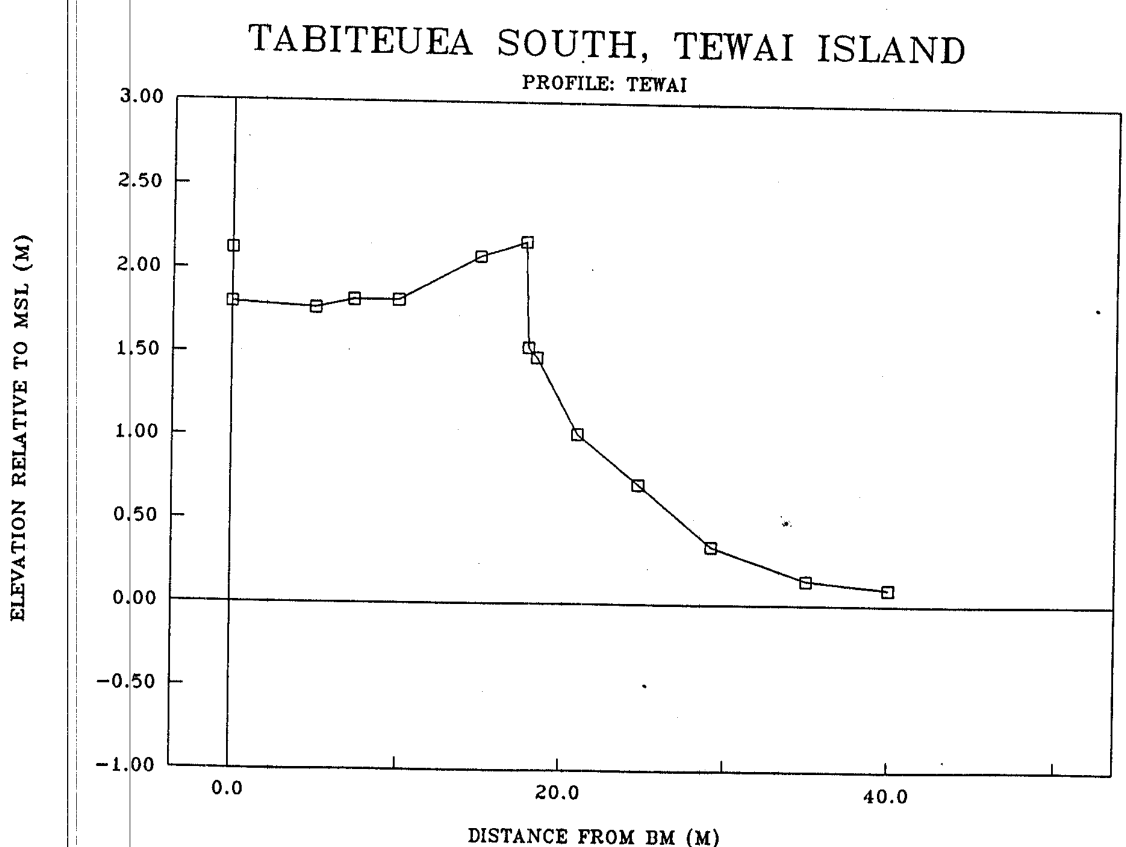


ISLAND: TABITEUEA SOUTH
SITE: SCHOOL AT TEWAI ISLAND
PROFILE: TEWAI
DATE: 12/08/92

BEARING = 319 MN

ELEVATION CORRECTION TO MSL = 1.8

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.32	2.12	BM, NAIL IN COCONUT TREE
0.0	0.00	1.80	GROUND LEVEL BESIDE TREE
5.0	-0.03	1.77	GROUND, COCONUT TREES
7.3	0.02	1.82	GROUND TO RIGHT OF COCONUT TREE
10.0	0.02	1.82	GROUND
15.0	0.28	2.08	SAND COVERED WITH COCONUT FRONDS
17.8	0.37	2.17	TOP OF SAND EROSION SCARP
18.0	-0.26	1.54	BOTTOM OF EROSION SCARP
18.5	-0.32	1.48	REMAINS OF COLLAPSED SEAWALL
21.0	-0.78	1.02	BOTTOM OF SEAWALL / BEACH
24.7	-1.08	0.72	BEACH
29.2	-1.45	0.35	BOTTOM OF BEACH
35.0	-1.65	0.15	SAND FLAT
40.0	-1.70	0.10	SAND FLAT

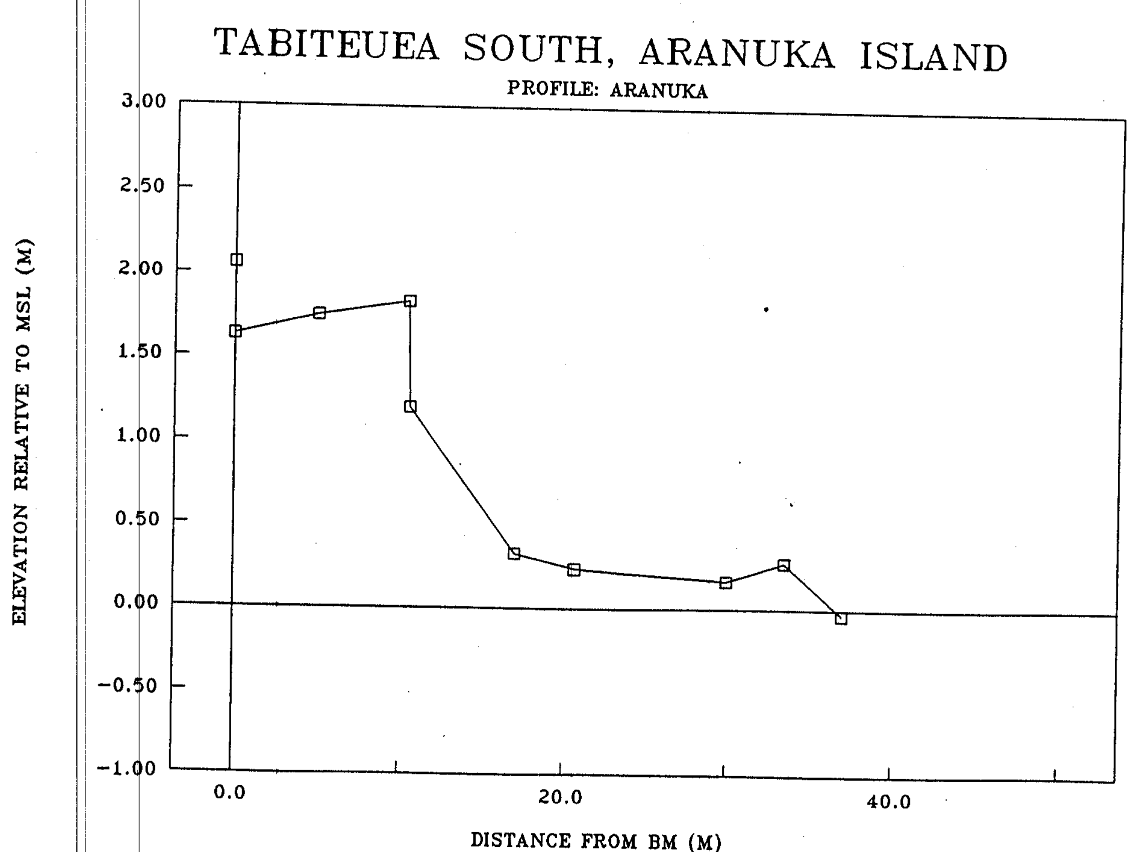


ISLAND: TABITEUEA SOUTH
SITE: ARANUKA ISLAND
PROFILE: ARANUKA
DATE: 11/08/92

BEARING = 222 MN

ELEVATION CORRECTION TO MSL = 1.63

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.43	2.06	BM, NAIL IN COCONUT TREE
0.0	0.00	1.63	GROUND LEVEL BESIDE TREE
5.0	0.12	1.75	GROUND, COCONUT TREES
10.5	0.20	1.83	TOP OF EROSION SCARP
10.6	-0.43	1.20	BOTTOM OF SCARP/TOP OF BEACH
17.0	-1.30	0.33	BOTTOM OF BEACH
20.7	-1.39	0.24	REEF FLAT (WATER LEVEL AT 14:31)
30.0	-1.46	0.17	REEF FLAT
33.5	-1.35	0.28	TOP OF BEACH ROCK OUTCROP
37.0	-1.66	-0.03	SAND ON REEF FLAT BEYOND BEACH ROCK



ISLAND: TABITEUEA SOUTH
SITE: NIKUTORA MANEABA
PROFILE: NIKUTORA
DATE: 12/08/92

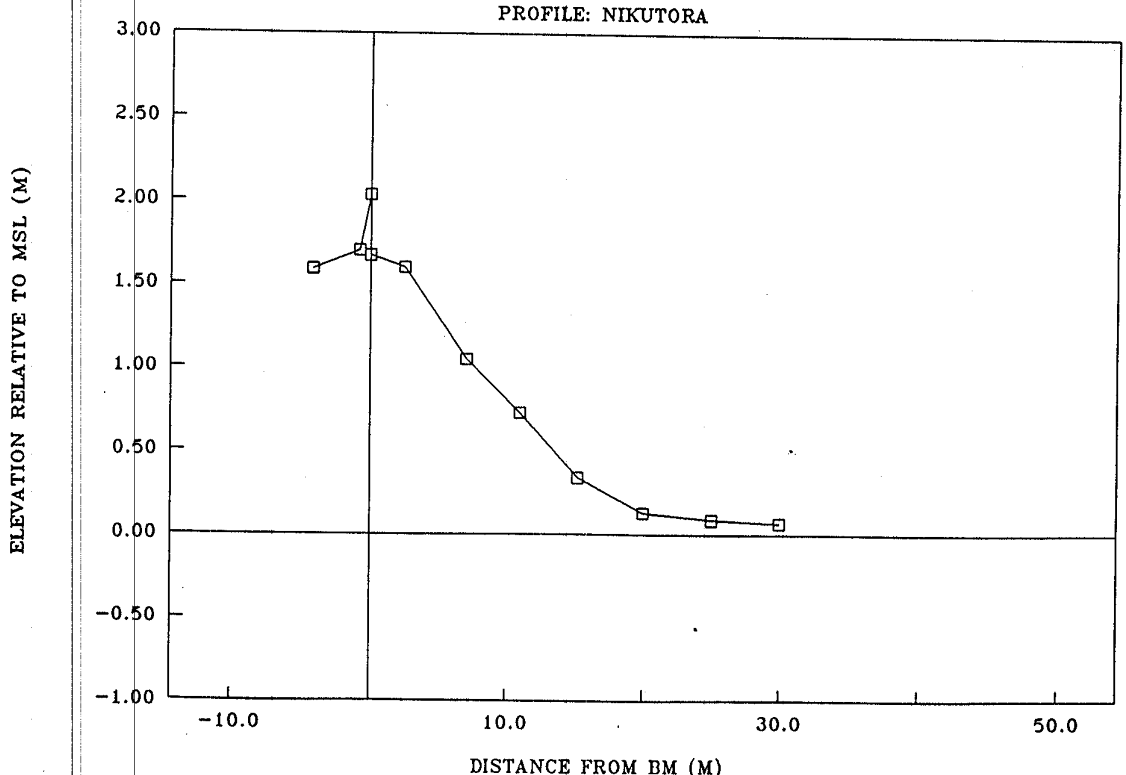
BEARING = 206 MN

ELEVATION CORRECTION TO MSL = 1.67

DIST	ELE REL	ELE ABS	REMARKS
-4.2	-0.08	1.59	GROUND BESIDE MANEABA WALL
-0.8	0.03	1.70	BASE OF WOOD FENCE
0.0	0.36	2.03	NAIL IN COCONUT TREE
0.0	0.00	1.67	GROUND BENEARTH NAIL
2.5	-0.07	1.60	MAXIMUM HIGH WATER MARK
7.1	-0.62	1.05	LAST HIGH TIDE LEVEL
11.0	-0.94	0.73	BEACH
15.2	-1.33	0.34	WATER LINE AT 15:06
20.0	-1.54	0.13	REEF FLAT, SAND
25.0	-1.58	0.09	REEF FLAT, SAND
30.0	-1.60	0.07	REEF FLAT, SAND

TABITEUEA SOUTH, NIKUTORA MANEABA

PROFILE: NIKUTORA

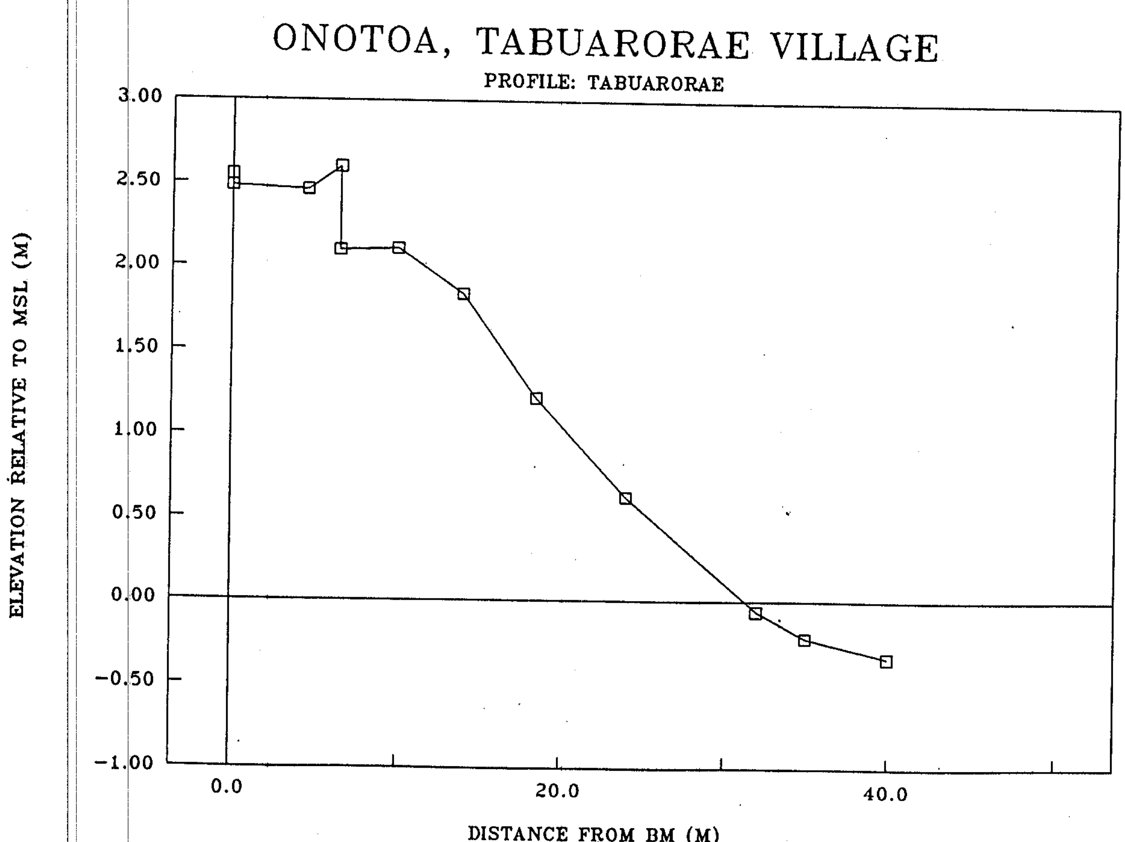


ISLAND: ONOTOA
SITE: TABUARORAE VILLAGE
PROFILE: TABUARORAE
DATE: 13/08/92

BEARING = 297 MN

ELEVATION CORRECTION TO MSL = 2.48

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.07	2.55	BM, CONCRETE FOOT OF ROCK PILLAR
0.0	0.00	2.48	STONES BESIDE FOOT OF PILLAR
4.5	-0.02	2.46	STONES ON GROUND
6.5	0.12	2.60	TOP OF SEAWALL
6.5	-0.38	2.10	BASE OF SEAWALL / TOP OF BEACH
10.0	-0.37	2.11	BEACH
14.0	-0.64	1.84	HIGH TIDE MARK
18.5	-1.26	1.22	BEACH
24.0	-1.85	0.63	BEACH
32.0	-2.54	-0.06	BOTTOM OF BEACH (WATERLINE AT 13:45)
35.0	-2.70	-0.22	REEF FLAT
40.0	-2.82	-0.34	REEF FLAT



ISLAND: NONOUTI
SITE: TEMOTU ISLAND, SITE 2, TETABAKEA
PROFILE: TETABAKEA
DATE: 14/08/92

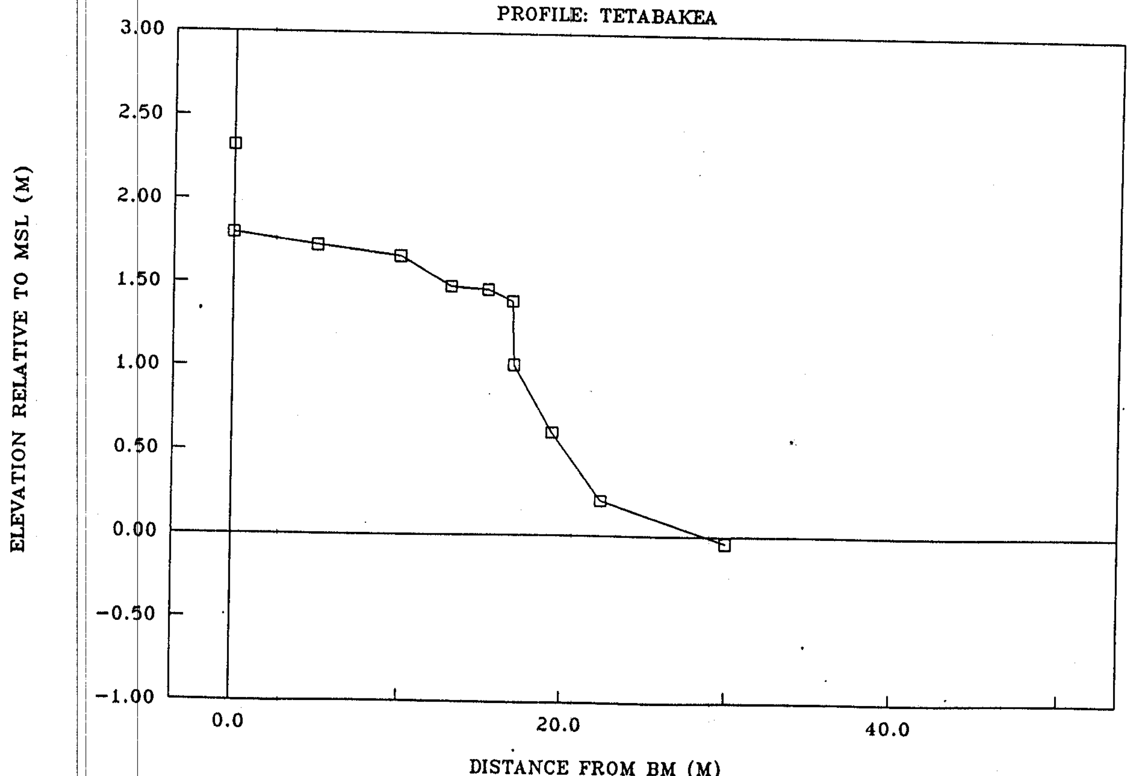
BEARING = 308 MN

ELEVATION CORRECTION TO MSL = 1.8

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.52	2.32	BM, NAIL IN COCONUT TREE
0.0	0.00	1.80	GROUND BESIDE TREE
5.0	-0.07	1.73	GROUND BETWEEN TREE AND ROAD
10.0	-0.13	1.67	GROUND BETWEEN TREE AND ROAD
13.1	-0.31	1.49	LANDWARD SIDE OF ROAD
15.4	-0.33	1.47	SEAWARD SIDE OF ROAD
16.9	-0.40	1.40	TOP OF EROSION SCARP
17.0	-0.78	1.02	BOTTOM OF EROSION SCARP
19.4	-1.18	0.62	MIDDLE OF BEACH AT HIGH TIDE LEVEL
22.4	-1.59	0.21	BOTTOM OF BEACH
30.0	-1.84	-0.04	REEF FLAT

NONOUTI, TEMOTU ISLAND, SITE 2

PROFILE: TETABAKEA

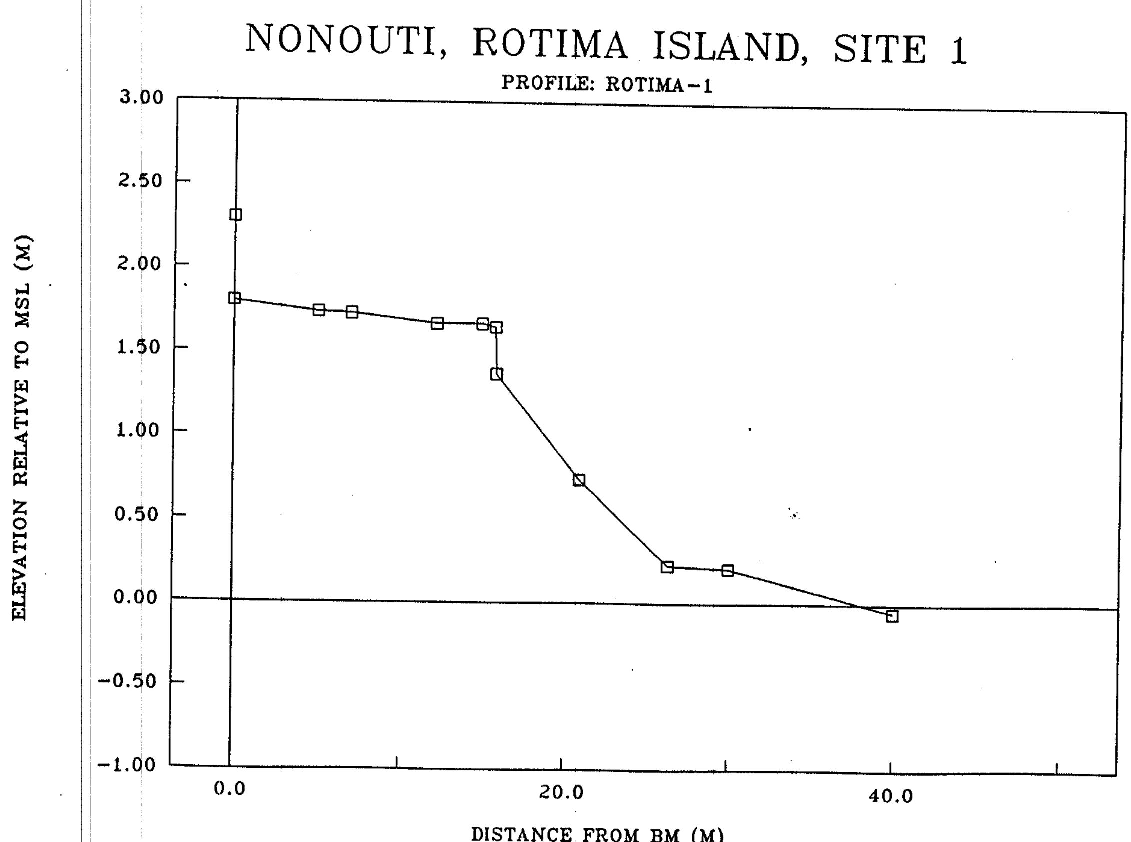


ISLAND: NONOUTI
SITE: ROTIMA ISLAND, SITE 1, ROAD BESIDE AIRFIELD
PROFILE: ROTIMA - 1
DATE: 15/08/92

BEARING = 191 MN

ELEVATION CORRECTION TO MSL = 1.8

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.50	2.30	BM, NAIL IN COCONUT TREE
0.0	0.00	1.80	GROUND BESIDE TREE
5.0	-0.06	1.74	GROUND BETWEEN TREE AND ROAD
7.0	-0.07	1.73	GROUND BETWEEN TREE AND ROAD
12.2	-0.13	1.67	LANDWARD SIDE OF ROAD
15.0	-0.13	1.67	SEAWARD SIDE OF ROAD
15.8	-0.15	1.65	TOP OF EROSION SCARP
15.9	-0.43	1.37	BOTTOM OF EROSION SCARP
20.9	-1.06	0.74	MID BEACH FORMER SEA WALL
26.3	-1.57	0.23	BOTTOM OF BEACH
30.0	-1.59	0.21	REEF FLAT, SAND
40.0	-1.85	-0.05	REEF FLAT, SAND



ISLAND: NONOUTI
SITE: ROTIMA ISLAND, SITE 1, AIRFIELD
PROFILE: ROTIMA - 2
DATE: 15/08/92

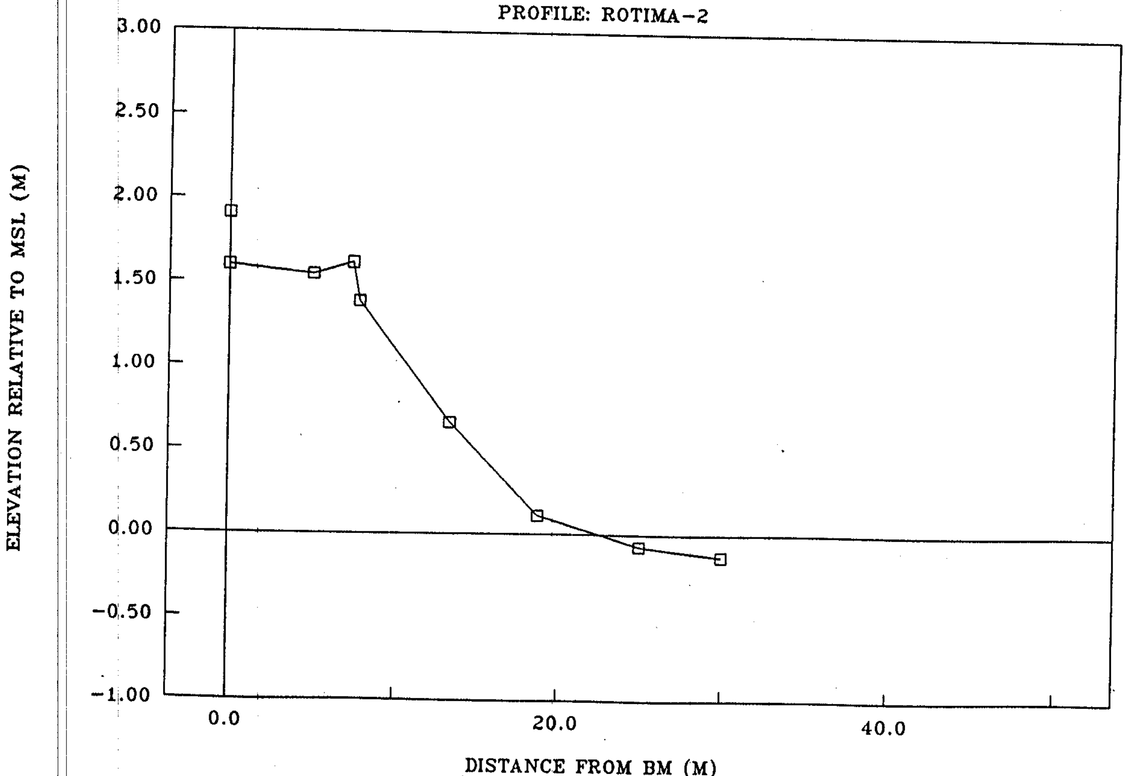
BEARING = 200 MN

ELEVATION CORRECTION TO MSL = 1.6

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.31	1.91	BM, NAIL IN COCONUT TREE
0.0	0.00	1.60	GROUND BESIDE TREE
5.0	-0.05	1.55	FOREWARD COCONUT TREE
7.4	0.02	1.62	TOP OF EROSION SCARP
7.8	-0.21	1.39	BOTTOM OF SCARP / TOP OF BEACH
13.4	-0.93	0.67	MIDDLE OF BEACH
18.8	-1.49	0.11	BOTTOM OF BEACH
25.0	-1.67	-0.07	REEF FLAT, SAND
30.0	-1.73	-0.13	REEF FLAT, SAND

NONOUTI, ROTIMA ISLAND, SITE 2

PROFILE: ROTIMA-2

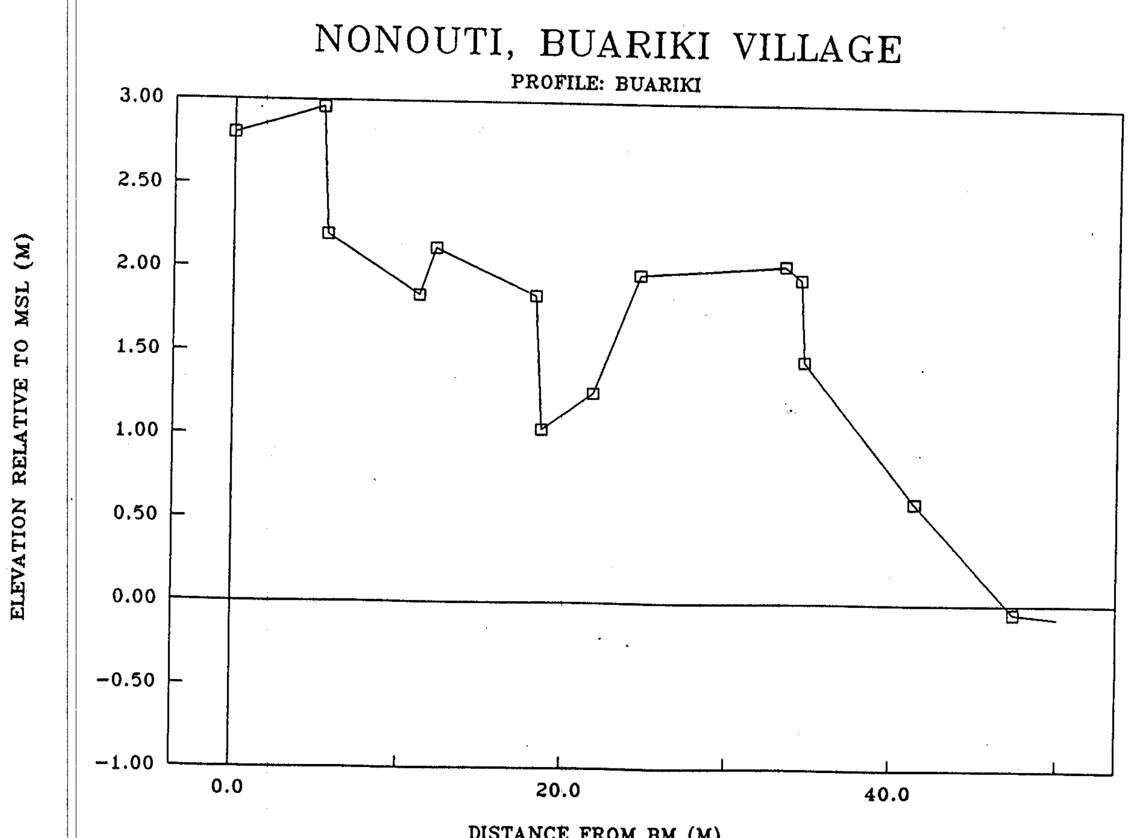


ISLAND: NONOUTI
SITE: BUARIKI VILLAGE
PROFILE: BUARIKI
DATE: 15/08/92

BEARING = 211 MN

ELEVATION CORRECTION TO MSL = 2.8

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.41	3.21	BM, NAIL IN COCONUT TREE
0.0	0.00	2.80	GROUND BESIDE TREE
5.3	0.16	2.96	EDGE OF BURROW PIT
5.6	-0.60	2.20	BOTTOM OF BURROW PIT
11.2	-0.96	1.84	EDGE OF BORROW PIT
12.2	-0.68	2.12	SANDBAGS AT LANDWARD SIDE OF ROAD
18.3	-0.96	1.84	SANDBAGS AT SEAWARD SIDE OF ROAD
18.7	-1.76	1.04	BOTTOM OF PIT
21.8	-1.54	1.26	BOTTOM OF SEAWARD SITE OF PIT
24.6	-0.83	1.97	TOP OF PIT SEAWARD SIDE
33.5	-0.77	2.03	CENTRE OF OLD ROAD
34.5	-0.85	1.95	TOP OF EROSION SCARP / EDGE OF ROAD
34.7	-1.34	1.46	BOTTOM OF SCARP
41.4	-2.19	0.61	MIDDLE OF BEACH, REMAINS OF SANDBAG SEAWALL
47.4	-2.85	-0.05	BOTTOM OF BEACH
55.0	-2.93	-0.13	REEF FLAT



ISLAND: ABEMAMA
SITE: TANIMAINIKU
PROFILE: TANIMAINIKU-1
DATE: 17/08/92

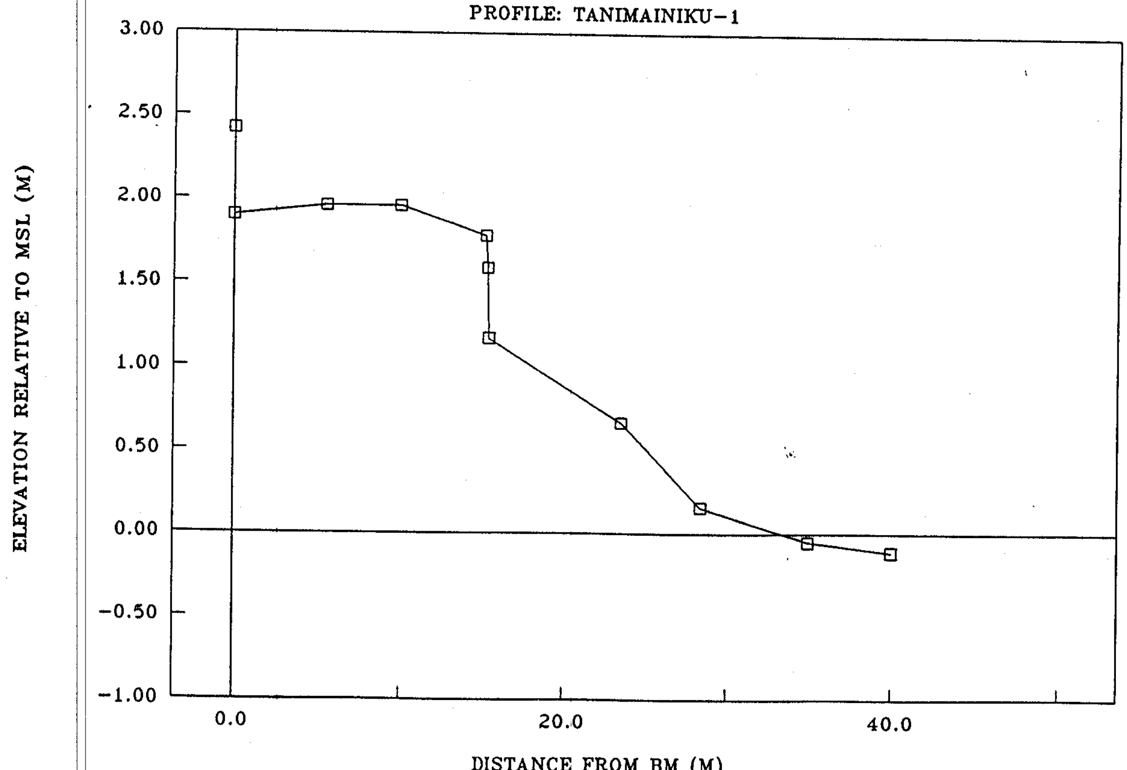
BEARING = 206 MN

ELEVATION CORRECTION TO MSL = 1.9

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.52	2.42	BM, NAIL IN COCONUT TREE
0.0	0.00	1.90	GROUND BESIDE TREE
5.5	0.06	1.96	LANDWARD EDGE OF THE ROAD
10.0	0.06	1.96	SEAWARD EDGE OF THE ROAD
15.3	-0.12	1.78	TOP OF EROSION SCARP
15.4	-0.31	1.59	BOTTOM OF SCARP / TOP OF BEACH
15.5	-0.73	1.17	BEACH BERM
23.5	-1.23	0.67	MIDDLE OF BEACH
28.4	-1.74	0.16	BOTTOM OF BEACH
35.0	-1.95	-0.05	REEF FLAT, SAND
40.0	-2.01	-0.11	REEF FLAT, SAND

ABEMAMA, TANIMAINIKU

PROFILE: TANIMAINIKU-1

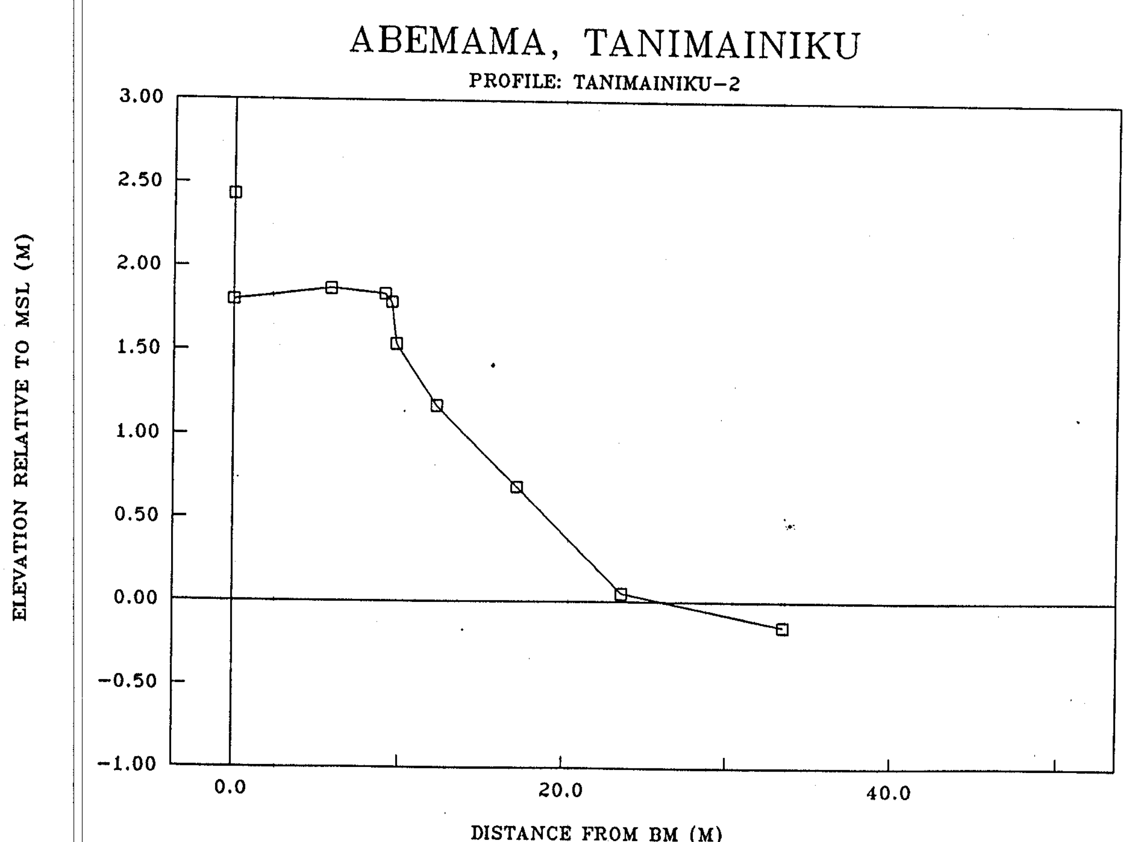


ISLAND: ABEMAMA
SITE: TANIMAINIKU
PROFILE: TANIMAINIKU-2
DATE: 17/08/92

BEARING = 206 MN

ELEVATION CORRECTION TO MSL = 1.8

DIST	ELE REL	ELE ABS	REMARKS
0.0	0.63	2.43	BM, NAIL IN COCONUT TREE
0.0	0.00	1.80	GROUND BESIDE TREE
5.8	0.07	1.87	LANDWARD EDGE OF THE ROAD
9.1	0.04	1.84	SEAWARD EDGE OF THE ROAD
9.5	-0.01	1.79	TOP OF EROSION SCARP
9.8	-0.26	1.54	BOTTOM OF EROSION SCARP / SEAWALL
12.3	-0.63	1.17	BOTTOM OF REMAINS OF SEAWALL / BEACH
17.2	-1.11	0.69	MIDDLE OF BEACH
23.6	-1.75	0.05	BOTTOM OF BEACH
33.5	-1.95	-0.15	REEF FLAT, SAND

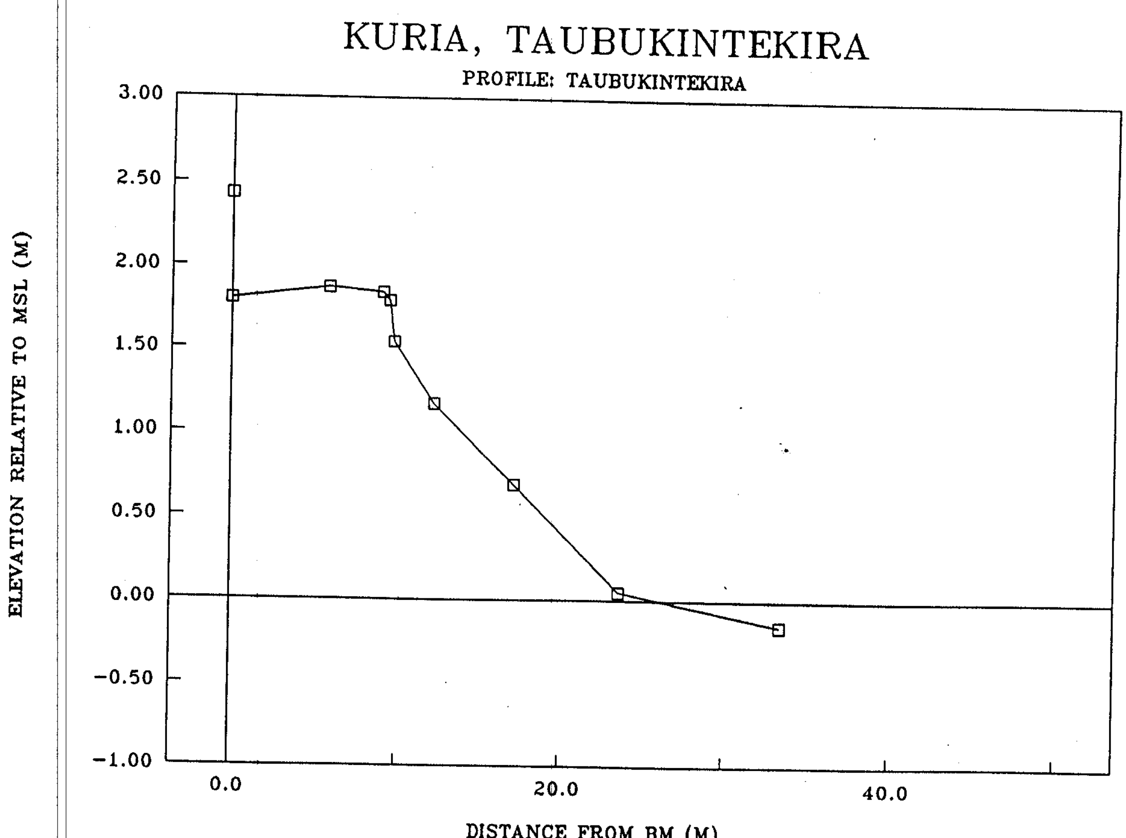


ISLAND: KURIA
SITE: TAUBUKINTEKIRA
PROFILE: TAUBUKINTEKIRA
DATE: 18/08/92

BEARING = SEAWARD

ELEVATION CORRECTION TO MSL = 2.86

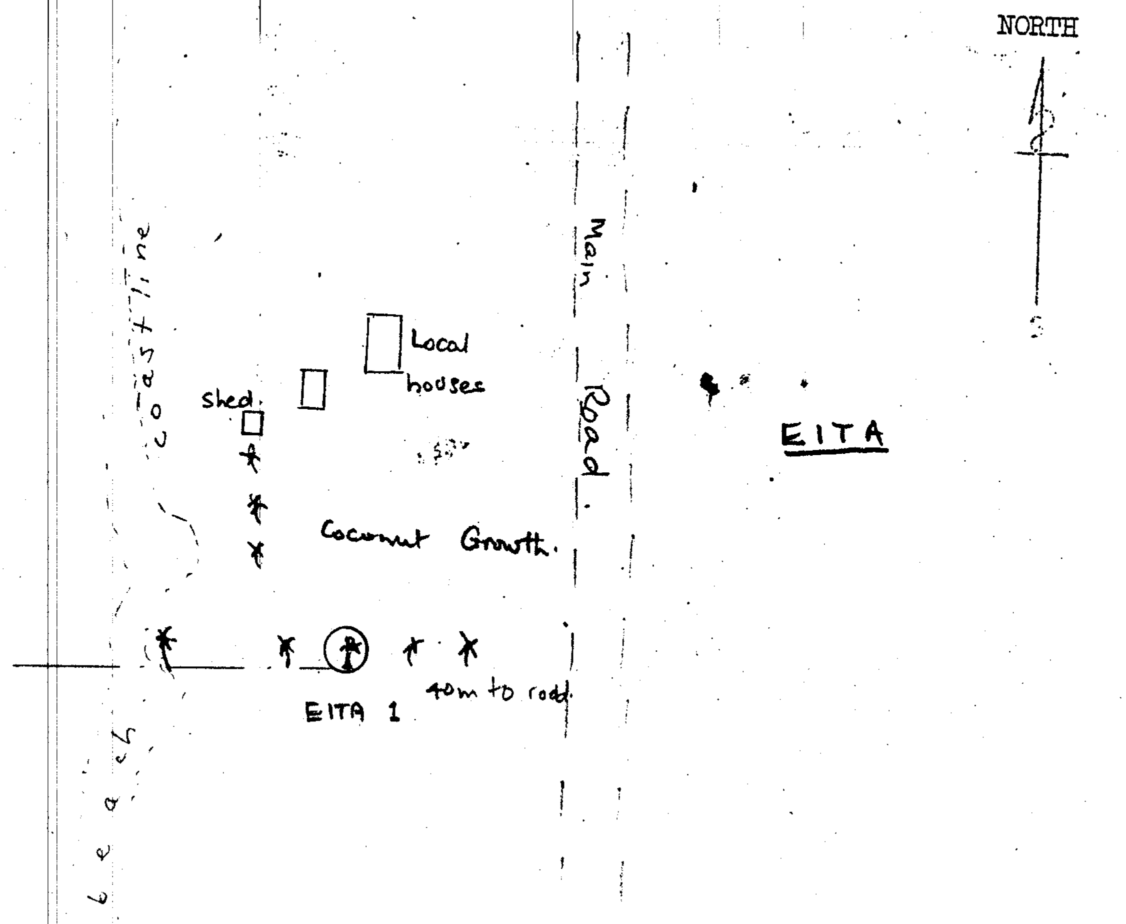
DIST	ELE REL	ELE ABS	REMARKS
0.0	0.09	2.95	BM, ALUMINUM NAIL IN CONCRETE MONUMENT K 149
0.0	0.00	2.86	GROUND BESIDE CONCRETE MONUMENT
2.0	0.12	2.98	LANDWARD EDGE OF ROAD
5.4	0.16	3.02	SEAWARD EDGE OF ROAD
6.5	0.33	3.19	CORAL RUBBLE
10.0	0.33	3.19	CORAL RUBBLE
11.2	0.03	2.89	TOP OF EROSION SCARP
11.3	-0.51	2.35	BOTTOM OF SCARP / TOP OF SAND BEACH
16.6	-0.71	2.15	BEACH BERM / SAND AND CORAL RUBBLE
24.0	-1.50	1.36	MIDDLE OF BEACH
35.1	-2.75	0.11	BOTTOM OF BEACH (WATER LINE AT 16:24)
42.0	-2.87	-0.01	REEF FLAT



APPENDIX 3

BEACH PROFILE BENCH MARK DESCRIPTIONS

LOCATION DIAGRAM



NOT TO SCALE TABITEUEA NORTH

NOTES:

CONTROL MARK NO: EITA / 1

LOCATION : 100m north of village Maneaba at Tarawa (Tab Nth)

DESCRIPTION: Galvanised nail in coconut tree approx. 12m behind beach (circled above) along line of trees. (sth. side of coconut tree)

REFERENCES:

S.R. NO:

SHEET NO:

HEIGHT:

CO-ORDINATES:(E): (N):

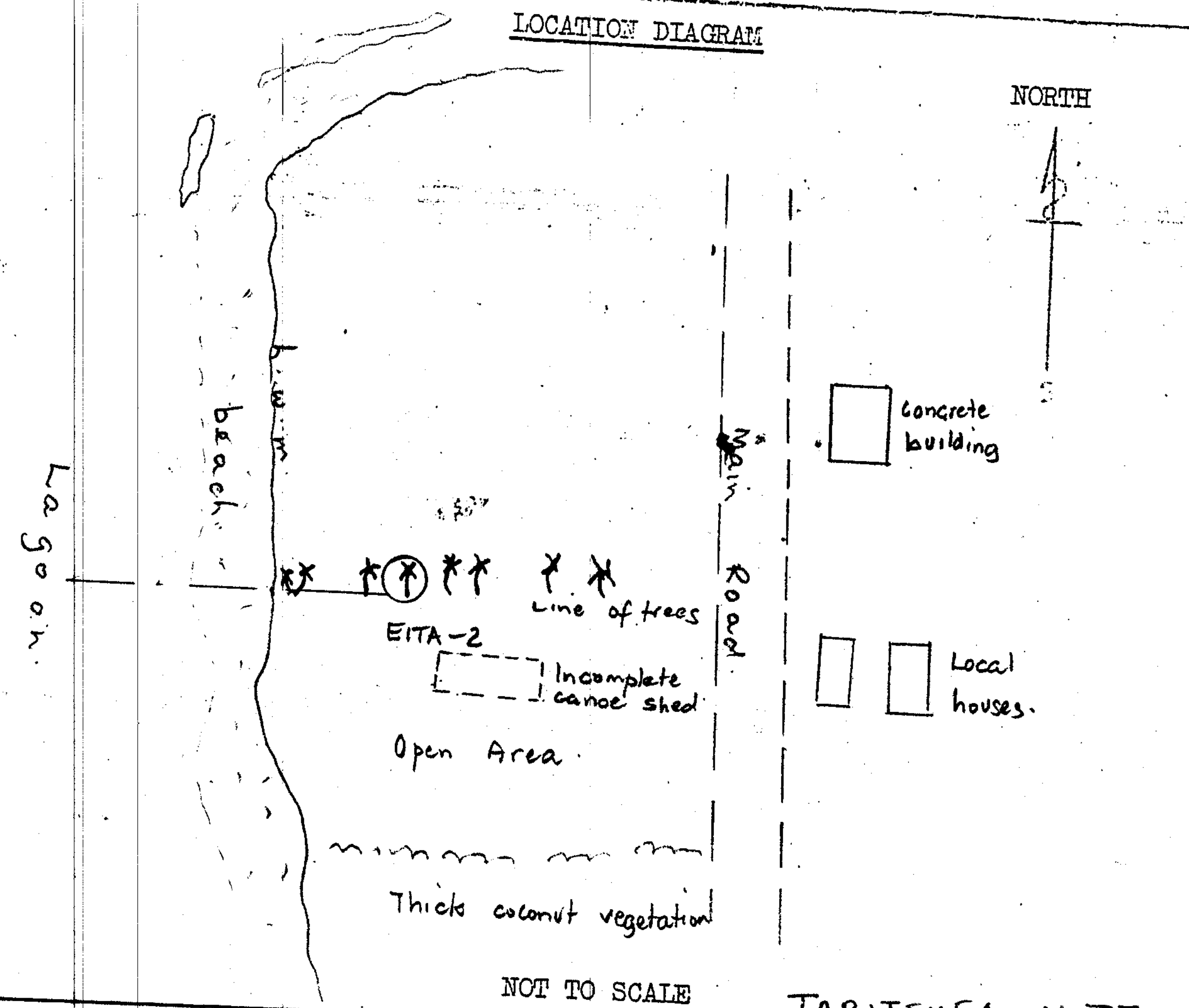
ESTABLISHED BY: R. Gillis + Amberoti 10 - 8 - 92
DATE

REPLACED BY:
DATE

GENERAL INFO:

OFFICE SURVEYOR

LOCATION DIAGRAM



NOT TO SCALE TABITEUEA NORTH

NOTES:

CONTROL MARK NO: EITA - 2 (TAB. NTH).

LOCATION : 80m SW of brick house - 2m from shoreline along line of trees.

DESCRIPTION: Galvanised nail in coconut tree (circled above) 0.35m above Grd. level - (1/2 an inch poking out). (SW side of tree)

REFERENCES:

S.R. NO:

SHEET NO:

HEIGHT:

CO-ORDINATES: (E): (N):

ESTABLISHED BY: Dr. R. Gillie + Amberoti 10 - 8 - 92.
DATE

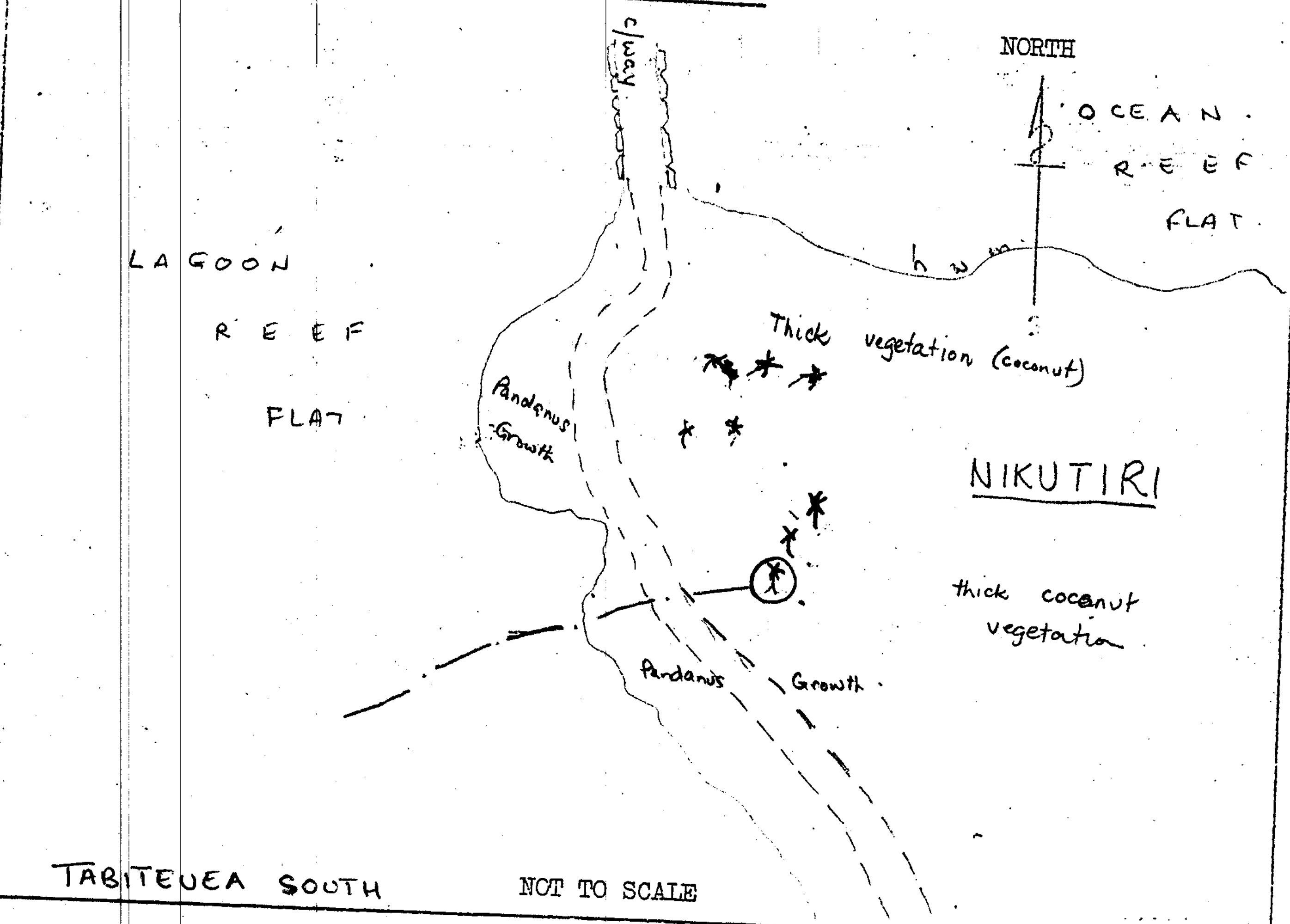
REPLACED BY:
DATE

GENERAL INFO:

OFFICE

SURVEYOR

LOCATION DIAGRAM



TABITEUEA SOUTH NOT TO SCALE

NOTES:

CONTROL MARK NO: NIKUTIRI (TAB. STH).

LOCATION : About 150m south of c/way between Nikutiri & Taungaeaka

DESCRIPTION: Galv. Nail in coconut tree approx. a foot above grd level. Approx. 20 m east of existing road and 30m to hwm nearest to most eroded site. (Nth side of tree).

REFERENCES:

S.R. NO: ....

SHEET NO: ....

HEIGHT: ....

CO-ORDINATES: (E): .... (N): ....

ESTABLISHED BY: AMBEROTI + Dr. Rick 11-8-92
DATE

REPLACED BY: ....
DATE

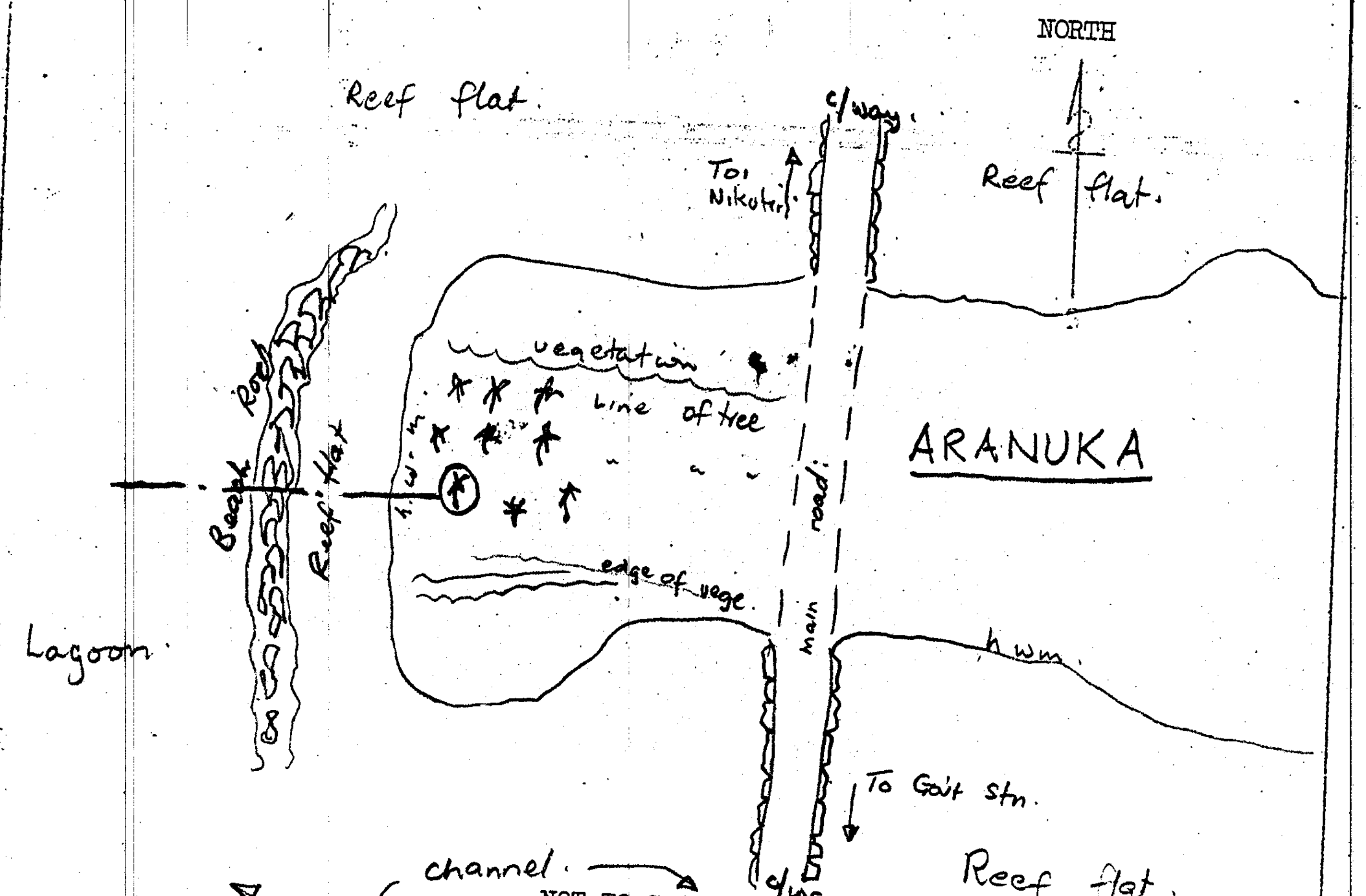
GENERAL INFO: ....

.... OFFICE

.... SURVEYOR

TABITEUEA SOUTH

LOCATION DIAGRAM



NOT TO SCALE

NOTES:

CONTROL MARK NO: ....ARANUKA.................(TAB. STH)

LOCATION : 10 m. from hwm. roughly half way along Lagoon shore of Aranuka.

DESCRIPTION: Galv. Nail in coconut tree (Sth. side) a foot above grd. level and approx. 250 m. to the existing road.

....

REFERENCES:

S.R. NO: ....

SHEET NO: ....

HEIGHT: ....

CO-ORDINATES: (E): .... (N): ....

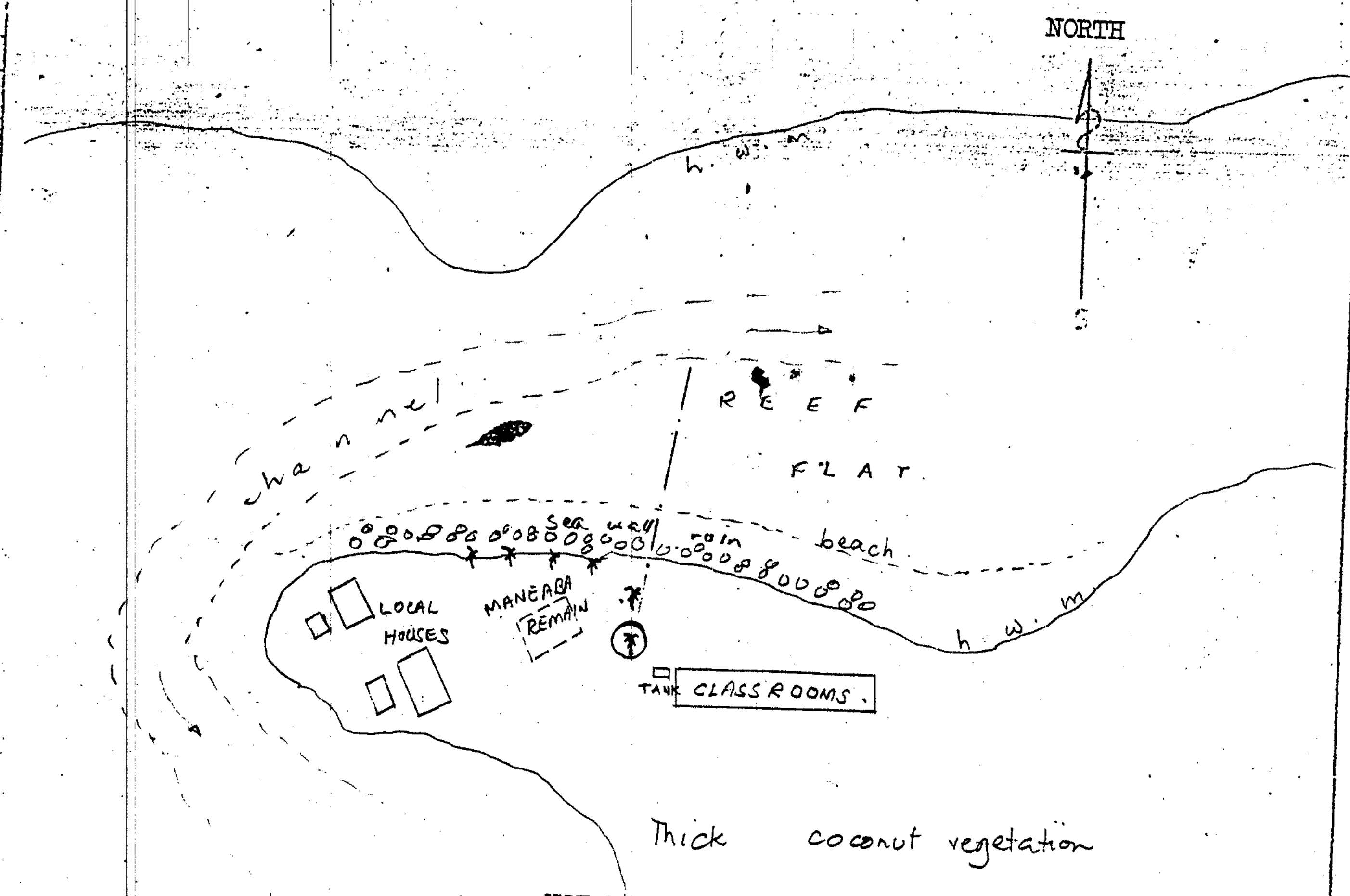
ESTABLISHED BY: Amberolz + Reck .... 11 - 8 - 92.
DATE

REPLACED BY: ....
DATE

GENERAL INFO: ....
....
....

....
OFFICE SURVEYOR

LOCATION DIAGRAM



NOT TO SCALE TABITEUEA SOUTH

NOTES:

CONTROL MARK NO: TEWAI (TAB. STH).

LOCATION : Northern tip of Tewai village

DESCRIPTION: Galvanised nail on west side of a coconut tree approx. 5m from NW corner classroom block

REFERENCES:

S.R. NO:

SHEET NO:

HEIGHT:

CO-ORDINATES: (E): (N):

ESTABLISHED BY: Rick and Gillie 12 - 8 - 92
DATE

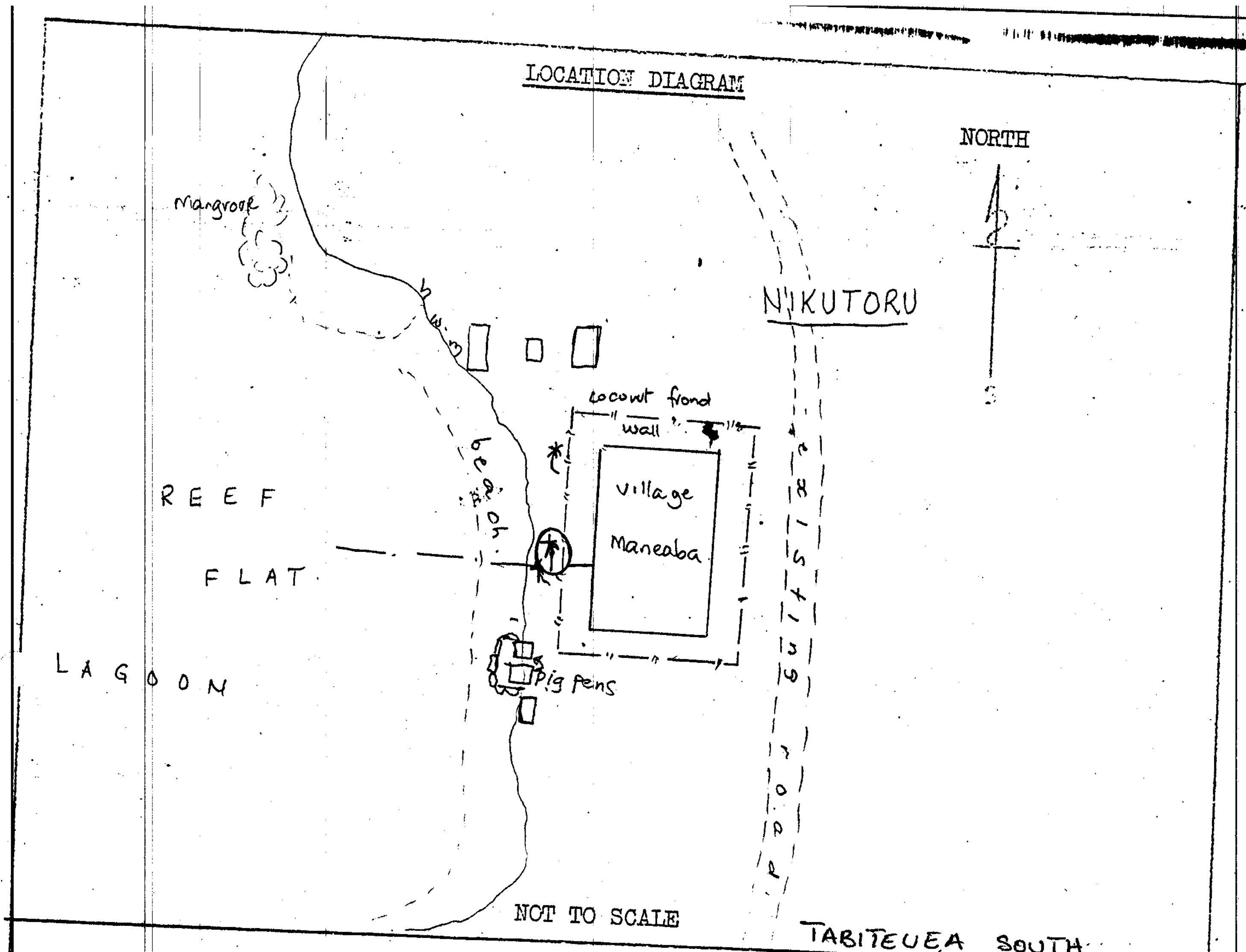
REPLACED BY:
DATE

GENERAL INFO:

OFFICE

SURVEYOR

LOCATION DIAGRAM



NOTES:

CONTROL MARK NO: ...NIKUTORU............(TAB. STH).

LOCATION : Lagoon side of village Maneaba along wall of fence.

DESCRIPTION: Galv. Nail on Sth side of coconut tree at near hwm.

....

....

REFERENCES:

S.R. NO: ....

SHEET NO: ....

HEIGHT: ....

CO-ORDINATES:(E): .... (N): ....

ESTABLISHED BY: Rickie and Amberoti .... 12 - 8 - 92

DATE

REPLACED BY: ....

DATE

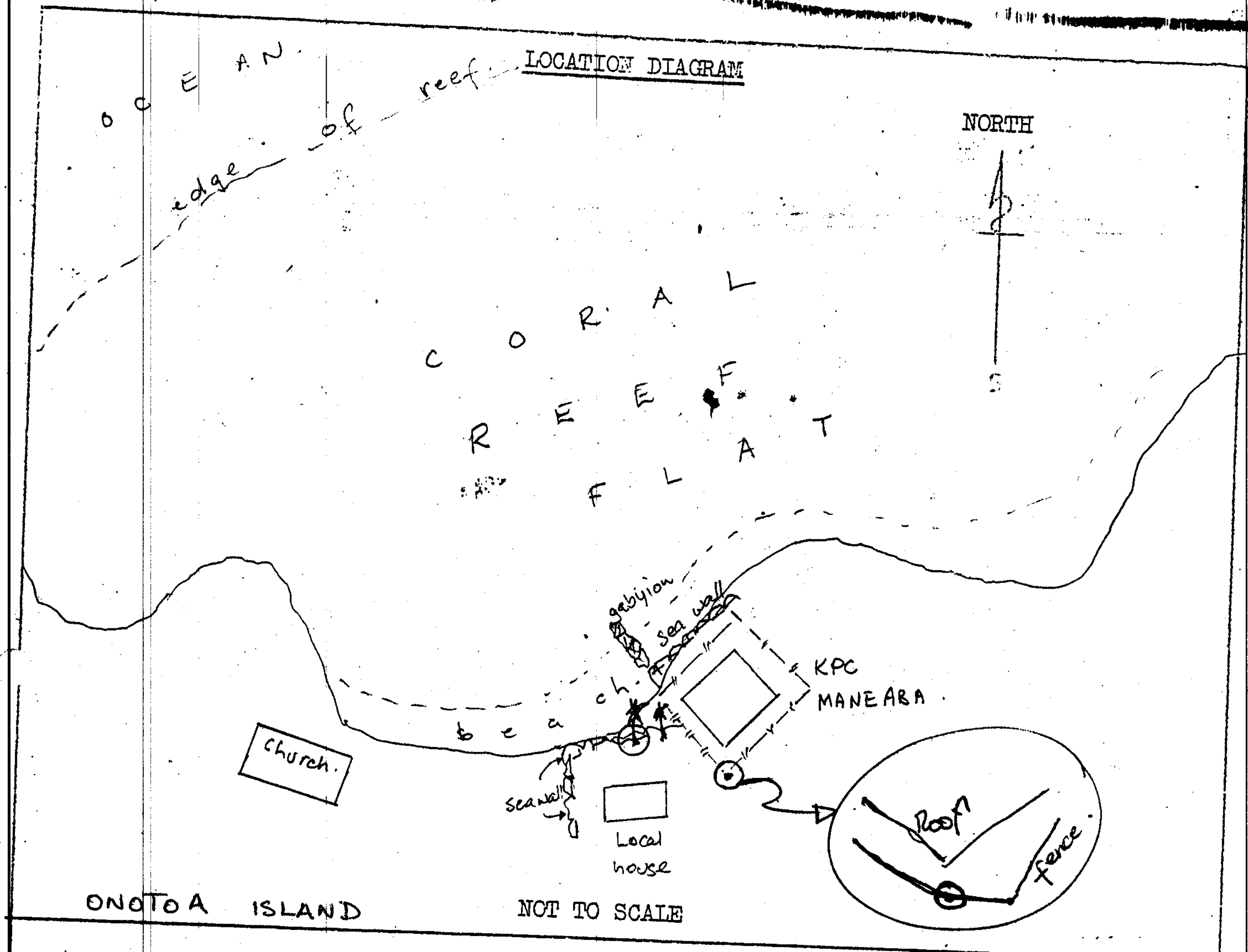
GENERAL INFO: ....

....

....

....

OFFICE SURVEYOR



NOTES:

CONTROL MARK NO: TABUARORA E

LOCATION: ~~South~~ SW corner of KPC fence of Maneaba

DESCRIPTION: Concrete foot ~~at~~ at base of ~~concrete~~ CORAL pillar on south corner of fence

REFERENCES:

S.R. NO:

SHEET NO:

HEIGHT:

CO-ORDINATES:(E): (N):

ESTABLISHED BY: A. Nikora 13/08/92

DATE

REPLACED BY:

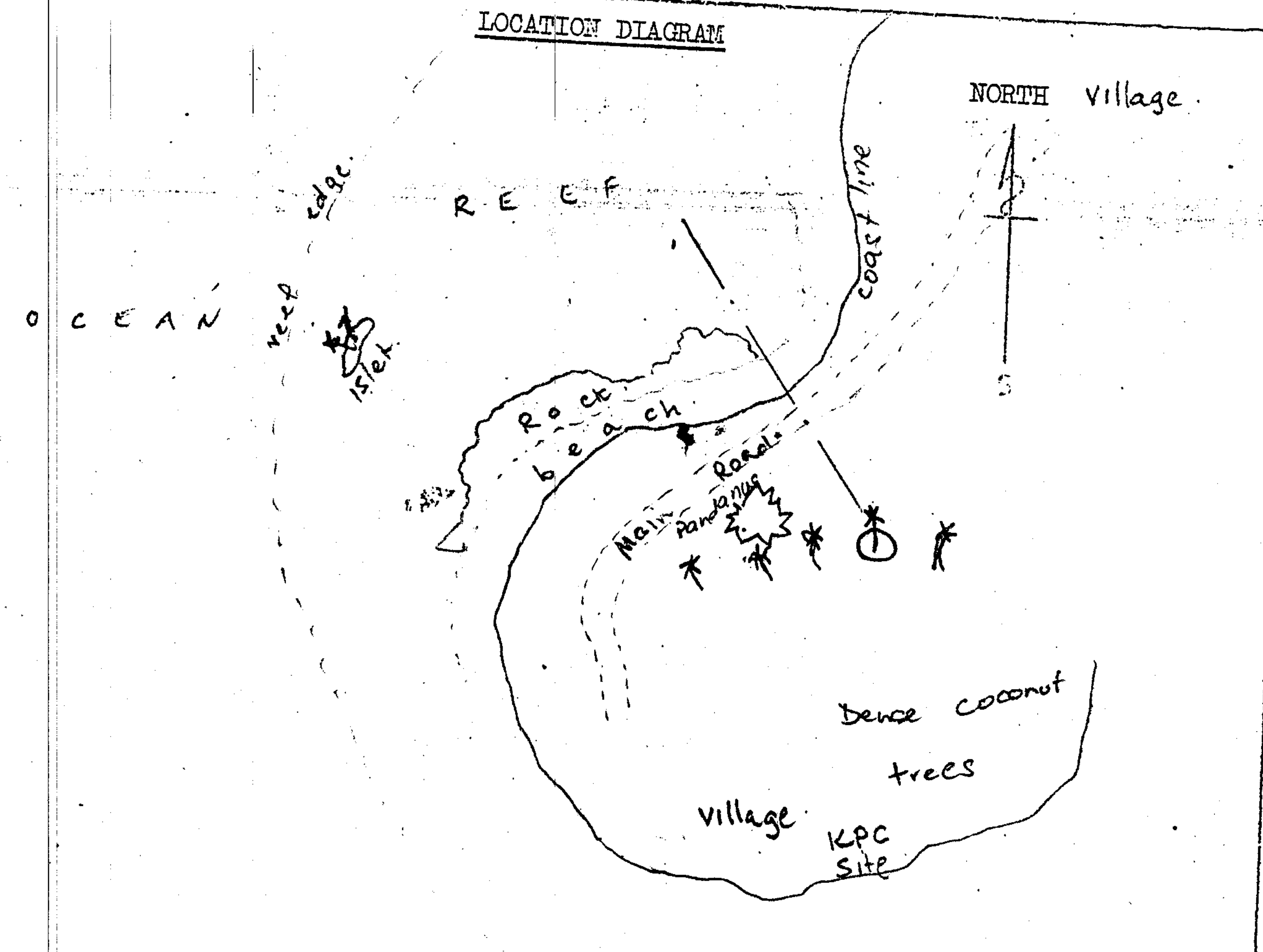
DATE

GENERAL INFO:

OFFICE

SURVEYOR

LOCATION DIAGRAM



NOT TO SCALE NONOUTI ISLAND

NOTES:

CONTROL MARK NO: TEMOTU

LOCATION : NW coast of Temotu

DESCRIPTION: Galvanised Nail in NE side of coconut tree ~~around~~ between KPC site and village Manoaba

REFERENCES:

S.R. NO:

SHEET NO:

HEIGHT:

CO-ORDINATES: (E): (N):

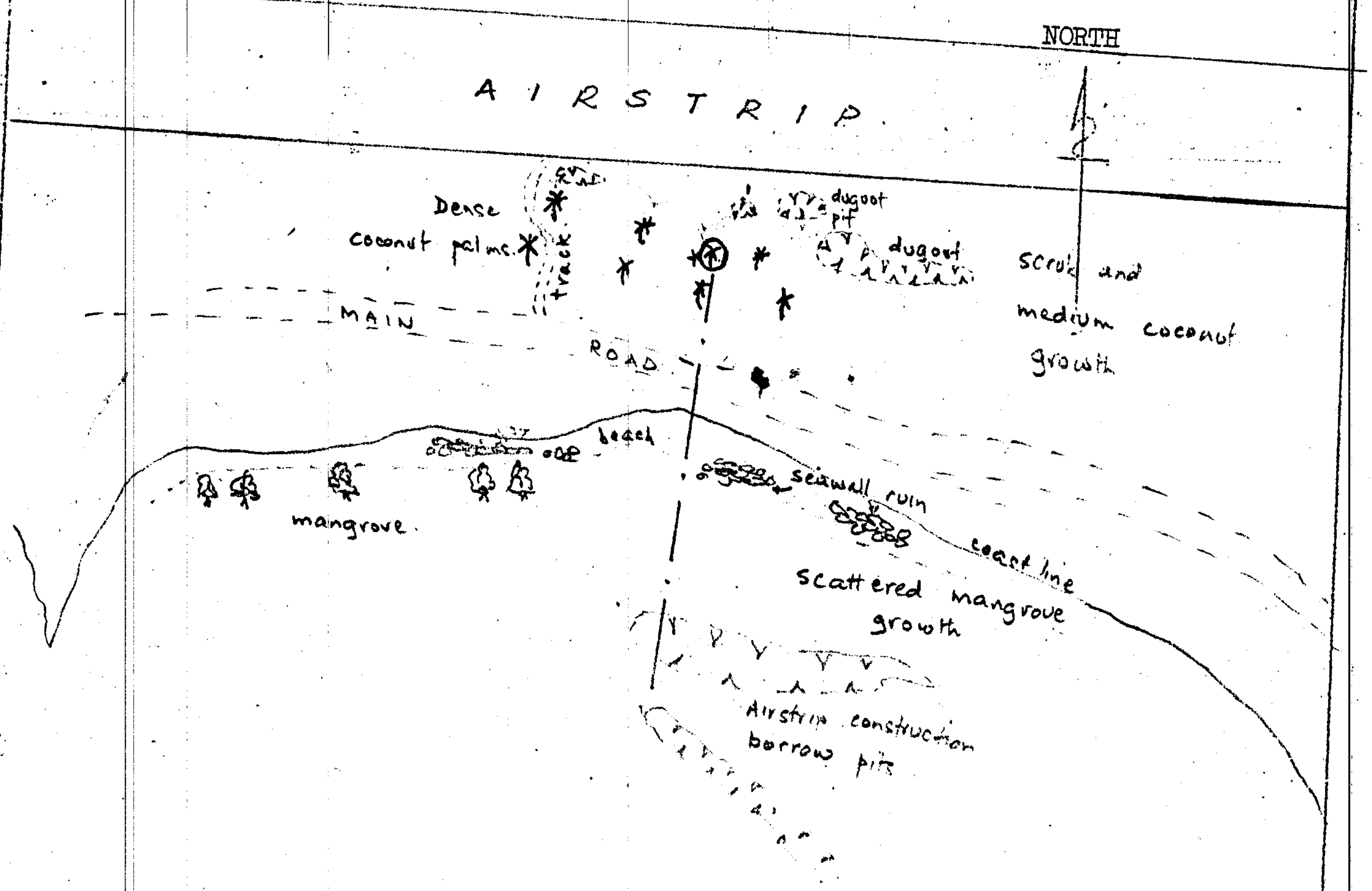
ESTABLISHED BY: Amberoti + Rich 14 - 08 - 92
DATE

REPLACED BY:
DATE

GENERAL INFO:

OFFICE SURVEYOR

LOCATION DIAGRAM



NOT TO SCALE NONOUTI ISLAND

NOTES:

CONTROL MARK NO: ROTIMA — 1

LOCATION : Immediately south of Airstrip

DESCRIPTION: Galv. nail in east side of coconut tree " ~~adj.~~ south of half way of airstrip approx. a foot above grd. and 15m from coastline

REFERENCES:

S.R. NO: ....

SHEET NO: ....

HEIGHT: ....

CO-ORDINATES: (E): .... (N): ....

ESTABLISHED BY: Amberoti Nikora 15 - 08 - 92
DATE

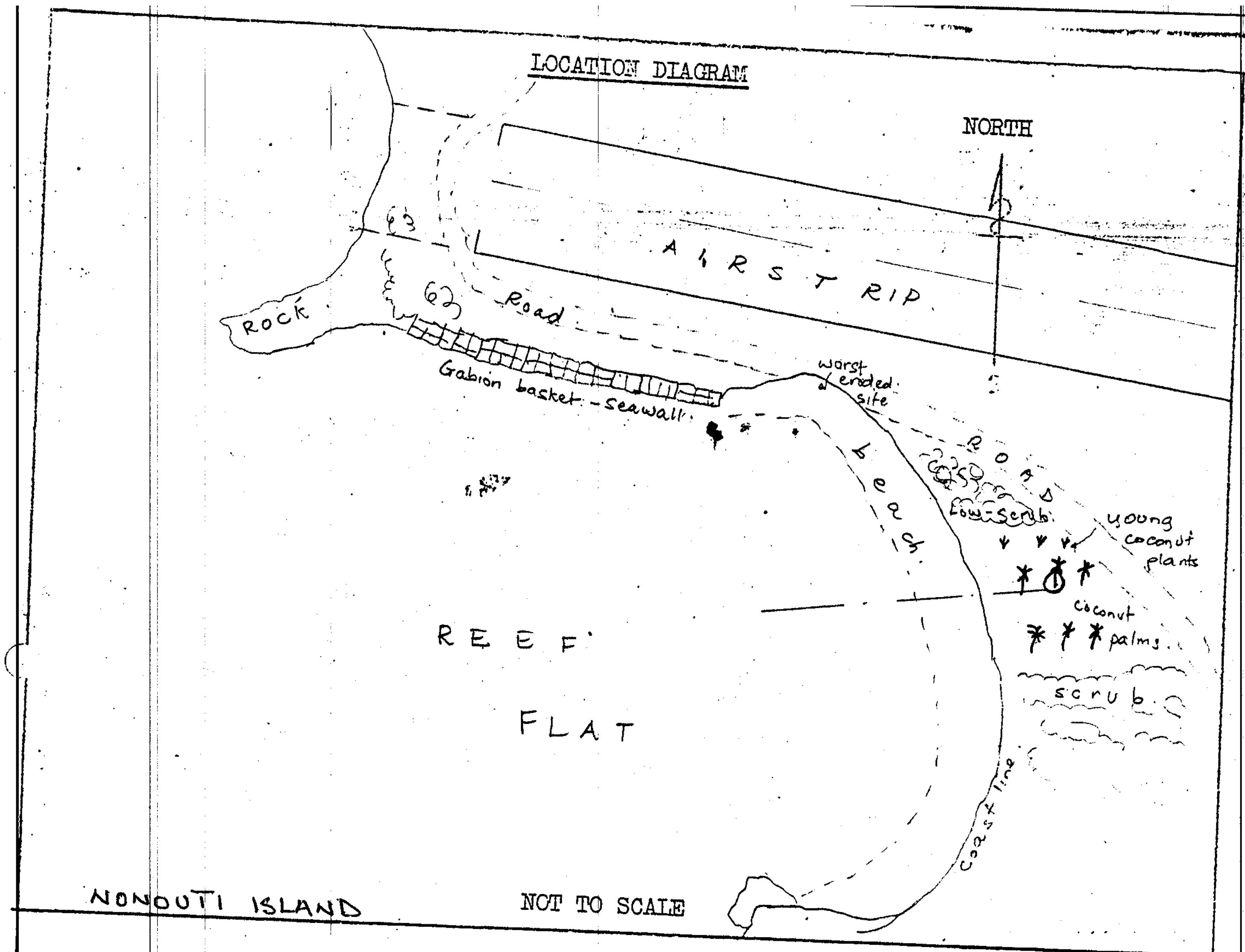
REPLACED BY: ....
DATE

GENERAL INFO: ....

....
OFFICE

....
SURVEYOR

LOCATION DIAGRAM



NONOUTI ISLAND NOT TO SCALE

NOTES:

CONTROL MARK NO: ROTIMA - 2

LOCATION : 150m from west end of strip

DESCRIPTION: Galv. Nail on NW side of second coconut tree from coastline and approx. 80m from end of seawall and 40m from south edge of airstrip.

REFERENCES:

S.R. NO:

SHEET NO:

HEIGHT:

CO-ORDINATES: (E): .... (N): ....

ESTABLISHED BY: Amberoti Nikora 15 - 08 - 92
DATE

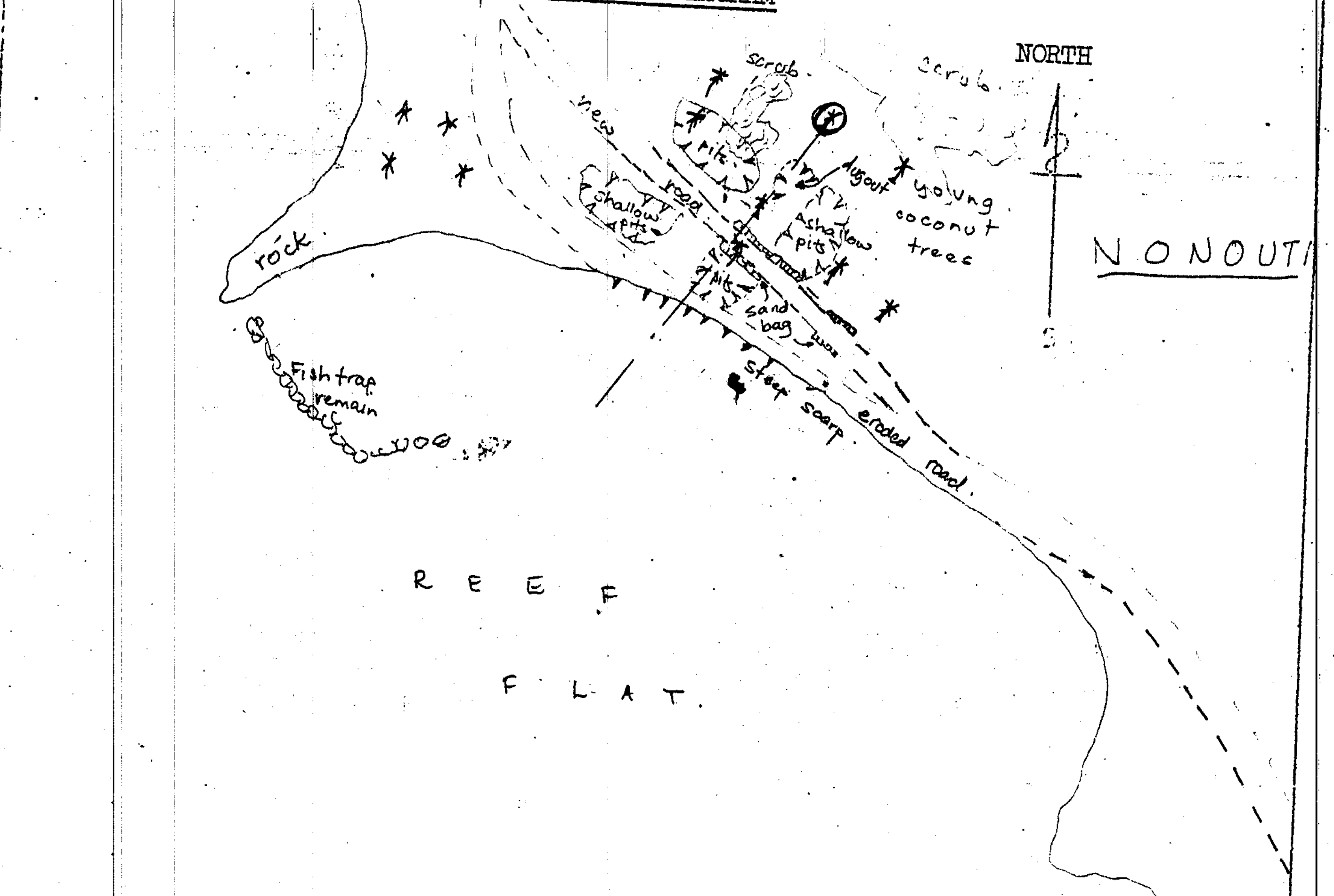
REPLACED BY: ....
DATE

GENERAL INFO:

....
OFFICE

....
SURVEYOR

LOCATION DIAGRAM



NOT TO SCALE

NOTES:

CONTROL MARK NO: BUARIKI

LOCATION: NORTH END OF POTIMA ISLAND

DESCRIPTION: BM. NAIL IN TREE ~~2m~~ LANDWARD OF BORROW PIT BEHIND NEW ROAD.

REFERENCES:

S.R. NO:

SHEET NO:

HEIGHT:

CO-ORDINATES: (E): (N):

ESTABLISHED BY: AMBEROTI NIKORA — 15/08/92 DATE

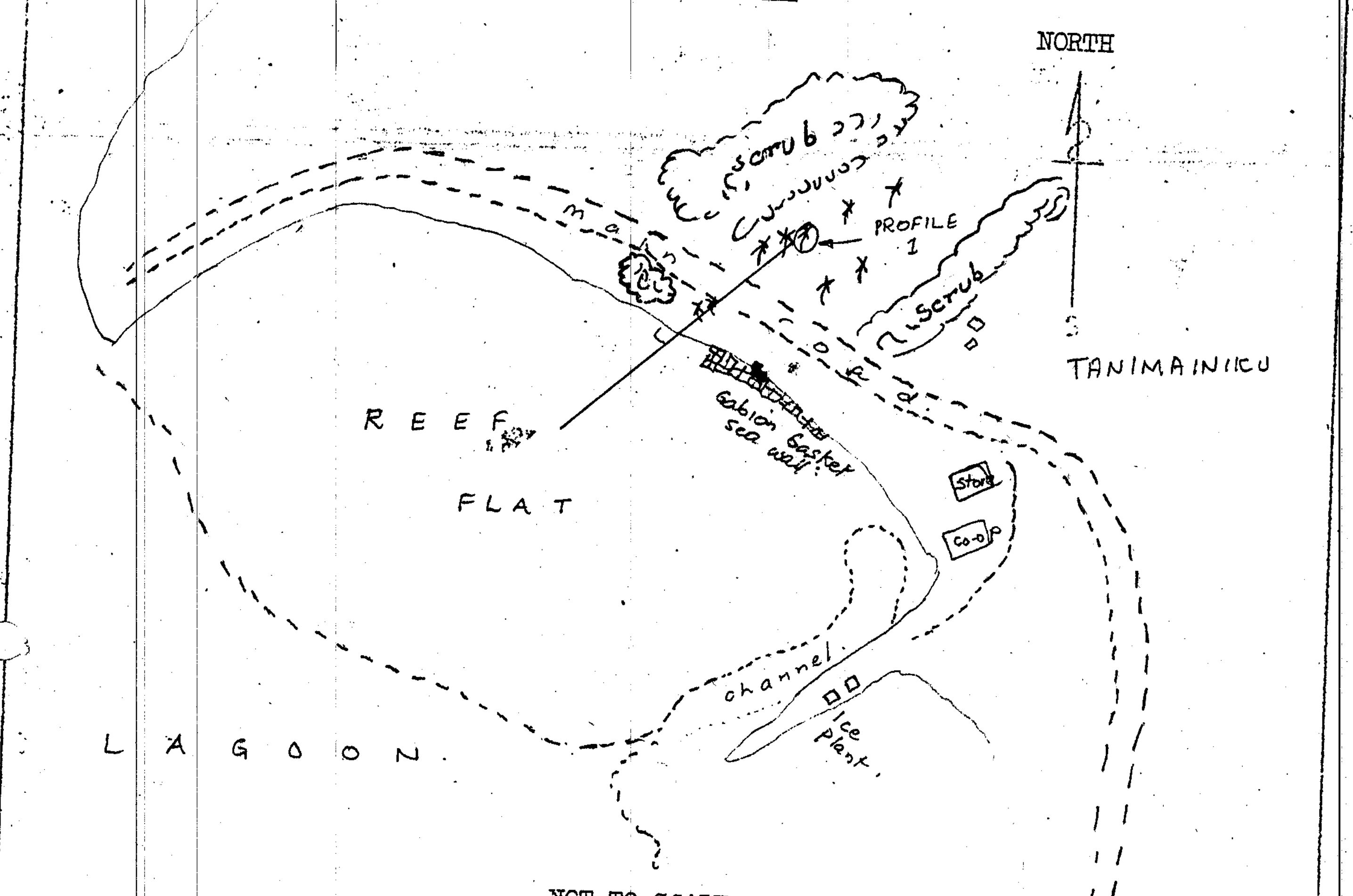
REPLACED BY: DATE

GENERAL INFO:

OFFICE

SURVEYOR

LOCATION DIAGRAM



NOT TO SCALE

ABEMAMA ISLAND

NOTES:

CONTROL MARK NO: TANIMAINIKU – 1

LOCATION : Approx. 200 m north of wharf and anchorage.

DESCRIPTION: Galv. nail on north side of coconut tree along north clearing: Approx a foot high and 8m from road.

REFERENCES:

S.R. NO: ....

SHEET NO: ....

HEIGHT: ....

CO-ORDINATES: (E): .... (N): ....

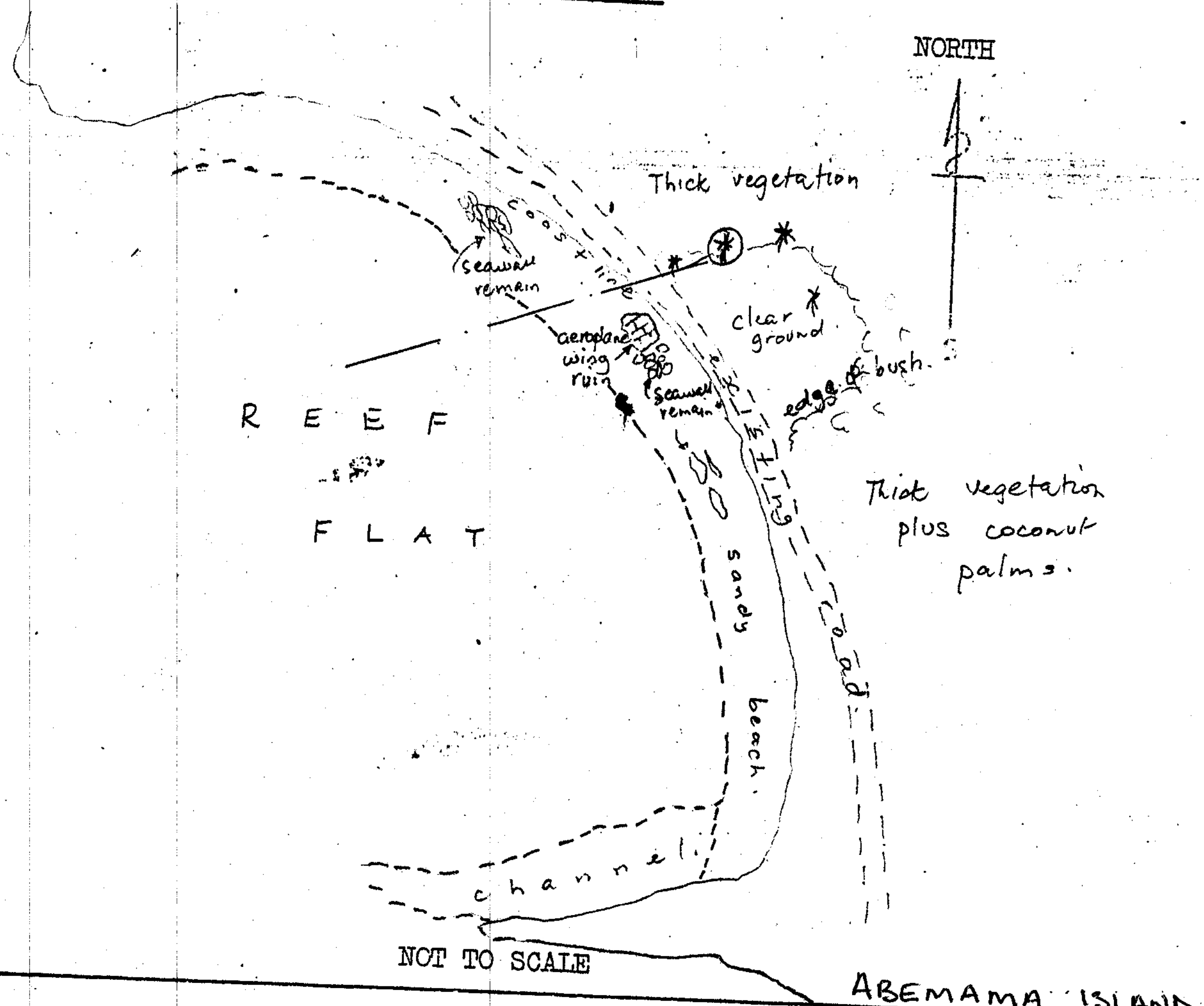
ESTABLISHED BY: AMBEROTI NIKORA 17 – 08 – 92
DATE

REPLACED BY: ....
DATE

GENERAL INFO: ....

....
OFFICE SURVEYOR

LOCATION DIAGRAM



NOTES:

CONTROL MARK NO: TANIMAINIKU - 2

LOCATION : Approx. 150m north of Profile No. 1

DESCRIPTION: Galva nail on north side of coconut tree east of severely eroded part and along lagoon road. Approx. 500m north of the Mautari Ice Plant

REFERENCES:

S.R. NO: ....

SHEET NO: ....

HEIGHT: ....

CO-ORDINATES: (E): .... (N): ....

ESTABLISHED BY: AMBEROTI NIKORA 17-08-92
DATE

REPLACED BY: ....
DATE

GENERAL INFO: ....

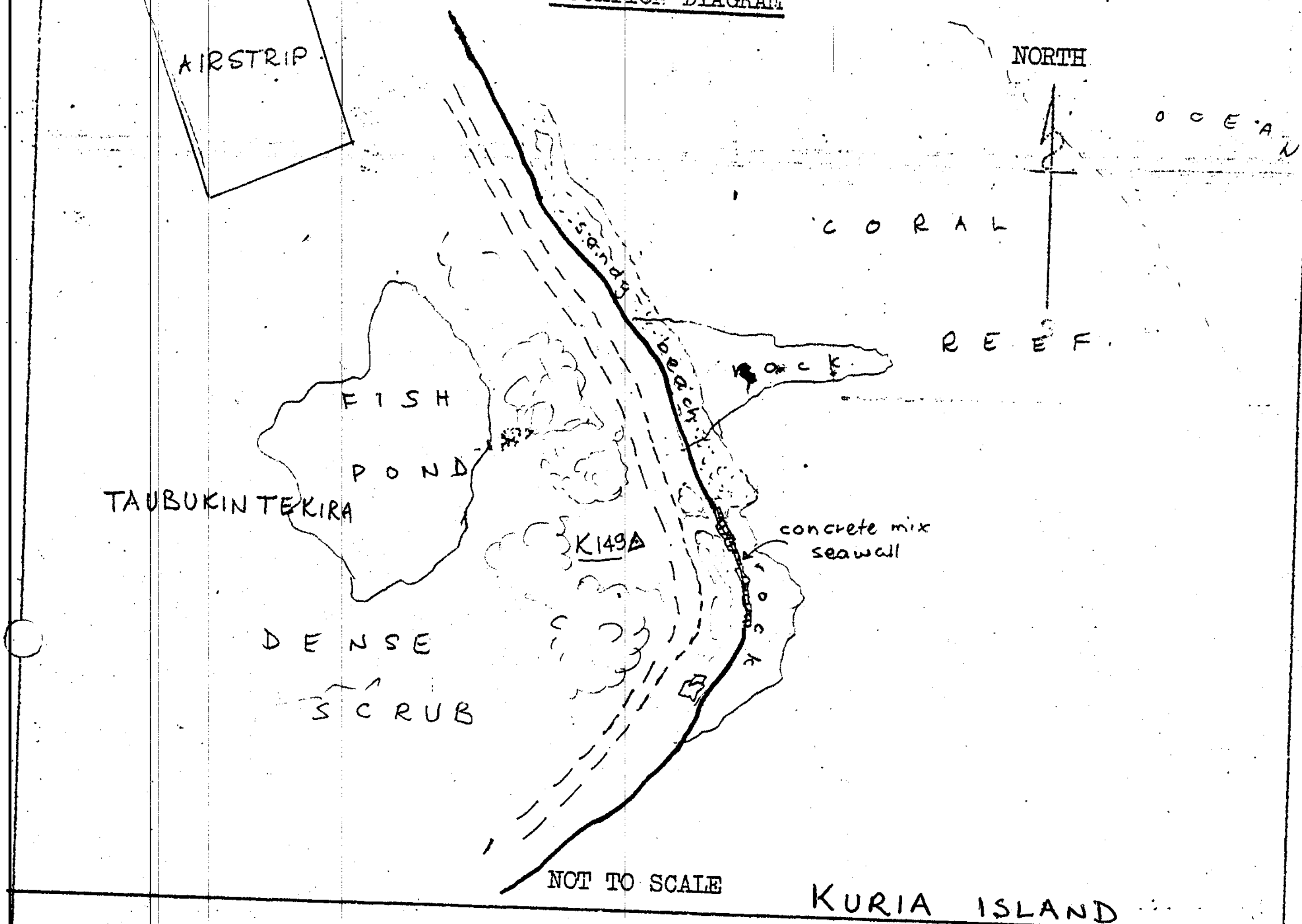
....

....

.... OFFICE

.... SURVEYOR

LOCATION DIAGRAM



NOTES:

CONTROL MARK NO: TAUBUKINTEKIRA – K 149

LOCATION : Approx. 200m. from south end of airport and 40m east of fish pond

DESCRIPTION: Lands and Survey Control monument – concreted with square top plus alluminium nail inserted and approx 0.10m above grd. level

REFERENCES:

S.R. NO:

SHEET NO:

HEIGHT:

CO-ORDINATES: (E): .... (N): ....

ESTABLISHED BY: LANDS & SURVEYS (18 – 08 – 92)
DATE

REPLACED BY: ....
DATE

GENERAL INFO:

.... OFFICE

.... SURVEYOR

APPENDIX 4

APPROXIMATE COSTS FOR

FORESHORE PROTECTION ALTERNATIVES IN KIRIBATI

Table A4. Approximate costs of foreshore response options.

COSTS (per linear m or km)	**TYPE OF RESPONSE OR FORESHORE PROTECTION, COMMENTS**
Approx. $ 5,000/km	Relocation of road back from shoreline. Does not included land use cost (see note 3 below).
Approx. $ 5-10/metre	No action. No construction or maintenance costs. For a site with long term erosion rate of 0.5m/yr, resulting land and tree losses would be valued at about $5-10 per linear metre of beach lost. This does not consider value of lost buildings which will vary from site to site.
Needs to be determined.	Relocation of buildings which can be easily moved or reconstructed. Does not include land use cost (see note 3 below).
$100-200/metre	**Low Cost Protection** Coral rock seawall, vertical (stone packed), no concrete used. *Unsuitable for exposed sites. High maintenance costs for labour.* Coral rock seawall, vertical or steeply sloping, with concrete. *Marginally better than above, depending upon amount of concrete used. Moderate maintenance costs.*
$200-400/metre	**Medium Cost Protection** Sandbag seawall, vertical, cement/sand grout filled bags. *Stability varies with site expsoure and foundation preparation. Low maintenace cost for sites with restricted wave action (for example, protected harbours and causeways at narrow inlets.* Gabion rock basket, 1 x 1 metre section, coral rock filled. *Life of structure usually limited to 3-5 years by corrosion of wire. Not suitable for exposed locations. Maintenance difficult and usually requires replacement of failed section.*
$400-600/metre	**High Cost Protection** Sandbag seawall, gently sloping, cement/sand grout filled bags. *Recommended only for protection of very valuable property. Costs may be 50% greater, depending upon thickness, height and concrete percentage used. Generally low maintenance.*

Notes:

1. Sources: AIDAB (1988), Holden (1992), and Woodroffe and McLean (1992).

2. Road costs are assumed to be formed of approximately 0.4 m of reef material, compacted and graded. It is also assumed that some compensation will be necessary for lost land and coconut trees.

3. Land use values: It is important to distinguish between urban land, which is only found in South Tarawa and non-urban land, upon which subsistence is practiced. An approximate figure which can be used for the value of land on the outer islands is $1000/acre (approx. $2500/ha). In this respect, all land in the Line and Phoenix Islands is owned by Government, which bought the remaining land that it did not own only a few years ago at this rate. Another approach towards calculating the value of land is to value it in terms of the coconuts it supports (one of the main cash crops). The value put on an individual coconut tree, should compensation be paid for development projects is $25. Coconut tree densities are typically 80-150/ha, representing land values of $2000-3750/ha. This assigns no capital value to other plants or resources on the land, despite their role in subsistence economy (Woodroffe and Mclean, 1992).

APPENDIX 5

COASTAL PROTECTION **ALTERNATIVES**

Note: The material in this Appendix is based upon the SOPAC Technical Report by Holden (1992) on coastal protection for Tebunginako Village, Abaiang Atoll. It has been modified to represent general conditions for the outer islands of the Gilbert Group.

COASTAL PROTECTION ALTERNATIVES

Several of the most common alternatives for beach protection are discussed below with respect to their advantages and disadvantages, their labor, equipment and materials requirements, and their maintenance problems. Some design specifications are given for each alternative and comments are made on their feasibility for the outer island in the Gilbert Group. This discussion provides a comparative summary of some shore protection alternatives and indicates those appropriate for outer islands in the Gilbert Group. A summary of these coastal alternatives is presented in Table A5 for ease of reference.

Groynes

A groyne is a structure placed approximatelv perpendicular to the shoreline on a beach. The groyne as as, a dam to the littoral drift process and accumulates material on the updrift side. The build up of the beach on the updrift side is an immediately apparent benefit, which makes the groyne initially look attractive. The major disadvantage is that while accretion is occurring on one side of the groyne, erosion is occurring on the downdrift side of the groyne. Since groynes cause erosion on the downdrift side, the net benefit is questionable unless the groyne is filled artificially when it is costructed. Groynes do not reduce the wave energy striking the shore. Groynes may also force litoral drift to move offshore around the groyne and thus beach material may be lost to the coastal system.

To mitigate the down-drift erosion, groynes must be filled artificially at the time of construction. Earth moving equipment (loader & truck) would have to be brought to fill the groynes with a sufficient quantity of material. Material to fill the groynes would need to be hauled from an alternate area with suitable sand. A well constructed groyne which is artificially filled at the time of construction should not require maintenance.

Groynes can be built with manual labour from locally available material such as rocks or logs fixed perpendicular to the shoreline. A rock mound' groyne must have the heaviest available stones placed on top to protect against wave action. Log groynes require some anchoring method to hold the logs in place.

Because, of the downdrift erosion effects and the possibility that they will force material offshore, in general groynes are not recommended.

Offshore Breakwater

An offshore breakwater is a breakwater structure which is located parallel to the shoreline a short distance offshore. *An* offshore breakwater causes the area behind the breakwater to be sheltered fro wave action resulting in a build-up of beach material like a tom bolo. An offshore breakwater will trap littoral drift land will also cause erosion on its downdrift side, like a groyne. Unlike a groyne, an offshore breakwater does reduce the wave energy striking the shore and will not force beach material offshore into deep water.

An offshore breakwater should also be artificially filled with beach material at a time of construction to avoid downdrift erosion. If an offshore breakwater is properly constructed and artificially filled at the time of construction, it should require no further maintenance.

An offshore breakwater must be built from heavy rock which can withstand the design wave forces. Since an offshore breakwater requires armor stone weights of several hundred kilograms, and construction offshore in deeper water, it cannot be constructed by manual labor. Heavy equipment is require to move and place the large quantities of heavy rock and to fill behind the breakwater.

An offshore breakwater is a very expensive structure for which neither the rock nor the heavy equipment is not generally available on outer islands in the Gilbert Group. Therefore, it is not feasible.

Artificial Nourishment

Artificial nourishment refers to the dumping of sand on an eroding beach. This artificially supplied beach material will gradually move along the eroded area and will continue to move down-drift with the littoral process. The principal advantage of artificial nourishment is that it does not create an construction on the beach and it leaves the beach with a natural appearance. The principal disadvantage is that artificial nourishment is' not maintenance free and it must be repeated from time to time as the material moves downdrift from the erosion area.

Artificial nourishment requires heavy machinery to transport and dump large amounts of beach material. The large amounts of material which must be transported cannot be handled by manual labor. There must be a readily available and suitable source of beach material. Material could only be borrowed and hauled from an area of coastal accretion or land based borrow pits. In general, reef flat materials do not make suitable material for beach nourishment since it is composed of a high percentage of angular, coarse material. Attempts to reclaim or put buildings on the artificially nourished area is not recommended and could only worsen an existing problem.

Since artificial nourishment needs heavy equipment and will need to be repeated periodically it is no practical on outer islands in the Gilbert Group.

Seawalls

A seawall is a structure built along the land-sea boundary which only protects against erosion of land does not attempt to protect or save the beach. Seawalls are constructed when valuable land or buildings have been built too close to the natural boundary of the sea, and are only advantageous when land or buildings are more valuable than the cost of the seawall. A disadvantage of seawalls is that they often cause erosion in front of the wall. The amount of maintenance required for a seawall depends inversely on how well the wall has been built.

The most durable seawalls are rubble mound structures with armour stone rock sizes of several hundred kilograms and appropriate filter layers. A properly constructed rubble mound seawall can absorb wave energy and minimize wave reflection. A vertical concrete seawall, on the other hand, reflects wave energy and is susceptible to cracking and concrete failure.

Heavy equipment would be required to move and place the large quantities of heavy rock and armour stone. As with the offshore breakwater, this is an very expensive structure for which neither the rock nor the equipment is available on outer islands. Therefore, it is not feasible.

Some possible alternatives to rubble mound or vertical seawalls are stepped seawalls or sandbag seawalls/ which may offer reasonable temporary protection against land erosion. Gabions (or rock-filled wire baskets) are another alternative form of seawall which are not long lasting and must be regarded as short term (2-4 years) structures only.

The only material which is abundantly available on outer islands is sand and some rock from previous attempts at protection. A reasonable armouring could be made by filling sand bags with a cement and sand mix (grout). A seawall cross section using these grout filled sand bags was proposed by Holden (1992).

The grout bags are a compromise alternative for armour stone and are not as durable as the rubble mound seawall. Because the grout bags are much smaller than the normal armour stone sizes, certain precautions are necessary for the seawall to be viable. The grout mix must be rich enough to give good bonding between individual bags and the two layers of bags must be carefully placed to insure 150% overlap in both horizontal directions to make a solid unit. The solid unit effect should compensate for the small size of the grout bags.

A seawall must be built on land or as close to the land as possible so it does not extend into the water any more than necessary for the following reasons:

(i) The toe of the seawall must extend below the beach level and construction would be difficult under water.

(ii) If the structure is in water, it will likely cause some beach erosion in front of the seawall.

(iii) Any protrusion into the water will cause the build-up and erosion effects of a groyne.

The ends of the seawall must be rounded and the wall tied back into the land to avoid end scour. The closer the seawall is built into the land the better are its chances of survival.

A seawall should be built only to protect property which is valuable to the community and cannot be moved back from the seashore.

Setbacks

Setback is the distance a building is built back from the natural boundary of the sea. By building permanent buildings at a safe setback distance, the beach and shoreline can be allowed to fluctuate and the buildings will not be lost or endangered. An advantage of setback of building is that the beach is left in its natural state and allowed to fluctuate naturally with no expensive structures be necessary to protect either the beach or the land. A disadvantage is that setbacks require government regulations and enforcement of these regulations. Some land owners perceive a disadvantage in being any distance from the shoreline with respect to loading and unloading of boats or fishing equipment.

The natural boundary is the high water "mark". It is not the high water level because it also includes the effects of common and normal storms and wave runup. The natural boundary is the natural park of the ocean on the land, made by the normal high tide plus the wave runup. Since the natural boundary represents the combined effect of both high tides and wave runup, and is easily seen on the soil and vegetation, it is the best mark from which to measure setback distances or elevations of coastal structures.

Considerable work has been done by Coastal Zone Management agencies to determine appropriate setback distances. The setback distance is usually chosen to save a building or other amenity from loss for ill specific period of time. The time period is often based on one of the following: the estimate life of the [structure (variable from less than 10 to 50 years) or an estimate of the 100 yr erosion limit, the 200 yr storm event, etc. Thus when considering setbacks in the outer islands of the Gilbert Group shoreline stability and/or rates of shoreline erosion need to be taken into consideration.

The setback distance should be appropriate to the cost and the intended life of the building. A setback of about 10-15m from the natural boundary would be appropriate for low cost and/or short term buildings for the lagoon shoreline of outer islands in the Gilbert Group. Buildings intended for long term use, such as churches, stores, government offices and meeting houses (maneaba) should be set back further (20-30 m) from the shoreline .

Table A5. Summary of Coastal Protection Alternatives

STRUCTURE	ADVANTAGE	DISADVANTAGES	APPROPRIATENESS FOR OUTER ISLANDS
Groynes	Immediate buildup on updrift side. Depending upon design may be easy to construct from local materials.	Immediate erosion on downdrift side. Beach obstruction. Movement of drift off shoreline.	Generally not recommend because of effects of disadvantages.
Offshore Breakwater	Buildup of material inside the breakwater. No beach obstruction	Erosion downdrift of the structure. Requires heavy equip-ment and construction supervision.	Large boulders and heavy equipment generally not available. Not feasible.
Seawall	Protects land area only. Depending upon design can be built on land by manual labour.	May cause beach erosion. Requires proper design and construction supervision.	To be used only where threatened property and buildings are valuable and cannot be relocated.
Artificial Nourishment	Preserves the natural beach. Does not disrupt natural processes.	Requires periodic replenishment. Requires heavy equipment and a supply of sand.	Problem with equipment being available. Not feasible for small projects.
Setback/Relocation	Preserves the natural beach. Avoids future coastal erosion problems.	Requires government regulation and enforcement. Requires compensation for land and trees. Offers no protection for existing shoreline.	Can be implemented by enforcement of regulations. Recommended.