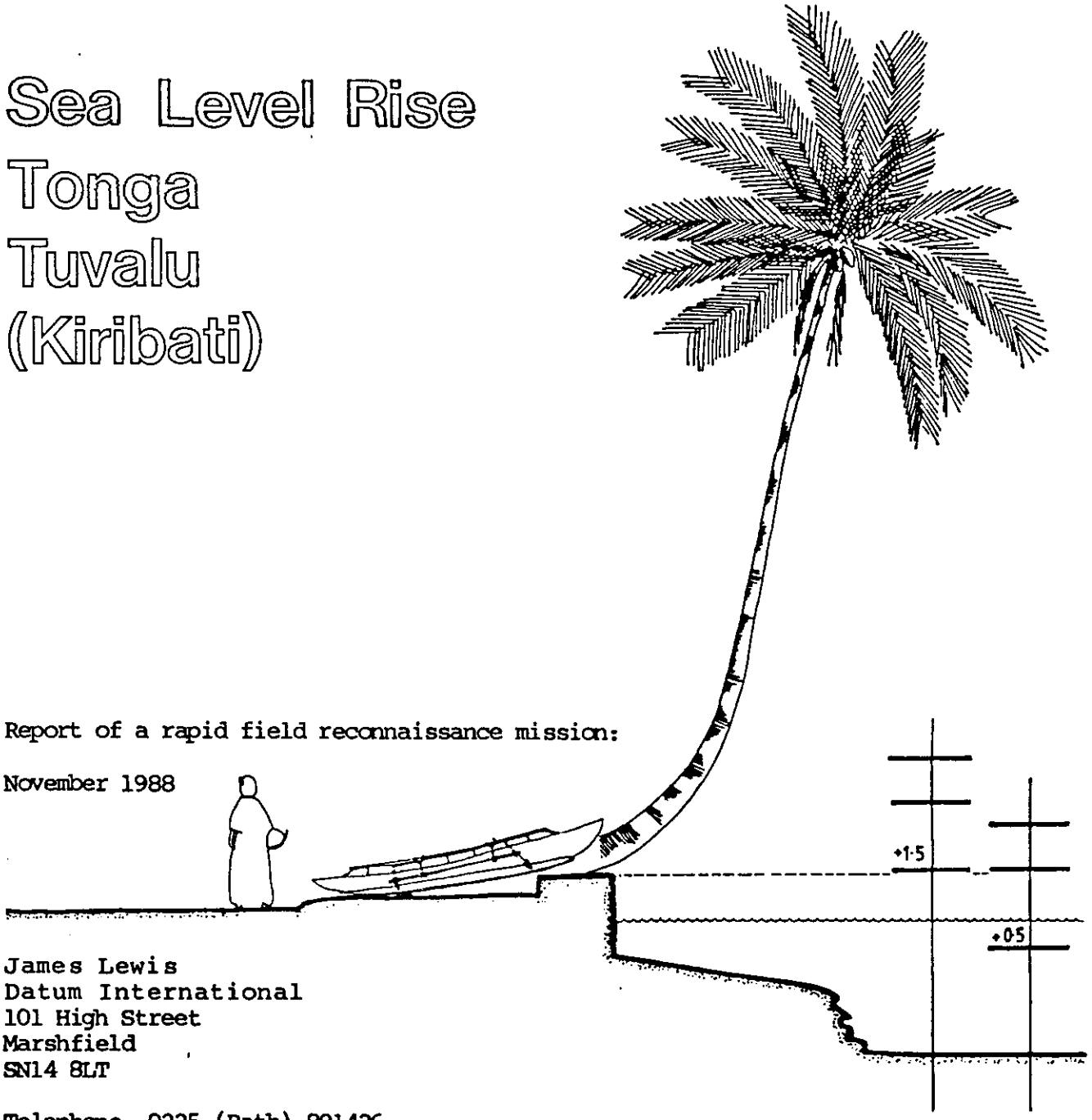
COMMONWEALTH SECRETARIAT

Commonwealth Expert Group on Climatic Change
and Sea-Level Rise

Sea Level Rise
Tonga
Tuvalu
(Kiribati)



Report of a rapid field reconnaissance mission:

November 1988

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Note:

A greenhouse is essentially a temperate zone construction of glass to achieve a longer growing season and/or higher temperatures for selected or delicate plants.

Although atmospheric warming is a global phenomenon, the term "greenhouse effect" may not always be understood in equatorial climates. It is therefore not a term used in this Report.

Acknowledgements

The unhesitating interest, co-operation and assistance of government and institutional officers in Tonga and Tuvalu, the Secretariat of the South Pacific Forum Suva, and the generosity of the Department of Overseas Surveys, Ordnance Survey, Southampton in supplying maps and other information, is acknowledged with grateful thanks.

Special thanks are acknowledged to Wessex Water and Dobbie and Partners for time and effort in obtaining data on sea defence costs.

Contacts are named in Appendix 6.

Information sources

For an unannounced rapid reconnaissance mission of this kind (see Itinerary: Appendix 5) reporting has been largely based on information availability, rather than information searched, researched or surveyed in detail.

The interest and co-operation at very short notice of officers of the Governments of Tonga and Tuvalu (and of the Secretariat of the South Pacific Forum) has been unhesitating, but information on land-use, land values, and production does not exist in all cases or for all requirements.

Ordnance Survey maps, generously supplied at the Department of Overseas Surveys (DOS), are based mainly on air photography. Spot levels are those of the survey reference point, which may not be at ground level. Contours are often impractical, especially on the atolls; and where shown (Tonga) are at five metre intervals, not appropriate for accurate half metre and one and a half metre elevational interpolations.

Some approximate interpolations and measurements have been made using DOS maps and field measurements have been taken using paces, tape and a reflecting hand level.

NB At the time of this mission, Marshall Islands Air Services were "suspended indefinitely"; Kiribati had consequently to be deleted from the itinerary (Appendix 5, p 90).

Exchange rates for currencies at the time of this report are:

£1.00 sterling = A$ 1.97
T$ 2.13
US$ 1.80

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1. Introduction and Summary

- Some Characteristics of islands and atolls

In the atolls and tiny landforms of the island developing countries to which this report relates, there are characteristics which present considerable impediments to conventional impact assessments more compatible with coastlines on continental and other large land masses. Some of these characteristics are:

1. An inter-relatedness of activities, production and land-use. Housing and agriculture tend to be intermixed and crops are often diversified and mixed on the same land areas.

2. Values of production thus cannot be related to specific land areas, even in the cases where figures exist. In the islands visited, most production is for direct domestic consumption. Where agricultural production values are obtainable (eg for copra Table 9: p 50) it is similarly not possible to relate copra production to specific areas of land-use. Even rough economic magnitudes of specific production and wealth, (if wealth only from that production) are unworkable.

3. Values for land, moreover, do not exist as such. In Tonga and Tuvalu, land is never sold, having a cultural value beyond any that economics would suggest. Land however may be leased, closer to its "economic" value (p 24) in Tonga than in Tuvalu (p 48).

In these atolls and tiny islands there certainly will be "increased rates of coastal erosion, salt intrusion into surface and ground water systems and coastal ecosystems, temporary and permanent flooding" which will have

impacts upon "agriculture, water resources, commercial and residential property, energy systems, transportation systems, and so on" (Warrick et al: 1988). In the atolls however, it becomes academic to separate one from another. The impact for example of temporary or permanent flooding will be upon all of these simultaneously, so the assessed effect upon the production and value sector cannot usefully be isolated from its assessed effect upon anything else. Everything will be affected at the same time - though perhaps not immediately to the same degree. Downstream tertiary impact upon health, economic production, and social disruption there will inevitably be but likewise, not usefully separable one from another.

Another problem of assessment in developing countries is of what levels are to be taken as datum for "secondary and tertiary impacts". Agricultural production is normally erratic, due to already variable climatic impacts, and production values fluctuate according to world prices (eg copra Table 9). Can conditions of poor environmental health, for example, be accepted as a basis upon which to assess deterioration?

Conversely, within these generalisations relevant in island countries and their separate atoll communities, there are some considerable differences between Tonga and Tuvalu, the two main countries to which this report relates (Sections 2 and 3). These are primarily:

1. Tonga's national population in 95,000 (Table 1: p 20) whilst that of Tuvalu is 8,500 (Table 6: p 36).

2. Tonga's total inhabited land area is 563 square kilometres (Table 1), whereas that of Tuvalu is 25 (Table 6).

3. Consequently, where Tonga's population density ranges from 246 to 49 persons per square kilometre (Table 2); that of Tuvalu is at a high of 1,152 to a low of 183 persons per square kilometre (Table 6).

4. Tonga has some variety in its 150 islands between steeply formed active volcanoes, steeply undulating islands of volcanic origin and raised coral islands - as well as low coral atoll formations. Tuvalu has nine islands, all low atolls - many attenuated linear and narrow landforms surrounding several hundred square kilometres of lagoon.

There is however one distinct similarity relevant to the subject of this Report. Both Tonga and Tuvalu have recent catastrophic experiences of the sea and its impact which must be built upon, both literally and metaphorically, as part of their strategies against a probable rise in the level of the sea.

In 1982, Hurricane "Isaac" and its associated sea-surge flooded extensive parts of Tonga's capital Nuku'alofa and adjacent areas (Report No 1: Lewis, 1988). In 1976, Hurricane "Bebe" entirely destroyed the then total of 125 houses on Funafuti, but even more significantly left an enormous hurricane bank of coral reef rubble, 19 kilometres long and up to 4 metres high on the ocean facing shoreline of Funafuti (and similarly in other islands eg Nukufetau). The hurricane bank formed a new enclosed lagoon and contributed probably as much as a fifth additional land area to Funafuti (Baines and McLean: 1976).

Towards a Strategy for island countries and their atolls

Where land is intensively occupied for industrial or commercial purposes and lease values reflect this use, the examples based upon Nuku'alofa, Tonga, (Table 2: p 27) suggest that foreshore construction of sea defences (with some associated land reclamation) is cost effective in terms of land use values alone. This may therefore be the case for South Tarawa (Bairiki and Betio), Kiribati.

On Funafuti, Tuvalu, however, in order to protect the entire 2.5 square kilometres of existing land area (Table 6: p 36) 54 kilometres of foreshore sea defences would be required, at an average cost of £500 per metre (Appendix 2). Tuvalu's copra exports of £16,500 a year (Table 9: p 50) will not pay for that total construction cost of £27 million plus landfill.

Atoll land forms are porous coral rock to depths far beyond those reached in normal civil engineering foundations (p 63 and footnote). Consequently, flooding could ensue from within "sea defences" as a result of a raised sea level, unless land levels were also raised within the area enclosed by sea defence works; but with severe complications for land already occupied by construction of any kind, or by tree crops (eg coconut, breadfruit, pandanus, etc).

Although therefore, it is conceivable that "citadels-in-the-sea" (p 62) could be created by the construction of sea walls on selected existing land, or on coral rock foundations in shallow water, with land levels within their enclosures raised by the pumping of sand/gravel slurry from the sea bed, it is similarly inconceivable that such citadels could maintain socio-cultural or economic life styles. Their creation would

immediately become a pole of attraction perceived as security against only a normally hazardous sea and overcrowded conditions would ensue to a degree well beyond those already being experienced.

Citadels-in-the-sea may have to be the ultimate alternative to mass evacuation, but other ways have to be found than the purely physical, technological or economic, which in the interim indeterminate but realistic meanwhile, will take account of and draw their inspiration from the following:

1. There is an increasingly aggressive uncertainty regarding the dimensions in time or depth of sea level rise (Linden, 1988; Scherer, 1988).

2. The imagery of catastrophe presented by ultimate increased sea levels should not be made to preclude interim measures for lesser conditions - particularly where there is uncertainty about what or when that ultimate might be.

3. Whatever dimensions materialise in time and depths of sea level rise, their first manifestation will not be that of a benign sea; it will be of high tides, storms and sea surges of which there is significant experience.

4. As percentages of land come to be lost to sea-level rise in the future, in the Tongan low islands, percentages of recent population decrease are higher in most cases (Table 6: p 35).

The effects of storms and surges may become more frequent and more damaging, but to refer to storms becoming more "penetrating" with reference to atolls, is superfluous where tiny land forms are already wholly subsumed by massive storms and hurricane formations! **It is the experience by islanders of already normally aggressive and hazardous seas that can be made a positive base upon which to develop a variety of strategies to take account of a rise in sea levels - certainly those of preliminary or lowest order of magnitude.**

Whilst Nuku'alofa, Tonga (Section 2), usefully provides an example of urban intensive land use and its possible protection, Tuvalu (Section 3) provides examples of conditions perhaps more typical to many atolls of island countries - including islands of Tonga and Kiribati (Section 4). Although it is invariably Tuvalu as a nation that is referred to as most predominantly in line for annihilation from a rising sea level(1), it is also Tuvalu that can demonstrate many measures that could be taken (many of which are being taken for other purposes) in an uncertain but long-term interim.

In any case, there is no one solution to problems presented by rising sea level; strategy has to be multi dimensional, multi sectoral and multi-disciplinary. No single 'solution' could be applied without creating further problems. Constructed 'citadels' possibly offer a technically feasible 'solution' though not removing issues of economic and social viability. Evacuation, though technically and logistically feasible for small

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(1) eg The Observer 9 October 1988

populations, raises social and cultural issues best discussed with their participation. Given that some relaxation may be feasible of immigration regulations called for by Tuvalu with reference to Australia and New Zealand, evacuation is not likely to take place all at once, or to even apply to everyone. There is at least one Pacific precedent (from Tonga) where evacuation en bloc following a volcanic eruption left those few behind who preferred defiant isolation to the unknowns of relocation, and brought about many more who were later to return (Lewis: 1979; and Rogers: 1986).

Strategies against the effects of sea level rise must therefore take account of uncertainty, current activities and objectives, incremental rise over time, the effects of high tides and storms, and a variety of variable perceptions, options and responses.

Within the extremes of citadels-in-the-sea on the one hand, and evacuation of the entirety on the other, are a range of other measures identified for Tuvalu (Section 3) which are relevant to many islands and all atolls. Most cannot be taken as isolated measures on their own, but are inter-dependent one with another. Similarly, most cannot be applied on behalf of specific projected levels of sea rise but most could be applied incrementally or selectively according to their locations and elevation. Their significance is that none are hitherto unknown; most are being pursued for a variety of reasons other than that of sea-level rise, are already components of the development spectrum and in need of development assistance.

Sea-level rise must now be included in development planning; some projects identified with specific reference to sea-level rise and others given greater impetus, resources or priority or account of sea level rise.

Problems associated with a rising sea cannot be left to the incumbent national governments of small developing and least developed island countries. As economic problems they are international, dependant upon development assistance; but also as cultural, social and political issues they belong to the international arena. Small island countries will sustain the greatest proportional damage and loss as a result of rising sea levels; losses they cannot accommodate without international assistance. Whilst the economic impact of sea level rise has to be computed nationally, social and cultural losses must be assessed and considered internationally.

> "Whilst it might be concluded on the basis of population size that in a global context the potential loss of Pacific micro-states constitutes an insignificant component of changes resulting from climate and sea level change, such a view takes no account of the loss of human cultural diversity . . . loss of cultural groupings through amalgamation and incorporation into neighbouring states would represent a significant loss of human heritage" (UNEP: 1988).

UNEP recommends that immediate regional attention be given to "ecological refugees" to avoid the social and cultural disruption that can otherwise be predicted. Thus, the supposed ultimate economic question of whether continued costs of development can be afforded in situations where rising sea levels remove all security for investment, must be replaced by wider understanding within development programmes and their accommodation and promotion of interim measures across a wide sectoral spectrum.

Increased resources are required in order for greater impetus and priority to be given to the following:

1. alternative food crops grown at or above ground levels;
2. housing with floors appreciably raised above ground levels;
3. improved potable water supply systems;
4. improved conditions of environmental health;
5. land fill and reclamation projects;
6. coastal erosion prevention projects of adequate construction designed for incremental increase as sea defence;
7. training in emergency management to be inclusive of sea-level rise implications;
8. relaxation of immigration controls by current and potential recipient countries of the Pacific.

This rapid reconnaissance mission has been in the nature of a pre-feasibility study. Recommendations for further study are proposed in Section 5.

2. THE KINGDOM OF TONGA

The Context

An archipelago extending 750 km north to south, Tonga's 150 islands form three principal sub-groups plus the two "Niuas" in the far north (Niuatopatapou and Niuafo'ou) (Figure 1). The Niuas and Vava'u group of islands are of volcanic origin. Mainly steep sided and sharply undulating, coastal areas would be affected by a rise of sea level but not to the same degree as lower islands of the other two groups, Ha'apai and Tongatapu to the south.

The Ha'apai group is a mix of low atolls and raised islands, the low atolls being at greatest risk to changes in sea level (eg Figures 15-19, pp 75-79).

Tongatapu, the largest island of that Group (Figure 2 and Table 1) is a raised island - though tilted upwards to the south. On its low northern coast is situated the capital Nuku'alofa on a promontory between the ocean and an inland lagoon (Figure 3). 'Eua is the other principal island of the Tongatapu Group, but is sharply raised.

The population density of Tongatapu has increased by 25% in twenty years (1966-86: Table 1) but has decreased by 15% in the Ha'apai island group over the same period.

Nuku'alofa had a population of 18,312 in 1976, 31% of the Tongatapu population and 20% of the national population total (Central Planning Department; 1981).

Figure 1.

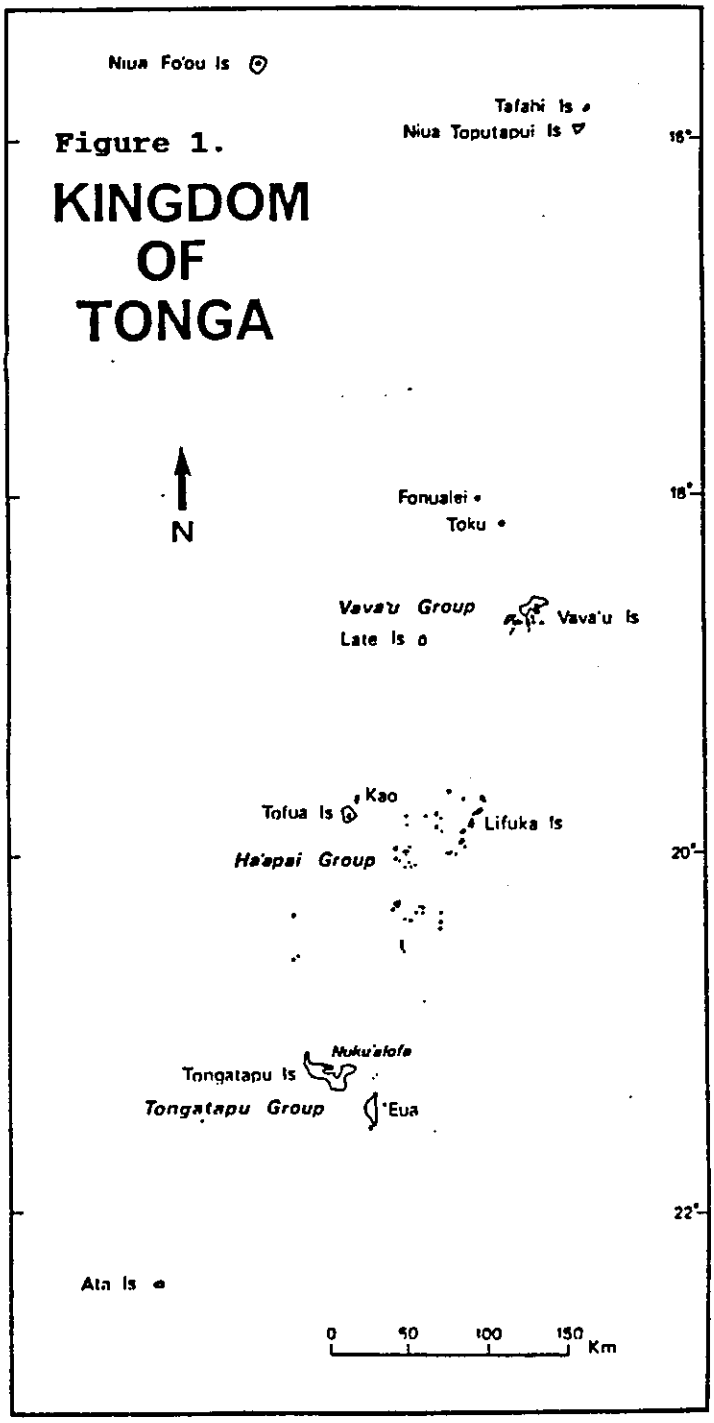
KINGDOM OF TONGA
Niua Fo'ou Is
Tafahi Is
Niua Toputapui Is
15°
N
Fonualei
Toku
18°
Vava'u Group
Vava'u Is
Late Is
Kao
Tofua Is
Lifuka Is
Ha'apai Group
20°
Nuku'alofa
Tongatapu Is
Tongatapu Group
'Eua
22°
Ata Is
0
50
100
150
Km

Figure 2: Tonga. Tongatapu Island: inset; Nuku'alofa contoured in Figure 4.

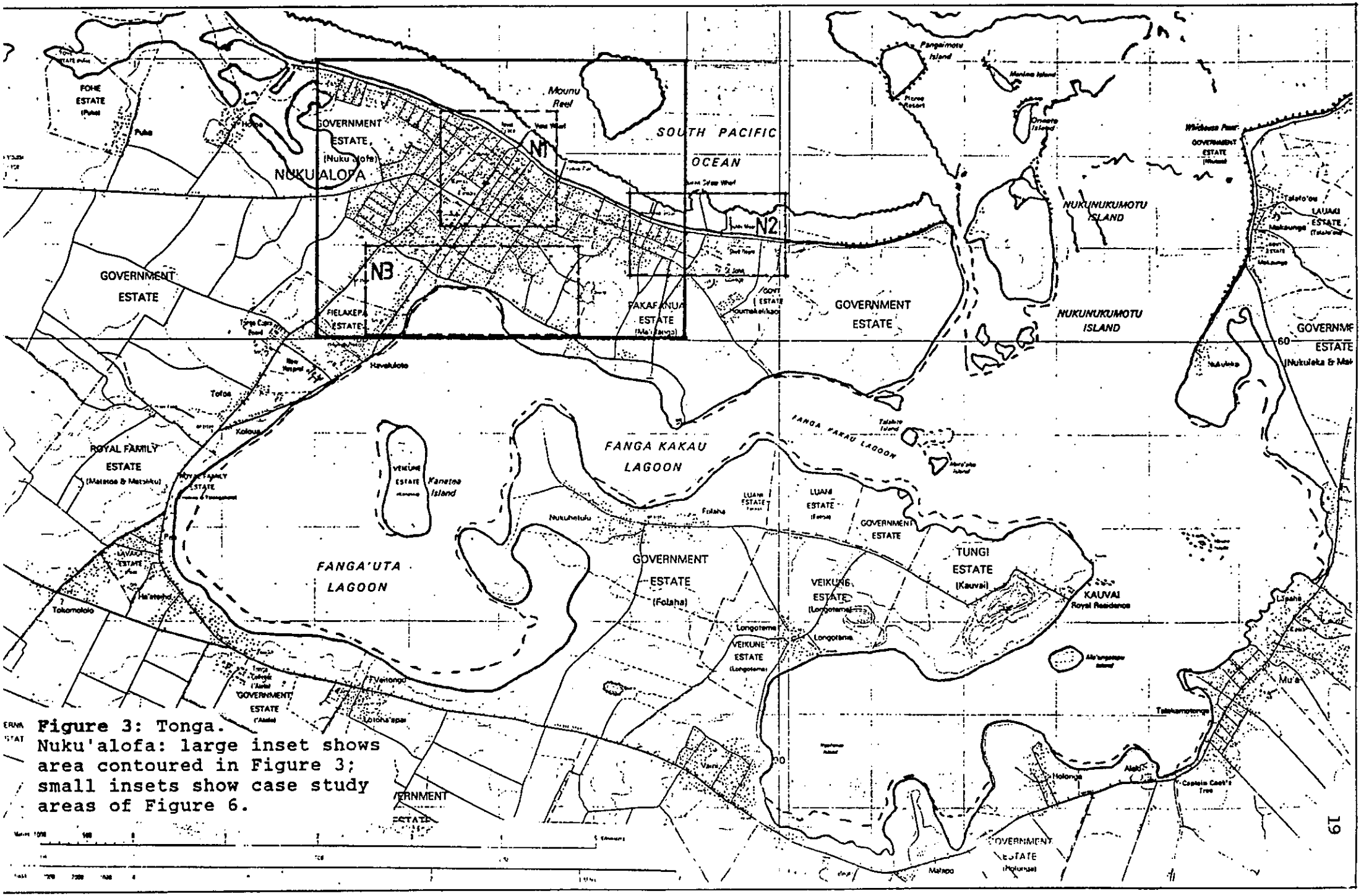

Figure 3: Tonga. Nuku'alofa: large inset shows area contoured in Figure 3; small insets show case study areas of Figure 6.

TABLE 1

Tonga: Island groups, areas, populations, and densities

	Land area:		Population		Density/km^2	
	km^2	%	1966	1986	1966	1986
Tongatapu	259	67.3	47,920	63,614	185	246
'Eua	116	4.6	3,391	4,393	29	50
Ha'apai	52	9.5	10,591	8,979	204	173
Vava'u	87	16.1	13,533	15,170	156	131
Niuas	49	2.5	1,994	2,379	41	49
Total	563*	100	77,429	94,535	138	168

* inhabited islands (excluding Tofua: not permanently inhabited; an active volcano)

(Source: Sauvinet: 1988: adapted)

Nuku'alofa

Much of Nuku'alofa is at or below mean sea level (msl) and considerable areas are between msl and 1.5 metres above msl (Figure 4). With a tidal range of one metre (approx: Belz 1985), msl is half a metre below high tide: that is, at high tide land levels are half a metre less above mean sea level than that shown on contour maps with datum msl. (Tidal change in the lagoon however, is half that of the ocean: Figure 16b).

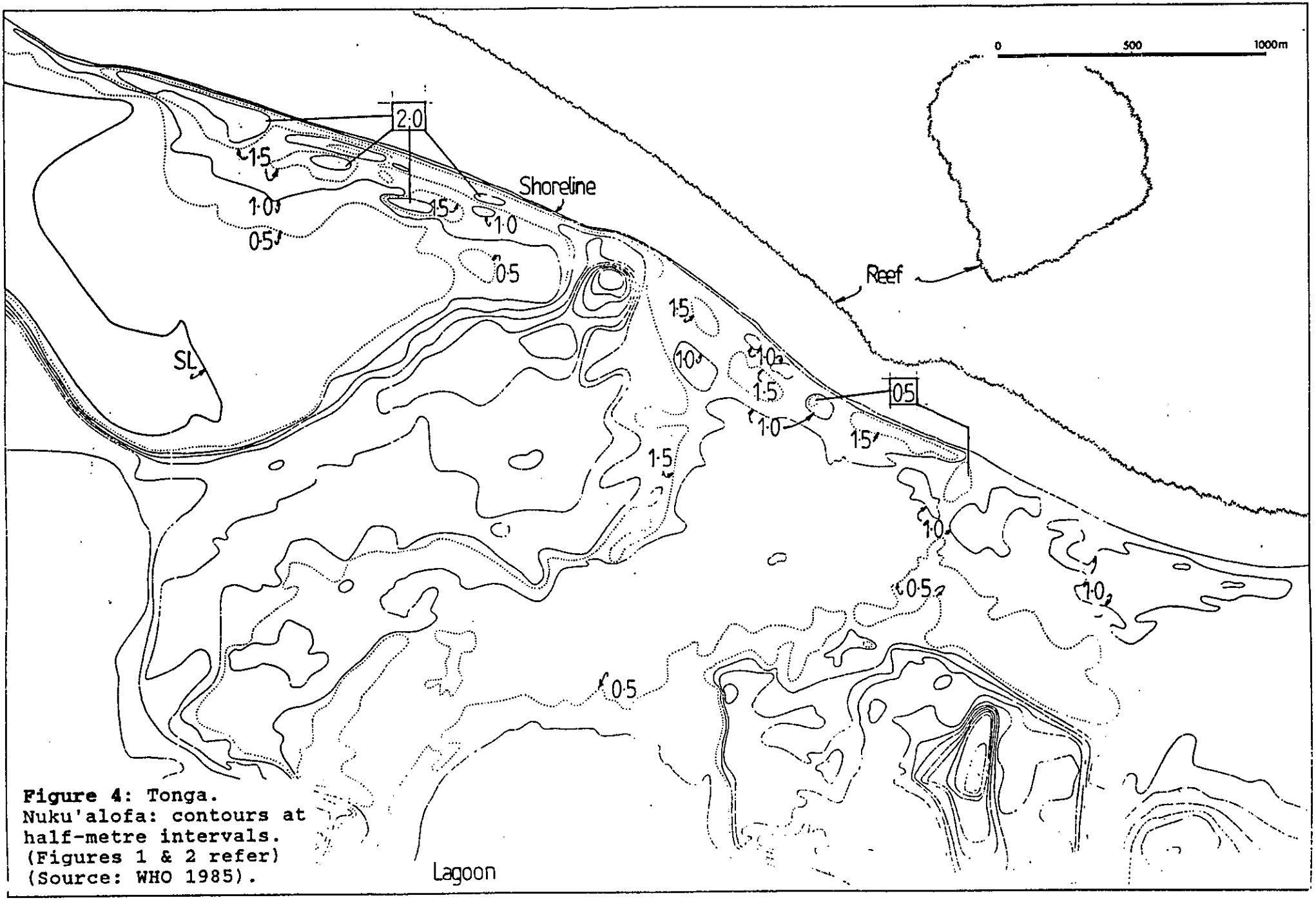

Figure 4: Tonga.
Nuku'alofa: contours at half-metre intervals.
(Figures 1 & 2 refer)
(Source: WHO 1985).

In 1982, Hurricane "Isaac" and its associated sea surge caused severe flooding in Nuku'alofa and especially to the area known as Sopu to the west of the town. (See Report No 1: Lewis 1988; pp 21-23 and map, Figure 4). As a result, "spontaneous" occupants of Sopu, largely migrants from Ha'apai, were relocated to Popua, to the east of the town. Popua is at sea level and waterlogged. Housing construction proceeded in conditions no better than at Sopu and in a location no less vulnerable to sea surge another time. (Lewis 1982; and referenced in Belz 1985). Popua has since been designated as the site for an industrial estate, as well as for housing.

Nuku'alofa has one fifth of the population of Tonga, as the result of migration as well as natural increase. Land available for housing is scarce, due to this and other socio-cultural constraints. Designation for housing of waterlogged land is thus a reflection of this prevailing context.

Another direct response to Hurricane "Isaac" has been two and a half kilometres of completed foreshore works along the Nuku'alofa seafront (German aid) and a current project of two and three-quarter kilometres under construction to the west of the town for Sopu and beyond, plus two and a third kilometres to the east for Popua (Japanese aid: see Figures 5, 15a, b, c, and 16a).

These projects use large coral rock (quarried inland) built up from the shallow reef platform to half a metre (approx) above foreshore land level. In some cases there is a short (600 mm) wall in the landward side, in others there is no wall. Interstices between the coral rock would allow

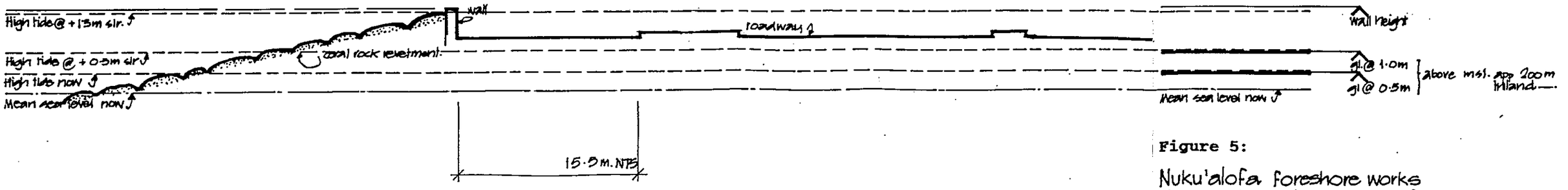

Figure 5:

Nuku'alofa foreshore works
First contract (German aid.)
Scale: 1 - 100

© Datum International: December 1988.

the sea to flow through, though the wave or surge force would be dissipated (Appendix 1).

A roadway runs parallel to these foreshore works; inland of that land falls to its natural levels (as noted; Figures 4: and Figure 5).

Some linear land creation or reclamation has accompanied these foreshore developments, realizing prime sites for possible future use, especially for tourism development, possibly in association with beach renewal.

All Tongan land belongs to HM The King and cannot be alienated (Rutherford: 1977). At the King's decree, land has been allocated to the nobility and as tax allotments of three and a third hectares to all males on coming of age (api: male population has long since exceeded land available for this purpose). Owners of land may lease plots for financial or other consideration, a process formalised through the Land Registry. New land created by reclamation automatically passes to the King's ownership.

Land thus cannot be sold and land itself does not therefore have a value. Leases however command financial consideration. The minimum plot that may be leased, 760 square metres, currently commands a lease value of T$ 5,000, but townland may be leased for up to T$ 100,000, reflecting its prime commercial value and scarce availability.

Land reclamation thus creates potentially high lease values; and moreover, it is reportedly cheaper to fill waterlogged land (as will ensue at Popua when it is protected by foreshore construction) than to lease other land.

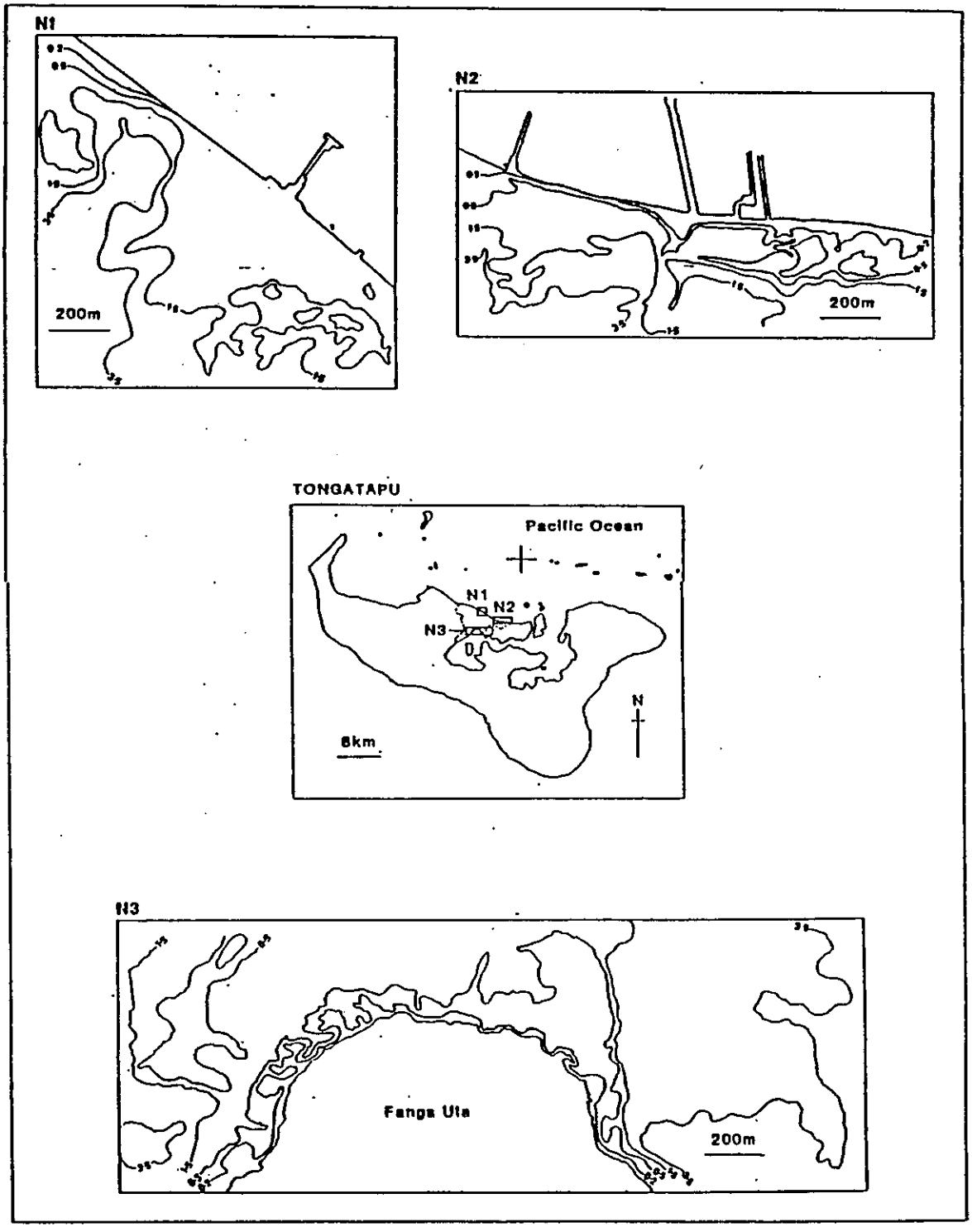

Figure 6: Tonga.
Nuku'alofa: case study areas N1, N2, and N3.
(Source: Nunn 1988).

Costs of foreshore construction thus realise considerable benefit potential from the leasing of land it creates or protects.

Table 2 suggests the highest cost of foreshore works to be 7 million Tongan pa'anga (Example 2) though likely to be less (Example 1) against the lowest potential lease income of 16 million Tongan pa'anga (Example 2), though likely to be much more (Example 1).(1)

It has to be emphasised that these current and projected foreshore constructions are in direct response to the events caused by Hurricane "Isaac" in 1982. They do not take account of any projections for rising sea levels. (The coincidence in Figure 6 of the 1.5 metre high tide level with wall height should not obscure the need for additional protection against storm and sea-surge on top of that sea level.)

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(1) The designation of part of Popua as an archeological site has not been taken into account in these calculations.

TABLE 2

Nuku'alofa (Popua):

A Comparison of current foreshore works costs with land lease potential values	EXAMPLE NO 1	EXAMPLE NO 2
Approx area of land designated (sq m)	2,520,000	
No of plots of minimum size (760 sq m)	3,315	
1. @ lease value (filled land) say T$ 10,000	T$ 33,150,000	
2. @ lease value say T$ 5,000		T$ 16,575,000
Cost of current foreshore construction (Popua); based on Sopu cost of T$ 1,030.86 per metre)	T$ 2,370,978	T$ 2,370,978
plus cost of lagoon sea protection (4,500 m @ half the tidal rise)		
1. @ say T$ 750 per metre	T$ 3,375,000	
2. @ same cost per metre as ocean foreshore		T$ 4,638,870
TOTAL ESTIMATED COSTS:		
EXAMPLE 1	T$ 5,745,978	
EXAMPLE 2		T$ 7,009,848

NOTES:

1. Costs are based on the Japanese contract for Sopu which is current. The town centre (German) foreshore costs for 1984-87 were T$ 474.12 per metre.

2. The Sopu foreshore is more exposed to deep ocean.

3. The costs of landfill are not included in any estimate (T$ 15.00 per cu metre).

4. Areas are approximate and values are semi-hypothetical ie based on rapid assessment within this short field mission (See itinerary: Appendix 4).

5. Contract costs in Deutchmarks and Yen have been converted at current exchange rates (Nov 3: courtesy the Bank of Tonga).

2. Nuku'alofa: projections taking account of rising sea levels

A report has been prepared for the United Nations Environment Programme, by staff and students at the University of the South Pacific (USP), Department of Geography (Nunn, April and October 1988). From detailed analyses of maps obtained as the result of extensive searches in and for the Cook Islands, Fiji, Kiribati, Tonga and Western Samoa, areas of land use in seven categories to be lost in four scenarios of sea level rise have been calculated. Details of the methodology are annexed in the preliminary report and accuracy ratings applied to each geographical area. Though prepared during only six months, credibility and methodology are thus much higher and more accurate than would be achieved in this Report of a short reconnaissance mission and it is with grateful acknowledgement that relevant data are abstracted here. The study of Nuku'alofa is described as one of the most detailed case studies of the USP Report. It is based upon the 1:1,000 map of Nuku'alofa (WHO: 1981 in Belz, 1985) with half metre contours examined as part of this mission (Figure 4).

Three sub-areas of Nuku'alofa were chosen for the USP project: central Nuku'alofa; the port area and its immediate hinterland; and a representative suburb on the inland lagoon shore (See Figure 7 and Figure 16b).

An abstract of the USP report (Table 3) shows 14.56 per cent of the total land area (of the three case study areas) to be lost as the result of a 0.5 metre sea level rise; and 37.98 per cent of the land area of the project lost as the result of a 1.5 metre sea level rise.

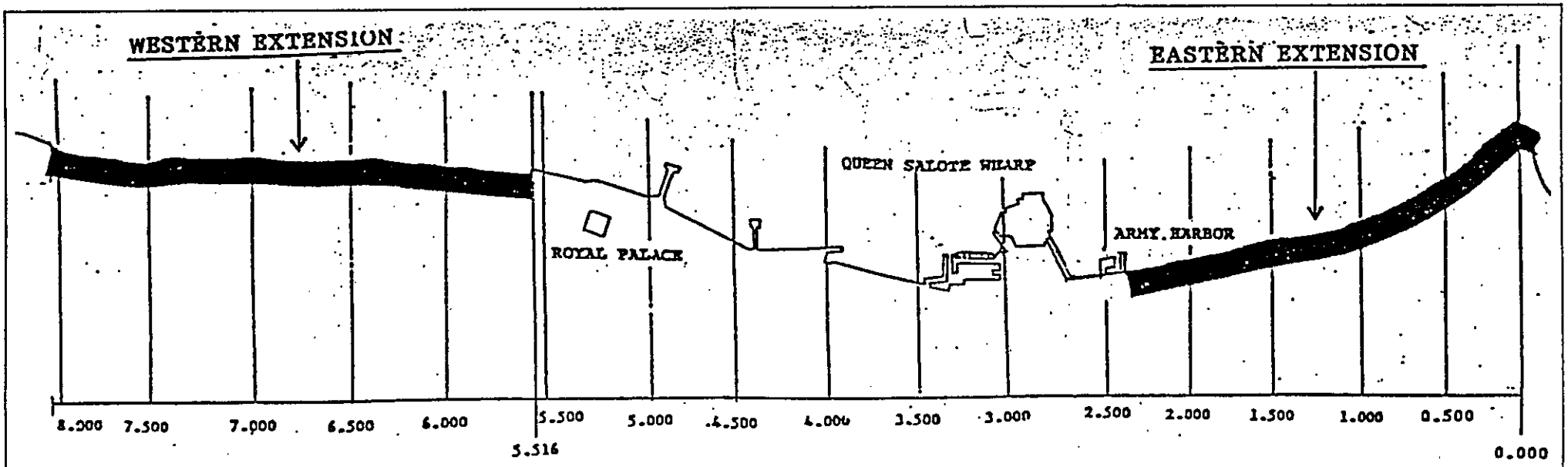


Figure 7: Tonga.
Nuku'alofa: extensions to foreshore works (current project shaded: Japanese aid. Central zone completed: German aid).
(Source: Ministry of Works, Nuku'alofa).

TABLE 3

Nuku'alofa:

Abstract of land losses° within case study areas N1, N2 and N3: Figure 6 refers
(Source: Nunn; 1988)
Areas in square kilometres

Type of land-use lost	Sea level rise (metres): Central Nuku'alofa (N1)		Port Area (N2)		Lagoon Suburb (N3)		Totals	
	0.5	1.5	0.5	1.5	0.5	1.5	0.5	1.5
Agricultural	-	-	-	0.002	-	-	-	-
Mangroves	-	-	0.008	0.008	0.048	0.048	0.056	0.056
Residential	0.011	0.011	0.035	0.130	0.285	0.890	0.331	1.031
Industrial	-	-	0.061	0.064	-	-	0.061	0.064
Commercial	0.019	0.129	0.019	0.053	0.003	0.003	0.041	0.185
Others: (school and church)	-	-	0.051	0.073	-	-	0.051	0.073
Total land loss	0.03	0.14	0.174	0.330	0.336	0.941	0.540	1.409
% total land area (see figure :N1*)	3.70	17.28	22.31	42.31	15.85	44.39	14.56	37.98

* Total land areas: N1: 0.81 sq km
N2: 0.78 sq km
N3: 2.12 sq km
3.71 sq km

° Accuracy rating for data in all these cases is given as high.

For the three main land-use categories (residential, industrial and commercial) land-lease values can be suggested, as the basis of an estimated economic impact of sea level rise.

Table 4 suggests that for a half metre sea level rise, total loss would be almost T$ 8 million; for a 1.5 metre sea level rise, total loss would be T$ 23 million. These figures represent the initial loss; recurrent losses have not been taken into account at this stage, neither have losses in production from industrial and commercial enterprises, and to repeat, these assessments are for the three areas selected by the USP Project.

Nuku'alofa, though itself low lying, is bounded to the west by a 5 metre contour, and the promontory between ocean and lagoon upon which it is located also contains some similarly higher ground. The area of Nuku'alofa bounded by a 1.5 metre contour can by interpolation, be approximately assessed as 8.25 sq kilometres. The area of the three cases of the USP Project for Nuku'alofa totals 3.71 sq km: thus the assessment above of land lease loss represents only 45% of the total area of Nuku'alofa within a 1.5 contour.

As a result of its catastrophic experience of Hurricane "Isaac" and its associated sea-surge in 1982, Nuku'alofa could be regarded as being a step ahead in matters of protection from rising sea levels. Previous aggressive seas have created a context of perception and response which will well serve future hazards, but manifestation of these perceptions are not designed for future increases in sea level. Though what has been and is being done will well serve increased hurricane incidence brought about by

increased sea-surface temperatures, more will need to be done to protect the political, cultural, social and economic centre of the Kingdom.

TABLE 4

Nuku'alofa

An economic assessment of sea-level rise (of three selected areas: reference Table 3)

Type of land-use lost		Total area lost		Land-lease value per sq km	Total land-lease loss (T$)	
		0.5	1.5	T$	0.5	1.5
Residential	N1	0.011	0.011	66,075,000	726,825	726,825
	N2	0.035	0.130	17,620,000	616,700	2,290,600
	N3	0.285	0.890	4,405,000	1,255,425	3,920,450
Industrial	N1	-	-			
	N2	0.061	0.064	44,050,000	2,687,050	2,819,200
	N3	-	-			
Commercial	N1	0.019	0.129	88,100,000	1,673,900	11,364,900
	N2	0.019	0.053	44,050,000	836,950	2,334,650
	N3	0.003	0.003	8,810,000	26,430	26,430
Grand total land-lease loss:					T$ 7,823,280	T$ 23,483,055

NOTES: Land-lease values are sensitive information difficult to find or to corroborate. Land lease values have therefore been interpolated between a minimum of T$ 5,000 and a maximum of T$ 100,000 per 760 sq metre plots: each square kilometre reduced by 33% to allow for roads and other access ways, giving 881 plots per square kilometre.

The Islands

The island of Tongatapu, upon which is situated the capital Nuku'alofa, has 67% of the total national land area of inhabited islands (See Table 5). 'Eua has 4.6%; Vava'u 16.0% and the Niuas 8.5%.

The Ha'apai Group totals the remaining 9.5% of land area, distributed amongst twenty eight villages on 15 inhabited islands (See Table 5). Population densities in all but three of the islands has decreased markedly over the past ten years (1976-1986: Central Planning Department 1988). Land areas of the inhabited Ha'apai islands are also shown on Table 5. Interestingly the outstanding example of population increase over the ten years (1976-86) is Kotu, with Matuku the smallest islands with an area each of 0.33 sq km. Population densities here are three times higher than in the United Kingdom for example (231 per sq km: Table 1 Report No 1; Lewis, 1988). Overall however, population of the Ha'apai Group as a whole has decreased by 17% over the ten years 1976-1986.

TABLE 5

Land Area and Population Density of Inhabited Islands in Ha'apai, 1976 and 1986

Island	Area km^2	1976 Pop.	Density	1986 Pop.	Density/ km^2
Hahake Sub-Region*					
Lifuka	11.42	2,938	257	2,840	249
'Uiha	5.36	1,112	207	913	170
Lofanga	1.45	428	295	351	242
Ha'ano	6.58	1,175	179	728	111
Foa	13.39	1,703	127	1,409	105
Mo'unga'one	1.17	321	274	164	140
Lulunga Sub-Region					
Ha'afeva	1.81	548	303	449	248
Tungua	1.53	439	287	305	199
Fotuha'a	1.14	203	178	192	168
'O'ua	0.98	257	262	267	272
Matuku	0.33	141	427	142	430
Kotu	0.33	180	545	233	706
Mu'omu'a Sub-Region					
Nomuka/Nomuka iki	5.34	966	181	692	129
Mango	0.65	116	178	93	143
Fonoifua	0.39	158	405	112	287
Total	151.87	10,685	206	8,890	171

* Excluding Tofua

(Source: Sauvinet 1988)

Ha'ano, Foa, Lifuka, Uoleva and 'Uiha are examples of low islands of the Group (Figures 15-19, pp 75-79). Others are raised islands (eg Lofanga) or not permanently inhabited (eg Tofua and Kao which are active volcanoes). These five islands are tabulated below (Table 6)

TABLE 6

Tonga: Five islands of the Ha'apai Group; Population and area decrease

Sources: Table 5 and Figures 15 to 19)

Fig No	Island	Area sq km	Population 1976	Population 1986	Population Decrease %	1.5 S/r land loss %
15	Ha'ano	6.58	1,175	728	38.00	7.60
16	Foa	13.39	1,703	1,409	17.3	2.24
17	Lifuka	11.42	2,938	2,840	3.3	14.27
18	Uoleva	2.82	-	-	-	7.17
19	'Uiha	5.36	1,112	913	17.9	21.10

Only in one case (Lifuka) would the percentage area of land lost to a 1.5 metre sea-level rise, be greater than the percentage of population decrease.

Average percentage land loss for these five islands is 10.5%. If the low islands can be assumed as numbering half the total (and for these purposes, half the land area?) then these examples indicate a total land loss to the inhabited Ha'apai islands of say 5 per cent to a rise in sea level of 1.5 metres.

This five per cent land loss over the next 62 years (to 2025) remains very much less than the 17% population loss over the past ten years. However, settlements, coconut palms and a fifth of garden land are located on coastal lowlands (where these exist) though these occupy only three per cent of the total land area (McLean 1980; writing of Lakeba in the Lau Islands of Fiji: UNESCO/MAB). Settlements invariably occupy some of the lowest land, affording easiest access to the sea for food and transportation.

Economic losses are therefore likely to be a higher percentage than land losses. None of the maps made available to this field reconnaissance mission, either by Ordnance Survey in Southampton or in Tonga, show land use in sufficient detail to make worthwhile assessments of economic loss in the islands. Apparent incompatability between information from different sources on cropped areas and crop production values has made not possible even semi-hypothetical assessments.

Moreover, as cropping is invariably diversified with two or more crops grown simultaneously per plot (eg coconuts with manioc or taro) assessments of production by crop may not be accurate as indicators of economic loss due to land use lost to sea level rise. The suggestions is that agricultural economic loss should be doubled to allow for diversified cropping, to which would be added the economic loss of animals and poultry.

Copra purchases in 1987 from the Ha'apai Islands were T$ 310,714, the highest for that year of all the island groups. If 5 per cent land loss can be assessed to equate to 20% production loss (due to some concentration on the coastal areas, then annual copra production would decrease to T$

248,571, a drop of T$ 62,000 as a maximum when a 1.5 metre rise in sea level has been reached. The world price of copra, and falls in production due to hurricanes for example, make fluctuations a normal experience of copra, and any other agricultural production. Would the effects of sea-level rise be to create a scarcity and thus raise the value of production lost?

These attempts to assess the economic impacts of rises in sea level, both for Nuku'alofa and for the islands assume a benign if rising sea. As hurricane incidence is likely to increase due to rise in sea surface temperatures, hurricanes and their associated sea surges are likely to cause even greater damage than in the past, and more severe losses to production (and to buildings) than accrued annual percentages of crop production deficit above. Losses to Tonga as a whole in 1982 due to Hurricane "Isaac" totalled T$ 23.5 million of which 60% was to infrastructure and agriculture ie other than to buildings. (US$ 20 million or £11 million: Lewis, 1988 Report No 1 p 21-23). The hurricane affected all island groups of the archipelago.

3. TUVALU

Context

Tuvalu is a chain, 580 kilometres long, of nine coral islands lying between five and eleven degrees south of the equator, just to the west of the International Date Line (Figure 8). Six of the islands are built around lagoons open to the ocean: Nanumea, Nui, Vaitupu, Nukufetau, Funafuti (Figure 9) and Nukulaelae. With the exception of Vaitupu, where the sea enters the lagoon at only one point, these six are all atolls consisting of numerous pieces of land (motu) linked by a reef and arranged like a string of beads. Of the other islands, Nanumanga and Niutau have completely landlocked lagoons while Niulakita has no lagoon at all, but a swamp, at its centre. Since it has never had a permanent population Niulakita, the southernmost island, was not taken into account in the naming of Tuvalu - "group of eight" (Laracy, Hugh; 1983). Each island has its own distinctive cultural identity, traditional dress and music.

Created by secession in 1975 from what formerly were the Gilbert and Ellice Islands, Tuvalu (Ellice Islands) became independent in 1978. A few years before, in October 1972, Hurricane "Bebe" and its associated sea surge riding on an exceptional spring tide, sent a series of waves of up to 15 metres onto Funafuti. Accompanied by winds of up to 150 knots, virtually all 125 village houses were destroyed together with government buildings damaged beyond repair. Five people died and 700 people were made homeless. Crops were annihilated (Ball 1973); copra production fell by 80%. An enormous ridge of coral-reef rubble, 19 kilometres long and up to 4 metres high, appeared overnight on the ocean facing coastline of Funafuti

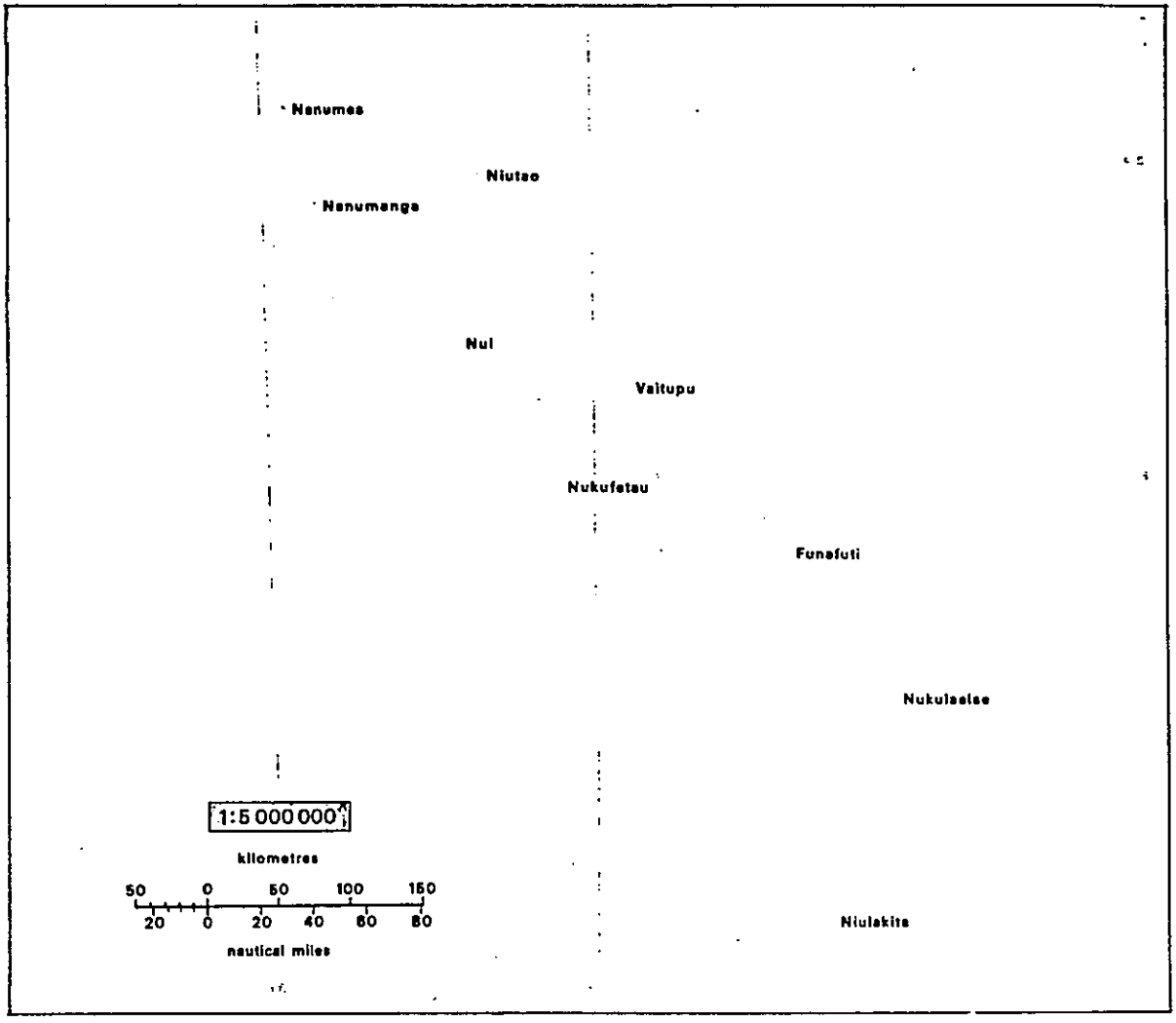


Figure 8: Tuvalu.

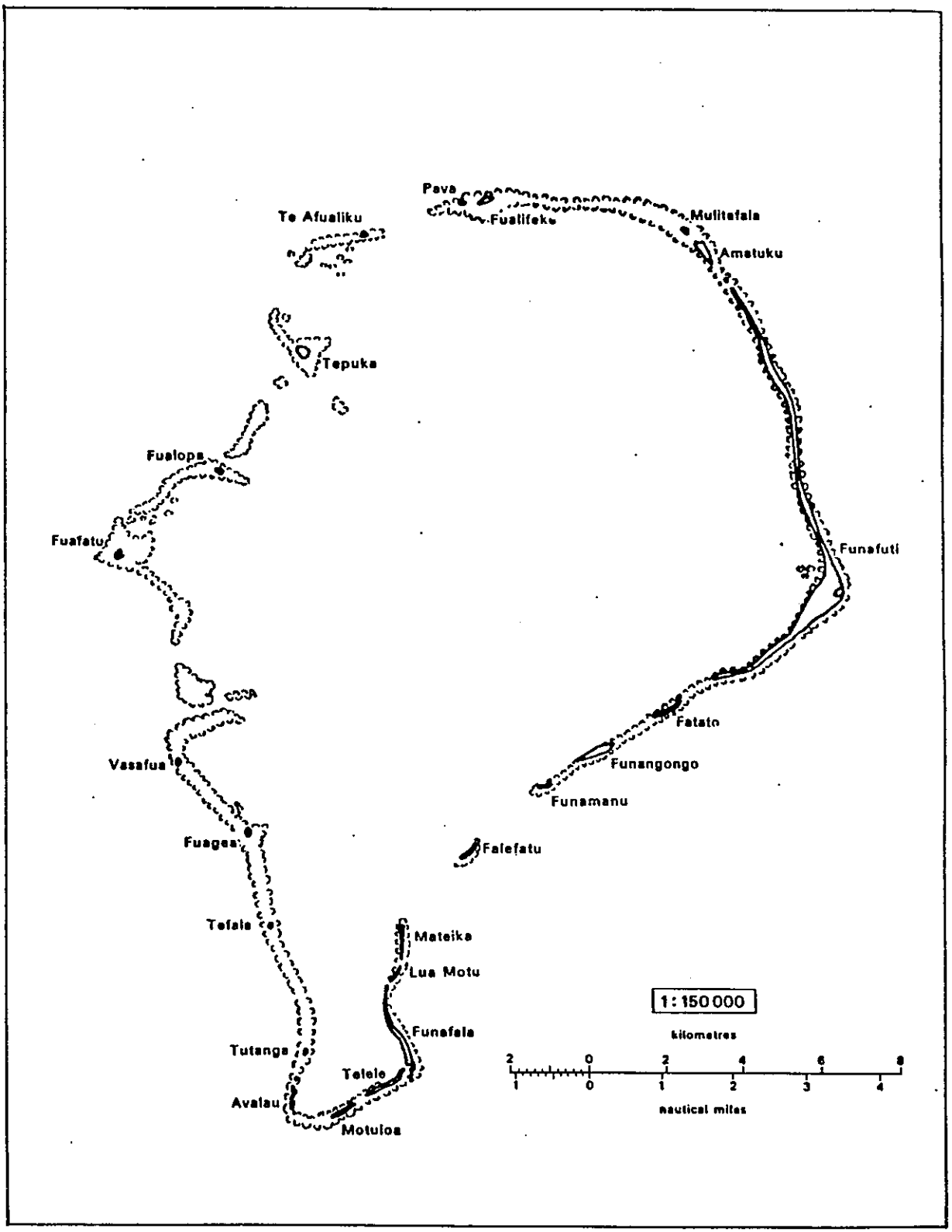


Figure 9: Tuvalu. Funafuti atoll.

enclosing a new inland lagoon (Baines and McLean 1976 and Figure 17a). Similar banks appeared on other islands, notably Nukufetau.

Hurricanes are comparatively rare in Tuvalu and nothing to compare with "Bebe" had occurred since 1891 (other hurricanes and severe storms are recorded for 1914, 1928 and 1958: Kerr, 1976). Total devastation, horrendous at the time, provided opportunity to replace and to reconstruct taking into account anticipated independence and growth of population on Funafuti - chosen as the capital principally because of the airstrip constructed by American forces during World War II (Ball 1973 and Figure 10). The 1968 population of Funafuti was 826; in 1979 it had increased to 2,120, and is now (1987) 2,718 (See Table 7).

High population densities have been normal on some islands since 1968 (and earlier); Vaitupu and Nukufetau showing marked increases, but no increase has matched that on Funafuti. Overall population for Tuvalu has increased by 32% since 1968, but over the same period population of Funafuti has increased by 70%, due to returnees since secession, natural increase and some migration from outer islands.

Tuvalu maintains a surplus on its current account by income from international aid and remittances from Tuvaluans working overseas (Government of Tuvalu; 1988). "Tuvalu's economy is small, fragmented and highly vulnerable to external influences": as is its economy, so it is in its topography and population.

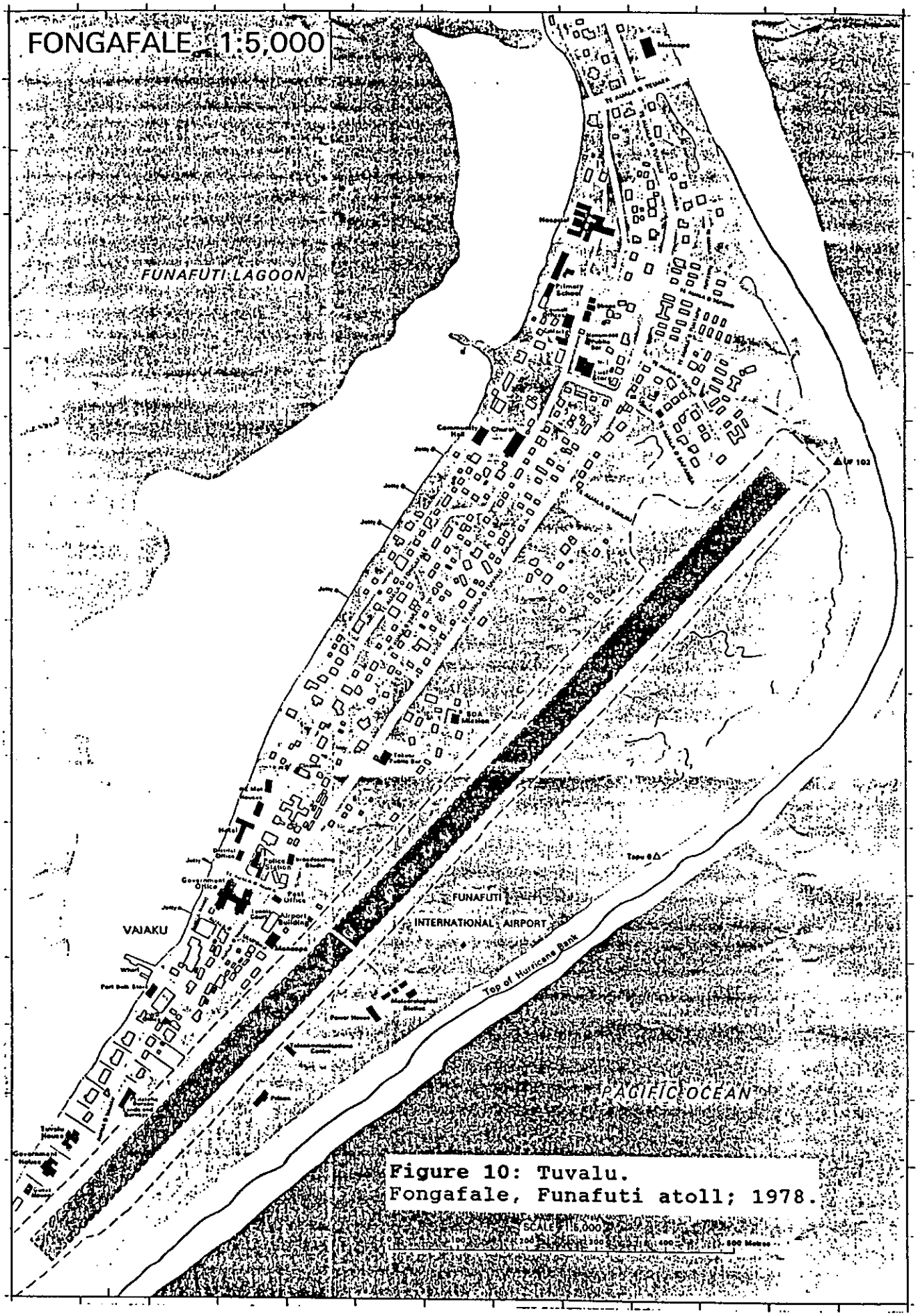


Figure 10: Tuvalu.
Fongafale, Funafuti atoll; 1978.

TABLE 7

Tuvalu: Island populations, areas and densities

Islands	Area (sq km)	1968	1968 %	1968 Population per sq km	1973	1979	1979 %	1979 Population per sq km	1983	1987	1987 %	1987 Population density/sq km (1987)
Nanumea	3.61	1,076	18.6	298	977	844	11.5	236	906	965	11.4	270
Nanumanga	3.10	585	10.1	188	587	605	8.2	205	762	717	8.5	243
Niutau	2.26	796	13.8	352	907	866	11.8	408	917	867	10.2	409
Nui	3.37	569	9.8	169	569	603	8.2	183	650	622	7.4	189
Vaitupu	5.09	876	15.1	172	948	1,273	17.3	260	320	1,437	17.0	293
Nukufetau	3.07	646	11.2	210	620	626	8.5	205	739	722	8.5	236
Funafuti	2.54	826	14.3	325	871	2,120	28.9	898	2,620	2,718	32.1	1,152
Nukulaelae	1.66	354	6.1	213	343	347	4.7	204	355	335	4.0	197
Niulakita	.41	54	0.9	131	65	65	0.9	156	95	75	0.9	183
Total	**25.11**	**5,782**	**100.0**	**230**	**5,887**	**7,349**	**100.0**	**301**	**8,364**	**8,458**	**100.0**	**347**

Land, land erosion and land values

The total land area of Tuvalu's nine islands is 25 sq kilometres (9 square miles). Areas of each island (Table 7) range between one and a half and five square kilometres. Tiny Niulakita (not permanently inhabited) is 41 hectares, less than half a square kilometre.

Nowhere do the islands of Tuvalu rise more than 4.6 metres above mean sea level (Government of Tuvalu: 1986), most land area being much lower. Detailed survey information is available only for part of Funafuti. Records of recent high tides (spring and autumn 1988) show that parts of Funafuti are prone to sea flooding at least twice a year (photographs on Government file September 1988: Secretary to Government and see Table 8).

A characteristic of Tuvalu's land formations is the extraordinarily high ratio of coastline length to island size. For example, although the land area of Funafuti atoll is 2.5 square kilometres, its total shoreline length is about 54 kilometres (McLean 1980a).

Exposure to the sea on the extended coastlines of tiny land areas makes land erosion a serious problem (Appendix 1). Storms, particularly when coinciding with high tides, have caused damage to coastlines and to sea walls, both on the ocean side of islands and on the lagoon side according to prevailing winds. (Westerley winds in November to April may cause storm damage on the normally sheltered lagoon side of Funafuti [Meteorological Service] and Figure 11a). Additionally, tropical storms and depressions in the area may be the cause of coastal damage (eg Tropical Cyclone "Ann" was a tropical depression over Tuvalu causing damage to coastline works at Funafuti: USAID/OFDA 1987).

TABLE 8

Tuvalu: Island elevations and high tide records

(Source: UN Cadastral Survey Project, Tuvalu)

Island	metres above zero datum(1)	metres above mean sea level(1)	recent highest tides above zero datum(2)
Nanumea	3.482	2.44	
Nanumanga	7.912	6.87	
Niutau	6.10	5.06	
Nui	3.162	2.12	
Vaitupu	3.382	2.34	
Nukufetau	3.302	2.26	
Funafuti	4.122(3)	3.08	2.496
Nukulaelae	3.162	2.12	
Niulakita	9.658	5.35	

(1) Reading taken from survey reference points: not necessarily the point these represent "average" elevations.

(2) 17/18 February and 17/18 March 1988.

(3) Survey data, available only for Funafuti, shows numerous elevations lower than this reference point. At times of highest tides, twice a year parts of Funafuti atoll are flooded to depths of up to 0.6 metres (1' 9").

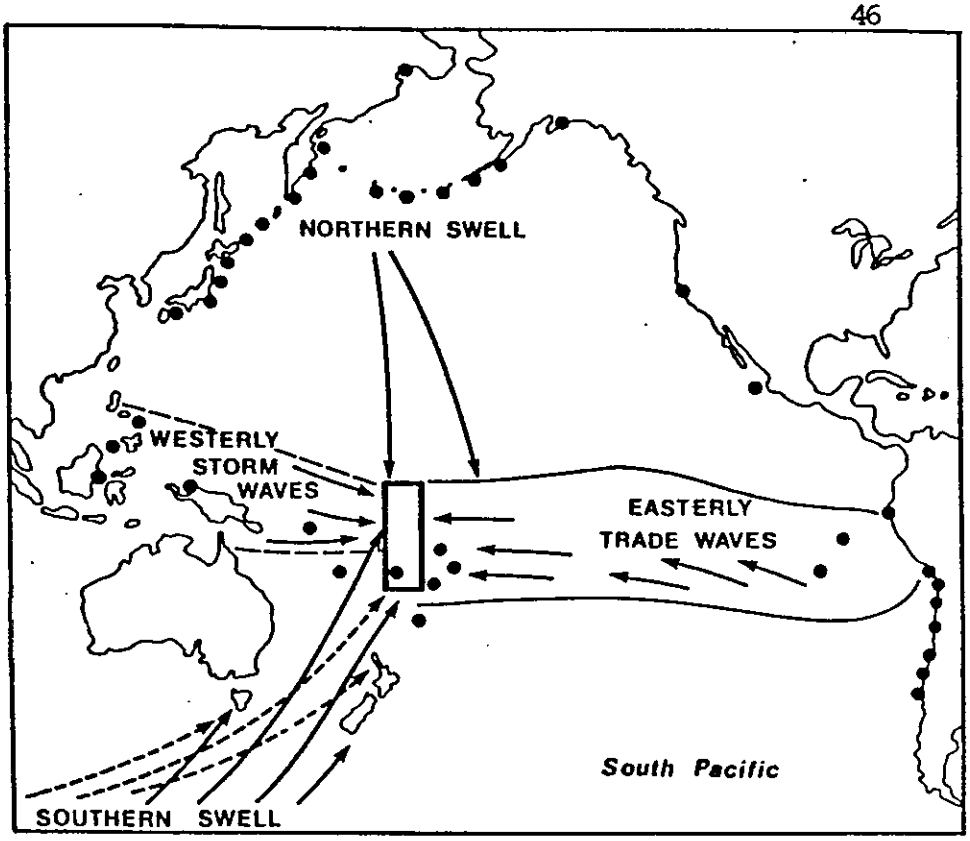
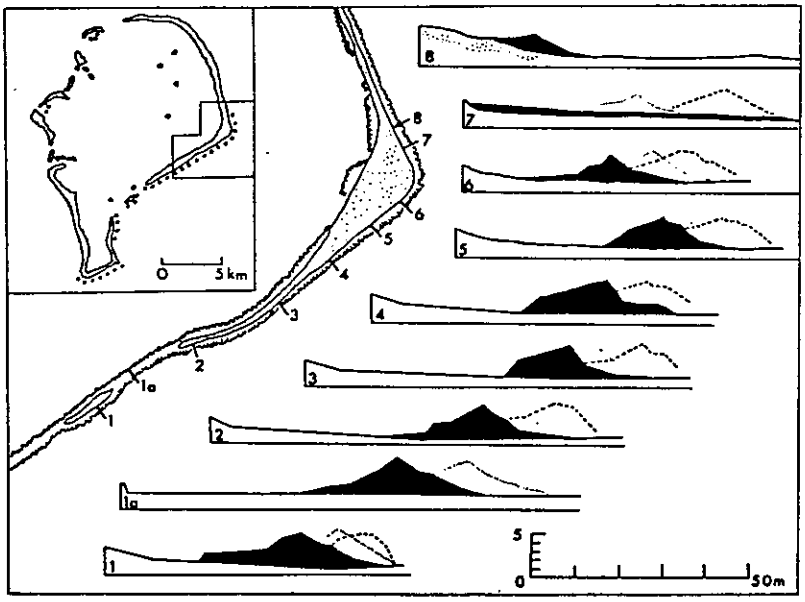


Figure 11a: Tonga & Tuvalu.
Swell, winds, waves and tsunami generating earthquakes. (Source: McLean 1980).



Rampart crest heights and landward movement of crests at eight locations in 1972, 1973 and 1975

Profile No.	Beach crest height (m)			Landward movement of crest between surveys (m)	
	1972	1973	1975	1972–1973	1973–1975
1	3.6	3.8	3.7	6.7	9.2
1a	—	4.0	4.3	—	16.5
2	3.9	3.9	3.6	9.4	7.0
3	3.9	3.9	3.5	9.2	9.0
4	3.6	3.9	3.2	6.7	2.7
5	3.5	3.9	3.7	10.0	2.7
6	3.6	3.7	3.3	7.0	9.2
7	3.1	2.7	—	20.0	—

Crest heights are related to reef flat level which is approximately low water level.

(Source: Baines & McLean, 1976).

Figure 11b: Tuvalu. Funafuti; hurricane bank profiles - in December 1972 (dashed) November 1973 (dotted) and January 1975 (solid) on reef flat (at approx. low water level). Dotted line on inset map indicates location of storm beach on Funafuti atoll. Profile 8 represents the expected final form - in the absence of severe storms - for all parts of the storm beach.

Tuvalu's land is too precious to be lost to the sea; conversely however, the sea has created land. The 19 kilometre "hurricane bank" created overnight by Hurricane "Bebe" and its associated sea surge, to a height of up to 4 metres by the shifting of thousands of tonnes of coral reef debris, added up to twenty per cent in land area to islands of Funafuti atoll. This additional "land" is an inland lagoon at Funafuti's widest part (adjacent to the air strip). Since its creation in 1972, the crest of the bank has reduced as the result of wave actions (and by the removal of material for construction), and has moved landward. (Baines and McLean 1976; Figure 11b and photographs: Figures 17b and c).

Tuvaluans value their land above any other of their possessions; so much so that monetary values are regarded as something separate from land. Money could not buy Tuvaluan land, money being unmistakably second to land in the Tuvaluan scale of values (Samuelu in Laracy 1983). As land is thus never sold, land values do not exist. Land is however occasionally leased, currently at A$ 123.50 per hectare per year for land leased by Government from its owners. (A$ 50.00 per acre: Lands Office, Funafuti).

Land-use; agriculture

A distinctive feature of Tuvaluan agricultural land-use are pulaka pits, found on all islands. These are flat bottomed, originally straight sided pits varying from 25 square metres to over a hectare (the largest pit in 1976 was 2.9 ha on Niutao) and dug down to just below the mean water table level. The bottom of the pits are covered with vegetative refuse to form a mulch to the level of high water of groundwater lenses which rise and fall with high tide (Flynn and Makin 1976). The pits are used mainly to grow pulaka (giant taro) and taro-edible root crops.

Many pulaka pits have been dug in natural land depressions or where the groundwater table is not a great depth from the ground surface; hence the pits are often sited near the sea where the groundwater lense is at its thinnest and where salt water is closest both laterally and vertically.

Many pulaka pits have become saline, either due to erosion of land by sea action (eg Nanumanga, where the sea is within a few metres of the pit) or where the groundwater lense has been disturbed. (There is no groundwater lense on Funafuti, said to have been destroyed as a result of air strip construction during World War II).

Ancient in origin, pulaka pits provide for a range of agricultural food produce, beyond that of coconuts and breadfruit, that in the coral sand and gravel would otherwise not be possible. However, in 1976, many pulaka pits had become abandoned due to salinity, principally by lateral seepage at high tides. (Flynn and Makin, 1976 p 55).

No survey exists of pulaka pits (though a survey is said to be under way), and no production figures for pulaka or taro are available.

Salinity is also caused, or exacerbated, by sea flooding and by blown spray.

Every household is engaged in some form of agricultural activity (Department of Agriculture, 1986) but on an "advanced subsistence" basis where extended family sufficiency in food is the main criteria on the basis of exchange, commercial gain being a secondary consideration. Economic values in agriculture therefore cannot be assessed. Dependancy on erratic

copra production has declined in favour of remittances from employment overseas. Production of copra has declined steadily in recent years. Copra production per island with the national total for 1986 is shown in Table 9.

TABLE 9

Tuvalu: Copra production by island, 1986

(Source: Department of Agriculture, 1986)

Island	Production Tonnes	Value A$
Nanumea	11.91	1,504
Nanumanga	42.57	6,050
Niutau	19.24	2,851
Nui	41.65	6,122
Vaitupu	97.64	13,651
Nukufetau	3.13	473
Funafuti	-	-
Nukulaelae	4.08	541
Niulakita	18.75	2,250
Total	**238.97**	**33,442**

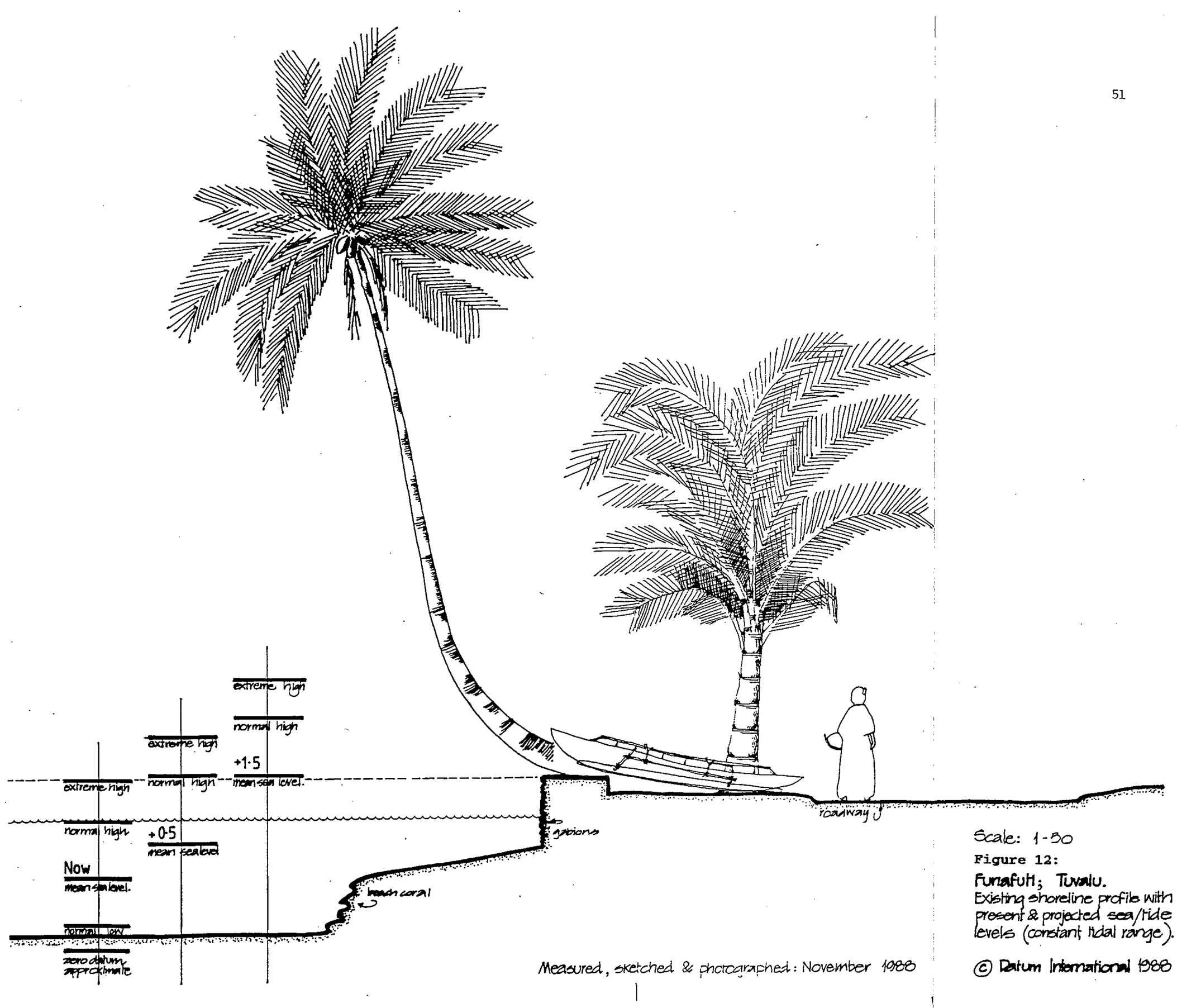
The effects of sea level rise

Pulaka pits and their agricultural food production are already the first casualties of intermittent rise in sea levels as the result of seasonal high tides. They would be the first permanent casualties to a long-term increase in sea level. Although the depth of groundwater lenses is not easily ascertained, because of prevailing salinity in the outer islands as well as in Funafuti, it can be assumed that any rise, not only that of half a metre, would have a severe effect on pulaka, taro and other crops given in the pulaka pits.

High tides for two to three days twice a year now kill or severely set back root crops. Tree crops are less easily affected by saline water penetrations to their roots; shallow rooted coconut palms are the least affected and said to have improved flavour when planted on the sea shore. Neither are breadfruit and bananas affected by porosity induced sanility. (Blown spray causes salt-burn to the foliage of both root and tree crops).

Large proportions of the total land area of Tuvalu would remain above the normal tidal range upon a sea level raised by half a metre. It is questionable however whether an already fragile material existence could continue, were the sea to rise for the long-term beyond that level (Figures 12; and 18a, b, c).

The sea however is not a benign or constant phenomenon. Abnormal, twice yearly high tides on top of a raised sea level of any dimension, would cause deeper and more extensive sea flooding than that which now occurs. Storm waves would cause more coastal erosion (and thus induce more



Measured, sketched & photographed: November 1988

Scale: 1-50

Figure 12:

Funafuti; Tuvalu.
Existing shoreline profile with present & projected sea/tide levels (constant tidal range).

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flooding), salt spray would be more penetrating and thus more damaging, and sea surge associated with a higher incidence of tropical cyclones (hurricanes) in seas of higher temperatures would inundate and cause catastrophic damage to more islands. All of these phenomena over and above a raised sea, are intermittent; only the level of the ocean is itself "permanent".

Assessments of economic loss to food production are not possible with existing limitations on information. They would in any case be academic, since if sea level were to cause whatever economic losses to any one production or activity sector, it would have already caused losses to other sectors at the same time, whether these were assessable or not, whether they were economic or social, and whether or not such losses were surmountable.

Inundation of atoll reefs offshore will result in increased wave energy on the shoreline and reduction in the natural supply of reef-rock protective debris. Sharp increases in coastal erosion can be expected as an early result of rising sea levels (USP 1988) unless the rate of rise is slow enough to allow natural coral growth.

Construction of defences against the sea could provide protection against its force (of waves or surge) but due to the porous nature of coral substrata, water would flood above ground level by seepage to a degree reflecting sea level at the time. Water will find its own level. Economic equation of the cost of sea defences is thus also hypothetical, as the land thus "protected" would remain subject to flooding and have consequently less production capacity. In any case, land itself has no economic value

(above). Moreover, because of the high ratio of coastline length to land area (above), sea protection measures could not possibly be cost effective on a purely economic basis; one sea wall on one side would be protecting the rear of the other - with little left of any usefulness in between!

A strategy for sea level rise

In view of the foregoing, it might seem that strategies for Tuvalu against a rise in sea levels are out of the question! In the view of this Report, this is not so. It is important to keep in mind the following:

1. Especially from academic and scientific sources within countries of the South Pacific, there is some argument against the probability of severe measures of sea level rise. A healthy cynicism prevails. Additionally there is information on oceanic phenomena which suggest a postponement of any rise in sea levels (eg Linden 1988; Scherer 1988).

2. Amongst scientists who are advocating a probability of sea level rise, there is no common agreement as to its dimension or its rate (though it would be prudent to accept the possibility).

3. For strategies to be proposed, understood and implemented it is crucial to replace the imagery of catastrophic inundation (which in its imagery is immediate in effect) with a more practical realism;

   a) the first effects of sea level rise will be intermittent, not permanent. Storms, flooding and salinity will increase and subside, and increase and subside again. Though the periodicity of increases may reduce and the number increase, there will be periods of "normality" in between.

b) Against the immediate imagery of catastrophe there is little that can be done; but against reality over time there are many things that can be done - some are already being undertaken, more than likely for reasons other than sea-level rise (below).

c) The threat of sea level rise cannot effectively be managed by any one sector; natural hazards have no sectoral boundaries. An overall strategy against the hazardous implications of a rising sea has to be formed from a simultaneous application of a variety of measures in numerous government sectors. For Tuvalu they belong to the following activity areas:

- agriculture and food production
- housing
- water supply
- health
- land reclamation
- sea defences
- emergency management
- emigration.

Agriculture and food supply

The possible further demise of pulaka pits suggests the need for a wider diversity of vegetable and other crops; both on Funafuti, where the need for housing has taken over land previously used for agricultural purposes and where population is way beyond that which food production on this island can sustain, and in the outer islands whose produce is sent for sale in Funafuti. Developments in sweet potato production have been successful, introduced to assist self-sufficiency in food production. Grown on mounds

upon natural ground level, not requiring mulch pits but grown by hydroponic methods, the sweet potato is thus not vulnerable to salination by ground porosity.

Where ground crops are at risk, fish become even more important as a food source. Fisheries development is also under way for the improvement of fishing for commercial production (with Japanese assistance). Developments of this kind, though pursued for different reasons, make domestic availability of an alternative food source the more assured. Or, conversely, in view of the possibility of sea level rise and its implications, fishing development will have to be even greater than hitherto if it is to keep up with the potential of increased domestic demand.

Fisheries development is inclusive of landing and offloading facilities, storage, transport and collection improvements, many of which will be of usefulness beyond that of fish marketing. Vegetable marketing, communications and overall cash economy will also be assisted.

Housing

On Funafuti, only eleven per cent of houses are of the traditional kind (Government of Tuvalu 1988, Table 8.1) with the floor raised up to a metre above ground level. Although some new non-traditional semi-prefabricated imported houses[1] do have a raised floor, these are relatively sophisticated, costly and so far few in number. The small number provided

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(1) Lami Modular Homes, Lami, Fiji.
Basic model (1001) 2 bedrooms/500 sq ft: F$ 10,500.00.
De Luxe model (1005) 3 bedrooms/9,000 sq ft: F$ 25,000.00

with Australian aid, are for government officers' use. Overall, it is anomalous on terrain so widely vulnerable to intermittent flooding, that there should have been a major shift to "westernised" house building with concrete or other floor at ground level.

A new building code however, aimed to become effective in 1989, will have amongst its objectives, the requirement of a raised floor level to a height 300 mm greater than that provided by the semi-prefabricated imported house types. The new code will also take into account construction quality sufficient to better resist strong winds.

Water supply

On Funafuti where there is no fresh water lense, and on other islands where lenses have become brackish, the collection of rainwater for drinking purposes is crucial for survival. A A$ 2 million UNDP project not yet completed, will provide every dwelling with a minimum 1,000 gallon rainwater tank (to provide 50 litres/day/person for a possible two week period without rain). The project also provides for community cisterns.

The new building code for 1989 will require the provision of rainwater storage to all but traditionally thatched houses. Traditional houses will continue to be supplied from community cisterns. A Save the Children (USA) project will provide outbuildings to all traditional dwellings, with sheet material roofs for the collection of rainwater into tanks.

Health

In a situation where natural hazards are likely to increase, the health condition of people is crucial for their own as well as community survival

and reconstruction. Housing conditions and accessibility to fresh water are constraints upon personal hygiene and health: the intake of salt in water and food (eg salted fish) can lead to hypertension and high blood pressure. The introduction of improved storage facilities will reduce the consumption of salted fish, and improved rainwater collection will reduce the intake of brackish water.

Common conditions of ill health in Tuvalu are skin sores and mild diarrhoea in infants, both exacerbated or transmitted by flies. Filiariasis (elephantiasis), an infection of the lymph glands, is transmitted by mosquitoes. Environmental health programmes for the eradication of these vectors are thus crucial to health and well-being. Methods for improved rubbish disposal should be introduced in Funafuti as soon as possible. Present use of "borrow pits" and other dumping grounds is both wasteful of land and has become an environmental health hazard.

There are areas of Funafuti (population density 1152/sq km: Table 6, p 35) that are beginning to display symptoms of overcrowding, environmental degredation and consequent health hazards comparable to some urban peripheries of major cities.

Land fill

Borrow pits still exist, having been created by the excavation of material for the construction by American forces of the airstrip on Funafuti during World War II[1]. These have become both official and casual rubbish dumps, flooding and drying according to tides. The filling of borrow pits,

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(1) Two other islands had airstrips constructed in World War II, Nukufetau and Nanumea; it is not known if borrow pits exist on these islands.

possibly by the pumping of coral sand and gravel from the sea bed, would both create land which is in short supply and remove an environmental health hazard.

In addition to the borrow pits, is the inland lagoon created by Hurricane "Bebe" and the hurricane bank. In the prevailing situation of land shortage on Funafuti, the filling of the lagoon would help materialise some of the twenty per cent of area created by the hurricane. (Baines and McLean, 1976). Sand and gravel pumping from the sea is accepted practice in some other locations and may be possible on Funafuti.

It is understood that were such landfill to be undertaken, questions of land ownership could arise, regard for land in this case militating against land creation. It is also understood however, that there are many ancient land claims to be settled (Samvelu in Laracy 1983), that surveys are underway which might help to clarify some of these - which could and should include those which might arise from land infill and reclamation.

Stabilisation of the hurricane bank

The hurricane bank provides protection to almost all of Funafuti (as do the hurricane banks on Nukufetau and other islands) from storms and lesser hurricanes and their sea-surges. Its erosion by removal of material for construction purposes should be stopped by immediate legislation and control.

Additionally, and with the advice of marine morphologists, ecologists and engineers, the stabilisation of the hurricane bank should be considered so

as to permanently capitalise on its protection in association with the landfill of its lagoon.

Prevention of coastal erosion

A current programme of protection against coastal erosion is in operation throughout the islands, but is said to be inadequate, having already suffered some destruction and damage by the sea (eg Nanumanga and Funafuti; 1987: reference also Fawcett, 1982). At least three times more costly construction is required to effectively protect land against the sea. Additionally, and so as to take account of rising sea levels, works of erosion protection should be designed as the first stage of foreshore works, to be incrementally increased as sea levels rise. It seems anomalous, once again, (see above: housing) that the Tuvaluan regard for land has not lead to the procurement of a greater investment in protection against land erosion by the sea. Erosion prevention not only stops the disappearance of land to the sea, but also prevents flooding of remaining land and salination of pulaka pits. Coastal erosion can also be resisted by strategic planting of coconut and mangroves, for example.

Along with coastline protection must be included protection for reefs. Coral reefs are a crucial natural and living protection of coastline against ocean waves and swell and must be protected at all costs. At least one recent report (not yet adopted) by a firm of civil engineers has recommended the blasting of reefs for construction material.

Emergency Management

With the likelihood of increased incidence of storms and tropical cyclones (hurricanes) and an increase in their damaging effects, the effectiveness

and scope of existing Disaster Preparedness should be upgraded, extended to include preventive measures and vulnerability reduction and to be a source of specialist advice to the Tuvaluan Government. Assistance can be made available from the Commonwealth Science Council and the United Nations (UNDRO). (See Report No 1: Sections 7 and 8; Lewis 1988).

Information on sea-level-rise and its implications should be incorporated into emergency management curricula, which in turn should be widened to include vulnerability management and its relationship to development planning.

Conversely, Tuvalu's heritage of hazard experience[1] particularly of those associated with the sea, should be made to become the source for future preparedness programmes.

Migration and Emigration

Migration within the Tuvalu island population is traditional; by common consent, communities in recent history have moved from one island to another and currently the community on Nukufetau is considering relocation on that island due to the effects of coastal erosion.

Emigration is also traditional, but in parallel with other strategies formulated and implemented "at home", Tuvalu requires the relaxation of immigration restrictions by other Pacific nations as a special case for itself and Kiribati. There are already Tuvaluan communities in New Zealand and in Suva, Fiji (and the island of Kioa in the Fiji group is

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(1) Tuvalu experiences hurricanes, tsunamis, drought and occasional earthquake (eg Richter 7.3: 1909). See also Figure 11a.

owned by Vaitupu, Tuvalu). These pioneer emigrant communities should be allowed to become the cultural and social base for further emigrants from Tuvalu; now, to reduce pressure of population already at impressive densities on most islands, and for a future expected rise in sea levels which will further diminish Tuvalu's 25 square kilometres of land area.

Development Assistance

Tuvalu receives development assistance principally from the United Kingdom, Australia, New Zealand, the EEC, Canada, USA and the Federal Republic of Germany (Government of Tuvalu; Planning Office 1988). Efforts may be required to increase the understanding and co-operation of aid donors, with regard to sea level rise and its associated environmental and social implications. Their assistance is crucial for projects contributory to Tuvalu's survival from sea level rise, which may otherwise appear to be out of proportion to Tuvalu's area, population and current budget.

Information and training

Requests have been conveyed to this mission for regular information on the subject of sea level rise and its likelihood and implications. In association with this expressed need, is the opportunity for short workshop and training programmes to cover the practical implications of the topic. Workshops could be arranged regionally through the auspices of the South Pacific Forum, or preferably could be arranged to travel from one island country to another, thus reaching larger audiences in each country. Tuvaluans have a healthy and informed interest in the topic of sea level rise that deserves specialist support (Puapua and Temoana 1988).

These recommended strategies to take account of the implications of sea level rise, range from the simple to the complex. However, some projects are already being undertaken in Tuvalu for other reasons and require only reinforcement; others are envisaged for the future and require an upgrading of their present priority. Strategy against the implications of sea level rise begins with a rearrangement of development priorities. In place of a current (almost) half of the present development budget being appropriately spent to 1988 on marine transport, agriculture, for example, will need to be increased from 7%; and works and communications will need to increase significantly from 3.5% to include coastal erosion and protection.

It will not be only for Tuvalu to relate the implications of sea level rise to development planning, but also that of the international development assistance fraternity. At a time when environmental issues are rapidly gaining ground in the national and international political arenas, sea level rise demands increased and wider understanding if the proportionally greater needs of countries like Tuvalu are to be responded to in time.

The implications of sea-level rise are not however matters only of economic and financial assistance; they require also understanding, social and cultural compassion, and above all - international political will.

Citadels-in-the-sea

Civil engineering works must be included as a part of the strategy for Tuvalu against any rise of sea levels, though the cost effectiveness of such construction will be negative, until social and cultural values and international political will is brought into account. That it would be "cheaper" to evacuate Tuvalu's eight and a half thousand people is not in

question, but the social and cultural consequences of such action certainly is.

Sea walls themselves however will not prevent flooding through the porous coral substrata of great depths[1]. Sea walls could however be accompanied by land reclamation and land infill to raise levels of selected areas of land.

Table 10 shows the overall cost per hectare of creating citadels-in-the-sea constructed upon existing land forms or upon lagoon-bed coral rock in shallow waters, linked by causeways and served by airstrips of similar construction (Figure 13). Circular constructions of diameters from one to ten kilometres are evaluated. Costs per hectare for a half metre depth (on top of existing land levels) are suggested as a minimum of A$ 14,000 (1 km diameter) rising to A$ 145,700 (10 km diameter). The cost of airstrips, similarly constructed, has not been included in these calculations; neither has the cost of linking causeways.

Thus, costs of creating new land are astronomic, compared to the annual payments for land leased by Government (A$ 123.50 per hectare: p 47) not to mention minimal production values. The cost of creating citadels would however be more cost-effective than the construction of sea defence (and raised land between) along the coastlines of existing linear and attenuated land forms.

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(1) Royal Society investigations in 1896/98 showed coral rock to be to a depth of 340 metres on Funafuti; in 1952 at Eniwetok coral rock was proved to go to depths of 1,290 metres before volcanic rock was found: Laracy 1983.

TABLE 10

Citadels-in-the-sea

Sizes, costs and unit costs (A$: A$ 1.97 = £1.00)

Diameter km	Area[1] (sq km)	Perimeter metres	Height	Costs[2] wall	+ fill[3]	= Total	per hectare
1	.7855	3,142	0.5	1,398,190	5,891	1,404,081	14,040
			1.5	2,796,380	17,674	2,814,054	28,140
2	3.142	6,284	0.5	2,796,380	23,565	2,819,954	28,199
			1.5	5,592,760	70,695	5,663,455	56,634
5	19.6375	15,710	0.5	6,990,950	147,281	7,138,231	71,382
			1.5	13,981,900	441,844	14,423,744	144,237
7	38.4895	21,994	0.5	9,787,330	288,671	10,076,001	100,760
			1.5	19,574,660	866,014	20,440,674	204,406
10	78.55	31,420	0.5	13,981,900	589,125	14,571,025	145,710
			1.5	27,963,800	1,767,375	29,731,175	297,311

Notes

(1) Airstrip and causeway costs not included.

(2) Costs based upon Tonga Foreshore Works (Japanese contract: see Appendix 2)
(T$ 484 = A$ 445 per metre)
0.5 m height inclusive of foundations; x 2 for cost of 1.5 m height on same foundations.

(3) Fill cost taken as A$ 15.00 per cu metre assumed pumped from lagoon sea bed.
NB **Not reef material.**

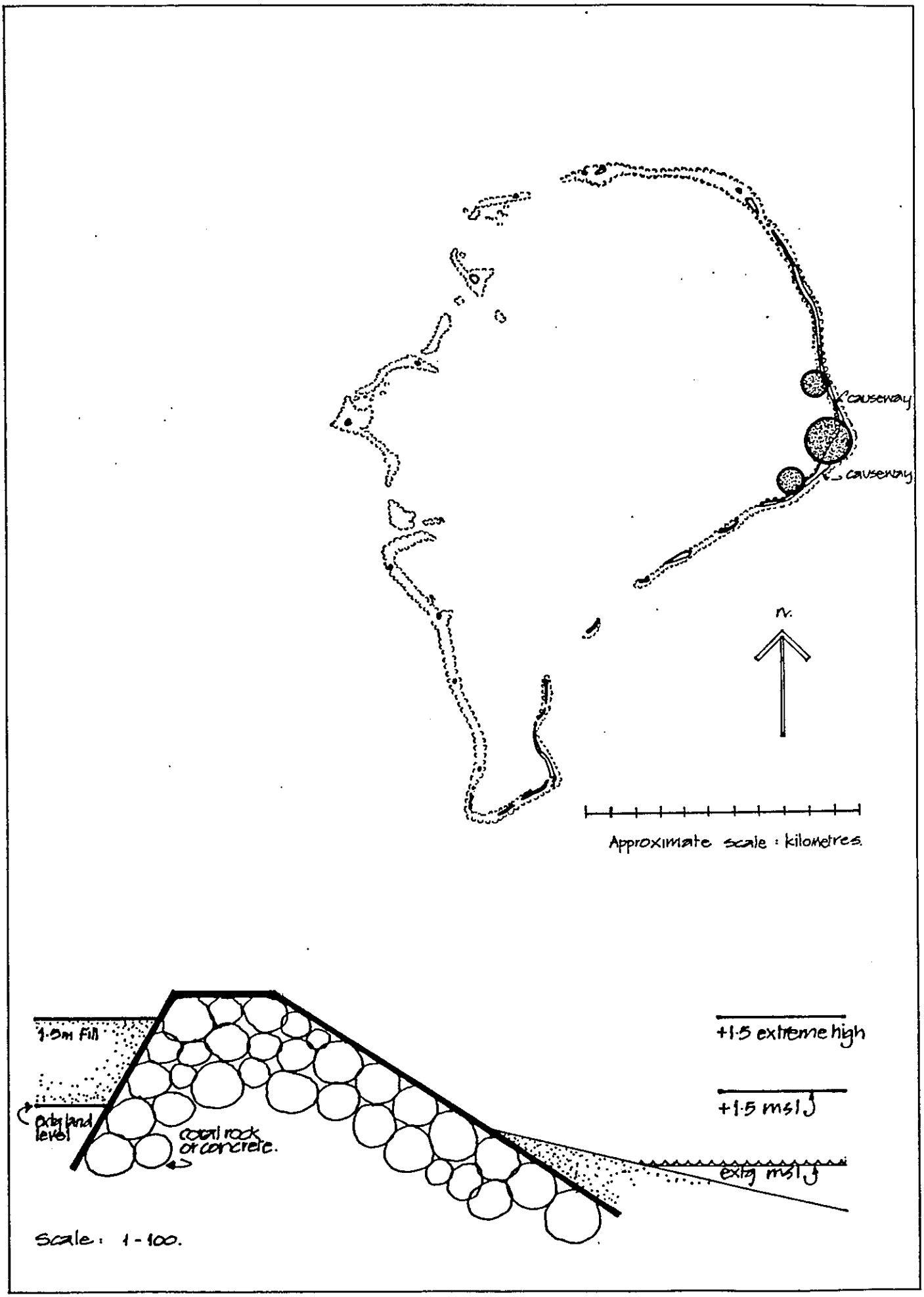

Figure 13: Tuvalu.
Funafuti atoll; citadels-in-the-sea.
© Datum International 1988

What kind of lifestyle might be possible on these "citadels", and the degree of social and cultural upheaval required for their construction and occupation, are questions in themselves possibly sufficient to rule out the possibility of their adoption - without the need for economic evaluation. Nevertheless, these figures convey the enormity of a problem perhaps best additionally considered in its cultural, social and political dimensions. The preservation of a strategic ocean outpost may well have an appeal in contexts of international political economy.

Lagoon infill has been undertaken in Malė, the capital of the Maldive Islands (Department of Public Works and Labour [Malė] 1986). It could be considered similarly for some islands of Tuvalu for selected areas of lagoon maintaining a natural reef line offshore.

4. KIRIBATI

Note: Prior to arrival and during time in Tuvalu, Marshall Islands Airways Services were "suspended indefinitely" due to problems with fuel supplies. Onward travel planned to Kiribati was thus not possible. Some research on Kiribati was undertaken in Suva by courtesy of the South Pacific Forum Secretariat.

Context

Kiribati comprises 33 islands in three groups:

a) the Gilbert Islands of 17 atolls, including Tarawa as the seat of Government (Figure 14a);

b) the Phoenix Group of 8 atolls halfway between the Gilberts and the Line Islands;

c) the Line Islands; 8 atolls spread over 2000 kilometres and some 3000 kilometres east of the Gilberts.

The total land area of Kiribati is 750 sq kilometres, but that of the Gilberts group is 285.5 sq km divided between its 17 atolls. Kiritimati (Christmas) Island in the Line Islands accounts for more than half of the total national land area (Table 11).

Population growth on urban south Tarawa (Figure 11b) has grown from 5% to 33% increase between the end of World War II (1945) and 1985. With increasing pressure on the viability of water, sewerage, power and road

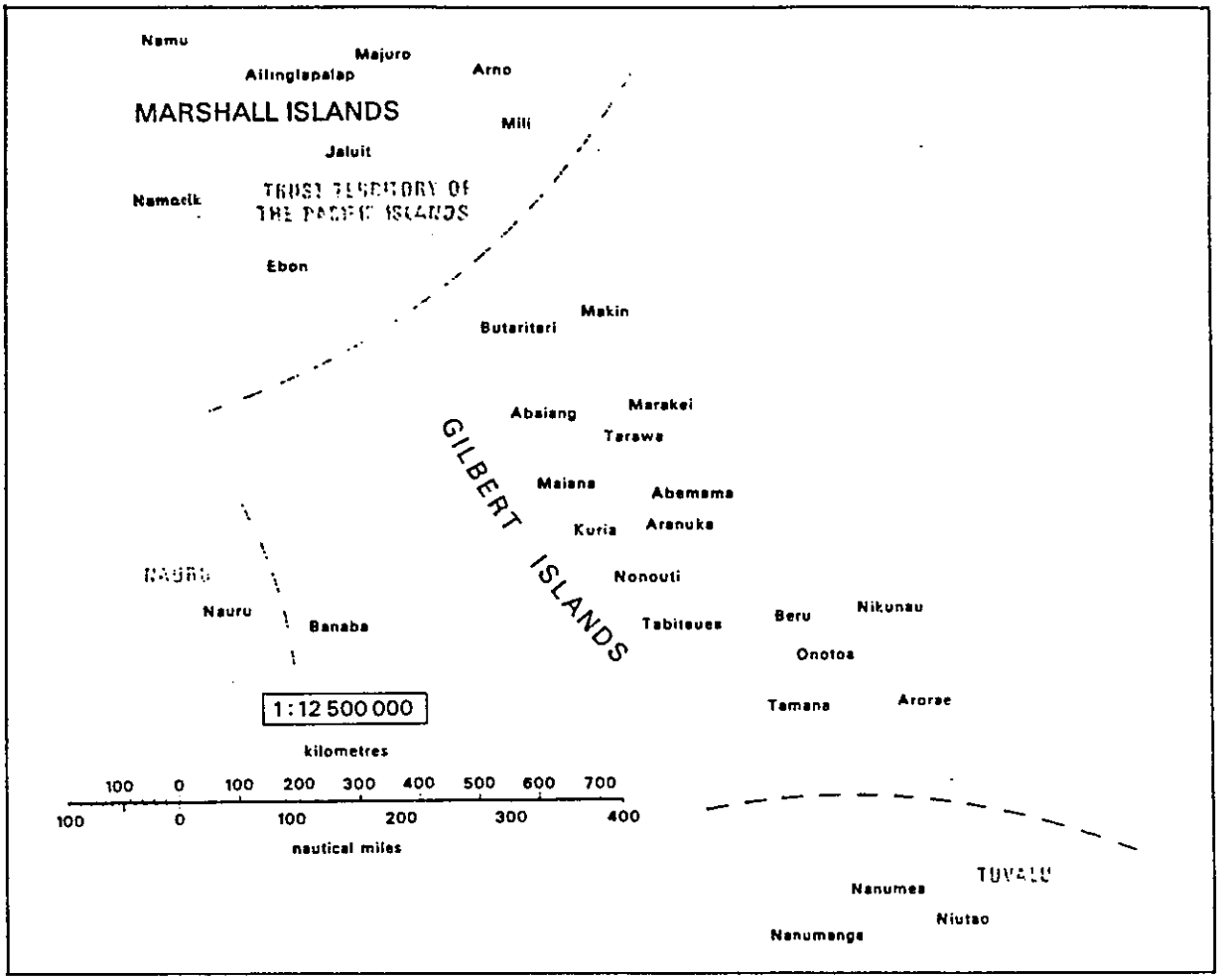

Figure 14a: Kiribati. The Gilbert Islands.

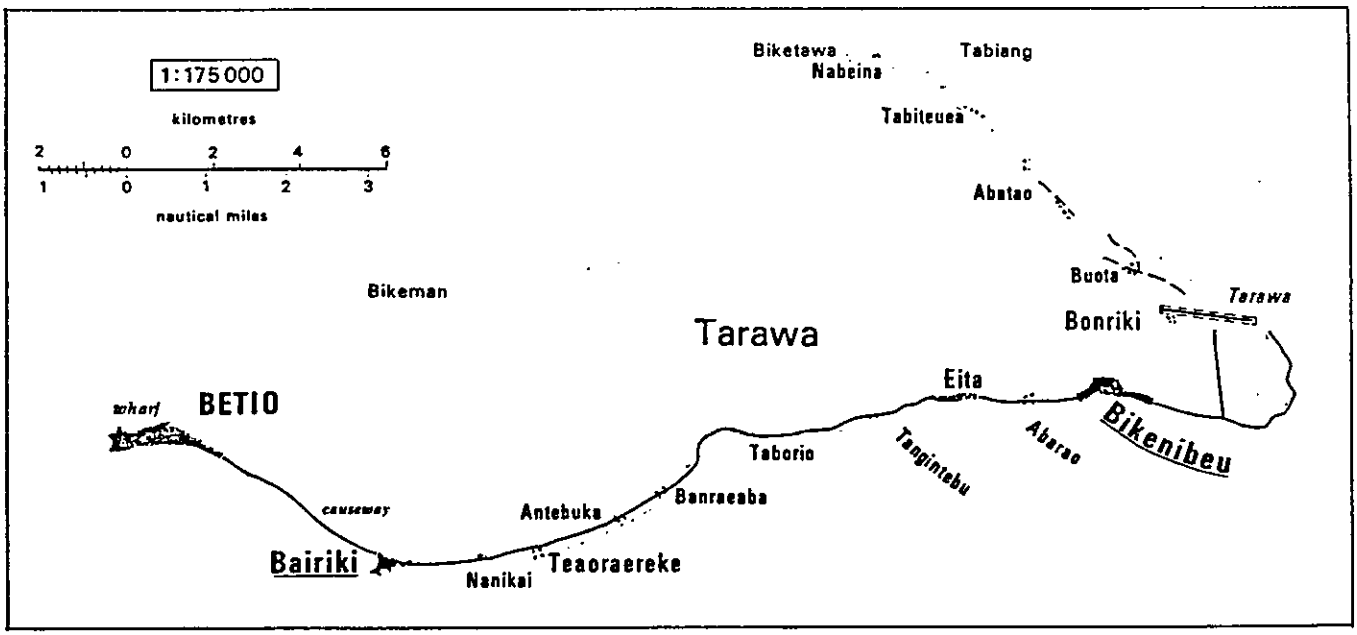

Figure 14b: Kiribati. Tarawa atoll.

TABLE 11

Kiribati: Areas and Populations by Island 1978 and 1985

Source: Government of Tuvalu, 1988

Gilberts Group	Est Area sq km	Population 1978 (Dec)	1985 (May)	1985 Pop Density
Banaba	6.2	2,201	46	7
Makin	7.9	1,419	1,777	225
Butaritari	13.5	3,149	3,622	268
Marakei	14.1	2,335	2,693	191
Abaiang	17.5	3,447	4,386	251
Tawara Rural	15.3	2,227	3,205	209
Tawara Urban	15.8	17,921	21,393	1,354
Maiana	16.7	1,688	2,141	128
Abemama	27.4	2,411	2,966	108
Kuria	15.5	803	1,052	68
Aranuka	11.6	850	984	85
Nonouti	19.9	2,284	2,930	147
Tabiteuea North	25.8	2,975	3,171	123
Tabiteuea South	11.8	1,182	1,322	112
Beru	17.6	2,212	2,702	154
Nikunau	19.1	1,829	2,061	108
Onotoa	15.6	2,034	1,927	124
Tamana	4.7	1,349	1,378	293
Arorae	9.5	1,527	1,470	155
	285.5	53,843	61,226	214
Line Group				
Tabuaeran (Washington)	14.1	416	451	32
Teraina (Fanning)	33.7	434	445	13
Kiritimati (Xmas)	388.4	1,265	1,737	4
	436.2	2,115	2,633	6
Phoenix Group	28.7	-	24	1

systems, if population growth in South Tarawa cannot be slowed, economic viability of the country will be greatly eroded (Ministry of Finance, 1988).

Principal exports are copra and fish. Phosphate mining ceased in 1979. Taro is grown for domestic consumption using pits dug to the freshwater lense (as the pulaka pits of Tuvalu).

Bairiki and Betio (Southern Tarawa) are connected by a causeway (Figure 14b) and are intensively developed for light industrial and commercial purposes, with an apparent correspondingly higher concentration of infrastructural and administrative infrastructure (than on say Funafuti, Tuvalu).

Kiribati atolls rarely rise more than 5 metres above sea level (Ministry of Finance, 1988). All land within the Gilberts Group is privately owned, except for small areas of reclaimed land which is Government owned. All land in the Line and Phoenix Groups is also Government owned.

With land-use saturation in Bairiki, Betio and Bikenibeu, one acres plots in the Line and Phoenix Groups are being offered for £1,000 to induce migration resettlement.

Nevertheless, this does not prevent squatter occupation of land on South Tarawa and Betio causing environmental health problems, although the last severe cholera outbreak was in 1977 causing 17 deaths and affecting a further 352 people.

Sea level rise: effects and strategy

With the significant exception of the intensive commercial and industrial activity of South Tarawa (Bairiki and Betio), the atolls of Kiribati appear to display similar characteristics and therefore have similar strategic requirements against sea level rise as the atolls of Tuvalu.

Bairiki and Betio are eligible for comparisons of the cost of sea defence construction with potential income from land and land use, of the kind relevant to Nuku'alofa (Section 2).

The causeway connection between Bairiki and Betio will be increasingly subjected to periodic inundation and severe erosion (Nunn 1988). Access will become more frequently interrupted by storms and high tides, and eventually will become unusable unless civil emergency maintenance programmes take into account the probability of sea level rise.

Plans for migration to, and resettlement of, Tabuaeran and Teraina (Washington and Fanning Islands), announced this year (Bauro 1988) could be given greater impetus by strategies against sea level rise being applied on behalf of these new settlements.

5. RECOMMENDATIONS FOR FURTHER STUDY

Further study is required and should be arranged to take account of the following:

1. The participation of representatives of the countries involved.

2. Workshops arranged in the region, or preferably in each country of those involved.

3. In most cases, the data required for calculations of areas of land use and production values are not readily or directly available (or do not exist); adequate project budgeting is required to allow man-hours for this process, working alongside appropriate locally allocated government officers.

4. Conventional economic assessments involving the value of land are not compatible with cultural traditions of land management. Future project frameworks must make allowances for alternative evaluation of land and land-use, based upon indigenous socio-cultural values.

5. The three island countries of this study comprise numerous islands: Tuvalu has nine; Tonga has 150; Kiribati has 17, 25 or 33. Not all islands in all cases are similar land formations. More inquiry is required to distinguish island types (atoll, raised; volcanic; etc) and to identify those low-lying parts of islands directly affected by sea-level rise. This will require local knowledge and/or island by island

field survey; maps with sufficiently sensitive contours and/or levels do not exist (with the exception of Nuku'alofa: WHO 1985).

Sample islands cannot be selected without the basis of their selection and representation being known.

6. Considerable care and attention must be devoted to the pre-arrangements for travel, if time wasting arrangements and rearrangements are to be minimised.

7. Arrival, departure, accommodation, local transportation and other project requirements need to be arranged in advance between the countries involved and the Commonwealth Secretariat.

The three countries of Kiribati, Tonga and Tuvalu are recommended (as a minimum) for further study. A project outline is proposed as follows:

- Team formation of environment/human settlements consultant, surveyor/ engineer, economist and social anthropologist.

- Local workshop to introduce project and to identify local team counterparts.

- Compare island types and characteristics (for each country), identify sample islands on a basis of known representation by type and quantification.

- Visit sample islands: survey and measure topographic elevations, land use and settlement characteristics.

- Obtain data on agricultural and other production values. NB data may not be directly available, requiring local abstraction or computation.

- Obtain data on built land use values.

- Obtain data on land values. NB data may not be directly available; traditional values may require understanding and alternative evaluation.

- Assess local perceptions and attitudes to sea hazards, and to sea-level rise.

- Obtain information on traditional responses to sea-hazards, including migration.

- Discuss and identify economic, social, cultural and political implications, a) locally b) regionally c) internationally with

  significant aid donors: eg World Bank, EEC, ODA, ADAB, New Zealand, etc and

  representatives from the countries involved of overseas communities in New Zealand, Australia, Fiji, etc.

- Ascertain the availability of relevant information and carry out research and calculations regarding survey levels eg at the Directorate of Overseas Surveys, Southampton in order to accurately determine topographic elevations.

- Identify implications of sea level rise (0.5 and 1.5 metres) for current patterns of agriculture, residence and other activities. Assess economic magnitudes of the effects over time upon production and wealth.

- Identify multi-sectoral strategies for feasible adaptation in the interim; and for longer term conditions to be associated with rises in sea levels of 0.5 and 1.5 metres. Make recommendations.

- Identify the implications of aspects of the proposed strategy (above) for neighbouring governments (of island countries and metropolitan countries) and international development assistance.

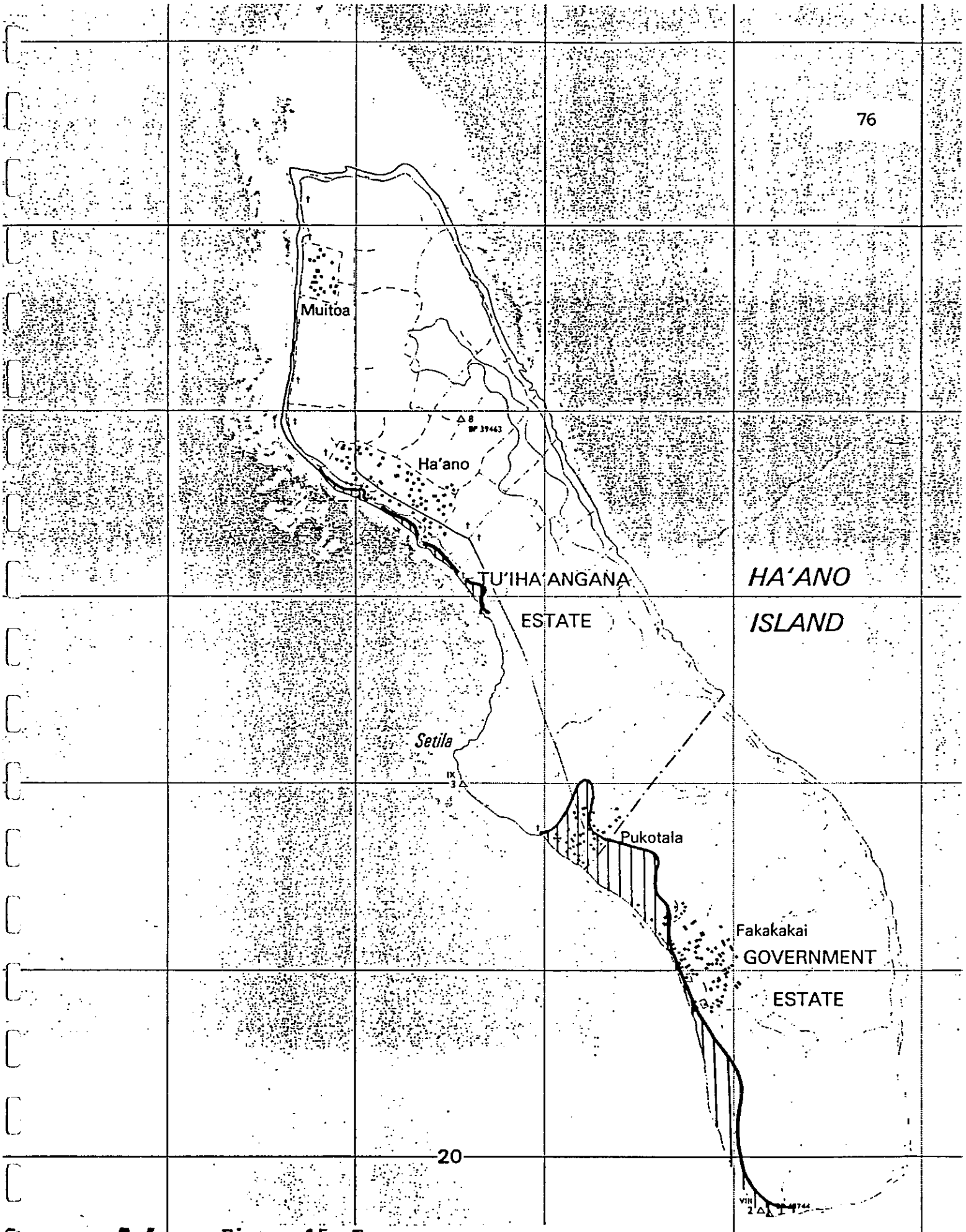

Figure 15: Tonga.
Ha'ano Island; 1.5 metre contour (shaded area would be below sea-level).
Scale: kilometre squares.

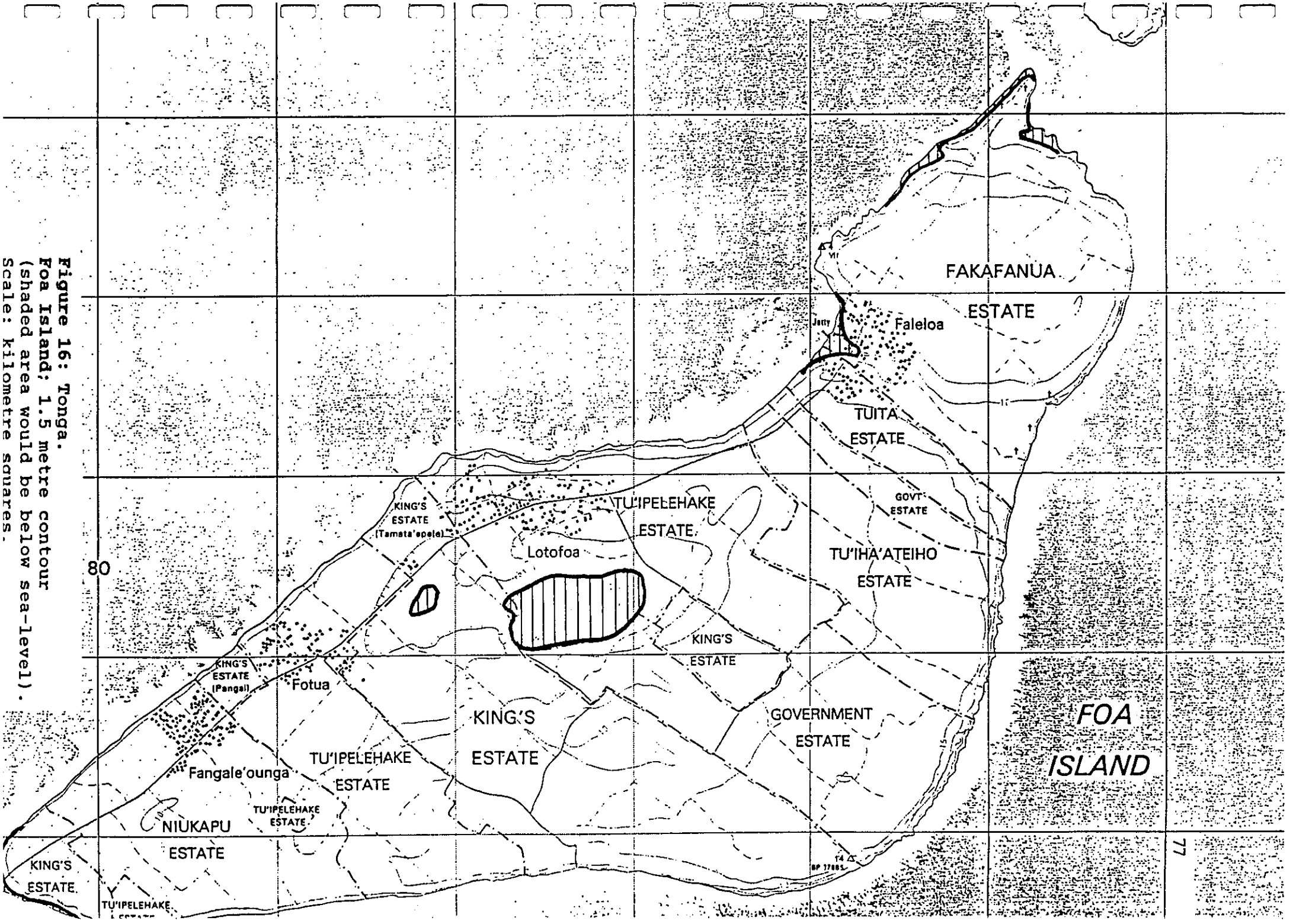

Figure 16: Tonga.
Foa Island; 1.5 metre contour
(shaded area would be below sea-level).
Scale: kilometre squares.

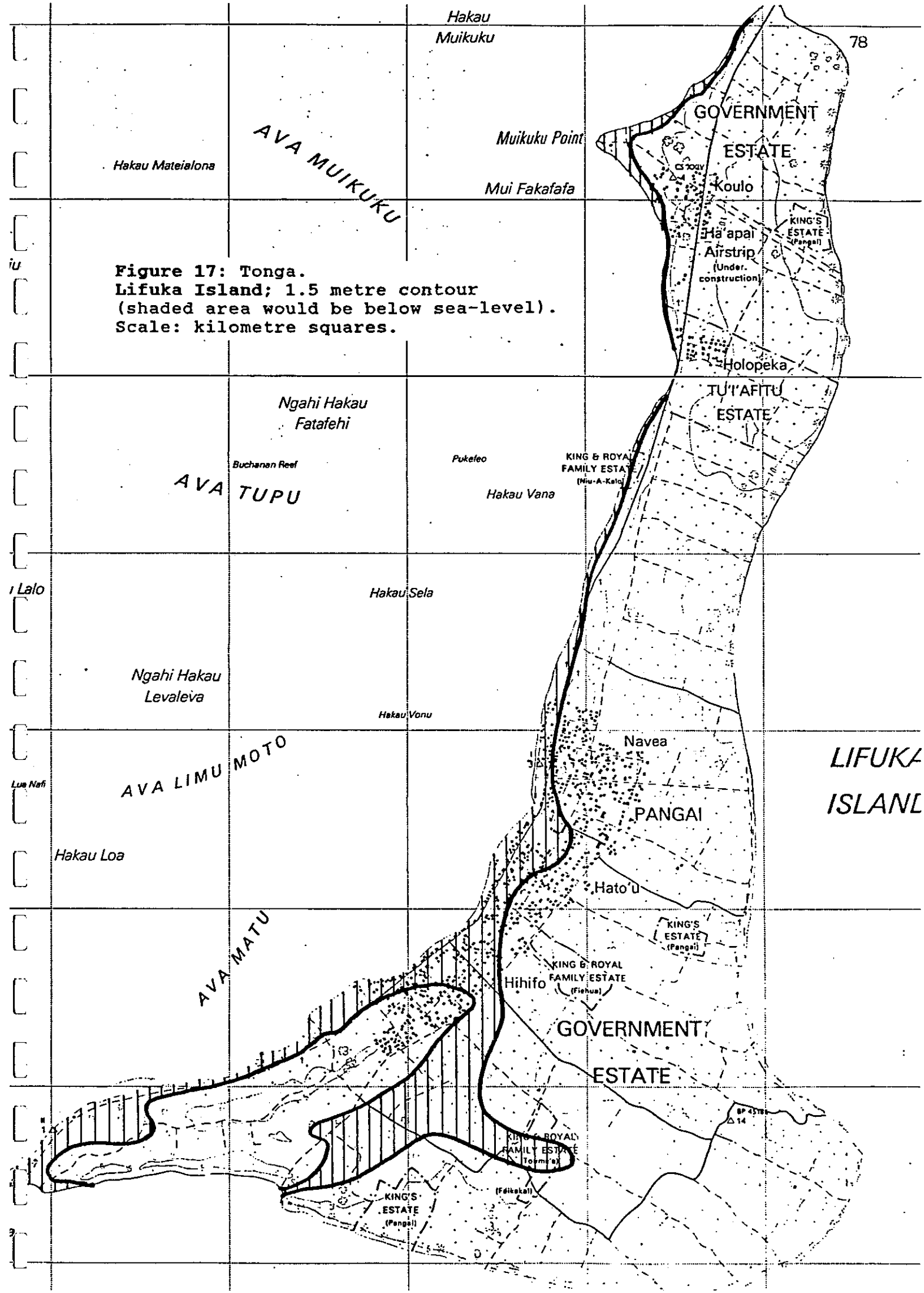

Figure 17: Tonga.
Lifuka Island; 1.5 metre contour (shaded area would be below sea-level).
Scale: kilometre squares.

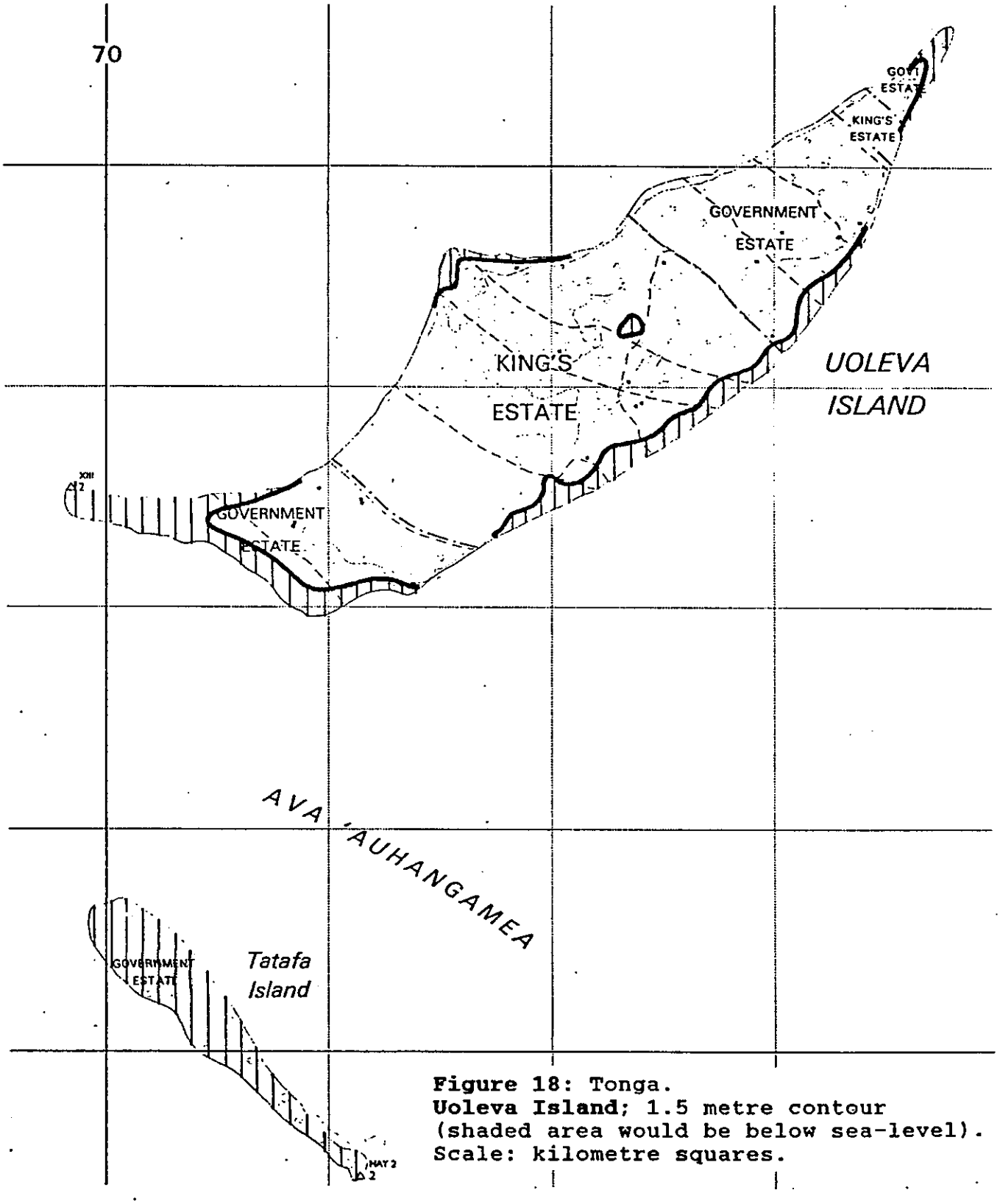

Figure 18: Tonga.
Uoleva Island; 1.5 metre contour (shaded area would be below sea-level).
Scale: kilometre squares.

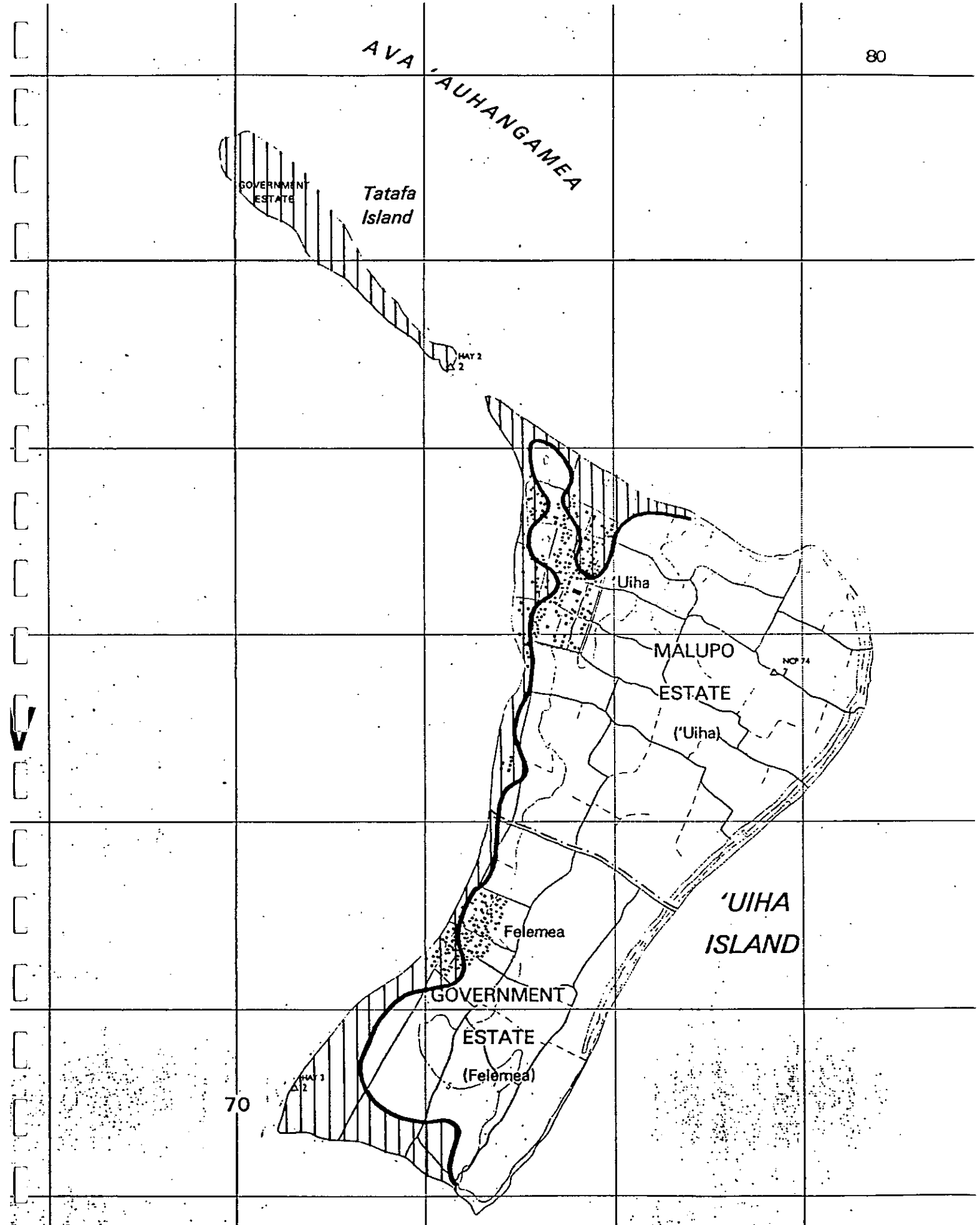

Figure 19: Tonga.
'Uiha Island; 1.5 metre contour (shaded area would be below sea-level).
Scale: kilometre squares.

Figure 20: Tonga.
Foreshore works; current contract, Japanes aid.

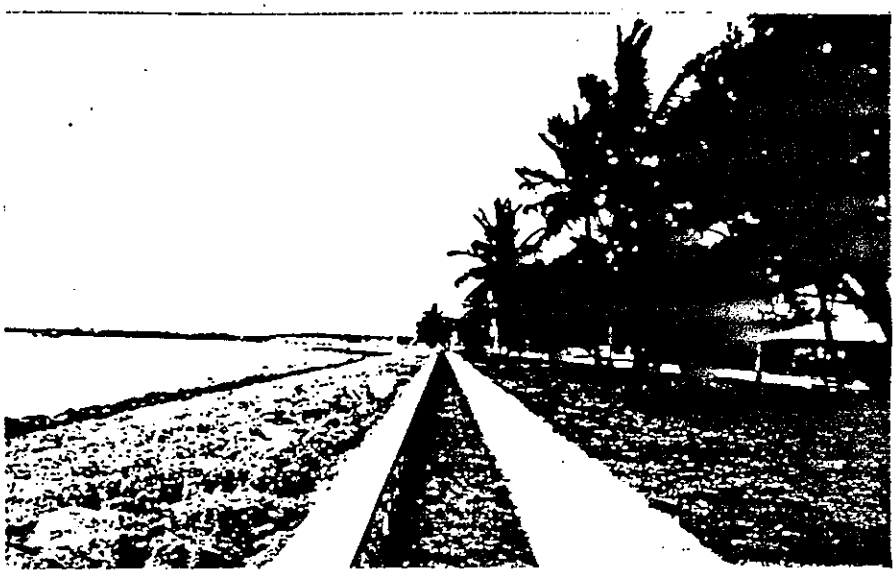

Figure 21a: Tonga.
Foreshore works; completed contract, German aid.

Figure 21b: Tonga.
Nuku'alofa; lagoon shoreline.

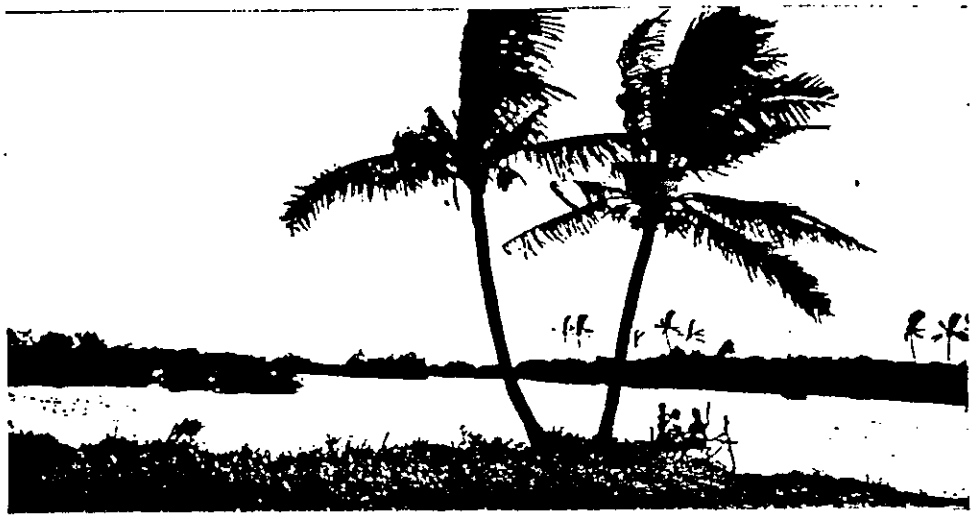

Figure 22a: Tuvalu.
Funafuti atoll; inland lagoon.

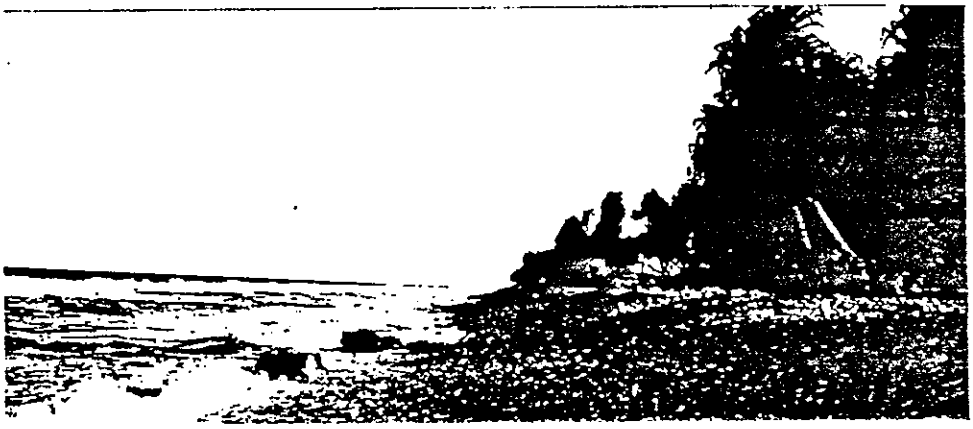

Figure 22b: Tuvalu.
Funafuti atoll; hurricane bank (ocean coastline).

Figure 22c: Tuvalu.
Funafuti atoll; hurricane bank (ocean coastline).
(There are dwellings on the crest of the bank).

Figure 23a: Tuvalu.
Funafuti atoll; lagoon shoreline gabions.
(see also Figure 12).

Figures 23b & c: Tuvalu.
Funafuti; lagoon shoreline.

APPENDIX 1: Sea conditions and wave action

Wave action results from combinations of swell, fetch and prevailing wind. Swell, the energy of water beneath the surface, is related to water depth and the nature of the sea bed. Fetch, the distance of open water across which the wind blows, determines partially wave action and largely the direction of wave approach. Where coincidence is gretest between fetch and prevailing wind, wave action will be the greatest. Impact upon the shoreline ensues from combinations of wave height, tide height and wave period; a short wave period being the most damaging.

The vast distances and depths of the Pacific Ocean surrounding small islands prevail to generate large waves, sustainable to the limits of deep water. Shallow lagoons cannot sustain large waves, the energy of which is spent on the protective reefs, the limit of deep ocean.

Four major types of waves occur in the tropical latitudes around the dateline (McLean 1980b): the easterly trade waves, southern swell, northern swell and westerly storm waves (Figure 11a) the relative importance of which varies seasonally.

In addition to locally produced storm waves are those developed in distant storms, which pass out of their area of origin and become swell. Heavy swell originating in the north Pacific has been known to cause damage in the South Pacific and vice versa, travelling over periods of several days.

Coral reef growth may be induced by increased water turbulence (Matos and Tiffin 1988) but should sea level "overtop" the reef, its capacity for

protection of the shore line to wave action would be reduced or altogether removed.

Greatest damage potential of wave action is upon a high tide, as is that of a surge of the sea created by low atmospheric conditions of a typical cyclone; but shelving of sea floor, coral reefs and opposing shore lines are no barrier to the colossal and subsuming forces of sea-surge (Report No 1: Lewis 1988, p 18). Massive sections of reef were uplifted and deposited on the coastline of Funafuti by Hurricane "Bebe" and associated sea surge in 1972 (Baines and McLean, 1976).

Seismic sea waves (tsunamis) are another aspect of wave action, especially in the Pacific Ocean. Earthquakes and other seismic events off Chile, Alaska, Japan, Kamchatka and the New Hebrides have affected South Pacific islands (Figure 11a) though recorded perception is limited of these as distinct from abnormally large waves.

Sea defence construction, as distinct from erosion prevention, is a more massive undertaking requiring an "apron" of preliminary wave reducing revetment before the sea wall itself (Figure 13).

APPENDIX 2: Sea defence and similar works: types and costs

1. **Severn Estuary**; Sandy Bay: — Pumped sand and gravel from sea bed to form shoreline embankment

   2 km length: Cost £3 million (350,000 tonnes sand and gravel transported)

   Cost per metre: £1,500

2. **Severn Estuary**, Burnham: — 3 metre high wall in reinforced concrete (including piling)

   Cost per metre: £3,500

3. **Severn Estuary**; — Earth bank plus 40 metre wide approach revetment

   Cost per metre: £650

4. **Tonga**:

   Japanese project: Nuku'alofa; — Coral rock revetment

   Sopu: 2,787 metres)
   Papua: 2,300 metres) — Cost per metre: £484.00 (T$ 1,030.86) (Cost of fill not included)

5. **Kiribati**: — Causeway between Bairiki and Betio (Tarawa)

   3.5 km
   Cost estimate 1966: A$ 500,000
   1969: A$ 635,000
   (incl mobilisation costs: A$ 200,000)

   Approx cost update 1988: A$ 1,500,000 — Cost per metre: £218.50 (A$ 430.00)

6. **Maldives**:

   Airport containment: — Rubble and gabions
   Cost per metre: £150.00 (US$ 270.00)

   Temporary protection to the city: — Rubble and gabions
   Cost per metre: £217.00 (US$ 390.00)

(Exchange rates: £1.00 sterling = A$ 1.97
T$ 2.13)

Sources: Birks, 1988
Gibb/Balfour Beatty, 1987
Taumoepeau, 1988;
Young, 1988

APPENDIX 3

Terms of Reference

In Kiribati, Tonga and Tuvalu:

(i) consult low level maps in order to establish areas of vulnerability to flooding or saline intrusion on given assumptions about sea level rise (essentially those provided by Dr Warrick at our first meeting with "high" and "low" possibilities considered). I suggest we take 1.5 metres and 0.5 metres for this purpose - bearing in mind that it is not merely averages but high tidal peaks that are relevant;

(ii) identify the implications for current patterns of agriculture, residence and other economic activities and for any future plans that are based on the assumption of unchanged sea level. To put rough economic magnitudes on the possible production and wealth effects over time;

(iii) to sketch out strategies for adaptation which seem feasible in the particular circumstances: relocation, sea defences, more ambitious systems of disaster management. To attempt rough estimates of the economic costs likely to be incurred, and when (looking for example, at the relative costs of incremental building of sea defences rather than new works);

(iv) to summarise the implications of possible sea level rise both for coastal management (maintenance of sea defences, natural and artificial; the protection of coral, replanting mangroves, etc);

(v) treating the above as being in the nature of a pre-feasibility study to suggest how more detailed work should be pursued.

(NB At the time, Marshall Islands Air Services from Tuvalu to Kiribati were "suspended indefinitely": Itinerary, Appendix 5).

APPENDIX 4

RADIO TUVALU

"ENVIRONMENT CONSULTANT VISITS TUVALU" 9.11.88 7.00 pm
10.11.88 7.00 am

AP.

An Environment and Human Settlements Consultant to the Commonwealth Secretariat in London is presently in Funafuti looking at the implications of rising sea levels.

Mr James Lewis arrived last Sunday from Tonga where he stayed for a week on the same mission. From Tuvalu he'll proceed to Kiribati.

This preliminary reconnaissance follows a request by Commonwealth Heads of Government made to the Secretariat during their meeting in Vancouver last year. This is part of a fact-finding study to assist the Secretariat to formulate a larger project. The results will be for the information of Commonwealth member states.

Mr Lewis says there are two other similar missions being undertaken - one in Bangladesh and the other in Guyana.

Mr Lewis hopes to meet the Ministry of Commerce and Natural Resources, the Ministry of Works and Communications and the Planning Office. He has already met the Acting Secretary to Government and the Chief of Police. Furthermore he would like to know more about Tuvalu when it was struck by Hurricane "Bebe" in 1972.

Mr Lewis is being assisted at work by the Assistant Secretary for Foreign Affairs, Mr Enele Sopoaga.

ENDS.

First part repeated on RADIO AUSTRALIA 7.00 pm 11 November 1988

APPENDIX 5

ITINERARY

Departure	London (via Los Angeles and Honolulu)	Saturday 29 October
Arrival	Tonga	Monday 31 October
	(Public Holiday; Constitution Day:	Friday 4 November)
Departure	Tonga (for Suva)	Friday 4 November
Arrival	Tuvalu	Sunday 6 November
	(Public Holiday; Prince Charles' Birthday:	Monday 7 November)
Departure	Tuvalu (for Suva)	Monday 14 November
Departure	Suva (via Honolulu and Los Angeles)	Tuesday 15 November

Note: Fiji Air serves Tuvalu (Funafuti) from Suva.

Marshall Islands Airways serves Kiribati from Tuvalu.

Prior to arrival and during time in Tuvalu, Marshall Islands Airways services were "suspended indefinitely" due to problems with fuel supplies. Onward travel planned to Kiribati was thus not possible and had to be deleted from the itinerary.

Some research on Kiribati was made possible in Suva by courtesy of the South Pacific Forum Secretariat.

APPENDIX 6

Listing of Contacts

TONGA:

Pelimi Aho, Ministry of Works, Nuku'alofa

Eleno 'Amanaki, Senior Planning Officer, Ministry of Agriculture, Fisheries and Forests, Nuku'alofa

Paul Fabian, British High Commissioner, Nuku'alofa

Robert Gatliff, British Geological Survey, Nuku'alofa

Stewart M Hadfield, Project Economist (Infrastructure), Central Planning Department, Nuku'alofa

Viliami Halapua, Assistant Manager, Primary Produce Division, Commodities Board, Nuku'alofa

Paea Havea, Chief Meteorological Officer, Tonga Meteorological Service, Nuku'alofa

Les Matthews, Chief Architect, Ministry of Works, Nuku'alofa

Don Seiler, Economic Analyst, Ministry of Finance, Nuku'alofa

Gregory Stutzman, Energy Planner, UNDP, Nuku'alofa

Sione M Taumoepeau, Director of Works, Ministry of Works, Nuku'alofa

Sione Tongelava, Chief Surveyor, Department of Lands and Surveys, Nuku'alofa

Taniela Tufui, Secretary to Government, Nuku'alofa

TUVALU:

Mike Keating, Transport Systems Manager, Marine Department, Vaiaku, Funafuti

Tom Kraweyzk, Director of Works, Ministry of Works, Vaiaku, Funafuti

Eseta Laupepa, Radio Tuvalu, Vaiaku, Funafuti

Imo Malo, Assistant Lands Officer, Vaiaku, Funafuti

Sautia Maluofenua, Acting Chief Fisheries Officer, Ministry for Commerce and Natural Resources, Funafuti

Seve Paeniu, Acting Planning Officer, Planning Office, Vaiaku, Funafuti

Sio Patiale, Assistant Transport Systems Manager, Marine Department, Vaiaku, Funafuti

Afa Pese, Radio Tuvalu, Vaiaku, Funafuti

Afelee Pita, Assistant Secretary, Ministry of Commerce and Natural Resources, Vaiaku, Funafuti

Fred Pullen, Agricultural Office, Ministry of Commerce and Natural Resources, Vaiaku, Funafuti

David Roberts, Officer in Charge, Meteorological Office, Vaiaku, Funafuti

Dr Falesene Salesa, Senior Medical Officer, Princess Margaret Hospital, Funafuti

Saluka Saluka, Assistant Agricultural Officer, Ministry of Commerce and Natural Resources, Vaiaku, Funafuti

Enile Sapoanga, Assistant Secretary Foreign Affairs, Vaiaku, Funafuti

The Hon Lale Seluka, Minister for Commerce and Natural Resources, Vaiaku, Funafuti

Seinu S Taafaki, Acting Secretary to Government, Vaiaku, Funafuti

Saloa Tauia, Chief of Police, Liaison Office: Disasters Emergency Committee, Vaiaku, Funafuti

Pokia Tihala, Prime Minister's Office, Vaiaku, Funafuti

Richard Weeks, Program Advisor, Tuvalu Field Officer, Save the Children (USA), Funafuti

Htun Yi, Project Co-ordinator, UNDP/UNCHS Survey Project, Lands Office, Vaiaku, Funafuti

SECRETARIAT OF THE SOUTH PACIFIC FORUM:

Ms Ilisapeci Gaunavinaka: Library Assistant

APPENDIX 7

REFERENCES:

Ball, David. "Funafuti Ellice Islands: Physical Development Plan". BRE/Department of the Environment. 1973.

Baines, Graham; McLean, Roger. "Sequential studies of hurricane deposit evolution at Funafuti Atoll". Marine Geology. 21. Elsevier 1976.

Bauro, Fulitua. "The view from Bairiki: How (and why) Kiribati is moving 4,720 of its people". Islands Business. October 1988.

Belz, Lloyd H. "Nuku'alofa: Sanitation and Reclamation". WHO/Ministry of Health. Nuku'alofa, July 1985.

Birks, C J. Personal communication. Regional Flood Defences Engineer, Wessex Water, Bridgewater. October 1988.

Carr, A P. "Size grading along a pebble beach". Journal of Sedimentary Petrology. 39 (March) pp 297-311. 1969.

Carr, A P; Blackley, M W L. "Ideas on the origin and development of Chesil Beach, Dorset". Proceedings: Dorset Natural History and Archeological Society. 95: pp 9-17. 1974.

Central Planning Department: "Fourth Five-Year Development Plan. 1980-1985". Nuku'alofa. 1981.

Colquhoun, Brian and Partners. "Feasibility Study of a Land Based Air Service". Interim Report. Government of Tuvalu/ODA. September 1984.

Commodities Board. "Banana export statistics 1960-1987 inclusive". Nuku'alofa.

Department of Agriculture. "Annual Report". Ministry of Commerce and Natural Resources. 1986.

Department of Public Works and Labour. "Malè land reclamation project". Republic of Maldives, Malè. July 1976.

Fawcett and Partners. "Report on prevention of coastal erosion". Government of Tuvalu/ODA. January 1982.

Flynn, G; Makin, J. "A survey of the Prospects for Agricultural Development in Tuvalu". Overseas Development Natural Resources Institute. 1976 (?)

Gibb, Sir Alexander; Balfour Beatty. "Report on flood damge in Republic of Maldives". British High Commission, Colombo. April 1987.

Government of Tuvalu. "Tuvalu: National Development Plan IV 1988-91". Funafuti 1988.

Government of Tuvalu. "Tuvalu: Development Fund Estimates 1988". Planning Office. 1988.

Htun, Yi (a). "Level of the highest tide for 1988". Letter: 24 March 1988. Cadastral Survey Project.

Htun, Yi (b). "Fonga Fale Map with relevant heights". Letter: 24 March 1988. Cadastral Survey Project.

Kerr, I S. "Hurricanes in Tuvalu". Memorandum. New Zealand Meteorological Service. 4 August 1976.

Laracy, Hugh (Ed). "Tuvalu: A History". University of the South Pacific. 1983.

Lewis, James. "Volcano in Tonga". Journal of Administration Overseas. pp 116-22. April 1979.

Lewis, James. "Vulnerability to a natural hazard: geomorphic, technological and social change at Chiswell, Dorset". Natural Hazards Research Working Papers No 37, Institute of Behavioral Science, University of Colorado. December 1979.

Lewis, James. "The long-term implications of Hurricane 'Isaac' (March 1982): Project identification and human settlement planning strategy for natural disaster mitigation for the Kingdom of Tonga". Mission Report TON/82/F01: May-June 1983. United Nations Centre for Human Settlements (Habitat) July 1983.

Lewis, James. "Change, and vulnerability to natural hazard: Chiswell, Dorset". The Environmentalist, 3, 1983. Elsevier.

Lewis, James. "The Implications of Sea-level Rise for Island and Low-lying Countries". Commonwealth Expert Group on Climatic Change and Sea-level Rise. Commonwealth Secretariat. March 1988.

Linden, Eugene. "Big Chill for the Greenhouse". Time Science. 31 October 1988.

Matos, Cruz; Tiffin, Don. "The Greenhouse Effect: Frightening predictions for atoll nations". Islands Business, Suva. October 1988.

McLean, R F (a). "The land-sea interface of small tropical islands: morphodynamics and man". Population-environment relations in tropical islands: the case of eastern Fiji. MAB Technical Notes 13. UNESCO. 1980.

McLean, R F (b). "Spatial and temporal variability of external physical controls on small island ecosystems". Population - environment relations in tropical islands: the case of Eastern Fiji. MAB Technical Notes 13: UNESCO 1980.

Ministry of Agriculture, Fisheries and Forests. "Reports on the Tonga Agricultural Census 1985". DRAFT. Nuku'alofa. 1987 (?)

Ministry of Finance. "Kiribati: Sixth National Development Plan 1987-1991". National Planning Office. Tarawa. 1988.

Nunn, Patrick D. "Future Sea-level Rise in the Pacific". Working Paper No 12. School of Social and Economic Development. University of the South Pacific (USP). October 1988. (Preliminary Version: April 1988).

OFDA "Report 1987" Office of US Foreign Disaster Assistance, Agency for International Development. Washington DC.

Puapua, Naomi. "The Greenhouse Effect". Lali. No 9. Newsletter of Motufoua School, Vaitupu, Tuvalu. 13 October 1988.

Riedel & Byrne. Consulting Engineers. Sea Level Rise: An Assessment. 1988.

Rogers, Garth (Ed). "The Fire has Jumped: eye witness accounts of the eruption and evacuation of Niuafo'ou, Tonga". University of the South Pacific. 1986.

Rutherford, Noel (Ed). "Friendly Island: A History of Tonga". Oxford University Press. 1977.

Sanvinet, Rachel. "Regional Development Plan: Niuas". Central Planning Department. Nuku'alofa. March 1988.

Scherer, Wolfgang: reported in Fiji Times 1 November 1988. (National Oceanographic and Atmospheric Administration: NOAA; Washington DC

Taumoepeau, Sione M. Personal communication. Director of Works, Ministry of Works, Nuku'alofa. 1988.

Temoana, Telepa. "The Greenhouse Effect". Lali. No 9. Newsletter of Motufoua School, Vaitupu, Tuvalu. 13 October 1988.

Tiffin, D L; Matos, C A. "Rising Sea Level: Is it time to worry?" CCOP/SOPAC Miscellaneous Report 46. 17th Annual Session of CCDP/SOPAC Consultative Committee for Offshore Prospecting in the South Pacific. Suva. August 1988.

United Nations Environment Programme (UNEP). "Report of Joint Meeting on Implications of Climatic Changes in the Mediterranean and Co-ordinators for the Caribbean, South-East Pacific, South Pacific, East Asian Seas and South Asian Seas Regions". Split. 3-8 October 1988.

Warrick, R A et al. "The Greenhouse Effect, climatic change and sea level: An overview". Commonwealth Secretariat. 1988.

Young, Steven. Personal communication: based on a Report prepared for the Resident Commissioner of Works, Bairiki, Tarawa 1969. Dobbie & Partners, Consulting Engineers. London. 1988.

MAPS

Tonga

1:25,000	Tongatapu	DOS/OS
	Niuafo'ou	DOS/OS
	Niuatoputapu Group	DOS/OS
	Vava'u (Late)	DOS/OS
	Ha'apai: Tofua and Kao	DOS/OS
	Ha'apai: Foa	DOS/OS
	Ha'apai: Lulunga	DOS/OS
	Ha'apai: 'Uiha	DOS/OS
	Ha'apai: Lifuka	DOS/OS
	Ha'apai: Kauvai	DOS/OS
	Ha'apai: Lofanga	DOS/OS
	Ha'apai: 'Otu Mu'omu'a	DOS/OS
1:250,000	'Eua	DOS/OS
1:50,000	Tongatapu	DOS/OS
1:2,500	Nuku'alofa	DOS/OS

WHO Sanitation Project. Contour Map of Nuku'alofa, Tongatapu, Tonga. 1:5000. 1985.

Tuvalu

1:50,000	Funafuti	DOS/OS
1:25,000	Nukufetau	DOS/OS
1:12,500	Nukulaelae	DOS/OS
	Nanumanga and Nui	DOS/OS
1:30,000	Nukufetau (manuscript tracing: February 1974)	DOS/OS

Kiribati

1:2,000,000	Kiribati West	DOS/OS
	Kiribati East	DOS/OS
1:25,000	Tarawa	DOS/OS
	Abaiang	DOS/OS
	Mainga	DOS/OS
	Abemama	DOS/OS
	Nonouti	DOS/OS
	Tabiteuea	DOS/OS
	Beru	DOS/OS
	Butaritari	DOS/OS