Climate Change and Sea Level Rise Issues in Guam

Report on a Preliminary Mission

by

Usha K. Prasad
University of Guam
Mangilao, Guam

and

Harley I. Manner
University of Guam
Mangilao, Guam

Published in July 1994
in Apia, Western Samoa

Acknowledgements

The authors wish to acknowledge the individuals and organizations that provided data needed for preparation of this report. Special thanks to Greg Ikehara of the United States Geological Survey for making his office and resources available for the duration of the study. Public agencies which provided data included the Guam Bureau of Planning, Guam Employment and Development Agency, Guam Environmental Protection Agency, Guam Historic Preservation Office, and the Office of Civil Defense.

In addition, Leroy Heitz of the Water and Energy Research Institute of the Western Pacific, at the University of Guam, provided much of the rainfall data. Rosalind Hunter-Anderson and David Gillespie offered helpful suggestions during the data gathering phase. Also, thanks to Thelma Sarmiento for preparing the Government of Guam Organizational chart, and Doreen Fernandez for photocopying USGS data.

Foreword

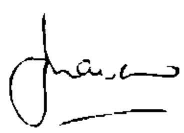
The first *Intergovernmental Meeting on Climate Change and Sea Level Rise for the South Pacific Region* was held in Majuro, Marshall Islands, in 1989. It was organised by the South Pacific Commission (SPC) and South Pacific Regional Environment Programme (SPREP) to create a public awareness on the future implications of these issues to the governments. Subsequently, necessary actions are being undertaken to address these issues in order to develop appropriate policies.

In this meeting, SPREP member governments gave the mandate to SPREP to coordinate and act as the clearing house on all climate change and sea level activities for the region.

The *United Nation Environment Programme* (UNEP) then provided financial assistance through SPREP (use of SPREP Climate Change Task Team Group) to undertake preparatory missions to Tonga, Kiribati, Tuvalu, Cook Islands, Guam, Palau, Federated States of Micronesia, Western Samoa and Tokelau to discuss the study with the governments, and to prepare reports before undertaking in-depth studies on the impacts of climate change.

The main task of this mission to Guam was to prepare a report in close consultation with the government officials, identifying areas for in-depth study into the potential impacts of expected climate and sea level changes on the natural environment and the socio-economic structures and activities of Guam. In addition, it identified suitable and available response options to avoid or mitigate the impacts of climatic changes.

It is anticipated that the Guam government will have the opportunity to closely examine these recommendations in the report, and to advise SPREP and other organisations accordingly.



Vili A. Fuavao

Director

Contents

1. Introduction

1.1 Background

As a result of previous studies carried out through the support of UNEP to the South Pacific Regional Environmental Programme (SPREP) Regional Seas programme in the Pacific, a number of island States are thought to be under immediate threat of major environmental change, should green-house-forced climatic warming and consequent sea level rise occur.

The problems identified have been set out in both summary and detail in the reports of the Association of South Pacific Environmental Institutions (ASPEI) Regional Task Team (Pernetta and Hughes 1989). In these reports Guam has been identified as one of the Pacific Island nations most vulnerable to any sea level rise which would result from climatic warming.

It is apparent however, that climatic warming and consequent sea level rise is simply one, and in many cases not the most urgent, of a number of environmental problems facing small island nations . Plans to deal with these climatic change problems can be most appropriately considered along with other environmental planning needs.

The remainder of this report follows the format used by Sullivan and Gibson (1991), in their report on climate change and potential sea level rise for the island of Kiribati.

1.2 Mission Brief

The Terms of Reference for this mission were established by UNEP and SPREP, and closely follow the 1991 mission to Kiribati (Sullivan and Gibson 1991).

1. The main purpose of the mission is to prepare, in close consultation with national counterparts, an in-depth study of the potential impact of expected climatic changes (primarily sea level and temperature rise) on the natural environment and the socio-economic structure and activities of the host country. This included the identification of response options which may be suitable and available to avoid or mitigate the expected negative impact of climatic changes.
2. Specifically, the mission is to prepare a report containing:

a. a general overview of the climatological, oceanographic, geological, biological and socio-economic factors which may be relevant to, or affected by, the potential impacts of expected climatic changes;

b. a preliminary identification of the most vulnerable components and sites of the natural environment, as well as the socio-economic structures and activities that would be critically affected by expected climatic changes;

c. an\ overview of current environmental management problems in the country and an assessment of how such problems may be exacerbated by climatic changes;

d. a detailed proposal for a joint program of assistance to the host country, or an in-depth evaluation of potential impacts of expected climatic changes on the natural environment and the socio-economic structures and activities of the country. The proposal should identify policy or management options suitable to avoid or mitigate the impact of climatic changes, together with the workplan, timetable, financial requirements of the in-depth evaluation and the possible institutional arrangements required.

1.3 Period of Study

The study took place over seven days in November 1991. Combined with site visits, the fieldwork involved meeting with, and obtaining data from, the appropriate government agencies and research facilities on island. A list of the public and private agencies and facilities consulted during the data gathering phase are listed in the Annex.

2. Guam - The Environmental Setting

2.1 Island Geography

Guam is a small (541 square km,) tropical island located in the Western Pacific. It is the southernmost of the Marianas islands and lies approximately 13^{O}N latitude and 144^{O}E longitude (see Fig. 1a and b). Guam's location, as well as its political recognition as a U.S. territory, make it a major port of entry for countries of the Asian region.

2.2 Geology and Physiography

Guam is classified as a high island with an axial trend northeast to southwest. It has 12 small islands located on its fringing and barrier reefs. The island is located on the eastern edge of the Philippine Plate and northwest of the Marianas Trench (see Fig. 2) where subduction of the Pacific Plate and other plate movements result in a high number of minor earthquakes and tremors. Emerging since the early Cenozoic, geological activity has continued on Guam up through the early Pleistocene (Tracey et.al. 1964).

Different geological processes have resulted in the marked topographical, vegetational and coastline variations which distinguish the north from the south. The older northern limestone plateau (dating to the early Eocene) consisting of mesa flatlands with no permanent rivers or streams, rises to 150 m above sea level. The southern portion of the island consists of a mountainous, volcanic terrain (formed primarily in early Miocene), with mountains up to 400 m in elevation. The isthmus connecting the two halves is only 7 km wide, with the capitol Agana on the western end and the University of Guam on the eastern end. The island is approximately 51 km long and between six to 14 km wide.

Based on its stratigraphy and geomorphology, the island of Guam has been divided into three major physiographic provinces: the northern plateau, the central mountains, and the southern mountains (Tracey et. al. 1964).

In turn these provinces have been subdivided into seven physiographic units:

a) the dissected Alifan limestone cap of southern Guam which consists of high knobs, sharp elongated hills, scarps and irregular depressions;

b) mountain land in southwestern Guam consisting of steep and dissected slopes formed on the Alutom and Umatac volcanics;

c) dissected and gently sloping foothills in southeastern Guam developed on the Alutom formation, the Mahlac shale, the Bolanos pyroclastic, and the Dandan flow;

d) hilly and rolling land/dissected limestone plateau developed on the Agana argillaceous member of the Mariana limestone of the central mountains and southeastern Guam;

e) the flat plateau of northern Guam and the Orote Peninsula capped by the Mariana limestone;

f) the interior basin of rolling lowlands and karst topography in south central Guam developed on volcanic materials, limestone, and alluvium; and,

g) the coastal lowlands and alluvial valley floors developed on alluvium, beach sands and the Mariana limestone (Tracey et. al. 1964).

The geologic formations and their ages are presented in Table 1, while the physiographic units are presented in Fig. 3.

The land surface of the island is divided into four categories: limestone plateau, dissected volcanic uplands, interior basin, and coastal lowland and valley floors (Tracey et. al. 1964). The limestone plateau, consisting of both flat and argillaceous limestone, slopes gently from 200 m to less than 70 m near the isthmus.

Dissected volcanic uplands are most prominent along the southern mountain ridges; Mt. Lamlam at 405 m, is the highest point on the island. The Talofofo, which flows west of the Mt. Lamlam-Mt. Alifan Ridge, is Guam's largest river system consisting of several large tributaries. The interior basin, extending south of the Fena Valley Reservoir, is a hilly area consisting of basalt flows overlain by limestone deposits.

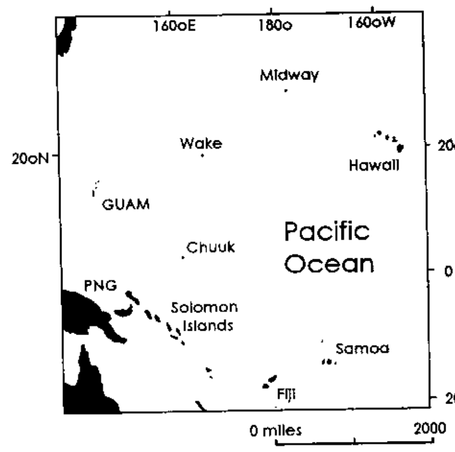


Fig. 1a: Guam's location relative to other Pacific islands.

Source: U.S. Bureau of Census, data for 1990.

Fig. 1b: Population and settlements of Guam

Source: U.S. Bureau of Census, data for 1990.

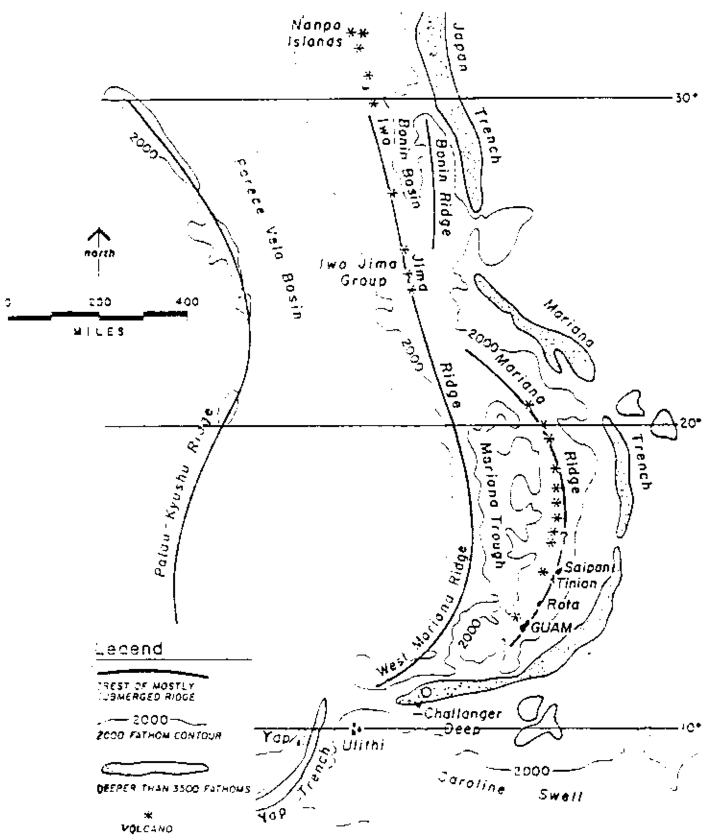


Fig. 2: Regional geological relations in the Western North Pacific Ocean.

Source: Tracey et. al. 1964.

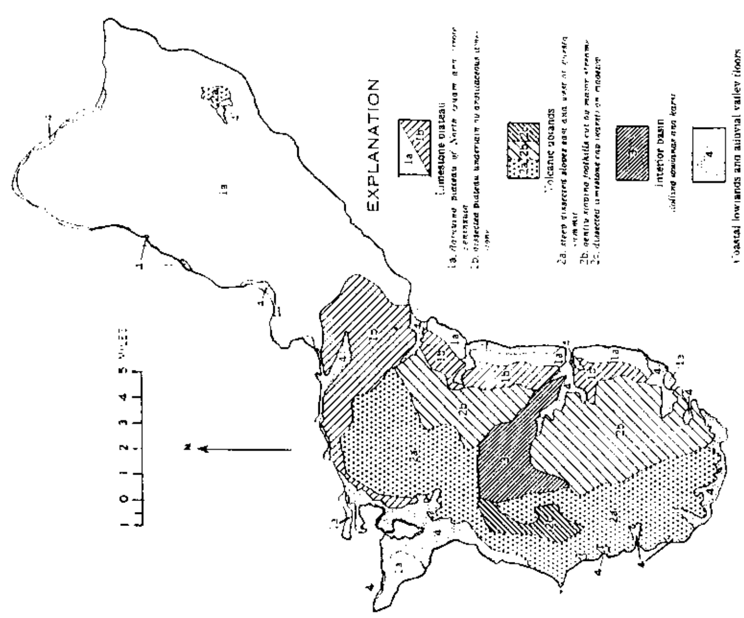
Table 1: Geologic formations according to Tayama.

Source: Tracey et. al. 1964.

Names of formations, according to Tayama (1952, Table 4)			Names of formations used in this report	
Age	**Order of succession**	**Formation**	**Age**	**Formation**
Recent	Recent Limestone	Recent Limestone	Recent	Alluvium, Reef deposits
	Raised beach deposits	Raised beach deposits		Beach deposits, Merizo limestone
	Younge raised coral reef limestone	Merizo limestone	Pleistocene and Pliocene	Mariana limestone
Pleistocene	Older raised coral reef limestone	Barrigada limestone	(Tertiary *h*)	Agana argillaceous member
	Terrace deposits	Terrace deposits and clay	Pliocene (Tertiary *h*) and	Barrigada limestone, Janum formation
	Mariana-Palau limestone	Mariana limestone	Upper Miocene (Tertiary *g*)	Alifan limestone, Talisay formation
Pliocene	*Halimeda* Group	Sumay limestone Talofofo peat bearing beds	Lower Miocene (Tertiary *f*)	Bonya limestone
Miocene	Erosion	Erosion	Lower Miocene	Umatac formation
Oligocene	*Eulepiaina* group	Asan limestone	(Tertiary *e*)	Dandan flow member Bolanos pyroclastic member
Eocene	*Camerina* group	Fena beds Nagas beds		Maemong limestone member Faepi volcanic member
	Andesite group	Baranos andesite Santa Rosa beds Umatac andesite	Oligocene (Tertiary c) and Upper Eocene (Tertiary *b*)	Autom formation Mahlac member
	Liparite group	Liparite gravel		
Pre-Tertiary	Base rocks	Diorite gravels		

Fig. 3: Physiographic Units of Guam.

Source: Tracey, et. al. 1964.



Coastal lowlands and valley floors vary between the rich alluvial clay soils supporting agriculture, to altered coral sands which can be highly acidic. Mangrove swamps and marshes are also found scattered throughout the southern half of the island.

2.2.1 Shoreline Features

According to Randall and Eldredge (1976) Guam's shoreline (perimeter is approximately 137,000 km) consists of :

1) rocky shorelines;
2) beaches;
3) low-lying shorelines which support mangrove vegetation; and,
4) man-made or altered shorelines.

"Much of this shoreline is bordered by fringing and offshore barrier reef platforms of various widths and origins" (Randall and Eldredge 1976:1). The rocky shorelines consist of limestone terraces, cliffs, steep slopes and sea-level benches, and are found primarily along the northern plateau. Beach composition differs between the reef-deposited formations along the northern plateau and the volcanic deposits resulting from drainage systems in the southern end. Low-lying shorelines are more common along central and southern Guam. Altered shorelines such as construction of the break water in Apra harbor, result primarily from dredging and land filling.

Due to Guam's proximity to the Marianas Trench (113 km southeast of the island), tectonic activity still influences physical changes to the island (Fig. 2). Despite a rapidly rising world ocean during the Holocene, relative sea level has fallen near Guam since the end of the Pleistocene indicating substantial tectonic uplift (Dye and Cleghorn 1990).

A 1978 study by Easton et. al. (quoted in Dye and Cleghorn 1990) revealed that the Merizo Limestone found along most of Guam's shoreline, formed as a result of a 2 m uplift in the last 5,000 years. Though little is known about the dynamics of this uplift, the nearly twice daily occurrence of recordable seismic shockwaves suggest that the process is continual and relatively gradual on a human time scale, rather than episodic or catastrophic. This uplifting is most visible along the northern cliffline.

2.3 Climate

2.3.1 Climatic and Oceanographic Setting

Guam and the Marianas Islands are located within the NE Tradewind Zone. Tradewinds from the east and northeast blow throughout the year, however they are strongest and most constant during the dry season.

Normal trade-wind waves range between 1.0 m to 1.5 m; wind induced waves higher than 3.0 m are usually associated with storms. Guam's ocean temperature is about 27.2°C the year round.

Tides are semidiurnal with a mean range of 0.5 m and a diurnal range of 0.70 m. Since 1985, USGS has been monitoring daily tide stages at the Agana Boat basin. An earlier tide gage was placed at the University of Guam Marine Laboratory in Mangilao but was removed in 1988 as it could not withstand the strong tidal surges along the western shoreline (Ikehara. pers. comm.). The Harbormaster at the Naval Air Station also maintains a tide gage in Apra Harbor. Data from the US Geological Survey (unpub.) indicated that mean daily ocean levels for 1985 were significantly higher than in 1991.

Guam's climate may be described as humid or semihumid tropical by virtue of its high annual temperatures and rainfall. Temperature and rainfall data from various meteorological stations throughout the island indicate that Guam's climate ranges from Aw (Koppen) in some coastal locations, to Af in upland locations where rainfall is higher. Average monthly and annual temperatures are high and show little monthly variation because of the island's low latitudinal position and its oceanic situation. For example, the mean monthly temperatures at Sumay range is between 26.2°C in January to 28.0°C in June, a difference of only 1.8°C, as shown in Table 2.

The difference between the extreme maximum and minimum temperatures, on the other hand, may be as high as 16°C. Temperatures over 38°C are rare, a reflection of the moderating influence of the ocean. Interior locations may be 1.7°C lower because of elevational effects. Daytime temperatures range between 28° and 31°C, and relative humidity averages around 82 per cent. Highest relative humidities occur at night during September and October and the lowest occur in the daytime during February through April (Blumenstock 1959).

Table 2: Temperatures (in °C) for selected stations.

Source: USGS, unpublished.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Sumay													
Mean	26.2	26.2	26.8	27.5	27.9	28.0	27.4	27.2	27.1	27.1	27.3	26.9	27.1
Mean Max	28.6	29.0	29.6	30.5	31.0	31.2	30.2	30.1	30.0	29.8	29.8	29.2	29.9
Mean Min	23.8	23.4	23.9	24.5	24.9	24.9	24.6	24.4	24.3	24.4	24.8	24.5	24.3
Extreme Max	31.7	33.9	32.3	33.3	34.4	34.4	33.3	32.8	32.8	32.8	32.2	32.3	33.0
Extreme Min	20.0	17.8	20.0	21.1	21.7	22.2	21.1	21.7	21.1	20.5	20.5	21.1	20.7
Agana Navy Yard - Mean	27.9	30.2	30.2	31.2	31.4	31.2	30.6	30.7	30.8	30.5	31.2	30.5	30.8
AFR Expt. Sta.	27.2	27.2	27.2	27.8	27.8	27.8	27.2	27.2	27.2	27.2	27.8	27.2	27.4

Average annual rainfall for most of the island exceeds 230 cm per annum, with upland areas receiving up to 50 cm more rainfall than coastal and lowland stations (see Table 3 and Fig. 4). The higher inland rainfall suggests an orographic effect associated with elevation. Almost all inland locations with rainfall greater than 300 cm per annum have more than 6.0 cm of rainfall per month, and thus fit Koppen's classification of an Af (tropical rainforest) climate.

The western coast and lowland areas receive less rainfall per year, with some stations experiencing drought conditions during the winter period. Such stations are classified as Aw climates. The pattern of precipitation is controlled by seasonal shifts of the oceanic subtropical high pressure system and the intertropical convergence zone. The steady NE tradewinds which blow 90% of the time from January to May (Ward et. al. 1965), are replaced in the summer by the intertropical convergence zone that brings unstable weather, variable winds, and large-scale regional disturbances which can develop into tropical storms or typhoons.

The dry season extends from January through May. Rainfall is heaviest from July through November, with monthly averages ranging between 28 and 38 cm. June and December are the transitional months and may also experience a significant amount of rainfall. Severe droughts are also a normal occurrence on Guam from February through April. The latest drought (1983), had the lowest rainfall on record during its first 6 months; Tables 4, 5 and 6 compare rainfall and riverflow data between 1950-82 and 1983.

December through June pan evaporation exceeds incoming rainfall (see Table 3). These moisture deficit months, in conjunction with shallow soils and a permeable limestone substrate often result in a moisture stressed vegetation.

Between July through November, rainfall greatly exceeds evaporation.

Rainfall patterns vary between the northern and southern halves of the island. Table 7 shows the 1989 annual totals from 10 of the 12 measuring stations around the island.

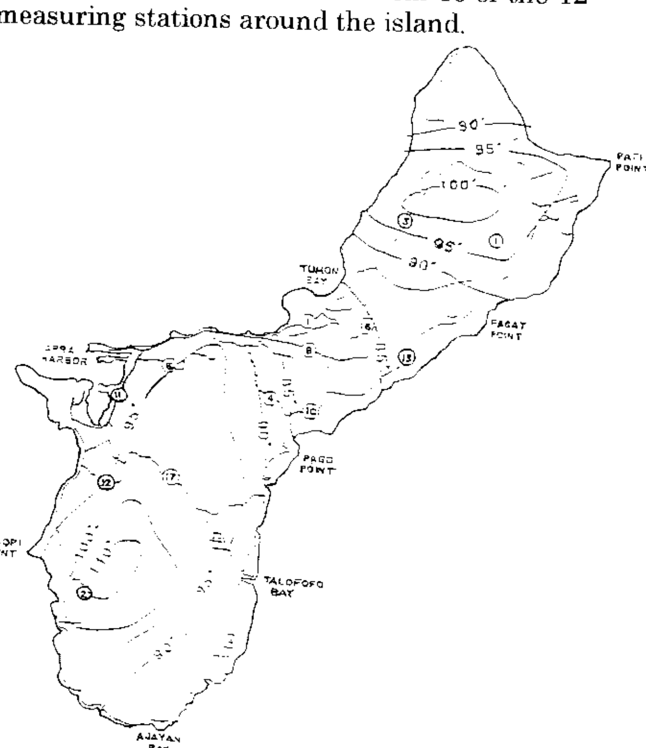


Fig. 4: Mean annual rainfall for Guam (in inches).
Source: USGS unpublished.

Table 3: Average rainfall, evaporation and pan evaporation data (in mm) for selected stations.

Source: USGS unpublished.

Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
US Weather Bureau (Taguac). Rainfall Record, 1956-1972; Evaporation Record, 1958-1973													
Rainfall	141	106	113	118	159	157	286	341	401	335	239	164	2561
Evaporation	139	151	184	194	195	165	148	131	123	130	132	146	1839
Excess Rainfall	2	0	0	0	0	0	138	210	278	205	107	18	722
P.E	139	151	184	194	195	166	148	131	123	130	133	146	1839
Anderson Airforce Base. Rainfall Record, 1952-1972													
Rainfall	128	111	95	105	130	123	245	294	254	248	204	145	2282
Evaporation	154	145	218	219	238	211	173	151	139	125	154	166	2063
Excess Rainfall	0	0	0	0	0	0	72	143	215	223	50	0	219
Naval Air Station. Rainfall Record, 1956-1972													
Rainfall	122	75	70	103	140	136	255	301	358	285	210	126	2181
Evaporation	160	213	294	223	221	192	166	148	138	153	152	190	2160
Excess Rainfall	0	0	0	0	0	0	89	153	220	132	58	0	21
Naval Magazine. Rainfall Record, 1947-1979. Some years incomplete													
Rainfall	124	83	79	88	160	243	246	330	297	344	247	221	2463
Agat. Rainfall Record, 1978-1984. Some years incomplete													
Rainfall	94	119	82	53	133	133	263	401	368	347	249	150	1943
Fena Dam/River. Rainfall Record, 1950-1975. Some years incomplete													
Rainfall	128	89	76	126	152	208	268	325	423	348	238	173	2558
Fena Filter Plant. Rainfall Record, 1951-1979. Some years incomplete													
Rainfall	125	93	94	77	130	150	292	340	337	354	221	150	2365

Table 4: Monthly rainfall, for January to June (in inches) for Guam.

Source: USGS 1983. (Data was from U.S. Geological Survey continuous-record rain gage; with all other rainfall data from U.S. National Oceanic and Atmospheric Administration, 1957-72, 1973-83)

	Jan	Feb	Mar	Apr	May	Jun	Total
National Weather Service Station: 1957-82 (26 years)							
Mean	5.80	4.75	4.46	4.48	7.27	6.28	33.04
Percent of annual mean	5.7	4.6	4.4	4.4	7.1	6.1	32.3
Minimum monthly	1.99	0.67	0.59`	0.50	0.90	1.52	—
Year of minimum	1964	1960	1965	1965	1959	1959	—
National Weather Service Station: 1983							
Rainfall	1.31*	1.21	3.34	1.83	1.10	0.80	9.59
Percent of mean	21	25	75	41	15	13	29
Departure from mean	-4.49	-3.54	-1.12	-2.65	-6.17	-5.48	-23.45
Umatac (USGS): 1950-82							
Number of years	30	30	28	25	28	30	—
Mean	4.89	4.19	3.41	3.43	5.55	6.26	27.73
Minimum monthly	0.90	0.43	0.17	0.23	0.61	0.59	—
Year of minimum	1966	1972	1978	1950	1975	1975	—
Umatac (USGS): 1983							
Rainfall	1.69	1.79	4.70	0.51	2.54	1.35	12.58
Percent of mean	35	43	138	15	46	22	45
Departure from mean	-3.20	-2.40	+1.29	-2.92	-3.01	-4.91	-15.15
Rainfall for other sites in 1983							
Anderson Air Force Base	1.08	1.40	3.69	2.02	1.92	0.55	10.66
Yigo	1.15	1.73	4.13	2.24	0.92	1.93	12.10
Dededo	1.59	1.83	4.75	---	1.67	0.53	—
Mangilao	0.96	0.74	2.75	0.79	2.21	0.67	8.12
Windward Hills (USGS)	0.95	0.53	2.30	0.76	1.25	0.45	6.24
Agat	—	1.14	2.65	1.50	1.92	1.59	—
Inarajan Ag. Station	0.54	1.58	1.20	0.46	3.81	—	—

**** New minimum monthly total***

Table 5: Mean monthly discharges, in January to July (in cubic feet per second), for two rivers on Guam prior to and in 1983.

Source: USGS 1983.

Station number	16847000			16858000		
Station name	Imong River near Agat			Ylig River near Yona		
Drainage area	1.95 mi^2			6.48 mi^2		
Years of record	21			30		
	1961-70	**1972-82**	**1983**	**1953-82**		**1983**
	Average of monthly means	**Lowest mean**	**Mean**	**Average of monthly means**	**Lowest mean**	**Mean**
January	5.34	2.10	3.60	16.6	2.63	5.20
February	6.23	1.62	3.01	13.9	1.33	2.62
March	4.03	1.39	2.93	7.6	0.71	2.07
April	3.89	1.00	2.20	7.0	0.36	0.83
May	5.52	0.59	1.93	15.8	0.15	0.48
June	4.81	1.00	1.60	10.9	0.38	0.23*
July	8.70	1.71	2.48	29.2	0.73	1.91
January to July	**6.45**	---	**2.97**	**14.5**	---	**2.24**
Annual	**10.3**	---	---	**28.7**	---	---

* New minimum mean discharge

Table 6: Lowest discharge (in cubic feet per second) of rivers in Guam.

Source: USGS 1983.

Station Number	Station Name	Drainage Area (mi^2)	Years of Record	Lowest instantaneous discharge Prior to 1983	In 1983
16809600	La Sa Fua River near Umatac	1.06	12	0.12 (1979)	0.16 (Jul 1)
16840000	Tinaga River near Inarajan	1.89	30	0.15 (1966, 1973)	0.36** Jun 26-30
16847000	Imong River near Agat	1.95	21	0.37 (1966)	1.2 (Jul 16,17)
16848100	Almagosa River near Agat.	1.32	10	0.13 (1979)	0.15 (Jun 26-Jul 1, 7, 8)
16848500	Maulap River near Agat	1.15	10	0.33 (1975)	0.31 Jun 28-Jul 1)
16854500	Ugum River above Talofofo Falls	5.76	5	3.4 (1979)	3.5 Jun 29-Jul 1)
16858000	Ylig River near Yona	6.48	30	0.07 (1973)	0.10 Jun 29-Jul 1)

** Minimum daily discharge

Table 7: Annual rainfall for Guam in 1989 (in inches).

Source: Water Resources Management Program 1989

Location	Annual Total	Maximum (inches/month)
(South)		
Umatac village	96.22*	14.04/Aug.
NASA Tracking Station	114.76	18.30/Oct.
Windward Hills Golf Course	97.83	17.35/Oct.
Fena Filter Plant	98.29	14.62/Oct.
Mount Chachao	96.24	22.18/Oct.
(North)		
Mangilao Agriculture Stn.	104.10	18.84/Oct.
U.S. Naval Oceanography Cmd. Cntr. (NAS)	108.44	17.45/Oct.
Ghura Dededo	96.11	15.11/Sep.
National Weather Service	105.39	14.38/Sep.
Anderson AFB	101.01	15.50/Sep.

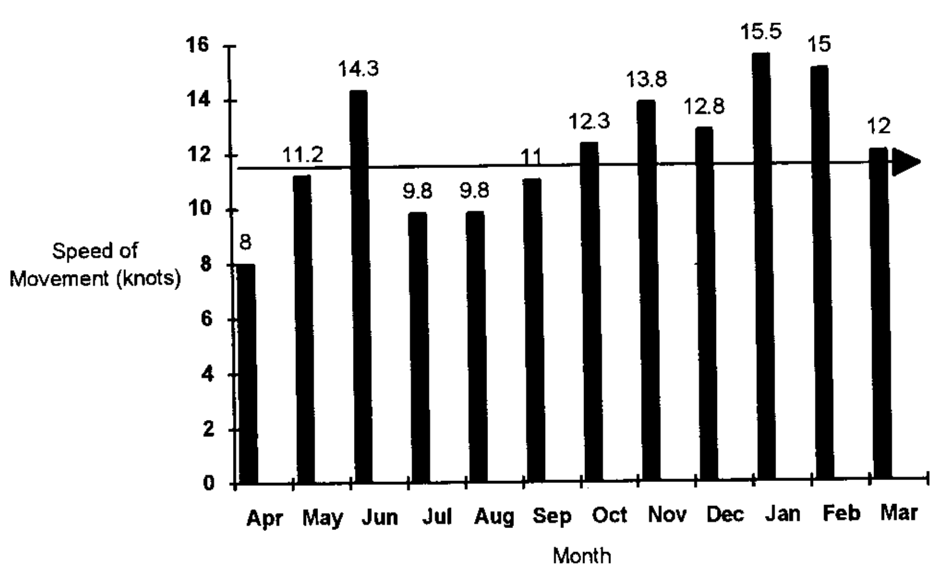
*Data missing for the months of February and March

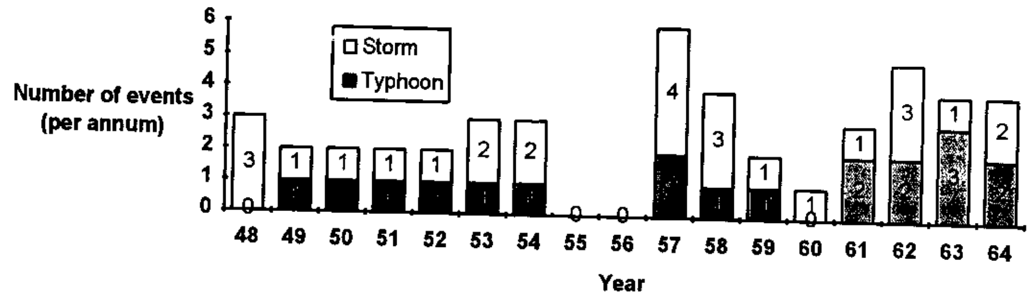
The typhoon season in Guam extends from July to December. "Guam is located within the breeding grounds for tropical cyclones in the Western North Pacific Ocean" (Weir 1983:1). Frequency of occurrence of these typhoons (average of 28 annually) is significantly higher than the number which actually threaten Guam. Fig. 5 shows the monthly average speed of movement for tropical cyclones at their closest points of approach to Guam, and Fig. 6 shows the yearly frequency of the passage of tropical storms and typhoons within 180 nautical miles of Guam.

Between 1948-1980, 94 tropical cyclones with at least tropical storm strength developed or tracked within 180 nautical miles of Guam (Weir 1983). Since 1980, there have been several "noteworthy" storm disasters in Guam: In 1990 typhoon Owen passed by Guam with winds gusting up to 153 km per hour; in 1991 typhoon Yuri passed to the southwest of Guam, causing extensive damage in the southern, low-lying village of Inarajan. However, the worst typhoon disaster in Guam was caused by Supertyphoon Karen in 1962; this event took most of the island's inhabitants by surprise (Yamashita 1965) and damaged Anderson Air Force Base as well as the Ship Repair Facility in Apra harbor.

Fig. 5: Monthly average speed of movement for tropical cyclones at their closest points of approach to Guam (1948-1980).

Source: Weir 1983.





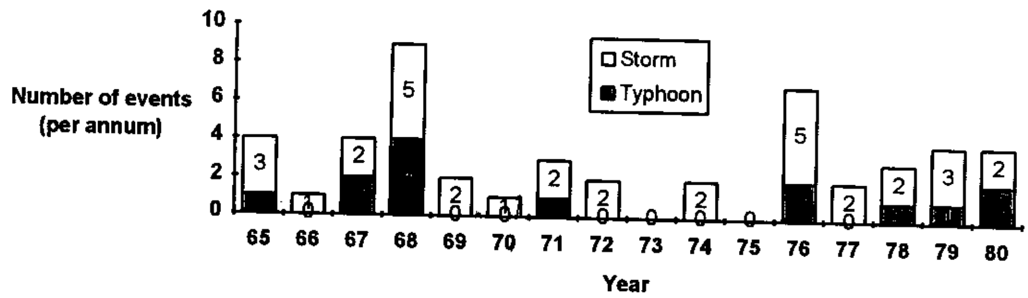


Fig. 6: Yearly frequency of tropical storm/typhoon passage within 180 nautical miles of Guam (1948-1980).

Source: Weir 1983.

2.4 Flora and Fauna

2.4.1 Endemism

Guam has a high rate of endemism and is ranked as an island most at risk from human impact, animal introductions, and noxious pests, such as the brown tree snake, *Boiga irregularis* (Dahl 1986). Table 8 presents details of the rate of endemism of Guam's native flora and fauna.

According to Dahl (1986), of approximately 330 native flowering plants and ferns, 69 are endemic to Guam and the Mariana Islands. Of these, 20 endemic species are threatened on Guam. An additional 30 non-endemic plant species are threatened. Threatened species include *Serianthes nelsonii*, *Heritiera longipetiolata*, *Tabernaemontana rotensis*, *Hernandia ovigera*, *Merrilliodendron megacarpum*, *Xylosoma nelsonii*, *Fagraea galilai*, *Solanum guamense*, *Ceratopteris gaudichaudii*, and *Potamogeton mariannensis*.

Among insects, the endemic *Neptis guamensis* has not been sighted on Guam since the early 1900s, and all native and endemic bird species are classified as either vulnerable, threatened or rare. These include: *Rallus owstoni*, *Ptilinopus roseicapilla*, *Myiagra freycineti*, *Gallinula chloropus guami*, *Aerodramus vanikorensis bartshi*, *Halcyon cinnamomina cinnamomina*, *Rhipodura rufifrons uraniae*, *Zosterops conspicillata conspicillata*, *Myzomela cardinalis saffordi*, *Apolinis opaca guami*, and *Corvus kubaryi*. An additional four species or subspecies of birds are now extinct on Guam.

Four native mammal species are either extinct or very rare locally (*Pteropus marianus marianus*, *P. tokudae*, *Emballonura semicaudata*, and *Dugong dugon*), while nine native land snails and *Ramphotyphlops pseudosaurus* are also threatened.

2.4.2 Fauna

The original inhabitants introduced pigs, dogs and chickens to Guam. Large grazing animals such as the water buffalo, cows, horses, deer, goats and sheep were introduced by the Europeans. With the exception of small groups of "wild" water buffalo, deer and pigs, most of these animals have been domestically maintained as beasts of burden and food sources. The only predatory animal, an introduced species of brown tree snake (*Boiga irregularis*), is largely responsible for the decline in Guam's endemic bird population.

Table 8: Rate of Endemism of Guam's Native Flora and Fauna.

Source: Dahl 1986.

Biological Group	No. Species	Endemic species	% Endemic
Plants	330	20	6
Insects	15	1	7
Other invertebrates	9		
Reptiles & Amphibians	10	1	10
Birds	12	2	17
Mammals	4	1	25

As indicated above, the cardinal honeyeater (*Myzomela cardinalis* or **egigi**) and the Marianas fruit dove (*Ptilinopus roseicapilla* or **totot**), are among two of the indigenous bird species to be severely reduced in numbers. The loss of endemic birds could have serious ramifications for pollination and seed dispersal of native plants. Other land animals include the fruit bat (**fanihi**); the Polynesian rat (*Rattus exulans* or **chaka**); the flightless Guam rail (*Rallus owstoni* or **koko**) which lives in the forests on the northern plateau; and the introduced giant African land snail (*Achatina* sp.).

Guam's marine fauna is one of the most diverse in the world. Over 904 species of inshore fish have been identified to date (Myers 1989). Two species of endangered sea turtles - the hawksbill (*Eretmochelys imbricata*) and green (*Chelonia mydas*) are found in Guam waters. There are also over 300 species of coral along Guam's reefs.

The marine fauna, the inland aquatic systems (rivers, streams, marshes, and estuaries) contain a variety of vertebrates and invertebrates. Among the mostly widely distributed freshwater fishes are *Gambusia affinis* and *Tilapia mossambica*; both of which are found in Guam's river systems (Best and Davidson 1981). Algae, aquatic insects (*Macrobrachium*), atyid shrimp, neritid snails, gobioid fishes, *Anguilla* eels and flagtails (*Kuhlia*) are also found in all of the major streambeds.

2.4.3 Vegetation

While Guam's climate is sufficient to support a forest vegetation, a significant proportion of the island's vegetation has been modified by human activities. The northern, drier plateau with its less arable soils, is covered by a mixed, moist, broadleaf forest vegetation (Fosberg 1960).

In relatively undisturbed sites, the forest is dominated by *Artocarpus*, *Ficus*, *Neiospora*, and *Pandanus*. *Cycas circinalis*, an understory species, may be present in high proportion (Fosberg 1960).

Where disturbance has been extensive, the vegetation consists of thickets of tangan-tangan (*Leucaena insularum*), a species endemic to the Marianas (Raulerson and Rinehart 1991), particularly along the coastal limestones and strand. *L. leucocephala*, which was introduced largely as a preventive measure for post-war soil erosion, is found throughout the southern volcanic half of the island (Fosberg 1960).

In contrast to the northern half, the southern end has a more dense and varied vegetation pattern. Low lying shrubs (i.e. *Stachytarpheta jamaicensis* and *Cuscuta campestris*) along with ferns (*Nephrolepis hirsutula* and *Angiopteris durvilleana*) and palms (*Veitvhia merrillii* and *Heterospathe elata*) are found along most of the streams and rivers. The coastal strands consist of several species of salt-tolerant plants such as *Pemphis acidula*, *Casuarina equisetifolia*, *Thespesia populnea*, *Pandanus tectorius*, and *Cocos nucifera*; the interior hills and valleys are swordgrass-shrub (plants of the *Miscanthus*, *Dimeria*, and *Phragmites* communities) covered savanna lands of possible anthropogenic origin.

Other vegetation types that reflect either disturbance or particular site conditions are mangrove and nipa swamp forests, mixed forests on volcanic soils in ravines, *Phragmites karka* reed marshes, secondary forest thickets, cultivated land, coconut plantations, open ground and pasture, and bare ground with herbaceous to shrubby vegetation at military installations (Fosberg 1960).

Isolated pockets of the limestone forest which once covered the northern landscape, are still found throughout the south but are rapidly vanishing as a result of development. According to Fosberg (1960), the original limestone forest consisted of large trees forming thick canopies. A long history of disturbance by humans and natural disasters,such as frequent typhoons,has left little undisturbed primary forest on the island. The effects of World War II and subsequent military activities appear to have intensified this destruction process. The northern landscape is now characterized by weed patches and thickets of soft-wooded, weedy trees, while the southern landscape continuously changes to reflect on-going use and development.

2.5 Soils

Volcanic materials and coralline limestone are the two primary parent materials of the soils on Guam. In general, the age of the parent material is related to the age and subsequent development of the corresponding soil. Volcanic deposition occurred during the Eocene, Oligocene, and Miocene epochs. The material is primarily andesite with some basaltic flows and it was deposited as tuff, tuff breccia, tuffaceous sandstone and shale, volcanic conglomerate, and basalt flows (Tracey, et. al. 1964). Limestone deposition occurred primarily in the Pliocene and Pleistocene epochs. Important components of the limestone soils include foraminiferal, molluscan, argillaceous, detrital, reef, and fore-reef facies.

Eight specific soil mapping units have been identified in Guam. There is a distinct difference between residual soils derived from limestone and those developed in volcanic material. Limestone soils such as the Pulantant series are well drained and support a more varied and denser vegetation. Volcanic soils such as the Akina and Atate series are strongly acidic and low in calcium content. Alluvium is another important parent material on Guam; the Togcha, Ylig and Inajaran soils formed in clayey alluvial deposits. Organic matter is the parent material of the troposaprists in Agana Swamp (Tracey, et. al. 1964). A total of 17 soil series have been identified for Guam.

2.6 Water Resources

The high coralline limestone plateau of the north, which rises to 400 m above sea level, is the primary source of fresh water for the island. Streamflow data has been collected by United States Geological Survey since 1950; recording stations at Fena Reservoir (which combines the Imong, Almugosa, Mauleg) and the Ugum and Ylig rivers provide current data in Fig. 7.

Annual runoff from the southern rivers that drain the southern province is approximately equal to aquifer leakage from the northern carbonate plateau. "River discharge responds quickly to rainfall because of the small size of Guam's watersheds and the relatively impervious nature of lateritic soils" (Matson 1991:113). The thin soil layer also cannot hold (store) groundwater for long periods; Matson estimates that at the rate of 43% of rainfall, evapotranspiration is more important than "stored" water.

As of 1991 there were 127 production wells, including 22 reservoirs, and 20 pump stations throughout Guam; 120 of these are located in the north (Water Resources Annual Report 1989). The breakdown of ownership is shown in Table 9.

The average annual well production (for 114 wells) in 1989, was 25.43 million gallons per day (MGD). Maximum production capacity can reach up to 28.94 MGD in the northern wells. Groundwater monitoring (under the "Safe Water Drinking Act") for nitrates, chlorides, selenium, and organic and inorganic water quality is completed quarterly by USGS. In addition, above ground well inspections are made semi-annually. Monitoring indicates that excessive pumping has resulted in saltwater intrusion of the freshwater lens (National Water Summary 1986).

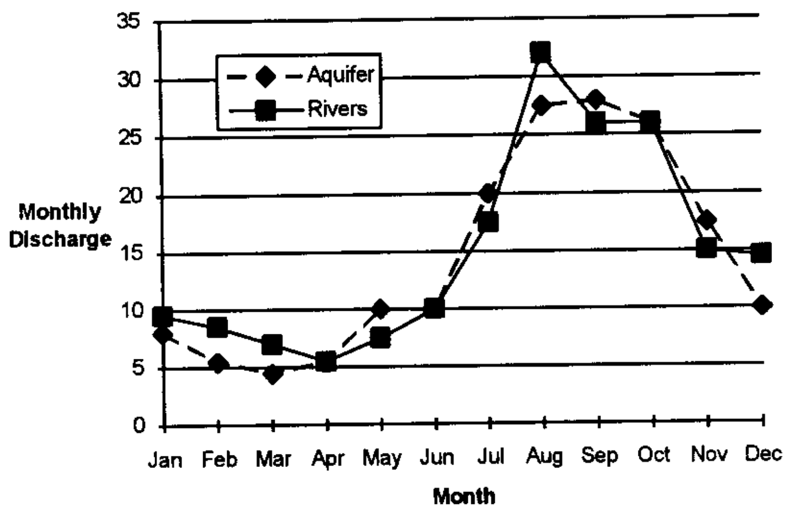
Table 9: Ownerships of water wells in Guam.

Source: Water Resources Annual Report 1989.

Owners	Number of wells	
	North	South
Public Utilities Agency of Guam (PUAG)	99	5
Military	15	0
Private	6	2
Total	**120**	**7**

Fig. 7: Average Monthly discharge (1985 to 1988) from all rivers and the northern aquifer lens.

Source: Matson 1991.



There are a total of 46 drainage basins distributed throughout southern Guam. The Talofofo River system is the longest (12.6 km) and the largest drainage basin on Guam; it includes the Fena Reservoir, which is a combined endangered and threatened species sanctuary and potable water source. Watershed projects, sponsored by the United States Department of Agriculture, are underway to help increase agricultural production whilst also protecting the groundwater from contamination.

The southern Guam Watershed projects (Fenile, Umatac, Inarajan, Manell-Sumay and Talofofo) focus primarily on measures to prevent and divert flood waters. The northern Guam special water quality project (Yigo) is being developed primarily as an agricultural incentive for farmers living in the northern villages. The program involves both (a) training farmers on pesticide use and application, animal waste management and groundwater protection, and (b) monitoring the groundwater for contamination.

2.7 Land Use

Although it is difficult to assess pre-contact (Spanish) land use patterns, archaeological finds indicate that villages existed both inland as well as along the coastal areas. The location of prehistoric sites, thus far, indicate that most settlements occurred on the volcanic-limestone plateaus of the southern half of the island.

It should be noted, however, that inland archaeology is still in its infant stages; inland sites were discovered only within the past 13 years. After contact, most of the settlement appears to have moved to the coastal belt.

Prior to WWII, agriculture formed a large part of Guam's economy. Agriculture was also inherently tied to the Chamorro cultural structure. In addition to the general chaos experienced by a military invasion, in its aftermath WWII restructured Guam's economy. The new economic structure, based largely on services to be provided to the military, was a wage-labor system. By the 1960's, trade, light manufacturing and tourism supplanted the previous focus on agricultural activities (1989 Economic Review).

The Guam Land Use Map (Fig. 8) shows the four major land-use divisions: urban, rural, agricultural and conservation. About 47% of Guam is privately owned; 35% is federally administered; the remaining 18% is administered by the Government of Guam (Guam Soil Survey 1988). The Government of Guam leases much of the land for agricultural use on both annual and long-term leases. Aquaculture is another important use of land; there are at least 10 operations underway, each using between 0.5 to 2.0 hectares per pond. Changes in land use indicate that urbanization is slowly encroaching on the rural, agricultural and conservation areas.

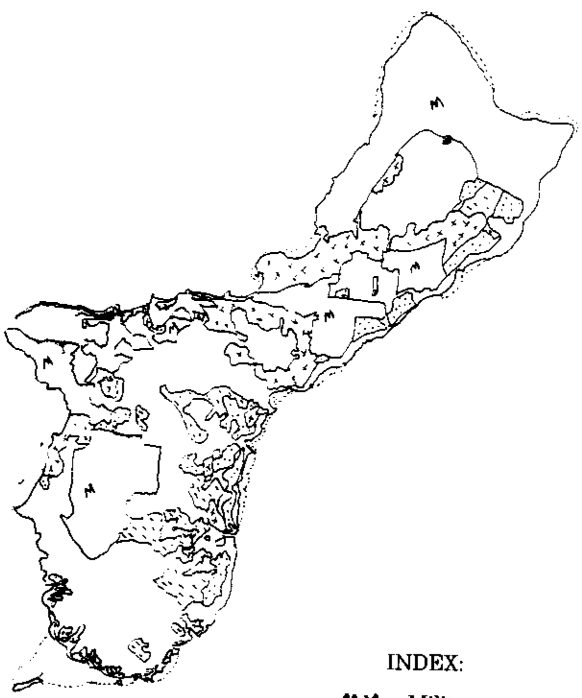


Fig. 8. Land use map of Guam.

Source: Guam Bureau of Planning c. 1986.

2.8 Cultural or Traditional Sites

Cultural or traditional sites can be categorized into:

1) historic (see Fig. 9); and,

2) prehistoric or precontact.

The prehistoric-precontact period includes human habitation before contact with the Spanish (Magellan's landing) in 1521. This prehistoric-precontact period is divided still further into **pre-latte** (c. 1485 to 150 BC), a **Transitional Period** (c. 150 BC to 800 AD) and **latte** (c. 800 to 1521) phases, the latter which lasted into early Spanish contact (Russell and Fleming 1989).

The **latte** phase is distinguished by distinct pottery shapes and the advent of **latte** stones (pillars most likely used for housing). Because of the large number of archaeological studies and prehistoric remains found here, human habitation is better understood for Guam than any other Micronesian island.

Archaeological data reveals at least a 1500 year habitation period on Guam. (Data recovery from Tumon Bay by Bath in 1988, may extend this period by another 1500 years; however these dates have not yet been replicated). Until recently, prehistoric evidence focused largely on a coastal habitation pattern; however archaeological work carried out by Dye and Cleghorn (1990), Prasad (1991) and Moore and Hunter-Anderson (in progress) all indicate that the southern volcanic half of the island was inhabited during prehistoric times. Most of these sites border the rivers and drainages found in the southern interior. The majority of archaeological data thus far however, clearly shows a coastal habitation pattern throughout the entire island. According to Hunter-Anderson (Pers. comm.), the coastal areas have the most dense archaeological deposits; this includes both pre-**latte** and **latte** sites.

Coastal sites reveal significant changes in the natural geomorphological processes of the island; there is strong evidence of an increasing shoreline between initial occupation to later **latte** settlements. Sub-surface stratigraphy throughout the island shows similar extensions of beach areas, however often with marked fluctuations between erosion and deposition periods. Overall, the archaeological data supports geological uplifting of the island. An important point to note is that most of the destruction and removal of coastal sites have been due to development along the shoreline.

Historic sites are also found throughout the island. Much of the commemorative structures, i.e. statue dedicated to Magellan, Fort Soledad, are located in the southern villages of Umatac and Merizo. Other sites include the Plaza de Espana in downtown Agana, Asan Beach (primary invasion site of the U.S. troops), and Two-Lover's Point (north tip of Tumon Bay).

There are numerous Japanese WWII defensive fortifications on Guam; these include pillboxes (bunkers), man-made tunnels, cave sites, and coastal defense positions. Tunnels along cliff faces and rock outcrops were constructed by special units known as the *Suidotai*; these were used extensively (along with cave sites) for gun positions, shelters, command posts and storage areas (Russell and Fleming 1989). The extent to which these sites will be affected by coastal changes varies; for example, Asan Beach is a coastal site, whereas Fort Soledad sits atop a hill overlooking Umatac harbor.

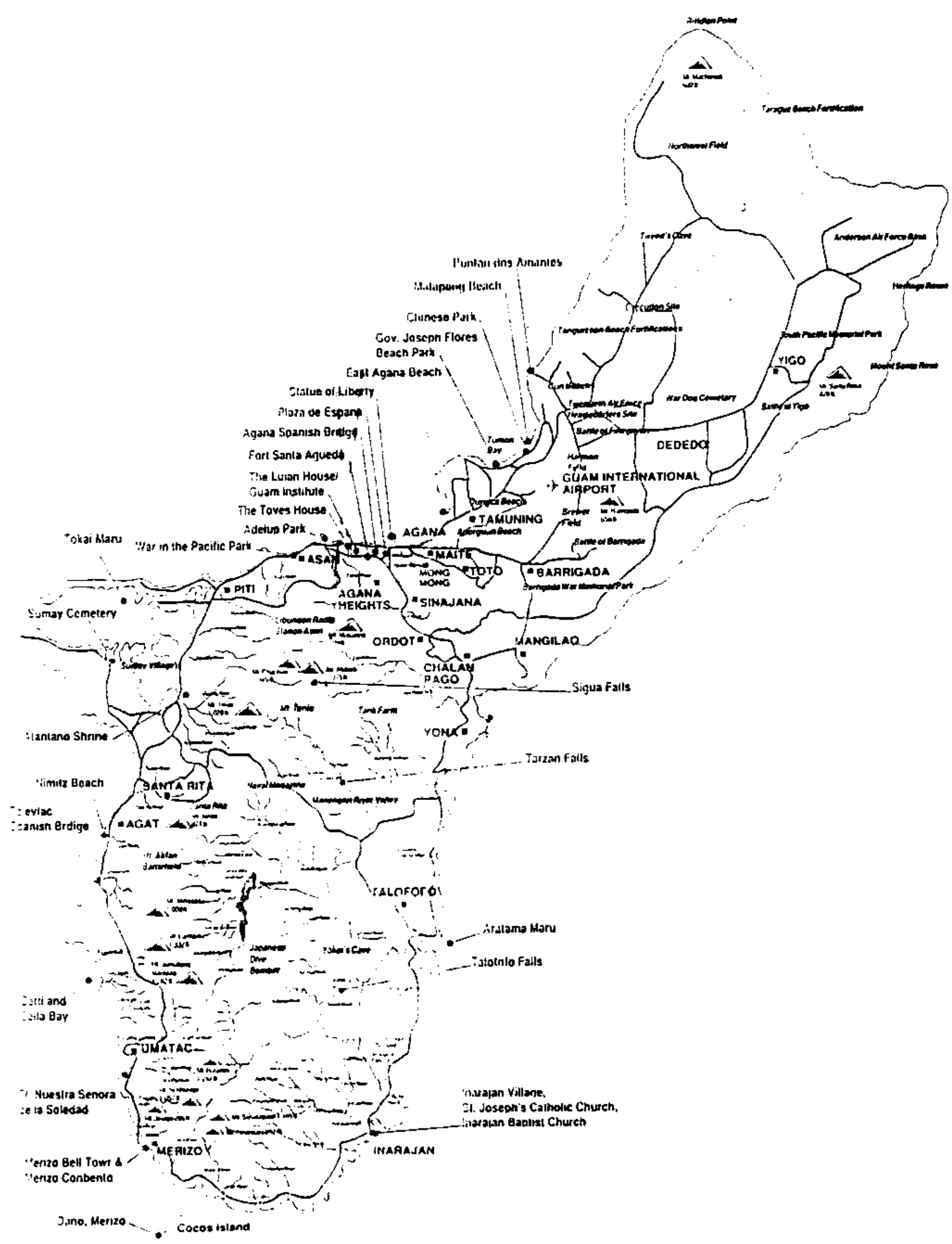


Fig. 9: Parks and historic places on Guam.

Source: Guam Department of Parks and Recreation.

2.9 Socioeconomic Setting

2.9.1 Administration

Guam is an unincorporated territory of the United States. Since contact with the Spaniards in 1521, and subsequent colonization in 1565, Guam has been administered by foreign powers In 1898, Guam became an American possession as a result of the Spanish-American War.

Japanese forces invaded and captured Guam from 1941 to 1944, at which time it was recaptured by the Americans. The U.S. Navy relinquished administration of Guam in 1962, however the U.S. military still plays a significant role in Guam's socioeconomic sector.

The people of Guam elected their first governor in 1970; since 1972, a single non-voting congressman has represented Guam in Washington. The non-voting status extends to all Guam residents for U.S. presidential elections. However a physical presence (not necessarily resident status) is all that is required of any U.S. citizen to vote in Guam elections.

Recent attempts to have Guam established as an American state have met with challenges from those who wish to establish an independent Chamorro nation.

2.9.2 Demography

After initial depopulation as a result of Spanish contact, Guam's population growth has been significantly enhanced by the introduction and migration of non-Chamorros to the island. Fig. 10 and 11 compare the changes in Guam's population distribution in 1970 and 1980. According to the 1990 Census, Guam has a population of 132,726 which includes 22,438 active duty military personnel and dependents. With an annual growth rate of 2.2%, the population will double in approximately 31 years.

The village of Dededo has the largest population with nearly 30,000, followed by Tamuning with a population of 16,932 and Yigo with a population of 12,916. Dededo and Yigo, with their close proximity to Anderson Air Force Base, are settled by many of the military families. Tamuning on the other hand, is the commercial center of the island. The capitol Agana, has one of the lowest populations, with just over 1100 individuals.

Guam's ethnically diverse population includes Chamorros, Caucasians, Filipinos, Chinese, Japanese, Korean, Indians and other Pacific Islanders, specifically those from the Federated States of Micronesia. The present ethnic breakdown is as follows: 45% Chamorro, 25% Caucasian, 21% Filipino, and 9% of other ethnicity. During the early 1980's Guam experienced a recession stage which led to a large-scale out-migration.

Perhaps the most significant demographic change to occur in the last 5 years has been as a result of the Compact of Free Association signed in November, 1986, by the United States and the Federated States of Micronesia. There are approximately 2,500 Micronesians currently living on Guam; Rubinstein (1991) estimates that by the end of the century, the Micronesian population will increase to 20,000. For FSM residents seeking better employment and educational opportunities, the Compact of Free Association has allowed unrestricted movement into Guam. Yet another change to the demographic structure may come from the relocation of military families from the Philippines.

2.9.3 Language, Culture and Education

Like other U.S. territories, English is the standard language used in Guam. Guam is, however, a multicultural and multilingual society. The indigenous population - Chamorros - speak an Austronesian language, which has been significantly influenced by Spanish, Tagalog and English but yet maintains some Pacific affinities. In addition to speaking English, non-Chamorros such as Filipinos, Koreans, Chinese and other Micronesian islanders retain and use their individual languages. Due to the large number of tourists from mainland Japan, Japanese is also spoken throughout the tourist industry.

Multiculturalism is perhaps most evident in the variety of cuisines available on Guam. The "Food Court" at Micronesia Mall is a good example of the many ethnic food varieties on island. Cultural events such as fiestas which honor the village patron saint(s) are held throughout the year. Clubs, e.g. the Filipino Women's Group, sports, e.g. cockfighting, and entertainment, e.g. island dance troupes, all represent the cultural diversity of Guam.

The education system resembles that of the mainland U.S. By the age of 5 children are required to attend primary schools. Post-secondary education is available through Guam Community College and the University of Guam; the latter also offers B.A./B.S. and M.A./M.S. degrees in selected fields. Enrolments with just over 3,000 students for the 1991 Fall semester, were the highest ever at the University. However, there is a shortage of school facilities and staff on Guam. The Department of Education is currently responding to the growing student population needs by increasing the number of classrooms and teachers.

2.9.4 Economy

Guam's standard of living (employment rates and per capita income) is generally better than that found in some of the poorer states of the mainland U.S. (Guam Annual Economic Review 1989). By December 1989, Guam's unemploy-ment rate dropped to 2.1%. Federal (Work Incentive Program) and State (Senior Community Service Employment Program) programs have been enacted during the past 10 years to help produce employment opportunies for Guam's residents. Fisheries, agriculture, aquaculture and manufacturing are also major sources of employment and revenue.

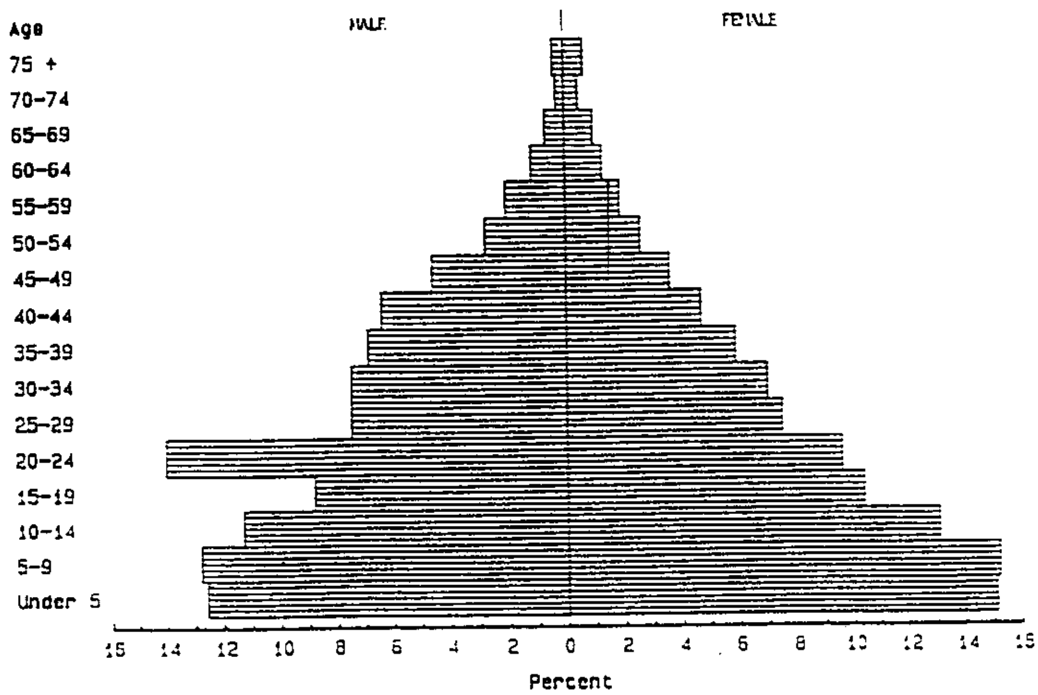


Fig. 10: Population pyramid for Guam, 1970.

Source: Guam Annual Economic Review, 1989.

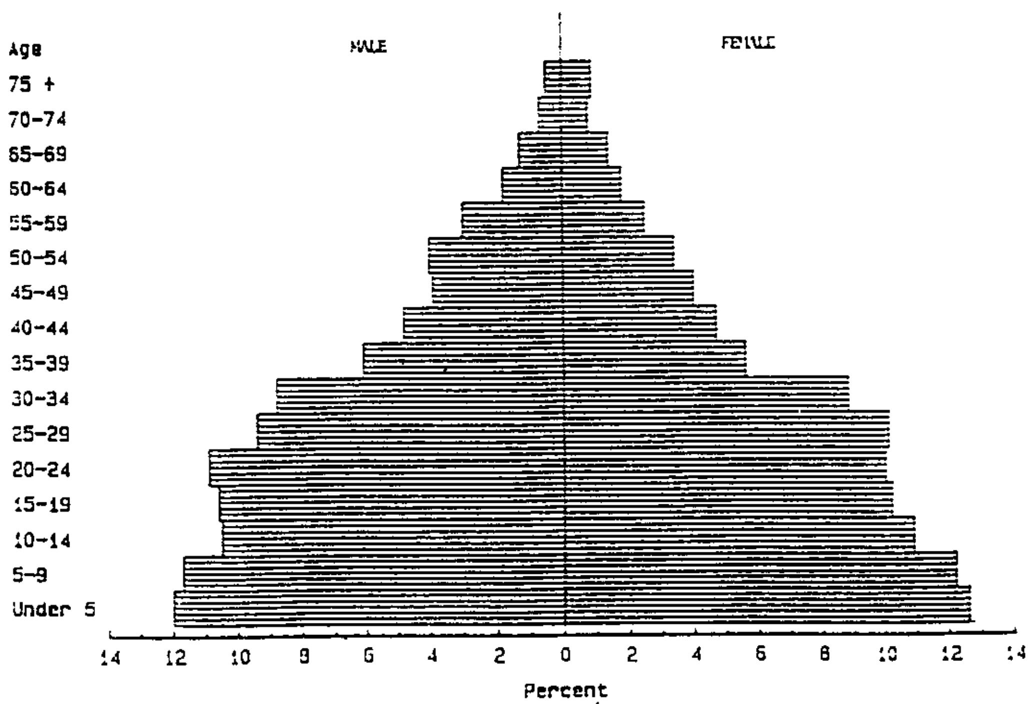


Fig. 11: Population pyramid for Guam, 1980.

Source: Guam Annual Economic Review, 1989.

The military bases also provide jobs for a significant portion of Guam's civilian population but the Government of Guam is the largest employer on the island. In addition to these, Guam has over 5,000 H-2 (labor law permitting temporary work visas to immigrant laborers) workers, mainly from Philippines, Korea, China and India. Fig. 12 and 13 show the labor force distribution of Guam, and labor distribution amongst the private, federal and territorial government sectors:

Tourism is also an important labor source for Guam. Tourism is Guam's largest private sector industry in terms of both employment and income; in 1989, retail and wholesale combined made up 21% of the total payroll employment (Guam Annual Economic Review 1989). According to the Guam Visitor's Bureau, visitor arrivals increased by more than 200% from 1980 (291,129 visitors) to 1989 (658,883 visitors).

In 1989, the annual average hotel occupancy rate was 90%, with 84% identifying Japan as their country of origin. Tourist accommodations are largely confined to Tumon Bay whereas tourist attractions are found island-wide. Cocos Island resort, Alupang Beach Cove and Fort Soledad are among the major southern attractions.

Inflation rates in Guam have risen significantly in the past decade; in 1989 the inflation rate reached over the 10% level as a result of population growth and the large number of imported goods. Some items such as fresh vegetable imports increased by more than 25%, while others such as fresh fish prices decreased by a similar margin.

2.9.5 Urbanization and Change

In many ways, Guam resembles any other growing U.S. city. Infrastructural needs, such as electricity, water, communications, have not been able to match the pace of population growth and development. Either demand has exceeded supply, or supply has not been able to maintain technological pace. For residents, "load-shedding" of electricity has become a normal part of the Guam experience.

With nearly 500 years of cultural change, few aspects of Chamorro life reflect what may have been pre-Spanish practices. Catholicism has replaced traditional religious practices; linguistic changes reflect mostly Spanish introductions; and the traditional socio-political structure has all but disappeared. Some forms of traditional agriculture and marine subsistence practices remain but only in the southern-most villages.

The Spaniards were not the only agents of change; U.S. militarization also created changes in traditional subsistence patterns. In his discussion of traditional sea law in Micronesia, Johannes (1977) explains how the pre-military means of exploiting marine resources was more efficient as it controlled over-exploitation.

More specifically "marine tenure systems were designed to enable islanders to control the types and degree of exploitation of their waters and thereby protect them against impoverishment ... ironically, westernization is simultaneously threatening to destroy the traditional Pacific island system of limited entry - and in fact has done so in some areas" (Johannes 1977: 122). The latter applies more specifically to islands such as Guam which rarely practice traditional law.

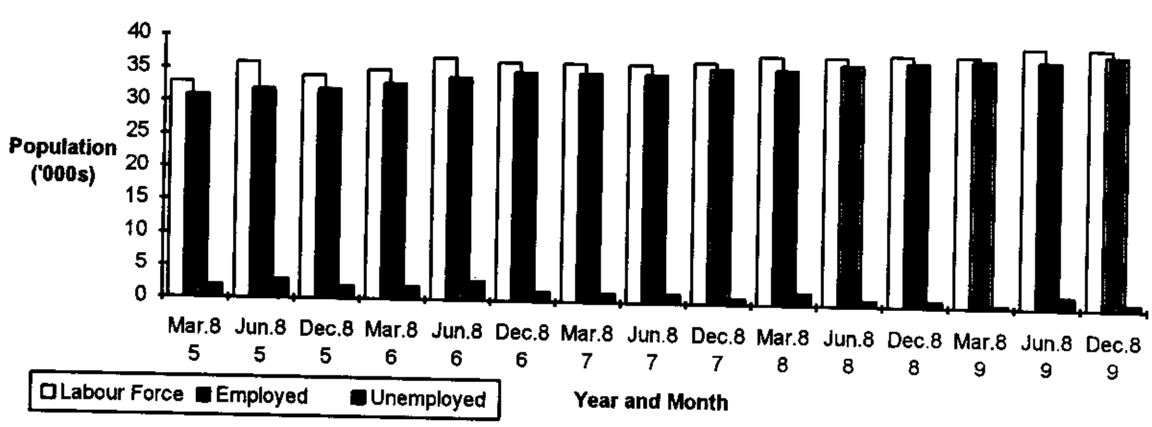


Fig. 12: Labor force data for Guam, 1985-1989.

Source: Guam Annual Economic Review 1989.

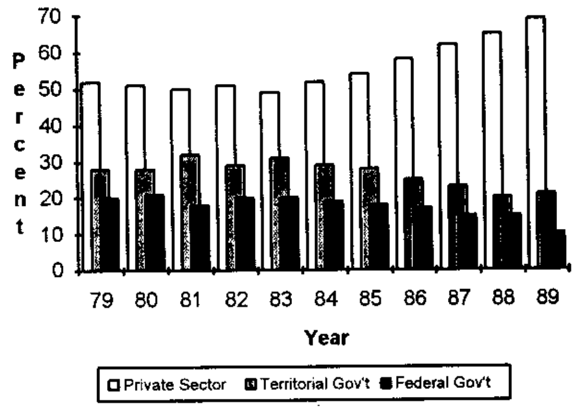


Fig. 13: Guam's employment data by sectors.

Source: Guam Annual Economic Review 1989.

As described above, change is not a new concept or experience for Chamorros (nor for many others who have resettled in Guam). Dramatic changes were introduced early on by the Spaniards, only to be followed by a much different culture dominating and directing future changes. For the most part, Guam residents appear to welcome changes which indicate their affinity with other U.S. cities. But history has also been "rewritten" for Guam, so much so that it is often difficult to assess what existed prior to European-western contact (it is equally difficult to resolve how such changes could have been prevented).

2.9.6 Health and Nutrition

The health and nutrition status of Guam residents are comparable, though slightly lower than, that of their mainland counterparts. In 1980, the U.S. life expectancy was 70.0 years for males, and 77.7 years for females. For the same year, Guam rates were 69.54 for males and 75.61 for females. The death rate was 4.0 (per 1,000) for the same year, with males recording a higher overall rate than females. The causes of death reflect the general pattern of societies undergoing change and succumbing to the diseases of development. Like many other developing countries, especially the Pacific islands, heart disease ranks as the major cause of mortality. Table 9 shows the causes of death for 1988.

Causes of morbidity fluctuate between diseases resulting from socioeconomic changes to infectious and parasitic diseases, which are common in the tropics. Guam is the only Micronesian island which has had a successful dengue control program, largely as a result of eliminating the *Aedes* mosquito vector which transmits dengue. However, isolated cases of leptospirosis and cholera (primarily in Micronesian migrants) still occur.

Morbidity from sexually transmitted diseases (STD's) is also increasing. Recent newspaper reports indicate that Hepatitis B is amongst the fastest growing STD on Guam. Thus far, only 13 cases of AIDS have been reported for Guam (although the actual number of HIV carriers is estimated to be much higher). Drug and alcohol abuse are also major causes of morbidity and mortality in Guam.

Still another group of sicknesses which lead to high morbidity rates are those resulting from natural and man-made toxins. Recently, 3 individuals died from eating seaweed containing a natural toxin lethal to humans. Warnings are usually posted along Guam's beaches alerting residents to contaminated coastal waters; much of the contamination is due to raw sewage dumping and industrial-hazardous waste materials.

Table 9: Causes of Death During 1988 Calendar Year.

Source: Guam Annual Economic Review 1989.

Causes	Number
1. Heart Diseases	128
2. Malignant Neoplasm	91
3. Cerebrovascular Diseases	28
4. Diabetes Mellitus	26
5. Pneumonia	19
6. All other accidents and adverse effects	18
7. Chronic liver disease and cirrhosis	17
8. Motor vehicle accidents	16
9. Homicide	16
10. Suicide	14
11. Other diseases of the central nervous system	14
12. All others	105
Total Deaths	**492**

Along with a host of general social and cultural changes, food preferences have turned towards a more western diet. Most of the traditional foods such as **kelaguen** and **red rice** which are commonly found at fiestas, reflect Spanish and Filipino introductions. Subsistence food items such as taro and fish are rarely consumed (except by other Pacific islanders); meats (beef, pork, and venison) appear to be the preferred choice of protein. The international cuisine on Guam offers a wide variety of foods, as do the numerous (and popular) fast-food restaurants.

2.10 Current Environmental Problems

2.10.1 Waste Disposal/Management

The Ordot dump currently serves as the main site for solid waste disposal. This dump has reached its filling capacity and plans are underway to develop a second site near Apra harbor. Studies are underway to establish a recycling program as well as establish a trash incinerator at Cabras Island in Piti (*Pacific Daily News*, 3-16-92). Problems of locating sites and methods for hazardous waste disposal still exist; currently all hazardous waste material is taken to the Hazardous Waste Transfer Station maintained by the Port Authority of Guam.

The Government of Guam recently contracted UNITEK Environmental Consultants to help dispose of hazardous wastes. UNITEK, which was supposed to have transported the material off-island, had reached its maximum waste storage capacity of 7,000 gallons in less than 6 months (*Pacific Daily News*, 2-28-92).

Existing waste management schemes are inadequate. Newspaper articles to date emphasize the inadequacies of having a single waste disposal company servicing all of Guam's apartment buildings, restaurants and hotels. Also lacking is a general education program for the public dealing with appropriate disposal measures. Recycling prospects are often viewed as not being feasible for the amount of waste produced on island (*Pacific Daily News*, 8-16-92).

2.10.2 Impact on Coastlines

Human behavior has resulted in significant changes to the coastline of Guam. General habitation patterns, military development such as Apra Harbor and tourism along Tumon and Agana Bays have all created irreversible, direct and indirect changes to the natural shoreline. Among the most damaging behaviors to Guam's reefs are: 1) geomorphological changes due to construction projects on, or near the shoreline; 2) sewage pollution from urban and industrial development; 3) mining of coral rock; 4) divers and underwater fisherman; and 5) indiscriminate collection of marine fauna (Yonge 1969).

Guam is a major tourist, commercial and business center. Guam's beaches and reefs are often the main tourist attractions and tourism is confined almost entirely to the coastal areas in the east (Tumon and Agana Bays). Construction along Tumon has left little undeveloped land area. Although regulated, sewage dumping and industrial related spills and leaks of toxic waste often occur accidentally (Guam Environmental Protection Agency 1987); as a result beaches will be periodically closed for recreational activities.

GEPA regularly makes newspaper announcements on warnings and closure of Guam beaches due to excessive bacteriological levels; Tumon and Agana Bays are often on this list. GEPA tests indicate that pollution levels have been steadily increasing during the past 3 years; this may possibly be due to better testing and reporting methods (Seventeenth Annual Report 1989).

Another notable change is the decreasing numbers of some marine organisms, while others increase and thrive in polluted waters. Stoddart (1968) has discussed the increased populations of echinoderms and the green sea algae, *Enteromorpha*, in association with sewage contamination. A measure which should be incorporated as a coastal management program is the monitoring of biological oxygen demand (BOD); this will help determine pollution levels in coastal waters.

In terms of deliberate destructive behavior, such as the mining of coral rock, two mainland visitors were caught removing coral in large quantities for shipment out of Guam (*Pacific Daily News*, 10-16-91). Both individuals were released based on their "lack of knowledge of the harm which they were causing". However, after their departure from Guam, it was established that both individuals belonged to a retail organization specializing in the sale of marine fauna.

In addition to corals, a variety of gastropods and other mollusks are collected and sold as curios. Past consequences to marine life have been witnessed in the overharvested *Tridacna gigas* (Yonge 1969) clams from the local coast.

One sport which is encouraging preserving rather than damaging coral, is underwater diving. The precious underwater environment is finally being recognized as not indifferent to human use.

While tourism is a necessary component of Guam's economy, it has also encouraged destructive behavior towards the coastline. Jet skis are currently amongst the more popular tourist toys on island; islands such as Oahu (Hawaii) have banned the use of these machines during the whale migrating season because of the danger they pose to the large mammals.

Perhaps the most controversial coastal development to take place in Guam, is the projected Piti Bomb Hole Observatory. The Observatory will be placed underwater in order to allow visitors a more natural view of subsurface marine life. Transportation of this mammoth 386 ton structure will involve breaking and removing a significant portion of Piti's reef. Requirements beyond construction will include proper sewage disposal, maintaining a fresh water supply, sustaining proper water circulation outside of the structure, and minimizing the impact to Piti village residents.

2.10.3 Erosion Inland Due to Development

Soil erosion is a major concern on Guam. According to Godden (1989), the badland areas in southern Guam were eroding at about 30 tons per acre per year, while the unburned savanna areas were eroding at an estimated 5 tons per acre per year. Mount Santa Rosa is the only area in northern Guam with erosion problems (USDA, 1989). Erosion, sedimentation and runoff resulting from human development and disturbance are outpacing rainfall influenced degradation (Godden 1989). The Pago River, which lies near the isthmus dividing the southern and northern halves of the island, has been inundated with debris and blocked as a result of hillside clearing upstream.

The Government of Guam has begun to require developers to clean out the rivers and streams and then install culverts in order to assure the waterflow process. However, once the hills of interior Guam (currently the site for several large-scale development schemes) are cleared, heavy rains add to the rapid erosion process. In some cases these development schemes have been abandoned after ground vegetation has been removed; this possibly poses the greatest threat for rapid erosion inland.

Fires deliberately set by hunters, as well as accidental roadside fires, also contribute to the accelerated pace of soil erosion inland.

In a study by USDA (1989), excessive erosion in barren areas was noted in the southern villages of Talofofo, Inajaran, Merizo, Umatac and Agat. The purpose of the study was to identify areas of soil erosion, flooding and inadequate water supply and distribution, that adversely affect and limit the current levels of agricultural production.

Guam's agricultural production has dropped from the cultivation of 3,800 acres prior to WWII, to less than 500 in 1989. Agricultural activities continue to use insecticides (malathion), weed sprays (round-up) and fertilizers which can potentially contaminate the aquifer. Because of the possibility of contaminating the groundwater lens, agriculture is largely limited to the southern villages; agriculture in northern Guam is limited to the Northern Guam Groundwater Protection Zone.

The extent to which inland erosion is impacting the marine and freshwater fauna is currently under study. According to Matson (1991), river inputs have thus far been calculated based only on a hypothetical reef which is 500 m from shore. However, smothering of the aquatic habitat by silt-laden runoffs and the subsequent decline in fishing success along coastal reefs, due to smothering of the benthic habitat by terrigenous sediments, is increasing island-wide (USDA 1989). Godden (1989) estimates that up to 5% of the reef system is negatively impacted each year by sediment from island watersheds.

The process of landscape change and resulting erosion is not a recent event; the reduction of forests and subsequent increase in grass and brush has been a process set into motion by initial human occupation on Guam. This long-term process and its effects are obvious today in increased run-off in streams, reduced percolation of rain into the soil, increased soil loss, reduced soil fertility, and increased damage due to fires.

Efforts by the Guam Department of Agriculture (Division of Forestry and Soil Resources - DR&SR) are underway to regenerate soil productivity through reforestation; several species of *Acacia* are being planted in the "badlands" areas. Within five years some of the barren areas have been able to re-establish a forest cover, allowing both soil improvement and a protective cover for agroforestry (Godden 1989).

Among the environmental amenities resulting from reforestation are a lowering of temperatures and enhanced global carbon dioxide balancing.

2.10.4 Impact on Production Wells

Of the 127 production wells distributed throughout the northern aquifer, 12 of these are concentrated in an area known as the "Dededo well field". The Dededo well field is the single largest concentration of production wells on Guam. These serve the villages of Dededo and Yigo - two of the heaviest populated areas on island. The development of the Guam Municipal Golf Course is located within the immediate area.

The location of the golf course in the well field poses several problems:

1) contamination of the fresh water lens through leakage of herbicides and pesticides;
2) limitation of available fresh water to residents and existing businesses; and,
3) overuse/exhaustion of individual wells as a result of the heavy demand for water by the golf course (Ikehara. pers. comm.).

Ikehara summarises water contamination on Guam as follows:

> "There are two categories of water contamination - 1) toxic contamination from lead, mercury, TCE's and selenium; and 2) non-toxic contamination from nitrates (naturally released from *tangan-tangan - L. leucocephala* and *L. insularum* plants). High levels of lead, resulting largely from water pipes and gas leaks, are a major threat to Guam's water supply. (High levels of lead were also noted in the 1982 Northern Guam Lens Study). TCE's, traced to the use of dry cleaning fluid by Anderson Air Force Base's dry cleaners, have been identified in samples taken from the Dededo wells. Selenium contamination has been linked to the use of fertilizers. Although nitrates have been categorized as non-toxics, high concentrations have been known to cause birth defects".

3. Global Climate Change

3.1 Previous Studies

The present study is perhaps the first to directly address climate change and sea level rise issues for the island of Guam. Recently, GEPA has become involved in planning strategies that address the possible impact of climate change and sea level rise. Federal legislation for future planning, such as the Coastal Zone Management (CZM) Act of 1972, call attention to the need for environmental planning. Section 302(l) of this law states: "because global warming may result in a substantial sea level rise with serious adverse effects in the coastal zone, coastal states must anticipate and plan for such an occurrence" (71:8002).

Existing federal regulations, such as those developed by CZM, are often designed for the contiguous states. These regulations need to be modified in order for them to be appropriate and applicable to the local island situation.

3.2 Projections of Global Climate Change

According to Poiani and Johnson,(1991) "if the current climate models are correct, within 100 years the earth will not only be warmer than it has been during the past million years, but the change will have occurred more rapidly than any on record". Poiani and Johnson(1991:611). The current projections generally agree on a Fig. of 2 cm increase in the average temperature and a 4 m rise in the sea level in agreement with the IPPC Scientific Report.(1990.Business as Usual Report) Measurement of greenhouses gases being released into the atmosphere provides a means by which to make such projections. Fig. 17 shows the increase in greenhouses gases (resulting from release of carbon dioxide, methane and other gases into the atmosphere) over the past 3 centuries:

Fig. 17. Carbon dioxide concentrations during the past 300 years.

Source: Climate Change and Sea Level Rise 1988

An international conference convened by the United Nations Environment Programme (UNEP), the World Meteorological Organization (WMO), and the International Council of Scientific Unions (ICSU) in 1985, concluded that based on present trends, carbon dioxide in the atmosphere would double from preindustrial levels by 2030 (Hulm 1989). Such an increase will affect both the marine and terrestrial ecosystems.

"Temperature increase will affect the oxygen holding capacity of the ocean waters in the shallow areas while higher evaporation rates will affect density gradients that will in turn, affect circulation" (Saha 1991:2). Along with the impact on marine areas, the coastal zone(specifically the coral reefs) will become more vulnerable to changes in wave patterns and increased deposition of sediments. Mangrove systems, which are important spawning grounds for a wide variety of fish and shellfish, will suffer the effects of saltwater intrusion. Water salinity, changes in soil composition, wind patterns and wave actions will also affect coastal zone vegetation.

Climate change will also affect the terrestrial ecosystem. Increase in water resources (rivers, rainfall and ground water) will enhance flooding with higher risks of erosion and sediment transportation. Under a dry scenario, water resources will be limited and competition for this valuable resource will increase (Saha 1991).

Climate change may also effect the reproduction and distribution of inland flora and fauna. For example, under a dry scenario, common fresh-water food fishes such as *G. affinis* may have a more limited environment.

Most land plants have a system of photosynthesis which will respond positively to increased atmospheric carbon dioxide but the response varies with species. The adaptability of plant species, however, may not be positive if the change is too rapid (*Policymakers Summary*, 1990). Rare, endemic species may become targets of extreme weather changes, which may in turn lead to a reduction of biological diversity. As it is, most islands have a low species diversity but with high endemicity; many of these species are already threatened by human population growth, invasion by introduced species, as well as natural climatic changes such as **El Niño**.

3.3 Impact of Climate Change in the Pacific

Climate change in the Pacific will vary: high volcanic islands such as Viti Levu in the Fijis, will feel less pressure from actual physical changes whilst atolls lacking substantial vegetation cover such as Majuro in the Marshalls, may become less inhabitable due to increased temperature rise. The threat to island ecosystems is somewhat difficult to predict since species respond differently to climatic change; while some will increase and thrive with warming temperatures, others will decrease. Ecosystems will therefore change in structure and composition but the greatest threat to them will be to the "rate" of change (IPCC 1990). While it is difficult to predict the impact of climate change on Guam, the current rapid rate of development and deforestation may intensify the negative effects of temperature rise.

There are also health implications if global warming takes place. Changes in water quality, i.e. salinity, contamination, etc. will also affect human health. Because of the high mineral content of the groundwater in Guam, many households currently drink bottled water. The reliance on water-purification systems and their availability to a growing population will most likely increase.

3.4 Sea Level Rise in the Pacific

According to Mark Lander of the Joint Typhoon Warning Center, climate change may not be as significantly experienced in the equatorial regions as a sea level rise, because seasonal variations would be minimal 20 degrees north and south of the equator. He adds that Hawaii experiences more climatic effects than other Pacific islands because it lies just outside this area. A sea level rise resulting from climatic change, though less predictable, causes greater concern for Guam (Lander. pers. comm.). Events (listed in order of duration) which Lander identifies as influences/causes for a rise in the world oceans include the following:

1. Catastrophic events such as the breaking off of the Ross ice shelf could result in a sea level rise of up to 2 inches.
2. Thermal expansion of ocean if sea temperature increases; this would be in the order of inches.
3. Melting ice caps - if all of the world's glaciers melted, an estimated 20 ft of water would spread over the ocean surface.
4. Greenland and Antarctica meltdown - if these polar icecaps which are up to 10,000 ft thick were to melt down, an estimated 200 ft of water would spread over the ocean surface. There is no evidence to date for such an event.

In the likelihood that one of these events is set into motion, the rate at which the ocean actually rises will determine the level of impact on the Pacific islands. For instance a meltdown of the polar ice caps would cause a gradual rise in the level of the oceans, thereby allowing island nations a longer response time to the potential impact.

Under a more rapid rising sea level scenario, islands need to be better prepared to respond to such potential hazards. In summary, the Intergovernmental Panel of Climate Change (Working Group III 1990) has developed a list of adverse ecological impacts which could result from a sea level rise. Those which apply specifically to the Pacific islands are:

1. Increased shoreline erosion;
2. Coastal flooding;
3. Inundation of coastal wetlands and other lowlands;
4. Increase in the salinity of estuaries and aquifers;

5. Alterations in tidal ranges in rivers and bays;
6. Changes to the locations where rivers deposit sediment; and,
7. Drowning of coral reefs.

Guam's marine and terrestrial environments would also be adversely impacted by these events. The following section addresses and provides examples of how the local terrestrial and marine environments would be impacted.

3.5 The Likely Impacts of Climate Change and Sea Level Rise on Guam

Whether or not rising sea levels will have a greater impact on Guam than climate change is uncertain. There is a need, however, to address the likely impact of both events in order to develop a plan of response. As suggested for Kiribati (Sullivan and Gibson 1991), adverse impacts will create both direct and indirect changes to Guam.

Some of the direct changes to Guam will be:

1. Severe discomfort and thermal stress as a result of increasing temperatures
2. A decline in economic activity as comfort working levels become less tolerable.
3. Increased need for atmospheric management in urban areas, i.e. building design and air conditioning to maintain reasonable comfort levels
4. Agricultural potential of food crops may change if crop varieties cannot adapt to increasing temperatures
5. Possible dieback of coral as a result of ocean temperature change

Indirect changes are more likely to occur if the areas which provide some of Guam's basic social and economic resources are severely affected. For example if the business district (which spreads along the low-lying west central coast of Guam), becomes inundated with water, accessibility and availability of these services would be severely compromised. The rate of climatic and sea level change, if gradual, will have less impact on the island (allowing a greater period of adjustment for plant and animal life) than a rapid rate of change.

3.5.1 Impact on Coral Reefs

The coral reefs surrounding Guam are subject to a great deal of stress from pollution,exploitation and development. Reef bleaching, due to greater exposure to ultraviolet rays and high temperatures, may be more of a cause for concern than the inundation of reefs. Although a local study of the bleaching process has yet to be undertaken , coral bleaching of Guam reefs may be comparable to that occurring elsewhere in the central Pacific region (C. Birkland. pers. comm.).

Studies have been completed however, on naturally occurring reef-bleaching due to low tides and catastrophic disturbances. Colgan (1981) studied the long-term recovery process of corals at Tanguisson reef after a 2 year (1968-69) invasion by *Acanthaster planci*; he found that recovery was gradual and continual 12 years after the predation. The invasion of *A. planci* occurred during the same time as the reefs of Guam were experiencing unusually low tides and warmer currents (R. Randall. pers. comm.); hence the bleaching process was enhanced by the simultaneous occurrence of 2 catastrophic events.

The combination of recreational activities and possible exposure to high temperatures, ultraviolet radiation and low tides are already placing a great deal of stress on Guam's reefs. Climatic change with warmer temperatures would increase the likelihood of bleaching on the reefs. Depending on the degree of sea level rise, i.e. whether its 20-30 cm or 1 m, some coral reefs may actually drown.

In summary, climate change and sea level rise would add to the stress currently effecting Guam's reefs.

3.5.2 Impact on Low-lying Areas and Shorelines

Low-lying areas can become inundated by a sea level rise. Along with increased water levels, changes in wave activity can damage vegetation, infrastructure, housing and recreational sites. The southern villages of Guam, which often suffer the greatest impacts of typhoons, are also likely to be most affected by increasing sea levels. Most of the damage done in the low-lying villages is to residential units, engineered structures and recreational areas.

One of the heaviest damaged areas during typhoon *Yuri* was the Inarajan cemetery. As a result of water damage, several gravesites were cutback exposing skeletal parts. If for instance a 1 m sea level rise coupled with a storm surge occurred, the entire cemetery would easily be submerged. A low lying area of Pago Bay in Chalan Pago was also heavily damaged; several homes were flooded, vehicles were swept away and vegetation was coated with a heavy sand-silt deposit.

Among the non-residential areas to be affected would be the recreational structures found along the shorelines of Guam. The Saluglula Pool in Inarajan no longer has its 3 pavilions as a result of wind and water damage from Typhoon Yuri. There are a total of 29 public beaches and parks along Guam's coastline, most of which include parking areas, shelters, and pavilions. A 2-3 cm rise may not significantly affect any of these structures, however higher levels of wave activity could cause damage and force closure of several of these recreational areas.

Typhoon damage to Cocos Island over the past two years has led to a virtual shutdown of this island resort. Damage resulting from storm generated wave surges affected both the natural and developed structures on the island, leaving it uninhabitable. The rebuilding process has been slow and costly. Such developments are important to the tourist industry and represent a considerable loss of capital investment.

Shorelines may recede as a result of sea level rise. Shoreline recession is also likely to occur from normal erosive processes including storm surges and wave attack. This may entail population movement to inland areas, particularly in the southern villages of Guam A decreasing coastline may also force harbors and ports to be relocated to areas with greater surge protection. The northern limestone plateau will be the least affected since activities are limited along its coastline. The southern and central low-lying areas would witness the greatest degree of change. Depending on the depth, sea level rise may also penetrate rivers and deltas.

3.5.3 Impact on Mangroves

Mangroves are currently protected under the Territorial Land Use Commission/Territorial Seashore Protection Committee Wetlands Rules and Regulations Title XVIII and XIV. This regulation applies to all inland and marine based areas such as mangrove swamps, which fall under the category of "wetlands".

As of 1990, 3.8% of Guam's land area was designated wetlands. The mangroves of Guam are home to a variety of plants, birds and animals. The mangrove swamp in Apra Harbor, perhaps the least affected by urban development, is home to a large number of fiddler crabs, mudskippers (*Periophthalmus koelreuteri*) or "macheng", and *Scylla serrata*, the mangrove crab.

Although mangroves are currently protected under the wetlands law, the areas to which they are confined make them vulnerable to a sea level rise. Guam's mangrove swamps are located primarily as isolated pockets along the southern villages of Apra, Asan, Umatac and Merizo. Many of these mangrove areas have already been subjected to human encroachment and natural disasters.

For instance, much of the mangrove strand along the western edge of Apra harbor has been removed during construction of the Naval ship repair facility. The current law which protects these areas as habitats for many animal and plant species does not take into consideration damage to the mangrove environment from natural disasters. Inundation of the mangrove habitat may result in a complete loss of the diverse lifeforms which this environment supports.

3.5.4 Impact on Water Tables

As suggested by Sullivan and Gibson (1991), island size and elevation are important in the development and maintenance of the freshwater lens. Saltwater intrusion is already being experienced throughout the northern aquifer; much of this results from overuse (GEPA, 1982). An increase in sea level would affect, and possibly change the existing transition zone which buffers the fresh water lens from salt water. In addition, if sea level rise is also accompanied by dry periods, the lack of rainwater will not allow groundwater recharge and refreshing to occur at the necessary rates.

3.5.5 Impact on Land Use

The physical effects of a sea level rise may be less noticeable than the social and economic consequences of inter-island movement and out-migration by neighboring Micronesian islanders. Micronesian migration into Guam has already placed a burden on the rapid growth of the island's population.

The in-migration of Micronesian islanders has been so significant that U.S. federal funds are available to assist in resettlement. This migration pattern is only likely to increase, especially if significant physical changes resulting from a sea level rise make the smaller islands and atolls of Micronesia uninhabitable.

As noted by Hulm (1989) in his report for UNEP and ASPEI, Guam would fall into "category B", in which severe impact would be felt as a result of socio-economic disruption, resulting from islanders fleeing for refuge from the severely affected low-lying islands. Although the degree of change cannot be fully anticipated, based on the existing pattern of in-migration, measures such as increased housing units, can be taken to aid the transition process. Along with basic needs such as food and shelter, socio-cultural needs of the incoming population will also have to be anticipated. One area of change may be marine exploitation, since many island cultures may wish to continue traditional marine subsistence practices.

In October of 1991, the Territorial Planning Council (TPC) was formed as a branch of the Territorial Land Use Commission, in an effort to update the antiquated land-use system and zoning maps which have been in use since the 1960's. New guidelines are being developed which include public input. Public meetings have already begun in several villages allowing village residents to voice their opinions on development concerns directly affecting them.

An important matter for the TPC to consider before the final **I TANO'-TA** or Land use Plan is prepared, is how land-use in individual villages would change because of climate change and sea level rise. For instance, the villages of Merizo and Inarajan, both lying along the shoreline and often subjected to typhoon-related storm surges, should incorporate plans that either encourage inland development or devise shoreline protective measures.

3.5.6 Impact on Engineered Structures

Engineered structures along the coastline are all threatened to varying degrees by sea level rise. Potential damage, e.g. breakage and/or inundation is foreseen for the following hard structures: coastal sea walls, the Port of Guam, Umatac Small Boat Harbor, Merizo Boat Pier, Agat Marina, and Agana Marina. Seawalls serve as the first line of defense against direct wave action and storm surges. Structural measures such as the elevation of piers can be developed.

These protective strategies, however, would need to take in consideration the impact and alterations which they themselves impose on the existing environment. Environmental impact assessments can estimate the possibilities of safe protective measures. Preventative measures such as beach filling and levee construction may also be possible.

3.5.7 Impact on Marine Exploitation/Fishing

Although marine exploitation/fishing is not as common on Guam as it was prior to WWII, changes in marine ecosystems will affect human activity here. If phytoplankton, the basis of marine food chains, is seriously threatened, then the availability of fish and marine animals me be reduced. Fish which have a surface dwelling larval stage may also be injured by increasing UV-B radiation (Amesbury and Myers 1982).

There are two types of fishing in Guam:

- small boat, commercial, sport and recreational, and subsistence; and,
- longline yellowfin and bigeye tuna offloading and transshipment (Guam Annual Economic Review 1989).

Local fisheries are mainly small scale operations, including offshore and inshore trawling, bottom fishing and spear fishing. Most small boat operations work out of Umatac Small Boat Harbor and Agana Marina. In the past two years there has been an increase in pelagic catches of skipjack, wahoo and yellowfin. There is also concern about encroachment by the larger commercial fishing boats which, although restricted to fishing grounds within the FSM Exclusive Economic Zone, still affect Guam's fisheries resources.

Marine aquaculture has also increased in recent years in . Commercial farms for freshwater fish such as tilapia, milkfish, chinese carp and catfish, and for marine shrimp have begun. The formation of the Pacific Aquaculture Association (PAA) in 1989 allows Guam to better co-ordinate aquaculture activities with its Micronesian neighbors.

Although Guam is increasing its marine aquaculture efforts, Palau and the Philippines are the main sources of fish consumed on Guam. Since most aquaculture projects lie in low-lying areas, a sea level rise could submerge the units (barriers and borders) that contain the fish and shrimp. Higher temperatures from climate change may also make it more difficult to contain fish and shrimp in small, shallow enclosures.

4. Future Environmental Planning in Guam

Future environmental planning for Guam, in the event of climate change and specifically a sea level rise, is urgently needed. Little effort has been made towards planning strategies in the event of natural disasters. Prior to 1962, the U.S. Navy largely determined the direction of environmental planning on Guam; it also was responsible for infrastructural preparation and prevention against natural disasters. As Guam became a U.S. Territory, independent government agencies resembling their counterparts on the mainland were established.

Even with the change to a more "localized" foci of services, U.S. federal guidelines still often determine the direction of local planning and development. State guidelines also often mimic similar directives established for the mainland. In most instances, there is an absence of transforming these directives into locally appropriate measures.

Data gathering for this report revealed that many local agencies have not established locally appropriate guidelines, and their adopted federal guidelines and regulations do not address the specific environmental needs of Guam. As an example, the Guam Coastal Management Program follows guidelines which do not reflect the dynamics of local marine ecosystems. In their *Final Environmental Impact Statement* (1979), only 1 page is devoted to exploring the "probable adverse environmental effects that cannot be avoided".

Based on the number of studies being released by the Marine Laboratory at the University of Guam, there are numerous human-related and naturally occurring adverse environmental effects to Guam's marine ecosystems. These EIS reports could, while fulfilling federal regulatory needs, also emphasize the local significance of issues that otherwise are of less concern to the mainland. The reports should also give more attention to local and regional issues concerning climate change and sea level rise.

Unlike many other Micronesian islands where environmental management concerns are not addressed by any one agency or unit, GEPA has been directed with such responsibility. GEPA does address environmental concerns, however; their efforts have not yet been directed towards future planning for the impact of climate change and sea level rise on Guam.

Planning efforts are continuously being made by various federal agencies such as USDA which is addressing water quality/flood control problems on Guam. Federal Emergency Management Agency's (FEMA) recent response to the aftermath of Typhoon Russ was to coordinate with other federal and territorial agencies and prepare a hazard mitigation plan for reducing future typhoon damage in Guam. Similar efforts could and should be made by local agencies.

Although GEPA has the authority to address environmental concerns, their activities seem to focus on consequences and not necessarily the planning and prevention required before problems arise. Resource and land use management, instead of being overseen by a single group, is divided between numerous agencies (Fig. 18 shows the various government agencies involved in land-resource use management).

While the main incentive for preparing this report has been to identify the potential impact of climate change and sea level rise on Guam, issues related to maintenance of environmental quality and the sustainable use of natural resources have also been raised. The data gathering process revealed that a wide body of knowledge and expertise on environmental use and planning, e.g. the University of Guam, USGS, is available on Guam; however these often exist independently of one another. In the following section, recommendations are made to designate one specific group/unit to coordinate, implement and oversee environmental planning needs for Guam.

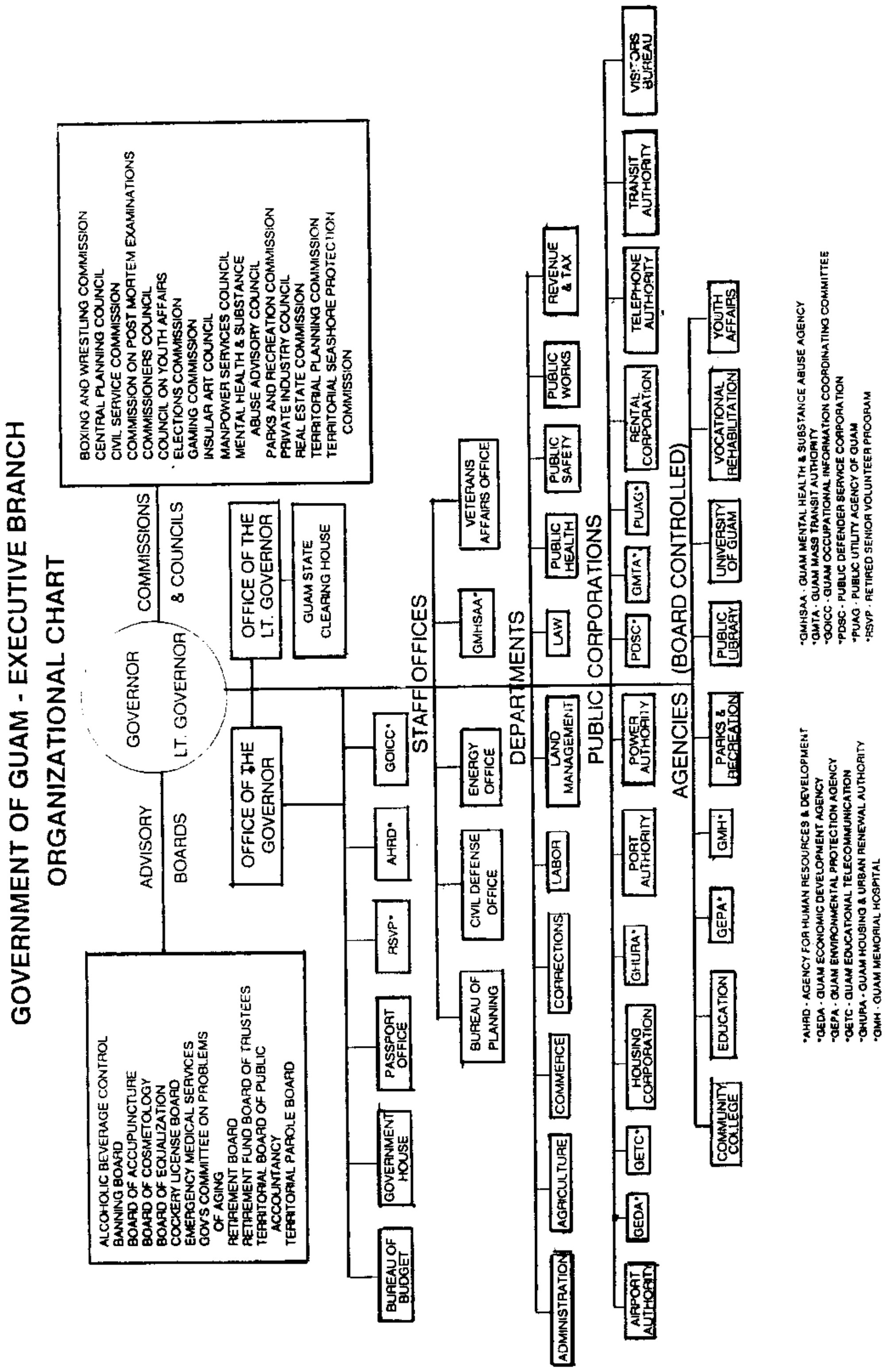


Fig. 18: Goverrnmental organizational structure.

5. Recommendations

Since Guam is a U.S. Territory, its rights, e.g. eligibility to International organizations such as UNEP, and privileges are largely determined by its political status and affiliation with the U.S. federal government.Unlike some of the other Micronesian islands such as Kiribati, Guam also has either access to, or already available resources, in terms of manpower and designated authority to address potential problems resulting from climate change and sea level rise. Based on these facts, the following recommendations offer the most probable and expedient direction for responding to the impact of climate change and sea level rise:

A. Environmental Change and Response Unit

1. Establish an Environmental Change Response and Planning Unit within the Guam Environmental Protection Agency.

a. Establish a Project Officer position. This individual will be responsible for data collection, networking and report preparation.

b. Establish an Environmental Monitoring Officer position. This individual will require technical expertise in physical, chemical and biological monitoring, the analysis and interpretation of such data and its role in environmental impact assessment.

c. Advisors to this Unit should include representatives from each of the agencies listed in recommendation #2.

Training for these individuals can be coordinated through SPREP.

2. A meeting-conference initiated by GEPA, requiring participation from all other federal and territorial agencies involved in environmental management.

This would include individuals from the United States Geological Survey, Typhoon Warning Center, Civil Defense, Army Corps of Engineers, Territorial Land Use Commission, Territorial Seashore Commission, Historic Preservation Office, Bureau of Planning, GEDA - Guam Economic Development Authority, USDA - Soil Conservation Unit, FEMA, and the Water and Energy Resources (WERI) and the Marine Laboratory at the University of Guam.

This initial meeting can serve as a information sharing mission to identify how each agency can contribute towards a climate change-sea level rise plan.

Some of the objectives to be covered in this meeting are to:

a. Identify potential areas at risk, i.e. shoreline structures, land reclamation, water-contamination, health risks to the community, etc.

b. Identify possible preventive measures which can reduce risk and harm to these areas, i.e. developing salt-tolerant crops, methods of solid and toxic waste transfer and disposal, educational resources, population planning, etc.

c. Each agency designate a representative who will collaborate with, provide data for, and serve as a liaison with the GEPA Project officer.

3. The Response Unit will develop policies and strategies to be implemented for specific areas and items affected by climate change and sea level rise,as outlined in this document.

4. The Response Unit will, in coordination with public and local educational institutions, promote awareness and knowledge of climate change issues.

Formal and informal educational programs and audio-visual aids, such as *Guam's Hidden Treasure* (prepared by USGS and GEPA, addressing the northern aquifer lens) should be produced for adults and children. Groups such as "Kids for Coral" that are already making substantial contributions towards educating the public on the anthropogenic impact on Guam's reefs, should be further encouraged and supported by the response unit.

5. The Response Unit will maintain updated records of environmental changes relating to sea level.

These would include climate, shoreline profiles and coastal erosion, rainfall patterns, ground water quality and contamination, and land and marine resource use and developments which affect these areas.

6. Networking with the various national, regional and international agencies.

These include agencies such as SPREP and IOC (Intergovernmental Oceanographic Comm-ission) which can gather data on areas and items affected by climate change and sea level rise. Numerous studies have been completed throughout the Pacific on the impact of climate change and sea level rise; these should be consulted and used as examples for developing a program in Guam.

As an example of developing effective strategies and responses for reducing and preventing adverse impacts of a sea level rise, the 10-year protocol developed by the Intergovernmental Panel of Climate Change (see Table 10) may be followed with modifications to meet local needs.

In addition to managing/monitoring the impact of sea level changes along the coastal areas, similar considerations need to be given to the potential impact of climate change. One area of critical concern is the availability of potable water.

B. Fresh Water supply

Guam currently experiences water problems in the dry, summer months. Along with increased residential needs, recreational activities such as golf courses place a heavy demand on the available water supply. Southern Guam is particularly susceptible to water shortages since the Fena Reservoir often falls below its normal level during the dry months.

Knowing that the current methods and sources of water will not be adequate to meet the needs of the island, the following measures should be taken:

1. Identify alternate sources of fresh water;
2. Service and repair pipes and wells that have been closed or have deteriorated;
3. Implement education and conservation measures;
4. Develop safe-drinking water measures;
5. Develop alternate sources of water for use in activities such as golf course greens that do not require tapping into the island's northern aquifer or Fena Reservoir.

C. Remote Sensing and Satellite Data

With the cooperation of NASA and NOAA, efforts are currently underway at the University of Guam to establish a Remote Sensing and Satellite Data Interpretation Center. This Center should be responsible for updating weather reports and changes for the island as well as for the region.

This will become a valuable resource for monitoring climate changes over short and long periods of time. The Center will also be capable of monitoring the indirect effects of climate change such as shifts in marine productivity and changes in terrestrial vegetation patterns.

Table 10: Suggested ten-year timeline for the implementation of comprehensive Coastal Zone Management Plans.

Source: IPCC,1992.

Year	Suggested Activity
1992:	Designate: (a) national coastal coordinating bodies, (b) national coastal work teams, (c) an international coastal management advisory group. to support the IPCC-CZM Subgroup and assist national work teams
1992-1994:	Develop preliminary national coastal management plans; begin public education and involvement
1992-1994:	Begin data collection and survey studies of key physical, social and economic parameters assisted by an international advisory group. For example: - Topographic information - Tidal and wave range - Land use - Population statistics - Natural resources at risk
1993:	Adoption of a "Coastal Zone Management and Sea Level Rise" protocol, with a secretariat of the parties, supported by the international coastal management advisory group
1993-1996:	Begin development of coastal management capabilities, including training programmes and strengthening of institutional mechanisms
1996:	Completion of survey studies, including identification of problems requiring an immediate solution and identification of possible impacts of sea level rise and climate change impacts on the coastal zone
1997:	Assessment of the economic, social, cultural, environmental, legal and financial implications of response options
1998:	Presentation to and reaction from public and policy makers on response options and response selection
1999:	Full preparation of coastal management plans and modifications of plans as required
2000:	Adoption of comprehensive coastal management plans and development of legislation and regulations necessary for implementation
2001:	Staffing and funding of coastal management activities
2002:	Implementation of comprehensive coastal zone management plans.

Bibliography

Aalbersberg, B. and J. Hay. 1992. *Climate Change and Sea Level Rise - Report on a Preparatory Mission to Tuvalu.* South Pacific Regional Environment Programme, Noumea, New Caledonia..

Amesbury, S. S. and Myers, R. F. 1982. *Guide to the Coastal Resources of Guam. Vol. 1, The Fishes.* University of Guam Press, Guam.

Best, B. R. and Davidson, C. E. 1981. *Inventory and Atlas of the Inland Aquatic Ecosystems of the Marianas Archipelago.* University of Guam Marine Laboratory Technical Report No.75, Guam.

Brodie, J. E., et. al. 1990. *State of the Marine Environment in the South Pacific Region,* UNEP Regional Seas Reports and Studies No. 127, Nairobi,Kenya.

Blumenstock, D. I. 1959. Climate. *Military Geology of Guam, Mariana Islands.* Intelligence Division, Office of the Engineer, Headquarters, U.S. Army Forces, Pacific. Vol. I,14-54.

Bureau of Planning. 1991. *The Wetlands of Guam: a Guidebook for Decision Makers.* Guam Coastal Management Program, Guam.

Colgan, M. W. 1981. *Long-term Recovery Process of a Coral Community after a Catastrophic Disturbance.* University of Guam, Marine Lab Technical Report #76, Guam.

Comparative Toxicity Test of Water-Soluble Fractions of Oils and Oil Dispersants to Marine Organisms. 1987. UNEP Reference Methods for Marine Pollution Studies No. 45, Nairobi,Kenya.

Dahl, A. L.. 1986. *Review of the Protected Areas System in Oceania.* IUCN Commission on National Parks and Natural Resources and UNEP.

Department of Parks and Recreation. 1976. *Guam Historic Preservation Plan.* Government of Guam, Agana, Guam.

Dye, T. and Cleghorn, P. L. 1990. Prehistoric Use of the Interior of Southern Guam. *Micronesica,* Supplement No. 2, 261-274.

Easton, W. H., Ku, T. L., and Randall, R. H. 1978. Recent Reefs and Shore Lines of Guam. *Micronesica* 14(1),1-11.

Economic Research Center. 1989. *Annual Economic Review and Statistical Abstract 1989.* Economic Research Center, Department of Commerce, Government of Guam,.Guam.

Fosberg, F. R. 1960. The Vegetation of Micronesia. *Bulletin of the American Museum of Natural History* 119(1),1-75.

Godden, R. 1989. *Guam River Basin Study: Island Wide Erosion Control Component.* USDA Report.

Guam Environmental Protection Agency.1982. *Northern Guam Lens Study: Summary Report.* GEPA, Harmon, Guam.

Guam Environmental Protection Agency Fifteenth Annual Report. 1987. GEPA, Guam.

Guam Environmental Protection Agency Seventeenth Annual Report. 1989. GEPA, Guam.

Guam Coastal Management. 1987. *Guam Shoreline Access.* Bureau of Planning, Government of Guam,Guam.

Hulm, P. 1989. *A Climate of Crisis: Global Warming in the South Pacific.* Association of South Pacific Environmental Institutions, Port Moresby.

Hunter-Anderson, R. L. (ed.) 1990. Recent Advances in Micronesian Archaeology. *Micronesica,* Supplement No. 2.

Hunter-Anderson, R. L. and Graves, M. W. 1990. Coming from Where? An Introduction to Recent Advances in Micronesian Archaeology. *Micronesica,* Supplement No. 2,5-16.

Interagency Hazard Mitigation Team 1991. *Hazard Mitigation Opportunities in Guam.* 1991. Federal Emergency Management Agency, document #887-DR-GU.

Intergovernmental Panel on Climate Change 1990. *Policymakers Summary of the Scientific Assessment of Climate Change.* Report from Working Group I to IPCC. Geneva.

Intergovernmental Panel on Climate Change 1990. *Policymakers Summary of the Potential Impacts of Climate Change.* Report from Working Group II to IPCC. Geneva.

Intergovernmental Panel on Climate Change. 1990. *Policymakers Summary of the Formulation of Response Strategies.* Report from Working Group II to IPCC. Geneva.

Intergovernmental Panel on Climate Change. 1990. *Strategies for Adaptation to Sea Level Rise.* Report prepared by the Coastal Zone Management Subgroup for IPCC. Geneva.

Intergovernmental Panel on Climate Change. 1992. *Global Climate Change and the Rising Challenge of the Sea.* Report of the Coastal Zone Management Subgroup. Geneva.

Johannes, R. E. 1977. Traditional Law of the Sea. *Micronesia* 13(2),121-127.

Kiste, R. C. 1986. *Implications of History and Culture for Sustaining Development of Renewable Resources on U.S. Affiliated Pacific Islands.* Report for the Office of Technology Assessment.

Matson, E. A. 1991. Nutrient chemistry of the coastal waters of Guam. *Micronesica* 24(1),109-135.

Moore, P. H. and Krizman, R. D. 1981. *Field and Garden Plants of Guam.* University of Guam,Guam.

Myers, R. F. 1989. *Micronesian Reef Fishes.* Coral Graphics, Barrigada, Guam.

New Zealand Ozone Protection Programme: Policy Statement, 1989.

Nilsson, A. 1990. *Saving the Ozone Layer.* The Swedish Society for the Conservation of Nature and Annika Nilsson.

Office of Coastal Zone Management and Guam Coastal Management. 1979. *Final Environmental Impact Statement and Coastal Management Program for the Territory of Guam.*

Pernetta, J. C. and Hughes, P. J. 1989. *Studies and Reviews of Greenhouse Related Climate Change Impacts of the Pacific Islands.* Report prepared for SPC/UNEP/ASPEI Intergovernmental meeting on climate change and sea level rise in the South Pacific.

Poiani, K. A. and Johnson, W. C. 1991. Global Warming and Prairie Wetlands. *BioScience* 41(9),611-618.

Potential Impacts of Greenhouse Gas Generated Climatic Change and Projected Sea-Level Rise on Pacific Island States of the SPREP Region, June-July 1988. Prepared by the ASPEI Task Team.

Prasad, U. K. 1991. *Summary of Archaeological Monitoring of the Miyama Hills Access Road, Mannenggon Hills, Guam.* Report for the International Archaeological Research Institute, Inc., Honolulu, HI.

Randall, R. H. and Eldredge, L. G. 1976. *Atlas of the Reefs and Beaches of Guam.* Coastal Zone Management Section, Bureau of Planning, Agana, Guam.

Raulerson, L. and Rinehart, A. 1991. *Trees and Shrubs of the Northern Marianas Islands.* Coastal Resources Management, Saipan, Northern Marianas.

Rubinstein, D. H. 1991. *Changes in the Micronesian Family Structure Leading to Alcoholism, Suicide and Child Abuse and Neglect.* Paper presented at the Child Abuse and Neglect Summit, University of Guam.

Russell, S. and Fleming, M. A. 1989. *Japanese World War II Defensive Fortifications on Guam, 1941-1944.* Guam Historic Preservation Office, Agana.

Russell, S. and Fleming, M. A. 1989. *The Initial Settlement of Guam 1,050 to 500 B.C.* Guam Historic Preservation Office, Agana,Guam.

Saha, R. 1991. *The Potential Impacts of Climate Change and Sea Level Rise on Island Ecosystems of the S.W. Indian Ocean Region.* Paper presented at the ICCLES Conference, Amersfoort, Netherlands.

South Pacific Commission 1989. *Action Strategy for Nature Conservation in the South Pacific Region.* Report prepared during the Fourth South Pacific Conference on Nature Conservation and Protected Areas for SPREP and IUCN,Noumea,New Caledonia.

Stoddart, D. R. 1968. Catastrophic human interference with coral atoll ecosystems. *Geography,* 53,25-40.

Stone, B. C. 1970. The Flora of Guam. *Micronesia,* 6,1-659.

Sullivan, M. and Gibson, L. 1991. *Environmental Planning, Climate Change and Potential Sea Level Rise: Report on a mission to Kiribati*. SPREP Reports and Studies No. 50, Noumea, New Caledonia.

Tracey, J. L., Schlanger, S. O., Stark, J. T., Doan, D. B. and May, H. G. 1964. *General Geology of Guam*. U.S. Government Printing Office.

United Nations Environmental Programme. 1984. *Hazardous Waste Storage and Disposal in the South Pacific*. UNEP Regional Seas Report and Studies No. 48, Nairobi.

United Nations Environmental Programme. 1988. *Interaction of the Oceans with Greenhouse Gases and Atmospheric Aerosols*. UNEP Regional Seas Reports and Studies No. 94, Nairobi,Kenya.

United States Department of Agriculture. 1989. *Guam River Basin Study for the Island of Guam*. Report prepared by USDA, Forest Service and Soil Conservation Service.

United States Department of Agriculture. 1989. *Guam River Basin Study: Plan of Work*. USDA Report.

United States Geological Survey. 1989. *Water Resources Management Program, 1989*. Annual Report by U.S. Geological Survey, Guam.

United States Geological Survey. 1986. *The 1983 Drought in the Western Pacific*. U.S. Geological Survey, Honolulu, Hawaii.

United States Geological Survey. 1986. National Water Summary, 1986 - *Ground Water Quality State Summaries*. U. S. Geological Survey Water-Supply Paper No. 2325.

Ward, P. F., Hoffard, S. H., and Davis, D. 1965. *Hydrology of Guam*. USGS Professional Paper 403-H.

Weir, R. C. 1983. *Tropical Cyclones Affecting Guam*. U. S. Naval Oceanography Command Center Joint Typhoon Warning Center, Comnavmarianas.

Yamashita, A. C. 1965. Attitudes and Reactions to Typhoon Karen (1962) in Guam. *Micronesia* 2(1),15-24.

Yonge, C. M. 1969. Conservation of Coral Reefs. *Micronesia* 5(2),307-310.

Annex

Government Agencies and Research Units consulted during the study period

U.S. and Guam State Agencies:

Fred Castro and Melvin Borja, Guam Environmental and Protection Agency (GEPA)

Greg Ikehara, United States Geological Survey (USGS).

Mark Lander, Meteorologist, Joint Typhoon Warning Center.

Guam Bureau of Planning/Coastal Zone Management Unit

Guam Civil Defense Agency

Federal Emergency Management Agency (FEMA)

Guam Economic Development Authority (GEDA)

Guam Historic Preservation Office (GHPO)

Guam Visitors Bureau (GVB)

Territorial Land Use Commission (TLUC)

Territorial Seashore Commission

United States Army Corps of Engineers

United States Census Bureau

University of Guam staff and facilities:

Charles Birkeland, UOG Marine Laboratory

Leroy Heitz, Water and Energy Research Institute of the Western Pacific (WERI)

United States Department of Agriculture Soil Conservation Unit