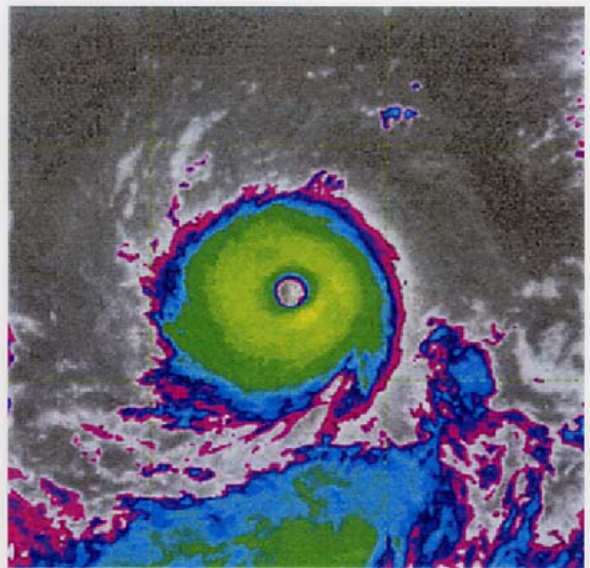


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# TYPHOON VULNERABILITY STUDY FOR GUAM

Charles (Chip) Guard  
Michael P. Hamnett  
Charles J. Neumann  
Mark A. Lander  
H. Galt Siegrist, Jr.



# WERI

WATER AND ENVIRONMENTAL RESEARCH INSTITUTE  
OF THE WESTERN PACIFIC  
UNIVERSITY OF GUAM

WERI TECHNICAL REPORT 85  
February 1999

Philippine Sea

Rindian Point

Oceanview

DEDEDO

Yigo

YIGO

Tamuning Bay

Deo

Agaña Bay

Tamuning

MANGILAO

Pagat Point

Agaña

Masa

Mongmong

Barrigada

Asan

Agaña Heights

Sinajana

BARRIGADA

SINAJANA

Ordo

CHALAN PAGO-ORDO

Chalan Pago

Mangilao

Chase Breakwater

Apra Harbor

Lockwood Terrace

ASAN

YONA

Pagat Bay

Pacific Ocean

PITI

YONA

Yona

Apra Heights

Santa Rita

SANTA RITA

AGAT

Talofof

TALOFOFO

# GUAM

## LAND AREA

212 square miles  
30 miles long  
4-8 miles wide  
Highest point: 1,332ft.  
Capital: Agaña  
19 districts

## POPULATION

152,695 1996 (Estimate)  
43% Chamorro  
23% Filipino  
14% Caucasian  
3.6% Micronesian  
16.4% Other

## ECONOMY

Gross Island Product in 1995  
Per Capita Income (1995)  
Payroll Employment in Dec. 1996

US \$2,999 Mil.  
\$ 19642  
68,220

Umatac

UMATAC

Merizo

MERIZO

Inarajan

INARAJAN

Mt Lamlam  
406 m

# **TYPHOON VULNERABILITY STUDY FOR GUAM**

**Charles (Chip) Guard  
Water & Environmental Research Institute  
University of Guam**

**Michael P. Hamnett  
Social Science Research Institute  
University of Hawaii**

**Charles J. Neumann  
Science Applications International Corporation**

**Mark A. Lander  
Water & Environmental Research Institute  
University of Guam**

**H. Galt Siegrist, Jr.  
Water & Environmental Research Institute  
University of Guam**

**Second Printing**

**UNIVERSITY OF GUAM**

**WATER AND ENVIRONMENTAL RESEARCH INSTITUTE  
OF THE WESTERN PACIFIC**

**PREPARED FOR THE GOVERNMENT OF GUAM THROUGH A GRANT FROM THE  
FEDERAL EMERGENCY MANAGEMENT AGENCY**

**February 1999**

Best of Luck,  
Chip Stewart

Front Cover: Enhanced infrared satellite image of a Pacific typhoon (hurricane).

Inside Front Cover: Map of Guam showing villages, rivers, and highways. (Source: Department of Commerce, *Guam Economic Review*).

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## FOREWORD

Guam has the highest risk of being hit by a typhoon or hurricane of any state or territory in the United States. It also has one of the highest risks for getting a typhoon strike of any densely populated area in the world. Furthermore, Guam is susceptible to being hit by the world's largest and most intense tropical cyclones. For these reasons, it is not only prudent, but essential, that Island leaders have a clear idea of the vulnerability of the Island and its various sectors to the typhoon hazard.

In 1995, a Hurricane (Typhoon) Program Needs Assessment was prepared for Guam at the insistence of the Federal Emergency Management Agency (FEMA). Among a multitude of other needs, it identified the need for a comprehensive Typhoon Vulnerability Study for the Island -- a requirement of FEMA for hurricane (typhoon) prone areas. The purpose of the following Vulnerability Assessment, while satisfying these requirements, is to give Guam's leadership a document on which it can base critical preparedness, response, recovery, and mitigation decisions.

This Vulnerability Study was designed as an operational manual and a planning document. It was also laid out to complement a Hurricane Evacuation Study being developed by the US Army Corps of Engineers for Guam. That study will refine the vulnerability of coastal areas to inundation caused by storm surge and wave run-up.

The Study contains data that is perishable due to Guam's changing demographics, valuation of assets, and economic dependence. Therefore, it should be updated periodically. Eventually, the study should employ the data available from the comprehensive new structures data base of the Bureau of Planning. The Study should also be applied to the Geographical Information System (GIS) data base at some future date.

While the people of Guam have responded admirably to past typhoons, most people are not cognizant of the increased destructive force that stronger typhoons can produce. Most cannot fathom the level of destruction that would result from a direct hit by a 170-190 mile-per-hour typhoon. This document should give the Island leadership a clearer idea of where we stand in terms of preparedness, recovery, and mitigation.



# EXECUTIVE SUMMARY

## 1. General Discussion

Chapter 1 is the Typhoon Vulnerability Study Plan. It outlines the purpose, scope, and layout of the Vulnerability Study for the Territory of Guam. The purpose of the Typhoon Vulnerability Study is to develop comprehensive assessments of the Island's risk and vulnerability to hazards imposed by tropical cyclone events of varying intensity. The Assessment is prepared for the Government of Guam, and is both an operational guidance document and a planning document. It provides information that can be used for decision making with respect to tropical cyclone preparedness, response, recovery, and mitigation. The Assessment is funded by the Federal Emergency Management Agency (FEMA) through a grant to the Guam Emergency Management Office (GEMO).

With respect to disasters, *risk* is the probability that an event will occur. Guam has the highest risk for being hit by a typhoon or hurricane of any state or territory in the United States. It is also one of the highest risk areas in the world. *Vulnerability* is the level of exposure of persons and property to a natural hazard, in this case, the typhoon hazard. Vulnerability addresses many different aspects of a society. Among these are infrastructure, public and private sector property, transportation systems, communication systems, income, agriculture, tourism, and a multitude of other societal areas. Critical infrastructure includes water and power production and distribution systems, sewage processing and disposal, tele-communications, typhoon shelters, healthcare facilities, and debris disposal. Transportation systems include airport and seaport operations, and Guam's highway system.

The Vulnerability Assessment consists of five parts: (1) Geopolitical Setting (2) Hazard Assessment, (3) Risk Assessment, (4) Vulnerability Assessment, and (5) Behavioral Analysis. The Hazard Assessment and the Risk Assessment were designed to cover the needs of this Assessment and the needs of the US Army Corps of Engineers for their Hurricane Evacuation Study for Guam.

Chapter 2 is the Geopolitical Setting. It provides a summary of Guam's geographical parameters, its political status, its demographics, economic/commercial information, and its meteorology and climatology. The meteorology/climatology section provides information about the temperature of Guam, the seasonal wind and rainfall patterns, monsoon affects, the effects of the El Niño cycle, and of course, tropical cyclones. The tropical cyclone climatology is discussed in Chapter 4, the Risk Assessment.

The Hazard Assessment is Chapter 3. The goal of the Hazard Assessment is to identify the primary tropical cyclone-related hazards that can impact the Island. Several hazards are identified and discussed.

The Risk Assessment is Chapter 4. A comprehensive Risk Assessment was produced by Mr. Charles Neumann of Science Applications International Corporation (SAIC) using a hurricane risk (HURISK) model. Other sources of risk computations were used to compensate for some shortfalls of the HURISK Model, which primarily stem from its development for the Atlantic basin. A range of return periods is provided using the output from HURISK and other techniques. This Chapter contains the majority of Guam's tropical cyclone climatology.

Vulnerability Assessments of various sectors are covered in Chapters 5 through 9. The Vulnerability Assessments primarily investigate the Island's exposure and vulnerability to destructive winds, and the impact of the winds on key sectors of Island property, resources, population, and activities. Chapter 10 summarizes the vulnerabilities of the various sectors on Guam.

## **2. Hazard Assessment**

Here, the various types of typhoon-related hazards are identified and their characteristics are discussed in some detail. The hazards are: (1) *destructive winds and wind-blown debris*; (2) *storm surge and inundation*; (3) *torrential rains and flooding*; (4) *wind shear and mechanical turbulence*; (5) *rough seas and hazardous surf*; (6) *tornadoes*; (7) *sea salt deposition*; (8) *erosion and pollution*; and, (9) *slope failures*. The first three are primary hazards and the last five are secondary, less impacting and less deadly. Historical data is provided about maximum wind extremes, inundation/storm surge, and rainfall extremes. The maximum wind gust measured on Guam was 171 mph in Typhoon Paka, while Typhoon Karen (Nov 62) was probably the most intense (estimated gust to 199 mph) typhoon to hit Guam in recent history. Wind measuring equipment on Guam has historically failed in high wind events. Guam needs more reliable and more survivable anemometers.

The effects of reefs on storm surge/inundation levels are discussed in detail to show how and where the reef affects inundation at the coastal areas of Guam. While the reefs generally act to reduce the inundation, they can sometimes lead to the production of large waves. Weather events that cause high wave events on Guam are identified, as are the causes for heavy rain events. With typhoons, maximum 24-hour rainfall amounts can be in excess of 30 inches and the hourly rain rates can exceed 5 inches per hour. Guam's terrain has a noticeable effect on typhoon winds, but is not high enough to greatly affect the rainfall during typhoons. Current building, paving, and back-filling practices are changing the natural flow patterns on Guam, and these practices are expected to increase the potential for flooding. New flood-plain maps will eventually be needed. Excavations of hills, cliff-lines, and slopes for roads, buildings, and agriculture are increasing the risk of slope failures, such as mudslides.

Large vertical and horizontal wind shear and strong mechanical turbulence are often exhibited in typhoons. There is a tendency to re-open the airport too soon after a typhoon moves away and the surface winds subside, but while higher-level winds do not decrease.

Wind shear and mechanical turbulence should be important considerations before re-opening the airfields. There should be close coordination between the National Weather Service and the Air Terminal Manager.

### 3. Risk Assessment

The Risk Assessment provides a tropical cyclone climatology for Guam. It consists of 18 charts that are accompanied by explanations and interpretations. Of major importance is a determination of the recurrence intervals or return periods of tropical cyclones of specified intensity. The entire analysis is fairly complex, but the results are summarized in Chapter 4, Table 4.2. The recurrence intervals (with some example typhoons) for various intensities of tropical cyclones on Guam are summarized in Table E-1.

**Table E-1. Recurrence intervals for typhoons of various intensities (sustained winds) affecting Guam. (For Category explanation see Table E-2).**

Intensity Category	Description of Storm	Return Period (Years)	Return Period (Years)
TS A	minimal tropical storm	1.4	1.4
TS B	destructive winds	2.2	2.2
TY 1	minimal typhoon; Brian (92)	4.0	4.0
TY 2	medium TY 2; Gay (92)	9-12	10
TY 3	medium TY 3; Omar (92)	17-25	21
TY 4	minimum TY 4; Pamela (76)	30-50	40
TY 4	Super Typhoon; Paka (97)	45-75	60
TY 5	minimum TY 5; Karen (62)	60-100	80
TY 5	medium TY 5; Yuri (91)*	140-210	175
TY 5	strong TY 5; Tip (79)*	500-900	700

\* If Guam had been hit directly; Guam did not get hit by maximum winds

### 4. Vulnerability Assessments

The Vulnerability Assessments are a determination of the level of exposure or vulnerability of various sectors of the Island. It concentrates on four major areas of interest, which include: (1) structures (residential, non-hotel commercial, hotels, and governmental); (2) transportation (Guam International Airport, Commercial Port, the Guam highway system); (3) infrastructure (water and waste-water systems, power generation and distribution systems, tele-communications systems, hospitals and public health facilities, schools and shelters, fuel storage facilities, and debris removal; (4) socio-economic areas (deaths, income, tourism, agriculture, employment, etc.).

The vulnerabilities of the various sectors are assessed with the use of information about the historical response of the sectors to typhoons of various intensity, with a new Scale that relates the level of damage to tropical cyclone wind speed and storm surge, and with engineering information. The Scale is the Saffir-Simpson Tropical Cyclone Scale (an

Atlantic scale modified for the tropical Pacific by Guard and Lander (1999)), and its parameters are summarized in Table E-2. The complete Scale with a description of damage and coastal wave action is shown in Appendix C.

**Table E-2. Saffir-Simpson Tropical Cyclone Scale categories, the corresponding sustained wind and wind gust ranges, levels of damage, and expected elevated water levels in bays and over reefs.**

Category	Sustained wind (mph)	Wind gust (mph)	Level of Damage	Storm Surge (ft) Bays/Reefs (ft)
1	30-49	40-64	Weak TS	<2/<1
2	50-73	65-94	Severe TS	2-4/1-2
3	74-95	95-120	Weak	4-6 / 2-3
4	96-110	121-139	Moderate	6-8 / 3-5
5	111-130	140-165	Strong	8-12 / 5-8
6	131-155	166-197	Extreme	12-18 / 8-12
7	156-194	198-246	Catastrophic	18-30+ / 12-20+

#### 4.1. Structures Vulnerability Assessment

Structures on Guam are classified into 12 residential types, 10 commercial types, and 3 hotel types. The vulnerability of each structure type to various wind Categories is shown in the Assessment. Wooden and sheet metal structures are categorized as old and new structures, and concrete structures are categorized as having or not having commercial grade typhoon shutters. In a medium to strong Category 5 typhoon, most windows, doors, and storm shutters on concrete structures and most wooden and sheet metal buildings hit by those winds would be exposed to heavy damage or total destruction. Large airborne debris could also damage concrete structures.

#### 4.2. Transportation Vulnerability Assessment

The Transportation Assessment considers three major parts of the infrastructure: the Guam International Air Terminal, the Commercial Port of Guam, and the Guam highway system. The airport and the seaport are both vulnerable to major damage from a Category 5 typhoon. At the Air Terminal, doors, windows, and jet ways will be severely damaged. At the seaport, warehouse doors, gantry cranes, fuel storage facilities, fuel piers, and the container yard will be severely damaged. It is not likely that the new sea wall in Inarajan will hold back seas generated by Category 5 typhoons passing within 75 miles of the south end of the Island. The most highly exposed road segments to storm surge are identified in the Assessment. Highways are more seriously affected by downed power poles and trees than by storm surge.

#### 4.3. Infrastructure Vulnerability Assessment

The infrastructure assessment included water and waste-water systems, power generation and distribution systems, telecommunications systems, hospitals and public health facilities, schools and shelters, fuel storage facilities, and debris removal. In a Category

5 typhoon, damage to the power production and distribution systems would be in the hundreds of millions of dollars. Even solid concrete poles and steel towers would likely be downed, while most power lines would be downed. The ensuing long power outages would seriously impact the water and waste water distribution systems and the health facilities upon failure of emergency generators. In a medium to strong Category 5 typhoon, debris could be 8-10 times that produced by Typhoon Paka.

#### **4.4. Socio-Economic Assessment**

The Socio-Economic Assessment uses historical information, and emphasizes data from Typhoon Paka. This was done for two reasons: (1) Paka had more complete records (other records were lost or misplaced), and (2) many socio-economic changes have occurred on Guam in the last decade. The most vulnerable segments of the population are the poor who live in sub-standard housing, have little reserve funds to fall back on, and who may not meet the requirements for US relief programs. These people include immigrants from the Freely Associated States, farmers, those occupying land of the Chamorro Land Trust, the elderly, the disabled, and the homeless. An intense Category 5 typhoon could cause damage costs to the Island equal to one year of the gross island product or in the neighborhood of \$4.5-5 billion. In such a typhoon, recovery would require years. It is likely that the standard of living on the Island would drop substantially for several years. Tourism would require several years to reestablish, and it might be a decade or two before a full recovery were possible.

#### **4.5. Summary of Guam's Typhoon Vulnerability**

In essence, the level of threat to the Island is the product of the risk and the level of exposure (vulnerability) of each of the Island's sectors. The risk of getting hit by a typhoon is greatest for weak typhoons and smallest for the most intense typhoons. The vulnerability of various sectors is greatest for intense typhoons and least for weak typhoons. In other words, the greatest vulnerability (level of damage, greatest disruption, and highest costs) is associated with the eye passage over Guam of the most intense typhoon. While the long return periods for these events indicate that they are rare, there is no way to tell when the last event occurred or when the next event will occur. Such an event will incur tremendous devastation on the Island, and there will likely be many deaths. While it is currently not practical or economical, the Island should move toward eliminating sheet metal and wooden structures, requiring all structures to have engineered storm shutters, and placing most power lines underground. A list of important conclusions is at the end of Chapter 10.

#### **5. Behavioral Analysis**

The behavioral analysis identified four primary reasons why residents do not evacuate their homes when necessary, requiring them to leave or to be rescued during the height of a typhoon. These reasons were: (1) lack of understanding of the warnings or confusion about the warnings; (2) questionable confidence in the warnings; (3) overestimating the

ability of their structure to endure the wind; and, (4) reluctance to leave the comfort of ones home for uncomfortable, restrictive shelters. Three actions could improve the responsiveness of the people: (1) implement the recommendations in the Paka Lessons Learned and the Paka Hazard Mitigation Survey Report, (2) implement use of the Saffir-Simpson Tropical Cyclone Scale to describe the potential level of damage from the expected winds, and (3) transition from the military "Conditions of Readiness" warning criteria to the civilian "watch-warning" criteria. These changes will require a program to educate the public.

## ACKNOWLEDGMENTS

A great many people assisted with the preparation of this report. They included officials and staff from the Office of the Governor, Port Authority of Guam, Guam International Airport Authority, Guam Office of Emergency Management, Agency of Human Resources Development, Bureau of Planning, Department of Commerce, Department of Health and Human Services, Department of Mental Health and Substance Abuse, Department of Revenue and Taxation, Department of Labor, Department of Public Works, Disaster Recovery Office, and the Guam Environmental Protection Agency. They also included staff of the Guam Visitor's Bureau, the Guam Hotel and Restaurant Association, the American Red Cross, and the University of Guam. At the Federal level, they include officials from the Federal Emergency Management Agency and the US Small Business Administration. We are very grateful for their help, and hope that this Study will assist in reducing the social and economic impact of future typhoons on Guam. Great appreciation is extended to Mr. Rey Dalisay for his superb computer graphics and word processing expertise, to Ms. Norma Blas and Dee Santos for their administrative assistance. Special thanks are extended to Mr. Herbert Saffir, an extraordinary wind engineer from Miami Florida who provided many useful materials and invaluable expertise. A very special thanks is extended to Mary who showed great understanding and made many sacrifices while the lead author was producing this document.

# 1. TYPHOON VULNERABILITY STUDY FOR THE TERRITORY OF GUAM -- STUDY PLAN AND OBJECTIVES

## 1.1. PURPOSE

The purpose of the Typhoon Vulnerability Study for the Territory of Guam is to develop comprehensive assessments of the Island's risk and vulnerability to hazards imposed by tropical cyclone events of varying intensity. The Study is prepared for the Government of Guam, and is designed as both an operational guidance document and a planning document. It provides information that can be used for decision making with respect to tropical cyclone preparedness, response, recovery, and mitigation. The Study was funded by the Federal Emergency Management Agency (FEMA) through a grant to the Guam Emergency Management Office (GEMO).

## 1.2. SCOPE

The scope of the Study is primarily limited to the Island of Guam, but it also addresses the oceanic areas that constitute the Island's economic zone. It spans all of the major Island sectors that are vulnerable to typhoons. These sectors are discussed in more detail in Section 1.4 below.

## 1.3. HAZARDS, RISK, AND VULNERABILITY

With respect to disasters, *risk is the probability that an event will occur*. Risk can be expressed in specific numeric values or in relative terms. Specific numeric values or quantitative probabilities for tropical cyclones are presented as recurrence intervals or return periods with respect to tropical cyclone intensity. Probabilities given in relative or qualitative terms often have the form of more general descriptions such as *low risk*, *average risk*, or *high risk*.

**Guam has the highest probability or risk for being hit by a typhoon or hurricane of any state or territory in the United States. It also is one of the highest-threat areas in the world.** Because of the Island's high threat of getting hit by a typhoon and its isolated location, it is paramount that the Island be more prepared to respond to, and to recover from, the effects of a typhoon/hurricane than any other locale in the United States.

***Vulnerability is the level of exposure of persons and property to a natural hazard, in this case, the typhoon hazard.*** Vulnerability affects many different aspects of a society. Among these are infrastructure, public and private sector property, transportation systems, communication systems, income, agriculture, tourism, and a multitude of other socio-economic aspects. Critical infrastructure includes water and power production and



distribution systems, sewage processing and disposal, typhoon shelters, healthcare facilities, and trash and debris disposal. Transportation systems include the airport and seaport, and the Island's highway system. Communications systems include local radio and television stations, local and long distance telephone and cellular telephone systems, and earth stations that are necessary for satellite communications.

## **1.4. STUDY PLAN**

### **1.4.1. General**

The Vulnerability Study consists of four primary parts: (1) Geopolitical Setting (2) Hazard Assessment, (3) Risk Assessment, and (4) Vulnerability Assessments. The Geopolitical Setting includes the geographical setting, the political setting, the demographics, and the general meteorological and climatological setting. The Hazard Assessment and the Risk Assessment were designed to cover the needs of the US Corps of Engineers and their Hurricane Evacuation Study for Guam as well as this study. The Vulnerability Study looks at the exposure and vulnerability to two major types of typhoon damage: (1) winds and (2) waves/inundation/storm surge. For the Island of Guam, and for most small tropical islands away from a continental shelf, wind is the most damaging of the two.

### **1.4.2. Hazard Assessment**

The goal of the Hazard Assessment is to identify the primary tropical cyclone-related hazards that pertain to the Island. Several are identified and explained in some detail. The hazards include:

- (1) *destructive winds and wind-blown debris;*
- (2) *waves, storm surge and inundation;*
- (3) *torrential rains and flooding;*
- (4) *wind shear and mechanical turbulence;*
- (5) *rough seas and hazardous surf;*
- (6) *tornadoes;*
- (7) *sea salt deposition;*
- (8) *erosion and pollution; and,*
- (9) *slope failures.*

This material is taken from a multitude of sources, including several recent studies by Guard and Lander. The Hazard Analysis addresses each hazard in some depth, especially those deemed to be major sources of destruction, such as: destructive winds and wind-blown debris; storm surge and inundation; and, torrential rains and flooding.

#### **1.4.3. Risk Assessment**

The Risk Assessment is very comprehensive, in part to support the needs of the US Army Corps of Engineers, Pacific Region, for their Hurricane Evacuation Study. Science Applications International Corporation (SAIC) was selected to produce the Risk Assessment using its HURISK Model. That Assessment was conducted by Mr. Charles Neumann, who has spent some 50 years studying the behavior of typhoons and hurricanes. While the HURISK Model output constitutes the bulk of the Risk Assessment, other sources have also been used to address some of the shortfalls of the HURISK Model, which stem from its primary development for the Atlantic basin. A range of return periods will be provided using the output of other techniques and sources (e. g., Rupp and Lander 1996).

#### **1.4.4. Vulnerability Assessment**

The Vulnerability Assessment concentrates on several areas, but will attempt to minimize redundancy with the US Army Corps of Engineer's Hurricane Evacuation Study for Guam. The Assessment will primarily look at the Island's vulnerability to destructive winds and the impact on key segments of Island activities. These segments include:

- (1) infrastructure (water and waste-water systems, power generation and distribution systems, telecommunications systems, hospitals and public health facilities, schools and shelters, fuel storage facilities, and solid waste and debris removal;
- (2) structures (residential, commercial, hotels, and governmental);
- (3) transportation (Guam International Airport, Andersen Air Force Base, Commercial Port, and the Guam highway system.
- (4) socio-economic (income, tourism, agriculture, employment, etc.).

The vulnerability to storm surge/inundation is addressed in terms of vulnerability of general coastal locations on Guam. The lateral and vertical water levels are addressed, but small-scale inundations at very specific locations are left to the US Army Corps of Engineer's Evacuation Study.

One of the largest efforts is determining the vulnerability of structures. Previous vulnerability studies (e. g., USACE 1985, 1992, 1994b) and a multitude of historical data are used to assess the vulnerability. The Saffir-Simpson Hurricane Scale (Simpson 1974) was adapted to the tropics by Guard and Lander (1992, 1999). The new Scale, called the

Saffir-Simpson Tropical Cyclone Scale, and the data used in developing the Scale, are used to determine much of the vulnerability of various structures, infrastructure, and vegetation.

A Transportation Assessment is conducted, but from a different approach from those usually conducted by the US Army Corps of Engineers (USACE 1995a, 1995b). This Transportation Assessment does not concentrate on evacuation, but will concentrate on the vulnerability of the airport, seaport, and the Island's highway system. An Infrastructure Assessment is conducted to evaluate the vulnerability of critical parts of the infrastructure and key facilities aside from the airport, seaport, and highway system. This includes such items as water distribution, sewage, power production and distribution, shelter facilities, fuel storage, and communications.

The Socio-Economic Assessment was primarily conducted by Dr. Michael Hamnett, Director of the Social Science Research Institute, University of Hawaii. For reasons that will become clear in the Study, Dr. Hamnett primarily used data from Typhoon Paka.

A Behavioral Analysis primarily addresses the confusion associated with the warning process and reasons for the lack of response of a segment of the population to the warnings. The Analysis will present some solutions to alleviate the confusion and hopefully improve the response.

## **1.5 OBJECTIVES**

The objectives of the study are to:

- 1) identify the greatest typhoon hazards and provide an understanding of each;
- 2) determine the level of risk for Guam to typhoons of varying intensity in terms of recurrence interval or return;
- 3) describe the level of exposure or the vulnerability for critical property and various socio-economic sectors;
- 4) summarize the Island's vulnerability to typhoons of varying intensity; and,
- 5) identify behavioral problems that lead to lack of proper response prior to the typhoon hazard.

## **1.6 NUMERICAL VALUES**

For ease of use for the civilian sector, distances will normally be given in statute miles and speeds will be given in (statute) miles per hour (mph). When values are given in nautical miles (n mi) or knots (kt), they will be so designated.

## 2. TYPHOON VULNERABILITY STUDY FOR THE TERRITORY OF GUAM—GEOPOLITICAL SETTING

### 2.1. GEOGRAPHICAL

Guam is the southern-most part of the chain of islands in the western North Pacific Ocean that comprise the Marianas archipelago. It is centered at 13°28' North latitude and 144° 45' East longitude and is located in the tropical western North Pacific Ocean, some 3801 miles west-southwest of Honolulu, Hawaii, 1597 miles east of Manila, Philippines, 1558 miles southeast of Tokyo, Japan, and 3304 miles north-northeast of Sydney, Australia.

The elongated, peanut-shaped island is oriented northeast-southwest, and is 30 miles long and 4 to 8 miles wide, being narrowest at the center and widest at the north and south ends. It covers an area of 212 square miles and contains about 100 miles of coastline. (see inside front cover for map). Guam is a volcanic island with basaltic mountains in the southern half and an uplifted coral plateau on the northern half. Mountains in the southern half of the Island rise to an altitude of 1,332 feet (406 meters), with 10 peaks rising to 1000 feet (305 meters) or more. The highest elevation is Mount Lam Lam. The northern half of the Island is a plateau approximately 200 feet (61 meters) to 600 feet (183 meters) in elevation with steep cliffs that rise abruptly from the sea. Guam is surrounded by live coral reefs, which rise from deep water and afford the Island considerable protection from ocean waves (see inside back cover for reefs). The reefs are primarily fringing reefs, but a barrier reef extends about 1 mile from the southern tip of the Island to a small barrier island (Cocos Island).

meter = 39.37"  
3.28'/meter



Figure 2.1. Relief map of Guam showing the physical characteristics of the Island including mountains, barrier reef (white area at southwest coast) and contours of adjacent ocean water depth (in feet). (Source: Chief of Engineers, U. S. Army, Pacific Explorer's Map of Guam U. S. A.)

The waters around Guam are very deep, and the deepest part of the world's oceans is located just to the east of the Island. Figure 2.1 shows the land and near coastal ocean relief of Guam and adjacent ocean areas.

## **2.2. POLITICAL**

Guam is an unincorporated territory of the United States, and was acquired from Spain in 1898 as a result of the Treaty of Paris, following the Spanish-American War. Its citizens are obligated to abide by the laws and Constitution of the United States under the specific terms of the Organic Act of 1950. Guam has a locally-elected Governor, a locally-elected Legislature consisting of 15 Senators, a judicial system composed of a Superior Court and a Supreme Court, and one non-voting Congressional Delegate, who is a member of the United States House of Representatives. Guam citizens (Guamanians) are United States citizens, but lack the right to vote for the President of the United States.

## **2.3. DEMOGRAPHIC**

Guam's population has grown almost 84 percent since 1970, and Guam has had one of the fastest growing economies in the western Pacific region since the early 1980s. The population of Guam is approximately 150,000 (projected 1998), which was based on the 1990 census of 133,152 people. The population is unevenly distributed on the Island with over 80 percent of the people located in the northern one-half of the Island, which is highly urbanized. The southern half of the Island is largely rural. There are 19 villages on the Island, the largest being the north-central village of Dededo, followed in size by the northern village of Yigo and the commercial center of Tamuning. The capital, Hagåtña (Agana), has a very small population. Table 2.1 gives the 1990 census and the projected population of Guam and each of the 19 villages for 1998, 2000, 2002, and 2004. The population that resides on military installations has been included in the villages as indicated -- Andersen Air Force Base in Yigo; Naval Activities in Santa Rita; Naval Information, Computer, and Tele-Communications Area Master Station Finegayan in Dededo; and, Nimitz Hill in Asan. Some of the major villages are shown in the Figure on the inside cover of this document.

## **2.4. ECONOMIC/COMMERCIAL**

Guam is the leading commercial, educational, and transportation center of Micronesia. The main economy of the Island is tourism. In 1996, 1,352,361 visitors arrived on Guam. Visitors from Japan comprised 76%; Korea, 12%; Taiwan, 5%; and the U.S., 6% (Gutiérrez et al. circa 1998). Following tourism, the main economy stems from the Government of Guam and the U.S. Military. The Gross Island Product for Guam during 1994 was \$3.011 billion and during 1996 was \$2.999 billion. Guam's commercial sector is primarily service oriented. These services largely support tourism, and the federal and local governments. There is little manufacturing on the Island. Figure 2.2 shows the annual number of visitors arriving on Guam and the visitor projections to the year 2004. It should be noted that there were dips in the growth of visitor arrivals in 1991 and 1993.

Table 2.1. 1990 census population and projected populations for the years 1998, 2000, 2002, and 2004 for the 19 villages of Guam and for the Island as a whole. Growth is based on extrapolation of 1980 to 1990 growth. (Source: Census and Population, Economic Research Center, Department of Commerce, Government of Guam)

Village	1990 (census)	1998 (projected)	2000 (projected)	2002 (projected)	2004 (project)
Agana	1139	1438	1506	1574	1642
Agana IHS	3646	4315	4517	4719	4921
Agat	4960	5914	6160	6406	6652
Asan	2070	2557	2677	2797	2917
Barrigada	8846	10,549	11,041	11,533	12,025
Chalan Pago-Ordot	4451	5274	5521	5768	6015
Dededo	31,728	38,039	39,815	41,591	43,367
Inarajan	2469	3037	3178	3319	3460
Mangilao	10,483	12,626	13,316	14,006	14,696
Merizo	1742	2078	2175	2272	2369
Mongmong-Toto-Maite	5845	7032	7361	7692	8023
Piti	1827	2238	2342	2446	2549
Santa Rita	11,857	14,225	14,889	15,553	16,217
Sinajana	2658	3197	3346	3495	3644
Talofofu	2310	2717	2844	2971	3098
Tamuning	16,673	19,978	20,911	21,844	22,777
Umatac	897	1119	1171	1223	1275
Yigo	14,213	17,101	17,900	18,699	19,498
Yona	5338	6393	6692	6991	7290
<b>TOTAL</b>	<b>133,152</b>	<b>159,827</b>	<b>167,292</b>	<b>174,899</b>	<b>182,435</b>

The former resulted from Japanese response to the US war with Iraq (Desert Storm) and a down-turn in the Japanese economy. The latter reflects the impact of the 1992 typhoons, primarily Omar and Gay, and the August 1993, 8.1 earthquake. Visitor numbers rose from 1994 through 1997, but due to an economic down-turn in Asia and the crash of a Korean Airlines B-747 in August 1997, tourism decreased to about 1 million. Hotel occupancy rates for Guam's nearly 8,500 rooms fell from 85% to about 70%. Such potential down-turns are not reflected in the projections, which reflects a 10% per year growth.

Guam is served by Continental Micronesia Airlines, Northwest Airlines, Japan Airlines, All Nippon Airlines, Asiana Airlines, and Air Nauru. There are non-stop or direct flights to Tokyo, Osaka, Nagoya, Sendai, Sapporo, Fukuoka, Okayama and Hiroshima in Japan; to Seoul, Korea; to Taipei and Kaohsiung, Taiwan; to Manila, Philippines; to Hong Kong; to Bali, Indonesia; to Cairns, Australia; to New Caledonia; to Honolulu and Johnson Island, Hawaii; and to the Micronesian Islands of Saipan, Belau, Yap, Chuuk, Pohnpei, Kosrae, Kwajalein, and Majuro. Commuter Airlines include Pacific Island Aviation and Freedom Air, which fly between Guam, Rota, Tinian, and Saipan.

Three United States and three foreign shipping companies serve the Island. The largest are American President Lines and SeaLand. There is also barge transportation between Guam and Rota, Tinian, and Saipan in the CNMI.

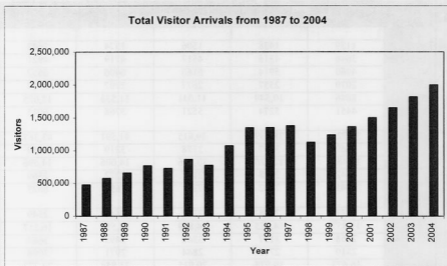


Figure 2.2. The annual number of tourists visiting Guam and the tourist projections through the year 2004. 1998 total based on 18% decrease for December 1998. Projections based on 10% growth per year from the 1998 low. (Source: Guam Visitors Bureau)

## 2.5. METEOROLOGICAL/CLIMATOLOGICAL SETTING

### 2.5.1. General

Guam is blessed with year-round warm weather, with temperatures being moderated by the surrounding ocean. It is a common occurrence in the tropics for the diurnal (day-night) differences in temperature to be greater than the seasonal differences (winter-summer). On Guam, the diurnal range is 15-20°F, while the seasonal difference is around 5°F.

Guam has two primary seasons, a wet season that generally lasts from June to December, and a dry season that runs from December to June. The dry season is characterized by relatively low relative humidity and breezes from the northeasterly *trade winds*. The wet season is characterized by high relative humidity values and weak southeasterly or southerly winds. There may be episodes of strong winds during tropical disturbances, tropical depressions, tropical storms, typhoons or monsoon surges, but the humidity values remain high. Monsoon surges can expose the Island to sustained southwest winds