CHAPTER 3 TROPICAL CYCLONES (HURRICANE) HAZARDS

3.1 INTRODUCTION

The hazards associated with tropical cyclones, of which hurricanes are most destructive, result from the high velocity winds, storm surge and high precipitation generated by these systems. In this chapter the general characteristics of tropical cyclone systems are described, followed by the results of a tropical cyclone assessment of the BVI.

3.2 TROPICAL CYCLONE SYSTEMS

Tropical cyclone systems are large, non-frontal low pressure, circulatory weather systems which develop over tropical waters, in regions known as tropical cyclone basins. The term Hurricane is the Mayan name given to tropical cyclones which occur in the Atlantic and northeast Pacific, also referred to as typhoons in the South Pacific. The Atlantic cyclone basin, where 75% of all tropical cyclones develop, consists of the Atlantic Ocean, the Caribbean Sea and the Gulf of Mexico.

In the Atlantic cyclone basin, hurricanes mostly develop in the north Atlantic off the west coast of Africa and to a lesser extent within the Caribbean Sea, and move from east to west. Hurricanes develop at latitudes of 8 to 15 degrees north or south of the equator by a complex set of processes resulting in the release of moisture and heat from the surface of tropical waters, and the balancing of atmospheric heat and moisture between tropical and non-tropical regions. The essential factor responsible for the formation of tropical cyclone systems is high sea surface temperatures of at least 27 degrees Celsius. Tropical cyclone systems therefore form in the Atlantic basin during the warm summer months between June and November which is known as the hurricane season.

3.2.1 TROPICAL CYCLONE (HURRICANE) FORMATION AND DEVELOPMENT

The life of a hurricane begins when moist warm air heated by warm surface waters rises and is blocked by warmer air carried by the easterly trade winds forming a tropical atmospheric inversion. Thunderstorms develop and when the inversion breaks a low pressure region is created within the storm. If the pressure in the centre of the storm falls below 1000 millibars while the outer pressure boundary remains the same the system develops. As the low pressure region develops prevailing easterly winds are directed into the low pressure region in a spiral pattern.

This circulatory system further lowers the pressure at the centre of the system and the process begins to perpetuate itself all the time being supplied with energy and moisture from the warm tropical seas. The system becomes more organized and the energy level increases. The pattern of air circulation is inwards towards the low pressure centre and upwards in a counter-clockwise spiral. The velocity of the winds increases as the pressure differential between the centre and outer boundary increases.

When the system has become an organized isobaric circulatory system it as called a tropical depression. If the system does not dissipate but develops further and the sustained wind velocity exceeds 39 mph the system is called a tropical storm and given a name. Sustained wind velocities refer to wind velocities which are fairly constant for a period of one minute near the centre of the system, When sustained winds exceed 74 mph the system is called a hurricane. At this stage the system has a large well defined circulating spiral of clouds and a small central region of low pressure called the eye. The system moves towards the west at an average speed of 12 mph.

The eye is a region of low wind speed, little rain and cloud cover with an average diameter of 50-80 km. Adjacent to the eye is found a dense wall of clouds, called the eye wall, with adjoining bands which spiral out for distances up to 225 km from the centre of the system. The highest winds and rainfall are located within the eye wall of the hurricane usually about

50 km from the centre of the system. The high velocity winds within the eye wall is tangential to the eye in a counter clock-wise direction.

Hurricanes are classified by their level of intensity which reflect the damage causing potential. The most commonly used classification is the Saffir-Simpson hurricane scale (SSH), which determines the hurricane category by a combination of central barometric pressure and maximum sustained winds near the centre of the hurricane. The five categories of the (SSH) with the corresponding maximum wind speeds, barometric pressure and expected damage level associated with each category is shown in **Table 3.1.**

TABLE 3.1: Saffir-Simpson Hurricane Scale (SSH)

Hurricane Category Number	Sustained Winds (Mph)	(Knots)	Atmospheric Pressure in eye (millibars)	Storm Surge (feet)	Damage Level
1	74-94	64-82	980	4.0-4.9	Low
2	96-110	83-96	965-979	5.9-7.9	Moderate
3	111-130	97-113	945-964	8.9-12.2	Extensive
4	131-155	114-135	920-944	13.0-18.0	Extreme
5	>155	>135	<920	>18.0	Catastrophic

Hurricanes eventually dissipate over colder waters or over land about 10 days after they form. As the system loses energy the stages of dissipation are determined by the sustained wind velocities and therefore degrade first to a tropical storm then to a tropical depression. If the tropical system travels into a nontropical environment tropical storms and depressions are referred to as subtropical storms and subtropical depressions respectively. The remainder of this chapter focuses on the hurricane as the most destructive tropical cyclone system affecting the BVI.

3.3 HURRICANE FORECASTING

There are a number of atmospheric parameters which determine the location and strength of hurricanes that form within tropical cyclone basins, many of which are not fully understood. However some of these parameters have been shown to be statistically related to seasonal variations in hurricane activity.

Dr. William Gray and his colleagues at Colorado State University have been developing statistical models to predict seasonal hurricane activity using these parameters as predictive indices. The main parameters used are listed below.

The Quasi-Biennial Oscillation (QBO): These are east-west equatorial stratospheric winds which circle the globe. The predominant direction oscillates between east and west. Hurricane activity more than doubles when these stratospheric winds are more westerly.

El Nino-Southern Oscillation (ENSO): This refers to the presence of warm or cold sea surface temperature anomalies in the eastern equatorial Pacific which influences the upper tropospheric westerly winds which occur over the Caribbean Basin and western Atlantic. Moderate to strong El-Nino (warm water anomalies) events enhance these winds which in turn create vertical wind shear that inhibits hurricane activity. In La Nina (cold water) periods the opposite occurs and hurricane activity is enhanced.

African Rainfall (AR): Rainfall activity is influenced by rainfall in the Western Sahel and the Gulf of Guinea regions of West Africa. Hurricane activity is enhanced if above average rainfall occurs in this area during the preceding summer and fall.

West Africa west-to-east surface pressure and temperature Gradients (dP,dT): Anomalous pressure and temperature gradients between a western region and a more eastern region in Africa during February and May influences hurricane activity the following year. Hurricane activity is enhanced if the east minus west surface pressure gradient is higher than normal and/or if the temperature gradient is below normal.

Caribbean Basin Sea Level Pressure Anomaly (SLPA) and upper tropospheric Zonal Wind Anomaly (ZWA): April and May values of SLPA and ZWA are modest indicators of hurricane activity during the following season. Low sea level pressures and predominantly easterly tropospheric wind conditions in the Caribbean enhance hurricane activity.

The values of these meteorological parameters are presently computed by Dr. Gray and his team to forecast the level of seasonal hurricane activity. Based on long term fluctuations of other factors, such as changes in deep cold water ocean currents, and prolonged drought conditions in the Sahel region of Western Africa, Dr. Gray has postulated that there are periods of increased hurricane activity which occur every thirty years or so. He further states that the current forecast model can explain 50-60% of the variability in hurricane activity from season to season. **Table 3.2** below shows a typical forecast as published by Dr. Gray and his team.

TABLE 3.2: Typical table included in Dr. Grays' seasonal hurricane forecast reports

Forecast Parameter	Forecast Activity	Long-term (1950-1990) Average
Named Storms (NS)	10	9.3
Named Storm days (NSD)	45	46.1
Hurricanes (H)	6	5.7
Hurricane Days (HD)	20	23
Intense Hurricanes (IH)	2	2.1
Intense Hurricane Days (IHD)	5	4.5
Hurricane Destruction Potential (HDP)	60	68.1
Net Tropical Cyclone Activity (NTC)	95%	100%
Maximum Potential Destruction (MPD)	60	66

DEFINITIONS

Named Storms (NS): A hurricane or a tropical storm

Named Storm days (NSD): As in HD but for four 6-hour periods during which a tropical cyclone is observed (or estimated) to have attained tropical storm intensity winds.

Hurricanes (H): A tropical cyclone with sustained low level winds of 74 miles per hour (33 mps, 64 knots) or greater.

Hurricane Day (HD): A measure of hurricane activity, one unit of which occurs as 6-hour periods during which a tropical cyclone is observed or estimated to have hurricane intensity winds.

Intense Hurricane (IH): A hurricane which reaches a sustained low level wind of at least 111 mph (50 mps, 96 knots) at some point in it's lifetime. This constitutes a category 3 or higher on the Saffir-Simpson scale, also termed a major hurricane.

Intense Hurricane Day (IHD): Four 6-hour periods during which a hurricane has intensity Saffir -Simpson category 3 or higher.

Hurricane Destruction Potential (HDP): A measure of a hurricanes potential for wind and storm surge destruction defined as a sum of the square of a hurricane's maximum wind speed for each 6-hour period of it's existence.

Net Tropical Cyclone Activity (NTC): Average seasonal percentage sum of NS, NSD, H, HD, IH, IHD. This gives an overall indication of Atlantic basin seasonal hurricane activity.

Maximum Potential Destruction (MPD): A measure of the net maximum destruction during the season compiled as the sum of the square of the maximum wind observed for each named storm.

3.4 HURRICANES AFFECTING THE BVI

The location of the BVI at the northeastern tip of the Caribbean chain places it in the direct path of tropical cyclones that develop in the Atlantic Tropical cyclone basin. The BVI has been affected by many tropical cyclone systems including tropical storms and hurricanes. A notable example was the hurricane of 1867 which caused significant damage in Tortola. The HMS Roane was also a casualty of this hurricane when it sank off the coast of Salt Island taking 12 men with her. Most of the systems which have affected the BVI have been tropical depressions and tropical storms bringing with them abnormally high rainfall. It is unclear how many hurricanes have made landfall in the BVI before 1886. **Figure 3.1** shows the tracks of the recent hurricanes which have affected the BVI.

Hurricane Donna which was a minimal category 4 hurricane, passed some 15 miles north of Anegada at its closest point of approach on September 5th. 1960.Though no lives were lost in the BVI, Tortola lost all telecommunications. Extensive damage was done in Anegada to boats and three dwellings were totally destroyed, and 27 houses badly damaged.

Hurricane Hugo, a Category 4 hurricane, passed about 60 miles to the south east of Tortola on September 13th.1989 with sustained wind speeds of 135 - 160 mph. causing significant damage throughout the BVI. The main damage was done to the electricity and telecommunication lines which were broken by downed utility poles and to hotel and housing structures. The damage done to the various sectors of the BVI is presented in **Table 3.3.**

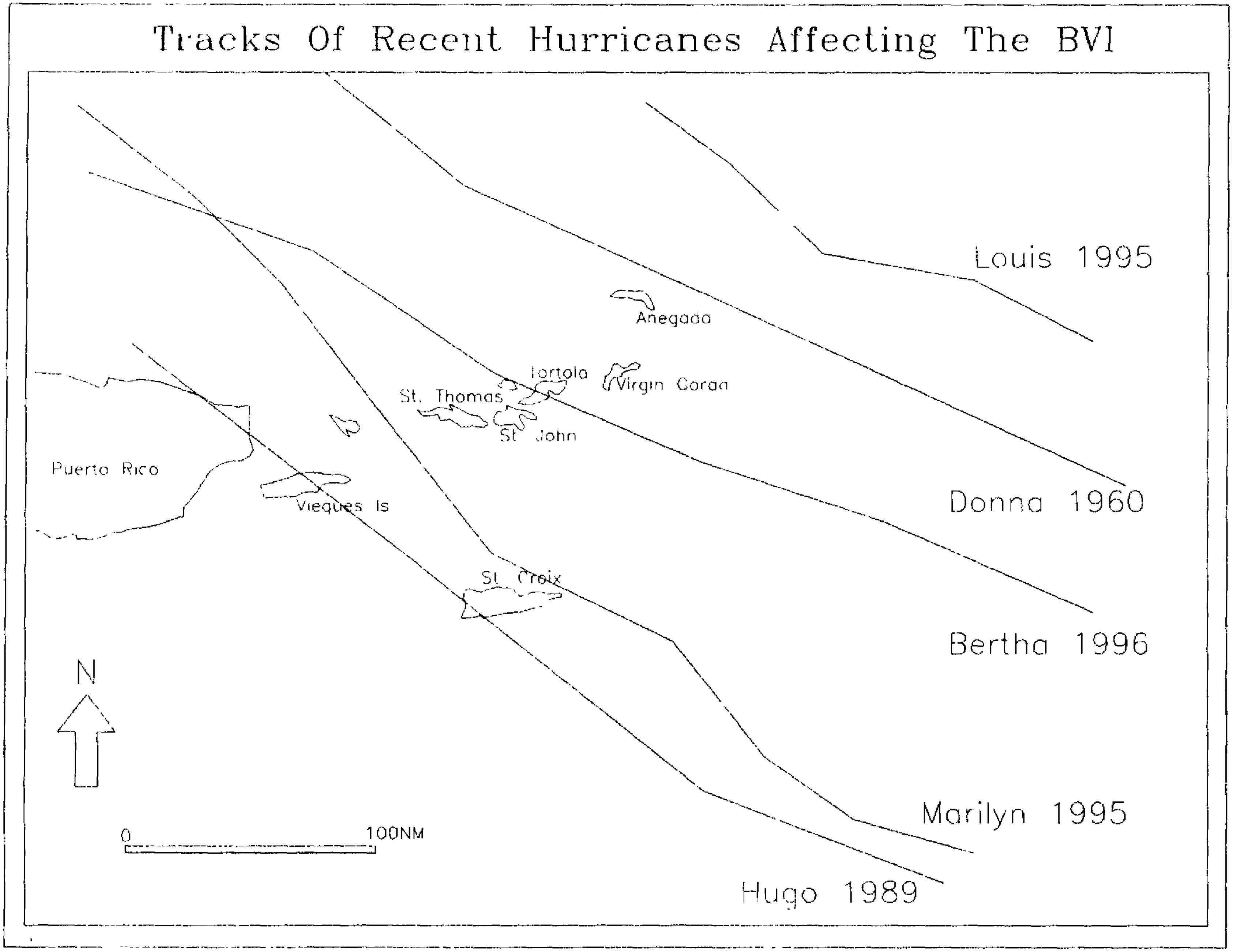
Tracks Of Recent Hurricanes Affecting The BVI
Louis 1995
Donna 1960
Bertha 1996
Marilyn 1995
Hugo 1989
Anegada
Tortola
Virgin Gorda
St. Thomas
St John
Puerto Rico
Vieques Is
St Croix
N
0
100NM

Figure 3.1

TABLE 3.3: Sectoral Estimates of Damage Caused By Hurricane Hugo

Sector	Damage Estimate
Agriculture	736,000
Fishing	415,000
National Parks	370,000
Ports	131,000
Electrical Power Generation	1,000,000
Water and Sewerage	121,000
Telecommunications	1,152,000
Health	165,000
Civil Aviation	15,000
Tourism (hotels)	12,000,000
Housing	14,640,000
Commercial Buildings	1,500,000
Education	600,000
Marinas and Boats	3,000,000
Roads	4,000,000
TOTAL	39,845,000

Source: Post Hurricane Hugo Assessment by Lynette Atwell. Dec '93.

Total damage was estimated at about $40 million which was more than the BVI governments recurrent expenditure for 1989. While no lives were lost, 100 persons were made homeless

On September 6th, 1995 Hurricane Luis passed 37 miles northeast of Anegada. This was a Category 4 hurricane with a eye diameter of 46 miles, where maximum wind gusts of 168 mph, and maximum sustained wind speeds of 115 mph were recorded when closest to Anegada. Minimum barometric pressure of 942 mb and wave heights at sea of 50 ft. were recorded. In Anegada significant losses resulted from damaged or lost fish pots, a few roofs were destroyed and one casualty was said to be related to the hurricane. In Tortola and the rest of the BVI only minor damage was reported, resulting from the heavy rainfall and high winds. There is no official estimate of the total damage caused by hurricane Luis. In Barbuda where Category 4 conditions were experienced the estimated damage to structures was 70%.

Hurricane Marilyn hit the US Virgin Islands on September 15 1995, as a strengthening Category 2 near Category 3 hurricane with an eye wall 23 miles in diameter. The northeastern eye-wall, the strongest part of the hurricane producing sustained winds of 109 mph, passed directly over St. Thomas. Hurricane Marilyn passed 40 miles to the south west of Road Town at about 9 PM on September 15th, when the barometric pressure measured at the BVI's EOC was 990 mb. Storm surge in Road Harbour and at West End was estimated at 3 feet.

While the eye wall passed well south of Tortola, wind gusts over 170 mph were recorded on the peak at Chalwell in Tortola. Roads were blocked by debris from small slippages along road cuts which were quickly cleared. Sections of road along the north coast road in Capoons Bay and Carrot Bay were washed out and sea protection works along the waterfront main road in Road Town was damaged. The electrical generation company recovery costs due to the downing of power lines mainly along the ridge road was close to $300,000 while an unknown sum was spent to repair a washed out sea-water inlet pipeline at the power generation plant at Pockwood Pond. It took about three weeks to restore electrical power to all areas of the BVI.

Damage to crops and farm structures was about $1 million, $2 million to the fishing sector and about 1 million worth of damage was done to the pleasure boats and yachts. The damage to houses due to roof and water damage was estimated at $1 million. Rough damage estimates collected, indicate a conservative total damage in the order of $10 million (ODP's Hurricanes Luis & Marilyn Report).

Hurricane Bertha passed directly over Tortola on July 8th 1996. This hurricane was a weak Category 1 hurricane with an eye diameter of 30 miles, maximum sustained winds were reported at 75 mph while gust of up to 96 mph was recorded at Chalwell in Tortola. The minimum barometric pressure measured at the BVI's EOC was 975 mb where 2.5 inches of rainfall was recorded. Electrical power was restored after 24 hours after the few damaged power lines were repaired. The other sectors suffered minor damage with the agricultural department estimating $600,000 to crops and the public works department indicating $550,000 damage to houses. Total damage to the BVI resulting from this minimal hurricane was estimated at $2 million(ODP's Hurricane Bertha Report).

3.5 TROPICAL CYCLONE ASSESSMENT OF THE BVI

A tropical cyclone study was carried out between December 1995 and March 1996 to determine the nature of hurricanes occurring in the region and to assess the potential threat posed by hurricanes to the BVI. The study was carried out by Chuck Watson of Rincon Atlanta who developed The Arbiter Of Storms (TAOS) computer model which determines the wind hazard and storm surge associated with hurricanes. The software is a GIS based model developed in conjunction with the Caribbean Disaster Mitigation Project (CDMP) that has been endorsed by NOAA. It is currently being utilized throughout the Caribbean for coastal zone hazard mapping. The study also included a hurricane frequency analysis to determine the return period of hurricanes affecting the BVI.

A return time analysis was conducted for five locations in the BVI as indicated in **Figure 3.2.** These locations were selected to demonstrate the variability of return times in the area. For each location, historical storm tracks were obtained from the US National Hurricane Center's "Best fit" track data (originally called the "HURDAT" data base). This data base covers the time period from 1886 to 1992. Each storm in the data base was processed to assess its impact on the target location using the TAOS wind model.

The data produced by the return period analysis includes first, general statistics such as how many storms affected the region, how many years had storms, how many years had multiple storms and how many of each Saffir/Simpson category storm occurred. Next an analysis of the length of time which passed between occurrences of each category of storm are presented. The maximum, minimum, and average length of time which passed between events of the stated category or greater are given. Finally, a distribution of return times is tabulated.

The general findings results of this analysis for Road Town, Virgin Gorda, Anegada, Jost Van Dyke, and Peter Island are presented below while the details are available in the tropical cyclone final report.

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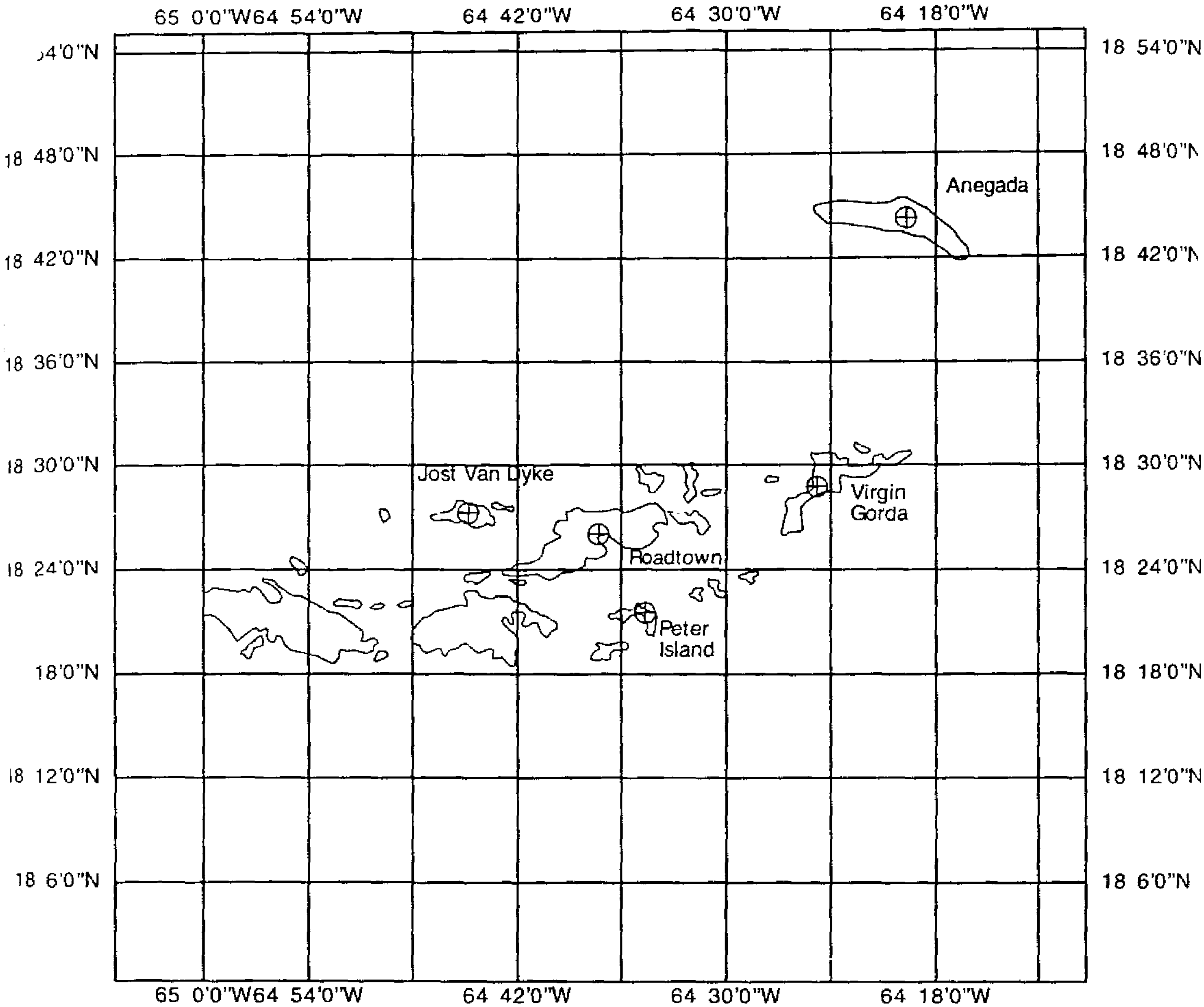


British Virgin Islands
Return Time Analysis Sites

Scale
20 0 Kilometers

N

Average Return Time Summary:

Site	TS	1	2	3	4
Anegada	2.9	5.5	8.2	9.5	na
Virgin Gorda	2.8	6.3	10.9	20.3	32?
Peter Island	2.7	5.6	9.8	20.3	61?
Roadtown	2.8	6.3	10.9	16.8	30?
Jost van Dyke	2.6	6.3	10.9	??	31?

Return times in years for specified event or greater.
?? indicates statistics based on fewer than 5 events.

Figure 3.2

Figure 3.3 shows the tracks of storms affecting the BVI from 1886 to 1992, and **Figure 3.4** shows the relative intensities of these storms. While in general tracks have a strong westerly component, there are a few unusual tracks, such as Klaus. The overall average motion and speed of the storms crossing the BVI is presented in **Table 3.4.**

TABLE 3.4: Average motion of Hurricanes and Tropical Storms in the BVI.

Class Storm	Number	Average Heading	Speed (kts)	Speed (mph)
Tropical Storm	44	289.0	12.8	13.8
Cat 1	8	298.4	10.5	12.0
Cat 2	6	307.5	8.2	9.4
Cat 3	2	283.5	12.8	14.7
Cat 4	3	298.7	11.8	13.6

The overall average motion is 292 degrees (Northwest) at 13.8 mph (12 kts).

Recent research by Dr. William Gray of Colorado State University, and others, indicates that there is a 25-30 year cycle to tropical cyclone activity in the Atlantic tropical basin. The data for the BVI seems to reflect these cycles. During the period of intense activity, the BVI may expect a category 4 storm, and several category 2 or 3 storms.

In between these more active periods, only scattered tropical storms or weak hurricanes may be expected. Since we are possibly entering a period of more intense activity, the return times noted below reflect the 'intense' period probabilities. Given the preceding analysis, the following return times presented in **Table 3.5**, are recommended for use in disaster planning, engineering design, and hazard mitigation in the BVI. The numbers in parentheses after the times for the more intense storms indicates the return time not factoring in the possibility that we are entering an intense period.

Figure 3.4 Storms Affecting the British Virgin Islands, 1886-1992

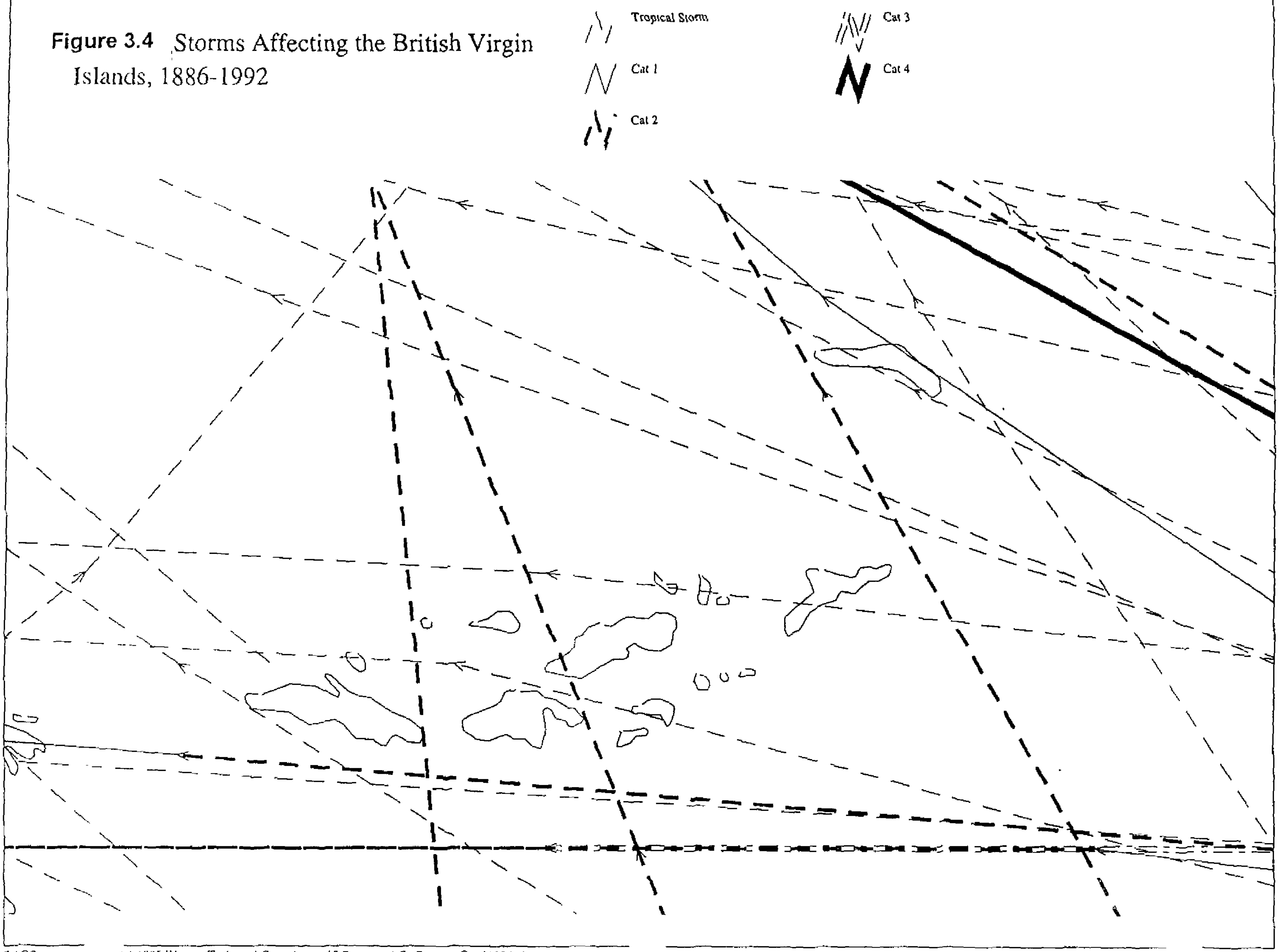


Figure . Storms near the BVI, 1886-1992

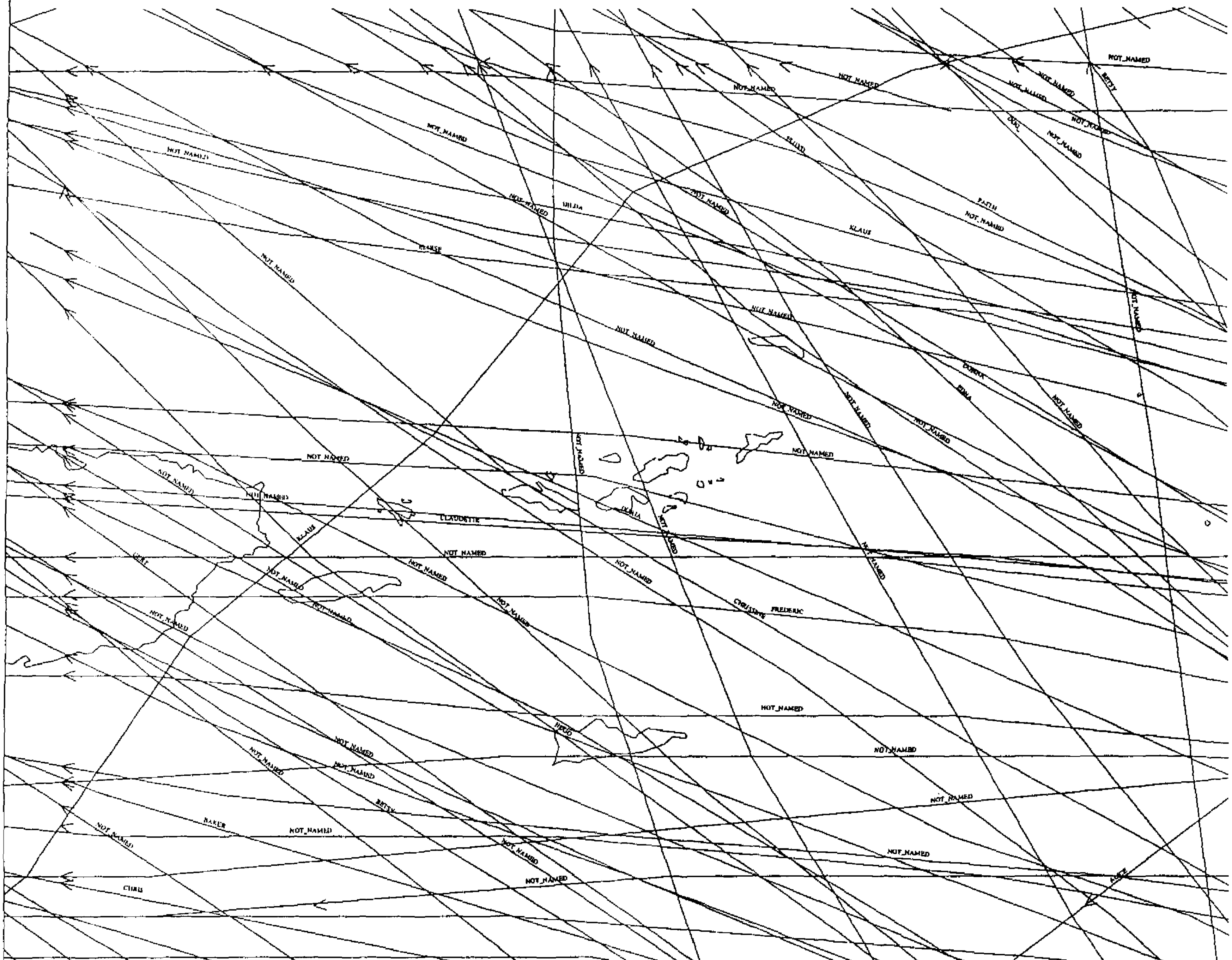


TABLE 3.5: **Recommended return periods of Hurricanes and Tropical Storms in the BVI.**

EVENT	RETURN TIME (years)
Tropical Storm	2 5
Cat 1	6
Cat 2	10 (15)
Cat 3	20 (35)
Cat 4	30 (65)
Cat 5	NA*

*A return time for a category 5 hurricane is not included as no hurricanes of this intensity affecting the BVI has been recorded over the period of reasonably accurate data.

Note that there have been no category 5 storm level winds or surge in the BVI over the period of reasonably accurate data. Therefore any assessment of return time for this event would be somewhat subjective, and based on the regional occurrence of events of this magnitude. However, given the fact that events of this magnitude do occur in the region, and given the extreme consequences of a category 5 event, **it is recommended that a category 5 storm be used as the design storm for lifeline infrastructure.** Other users should examine the economic and physical consequences of a category 4 event versus a category 5 event, and decide if the loss is acceptable when compared to the expense of protecting from a category 5 event.

3.6 WIND HAZARDS

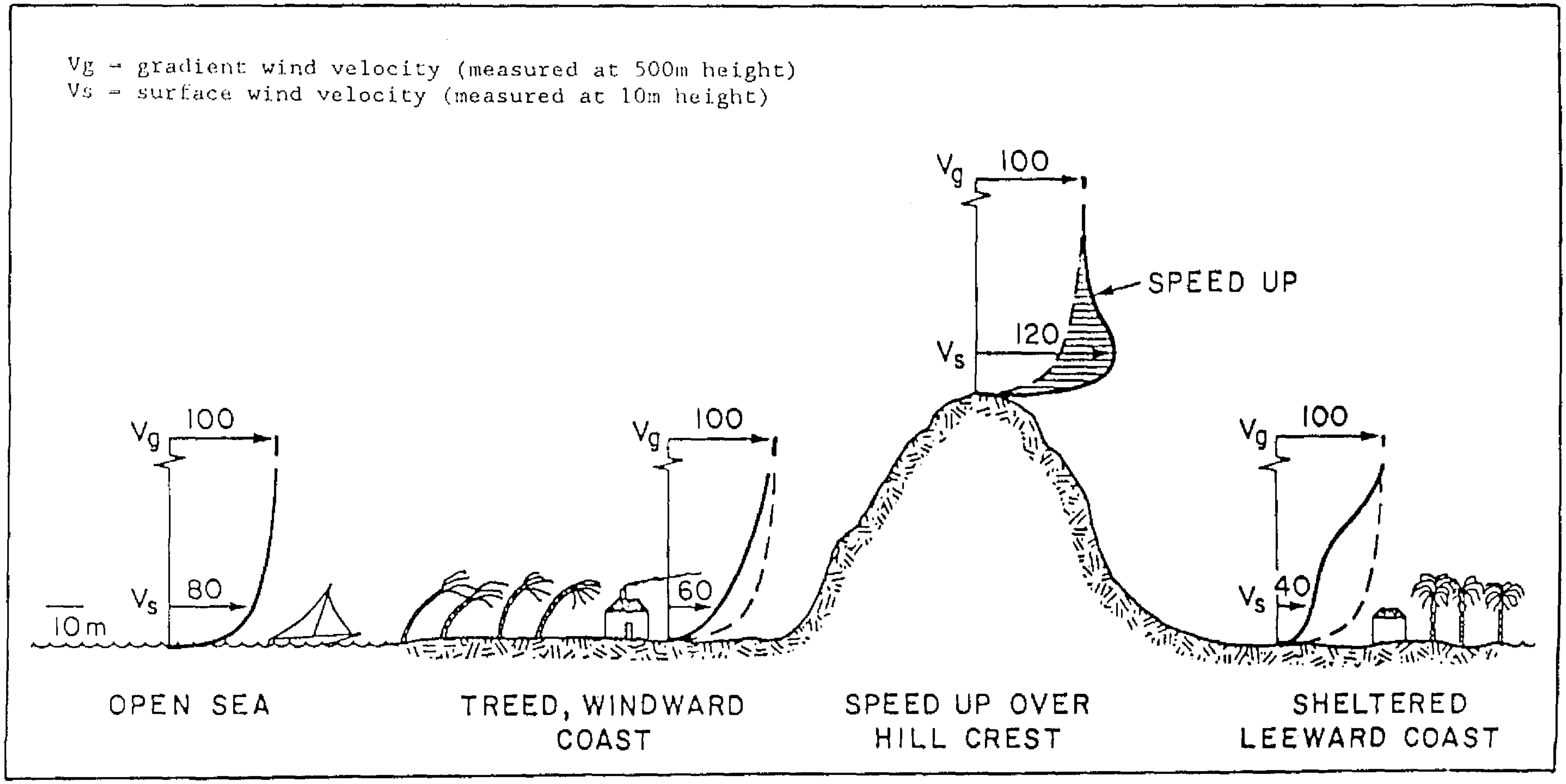
Sustained hurricane wind speeds can be in excess of 150 mph with gusts of over 200 mph. The destructive force of hurricane winds varies with the square of its velocity so that a doubling of wind speed increases the destructive potential four times. Overland wind speeds associated with hurricanes depend on the topography of the landscape. Wind speeds increase over exposed ridge crests and tend to be slower at lower elevations due to the surface roughness produced by obstacles. Sheltered areas such as the leeward side of mountains have significantly lower wind speeds. **Figure 3.5** indicates that wind speeds over exposed ridge crests can be as much as 120% higher than wind speeds over open water while winds speeds over low lying areas on the windward and leeward side of mountains can be 40% and 60% lower respectively.

An analysis of winds which may be expected over the BVI during various hurricane events was made using the TAOS wind field model. Surface winds were determined by modeling the effects of terrain on upper level winds. This was accomplished by using a boundary layer model and the TAOS upper level wind model. Winds were calculated at 50 meter intervals, resulting in a raster GIS base.

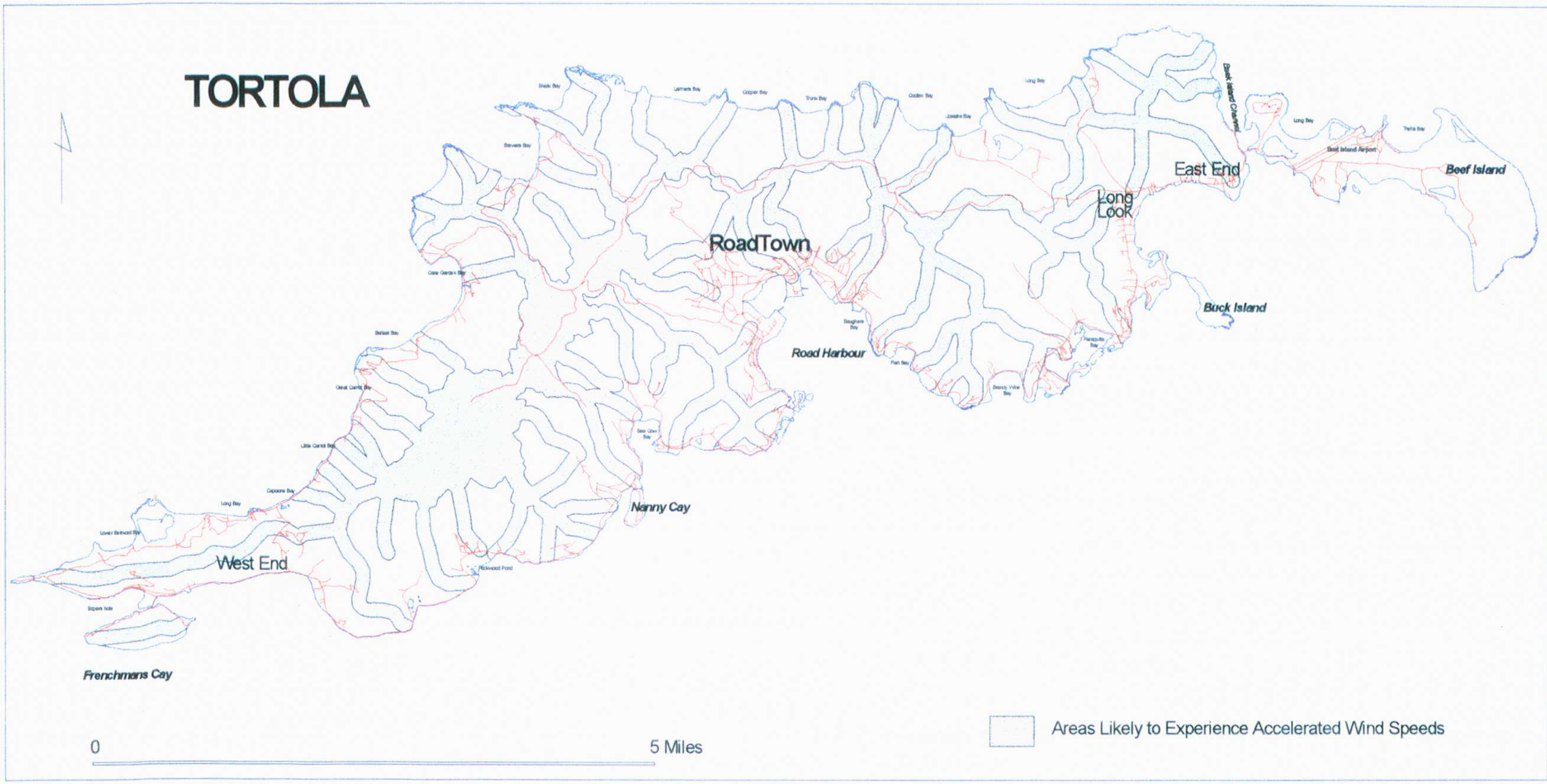
While some variations in the wind field were noted, especially in higher elevations and along ridge lines, the variations were well within the margin of error of the modeling process. Therefore specific wind hazard maps could not be generated from the TAOS model. For planning purposes all locations should be assumed to be subject to the full force of the wind in any hurricane event.

Ridge-lines and areas above 1000 feet which are exposed should be considered at some additional risk. A factor of 1.2 times the base winds should be used to estimate wind speed at these locations, for planning purposes. Based on this relationship **Map 3.1** and **3.2** indicate areas in Tortola and Virgin Gorda which are likely to experience accelerated wind speed. Wind damage is caused by the force exerted on structures by the direct impact of high velocity wind and by impact from airborne debris. Agricultural crops, trees, roofs and utility poles are usually severely damaged by direct wind impact. Wind related deaths are generally caused by flying debris.

Figure 3.5

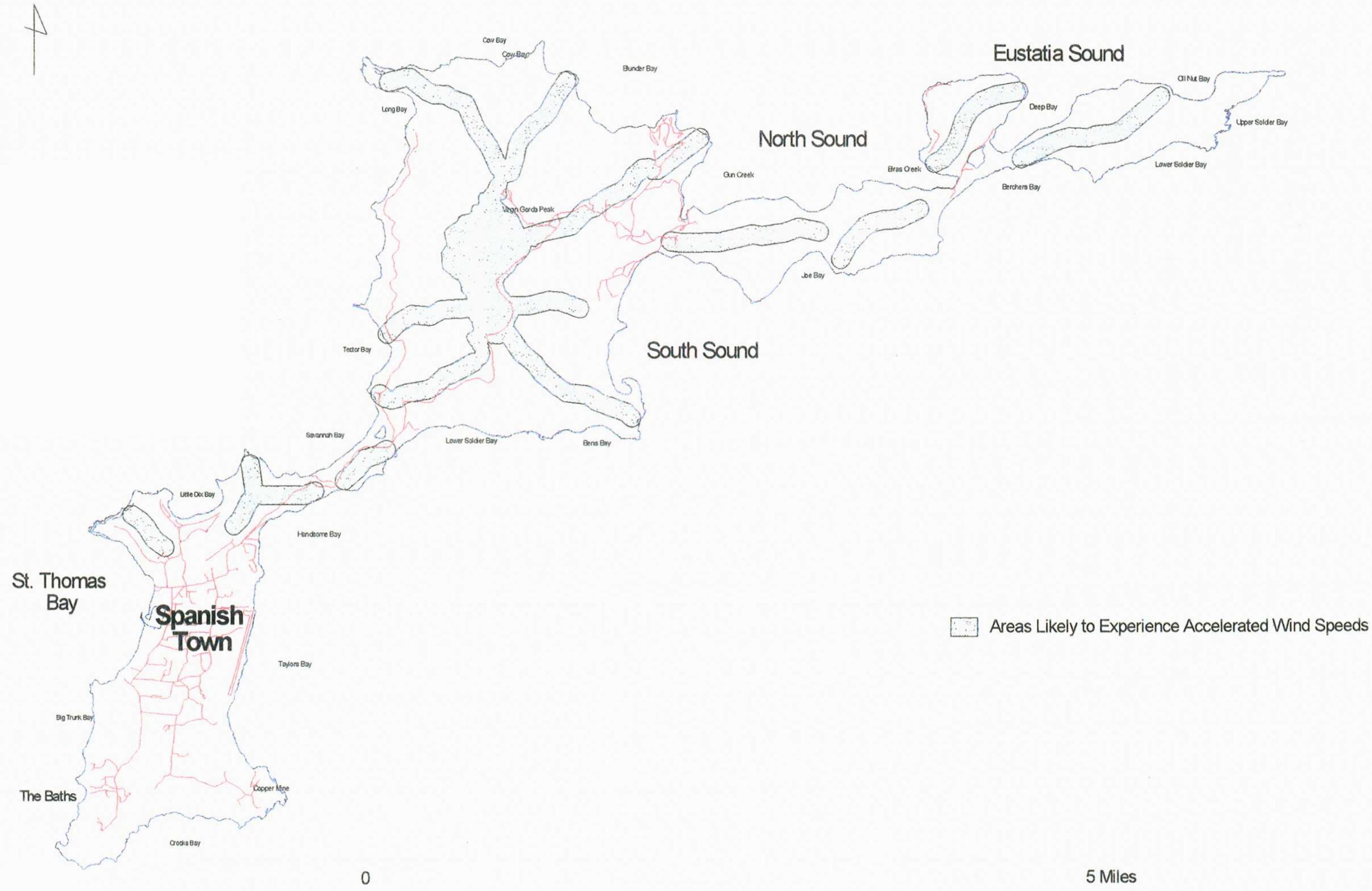


Source: Davenport, A.G. Georgiou, P.N., and Surry, D. A Hurricane Wind Risk Study for the Eastern Caribbean, Jamaica and Belize with Special Consideration to the Influence of Topography. (London, Ontario, Canada: Boundary Layer Wind Tunnel Laboratory, The University of Western Ontario, 1985).


TORTOLA
RoadTown
East End
Long Look
West End
Beef Island
Buck Island
Road Harbour
Nanny Cay
Frenchmans Cay
Areas Likely to Experience Accelerated Wind Speeds
0
5 Miles

MAP 3.1

VIRGIN GORDA



MAP 3.2