=====PREFACE=====

The Commonwealth Caribbean Countries are at risk to many natural hazards including hurricanes and earthquakes and, within the last few years, have been subject to two major hurricanes that have caused severe damage to health care facilities.

Particularly devastating was the damage done to hospitals throughout Jamaica by hurricane Gilbert in 1988, and to the main hospital in Montserrat by hurricane Hugo in 1989.

The costs of restoration of these facilities have already run into millions of United States dollars, at a time when almost all of these countries are experiencing adverse economic pressures, and when some have already entered economic structural adjustment arrangements with the International Monetary Fund.

Many governments are finding it extremely difficult to meet their budgeted recurrent expenditures, and except for Trinidad and Tobago, are becoming increasingly dependent on tourism as their principal source of income and the main prop for their economies.

On the other hand, funds are being received for major capital projects in the service sectors of governments, mainly by grants and loans from international agencies. In particular, funding for capital projects for the restoration, retrofitting and expansion of hospitals are being made available to many of these countries either by the Inter-American Development Bank or the European Economic Community.

A major consideration when executing these capital projects must be to ensure that any construction and retrofitting of facilities are done in such a way that they not only achieve their primary health objectives, but also have a minimal adverse impact on the future earnings and recurrent expenditures of governments. This can only be accomplished by utilising design and construction techniques which will enable the facilities to have a long viable life by ensuring that they are adequately resistant to damage by any type of hazard, and can be cost-effectively and affordably maintained and managed.

Unfortunately, it is only within the last decade that in the Commonwealth Caribbean Countries systematic consideration has been given in the design and construction of health care facilities to the impact of natural hazards on building and plant.

It is generally recognised that designing buildings against the hazards of hurricanes and earthquakes is difficult because of the marked differences between the effects of their respective forces on building structures. There are however well established cost-effective design and construction techniques that are available for reducing property losses due to these hazards.

Appropriate standards are contained in the Caribbean Uniform Building Code which is called CUBiC. This code was formally accepted by the Caribbean Council of Ministers of Health in 1988, but has not yet been made mandatory in any of these countries.

This booklet is consistent with the philosophy and aims of CUBiC. It identifies and explains in layman's terms the characteristics necessary in the design and construction of buildings to effectively resist both hurricanes and earthquakes, and highlights the factors which are considered to be critical and cost-effective. It is intended to help health and hospital administrators, and construction and maintenance personnel, understand the design and construction requirements which must be met to adequately mitigate the hazards of hurricanes and earthquakes to which health care facilities may be exposed. It also provides them with a basic knowledge to communicate sensibly, viligantly and purposefully with the architects, engineers, and contractors involved in the construction, restoration, and retrofitting of their facilities.

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CHAPTER 1

SCOPE AND OBJECTIVES

1.1 INTRODUCTION

This booklet has been prepared having non-engineers in mind, such as building owners, health care officials, managers, and maintenance personnel. It is intended to inform those officials involved in the planning, operation and management of health care facilities of the potential magnitude of the impact caused by natural hazards, and provide a useful tool to assist them in the risk mitigation of existing facilities and the reliable design of new constructions.

It deals specifically with the potential problems that may be generated by hurricanes, earthquakes and floods, which are the natural hazards to which the Commonwealth Caribbean Countries are primarily at risk, and the measures that may be taken to mitigate these hazards. Consideration is given to the special requirements of health care facilities so that they may be designed to remain functional during and immediately after hurricanes, floods and earthquakes, and in particular, to ensure that any damage should be limited in order to preclude evacuation of hospital buildings, although disruption of some of the functions may be unavoidable.

The intent is to explain in simple terms the possible sources of problems created by these hazards and point the way towards countermeasures to be considered in coping with these problems. The enforcement of engineering design codes, such as CUBiC[1] is the first basic step in order to reach that objective.

A Summary of Recommendations and Checklists are included as Annexes to serve as an aide-memoire for quick and easy reference by the busy health care executive.

(1) Caribbean Uniform Building Code (CUBiC), Caribbean Community Secretariat, Georgetown, Guyana, 1985

It is important to stress that the contents of this document represent a simplified version of very technical and scientific knowledge, and there are therefore many areas where the appropriate expertise needs to be enlisted. It is expected that the guidelines given for hazard mitigation will be used wisely and that expert advice will be obtained where necessary.

1.2 OBJECTIVES

This booklet is intended to:

1. Provide decision-makers and managers in the Health Sector with a tool for use in the commissioning of the design, construction, and retrofitting of health care facilities.

2. Identify priorities in the construction and retrofitting of buildings in the health sector, taking into account the financial constraints and the relationship between the intensity and frequency of natural hazards.

3. Increase awareness and provide a means for the identification of vulnerable situations in existing facilities.

4. Facilitate communication between technical and non-technical parties involved in the design and construction of new facilities and in the reduction of the vulnerability of existing ones.

CHAPTER 2

THE NATURE OF NATURAL HAZARDS IN COMMONWEALTH CARIBBEAN COUNTRIES

2.1 INTRODUCTION

There is a widely held expectation that health care facilities are in a state of preparation to deal with emergency situations. The impact of past earthquakes and hurricanes has proved that hospitals and health care installations may be vulnerable and rendered unable to respond.

During the last two decades more than one hundred hospitals in the Americas have reported severe disruption, if not total collapse, as a consequence of earthquakes. For instance, during the San Fernando, California, earthquake of 9th February 1971, four hospitals were damaged so severely that they were no longer operational just when they were most needed. Furthermore, the majority of deaths caused by that earthquake occurred in two of the hospitals which collapsed. It was an ironic feature of that earthquake that the most hazardous place to be in San Fernando was in a hospital!

In the Caribbean, hurricanes have caused severe damage to hospitals in Dominica, Jamaica, Montserrat, and St.Kitts. In Jamaica, some hospital buildings had to be evacuated because of damage by hurricane Gilbert in 1988.

There are indeed many similar examples worldwide in respect of earthquakes, hurricanes, and floods.

2.2 GENERAL DEFINITIONS

At the outset, some basic concepts and information are necessary in order to better understand the contents of this booklet.

2.2.1 Hazard

A Hazard is a phenomenon which, when it manifests itself in a given area over a specific period of time, has the potential for severe social disruption, trauma and property damage and loss.

The potential impact of a hazard is normally expressed in terms of its magnitude or intensity, which are expressed as a probability function over a specified time period according to hazard type.

Hazard functions can be derived for different sites if there are sufficient relevant records going back over a significant period of time. For example, if we analyze the known history of earthquake occurrences in the Eastern Caribbean countries, and we measure their size in terms of the intensities given by the Modified Mercalli Intensity Scale, we will find that not all countries are under the same seismic hazards.

2.2.2 Vulnerability

Vulnerability is a measure of the intrinsic susceptibility of structures, contents and processes to fail once they are exposed to potentially damaging natural phenomena.

Vulnerability is generally expressed as the degree of expected damage or loss, given in a certain scale, as a function of hazard intensity.

2.2.3 Risk

Risk is a measure of the probability of expected loss for a given hazardous event.

2.2.4 Structural Elements

The portions of a building that hold it up and resist gravity, earthquakes, hurricane winds and other type of loads are said to be the structural elements.

The structural elements of buildings include columns (pillars), beams (girders and joists), floor or roof sheeting, slabs or decking, load bearing walls and foundations.

2.2.5 Non-structural Elements

The non-structural elements of a building include every part of it and all of its contents with the exception of the structure.

Common nonstructural items include ceilings, windows, laboratory equipments, inventory stored on shelves, computers, electrical equipments, furnishings and light fittings.

2.3 EARTHQUAKES

2.3.1 Definition and Measurement

Earthquake

An earthquake is a sudden motion or trembling of the ground produced by the abrupt displacement of rock masses. Most earthquakes result from the movement of one rock mass past another in response to tectonic forces.

The focus is the point where the earthquake's motion starts, and the epicenter is the point on the earth's surface that is directly above the focus.

Figures 2.1 and 2.2 show maps of Eastern Caribbean earthquake epicenters for the periods Jan to June and July to Dec 1989 respectively.

Earthquake Magnitude

Earthquake magnitude is a measure of the strength of an earthquake as calculated from records of the event made on a calibrated seismograph.

In 1935, Charles Richter first defined local magnitude, and the Richter scale is commonly used today to describe an earthquake's magnitude.

Earthquake Intensity

In contrast, earthquake intensity is a measure of the effects of an earthquake at a particular place.

It is determined from observations of the earthquake's effects on people, structures and the earth's surface. Among the many existing scales, the Modified Mercalli Intensity Scale of 12 degrees, symbolized as MM, is frequently used (see Annexe 1).

EASTERN CARIBBEAN EARTHQUAKE EPICENTRES JAN — JUN 1989

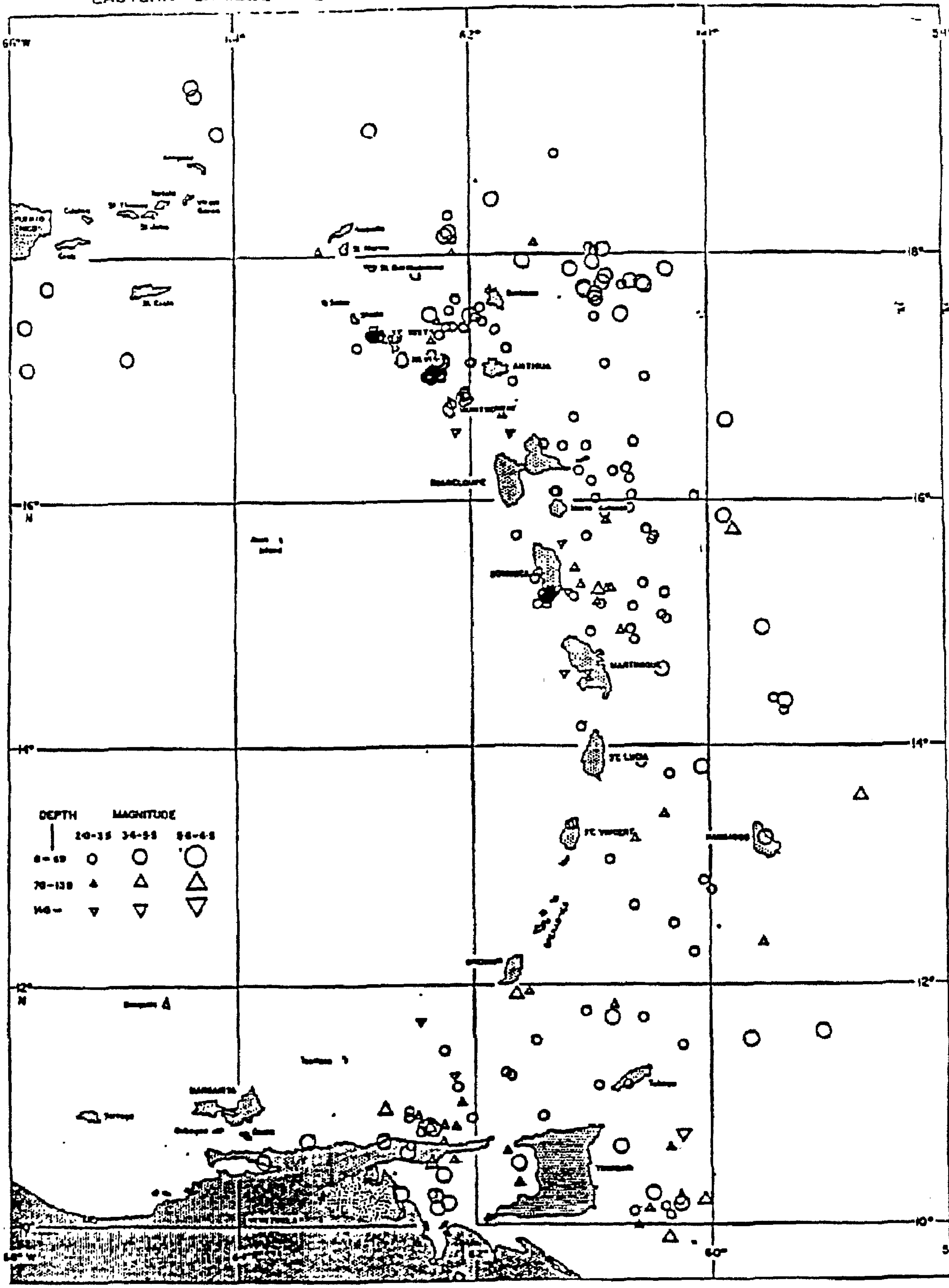


FIGURE 2.1

EASTERN CARIBBEAN EARTHQUAKE EPICENTRES JUL — DEC 1989

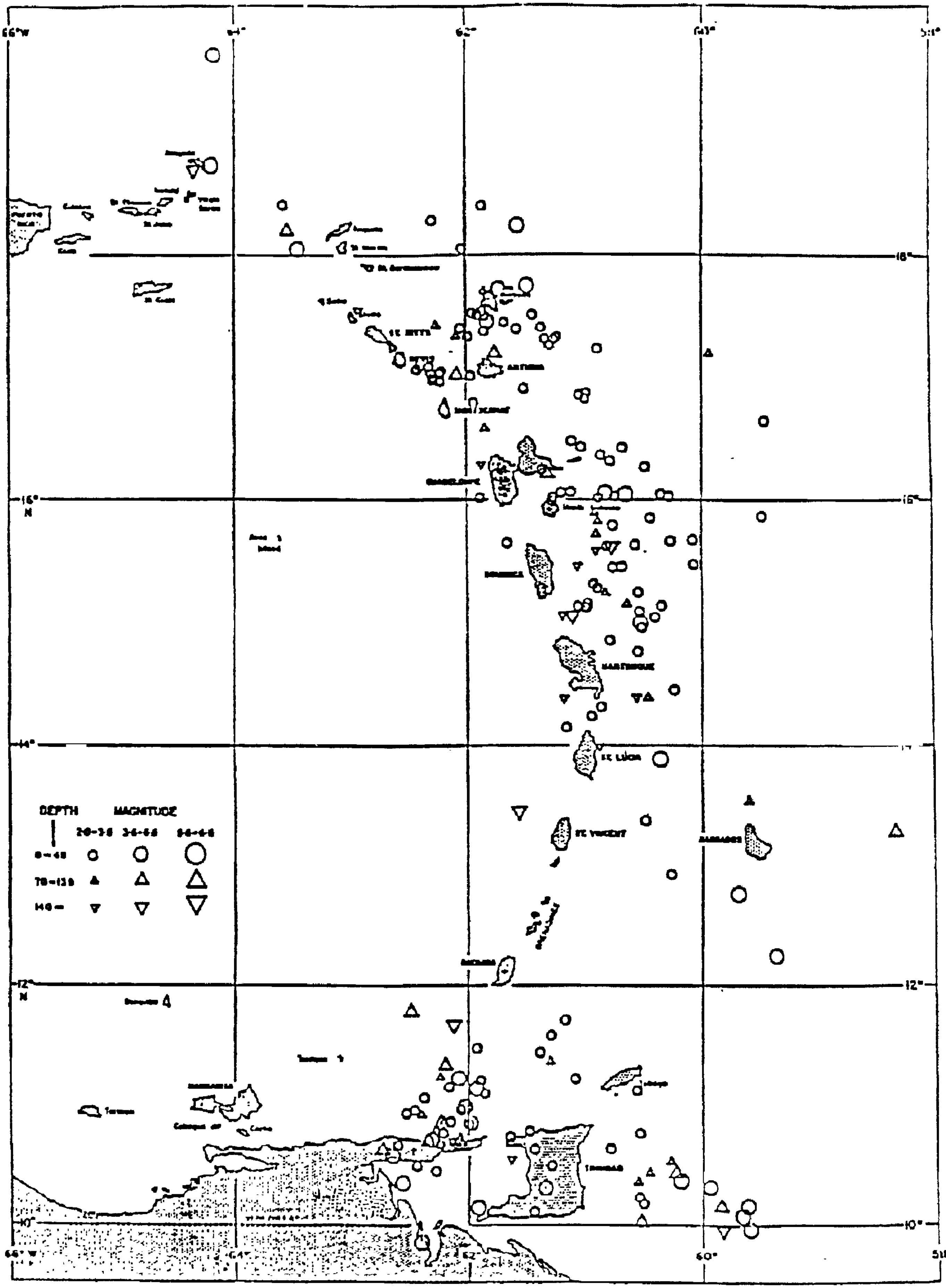


FIGURE 2.2

Table 2.1 lists some of the strongest earthquakes that have affected the Larger and Lesser Antilles. The given degree of MM intensity is representative of the most affected inhabited area. The name of the island is stated even if the intensity only occurred in specific sites of that island.

Based on the known effects of past events, mean return periods of the expected MM intensity are given in Table 2.2. The values given must be properly interpreted. When it is said that in Barbados the mean return period of intensity grade V11 lies between 50 and 70 years, it means that according to available data, the expected number of years between occurrences of that intensity ranges from 50 to 70 years, although it can be shorter or longer.

Figures 2.3, 2.4 and 2.5 show maps of three of the reported earthquakes. The impact of these earthquakes has shown that the local effects of earthquakes can have an enormous range in both space and time. This was clearly demonstrated by the 1766 earthquake (Figure 2.3), centred in northeast Venezuela, which generated after-shocks for 14 months and caused severe damage in West Trinidad and as far afield as Encaramada in the Orinoco river. Figure 2.4 shows the wide area of impact of the 1843 earthquake in the Caribbean. Centred in the northeastern Caribbean, heavy damage was done in Antigua (40 killed and the sinking of English Harbour), Montserrat (16 killed), Guadeloupe, Dominica, St. Kitts. Landslides, liquefaction and permanent settlements occurred. In the 1907 earthquake in Jamaica (Figure 2.5), the number of persons killed was estimated at 1200, and material losses was about 2 million pounds sterling. Intensive landsliding, submarine sliding and tsunamis occurred. The map of intensity distribution in the Rossi Forel 10 degrees scale by Cornish[2] was based on extensive field work throughout the island.

[2] V. Cornish - "The Jamaica Earthquake (1907)" : The Geographical Journal Vol XXX1:3 March 1908, pages 245-276.

TABLE 2.1

List of Destructive Earthquakes in the Larger and Lesser Antilles (Caribbean)

DATE	MAGNITUDE	COUNTRY	MM INTENSITY
1690-Apr-05	7.5-8.0	St.Kitts,Antigua	V111
1692-Jun-07	-	Jamaica	1X
1701-Nov-09	-	Hispaniola	V11
1751-Oct-18	-	Hispaniola	V111-1X
1766-Jun-11	-	Cuba	1X
1766-Oct-21	7.9	Trinidad	V111
1770-Jun-03	-	Hispaniola	V111
1810-Oct	-	Cuba	V11-V111
1824-Apr-20	-	St.Thomas	V111
1827-Nov-30	-	Guadeloupe, Martinique	V11
1839-Jan-11	7.5-7.8	Martinique	1X
1842-May-07	7	Hispaniola	1X
1843-Feb-08	7.8-8	St.Kitts, Montserrat, Antigua, Guadeloupe, Martinique	1X
1844-Apr-16	-	Puerto Rico	V11
1844-Aug-30	7	St.Vincent	V11
1851-May-16	7	Guadeloupe	V11
1852-Aug-20	-	Cuba	1X
1867-Nov-18	7.5	St.Croix, Virgin Islands	1X
1875-Dec-08	-	Puerto Rico	V11-V111
1880-Jan-22	-	Cuba	V111
1887-Sep-23	-	Hispaniola	V111
1888-Jan-10	7.5	Grenada Trinidad	V11 V11-V111
1897-Apr-29	7	Guadeloupe	V11
1904-June	-	Hispaniola	V11-V111
1906-Feb-16	7	Martinique, St.Lucia	V11-V111
1907-Jan-14	7	Jamaica	1X
1918-Feb-24	6.2	Trinidad	V11-V111
1918-Oct-11	7.5	Puerto Rico	1X
1928-Sep-26	6.5	Barbados, Tobago	V1-V11
1932-Feb-03	6.7	Cuba	V111
1939-Aug-14	-	Cuba	V11
1945-Dec-23	6.5	Trinidad	V11
1946-May-21	7	Martinique	V11-V111
1946-Aug-04	8.1	Hispaniola	1X
1953-Mar-19	7.5	St.Lucia, St.Vincent	V11
1957-Mar-01	6.5	Jamaica	V111
1968-Sep-20	6.9	Trinidad	V11
1974-Oct-08	7.5	Antigua, Barbuda	V111
1976-Feb-19	5.7	Cuba	V11-V111

TABLE 2.2

MEAN RETURN PERIODS OF MODIFIED MERCALLI INTENSITY IN YEARS

	MODIFIED MERCALLI INTENSITY		
	V11	V111	1X
Any Site in one of the Larger Antilles(Cuba, Hispaniola)	<10	25-35	90-110
Given Site in one of the Larger Antilles	<10-15	35-45	140-160
In the Leeward Ismands Area	<10	25-35	70-90
In any of the Antilles Windward Volcanic Islands	~10	30-40	120-130
Barbados	50-70	170-200	700-900*

* Not observed in Historical Times

FIGURE 1.2

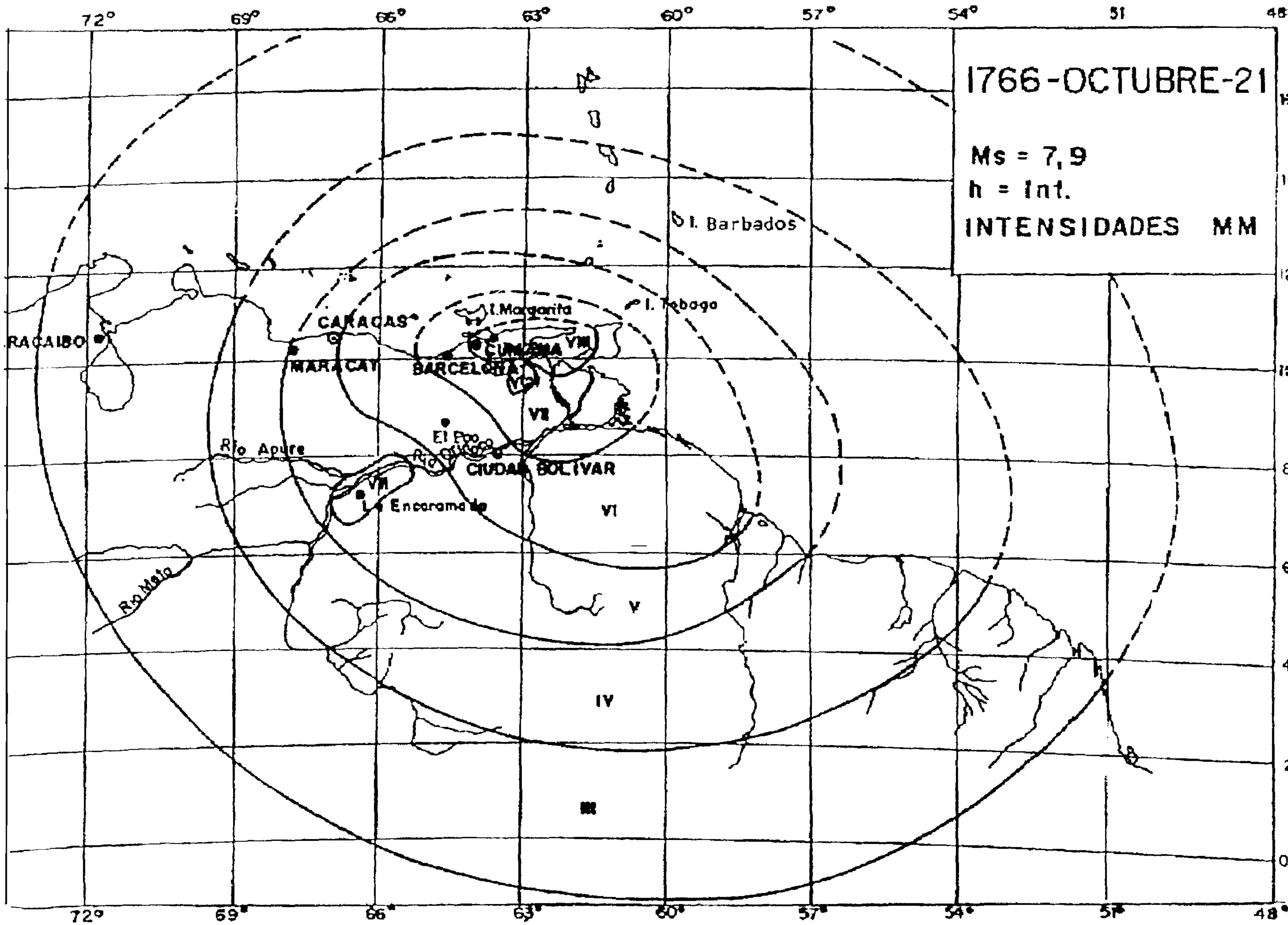
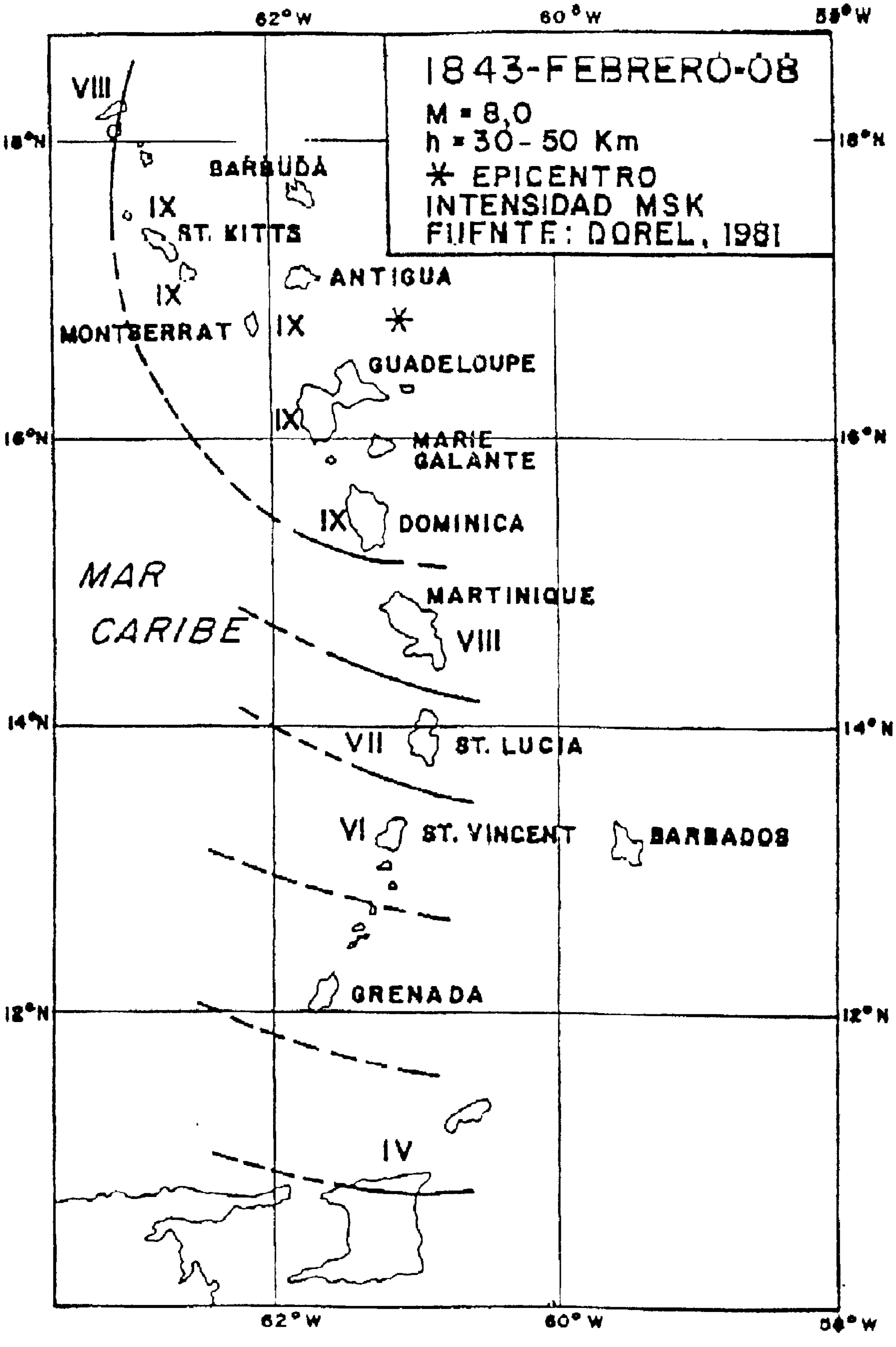
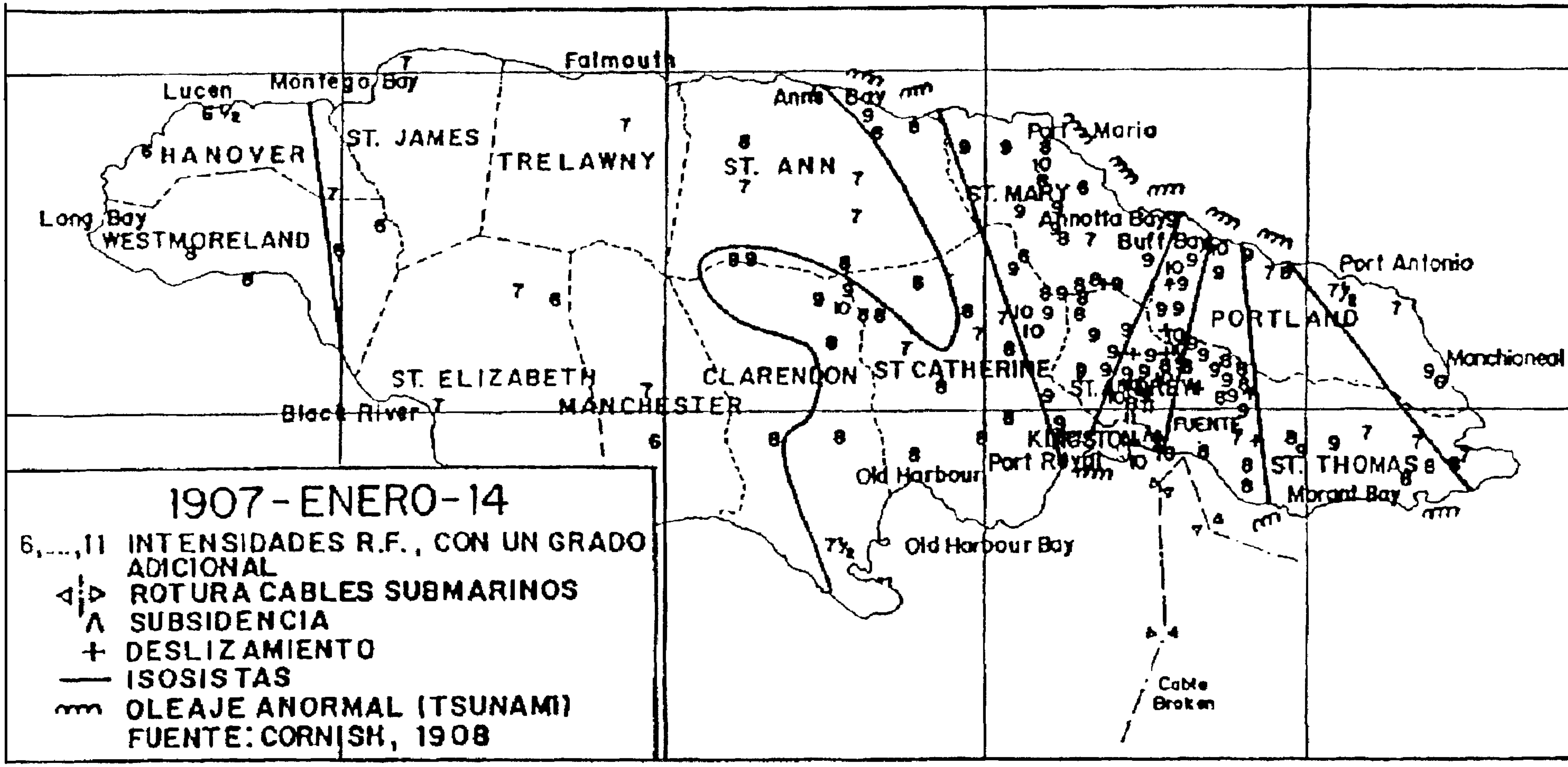

1766-OCTUBRE-21
Ms = 7,9
h = Int.
INTENSIDADES MM
I. Barbados
I. Margarita
I. Tobago
CARACAS
MARACAY
BARCELONA
CUMANA
CIUDAD BOLIVAR
El Pao
Rio Apure
Rio Meta
La Encaramada
VIII
VII
VI
V
IV
III
72°
69°
66°
63°
60°
57°
54°
51
48°
14°
12°
10°
8°
6°
4°
2°
0°

FIGURE 1.4



62° W
60° W
58° W
18° N
16° N
14° N
12° N
1843-FEBRERO-08
M = 8,0
h = 30 - 50 Km
* EPICENTRO
INTENSIDAD MSK
FUENTE: DOREL, 1981
VIII
BARBUDA
IX
ST. KITTS
ANTIGUA
IX
MONTSERRAT
IX
GUADELOUPE
IX
MARIE GALANTE
IX
DOMINICA
MAR CARIBE
MARTINIQUE
VIII
VII
ST. LUCIA
VI
ST. VINCENT
BARBADOS
GRENADA
IV


1907 - ENERO - 14
6,...,11 INTENSIDADES R.F., CON UN GRADO ADICIONAL
ROTURA CABLES SUBMARINOS
SUBSIDENCIA
DESLIZAMIENTO
ISOSISTAS
OLEAJE ANORMAL (TSUNAMI)
FUENTE: CORNISH, 1908
Lucen
Montego Bay
Falmouth
Anns Bay
Port Maria
Annotta Bay
Buff Bay
Port Antonio
Manchioneal
Long Bay
HANOVER
WESTMORELAND
ST. JAMES
TRELAWNY
ST. ANN
ST. MARY
PORTLAND
ST. ELIZABETH
MANCHESTER
CLARENDON
ST CATHERINE
ST. THOMAS
Black River
Old Harbour
Old Harbour Bay
Port Royal
FUENTE
Morant Bay
Cable Broken

2.3.2 Earthquake Hazards

Earthquake hazards can be categorized as either direct hazards or indirect hazards.

Direct Hazards are:-

- Ground shaking;
- Differential ground settlement;
- Soil liquefaction;
- Immediate landslides or mud slides, ground lurching and avalanches;
- Permanent ground displacement along faults;
- Floods from tsunamis or seiches.

Indirect Hazards are:-

- Dam failures;
- Pollution from damage to industrial plants;
- Delayed landslides.

Most of the damage due to earthquakes is the result of strong shaking of the ground. For large magnitude events, trembling has been felt over more than 5 million sq.km (1.93 sq.miles). As a consequence, engineering decisions are normally taken on the basis of ground shaking evaluations, expressed in terms of expected maximum ground accelerations.

Figure 2.6 compares the seismic hazard of two sites in terms of mean rates of occurrences, site A being in a low siesmic area, and site B in a high one. Seismic zonation maps are normally based on this type of evaluation.

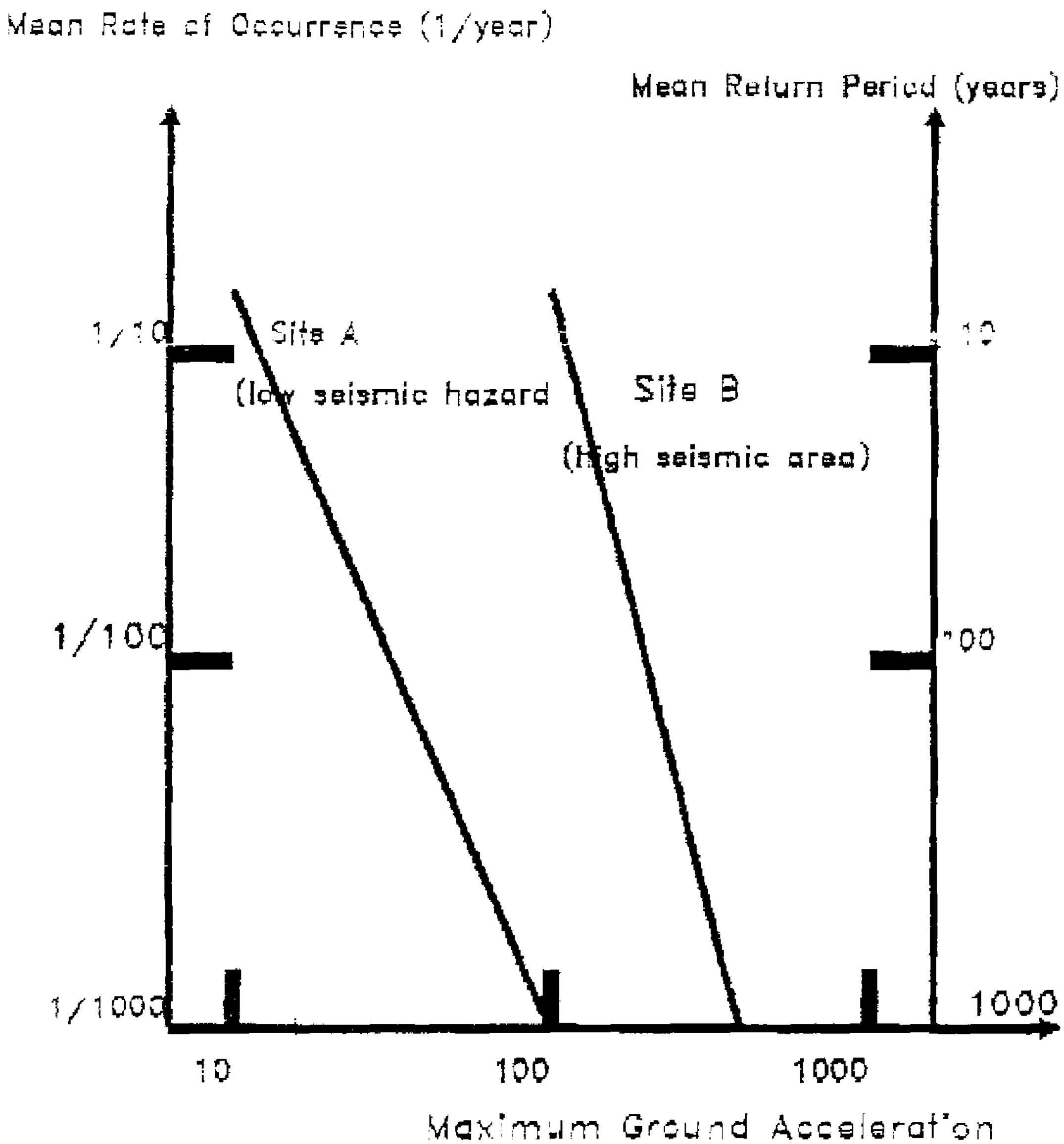
2.3.3 Site Risks

Some common site risks are :-

(i) Slope Risks - Slope instability may be triggered by strong shaking causing landslides. Rocks or boulders may roll down and reach considerable distances.

(ii) Natural Dams - Landslides in irregular topographic areas may create natural dams which may collapse when they are filled. Field inspections are therefore necessary to avoid potentially catastrophic avalanches after strong seismic shaking.

Figure 2.6 Seismic Hazards expressed in terms of maximum ground acceleration



p 7 (cont.) shaking hazard evaluations, expressed in terms of expected maximum ground accelerations. Figure 1.5 compares the seismic hazard of two sites in terms of mean rates of occurrence: Site A being in a low seismic scenario and Site B in a highly seismic area.

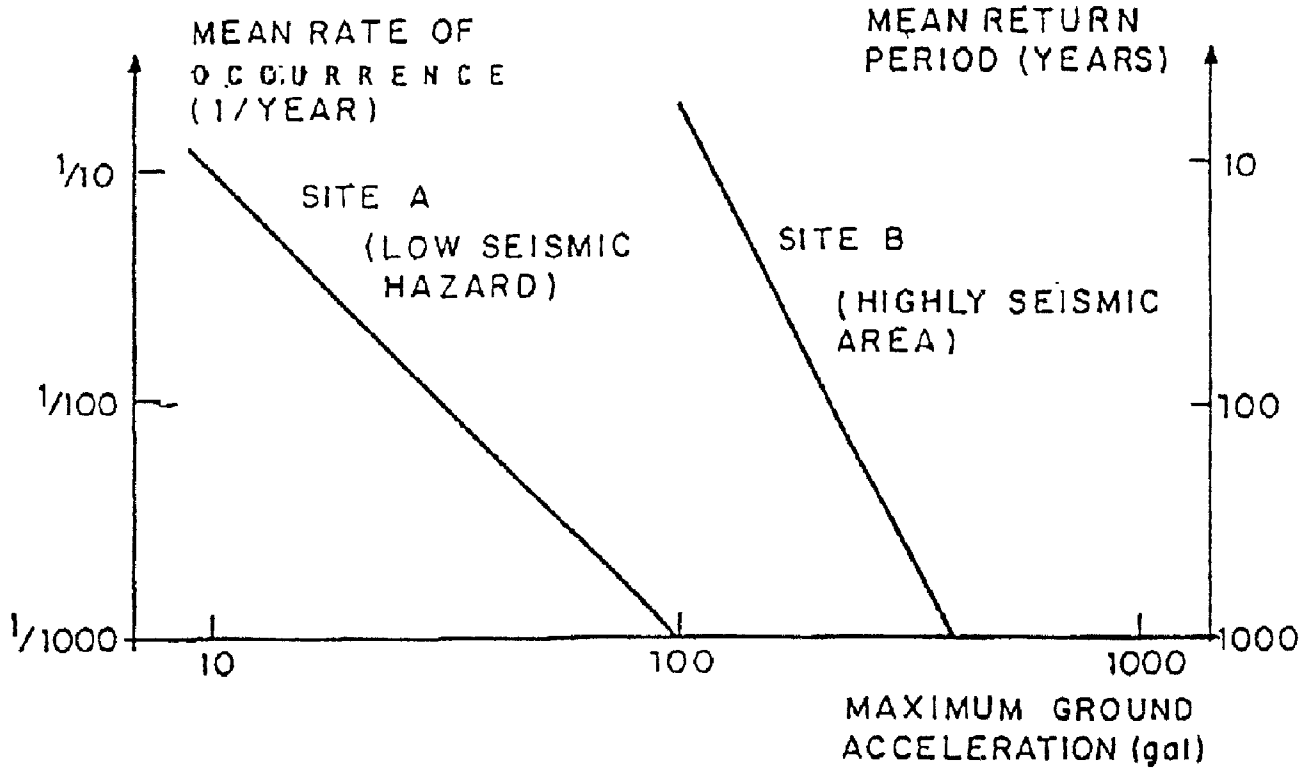


FIGURE 2.6 Seismic hazard of two sites, expresed in terms of maximum ground acceleration

Seismic zonation maps are normally based on such type of evaluations.

line -7 "...catastrophic avalanches after strong seismic shaking."

line -5 "...which has occasionally been."

p 8 line -14 "...scale weather system,"

p 9 line -2 "...across the Hispaniola. The..."

p 10 line 10 "..., Trinidad and Venezuela (1933),..."

p 11 lines 14 and 15 "...long duration, low-to-moderate intensity events, where..."

p 12 and 13 Chapter 2. Perhaps a new section could be added; for instance, some guidance as to how can be the booklet

(iii) Volcanic Activity - Earthquakes may be associated with potential volcanic activity which may occasionally be considered as precursory phenomena. Precautions should therefore be taken against explosive eruptions which are normally followed by ash falls and/or pyroclastic flows, volcanic lava or mud flows, and volcanic gases.

2.4 VOLCANOES

There are active volcanoes in the Caribbean region, and Table 2.3 shows their associated hazards and periodicity over the last 10,000 years. Within recent times, Mt. Soufriere in St. Vincent has been the most active of these volcanoes. Although the return period of these volcanoes may be exceedingly long, it is well advised not to locate any permanent health care facilities within their immediate vicinity.

It is however recognised that the environs of volcanoes tend to be endowed with extremely fertile soil and are therefore attractive areas for settlement by populations. In these cases, low cost chattel buildings to accomodate local health care resources for the delivery of health services to these populations are highly recommended.

2.5 HURRICANES

2.5.1 Definitions

The Caribbean region is located in the North Atlantic Ocean, one of the six main tropical areas where cyclones may develop each year.

Cyclone - The term "cyclone" refers to all classes of storms with low atmospheric pressure at the centre. Cyclones are formed when an organised system of revolving winds, clockwise in the Southern Hemisphere, anti-clockwise in the Northern Hemisphere, develops over tropical waters.

TABLE 2.3 Page 76 in GAS publication - "Disaster. Planning and Development : Managing Natural Hazards to Reduce Loss ".

Cyclones are classified on the basis of the average speed of the wind near to the centre of the system as follows:-

Wind Speed	Classification
Up to 61 km/hr (39 mph)	Tropical Depression
61 km/hr (40 mph) - 115 km/hr (73 mph)	Tropical Storm
Greater than 115 km/hr (73 mph)	Hurricane

Hurricane - A hurricane is a low pressure, large scale weather system which derives its energy from the latent heat of condensation of water vapour over warm tropical seas. In order to develop, a hurricane requires a sea temperature of at least 26°C maintained for several days and a large expanse of sea surface (about 400 km or 250 miles in diameter). A mature hurricane may have a diameter ranging from 150 to 1000 km (93 to 621 miles) with sustained wind speeds often exceeding 187 km/hr (116 mph) near the centre with still higher gusts.

A unique feature of a hurricane is the Eye. The system of revolving winds does not converge to a point, but becomes tangential to the wall of the eye at a radius of 8 to 12 km (5 to 7.5 miles)from the geometric centre of the hurricane. There is therefore very little wind in the eye, and as it passes over a point on the earth's surface, there is a dramatic reverse in the wind direction at that point. The eye provides a convenient frame of reference for the system, and can be tracked with radar, aircraft or satellite.

2.5.2 Classification

The Saffir/Simpson scale is often used to categorize hurricanes based on their wind speed and damage potential. The following five categories of hurricanes are recognised:

Category	Wind Speed(Fastest Mile)			Damage
	m.s	km/ph	mph	
HC1	33-42	119-151	74-95	Minimal
HC2	43-49	152-176	96-110	Moderate
HC3	50-58	177-209	111-130	Extensive
HC4	59-69	210-248	131-155	Extreme
HC5	>69	>248	>155	Catastrophic

The destructive potential of a hurricane is significant due to the high wind speeds, accompanying torrential rains which produce flooding, and storm surges along the coastline.

2.5.3 Caribbean Experience

The occurrence of cyclones in the Caribbean has been widely documented over the last five hundred years. It is estimated that over 4000 tropical storms have occurred in the Caribbean region during that time. Of these, about 50 percent fell under the wind speed classification for hurricanes. This amounts to an average of 4 hurricanes occurring within the region every year.

Some significant post-Columbus hurricane events are listed in Table 2.4. The greatest of all hurricanes occurred from October 10th to 16th 1780. Nearly 20,000 people perished as the storm hit virtually every island from Tobago in the southeast through the Leeward Islands and across to Hispañiola. The death toll was 4,500 in Barbados, 9,000 in Martinique, and 4,500 in St. Eustatius.

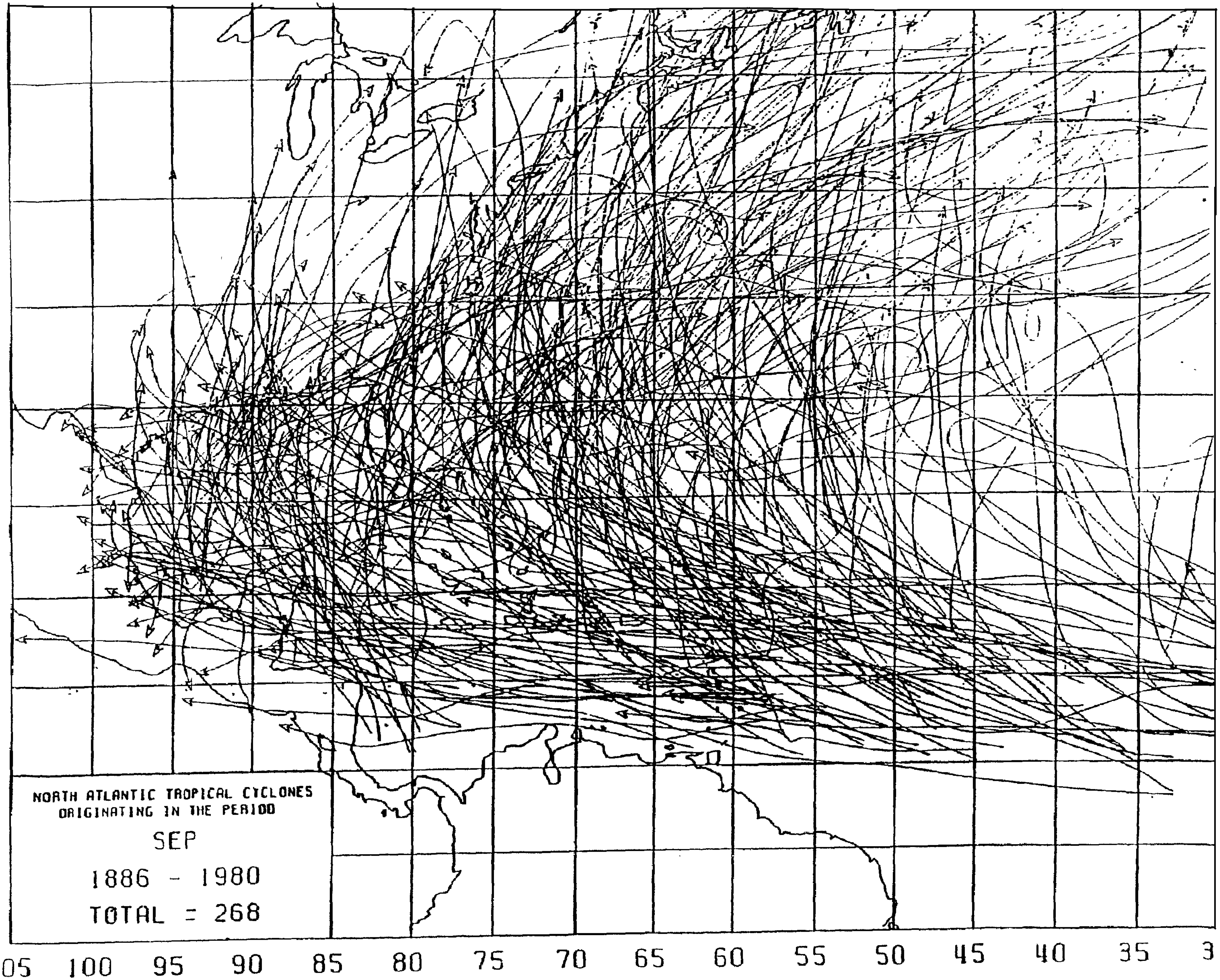
Analyses of the available data using sophisticated data-processing techniques on the computer allow the frequency and intensity of regional hurricanes to be presented in various useful ways. This information is also being used, together with extensive meteorological statistics, to help predict the occurrence and intensity of future hurricanes.

Although the general direction in which a hurricane may travel can be predicted with a fair amount of accuracy, their tracks can be tortuous as shown in Figures 2.7 and 2.8. Figure 2.7 shows the hurricane activity in the Atlantic and Caribbean for 1955 which was a relatively active year with 12 tropical storms occurring, 9 of which developed into hurricanes. Figure 2.8 shows the collection of plots for 845 known tropical storms occurring during the period 1886 to 1986.

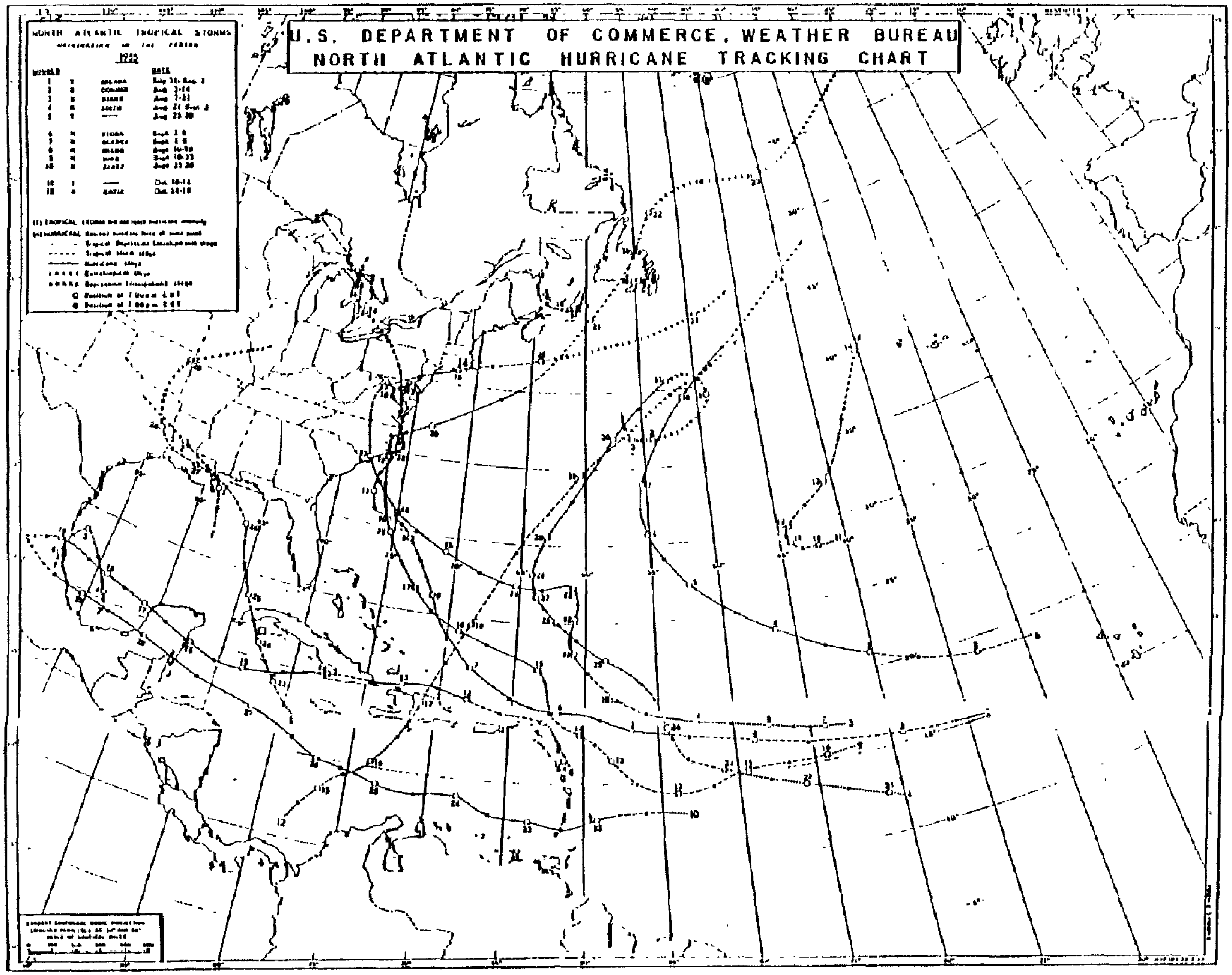
TABLE 2.4

SOME SIGNIFICANT POST-COLUMBUS HURRICANE EVENTS

YEAR	HURRICANE	DEATHS	HISTORIC COSTS (U.S$)/DAMAGE
1509			Santo Domingo destroyed
1667			St.Kitts mostly destroyed
1768			4000 houses destroyed in Havana, Cuba
1772			Extensive damage in Dominica, Antigua, Montserrat, Nevis, ST.Kitts, The Virgin Islands, Puerto Rico
1780-Oct 3			Savanna-la-Mar, Jamaica destroyed
1780-Oct 10-16	Great Hurricane	Nearly 20,000	Severe damage in every island from Tobago to Hispaniola
1825	Santa Ana		7000 houses destroyed in Puerto Rico
1831		1500	$ 7.5 million damage in Barbados
1912			Jamaica struck
1926			Cuba struck
1928			Guadeloupe, St.Kitts, Montserrat, Virgin Islands and Puerto Rico struck
1933			Trinidad struck
1935			Bimini Islands, Bahamas struck
1951			Jamaica struck
1955	Janet		Barbados and Grenada struck
1961			Belize struck
1963	Flora	>7000	US$ 625 million in damage to Tobago, Grenada, Dominican Republic, Haiti, Jamaica, Cuba, Bahamas
1979	David		Extensive damage in Dominica and the Dominican Republic. Over 200,000 homeless, and damage over US$ 1 billion
1980	Allen		St.Lucia and Dominica struck
1988	Gilbert		Extensive Damage in Jamaica
1989	Hugo	82	Extensive damage in Montserrat and South Carolina, U.S.A. Total damage over US$ 10 billion


NORTH ATLANTIC TROPICAL CYCLONES
ORIGINATING IN THE PERIOD
SEP
1886 - 1980
TOTAL = 268
45
40
35
30
25
20
15
10
5
0
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
3

Ref National Oceanographic and Atmospheric Administration North Atlantic Hurricane Tracking Charts.



2.6 FLOODS

2.6.1 Rainfall

Rainfall events in the Caribbean are characterised by short duration and high intensity, although rainfall events of long uninterrupted duration do occur. These events are usually of low intensity. Most of the more severe storms occur during the period known as the hurricane season (from June to October) although many of the storms are not associated with hurricanes, but rather with tropical depressions or tropical waves.

Rainfall intensities in the Caribbean usually increase with elevation for any given island. Intensities are also higher closer to the equator.

Records from recording rain gauges are available from Grantley Adams International Airport in Barbados from 1942, and from some other of the islands (Jamaica, Trinidad and Tobago, St.Lucia) from 1963 onwards. Some of the island states do not yet have recording rain gauges. These records are necessary for the compilation of rainfall-intensity-duration frequency maps. Typical rainfall-duration-frequency curves, rainfall isohyets and rainfall intensity-duration-frequency curves for Barbados are given in Figures 2.9, 2.10 and 2.11 respectively.

2.6.2 Flooding

Flooding can be caused either by short duration, high intensity events where the drainage facilities are inadequate to cope with the rate of runoff, or by long duration, low to moderate intensity events because the substrata becomes saturated, and most of the rainfall results in runoff.

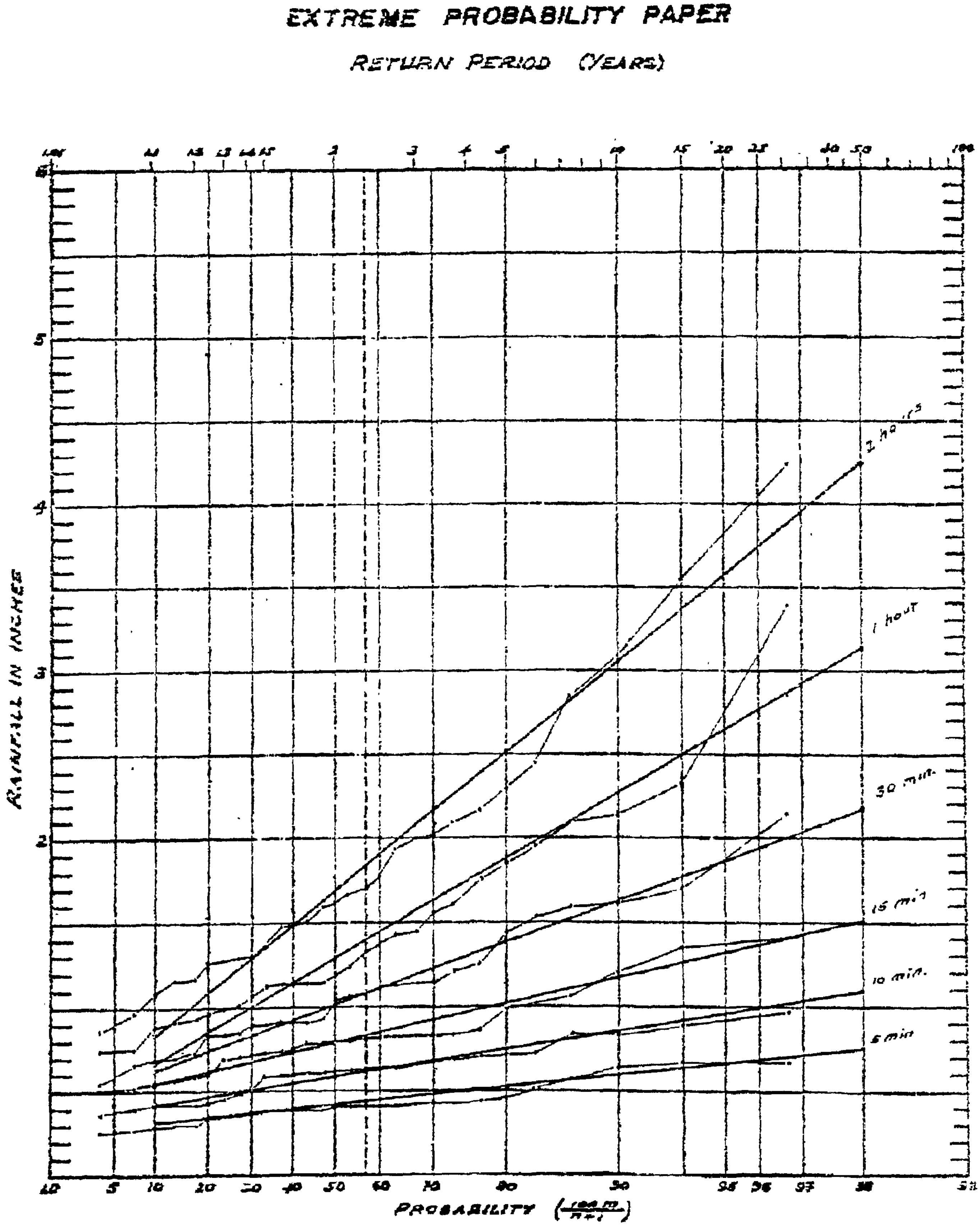


Figure 4. - Rainfall-duration-frequency curves for Seawell Airport; based on recording rain gauge data for the period 1942-1970. Station elevation = 183 feet above MSL.