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Pan American Health Organisation
Christ Church, Barbados

Organisation of Eastern Caribbean States
Disaster Mitigation and Preparedness Project Office
The Morne, St Lucia

Vulnerability Assessment of the Restoration Works

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1.0 INTRODUCTION

The Organisation of Eastern Caribbean States, with the assistance of the Pan American Health Organisation, is currently conducting a disaster mitigation and preparedness project. The headquarters for this project will be located in an historic building at The Morne in St Lucia which is being renovated and restored for this purpose. Dr Bordonado is in charge of the project and will work out of this office.

The Pan American Health Organisation, through Dr Jean-Luc Poncelet, has funded a vulnerability analysis of the designs and construction of the restoration works with a view to reducing the risk of damage to the facility in the event of the natural hazards of earthquakes, hurricanes and torrential rains. To this end the services of Mr Tony Gibbs of Consulting Engineers Partnership Ltd were contracted:

"to conduct a vulnerability assessment of the restoration works necessary for Dr Bordonado's office in St Lucia, including the technical audit of the design and construction details prepared by others"

2.0 HAZARDS

2.1 Earthquakes

Seismic events in the Eastern Caribbean, where St Lucia is located, are principally associated with a subduction zone at the junction of the Caribbean Plate and the Americas Plate. The Caribbean Plate is moving eastwards relative to the Americas Plate at a rate of about 20mm per year. The Americas Plate dips from east to west beneath the Caribbean Plate along a north-south line approximately 150km east of St Lucia. This leads to a moderate level of inter-plate seismicity in the vicinity of St Lucia. The maximum historical intensities of earthquakes in St Lucia as reported by Dr John Shepherd (formerly of the Seismic Research Unit, UWI, Trinidad) are VII and VIII on the Modified Mercalli Scale. The Caribbean Uniform Building Code (CUBiC) recommends a Z-factor of 0.75 for St Lucia. However, a 1983 study by Faccioli, Taylor and Shepherd recommends a Z-factor of 0.5 and a design ground acceleration of less than or equal to 0.1g. This places St Lucia somewhere between zones 2 and 3 of the UBC and (old) SEAOC codes of the USA. In other words, the level of seismicity in St Lucia is moderate but sufficiently important not to be ignored.

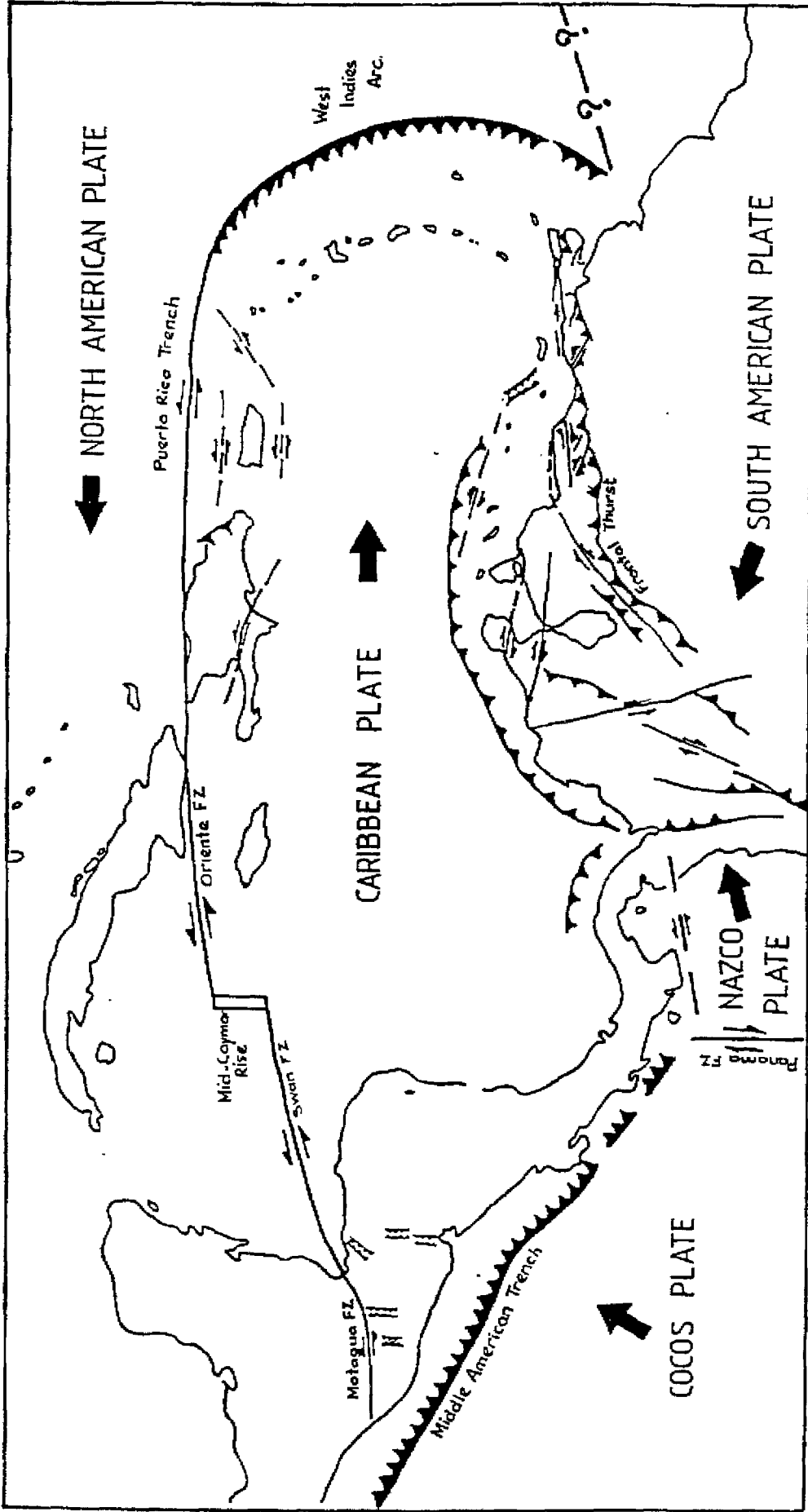
Figures 1, 2 and 3 (at the end of this sub-section) show the tectonic setting of the Caribbean, the main physical features of the Eastern Caribbean and a cross section through the island arc.

The two most recent earthquakes to have caused significant damage in St Lucia are:

19th March 1953 - Richter magnitude 7.5, Modified Mercalli intensity VII
in St Lucia

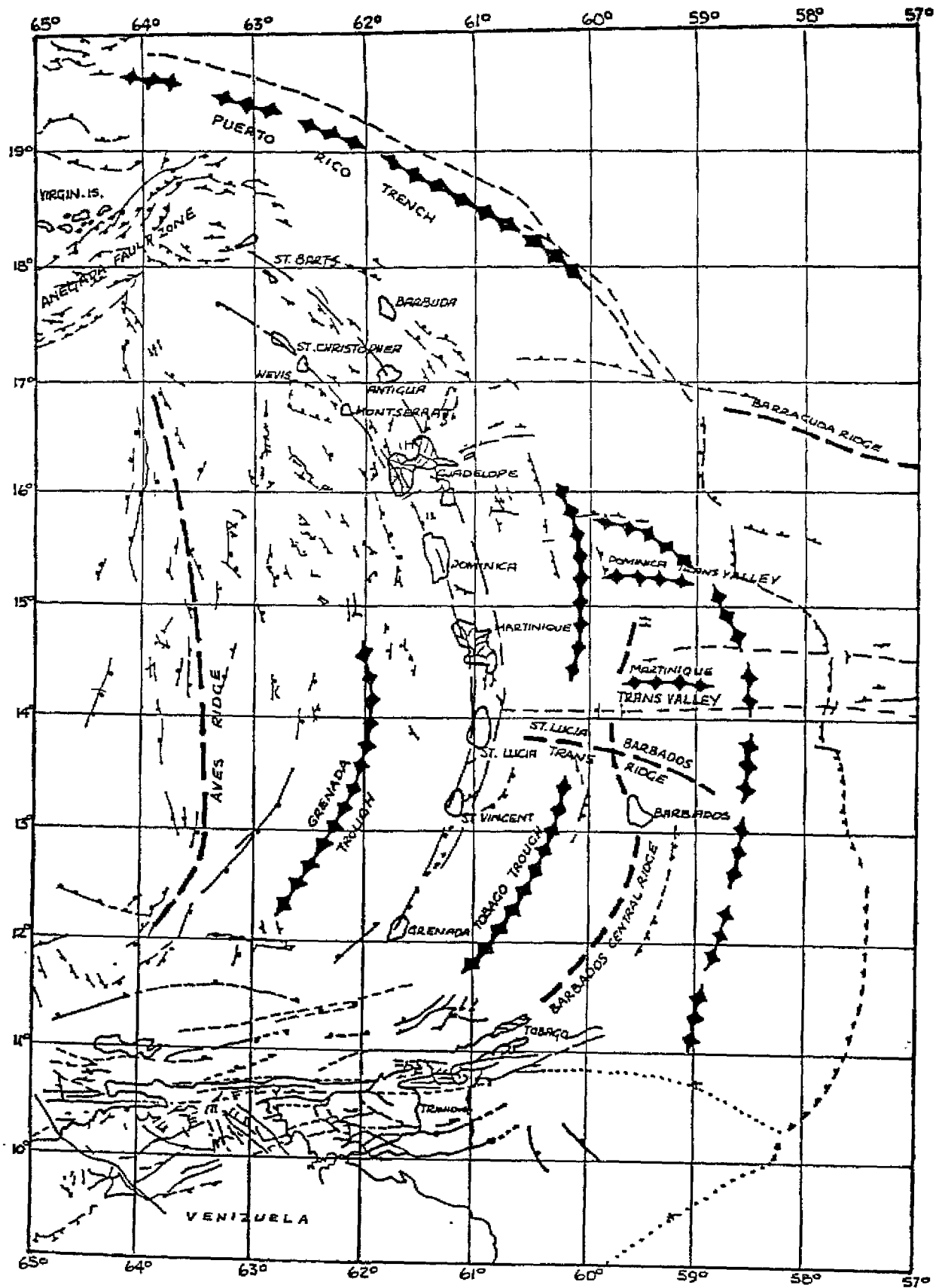
16th February 1906 - Richter magnitude 7.0, Modified Mercalli
intensity VII-VIII in St Lucia

The catastrophic Guadeloupe earthquake of 8th February 1843 produced a Mercalli-Sieberg-Cancani intensity of VII in St Lucia. An isoseismic map of that event is reproduced in figure 4 (at the end of this sub-section).



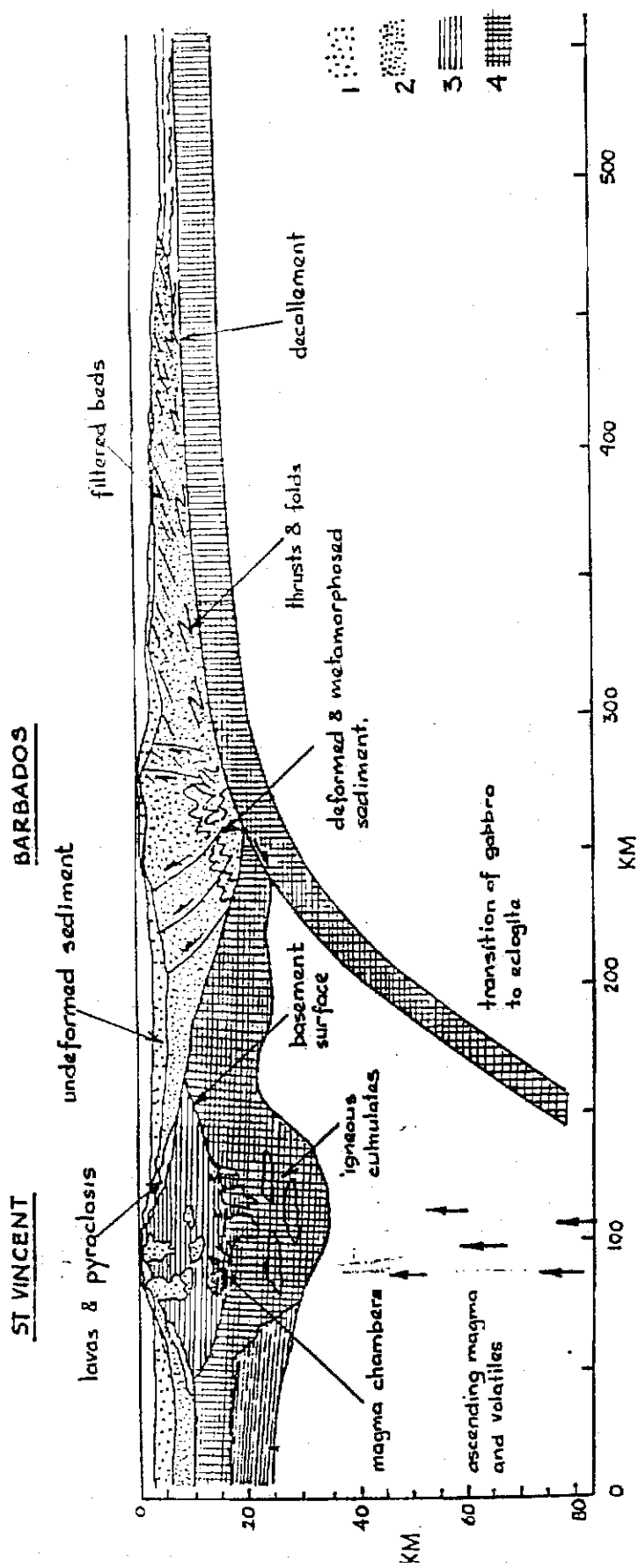
Tectonic Setting of the Caribbean
 (after Molnar and Sykes, 1969)

Figure 1



Main Features of Eastern Caribbean
 (based on compilation by JE Case and TA Holcomb USNOO
 and from Peter and Westbrook, 1976)

Figure 2



Diagrammatic cross-section of the Eastern Caribbean island arc illustrating the structure and the processes acting on it. 1. Undeformed sediment. 2. Deformed and/or consolidated sediment. 3. Igneous crust produced by the volcanic arc. 4. Main oceanic crustal layer and lower crust of arc. Vertical exaggeration 2:1.

Structure in Region of Barbados
(Westbrook, 1970)

Figure 3

2.2 Hurricanes

St Lucia lies in the North Atlantic Ocean, one of the six main tropical areas of the earth where hurricanes may develop every year. In its April 1991 Information Bulletin, the Caribbean Cyclone-Resistant Housing Project (UWI) states that over 4000 tropical storms have occurred in the region within the past 500 years, half of which developed into hurricanes. A general historical record of those hurricanes affecting St Lucia from the seventeenth century to 1980 is given in Table 1 (at the end of this sub-section).

Cyclones are formed when an organised system of revolving winds, clockwise in the Southern Hemisphere and anti-clockwise in the Northern Hemisphere, develop over tropical waters. The classification of a cyclone is based on the average speed of the wind near the centre of the system. In the North Atlantic they are called tropical depressions for wind speeds up to 17 metres per second (m/s). Tropical storms have wind speeds in the range 18m/s to 32 m/s. When the wind speeds exceed 32 m/s the system is called a hurricane.

A hurricane is a low-pressure, large-scale weather system. It 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 which must be maintained for several days for the system to sustain itself. A large expanse of sea surface is required for the formation of a hurricane, about 400 kilometers (km) in diameter. A mature hurricane may have a diameter anywhere from 150 km to 1000 km with sustained wind speeds often exceeding 52 m/s 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 from the geometric centre of the disturbance. The eye is an area of light winds, thin cloud cover and the lowest barometric pressure. The eye provides a convenient frame of reference for the system and can be tracked with radar, aircraft or satellite. Figure 5 (at the end of this sub-section) shows the variations of wind speed and barometric pressure with distance from the eye of the hurricane.

In Figures 6 and 7 (at the end of this sub-section) are presented a probability chart and table (CCRHP-UWI) of cyclone risk in a 2-degree square (approximately 220 km x 220 km) centred on Barbados. The statistics for St Lucia are not readily available but are likely to be very similar to those for Barbados. It is estimated that the probability of a direct hit on St Lucia is about 65% of the probability of a passage through the 2-degree square as shown on figures 6 and 7.

The destructive potential of a hurricane is significant due to high wind speeds, potential torrential rains which produce flooding and occasional storm surges with heights of several metres above normal sea level.

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

Category	Wind Speed		Damage
	m/s	mph	
HC1	33 - 42	74 - 95	Minimal
HC2	43 - 49	96 - 110	Moderate
HC3	50 - 58	111 - 130	Extensive
HC4	59 - 69	131 - 155	Extreme
HC5	> 69	> 155	Catastrophic

The Caribbean Uniform Building Code and the BNSI/NCST/OAS/BAPE Wind Code set out the basic wind parameters for the design of buildings in St Lucia. The normal requirement is the 1-in-50-year wind, ie a wind speed which on average is not expected to be exceeded more than once in 50 years. In St Lucia this produces a basic 3-second gust wind speed of 58 m/s. This represents a category 3 hurricane. For a category 4 hurricane, a wind speed is experienced which on average is not expected to be exceeded more than once in 100 years. The 1-in-200-year wind is experienced in a category 5 hurricane.

ST LUCIA

1600-1700

October 23 or 24, 1694

1700-1800

June 12-14, 1780

October 10-18, 1780 - "Great Hurricane"

1800-1900

October 23, 1817

October 21, 1818

September 21-22, 1819

October 13-15, 1819

July 9, 1837

October 6, 1841

1900-1980

September 2-5, 1951

October 30 - November 6, 1956 - heavy swells from "Greta" to west-northwest

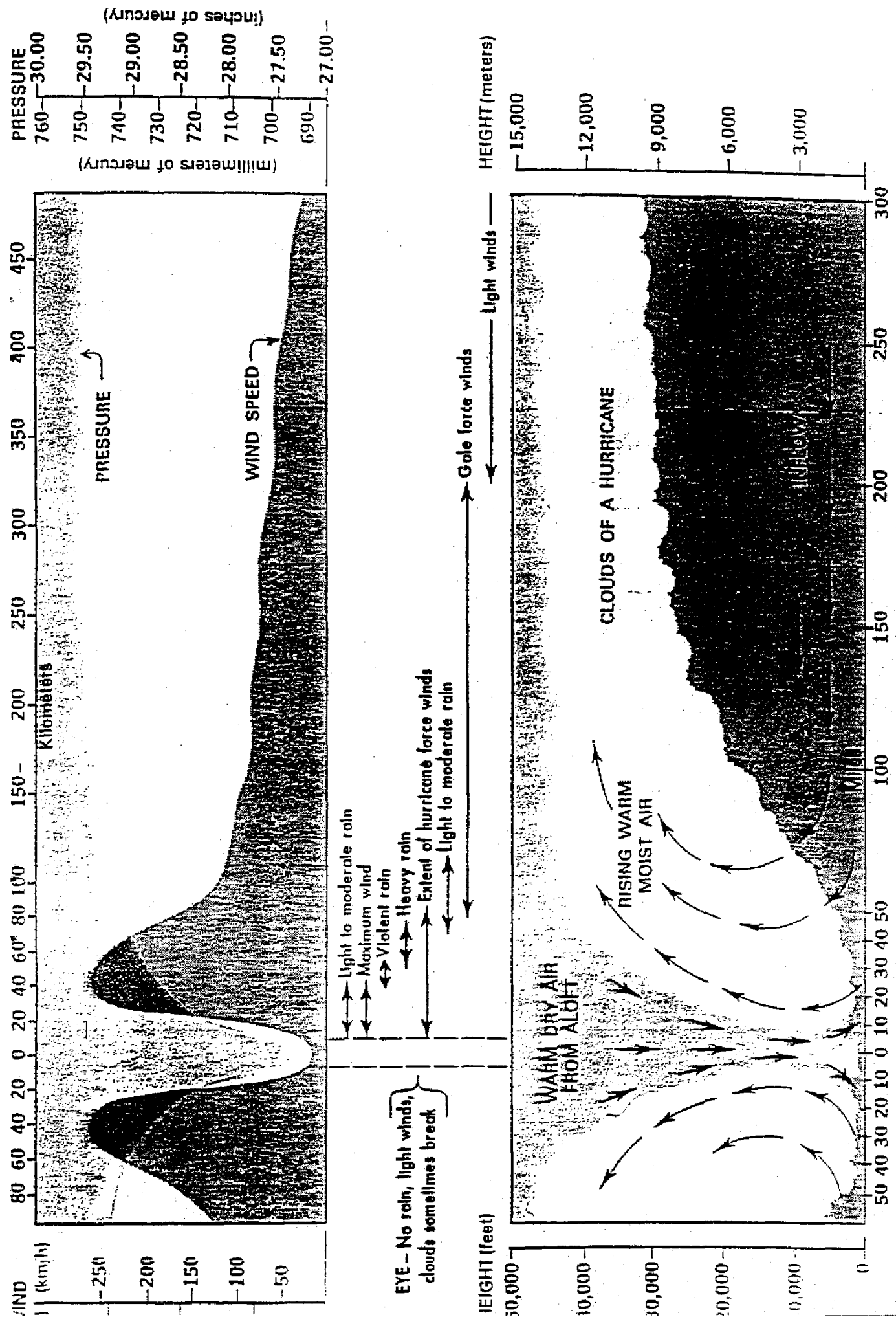
July 10, 1960 - "Abby" - destruction most severe in memory

September 25, 1963 - "Edith" - \$3,465,000 in damages

September 5-22, 1967 - "Beulah" - torrential rains; \$3 million in damages

August 4, 1980 - Hurricane "Allen"

Table 1



upper chart shows:
 Variations of Wind Speed and Barometric Pressure
 with distance from the eye of the hurricane

Figure 5

Cyclone Risk - Barbados

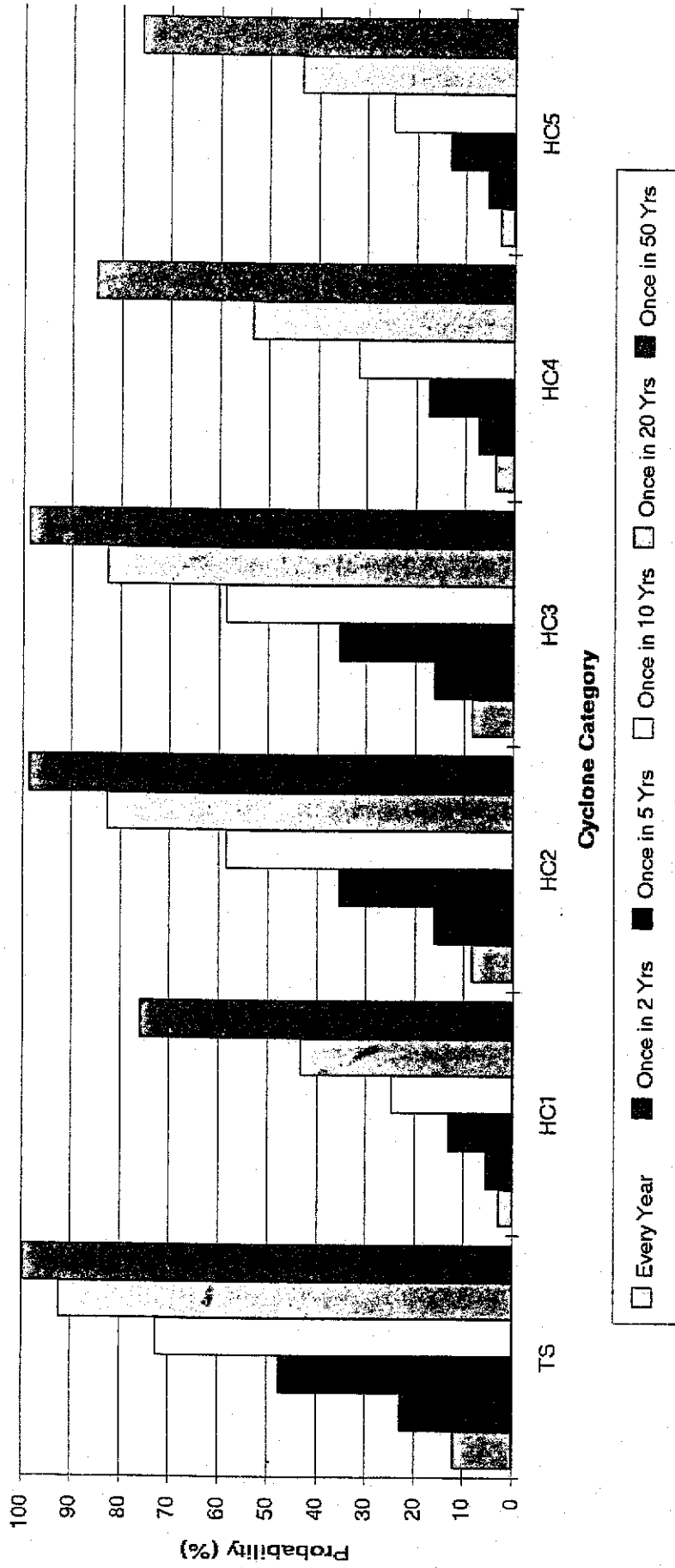
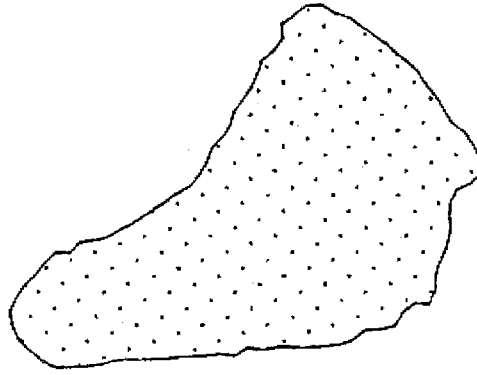
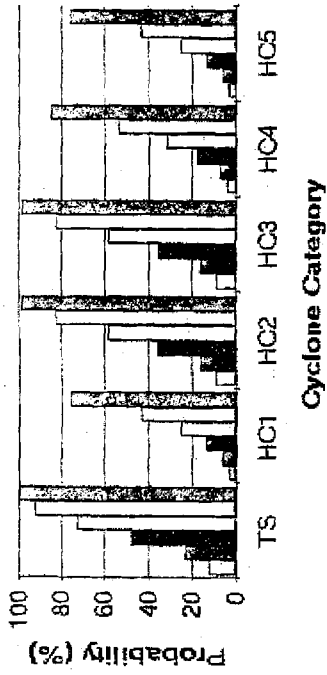


FIGURE 6

Cyclone Risk - Barbados



Number of Years	Probability of Cyclone (%)					
	TS	HC1	HC2	HC3	HC4	HC5
1	12	3	8	8	4	3
2	23	6	16	16	7	6
5	48	13	36	36	17	13
10	73	25	58	58	32	25
20	93	43	83	83	53	43
50	100	76	99	99	85	76

FIGURE 7

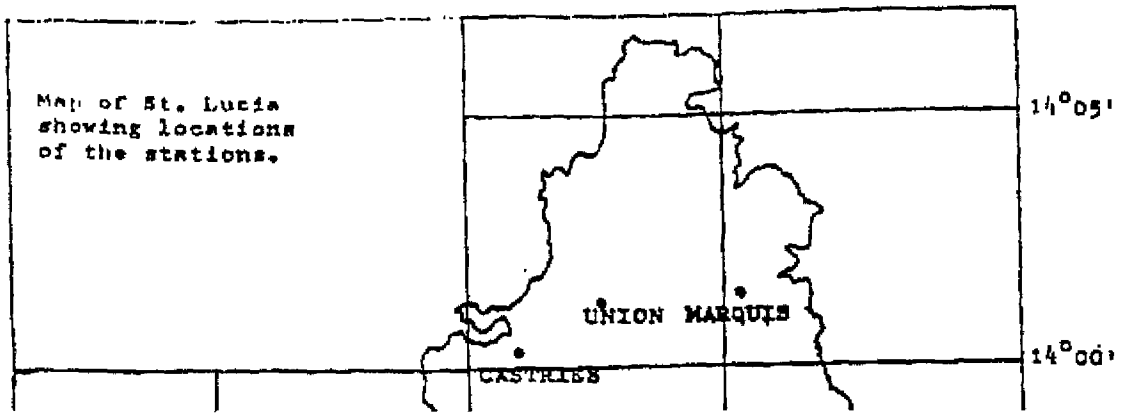
2.3 Torrential Rains

Although hurricanes are often accompanied by heavy rains, severe rainfall events resulting in flooding in St Lucia are also, and frequently, associated with troughs and tropical depressions. The risk of flooding is therefore not restricted to, nor more likely to occur during hurricane events.

Drainage systems and structures in St Lucia are generally designed for rainfall events having return periods of 20 years. This means that such systems are likely to become overloaded and cause some degree of flooding when rainstorms are experienced with return periods greater than 20 years. Figure 8 and 9 (at the end of this sub-section) show the rainfall intensity-duration-frequency curves for two locations in St Lucia.

Generally, lower lying areas will be more susceptible to flooding than higher and sloping ground.

The damage caused by flooding depends on the type and elevation of facilities in the location. The results of flooding may range from the inconvenience of temporarily submerged driveways to the loss of equipment and finishes inside flooded buildings and consequential disruption of the functions.



RAINFALL INTENSITY-DURATION FREQUENCY CURVES

UNION

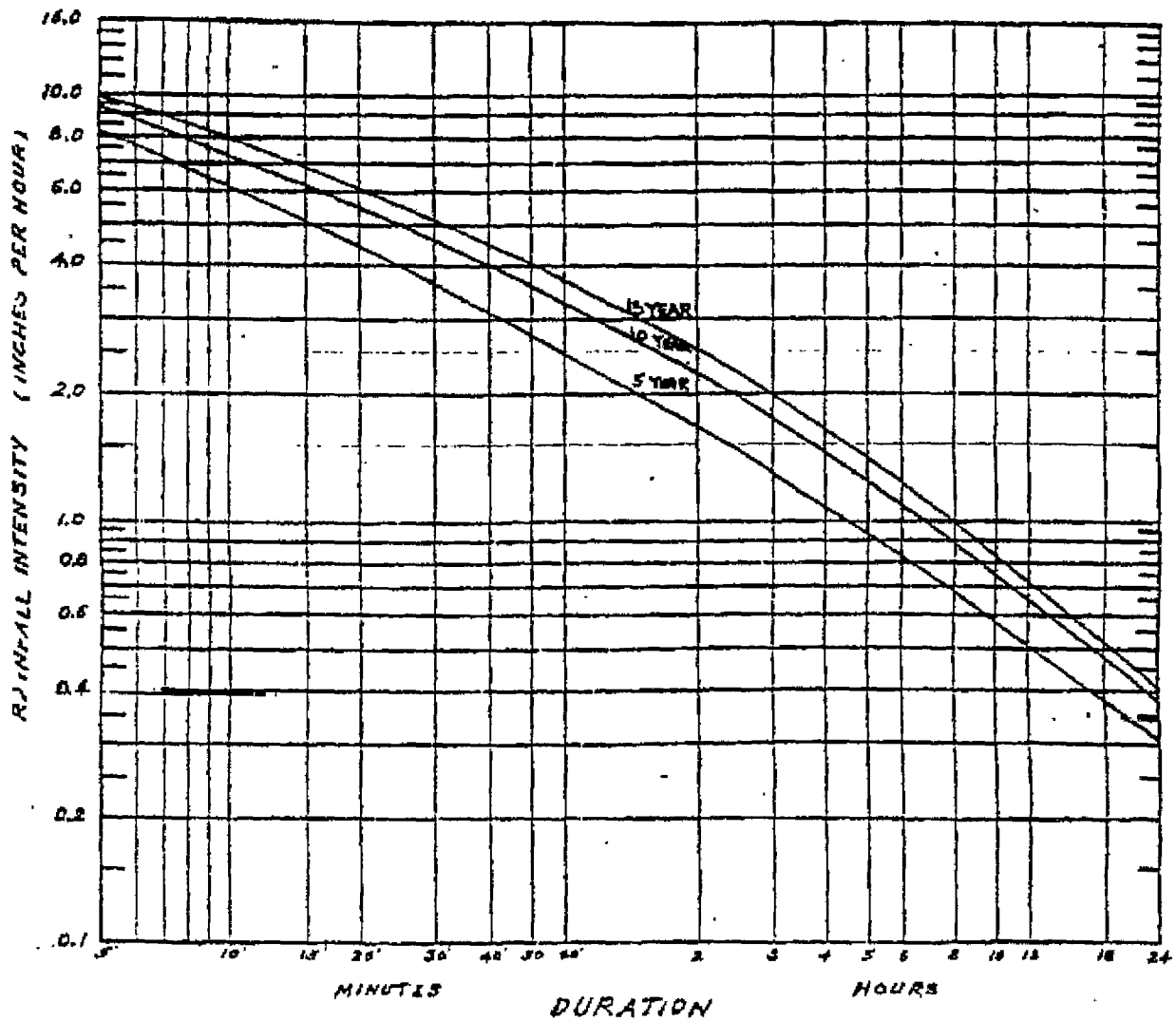


Figure 8

RAINFALL INTENSITY-DURATION FREQUENCY CURVES

LA PERLE, SOUFRIERE,
ST. LUCIA

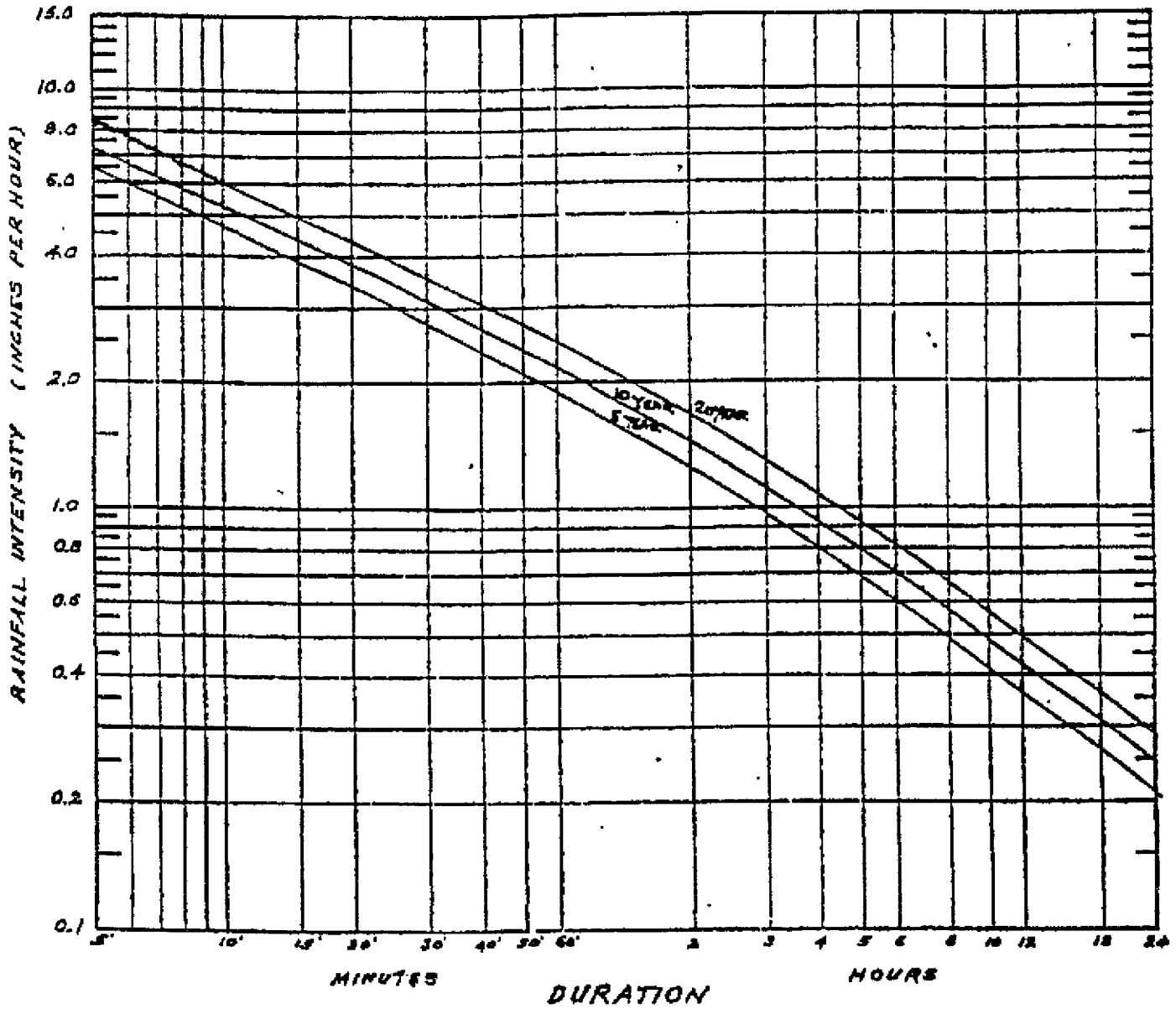


Figure 9

3.0 STUDY PROCEDURE

3.1 Site Visit and Office Meeting

A site visit was made in January 1993 in the company of Mr Brian Camacho of TVA Consultants Ltd. Photographs taken at that time by Tony Gibbs are reproduced at Appendix A (Plates 1,2,3 and 4).

A meeting was convened in St Lucia on the 6th May, 1993.

Present were:

Mr Robert Fredericks, TVA Consultants Ltd

Mr Lyndell Gordon, Gordon Belizaire and Partners, Consulting Engineers

Mr Tony Gibbs, Consulting Engineers Partnership Ltd, Vulnerability Consultant

The following architect's drawings were received:

Ground Floor Plan, Drawing No. 01

Roof Plan and Details, Drawing No. 02

Elevations, Drawing No. 03

These are reproduced at a reduced scale at Appendix B.

Photographs of the existing building were provided by the Architect. These are reproduced as Plates 5 to 12 at Appendix A.

The general principles of the design were discussed and the implications for hurricane and earthquake vulnerabilities were examined. Suggestions were made at that time for adjustments to the fixing details for the roof structure to improve its hurricane resistance. These suggestions were readily agreed to.

3.2 Construction Details

The building to be renovated is part of a much larger "Garrison" type complex constructed in the 19th century, generally of brick walls and timber roof structures with wood shingles. The construction of the original building was not analysed in detail, but generally the shape of the roof and the construction of the walls would indicate a reasonable resistance to hurricane forces. However, the additions to the larger adjacent buildings, made to provide additional office accommodation for the

OECS Secretariat, have not always been designed and constructed consciously to resist hurricanes. Nor were the original buildings consciously designed to resist earthquake forces. This poses problems for the small "PAHO" office, since there are the possibilities of collateral damage to this office due to damage to the larger adjacent buildings.

Maintenance of the OECS buildings is also lacking. The probability of these buildings being badly damaged by hurricane forces is great due, in part, to lack of maintenance of the roofs and badly constructed additions such as the verandahs.

The constraints, and challenges, in the renovations, restorations and additions to this group of buildings are the needs to preserve its architectural integrity and historical heritage. There are instances where the need for such preservation would be at odds with the technical requirements of modern building codes. The certainty of damage to historical/architectural integrity of insensitive strengthening methods in the present must be balanced against the possibility of damage to the functional building in future, infrequent hazardous events.

The office being constructed for Dr Bordonado is inherently less vulnerable than the larger adjacent structures of the complex. It is a renovation of a small block of about 400 square feet (external dimensions) in three rooms sandwiched between two larger two-storey blocks.

The main construction details of Dr Bordonado's office are:

- | | |
|--------|---|
| Walls: | 9" brick. |
| Roof: | a) for main building - hipped roof with rafters of 2"x 6" pitch pine at 2-ft centres. |
| | b) R-panel roof sheeting on 1"x 4" timber battens nailed to 1"x 6" groove-and-tongue close boarding. |
| | c) 3"x 4" pitch-pine wall plate bolted to top of wall. After discussion of this detail a reinforced concrete ring beam of about 8"x 8" was introduced and the wall plate bolted to the concrete ring beam. The ring beam itself was dowelled to the original masonry wall to increase the anchorage for the roof. |
| | d) The roof pitch is about 30 degrees. |
| | e) For the small additions as shown on the plan, 6" concrete slab. |
| | f) For the existing walkway, the roof construction is the same as that of the main roof, ie 2"x 6" rafters at 2-ft centres. After discussion it was agreed to change the bolting detail for the roof rafters at the arched wall so as to provide a more positive anchorage. |
| Floor: | Concrete on grade. |

The drawings indicate that there will be metal hurricane anchors connecting the roof rafters to the wall plate.

Reduced-size copies of the TVA drawings are included at Appendix B.

3.3 Analysis

In order to determine the level of forces on the structure from hurricane winds it was necessary to carry out analyses on some of the details of construction. The structural analyses determined the minimum sizes and spacing of members required to resist the

forces resulting from hurricanes of different intensities. For these analyses a 50-year return storm was used.

One of the main problems to be solved is the provision of adequate resistance (or weight) to prevent the entire roof structure from being lifted away from the brick walls. The construction detail as shown on the plans required holding down bolts to be drilled into the brick walls. This detail was suspect and it was subsequently changed. The holding down bolts now connect the wall plates to a concrete ring beam which, itself, is connected by dowel to the wall.

The analysis of the structure was carried out on the basis of the information supplied on the plans and informed by the site visit. The calculations are at Appendix C. The results show:

- a) The critical wind directions are 60 degrees to the transverse axis of the building for the main enclosing roof and 0 degrees (from the landside) for the walkway roof.
- b) The more vulnerable roofs are, as shown on the accompanying sketches in the Appendix C, the roof of the walkway and the area of the roof of the office adjacent to the walkway roof.
- c) The critical roof areas with highest local suction forces are the eaves and ridges.
- d) 4-ft spacing of the battens is generally satisfactory, but 2-ft spacing is required in the high suction areas of the roof.
- e) 40mm, S-Point, self-tapping screws (for timber) or equivalent are required for the connection of roof sheets to battens - 5 fixings per sheet at the eaves and ridges are required.
- f) The 2"x 6" rafters at 2-ft centres are satisfactory.
- g) The weight required to resist the uplift forces at the critical areas of the roof is equivalent to a beam of 2 cubic feet of concrete per foot run. The ring beam constructed would supply no more than about 70 lbs per foot run. It is recommended therefore that the dowels holding the ring beam to the wall penetrate through three courses of the brick wall.

- h) The roof over the walkway - a monopitch roof - is the most vulnerable for winds approaching at right angles from the land side. If the holding down bolts are installed as recommended the vulnerability of this roof will be reduced considerably.

It should be pointed out that it is only for certain critical directions that there would be significant risk to the roof as detailed. The chances of those critical wind directions being experienced are necessarily more remote than the occurrence of the hurricane itself.

No engineering calculations were carried out to determine the resistance of the structure to earthquake forces. The building has good geometry however - small rooms, many cross walls. The construction of the concrete ring beam will make the building more resistant to earthquakes than hitherto. It is considered that in the event of an earthquake the adjoining buildings will, in all probability, suffer severe damage before the small office of Dr Bordonado is materially affected. The office could, however, suffer collateral damage and as such may become unusable.

The location of the building is at the top of a ridge. The risk of flooding is self-evidently minimal to non-existent.

4.0 CONCLUSIONS

1. The building to be converted is very small and compact with 9" brick walls and a timber hipped roof of 30-degree pitch for the main building. There is a concrete slab roof for the newer section.
2. In general the construction details would provide adequate resistance to hurricane forces if the main recommendations with respect to the installation of holding-down bolts and the installation of roof fixings are followed. These are:
 - a) Five fixings per sheet at the eaves and at the ridges.
 - b) Holding down dowels to connect the concrete ring beam and to three courses of the brick wall.
 - c) The battens to be placed at 2-ft centres in the high suction areas of the roof.
 - d) The concrete roofs over the small additions to be repaired where deterioration is evident.
3. It is possible that with a hurricane of greater intensity than that used for the analysis, the roof of the covered walkway may be damaged. However the building analysed is sandwiched between two larger and taller buildings and would to some extent be shielded from the full force of the winds for most wind directions. Also the loss of the walkway roof would not, "ipso facto", prevent the functioning of Dr Bordonado's office.