CCRIF SPC

The Caribbean Catastrophe Risk Insurance Facility

A Collection of Papers and Expert Notes on

# DISASTER RISK FINANCING AND DISASTER RISK MANAGEMENT

...Highlighting academic papers prepared by a selection of CCRIF scholarship winners

**CCRIF TECHNICAL PAPER SERIES** VOLUME 4

October 2020

The papers presented in this publication do not represent the views or thinking of CCRIF SPC and are solely that of the authors

# MESSAGE FROM THE CHIEF EXECUTIVE OFFICER

I am pleased to present this fourth publication of technical papers, which highlights academic papers completed by recipients of CCRIF scholarships who have completed degrees in areas related to disaster risk management at The University of the West Indies and other universities in the United Kingdom. These scholarships are offered within CCRIF's larger Technical Assistance Programme, which is aimed at building capacity among key organizations as well as individuals and non-governmental organizations for improved disaster risk management in the Caribbean region.

CCRIF is committed to supporting the sharing of knowledge and experiences in disaster risk management through publications such as this. We believe it is important to share research and lessons learned within our Technical Assistance Programme among national ministries and agencies and regional organizations to create synergies and build on work done.

To further illustrate this sharing of information, this publication also includes a selection of expert notes which are in the form of speeches that were delivered at meetings and conferences addressing disaster risk financing within the context of disaster risk management and climate change. Throughout the years, members of the CCRIF management and team have participated in a range of events throughout the world, hosted by national governments and international development partners – as these entities seek to learn more about CCRIF and its products and services. We are pleased to share our experiences and insights into disaster risk financing that we have gained over the 13 years since CCRIF's inception in 2007. We hope that the expert notes included in this publication will help to deepen understanding of disaster risk financing – including CCRIF's parametric insurance – and how this can help governments reduce budget volatility in the aftermath of natural disasters.

**Isaac Anthony**
Chief Executive Officer

## Message from the
# CHAIRPERSON OF THE TECHNICAL ASSISTANCE COMMITTEE

This collection of papers highlights research conducted by nine recipients of CCRIF scholarships between 2010 and 2017. Begun in 2010, CCRIF's scholarship programmes form a key part of the Facility's Technical Assistance Programme, which aims to help Caribbean countries deepen their understanding of natural hazards and catastrophe risk, and the potential impacts of climate change on the region – and to develop solutions to improve resilience to natural hazards and climate change. The scholarship programmes are part of CCRIF's commitment to building capacity among the young people of the Caribbean, thereby developing the next generation of disaster risk specialists.

The student theses and papers included in this publication demonstrate the diversity of research topics undertaken by CCRIF scholarship recipients – which include social issues such as a discussion on whether disaster scenes should be "off-limits" to victims' relatives and climate and risk communication; an analysis of the financial services sector responses to climate change risks; and more technical discussions, such as seismic analysis and fragility assessment of reinforced concrete structures. We are pleased that the students have also brought the knowledge and skills obtained during their studies back to their work on returning to the Caribbean – at national meteorological agencies and ministries with responsibility for infrastructure and environment as well as institutions such as the UWI Seismic Research Centre.

This publication supplements CCRIF's 3rd Technical Series, *A Collection of Papers ... Showcasing the Work of CCRIF Scholarship Recipients 2010 – 2012*, published in 2014, which also focused on research conducted by other CCRIF scholarship recipients. We believe that the collective body of work conducted by these Caribbean students can inform other substantive research and initiatives in the region.

The CCRIF scholarship programmes are also complemented by an internship programme, which grants internships to recent university graduates, at organizations throughout the Caribbean, providing opportunities to extend their studies through experiential learning. Through both of these programmes, we believe that we are building a cadre of professionals who can play a key role in the future development of national and regional strategies that will lead to improved disaster risk management and increased climate change resilience.

**Desirée Cherebin**
Vice-Chairperson, CCRIF SPC
and Chairperson of the Technical Assistance Committee

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# INTRODUCTION

This publication – CCRIF's 4th Technical Papers Series – presents a collection of academic papers by Caribbean nationals who have received CCRIF scholarships to pursue study in areas related to disaster risk management, environmental management and civil engineering at The University of the West Indies and universities in the United Kingdom[1].

This publication also presents a selection of Expert Notes, in the form of speeches presented by members of the CCRIF Management and Team at regional and international fora, focusing on disaster risk financing.

The purpose of this Technical Papers Series is to share with our stakeholders some of the innovative research and ideas about disaster risk management, disaster risk financing and climate change – as well as the role that CCRIF and its parametric insurance policies can play in advancing sustainable development in the region.

***This book complements and builds on the first three Technical Series:***

***Volume 3:*** *A Collection of Papers … Showcasing the Work of CCRIF Scholarship Recipients 2010 – 2012. November 2014*

***Volume 2:*** *A Collection of Papers, Articles and Expert Notes. November 2011*

***Volume 1:*** *A Collection of Papers and Articles. November 2009*

***The publication includes the following sections:***

***Section 1:*** *Background information on CCRIF*

***Section 2:*** *The academic papers*

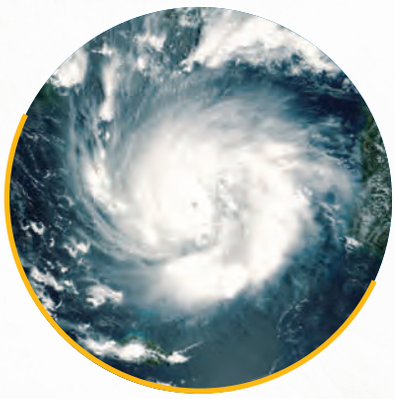
***Section 3:*** *The expert notes*

[1]CCRIF provides scholarships for study also at other universities in the Caribbean as well as universities in the USA and Canada.

SECTION 1

# BACKGROUND INFORMATION

# ABOUT **CCRIF**



In 2007, the Caribbean Catastrophe Risk Insurance Facility was formed as the first multi-country risk pool in the world, and was the first insurance instrument to successfully develop parametric policies backed by both traditional and capital markets. In 2014, the Facility was restructured into a segregated portfolio company (SPC) to facilitate offering new products and expansion into new geographic areas and is now named CCRIF SPC. It is owned, operated and registered in the Caribbean.

CCRIF SPC limits the financial impact of natural hazard events to Caribbean and Central American governments by quickly providing short-term liquidity when a policy is triggered. CCRIF offers parametric insurance policies for tropical cyclones, earthquakes, excess rainfall, fisheries and electric utilities, giving members the unique opportunity to purchase disaster risk insurance with lowest-possible pricing.

Since its inception CCRIF has made 45 payouts totalling over US$163 million to 14 member governments on their tropical cyclone, earthquake and/or excess rainfall policies.

CCRIF was developed under the technical leadership of the World Bank and with a grant from the Government of Japan. It was capitalized through contributions to a Multi-Donor Trust Fund (MDTF) by the Government of Canada, the European Union, the World Bank, the governments of the UK and France, the Caribbean Development Bank and the governments of Ireland and Bermuda, as well as through membership fees paid by participating governments.

In 2014, an MDTF was established by the World Bank to support the development of CCRIF SPC's new products for current and potential members, and facilitate the entry for Central American countries and additional Caribbean countries. The MDTF currently channels funds from various donors, including: Canada, through Global Affairs Canada; the United States, through the Department of the Treasury; the European Union, through the European Commission, and Germany, through the Federal Ministry for Economic Cooperation and Development and KfW. Additional financing has been provided by the Caribbean Development Bank, with resources provided by Mexico; the Government of Ireland; and the European Union through its Regional Resilience Building Facility managed by the Global Facility for Disaster Reduction and Recovery (GFDRR) and The World Bank.

***CCRIF currently has 23 members:***

**19 Caribbean governments** – Anguilla, Antigua & Barbuda, The Bahamas, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands, Dominica, Grenada, Haiti, Jamaica, Montserrat, St. Kitts & Nevis, Saint Lucia, Sint Maarten, St. Vincent & the Grenadines, Trinidad & Tobago, Turks & Caicos Islands

**3 Central American governments** – Guatemala, Nicaragua, Panama

**1 electric utility company** – ANGLEC

# CCRIF STRATEGIC **FRAMEWORK**

## VISION

- A resilient Caribbean region and beyond with optimized disaster risk management and climate change adaptation practices supporting long-term sustainable development.

## MISSION

- Our Mission is to assist member governments and their communities in understanding and reducing the socio-economic and environmental impacts of natural catastrophes.

- We do this by being a global exemplar in providing immediate liquidity through a range of affordable insurance products, developing innovative and dynamic tools and services, engaging in effective partnerships and operating in a way that is financially sustainable and responsive to the needs of the members.

## CORE VALUES

### CCRIF PROMISES TO:

- Fill a gap in available insurance offerings for natural catastrophes
- Ensure speedy payout when a policy is triggered
- Charge lowest possible premiums consistent with long-term sustainability
- Facilitate capacity building in disaster risk management and ex-ante risk financing
- Be transparent and accountable
- Be innovative and provide new products to meet the needs of our members

## STRATEGIC OBJECTIVES

- To provide products, services and tools responsive to the needs of members
- To enhance capacity for disaster risk management and climate change adaptation
- To sustain financial solvency and integrity
- To sustain corporate integrity
- To deepen our relationships with our member governments and to strengthen engagement with members
- To increase member coverage, expand membership and develop new products and services
- To expand and deepen strategic partnerships

# CCRIF TECHNICAL **ASSISTANCE PROGRAMME**

CCRIF has developed a Technical Assistance (TA) Programme for its Caribbean members to enable the Facility to achieve its mission ***of assisting member governments and their communities in understanding and reducing the socioeconomic and environmental impacts of natural catastrophes,*** while at the same time contributing to the long-term sustainability of the region.

Under the TA Programme, CCRIF supports member countries, regional organizations, non-governmental organizations and academic institutions to develop and implement disaster risk management projects and programmes and also implements capacity building initiatives. Since the launch of the Technical Assistance Programme in 2010, CCRIF has provided US$3.7 million to support disaster risk management efforts in the region.


The TA Programme has three components:

- **Component 1** focuses on support for tertiary level scholarships and professional development programmes, which include an internship programme designed to provide opportunities for recent university graduates who have studied in areas such as disaster risk management, environmental management, actuarial science, geography, and climate studies to be assigned to national and regional organizations where their educational experience can be enhanced through practical work assignments.
- **Component 2** focuses on regional knowledge building and involves the development and implementation, in collaboration with regional partner organizations, of strategic regional projects in support of disaster risk management.
- **Component 3** is centred on support for local disaster risk reduction projects and programmes, implemented by non-governmental organizations, community organizations, and academic institutions.

Under the TA Programme, CCRIF has among other things:

- Awarded approximately 100 scholarships totalling over US$1.2 million to Caribbean nationals
- Placed 103 interns at 28 host organizations, with an investment of over US$300,000 through the CCRIF Regional Internship Programme

- Provided 16 grants totalling over US$400,000 to 8 NGOs and 2 departments at The University of the West Indies to implement disaster risk reduction activities through the CCRIF Small Grants Programme
- Established strategic alliances with key regional organizations and donors through the signing of MoUs and other mechanisms, which are aimed at developing programmes and other initiatives to reduce existing vulnerabilities in the small island and coastal states of the region. Partner organizations include the Caribbean Disaster Emergency Management Agency, Caribbean Institute for Meteorology and Hydrology, UN Economic Commission for Latin America and the Caribbean, Caribbean Community Climate Change Centre, Organisation of Eastern Caribbean States, Association of Caribbean States and The University of the West Indies, among others.

This publication focuses on CCRIF's scholarship programmes, which are designed to help create a cadre of professionals who will become leaders in facilitating improved disaster risk management and climate change adaptation strategies and initiatives. Through two scholarship programmes, CCRIF provides scholarships to Caribbean nationals to pursue studies in areas related to disaster risk management at universities in the Caribbean (including but not limited to The University of the West Indies) as well as the UK, USA and Canada.

Recipients of CCRIF scholarships are employed at a range of institutions such as the Caribbean Institute for Meteorology and Hydrology, UWI Seismic Research Centre, and the National Conservation Trust Fund of Jamaica, as well as national meteorological and disaster management agencies, and work in the fields of environmental risk management, environmental engineering, disaster/emergency response, national planning, climate change policy, sustainable development and meteorology.

SECTION 2

# ACADEMIC PAPERS

# LIST OF
# ACADEMIC PAPERS AND AUTHORS

## Papers about **Disaster Risk Management**

***A Preliminary Natural Hazards Vulnerability Assessment of the Norman Manley International Airport (Jamaica) and its Access Route***

### Author
**Kevin Douglas – Jamaica**
MSc Disaster Management
The University of the West Indies, Mona

Kevin Douglas works at the Jamaica Red Cross as a project Manager of the Resilient Islands by Design Project, which focuses on integrating ecosystem- and community-based approaches to enhance climate change adaptation and disaster resilience in vulnerable coastal communities. Previously, he worked as a Climate Change and Disaster Risk Management Training Officer at the Office of Disaster Preparedness and Emergency Management in a project funded by the Adaptation Fund and focused on building climate resilience of tourism interests, fishers and coastal communities. Also, he was the Natural Resources Manager of the USAID-funded Jamaica Rural Economy and Ecosystems Adapting to Climate Change (Ja REEACH II) Project. ***Mr. Douglas received a CCRIF scholarship to pursue an MSc in Disaster Management at The University of the West Indies, Mona.***

***Seismic Analysis and Fragility Assessment of Reinforced Concrete Structures through Numerical Modelling***

### Author
**Cory George – Trinidad and Tobago**
MSc Earthquake Engineering with Disaster Management
University College London

Cory George is a Research Earthquake Engineer at The University of the West Indies Seismic Research Centre, St. Augustine, Trinidad and Tobago. Currently, Mr. George is involved with the Trinidad and Tobago Seismic Microzonation project which entails identifying the seismic hazard, i.e. ground shaking and liquefaction susceptibility, at different locations within the country and the Caribbean. It provides the basis for site-specific risk analysis, which assists in mitigating earthquake damage. ***Mr. George received a CCRIF scholarship to pursue an MSc in Earthquake Engineering with Disaster Management at University College London.***

***Barriers to Flood Mitigation Among Households In St. Mary, Jamaica***


## Author

**Sean Hylton – Jamaica**

MSc Sustainability (Environment and Development)
University of Leeds


Sean Hylton from Jamaica is an Urban and Regional Planner. He has worked at The St. Mary Municipal Corporation as Physical Planning Coordinator, Parish Coordinator – Disaster Preparedness, Planning Technologist and Director of Planning. Currently, he is seconded to the Office of the Prime Minister in the post of Development Analyst (Acting). ***Mr. Hylton received a CCRIF scholarship to pursue an MSc in Sustainability (Environment and Development) at the University of Leeds.***

***Flood Risk Perception, Risk Communication and Flood Management in the Commonwealth of Dominica: A case study of Coulibistrie***


## Author

**Viola Pascal – Jamaica**

MSc Risk, Crisis & Disaster Management
University of Leicester


Viola Pascal is a Weather Forecaster at the Dominica Meteorological Service (DMS). Previously, she worked as a forecaster at the Jamaica Meteorological Service, providing weather products to the general public and the aviation industry. Her current focus is on enhancing the early warning platform of the DMS through increasing the forecast and warning products available to the public. She has also done collaborative work with the Office of Disaster Management where the focus was on increasing public awareness on natural hazards that affect Dominica. ***Mrs. Pascal received a CCRIF scholarship to pursue an MSc in Risk, Crisis and Disaster Management at the University of Leicester.***

***Discussion: For reasons of taste and decency and to speed investigation, disaster scenes should be "off-limits" to victims' relatives***

## Author

**Renata Philogene-McKie – Saint Lucia**
MSc Risk, Crisis & Disaster Management
University of Leicester

Renata Philogene-McKie is a Civil Engineer with the Ministry of Infrastructure, Ports, Energy and Labour in Saint Lucia. She has acquired extensive experience in the areas of civil engineering and project supervision. As the Projects Coordinator for the Special Projects Unit within the Ministry's Technical Department, she oversees the implementation of several externally funded projects such as the Millennium Highway and West Coast Road Upgrading project funded by the United Kingdom Caribbean Infrastructure Fund. A certified facilitator in Damage Assessment and Needs Analysis (DANA) and Initial Damage Assessment (IDA), she is highly involved in disaster risk management. ***Mrs. Philogene-McKie received a CCRIF scholarship to pursue an MSc in Risk, Crisis & Disaster Management at the University of Leicester.***

***A Flood Vulnerability Assessment for the Downtown Port of Spain Area, Trinidad, W.I.***

## Author

**Gerarda Ramcharansingh – Trinidad and Tobago**
MSc Disaster Management
The University of the West Indies, Mona

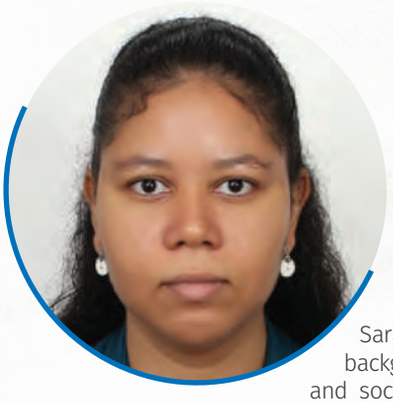
Gerarda Ramcharansingh is a Geography teacher at Naparima Girls' High School in Trinidad. Prior to that she was the Hazard Mitigation Specialist at the Office of Disaster Preparedness and Management (ODPM), the coordinating agency for disaster risk reduction in Trinidad and Tobago. Gerarda has also worked with key stakeholders in the disaster risk management arena to effect change in the behaviour of those tasked with managing disaster risk. ***Ms. Ramcharansingh received a CCRIF scholarship to pursue an MSc in Disaster Management at The University of the West Indies, Mona.***

## Papers about **Climate Change Adaptation**

***Analysis of the Financial Services Sector Responses to Climate Change Risks in Antigua***

**Author**
**Delamine Andrew – Antigua and Barbuda**
MSc Sustainable Development (Climate Change & Risk Management)
University of Exeter

Delamine Andrew is the Senior Projects Officer at the National Office of Disaster Services (NODS) in Antigua and Barbuda. After receiving a BA (Hons) in Town and Country Planning from the University of Oxford Brookes, she joined the Department of Environment within the Government of Antigua and Barbuda in 2010 as a Senior Environment Officer. Following the successful completion of an MSc (merit) in Climate Change and Risk Management at the University of Exeter, Ms. Andrew joined NODS and is currently the technical lead and focal point on developing and executing disaster risk management projects within Antigua and Barbuda. ***Ms. Andrew received a CCRIF scholarship to pursue an MSc in Sustainable Development (Climate Change & Risk Management) at the University of Exeter.***



***Effective Communication for Climate Information Services: A Jamaican Case Study Assessment Using Perspectives from Multi-End-User Stakeholder Feedback***

**Author**
**Sarah Buckland – Jamaica**
BSc in Geography
The University of the West Indies, Mona

Sarah Buckland from Jamaica is an interdisciplinary researcher with a background spanning Bible evidences, language studies and the environmental and social sciences. Sarah is presently a PhD candidate in the Department of Geography and Geology, UWI Mona, where her research explores entry points for drought risk reduction in crop production systems across Clarendon, Jamaica, one of the country's most intensive and expanding agricultural regions. Ms. Buckland's academic work has received recognition through the Prime Minister's National Youth Award for Excellence in Academics (2017) and UWI's Postgraduate Wall of Excellence (UWI Research Days, 2018). ***Ms. Buckland received a CCRIF scholarship to complete a BSc in Geography at The University of the West Indies, Mona.***

***Temperature Susceptibility of Asphalt Binders for Climate Change***

## Author

**Kellesia Tricia Williams – Barbados**

BSc in Civil with Environmental Engineering
The University of the West Indies, St. Augustine

Kellesia Tricia Williams is a postgraduate student at the Centre for Resource Management and Environmental Studies, The University of the West Indies, Cave Hill, Barbados with specialisation in Water Res ources Management. She holds a BSc degree in Civil with Environmental Engineering from The University of the West Indies, St. Augustine. Her interests lie in evaluation of critical interdependent relationships between the natural and built environment, including but not limited to water, wastewater and pavement management and design. ***Ms. Williams received a CCRIF scholarship to complete a BSc in Civil with Environmental Engineering at The University of the West Indies, St. Augustine.***

# A Preliminary Natural Hazards Vulnerability Assessment of the Norman Manley International Airport and its Access Route

*By Kevin Douglas*

This thesis paper was written as the final evaluation for the MSc Programme in Disaster Risk Management at the University of the West Indies Mona – 2012

## Introduction

The Norman Manley International Airport (NMIA), Jamaica's second largest international airport, located in the capital city of Kingston and its single access route, may be vulnerable to a number of natural hazards, primarily based on their location. These hazards, if not carefully analyzed and effectively mitigated against, may result in restricted access, serious structural damage and loss of lives at this facility which holds a place of significant social and economic importance to Kingston and the country at large.

Jamaica, like many other countries in the Caribbean, due to its geology, topography and geographic position is subject to multiple hazards; these include earthquakes, landslides, hurricanes and flooding (Ahmad and Mason, 2005). Also the on-shore and off -shore geologic-tectonic geophysical framework, common to Caribbean nations by their geographic location within the boundaries of the Caribbean Plate, affects the distribution of geologic and hydrologic hazards (Ahmad, 1992)

These hazards which may occur independently or trigger other events can result in severe disruptions and reduce development by causing damage to vital socio-economic entities such as the NMIA.

The Coastal location of the NMIA on an Alluvial Fan deposited by the Hope River makes it vulnerable to a number of natural hazards, primarily earthquakes, hurricanes and storm surge flooding. Changes due to Climate Change may also have negative impacts on the structure and operation of the NMIA, as well as on the single road entrance and exit from the facility.

The NMIA's vulnerability to earthquakes is enhanced by its location. Between 1677 and 1993, seventeen earthquakes, with all except three (3) having Maximum Mercali Intensity (MMI) of V or above have affected the Port Royal and Palisadoes area (Ahmad and Mason, 2005). These earthquakes and their various effects have resulted in considerable damage to the area and the potential exists for future events to cause serious damage to the NMIA.

The area which comprises the NMIA has also been affected by hurricane winds and flooding from storm surges, notably during Hurricane Ivan in 2004 which led to serious damage to the only road network access to the NMIA. Accordingly, the infrastructure and operations of the airport are vulnerable to these hazards. The impact of rising sea levels resulting from climate change also has serious implications for the continued operation of the NMIA as the entity, particularly its runways and taxiways, may be affected.

This study therefore seeks to undertake an analysis of the vulnerability of the NMIA and its access route to natural hazards by focusing on their hazard history and location, critical facilities as well as mitigation measures which have been or may be put in place. While studies have been done on hazard vulnerability of the Kingston area by the Unit for Disaster Studies, UWI Mona and others, specific focus and research on the Norman Manley International Airport is needed, given its high value as a social and economic hub to Kingston. The economic fallout and domino effect which could result from lack of access or serious damage or disruption of normal operations at this facility would have a negative impact on the entire country.

This study is a preliminary one and may also serve as a platform for more in depth and extensive analyses and a possible detailed risk assessment of the NMIA and its access route to the various natural processes.

## Conceptual Framework

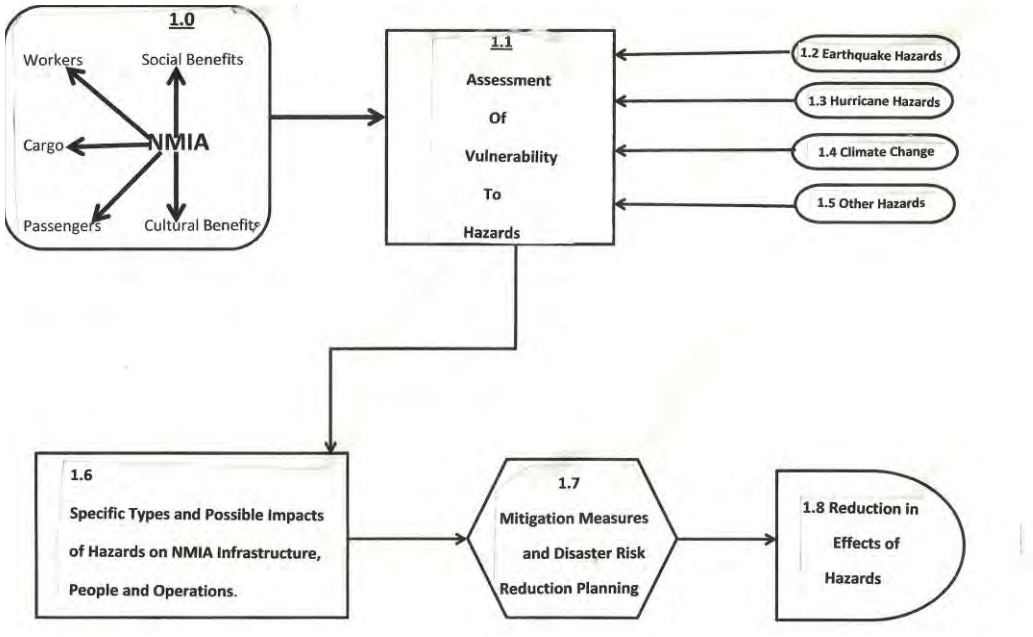



*Figure 1: Conceptual Framework Diagram*

As shown in Figure 1, sections in this paper:

- Highlight the Norman Manley International Airport (NMIA), an entity of tremendous social, economic and cultural significance to the capital city of Kingston and Jamaica in general, as it is the main entrance and exit point for passengers in the central and eastern sections of Jamaica, and is the main handler for air cargo in the island.
- Illustrate what the research will seek to undertake, which is a hazard vulnerability assessment of this very important entity, including an assessment of its disaster plan of action.
- Highlight some of the major hazards which the NMIA may be vulnerable to based on its location and other natural or anthropogenic factors.
- Present data on hazard vulnerability, which will be gathered from a variety of primary and secondary sources and will be analyzed and critiqued so as to provide a hazard profile for the Norman Manley International Airport.
- Present the analysis of the collected data will aim to provide the specific types and impacts of natural hazards to which the NMIA is vulnerable, with specific attempts to analyze past and future effects on its infrastructure, people and operations.
- Provide information that will assist the relevant authorities to develop, assess or retrofit their disaster plan or mitigation measures to reduce the risk of the NMIA to the effects of natural hazards.

## Study Area (Regional, National and Localized Setting)

The study area encompassed a strip of approximately 3.5 km from Harbour View roundabout to the main study site, the Norman Manley International Airport.


*Figure 2: Google Map Showing Study Area (Adopted from Google Earth)*


*Figure 3: Google Map of Jamaica showing study area (Adopted from Google Earth)*

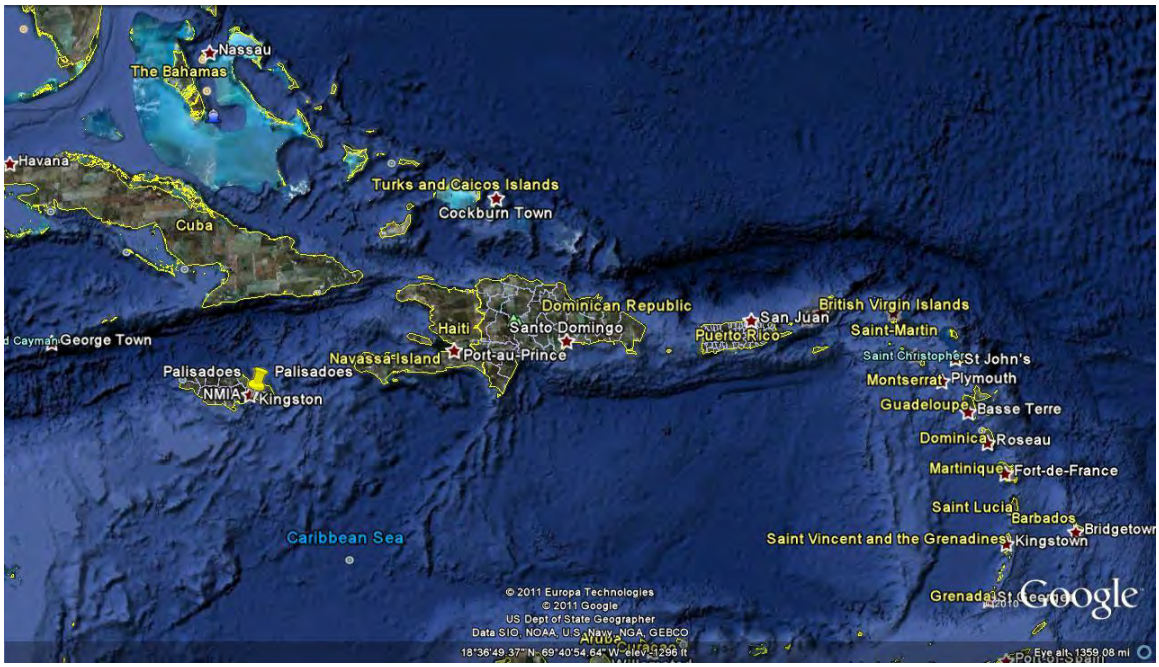



*Figure 4: Google Map Showing Regional Location of Jamaica in the Caribbean (Adopted from Google Earth)*

## Research Aim and Objectives

### *Aim*

To investigate the vulnerability of the Norman Manley International Airport and its access route to Natural Hazards and analyze mitigation measures which have been put in place.

### *Objectives*

- To investigate which natural hazards have affected the Norman Manley International Airport and access route in the past and their impacts
- To determine the natural hazards to which the Airport and access route are now most vulnerable
- To examine the disaster plans and mitigation measures that have been or may be implemented to deal with effects of natural hazards

### Research Question

What hazards are the NMIA and access route most vulnerable to based on their history, location and coping strategies (safety mechanisms)?

### Research Limitations

The research is a preliminary one and therefore has a number of limitations. One major limitation is the absence of an in depth multi-hazard vulnerability assessment, due to the limited time and resources on the part of the researcher to undertake such. In depth and detailed hazard assessments normally require a multidisciplinary team of experts and involves the generation of hazard vulnerability zonal maps. These would have provided more accurate prediction capabilities, as well as more effective mitigation strategies.

Therefore in the limited time available, the researcher conducted an analysis based on the hazard history, physical characteristics and location of entities, as well as the hazard preparedness levels. In future research of this nature, a team of experts may be gathered and provided with enough funding and expertise to undertake the ventures that this study could not.

Finally, an analysis of the disaster knowledge and attitudes of the stakeholders (management, workers and users) of the NMIA would assist in highlighting possible preparedness gaps and advise on training and education programmes if needed. This research was unable to undertake such a survey.

## Literature Review

The discipline of Natural Hazards Vulnerability Assessment is of paramount importance for the Caribbean Region, including Jamaica, as it has the potential to significantly reduce damages from the effects of natural hazards, as better planning and mitigation measures may be put in place based on these assessments. This is especially important in areas which, based on their location and other factors are considered by experts to be highly vulnerable to natural hazards, such as the Palisadoes area in Kingston, Jamaica. Developing states like Jamaica whose economic progress is constantly threatened by natural disasters, must allow disaster mitigation to form the basis on which growth options are selected and development plans generated (Ford 1996). The issue of determining the level of vulnerability in various locations is important as this information may be used to identify the most feasible growth options based on the physical factors that exist. This determination is arrived at by hazard vulnerability assessments, which allow disaster mitigation to spearhead the development process, rather than simply being an input during implementation. In addition to countrywide assessments, hazard vulnerability assessments of important sources of economic livelihood (direct and indirect), such as the NMIA have been supported in research by Twigg, 2001, who recognized an important link between the levels of livelihood security and levels of vulnerability to disasters, and that ensuring livelihood security is an integral component of any sustainable disaster mitigation measures.

Disaster risk reduction is important to Jamaica as the country has been affected by several major disasters such as the Port Royal Earthquake of 1692 and Kingston 1907, Hurricanes Gilbert and Ivan in 1988 and 2004 respectively. Regionally over the period 1846 to 1978, 34% of all recorded disasters took place in the Latin America- Caribbean (Jovel, 1982).

Both the global and Caribbean emphasis on disaster risk reduction, including hazard vulnerability assessments began in the 1980s. Prior to this period, disasters were regarded as one- off events caused by natural forces which were responded to by governments and relief agencies after they occurred (Yodmani, 2000). However as the impact of disaster events increased, it was realized that a more proactive approach was needed. On December 11, 1987 at its 42$^{nd}$ session, the General Assembly of the United Nations designated the 1990s as the International Decade for the Natural Disasters Reduction (IDNDR). The major objective of the decade was to reduce the loss of life, property damage and socio - economic disruptions caused by natural disasters. One major goal of the decade was the improvement of the capacity, of especially developing countries to lessen the effects of natural disasters by enhancing measures for the assessment of disaster damage potential, as well as the prediction, prevention and

mitigation of hazard events (www.unisdr.org). In the early 1980s the Caribbean also established a regional effort to improve disaster preparedness in the region by the implementation of the Pan Caribbean Disaster Preparedness and Prevention Project (PCDPPP), which was designed as a short term project but which ran for 10 years until 1991.

The global focus on disaster risk reduction and vulnerability assessment continued with a mid-90s review of the IDNDR, which brought about the 1994 Yokohama Strategy and Plan of Action for a safer World, which placed more emphasis on risk assessment as a required step for adequate disaster risk reduction. In 1999 the United Nations International Strategy for Disaster Reduction (UNISDR) was created, which is a secretariat set up to guide and coordinated efforts to achieve reduction in disaster losses and serve as a focal point for the Hyogo Framework for Action (HFA).

In 2005 the United Nations adopted the Hyogo Framework for Action (HFA): Building the resilience of nations and communities to disasters, which is a 10 year plan with the goal of sustainably reducing disaster losses, including loss of lives and social, economic and environmental assets by 2015 (www.unisdr.org). A major step in achieving this reduction as set out by the HFA is the focus of this research, the effective undertaking of hazard vulnerability assessments.

The early to mid-90s into the 21st century also saw remarkable advances in the Caribbean in disaster risk reduction policy and measures, including an increased focus on vulnerability assessments. In 1991 the Caribbean Disaster Emergency Response Agency (CDERA) was formed, which was changed in 2009 to the Caribbean Disaster Emergency Management Agency (CDEMA) to more fully embrace the concept of comprehensive disaster management (CDM), which is an integrated and proactive approach to disaster management (www.cdema.org). The Comprehensive Disaster Management Framework emerged in the Caribbean in 2001 and was re-articulated in 2007 as the Enhanced CDM Strategy with outcomes to strengthen regional and national capacity for mitigation, management and response to disaster events. Jamaica also saw the change from ODIPERC to the Office of Disaster Preparedness and Emergency Management (ODPEM) in 1993.

The global and Caribbean journey from post disaster response to proactive disaster risk reduction, of which hazard vulnerability assessments are a major part, provides the foundation for research undertaken in the area of hazard vulnerability assessments. However, while the importance of these assessments has been underlined by documents such as the HFA and Enhanced CDM, these documents do not explain or prescribe how to conduct these assessments or provide best or worst practices in this regard.

There have been various studies carried out within the area of hazard vulnerability assessment which were found relevant to this research, such as in the area of methodology, which proved beneficial to this study. The vulnerability of the area containing the NMIA and its access route, the main factor which underscores the importance of hazard vulnerability studies, is highlighted by Ahmad 2011 whose work states that Harbour View and the Palisadoes area are located on the Hope River Alluvial Fan and are subject to a number of hazards, including hurricane- storm surge, flooding, earthquakes-tsunamis and liquefaction. Ahmad and Mason, 2005 quoting from Shepherd (1975. 35) state that from the point of view of a seismologist, the parishes of Kingston and St. Andrew were probably the worst locations to put the capital city.

The methodologies used to gather data for the purpose of hazard vulnerability assessments were found to be similar among researchers and this study has sought to compile these methods in an effort to formulate its own methodology. One of the first steps in vulnerability assessment is the gathering of historical hazard events. Ahmad and Mason (2005) and Harris and Green (2008) relied on published records, including aerial photographic interpretations to analyze the effects of past hazard events. Carter (1984) and Harris and Green (2008) were also similar in the methodology and sources of information to carry out hazard vulnerability assessments.

Carter (1984) declared that much of the information needed for a hazard vulnerability assessment is available from local sources, for example national records, past experiences as recorded or noted by organizations and individuals and publications from previous studies. Some of these sources, which were used by Harris and Green (2008), include comprehensive interviews with individuals who experienced past events, anecdotal evidence, any organizational records as well as any available analysis of risk or vulnerability. These sources and data gathering techniques were also employed as a part of the methods of data collection in this research, to assist in the hazard vulnerability analysis of the NMIA and its access route.

Carter (1984) recommended the creation of a Disaster Threat Matrix based on the data collected under the headings: Types of threats, damage threatened, consequences, preventative measures. The approach of a threat matrix was modified and used to classify the threat posed to the critical facilities of the NMIA and its access route (may be seen in appendix 2). In the Caribbean, like many other areas, the field and practice of hazard vulnerability assessments receives large contributions from multilateral entities and non-governmental organization, prominent among these are the Organization of American States (OAS) and the United States Agency for International Development (USAID).

The OAS spearheads vulnerability assessments for entire countries, as in the cases of St. Kitts and Nevis or for particular sections of countries, such as the seismic hazard vulnerability assessment of Kingston, Jamaica. St. Kitts and Nevis' Hazard vulnerability Assessment: Final Report 2001 was found to be similar in many respects to a hazard assessment of Islamabad, Pakistan undertaken by the Asian Disaster Preparedness Centre in 2005. Both studies emphasized the importance of investigating the hazard history of the areas, as well as the identification of critical resources and facilities. The generation of hazard vulnerability maps was also a critical part of the assessment process in both studies and therefore any assessment study without such maps may be considered as preliminary. However a hazard vulnerability study of the Palisadoes by Robinson and Rowe 2005 focused on the location, formation and hazard history of the area and sought to make predictions on possible impacts of specific hazards, without the generation of hazard vulnerability maps.

However a major gap or omission in these two and many other comprehensive hazard vulnerability assessments, is the assessment of the disaster knowledge, mental readiness or social structure of the people who occupy or use these areas. A very knowledgeable, well organized and cohesive society armed with information on how to respond before, during and after hazard events may be a major factor in reducing vulnerability of the inhabitants and possible loss of lives (Twigg, 2001). Therefore, incorporating a social survey in hazard vulnerability analyses should be considered in future studies, as it can improve the overall picture of vulnerability, as well as provide an avenue to glean information that may be used in devising both structural and non-structural mitigation measures, as local knowledge if often very valuable.

The structural assessments of buildings to natural hazards have also occupied a central place in the literature and practice of hazard vulnerability assessments. Research conducted under the Caribbean Hazard Mitigation Capacity Building Program (CHAMP) 2004, a partnership project between CIDA, OAS and CDEMA highlights the fact that building practices and resilience are critical factors in determining vulnerability to hazards. Therefore structural assessment projects were undertaken mainly in the Eastern Caribbean and were limited to schools, shelters and governmental buildings. In addition to the non- extension of the CHAMP Structural assessment programme to Jamaica, the assessments did not focus on entities that were not used as disaster shelters, but may have tremendous potential to disrupt the lives and livelihoods of thousands of people if damaged by disaster events, such as the NMIA in Kingston, Jamaica. If the livelihoods of people are disrupted, then the recovery process from disasters will be slower.

Hazard Assessments Research on the Palisadoes has been conducted by Professor Edward Robinson, Rafi Ahmad from the Unit for Disaster Studies, UWI Mona among others. However given the importance of

the Norman Manley International Airport, a hazard vulnerability analysis for that facility would provide for better risk reduction planning and the implementation of mitigation measures to deal with the effects of hazards.

## Research Rationale and Methodology of Data Collection

### Research Rationale

The last few decades have seen an exponential increase in human and material losses from disaster events, without any clear indication of an increase in extreme hazard events (Yodmani, 2000). This indicates an increase in the vulnerability of people and important economic entities and sources of livelihood. This realization of an increase in vulnerability has led a global, as well as Caribbean emphasis on Disaster Risk Reduction and a move away from simply responding after disasters occur. The global community emphasized the reality of the need for collective understanding of vulnerabilities, in order to reduce disaster risks.

The Hyogo Framework for Action (HFA) 2005- 2015 represents the premier global effort in disaster risk reduction, as its main goal is to build resilience of nations and communities to disasters. A vulnerability analysis of an important economic resource such as the NMIA directly ties in to particularly Priorities 2 and 4 of the HFA. Priority 2 of the HFA is to "Identify, assess and monitor disaster risks and enhance early warning". This priority emphasizes that knowledge of the hazards, as well as of the physical, social, economic and environmental vulnerabilities faced by a community or large scale entity such as the NMIA is critical to reducing disaster risks, hence hazard identification and analysis are critical.

Priority 4 of the HFA is to reduce underlying risk factors, by analyzing and preparing for the hazards associated with geologic events, weather and climate change. This research aims to provide such information to assist in such a reduction for the NMIA and its access route, which are important sources of livelihoods and economic benefit. The Caribbean, including Jamaica has also recognized the importance of reducing disaster risk, evidenced mainly by the adoption of the Enhanced Comprehensive Disaster Management Framework 2007-2012, in which the third of four outcomes is the mainstreaming of disaster risk management at national levels and its incorporation into key sectors of national economies, such as tourism and agriculture. The NMIA and its access route hold places of critical economic importance, especially to Jamaica's capital and failure to properly identify, assess and mitigate against natural hazards may have serious adverse consequences for the city and the livelihoods of thousands of Jamaicans. Hence the following methodological processes were employed to assist in this objective.

The method of vulnerability analysis employed was a modified adaptation of the Community Vulnerability Assessment Tool ( CVAT), which is a risk and vulnerability assessment methodology designed by the National Oceanic and Atmospheric Administration's (NOAA) Coastal Services Centre to assist planners and emergency workers in reducing hazard vulnerability through hazard mitigation measures. The CVAT has attained global recognition as a vulnerability assessment tool and hence was seen as a viable method to be applied in this research.

### Method of Data Collection

The preliminary hazard vulnerability assessment project of the Norman Manley International Airport and its access route consisted of the following stages:

1. Hazard Identification and Prioritization
2. Basic Hazard Analysis and Identification and Assessment of Critical Facilities
3. Mitigation Measures Assessment

#### *Hazard Identification and Prioritization Process*

This process involved the identification of the hazards to which the NMIA and its access route are most vulnerable and the ones that will be evaluated in this project. This was done mainly by an investigation of the hazard history of the NMIA and the Palisadoes, as in most cases the hazards that affect an area in the

past are more likely to impact the same area in the future. The qualitative approaches of document analysis and in-depth interviews were the main tools employed in the hazard identification process, and hazards were prioritized based on frequency and likelihood of occurrence. The published records of past hazard events, including newspaper reports and journal articles were consulted, as well as visits to the Library of the Office of Disaster Preparedness and Emergency Management (ODPEM).

Documentary evidence was also sought at the University of the West Indies': Physics Department, Earthquake Unit, Unit for Disaster Studies, Department of Geography and Geology and the Disaster Risk Reduction Centre. Hazard Maps of the Kingston Metropolitan Area and Palisadoes were also consulted to identify and prioritize hazards.

Anecdotal accounts were secured through interviews with long serving employees of the NMIA. In depth interviews were chosen as they would provide a wealthier body of knowledge, in comparison to questionnaires.

***Identified Hazards***

These investigations produced five hazards which pose some threat to the NMIA and are organized in order of priority, based on frequency and impact of past events, magnitude and damage potential of such hazards:

- Flooding (mainly of single access route to NMIA)
- Storm Surges
- Wind/Hurricanes
- Earthquakes (Shaking, Liquefaction, Tsunami)
- Climate Change (Sea level rise)

***Basic Hazard Analysis and Identification and Assessment of Critical Facilities***

In most hazard vulnerability studies, the hazard analysis process usually involves the study of the area or facility by a team of hazard experts and the generation of hazard vulnerability zone maps. However, these capabilities and time required were unavailable for this investigation and therefore a more basic approach was taken. The location and physical characteristics of the Palisadoes area and the NMIA were examined and the threat potential for the hazards identified analyzed. A Hazard/ Disaster Threat Matrix was also generated (Appendix 2).

The process of identifying the facilities and resources for assessment consisted of the creation of a critical inventory, as well as the collection of data and basic vulnerability assessments of these areas to specific hazards. The facilities on the NMIA to be considered were arrived at, through the examination of similar research projects and consultations with a local hazard vulnerability analysis and disaster management expert (Mr. Keith Ford). Facilities and resources that are essential to effective day to day operations of the NMIA which would be of paramount importance before, during and after a hazard impact were considered critical. The Critical Facilities were defined as follows:

- Jamaica Meteorological Service Station
- Air Traffic Control Base and Equipment
- Aircraft Runway and Taxiway
- Power Plant/ Fuel Storage Facilities
- Fire Station and Equipment
- Medical Station
- Police Station

The critical facilities were assessed in terms of damage history, operational vulnerability as well as location and structural vulnerability to relevant hazards identified. A major tool of data collection was the use of personal in detailed interviews with senior personnel or the head of each of these critical facilities,

as well as key management officials. It was thought that the head or senior personnel could provide more detailed and accurate information and would have the greatest policy and operational knowledge to assist in the assessment of each facility.

***Mitigation Measures Assessment***

This phase consisted of a critical analysis of the hazard mitigation measures put in place by the NMIA and relevant authorities. Thin included a look at the successes or failures of these measures in past hazard events, as well as potential weaknesses of these measures and the making recommendations for improvements. Interviews were carried out with key NMIA management staff and pertinent documents examined, such as emergency procedures for specific hazards.

***Format of Assessment***

The assessment considered each hazard, the features and facilities that are most vulnerable and the underlying reasons for their vulnerability to the hazard. The vulnerability assessment method for each hazard is outlined at the beginning of each chapter. The mitigation measures in place or lack thereof were also assessed for each hazard. The disaster knowledge and readiness of the NMIA staff were also assessed for the relevant hazards

## Social and Economic Importance of NMIA and Access Route

### Socio-Economic Importance of NMIA and Access Route

The Norman Manley International Airport (NMIA) which has been dubbed by the Airport's Authority of Jamaica as the "the Gateway to the World", which connects the capital city to destinations worldwide, is of extreme social and economic importance to Kingston, as well as the country at large. The Palisadoes road, which is the only access route to the NMIA, is also of critical importance. The livelihoods of thousands of Jamaicans are directly or indirectly tied to the operations of the NMIA and therefore any significant disruptions in its normal functions and operations, as well as any serious damage to its single access route may have tremendous adverse socio- economic consequences.

The NMIA is located on 228 hectares of the Palisadoes Peninsula, adjacent to the Kingston Harbour and is approximately thirty minutes away from the main business district of New Kingston (www.airporttechnology.com). The NMIA is a major economic catalyst for the Kingston Metropolitan Region (KMR), which according to the NMIA's website www.nmia.aero.com has economic activity valued at $J 15.2 Billion or 5.6% of Jamaica's Gross Domestic Product (GDP). In 2008, the passenger movement through the NMIA totaled 1.7 million and freight weight was 16.8 million kilograms, which is 70% of Jamaica's total air freight weight. The average daily passengers and flight numbers were 4685 and 67 respectively. The airport is expected to annually handle 1.9 million passengers by 2013 and 2.5 million by 2022 (www.airporttechnology.com).

The NMIA, according to its website, has a business network of over 70 companies and government agencies with over 3500 persons directly employed to the airport and another 8000 persons benefiting from indirect employment. Some of the direct employment at the NMIA comes from its over 30 shops, airline employees, as well as hundreds of government workers among others.

### Significance to Tourism and Business

Tourism is one of Jamaica's most potent earners of foreign exchange and the Jamaica Tourist Board and Tourism officials have been making an effort to diversify tourist attractions and offerings. A major initiative to achieving this end is the increased promotion of Kingston and the eastern end of Jamaica, particularly Portland as the cultural and high-end eco-tourism centres of the island respectively. The NMIA is absolutely crucial to this tourism expansion plan, as it is the main avenue of arrivals and departures to these areas. In 2010, the Ian Flemming International Airport was opened, however the capacity of this facility is inadequate to accommodate the desired tourist and flight numbers.

The NMIA is also the main gateway for business travelers into Jamaica, as according to Immigration statistics, the majority of non-nationals who arrive at the NMIA are business travellers, compared to the

Sangster's International airport in Montego Bay at which most non-nationals arrive mainly for the purpose of leisure. Therefore a significant number of guests at the major hotels in Kingston (Pegasus, Wyndham, Courtleigh, Knutsford Court, Spanish Court, Terra Nova, Morgan's Harbour and Hotel Four Seasons) are overseas business travellers who mostly arrive through the NMIA. The economic spin-offs from these guests are significant, through the employment of taxi operators, vendors, entertainment spots, and hotel staff among others. This highlights the extent of the number of livelihoods which are tied to the NMIA and the number of persons that would be adversely affected should any serious disaster damage occur, which prevents access or normal operations of the NMIA for any considerable period of time.

Also if the air freight handling capacity of the NMIA (almost 17 million kg/year) is adversely affected by a disaster event, it could result in serious negative economic consequences. This would probably lead to more air freight being shifted to the Sangster's International Airport (SIA) in Montego Bay, which could have two serious economic consequences:

1) The SIA may be unable to handle the entire additional freight load, which would lead to the country losing income, as well as employment, such as in reduced handlers and local ground courier services among others.

2) There would be significant increases in transportation costs to move freighted goods into Kingston from Montego Bay by road, which could result in these costs being passed on to local consumers.

### Socio-Cultural Significance of NMIA

The socio-cultural value of the NMIA is also of extreme importance as it provides the main portal of cultural exchange between Jamaica's capital and the world, as arrivals and departures by sea are mostly limited to commercial vessels. Therefore without a full access and operational viability of the NMIA, Kingston's many cultural spots and activities may go unsupported by the Jamaican Diaspora and foreigners alike, as it would prove expensive and sometimes impractical to travel from Montego Bay into Kingston. Some of these activities include international sporting activities such as football, cricket and track and field events in addition to other cultural showcases such as Caribbean Fashion Week and music festivals. The NMIA is in essence the door through which the world experiences the culture of Jamaica's capital city.

### NMIA's Role in Relief and Response

The NMIA has played a significant role in emergency response and recovery after disaster events in the past by being one of the main portals through which aid relief entered the island. The NMIA also played a critical role in emergency response in Haiti after the January 12, 2010 earthquake by being the main hub and launching pad for aid storage and flights from North America to Haiti, particularly the Canadian and US Air Force.

Therefore with such a significant measure of the social, cultural and economic viability of particularly Kingston and Eastern Jamaica connected to this one facility and the need for its accessibility, an assessment of its vulnerability to natural hazards is important to guide mitigation measures to avert or minimize negative consequences.

## Hazard History of NMIA and Palisadoes Area

Both natural and anthropogenic forces continually bend the natural environment and its landscapes to change and adjust to their will. These changes may either be gradual and imperceptible or catastrophic (Ahmad 2011). The challenge, especially for developing countries is to understand and respond accordingly to these changes by allowing this understanding to dictate decisions of land use, avoidance and disaster risk management measures. A major step in this direction is an in depth knowledge of the history of hazardous events and their impacts on particular areas. An objective of this research is to investigate such a history of the Palisadoes and its adjoining areas in which the NMIA is located.

## Genesis/ Origin of The Palisadoes

In order to arrive at an intelligent assessment of any possible future hazardous events that may occur on the Palisadoes, one need to analyze the genesis of this area. It may be said that much of the vulnerability faced by the NMIA and the Palisaodes road lies in the development and present structure of the Palisadoes Tombolo on which both sits.

According to Robinson and Rowe 2005, the Palsisadoes is a strip of land which measures some 14km in length and almost completely encloses the Kingston Harbour. Scientists have called the Palisadoes both a spit and a tombolo:

> Tombolo: "A deposition of sand made by waves and currents that connect an island to a mainland" (Gutterrez et al. 1998, 99)
>
> Spit: "A long and narrow ridged of sand or shingle with one end attached to the land, while the other end lies in the open sea." (Bowen and Pallister 2006, 73)

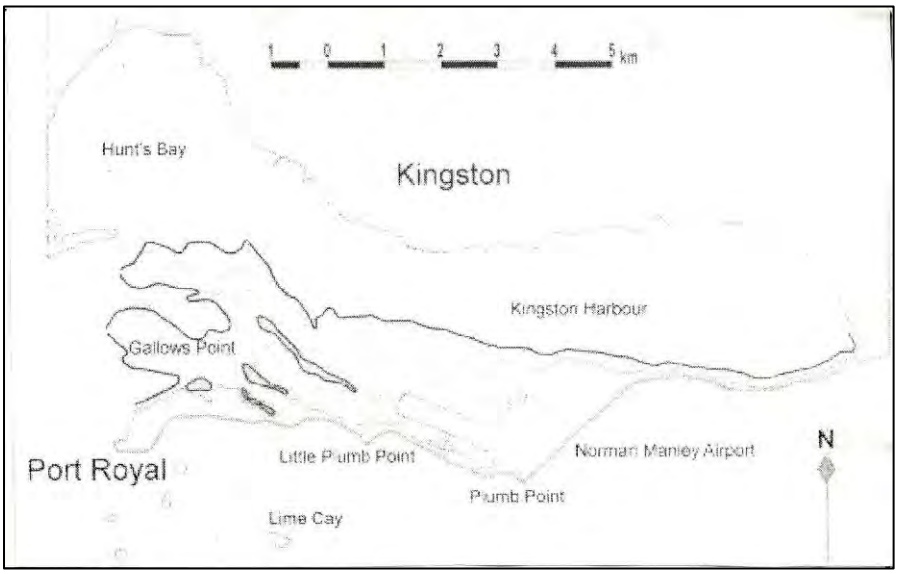
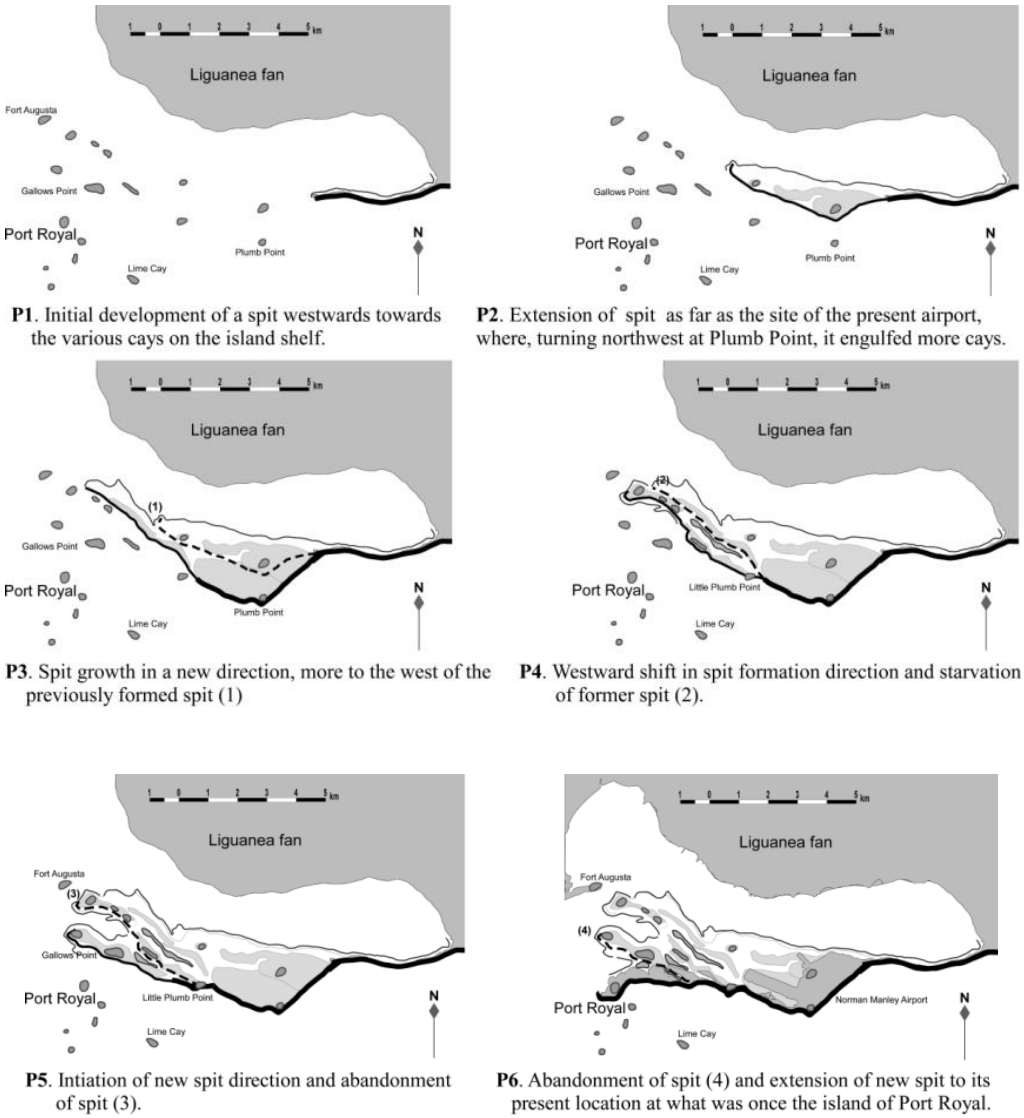



*Figure 5: Map of Palisadoes (Adopted from Robinson and Rowe, 2005)*

The Palisadoes in its present form probably dates back 4000 years. Also Port Royal which records show was once an isolated island and other cays were probably joined to the mainland by a series of spits, to establish the Paliadoes, according to Professor Edward Robinson and Rowe 2005. Perhaps the most important research undertaken on the origins of the Palisadoes to date, has been undertaken by Professor Edward Robinson of the University of the West Indies, Mona. However this formation process is at best speculative and is shown in figure 6 of P1 to P6 below (Adopted from Robinson and Rowe 2005).




**P1**. Initial development of a spit westwards towards the various cays on the island shelf.

**P2**. Extension of spit as far as the site of the present airport, where, turning northwest at Plumb Point, it engulfed more cays.

**P3**. Spit growth in a new direction, more to the west of the previously formed spit (1)

**P4**. Westward shift in spit formation direction and starvation of former spit (2).

**P5**. Intiation of new spit direction and abandonment of spit (3).

**P6**. Abandonment of spit (4) and extension of new spit to its present location at what was once the island of Port Royal.

*Figure 6: Formation Process of the Palisadoes*

## Vulnerability Created Through Development Process

The very means by which the Palisadoes developed is a source of vulnerability for the structure itself and dependent features, such as the NMIA and its access route. The development process of the Palisadoes has caused the continued existence of the structure to be dependent on the continuation of certain natural processes. If these processes are interrupted by natural or anthropogenic factors, it could result in serious adverse consequences for the Palisadoes and by extension the NMIA and access to that facility. The major vulnerability arises from the sources of sediments and the natural processes that maintain the Palisadoes (Robinson Rowe and Khan 2006).

The main sources of sediments for the Palisadoes are the Hope River, Cane River and to a lesser extent the Chalky River, which are all located to the east. Figure 7 shows the Palisadoes sediment sources.

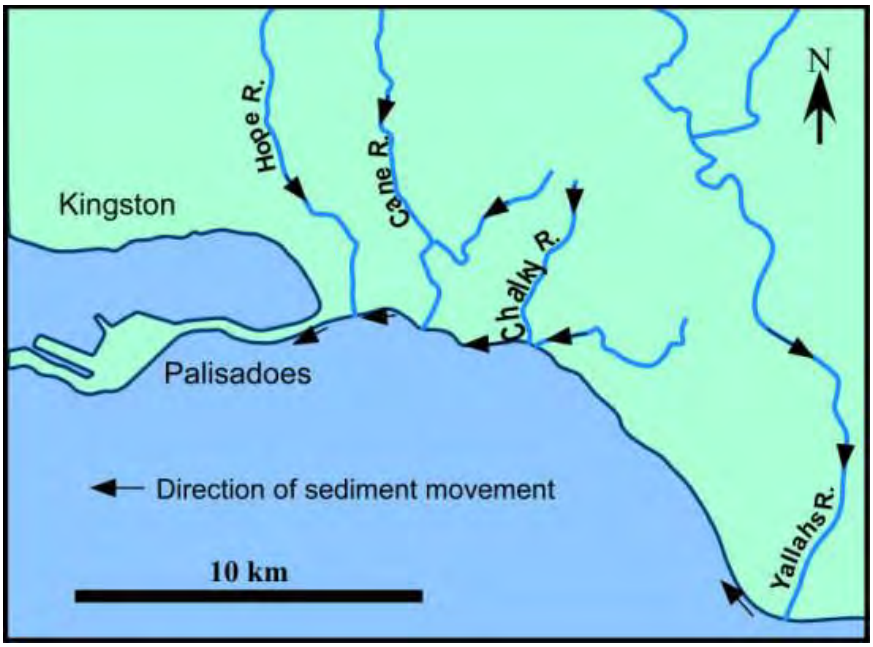



*Figure 7: Map Showing Palisadoes Sediment Sources (Adopted from Robinson, Rowe and Khan 2006)*

These rivers are responsible for bringing down sand, gravel and other sediments to replace beach materials removed by longshore drift at the Harbour View end of the Palisadoes. After being added to the beach system, the sediment is gradually moved west by longshore drift to supply and build up the Palisadoes. This creates a form of equilibrium between sediment demand and supply (Robinson and Rowe 2005). However as this is an ongoing process, there must be a continuous supply of fresh river sediment produced from the east to replenish the Palisadoes. If a cessation or considerable reduction in sediment supply should occur, the integrity and stability of the Palisadoes Peninsula and airport road could be compromised, as the Harbour View end of the Palisadoes could become detached from the mainland and get progressively smaller and eventually cease to exist. This would mean the absence of a through road to the NMIA.

There are several factors which could lead to a compromise in sediment supply over a prolonged period and the possible demise of the main access route the NMIA.

1) The Hope and Cane Rivers are seasonal rivers, and therefore flow usually reaches the sea less than once per year. Also the sediments brought down from these rivers only get to the Palisadoes when they are in flood, and even at that time, most of the sediment goes out to sea (Robinson et. al. 2005). Therefore, during prolonged periods of drought, sediment supply that sustains the Palisadoes may be considerably reduced.

(a)

(b)

*Figures 8 a and b showing: Aggregate Mining on Yallahs River, a Palisadoes sediment source river (photos K.Douglas)*

2) Aggregate mining which is practiced in Harbour View and other areas along river courses close to the Palisadoes (Figures 8 a and b above) , removes some of the sediment before it gets to the Palisadoes. Therefore a significant increase in mining activity, (legal or otherwise) has the potential to undermine sediment supply to the Palisadoes, which would compromise its integrity.

### History of Significant Hazard Events

The major hazard events to affect the Palisadoes Tombolo, which accommodates the NMIA and its only access route are earthquakes and tropical cyclones (Robinson et. al. 2005), however the "new" threat of climate change (rising sea levels) may have adverse impacts in the near future. However, with the exception of fairly well documented major hazard events, not enough is known about the impacts of natural events on the Palisadoes before 1939, when the airport commenced operations.

### Earthquake History

The City of Kingston, including the Palisadoes, which houses the NMIA has been affected by a number of earthquakes over the centuries, the reasons for the seismic vulnerability of this area will be later analyzed in this study.

Between 1677 and 1993, fourteen earthquakes having a Maximum Mercalli Intensity (MMI) of V or above, have affected the Port Royal and Palisadoes area (Ahmad and Mason 2005). However the Port Royal and Kingston Earthquakes of 1692 and 1907 respectively are the most significant events. The Port Royal Earthquake occurred on June 07, 1692 and though it was felt island wide, the most significant damage and loss of life occurred in Port Royal (ODPEM publication, 2011), which is located less that 1 mile from the NMIA. At least 2000 people died and 3000 buildings destroyed, with an additional 3000 persons dying afterwards as a result of an outbreak of yellow fever, which developed after the earthquake (ODPEM publication 2011).

The Great Kingston Quake of January 14, 1907 significantly affected the Palisadoes, as it resulted in a part of Port Royal slumping into the harbour channel by liquefaction.

An earthquake in 1957 which damaged a significant part of Montego Bay also caused minor beach slumping on the Palisadoes (Robinson, Rowe and Khan 2006). Therefore based on past seismic events, the area containing the NMIA and its access route has a great liquefaction and seismic shaking potential.

### History of Hurricanes and Tropical Storm Events

Hurricanes have affected and are likely to affect the NMIA and its access route in the future. The worst hurricane on record occurred in 1722, which resulted in a 5metre storm surge in the Port Royal area (Robinson and Rowe. 2005). However, in the last 10- 20 years, the NMIA access route in particular have been severely affected by hurricanes, particularly Hurricane Ivan in 2004 and Hurricane Dean in 2007. Hurricane Ivan resulted in the total blockage of the airport road by debris and the Palisadoes became an island again, as storm surges completely inundated some sections of the road, rendering the airport inaccessible. In 2007 Hurricane Dean also adversely impacted the NMIA access route as the waves deposited coarse sand and small boulders which averaged a thickness of one metre covering the road way (D'Aguilar and Bhalai 2007). The waves were estimated to have reached 2m in average height, but may have reached 3m based on water marks (D'Aguilar and Bhalai 2007). Hurricane Dean also undermined the bed of the road in several places and the boulders that were placed along the roadway to protect it from wave action became one of the major sources of bounce damage to the roadway.

### Tsunami History

There are records of tsunami affecting the Caribbean and Jamaica, particularly the Port Royal and Palisadoes area of the Island and hence highlight the vulnerability and potential for recurrence. Figure 9 shows Tsunami that have occurred in the Caribbean since the 16$^{th}$ century.

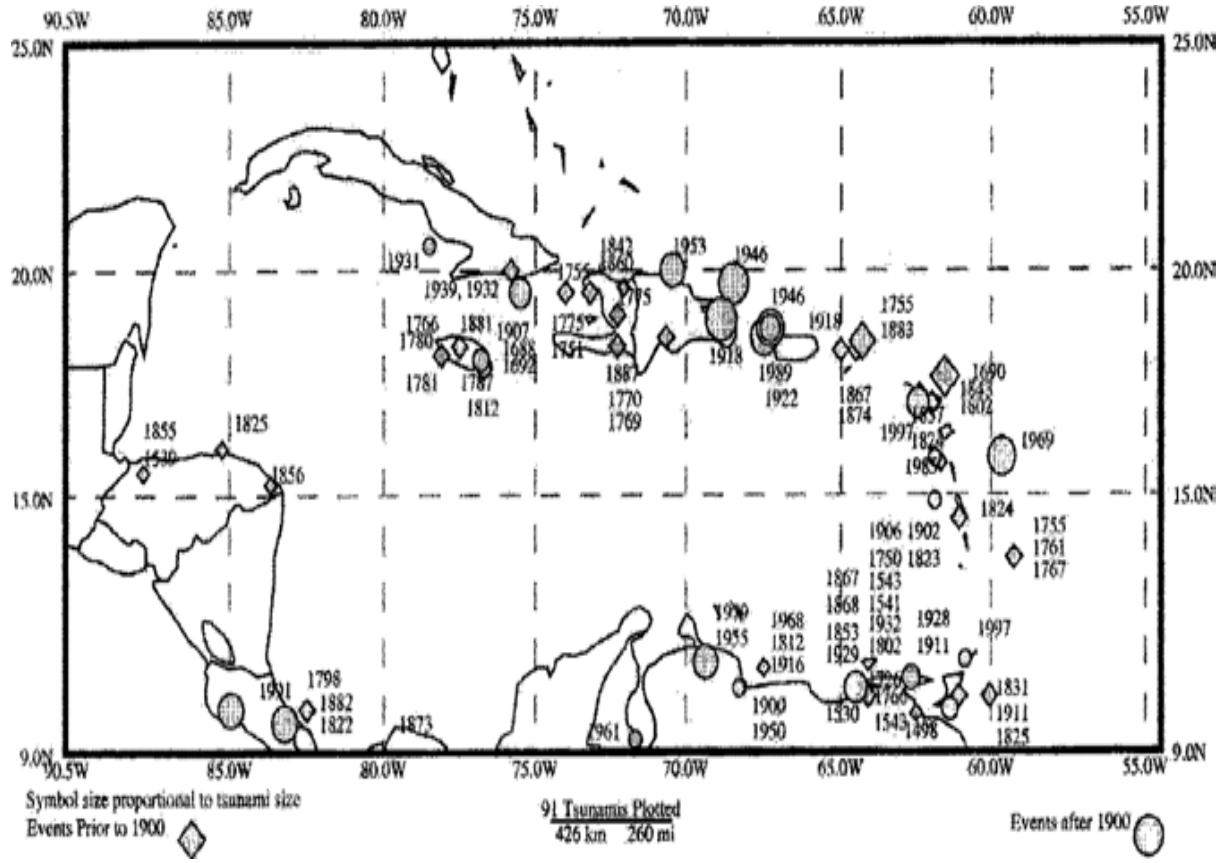



***Figure 9: Map showing Tsunami that have affected the Caribbean since the 16th Century***
*Adapted from UNDP, 2009 who quoted from Lander, 1997. Events prior to 1900 are shown with a diamond and events after by a circle*

In the 1692 Port Royal earthquake, a significant number of the 2000 people killed resulted from a tsunami, which was generated by an earthquake induced landslide in the Kingston Harbour, which destroyed 90% of the buildings in that city. Along the Liguanea Plain, the sea withdrew some 274 metres, with the returning water covering most of the shore. (www.USGS.gov.earthquakes)

The threat of rising sea levels will also be analyzed later in this study. Therefore, the NMIA with its tremendous social and economic importance being located in an area with such an active hazard history, a hazard vulnerability analysis of this facility and its access route is important to inform mitigation measures, so as to reduce possible losses and economic fallout, in the event of natural hazards.

## Earthquake Vulnerability (Shaking, Liquefaction and Tsunami)

### Vulnerability Assessment Method

The method used to assess vulnerability to seismic hazards included documentary investigations of the underlying geology of land that supports the NMIA and access route, as well as the seismic hazard history of the area. The assessment methods also included observation of building structures for visible signs of cracks or weaknesses, as well as observing the building materials, ascertaining the age of buildings and assessing the design plans where available. The nearness to the sea, as well as height of critical facilities and equipment were taken into account for assessing tsunami vulnerability. However to provide a more accurate account of structural seismic vulnerability, structural assessments of buildings must be undertaken by trained engineering experts, as well as mathematical calculations of building wall and column indices among other factors, to calculate possible seismic vulnerability. These methods however are beyond the scope of this research.

The NMIA and its access route, for a number of reasons, are highly vulnerable to seismic activities, including ground shaking, liquefaction and even the possibility of tsunami. Jamaica is located in the seismically active plate boundary zone of strike slip faulting, along the northern margin of the Caribbean Plate and the presence of very active faults on the island increases seismic vulnerability (Ahmad 2011).

However, the NMIA and its access route may face a higher level of seismic vulnerability because of their location on the Hope River Alluvial Fan, and ground material with high water content. These factors increase the ground shaking and liquefaction potential of the area in specific ways. The amount of ground motion during an earthquake is strongly influenced by the area's geological structure and nature of the local earth material (Ahmad 2011). Various earth materials behave differently in earthquakes, due to their degree of consolidation. The seismic or earthquake waves which causes surface shaking moves faster through consolidated bedrock than they do through unconsolidated sediments and soil. Therefore there is likely to be less intense and shorter ground shaking in areas of consolidated bedrock.

However unconsolidated, water saturated materials as that which underlie the NMIA and access route on the Palisadoes Tombolo causes seismic waves to slow down considerably. As seismic waves slow down, the energy that was once directed forward is transferred to the vertical motion of surface waves. This action is known as material amplification and results in more intense and longer surface shaking (Ahmad 2011). This action is shown in Figure 10.

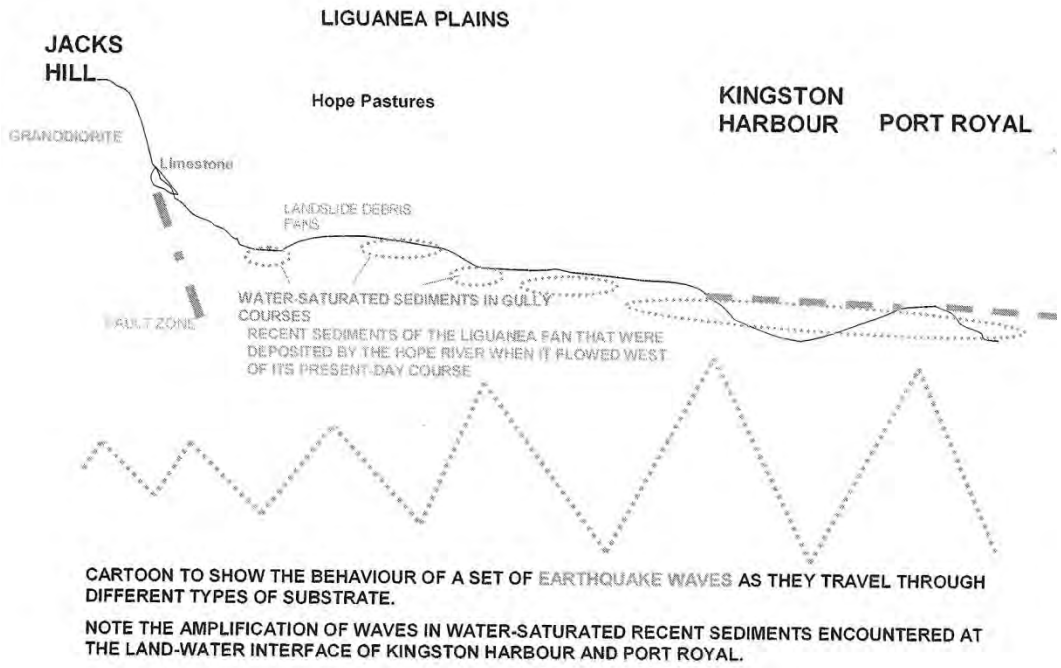



*Figure 10: How Earthquake Waves Affect Us (Adopted from Ahmad, 2011)*

Therefore during an earthquake, the NMIA and its access route may have comparatively more severe ground shaking than facilities built on areas of consolidated bedrock. More intense earth shaking could result in greater damage to the physical facilities at the NMIA. The Palisadoes access road could also be severely affected by intense ground shaking as the roadway could become fractured or displaced, resulting in the denial of access to the NMIA. The NMIA and its access route are underlain by similar unconsolidated materials, which mean that seismic waves from distant earthquakes will be enhanced upon encountering the local geology of this area.

***Mexico City effect***

The city of Kingston and more so coastal zones, such as that which supports the NMIA and its access route is susceptible to what Natural Disasters Rafi Ahmad calls the "Mexico City Effect", because of its unconsolidated and water saturated underlying material. In 1985 Mexico City had considerable damage to its infrastructure and loss of lives from an earthquake that had its origin a considerable distance away from the city, but which seismic waves were very far reaching. This occurred because the unconsolidated underlying material of Mexico City resulted in the amplification of seismic waves, greater surface shaking and more damage. Therefore the waves travelled great distances through consolidated bedrock, causing comparatively little surface shaking, but as the waves reached Mexico City, with its sub-surface geology, they were amplified, in a similar way to what occurred in Fig. above.

The NMIA and its access route are underlain by similar unconsolidated materials, which mean that seismic waves from distant earthquakes will be enhanced upon encountering the local geology of this area.

## Vulnerabilities and Mitigation Measures for Ground Shaking

Some of the critical facilities identified were found to possess some factors of vulnerable to ground shaking, which could seriously hamper the smooth operation of the NMIA. However, according the senior NMIA Engineer interviewed, the facility has never suffered any damage from earthquakes.

The aircraft runways and taxiways are vulnerable to cracking and/or subsidence caused by vigorous surface shaking and if this should occur, this may prevent the normal operations of the facility until corrected. The airport runway, according to the NMIA's engineering department has a surface layer which is six inches thick and is made of asphaltic concrete, a substance which is vulnerable to cracking and rupture during earthquakes. The nature of asphaltic concrete means that if it is broken or severely cracked by earth movement, the broken areas have to be cut out and replaced by similar material and depending on the local availability of such replacement materials, repairs could take several days at worse. The prevention of aircraft activity at the facility for even one week may result in the losses of millions of dollars in revenue.

The age of buildings and the absence of seismic retrofitting may also be factors that may contribute to the seismic vulnerability of some buildings. The NMIA is divided into two sections, the new terminal building which is constructed of steel frame columns and sheet glazing and was only opened in 2006. The other section comprises of many older buildings, including the critical facilities identified and many of these buildings are over 30 years old. The dominant building materials used, which are block and steel with reinforced concrete generally provide good protection from seismic movements, but their seismic resistance deteriorates with age and must be modified to maintain optimum strength (Otani and Kaminosono 2000, 6). The occurrence of small to moderate earth tremors over time, though not having any significant damage at any one time, may serve to weaken structures and increase their vulnerability to large quakes in the future.

The newer terminal building, with steel frame columns may be structurally stronger and more ductile in comparison to older structures and may be less vulnerable to seismic movements. However, according to the senior engineering staff member interviewed, he has no knowledge of there being any seismic retrofitting of the NMIA facility, particularly the older buildings, since their construction. Seismic retrofitting is the process of strengthening the resistance of existing buildings to earthquakes. The only retrofitting that has been undertaken is in relation to hurricanes. Therefore the natural wear and tear caused my atmospheric elements along with exposure to tremors within the minor to moderate range during the life of these buildings may increase their vulnerability to damage if a major quake, that is above 5 on the Richter or Modified Mercalli Scale should occur

In terms of mitigation to ground shaking, the NMIA buildings were not specifically designed to withstand any particular magnitude earthquake, unlike many other buildings which are designed with specific

features to withstand the effects of up to a particular magnitude quake, determined by the earthquake history and local geology of the area.

### Liquefaction and Subsidence Vulnerability

Prolonged shaking of unconsolidated water saturated ground, similar to that which exists under the NMIA and access route is prone to Liquefaction. After a period of shaking from being loaded with seismic waves, the earth material loses cohesiveness and collapses under its own weight. The phenomenon of liquefaction is not new to this area as it occurred in both the 1692 Port Royal Earthquake and the 1907 Kingston Earthquake, as shown in Figures 11 and 12.

It is of extreme interest to note that structurally well built, shake resistant buildings offer little immunity to Liquefaction, as in most cases the subsided buildings themselves are not physically damaged, but collapses nonetheless as their foundation fails. Examples of this is the Old Artillery House (Giddy House) in Port Royal, and Buildings in the Niigata Earthquake in Japan on June 16, 1964 as seen in Figures 13 and 14.

*Figure 11- Illustration showing contemporary engraving of Port Royal after 1692 Earthquake (Adopted from Ahmad, 2011)*

Note that the buildings in the foreground have subsided.

*Figure 12: Liquefaction and Foundation Failure in Harbour View and Port Royal in 1907 Earthquake Area close to Harbour View end of Palisadoes (Adopted from Ahmad 2011)*

*Figure 13: Old Artillery House/ Giddy house in Port Royal that suffered foundation failure in 1907 (Ahmad , 2011)*

*Figure 14: Photograph showing earthquake-resistant buildings affected by Liquefaction in Niigata, Japan- June 16, 1964 (www.USGS.gov.earthquakes)*

Note that the building structures are hardly damaged.

The same possibility exists for the NMIA, in that even if its buildings may be resistant to a certain degree of surface shaking, however damage could be considerable if the ground beneath it should liquefy, as what occurred in previous earthquake events in the past in the area which the NMIA is located. The Fire Station and Runways, which are located closer to the sea than the other critical facilities may face a greater danger of being liquefied during rigorous surface shaking. However all the other critical facilities are in danger of liquefaction, if the material supporting the NMIA gives way, causing the collapse of sections of the facility. There are no specific measures in place at the facility to mitigate against possible liquefaction caused by earthquakes.

### Tsunami Vulnerability

As was mentioned earlier, based on its hazard history the Palisadoes area is vulnerable to Tsunami. The most recent examples of the devastating power of tsunamis are the December 26, 2004 Asian Tsunami and March 2011 in Japan. However, while Tsunami have occurred and are a threat to Jamaica's Coastal Areas, the likelihood of an event of similar magnitude to that of the Asian Tsunami is unlikely (Robinson and Rowe 2005). A Tsunami of even moderate proportion may create channels across the narrow sections of the spit, including roadways, which would impede access. The physical infrastructure of the NMIA however is probably less likely to suffer any serious damage from a moderate tsunami, of height below two metres. However higher waves may cause damage especially to critical internal equipment, such as those possessed by Air Traffic Control Centre and the Meteorological Office. Perhaps the Power Plant, Fuel Storage facility and Fire Station are the most vulnerable to even moderate tsunami waves, since they are located closer to the sea than the other critical facilities. Waves could result in damage to vital equipment or cause oil spills if storage devices are destroyed.

There are no measures in place at the NMIA facility to mitigate against the effects of Tsunami Waves or large waves on a whole that may affect the entity, even though large waves have never made their way onto the facility, even during heavy storms, according to NMIA records.

## Storm Surges and Flooding Vulnerability

### Vulnerability Assessment Methods

The assessment methods used involved analyzing the storm surge and flooding history of the NMIA and access route. The roadway's height above sea level was observed at various points, and the state of the structural mitigation measures put in place to protect the roadway from flooding were analyzed. The location and height of critical facilities were also observed. The drainage system of the NMIA was also analyzed.

### Vulnerabilities and Mitigation Measures for storm surges and flooding

The NMIA and its access route are very vulnerable to storm surges and coastal flooding. Jamaica is located in the Atlantic Hurricane Belt and is prone to be affected by storms and hurricanes, particularly during the hurricane season of June to November of each year. However, non-hurricane heavy rainfall, for example from frontal systems also causes flooding.

The NMIA access route is particularly vulnerable to both flooding from the sea, as well as sediment and debris flood. The NMIA access route is an "island road", meaning it has the sea on both sides and the roadway is less than a metre above sea level.

Therefore flooding from the sea is likely, even with only marginal increases in wave height and reach. The stretch of road between Harbour View and the airport is on the narrowest part of the Palisadoes and suffered significant loss of sand during Hurricane Ivan in 2004 and Hurricane Dean in 2007 and an onslaught by other category 5 storms, like Ivan may actually lead to a breaching of the roadway, which could completely separate the airport from the mainland to Harbour View, creating a Paliadoes island (Robinson and Rowe 2005).

The roadway leading to the NMIA is also vulnerable to sediment and debris flooding, as its beginning at Harbour View is located at the foot of the Hope River, on an Alluvial Fan. In fact, as highlighted earlier, the Alluvial Fan on which Harbour View is located was created as a result of sediment deposition by the Hope River over time. This process is likely to continue, especially during periods of heavy rainfall and sediment and debris, particularly large boulders may cause blockage and serious damage to the roadway.

The vulnerability of the physical structure of the NMIA to small storm surges, two metres or under, as what occurred during Hurricane Ivan in 2004, is similar to that for small scale tsunamis which is no serious structural damage. However higher surges may cause damage to buildings, critical internal equipment as well as loss of lives. However the NMIA usually ceases operations as a hurricane approaches, therefore it is expected that not many staff members would be present at the facility should it be hit by dangerous storm surges and according to the NMIA's engineer department, the facility has never suffered damage from storm surges.

Over the years, the dominant structural mitigation measures implemented to protect the NMIA's access route have been in the form of groynes, protective sand dunes and boulders piled along the most sensitive points of the roadway (shown in Figures 15 and 16).

*Figure 15: Photographs showing groyne (a) and boulders (b) along NMIA's access route (a) Photograph by Monica Howard (b) Photograph by K. Douglas*

However, many of the groynes (built in the 1950's after Hurricane Charlie) along the roadway have been destroyed and have not been repaired or replaced, thus reducing protection from the sea. The creation of dunes with wave deposited sand has also been employed along the roadway; for example after hurricane Ivan in 2005 wave deposited sand was piled on the seaward side of the road and was partially vegetated (Robinson and Rowe 2005). However during Hurricane Dean in 2007, almost all these dunes were flattened almost to road level, exposing the roadway to the wrath of waves which undermined the roadbed in many areas. The use of limestone boulders along the most vulnerable areas of the roadway after Hurricane Ivan in 2004 and Hurricane Emily in 2005 also proved ineffective in protecting the NMIA access route. The boulder rampart was flattened during Hurricane Dean. Also ironically, the very boulders placed to protect the roadway became an agent of its destruction as the waves dislodged the boulders, causing them to bounce and roll up to 70 metres across the roadway causing severe damage to sections of the road way (D' Aguilar and Bhalai 2007). Figure 16 shows section of road badly damaged by Hurricane Dean.

***Figure 16: Photograph showing section of NMIA Roadway damaged during Hurricane Dean Adapted from Marine Geology Unit, UWI 2007***

The failure or only partial success of many of these mitigation measures to protect the NMIA access route from consistent surges from flood rains, storms and hurricanes has emphasized the need for more substantial protection of the access route to the NMIA, this has led to the commencement of the "Palisadoes Peninsula Shoreline Protection and Rehabilitation Project." The project is a partnership between the Governments of Jamaica and China with a contract sum of US$ 65,377,404.62 to be undertaken by the China Harbour Engineering Company (CHEC) over a contract period of 18 months (www.nwa.gov.jm). The scope of work of the project involves the raising of the road from its existing level of 0.6-1.0 metre to 2.4-3.2 metres above sea level as well as the construction of rock revetment walls along the shoreline and along the harbour side. Inlets and culverts will also be placed along the roadway to conduct run off. The majority of the work is concentrated on the stretch of road from the Harbour View Roundabout to the NMIA.

The rehabilitative and protective works have been designed to withstand storm surges with a 100 Year Return Period and a rainfall intensity of 178mm per 24hours period. However according to research conducted by the Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration (NOAA), global warming is likely to lead to an increase in the "numbers of very intense hurricanes", in the region of between 2-11% according to model projections for an IPCC A 1B Scenario. This change would imply an even larger percentage increase in the destructive potential of hurricanes. Also increased warming will also cause hurricanes to have "substantially higher rainfall rates than present day hurricanes with a model projected increase of about 20% for rainfall rates averaged within about 100 km of the storm centre".

These projections are important to the Palisadoes Rehabilitation Project because the situation may arise where because of Global Warming the frequency of storm surges with one hundred year return periods may increase and also rainfall intensity may exceed the designed standard of the project on a more regular basis than anticipated. If that occurs, the integrity of the rehabilitation works may be threatened. However constant monitoring and undertaking reinforcements and retrofitting where necessary may alleviate any catastrophic damage.

Also of significance in terms of vulnerability to the Palisadoes Road is the nature of the boulders being used as revetments. The Palisadoes Rehabilitation Project is employing the use of Limestone Boulders, particularly on the seaward side of the road. According to an assessment report conducted by the ODPEM in 2006 on the impacts of Hurricanes Dennis and Emily, the use of limestone boulders for these purposes should be avoided as the limestone rocks may be physically strong but is weak chemically and will disintegrate when exposed to seawater. The photograph below shows one of the boulders along the Palisadoes Road.

*Fig. 17: Photograph showing a limestone boulder used as revetment along Palisadoes Road – showing Areas of weakness which can be chemically weathered over time*
(Photograph K. Douglas)

The NMIA facility occupies an area of flat relief and is therefore vulnerable to flooding from heavy rainfall. The facility has been significantly affected by heavy rainfall flood events in the past, for example during hurricanes and frontal systems. According to information gathered from the NMIA Engineering, Maintenance and Planning (EMP) Division past flooding effects include the flooding of manholes, large scale leaking of roofs (in one case, the popular retail shop "Books and CDs" located in the old departure lounge was so severely flooded from the roof that the NMIA had to compensate the entity for losses incurred. Also the front areas of the fuel farm and sewage system have also been flooded in the past during heavy rainfall according to EMP staff reports.

While there are no mitigation measures in place to protect the building themselves against storm surges and flooding, the vulnerability to flooding has been reduced by improvements in the drainage system. In 2006-2007 a new drainage pump and drainage channel were installed under the roadway leading from the Airport roundabout to the NMIA. Also other roads in the facility are slated to be elevated to reduce the risk of flooding.

As in the case with tsunami waves, the critical facilities located closer to sea (power plant, fire station, runway and taxiway) have the greatest level of susceptibility to the adverse effects of storm surges as they are directly in the "line of fire". The Meteorological Office and Air Traffic Control Centre are less vulnerable, as they are situated in elevated buildings and storm surges would have to have a considerable height and reach to cause serious damage.

## Hurricanes/Wind Vulnerability

### Vulnerability Assessment Methods

The wind vulnerability for the roadway was assessed by observation of the number of large trees, utility poles and any other factors which could contribute to blockage of the road way by strong winds. The vulnerability of the NMIA buildings was determined by the adoption and slight modification of the methodology employed to buildings in the "Structural Vulnerability Assessment for St. Kitts and Nevis" 2001 undertaken by the Organization of American States (OAS). Wind vulnerability was determined based on the following:

- Poor condition of building generally
- Poor condition of metal roof sheeting
- Roofed with common asphalt shingles or built up roofing
- Roof overhangs exceeding 2 feet where there are no soffits
- Unprotected windows

Characteristics were not weighted and high vulnerability was assigned where any facility exhibited above two characteristics and vulnerability was considered low if facilities exhibited no more than one.

The type of utility poles and location of communication equipment were also observed.

### Vulnerabilities

The NMIA's physical structures and critical facilities may face a lower level of vulnerability to wind damage, in comparison to most of the other hazards identified. The same may hold true for its access route, however there are certain vulnerable factors.

The NMIA access route from Harbour View has low coverage of large trees, as trees only extend from the area close to the Caribbean Maritime Institute to the NMIA Roundabout. Therefore the vulnerability of wind damage to large trees, causing road blockage is low. Utility poles are located all along the roadway and are susceptible to being blown down by strong winds, as was the case during hurricane Dean in 2007. However along approximately half the roadway, the wooden utility poles have been replaced by concrete poles which are less vulnerable to being blown down by strong winds, but wooden poles are still being used on the remainder of the roadway and thus have a greater vulnerability to collapse due to heavy wind.

The following was observed based on the characteristics of vulnerability applied to the NMIA buildings:

| NMIA Facility | Poor General Condition of Building | Poor Condition of Roofing from Observation | Roofed with common asphalt shingles | Roof Overhang > 2ft | Unprotected windows |
|---|---|---|---|---|---|
| Met. Office | | | | | X |
| Air Traffic Control Tower | | | | | X |
| Police Station | | | | | X |
| Med. Station | Located inside main terminal | | | | |
| Fire Station | | | | | X |

*Figure 18: Table Showing wind vulnerability characteristics of NMIA Critical Facilities*

The facilities of the NMIA with the exception of a lack of storm shutters on most elevated buildings exhibited low vulnerability to wind damage. Also observations of utility poles and communication equipment also revealed a low vulnerability as all utility wiring on the facility are run below ground and public lighting on the facility is provided on metal poles with concrete bases (shown in Figure 19) which in comparison to wooden poles, have a reduced susceptibility to wind damage.

*Figure 19: Photograph showing type of utility pole at NMIA Facility (Photograph K.Douglas)*

Another source of vulnerability to wind damage, on the NMIA facility is the extensive use of glazing (the use of a sealant as an adhesive for attaching a glass panel to a structure) and glass on many building structures, particularly on the new terminal building- a section of which is shown in Figure 20.

Similar use of glazing and glass is employed on critical facilities including the meteorological office and air traffic control tower. In addition to the possibility of wind and projectile damage to glass during high intensity hurricanes, there is also the danger of damage to personnel from shattered glass during earthquake events. However, there are certain mitigation measures employed, which are discussed below.

## Hurricane Mitigation measures in place at NMIA

The older buildings of the NMIA facility, including the critical facilities identified are roofed with concrete slabs as opposed to shingle of aluminum zinc roofs. Also a protective membrane is placed over the roofs to prevent water intrusion. This type of roofing almost entirely el iminates the possibility of wind damage to roofs from storms and hurricanes. However the new terminal building is roofed with aluminum sheeting, but designed with minimum overhang to prevent wind getting under and lifting the roof. The roof is also secured by metal bolts to reduce vulnerability.


*Figure 20: Photograph showing large glass section of new terminal building at NMIA (Photograph by K. Douglas)*

With regards to reducing the vulnerability of building glazing and glass to wind and other damages, the following mitigation measures have been put in place according to the NMIA Engineering Personnel. The new terminal building is equipped with Tempered glass, which is a safety glass which is four to five times stronger than regular glass. Tempered glass, according to information website www.wisegeek.com, despite its superior strength has a brittle nature that results in it being shattered into oval shaped pebbles when broken, this eliminates the danger of sharp edges which may cause bodily harm to personnel during hurricanes or earthquakes. The glazing and tempered glass used in the new departure terminal is designed to withstand the winds and projectiles of up to a Category 4 Hurricane on the Sapphire Simpson Scale which represents wind speeds between 210-249 km/h. The Saffir Simpson Wind Scale is shown in Figure 21.

| Hurricane Category | Wind Speeds (km/h) |
|---|---|
| Category 1 | 119- 153 |
| Category 2 | 154-177 |
| Category 3 | 178-209 |
| Category 4 | 210-249 |
| Category 5 | Greater than 249 |

*Figure 21: Table showing Saffir Simpson Hurricane Wind Scale* ***Source: National Oceanic and Atmospheric Administration (NOAA)***

However, only the new terminal building is equipped with this type of glass, so all the other structures are equipped with standard glass and glazing, susceptible to shatter and cause personnel injury during earthquakes and hurricanes. However most of the critical facilities: fire department, meteorological office, air traffic control tower and administrative buildings all have tracts for hurricane shutters, which are installed when a hurricane warning is issued, according to NMIA engineering staff. In addition, the glazing and glass cover on the Met. Office has been reduced to minimize the risk of the risk of wind damage and water intrusion and there are plans to shutter all remaining buildings in the near future.

An examination of the Hurricane Plan of the NMIA which is outlined in the NMIA Hurricane Manual, revealed a very proactive, preventative and preparedness approach rather than a sole focus on response and recovery, which served to reduce the vulnerability and risk of the facility to damage from hurricanes. The management of the NMIA recognizes that adequate prevention and preparedness planning can help to reduce losses and assist in speedy resumption of business after a hurricane event.

The hurricane year for the Engineering, Maintenance and Planning (EMP) Division actually begins on April 1 of each year and not the June 1 commencement of the Atlantic Hurricane Season. On April 1 of each year an extended meeting of EMP Division staff meeting is held, the EMP comprises of four areas: Electrical/ Mechanical, Pavements and Structures, Work Control and Environment and Occupational Health. This meeting facilitates an assessment of the last hurricane season, necessary changes to the

hurricane manual and present plans for the new season, in which each of the four departments are presented with their responsibilities and tasks. The procurement or necessary resources and staff, as well as the assessment of various critical equipment are also undertaken. The EMP staff meets no less than three times before the beginning of the Atlantic Hurricane Season on June 1 after which the responsibility for hurricane planning and execution is handed over to the NMIA Emergency Manager who controls the reins until November 30 each year.

These hurricane procedures work as a part of the NMIA Emergency Management System in which emergency management is centred in the Emergency Operation Centre (EOC) which falls under the control of the NMIA Emergency Services Manager. However the NMIA Hurricane Manual does not specify the personnel who should report to the various centres and undertake the required actions, but it is possible that these individuals are made aware through other means.

Therefore the well-organized hurricane disaster plan present at the NMIA together with constant assessment and repairing of damaged entities serves to reduce the hurricane vulnerability of the entity, however there are recommendations that if implemented will serve to enhance the preparedness level of the facility.

## Climate Change (Sea Level Rise) Vulnerability

### Assessment Method

The vulnerability assessment method involved the analysis of projections and climate change research undertaken for coastal areas of the Caribbean and in particular Jamaica. The location and nearness of critical facilities and/ or equipment was also assessed, as well as the mitigation measures, if any, which are in place against this threat.

### Vulnerabilities

According to the United Nations Development Programme's Human Development Report 2007/08, "Climate change is the greatest challenge facing humanity at the start of the 21st Century. Failure to meet this challenge raises the spectre of unprecedented reversals in human development."

The Intergovernmental Panel on Climate Change (IPCC) in its 2007 report stated that climate change would have an even greater impact on small island development states like Jamaica because of certain characteristics, such as small land masses and the concentration of population and infrastructure along coastal zones. According to the Caribsave sea level rise modeling project 2009 (probably the most significant research done on Climate Change in the Caribbean), Caribbean countries will be among the first countries to be affected in the coming decades by the direct and indirect impacts of climate change, such as sea level rise, coastal erosion and an increase in extreme natural hazard events. The coastal location of the Norman Manley International Airport and its access route makes them vulnerable to these effects of climate change and if the entity fails to adequately respond or mitigate against these threats, its operations could be severely curtailed or worse.

The NMIA runways and taxiways are particularly vulnerable to coastal erosion and sea level rise associated with climate change as they are, from observation probably less than half of a metre above sea level.

The rise of sea levels in the Caribbean has been commensurate with global sea level rise in the last 50 years. This was reported by the Inter-Governmental Panel on Climate Change (IPCC) Report of 2007 was a 1.8mm/year rise from 1961-1993 and a 3.1mm/year rise between 1993 t0 2003 (UNDP 2009). However these are average figures, which means that sea level rise (SLR) in some islands in the Caribbean may have been greater. Also recent evidence such as the behavior and melting of the Greenland and Antarctic Ice Sheets, suggests that the global and Caribbean mean SLR put forward by the IPCC will increase in years ahead, possibly reaching 1.5- 2metres above present levels by 2100. (UNDP 2009). Also of possible dire consequences to the Jamaican and Caribbean coastlines is the fact that recent modeling suggests that the greatest sea level rise will occur along the western and eastern coasts of North America. This means

that SLR in the Caribbean may be greater than the global projections of 1.2- 2,5metres by 2100(UNDP 2009).

This rise in sea levels could affect the NMIA and Access Route through possible inundation and may force very costly raising exercises. Both of Jamaica's international airports are similarly located on flat land along the country's coast, therefore figure 25 below which shows the possible effects on the Sangster's International Airport in Montego Bay of a 1-2metres rise in sea level could also be applied to the NMIA. The model shows that a 1-2 metre SLR along the coast in Montego Bay would severely affect the airport runways and facilities.

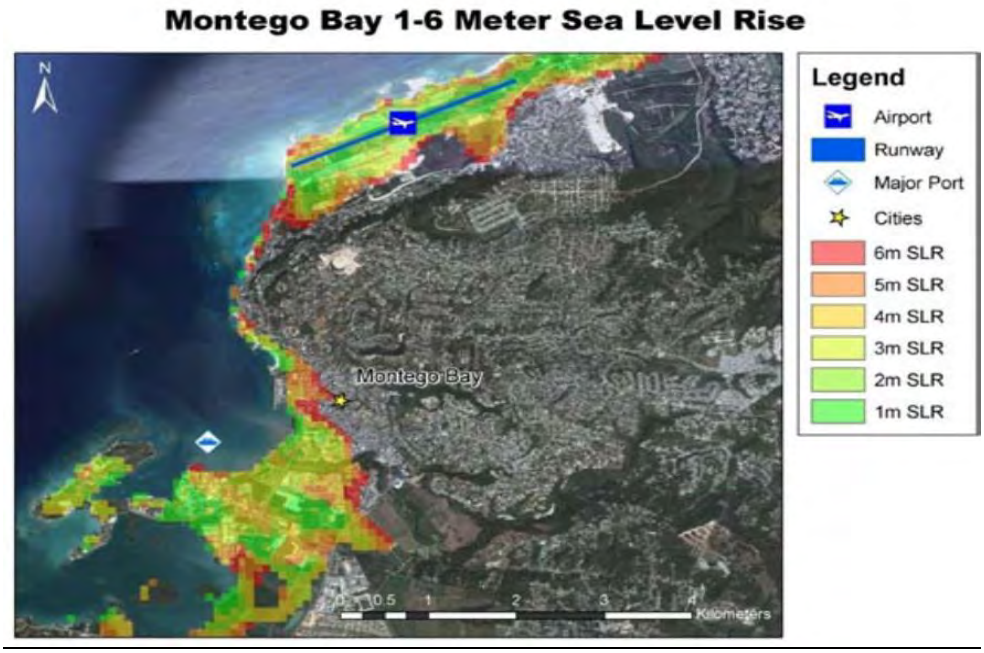



*Figure 22: Model showing effects of 1-2 metres rise in sea levels in Montego Bay (Adopted from UNDP 2009)*

Note that the 1-2 metre SLR would cause inundation of the airport runway.

Also Figure 23 shows that the second greatest impact of sea level rise on Jamaica will be on its airports, second only to its effects on wetland areas.

| JAMAICA | 1M SLR | 2M SLR | 3M SLR | 4M SLR | 5M SLR | 6M SLR |
|---|---|---|---|---|---|---|
| Land Area | 1% | 2% | 2% | 3% | 4% | 5% |
| Population | 1% | 1% | 2% | 3% | 4% | 5% |
| Urban Area | 0% | 1% | 2% | 3% | 4% | 5% |
| Wetland Area | 22% | 26% | 34% | 40% | 46% | 48% |
| Agricultural Lands | 2% | 3% | 5% | 7% | 10% | 11% |
| Major Tourism Resorts | 4% | 4% | 10% | 29% | 54% | 73% |
| Airports | 20% | 20% | 40% | 40% | 40% | 80% |
| Road Network | 1% | 1% | 2% | 4% | 5% | 6% |
| GDP (2008 est) | 1% | 1% | 2% | 3% | 4% | 5% |

*Figure 23: Table showing projected impacts of sea level rise on Jamaica (Adopted from UNDP, Climate Change Modelling 2009)*

Also of all the 15 Caribbean nations studied in the 2009 UNDP's Climate Change Modelling Projects, the vulnerability or airports to a 1 metre rise in sea level was greatest for Jamaica, followed by the Bahamas.

The Norman Manley International Airport, its access route and other coastal entities will also be impacted by climate change in that, along with a rise in sea levels which could cause subsidence of its taxi and runways, hurricanes and tropical storms will have an increase in their "range of inundation and capacity for coastal erosion" (UNDP Climate Change Modeling 2009, 41). The adverse effects of storm surges on coastal areas can be dramatically increased with even very small changes in sea levels and therefore this effect on the NMIA, its access route and other coastal entities can be felt in the very short term. (UNDP Sea Level Rise Modelling 2009). The same increase in wave damage potential will also apply to Tsunamis. Therefore even though the NMIA has been fortunate enough that storm surges in past hurricane and tropical storm events have not reached on site to cause any damage, there could be drastic changes in fortune with expected rise in sea levels, unless mitigation measures are swiftly implemented. There could also be increased damage to the NMIA's access route with larger storm surges.

Also, while it is uncertain that the frequency of hurricanes may increase as a result of climate change, there is observational evidence which may indicate that the intensity of hurricanes are increasing and will continue with climate change. Research conducted by the United States Global Change Research Program and published on their website www.usgcrp.gov suggests a co-relation between increases in tropical cyclone intensity and increases in sea surface temperatures in the North Atlantic since the 1970's. Also it appears that the barometric pressures in the strongest hurricanes to affect the Caribbean Region are getting lower and lower pressures mean increased wind speeds and larger more intense storm surges. The tables 28a and 28b below shows the minimum barometric pressures for the most intense Atlantic hurricanes and the storm surge heights associated with each category of hurricane.

An increase in the intensity and a possible rise in frequency of tropical storms and hurricanes, especially more than one in a single season or even consecutive seasons, could possibly overwhelm mitigation measures such as boulder barrier on access route. This could also result in considerable damage to NMIA facilities, especially if storm surges actually reach on site as there are no structural mitigation measures in place for these hazards at the NMIA.

| Rank | Hurricane | Season | Minimum Pressure |
|---|---|---|---|
| 1 | Wilma | 2005 | 882mb |
| 2 | Gilbert | 1988 | 888mb |
| 3 | "Labour Day" | 1935 | 892mb |
| 4 | Rita | 2005 | 895mb |
| 5 | Allen | 1980 | 899mb |
| 6 | Katrina | 2005 | 902mb |
| 7 | Camille | 1969 | 905mb |
| 7 | Mitch | 1998 | 905mb |
| 9 | Ivan | 2004 | 910mb |
| 10 | Janet | 1955 | 914mb |

*Figure 24: Table showing the most intense Atlantic Hurricanes and their barometric pressures (Adopted from UNDP Climate Change Modelling 2009)*

| Category | Wind Speed (mph) | Storm Surge (metres) |
|---|---|---|
| 1 | 74-95 | 1.2- 1.5 |
| 2 | 96-110 | 1.8-2.4 |
| 3 | 111-130 | 2.7-3.7 |
| 4 | 131-155 | 4-5.5 |
| 5 | > 155 | > 5.5 |

*Fig. 25: Table showing Saffir Simpson Hurricane Scale and Accompanying Storm Surge Heights (Adopted from US National Hurricane Centre)*

## Conclusion and Recommendations to Reduce Vulnerability

### Conclusion

The NMIA and its single road access route, because of the Palisadoes area in which they are located were found to be vulnerable to a number of natural hazards, these were earthquakes, hurricanes/ strong winds, storm surges and flooding and climate change mainly with its accompanying feature of sea level rise. However the levels of vulnerability were found to be higher for some hazards than others and some yet to be tested by any significant events. The Palisadoes was found to be a historically active seismic area which has seen the occurrence of severe ground shaking, liquefaction as well as Tsunami, this history and current geological composition, especially being located on an alluvial fan of loosely compacted ground materials increases the vulnerability of the entities to seismic damage. The building structures of the NMIA, from observation gave no serious indication of seismic weakness; however there has not been any seismic retrofitting undertaken and the true state of vulnerability is not entirely known.

In regard to hurricanes and their associated hazards, the NMIA was found to have a very proactive and comprehensive disaster plan that was updated regularly as was needed. Therefore the vulnerability to strong winds and flooding from rainfall was fairly low. However the threat of storm surges posed a much greater danger to both the NMIA and its Access Route, even as mitigation measures are taken to reduce such vulnerabilities. The NMIA was found to have no specific mitigation measures against storm surges, as these have never seriously affected the entity.

The threat of climate change with sea level rise was found to be a threat to which the entities were highly vulnerable and that could force the closure of the airport in coming decades or at best force very costly elevation exercises. With the varying levels of vulnerability of the Palisadoes Road and various critical facilities at the NMIA, there are mitigation measures that may be implemented to reduce such vulnerabilities and increase the resilience of the entities. Some of those mitigation options are outlined below.

### Recommendations to Reduce Vulnerabilities

There are a variety of measures, structural and non-structural, that can be employed to reduce the vulnerability of both the NMIA and its access route to the natural hazards identified as those they are most susceptible to. These recommendations will be outlined based on specific hazard threats to the NMIA and its access route.

### Recommendations to reduce vulnerability to Storm Surges and Flooding on NMIA's Access Route (Harbour View Roundabout to NMIA Facility)

As outlined in previous chapters, the NMIA's access route has been and continues to be affected by flooding from the sea and sometimes inundation of parts of the roadway, either during hurricanes/ storms or periods of heavy rainfall. Some of the key recommendations that were considered by this research are already being pursued under the "Palisadoes Peninsula Shoreline Protection and Rehabilitation Project". These include the erection of a seawall to protect the NMIA's Access Route against direct wave attacks and the construction of boulder revetments to provide protection against high tides and storm surges (both features seen in Figure 26) as well as the raising of the roadway from 0.6-1.0 metre to 2.4-3.2 metres.

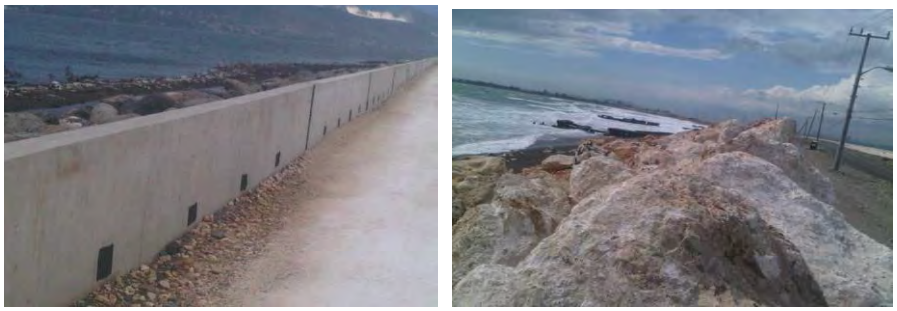


***Figure 26: Photographs showing sea wall and boulder revetments along NMIA Access Route***
*Photographs by Christopher Grant*

This research will not repeat such initiatives as recommendations; (however these measures must be properly maintained) but attempts to make suggestions to accompany those projects in providing greater protection against wave action. The Groynes along the Palisadoes Shoreline which were installed after Hurricane Charlie in 1951 are mostly nonexistent or tenuous at best, this study proposes the replacement of protective devices along the shoreline, however not the same groyne structure that was originally in place. The use of Wave Attenuation Devices is being recommended along the NMIA's Access Route from the Harbour View Roundabout to the NMIA, as when combined with the other onshore protection initiatives being employed will build up resistance in the protective barrier.

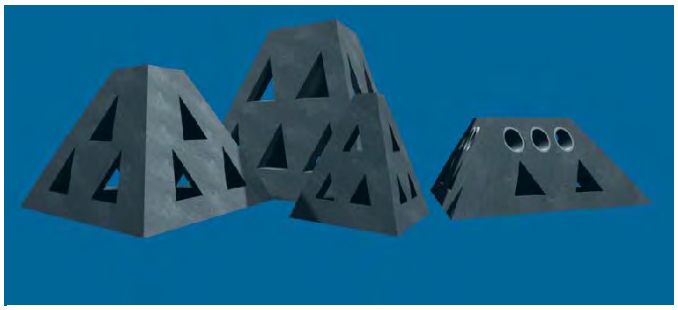


*Figure 27: Wave Attenuation Devices (Adapted from Nushore, Beach Management)*

Wave Attenuation Devices are designed in various forms and sizes to fit to different coastal environments. They are made of marine concrete and reinforced steel rebars. These devices when placed close to the shoreline cause a lowering of the water depth below the surface. The lowering of the depth will result in a lower wave height, reducing the wave energy and the impact of the waves on the shoreline (www.nushore.com). This action is illustrated in Figure 28.

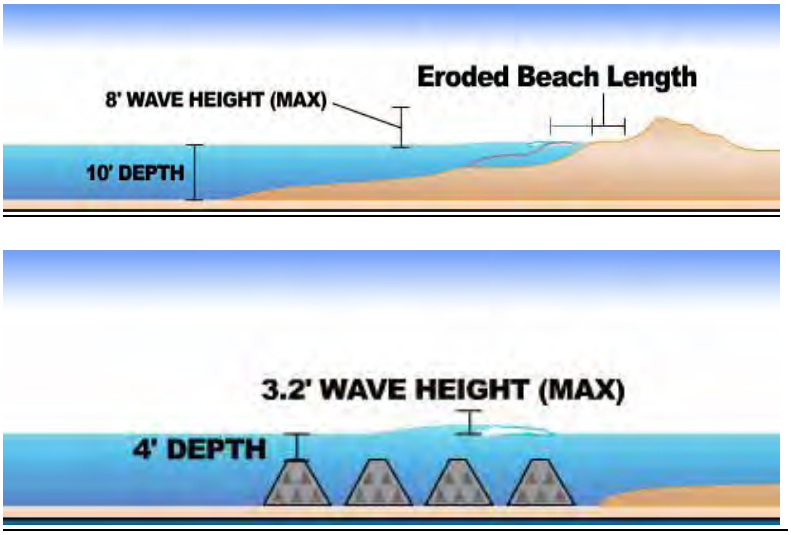



*Figure 28: Illustrations showing how wave attenuation devices reduce wave height and impact on shoreline*

The illustrations show the considerable reduction in wave height caused by the use of the attenuation devices. These devices, along with measures being pursued will increase shoreline protection.

The use of these devices in addition to Beach Nourishment is also recommended for use along the section of the Palisadoes Road that is not covered by the Palisadoes Rehabilitation Project, but is still adjacent to the NMIA (area shown in map below, adapted from Google Earth). Beach Nourishment is "the artificial replacement and/or addition of sediment to beaches." (www.oas.org).

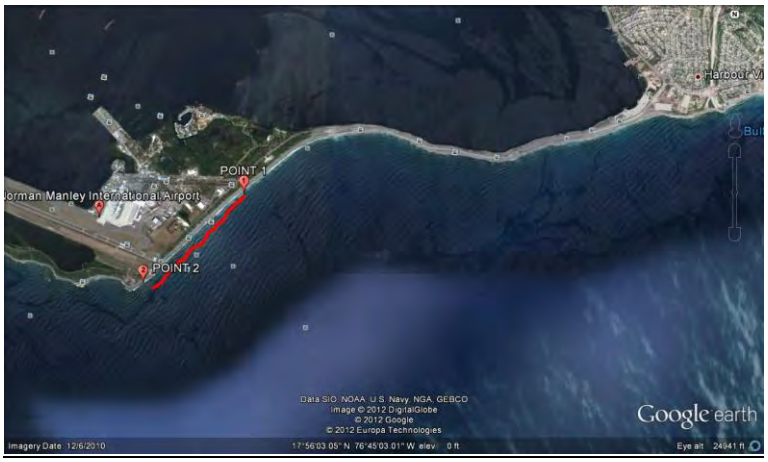



*Figure 32: Map showing area recommended for Beach Nourishment and Wave Attenuation Devices*

The recommended area lies between Point 1 and Point 2 on map above as the Palisadoes "Shoreline Rehabilitation Project" only extends from Harbour View to Point 1; however the area between Point 1 and Point 2 is only protected by natural barriers (sand dunes and small vegetation) and if storm surges are able to clear these barriers, the NMIA is in direct threat, as only the road separates the facility from the sea. Storm events and wave action will reduce natural sand protection over time and with the expected increase in storm surges due to sea level rise, surges which would not normally reach on NMIA property may begin to, if there is inadequate protection in that vulnerable area. Therefore the artificial periodic replacement of eroded sand to build up sand dunes, as well as the placement of beach protection devices will reduce susceptibility of the NMIA being affected by storm surges. The maintenance and the increase in vegetation cover may also increase protection in this area.

### Reducing storm surge and flooding vulnerability at NMIA facility

The suggested recommendations above, if applied to the section of the Palisadoes Road adjacent to the NMIA facility will serve to reduce vulnerability of the facility to storm surge flooding. In addition, the NMIA may have to consider some form of protection such as a protective wall on the harbour side of the entity, to guard critical facilities such as the fire station and fuel farm which are located closest to the sea. Also the planned improvement of underground drainage at the NMIA facility should also serve to reduce the possibility of flood waters settling and causing possible inundation of parts of the airport. If necessary, the NMIA can also undertake capacity improvements to their water treatment facilities and pumping stations to reduce flooding.

### Recommendations to reduce vulnerability to earthquakes

The first recommendation offered to reduce possible vulnerability of the NMIA to ground shaking from earthquakes is to conduct a seismic audit of all buildings, particularly those older than 30. This main purpose of this audit is to identify possible areas of structural weakness and perform subsequent appropriate seismic retrofitting. The choice of retrofitting methods will depend on the results of the audit and the extent of structural weakness. However there are some conventional as well as new and emerging methods of retrofitting that could be considered, if found to be necessary by experts. Conventional retrofitting methods, according to the Information Services and Technology Department (IST) of the Massachusetts Institute of Technology (MIT) include the addition of new structural elements to existing buildings and enlarging the existing members (www.mit.edu). These may include post cast addition to shear walls and implementation of steel bracings. These are the methods most familiar to construction experts and among are the least costly. These initiatives help in taking pressure off the columns and beams in building structures and therefore increase their strength (www.mit.edu). However one non-traditional method, though costly, that could be examined is the use of Fibre Reinforced Plastic (FRP) composite materials for structural strengthening and repair. This method involves the wrapping of

columns and beams with FRP material to increase their load carrying capacity, stiffness and ductility (www.mit.edu).

It is also being recommended that the Tempered Glass that is used in the new terminal building, which is 5 times stronger than conventional glass and shatters into small oval pieces when broken, should be used on all buildings throughout the NMIA facility. This will reduce the likelihood of personnel damage during earthquakes and even from winds and projectiles during hurricanes. In regard to Tsunami, possibly the best protection is a Tsunami warning system which may be beyond the capacity of NMIA management. However an effective response and evacuation plan, as well as informed NMIA stakeholders may assist is saving lives if such an event should occur.

### Recommendations to reduce vulnerability to hurricanes/strong winds and sea level rise

The NMIA, in the opinion of this research has a very proactive and effective disaster plan for hurricanes/strong winds. Therefore the recommendations are for the continuation and expansion of certain aspects of that disaster plan. Such expansion includes the wind proofing of all remaining buildings on the facility by the installation of hurricane shutters and the installation of the protective membrane which exists on some slab roofs and all similar roofs to protect against water intrusion. The existing regular assessment of structures by NMIA engineering and emergency personnel, as well as the high priority placed on repairing identified breaches must continue.

In regard to the NMIA access route, it is recommended that the process of replacing wooden utility poles with concrete ones be completed to reduce vulnerability of being damaged or destroyed by strong winds.

### Recommendations to reduce vulnerability to sea level rise

It is perhaps inevitable that the NMIA's runways and taxiways may have to be elevated to protect against the reality of possible inundation by rising sea levels, as well as possible increases in size and intensity of storm surges associated with the phenomenon. The level of elevation will have to be determined by experts. However if sea level rise is more rapid than anticipated by experts and climatic modeling, the NMIA may have to be abandoned all together as the critical facilities needed to run the entity may become inundated to the point where mitigation is impossible or simply too costly. The government and other stakeholders may be forced by sea level rise to abandon both our two international airports and focus on inland locations, rather than ones close to the coastline.

# Seismic Analysis and Fragility Assessment of Reinforced Concrete Structures through Numerical Modelling

*By Cory George*

This dissertation was submitted in partial fulfilment of the requirements of the degree of Master of Science in Earthquake Engineering with Disaster Management at University College London – 2018

ABSTRACT

This research investigates the differences observed in structural responses produced by the Opensees and Seismostruct numerical modelling software. The study aims on developing models to represent low rise reinforced concrete structures which will be studied under both static and dynamic loading. The structures are modelled using well known numerical modelling approaches; lumped plasticity and distributed plasticity. Each program has specific methods to apply these approaches however the aim is to generate accurate models in both to ensure proper results. The lumped plasticity approach would be applied in Opensees and the distributed plasticity in Seismostruct.

The nonlinear analyses conducted in this study were nonlinear static pushover analysis and the nonlinear time history analysis. To conduct the nonlinear time history analysis, 20 well known earthquake records typically used by earthquake engineers are utilized. To gain further insight on the impact the results from each software, may have on a wider scale, a probabilistic assessment was conducted showing how the responses from the programs can affect risk.

The results from the pushover analysis resulted seimostruct producing conservative results, where the frames yielded at lower base shears compared to that of Opensees. However when conducting the nonlinear time history analysis, Opensees produced lower peak responses compared to Seimostruct. This therefore shows that precautions are required when selecting numerical modelling techniques to conduct analysis. It illustrates that some level of understanding of the structure to be analysed as well as the limitations of each approach is required to get a better understanding. This research would provide some insight on what should be considered when using these modelling approaches.

## Introduction

### Background

The emergence of performance based earthquake engineering seeks to enable more accurate and transparent assessment of life safety risks and damage by simulating the nonlinear response of a structural system to seismic excitation. (Filippou and Fenves 2004, Zendaoui, Kadid and Yahiaoui, 2016). The first generation of performance-based assessment provisions, such as FEMA 273 and 356 (ASCE 1997; ASCE 2000b) and ATC 40 (ATC 1996), provided an excellent first step toward codifying approaches that embrace nonlinear analysis to simulate system performance and articulate performance metrics for the onset of damage up to structural collapse. These nonlinear analysis techniques are generally seeking practical design applications to assess the performance of buildings under static and dynamic loads.

However, new performance based guidelines, according to FEMA -273 (1997), states that buildings are required to be analysed using nonlinear static pushover analysis or non-linear dynamic analyses to regulate the global and local demands. Therefore, the use of nonlinear analysis demands the availability of robust and computationally efficient models for performing analyses in a reasonable amount of time (Coleman and Spacone 2001).

Therefore, accurate and computationally efficient numerical models that represent the cyclic loading of plastic hinges in beam–column elements, including the effect of degradation, are thus required to simulate the seismic response and evaluate the performance of structural systems (Scott and Fenves 2006).In this research the use of two well-known modelling techniques will be used in Opensees and Seismostruct programs and the responses would both be compared.

## Aims and Scope

The aim of this research is to understand the impact and extent of utilising different numerical software (Opensees, Seismostruct) on the obtained seismic performance and consequently the damage assessment, by focusing on low-rise reinforced concrete structures. To achieve this research goal, three mid-rise RC residential buildings, each 2 storey high and having same plan dimensions with different structural member configurations, were selected and analysed in both software and their resulting seismic responses are compared using a modified capacity spectrum method (FRACAS).The chosen RC buildings configurations are classified as generic building type C1L (Low-Rise Concrete Moment Frame) according to HAZUS documentation provided by FEMA. Three generic buildings were analysed using both Nonlinear Static Pushover Analysis and Nonlinear Time History Analysis (NLTHA) where the buildings performances for three limit states including slight damage, moderate damage and collapse were determined from the Nonlinear Static Pushover analysis. Then the fragility assessment is performed where the fragility curves are developed for the three limit states and fragility curves of the three buildings in both software are compared to determine the sensitivity of the software.

## Objectives

The objectives of this research are:

1) A comprehensive review of available literature on comparing the seismic evaluation through the considered software (Opensees and Seismostruct).
2) Identify the advantages and disadvantages of each software by focusing on their approach to modelling components and estimating the nonlinearity in both material and geometry.
3) Identifying and modelling a number of existing residential buildings with highest possible detailing and components through each software.
4) Analysing the numerical models through Static Pushover and Non Linear Time History Analysis, to evaluate the seismic performance of the building and its potential deficiencies.
5) Identify the most applicable damage states and thresholds based on the results obtained through each model.
6) Deriving and comparing the analytical Fragility Functions.

## Thesis Organisation

This research contains seven sections that explain the seismic responses of the three low rise RC generic buildings modelled as two-dimensional frame and 1, three-dimensional building. The design of the generic structures were obtained from a structural member database produced by Berry et al and analysed using the Nonlinear Static Pushover Analysis (NLSPOA) and Nonlinear Time History Analysis (NLTHA) using both software. Three limit states were then determined from Push over curves and fragility curves were developed for the three buildings in the x direction for the 2 dimensional frame.

### *Background*

This chapter gives a general background of the research including the purpose and understanding of how numerical analysis is conducted in specific software and how it approaches modelling components as well as considerations that need to be addressed for engineers who intend on conducting numerical analysis using these programs. Also in this chapter the main objectives of the research and thesis is outlined.

### *Theoretical Background*

This section provides a comprehensive review available literature on comparing the seismic evaluation through the Opensees and Seismostruct software. First, a discussion about techniques used to model structural elements in order to simulate the response of reinforced concrete buildings subjected to seismic

activity. Secondly, previous studies and history on the development of the concentrated and distributed plasticity nonlinear modelling techniques. Third, the advantages and disadvantages of the both nonlinear modelling techniques are discussed. Finally, the approach each software uses to model the components and estimating nonlinearity in both material and geometry using the concentrated and distributed plasticity.

***Methodology***
This section describes the approach used to conduct the study in the form of a flow chart.

***Design***
This chapter discusses the description and RC design of the three generic RC frames. It first describes the structural configuration of the sample generic frames under investigation illustrating their elevation view. Then a description of the structural database being used and purpose in this research project. Finally, all the building member cross sections illustrated as well as the associated structural properties are listed.

***Numerical Structural Model***
This chapter explains the nonlinear modelling of the three, 2 dimensional RC frames and 3 dimensional building for numerical simulation in Opensees and Seismostruct with the intention of ensuring both models are identical. The geometric and material nonlinearities and materials types (i.e. Reinforcement and concrete) used in this research are highlighted and discussed. The results are the natural periods and the first three translational modes.

***Pushover Analysis***
This chapter focuses on the nonlinear static pushover of the building models discussed in the chapter four and five. Firstly, the modal analysis results are shown including the modal periods and shapes to validate numerical models in Opensees and Seismostruct models. The target displacement is determined. The chapter concludes with a discussion

***Nonlinear-Time History Analysis***
This chapter contains the assessment of the nonlinear dynamic time history analysis in great detail by comparing the seismic responses of the three sample generic two dimensional frames. The results are presented and compared with PA's results. The fundamental periods would then be used to develop representations of the Intensity Measure (IM) vs Engineering Demand Parameters (EDP) plots. The chapter concludes with a discussion of the results.

***Fragility Analysis***
This chapter discusses the development of the modified capacity spectrum method and the procedure used to generate the fragility curves. A comparison of the fragility curves for two frames models are shown aiming to show the sensitivity of the results or responses from each software.

***Further Analysis***
The chapter contains the investigation of the structural response regarding a 3 dimensional structure using fibre based model in Opensees and comparing with the force based concentrated plasticity and displacement based distributed plasticity in Seismostruct. A pushover analysis is conducted and the results are compared and discussed.

***Conclusion***
Main conclusion and remarks are presented

## Literature Review

### Element Modeling

In order to simulate the response of under designed reinforced concrete buildings subjected to seismic activity, it is essential to take into account the flexure behaviour of beams and columns, shear behaviour of columns and failure in connections. These behaviours are simulated using numerical models to replicate the non-ductile behaviour of structural elements in which the results can be further used to

perform collapse risk assessments. Currently, there are five idealized model types **(See Figure 2.1)** that can be used to represent the inelastic flexural response of beam –column elements which are used to estimate the lateral displacements due to flexure, bar slip and shear.

These fall into two main categories. These are 1) lumped plasticity at the ends of the element or 2) distributed plasticity along its length **(NIST GCR 10-917-5, 2010)**:

- Firstly, as illustrated in Figure 2-1 below, the most simplified approach , lumped plasticity, implies that all inelastic deformations is concentrated at the ends of the element.
- The second approach that has become very popular is the distributed plasticity approach. This modelling method is can be idealised as either having an inelastic response within a specified length (finite length hinge model) **(Figure 2-3.c),** or a fibre section formulation **(Figure 2-3.d).**The fibre section considers the inelastic behaviour to be distributed along the length of the member using plate like sections consisting of the structural member properties along the member length in each fibre cross section. The last model type is the considered the most complex numerical modelling technique, which discretizes the member cross section into finite elements along the member length. **(Figure 2-3.e)**

Presently, the fibre model type **(Figure 2-3.d)** is the most commonly used approach due to its computational efficiency. This approach utilizes uniaxial stress–strain relationships for both concrete and steel reinforcement resulting in the ability to model, various concrete regions and steel reinforcement independently.

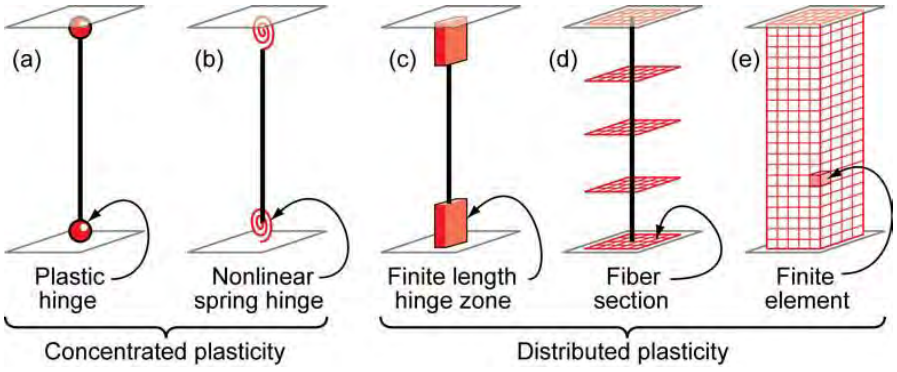



**Figure 2-1 Idealization of structural component (from NIST GCR 10-917-7, 2010)**

These existing models may not accurately predict the shear capacity for columns that undergo flexural yielding before shear failure due to the fact that they don't account for degradation of shear strength with inelastic flexural deformations. However, they are appropriate for flexure-controlled columns or pure shear failures. In addition to the above, no guidance is provided for simulating the response once shear failure is detected. According to (ATC-95 (2013), models that are computationally efficient, calibrated to a wide range of column failure modes, have the ability to transit between shear and flexure failures, capable of simulating the degrading lateral-force response including in cycle and cyclic degradation, compatible with joint and bar slip response and ability to adjust to different boundary conditions should be used to simulate nonlinear response of existing columns leading to shear and subsequent axial failure.

In retrospect of the above mentioned issues, three models were developed by Elwood (2004), LeBorgne and Ghannoum (2009), and Haselton et al. (2008) which were overcame these concerns and contain the main features suggested by ATC -95 (2013) listed above. A review of Haselton et al.(2008), is presented in chapter 5 as it is used in this study.

## Previous studies and development of Concentrated and Distributed plasticity models.

### *Concentrated Plasticity*

The lumped plasticity model as mentioned in section 2.1, is conceptualised by modelling elements with its nonlinear capabilities concentrated at member ends. The general model can be envisioned by separating a line element into linear elastic and elastic perfectly plastic components. The elastic member accounts for the strain hardening characteristics of the reinforcing steel, while the elastic perfectly plastic member accounts for yielding (plastic deformations) of the reinforcement concentrated in the plastic hinges at the element ends. The plastic hinges are represented as zero length rotational springs elements. The plastic behaviour of the rotational springs when subjected to seismic loads, is provided by means of hysteresis models which have a better chance of capturing the nonlinear degrading response of members. This is due to calibration of the springs to test data of various reinforced concrete sections on moment –rotation and hysteresis curves.

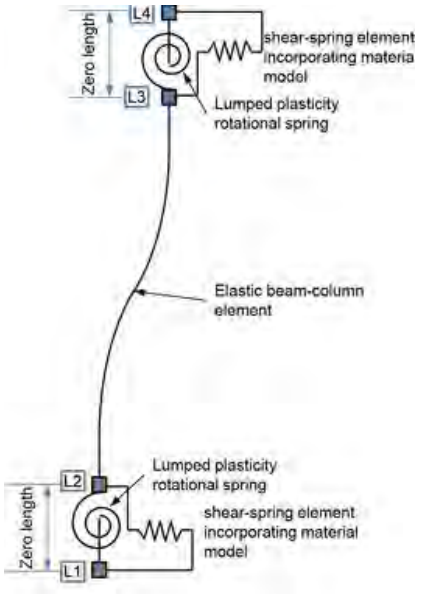



**Figure 2-2 Showing elastic beam column line element and zero length lumped plasticity rotational springs**

The earliest component model element was introduced by Clough and Johnston (1967) and was only restricted to the bilinear-type hysteresis moment rotation**.** This model was known as the two component model whereby both elastic and inelastic components acted in parallel with each other. Following this, further research was conducted by Giberson (1967) resulting upgrading the model removing the restriction. This updated model was referred to as the one component model as it consisted of two rotational springs attached in series at the ends of an elastic element. This model is more popular than the two component model because of its simplicity and the fact that the member end deformations depends exclusively on the moment acting at the end. This therefore, allows for modelling various complex hysteretic responses. There were later models which were developed allowing the variation of the location of the plastic hinges which was found to perform well in low rise structures according to (Roh, Reinhorn and Lee, 2018).The results showed that this model provided a good evaluation of the base shear and global responses compared to its ability to capture inter-storey deformations and local responses.

Presently, there exist several hysteretic models with calibrated parameters that can be used to represent moment-rotation relationships for non-linear springs. Such models include cyclic stiffness degradation in flexure and shear, (Takeda et al .1970), pinching under reversal, Brancaleoni et al. (1983) and fixed end rotations at the beam – column joint interface due to bar pull out (Filippou and Issa 1988). Therefore the choice of hysteretic models depends on the user.

### *Distributed Plasticity*

According to Spacone and El-Tawil, 2004, distributed plasticity approaches are more accurate than lumped plasticity approaches, because in reality, it is impossible to achieve all inelastic behaviour at the ends of a member. The behaviour of the cross section is either in agreement with plasticity theory of stress and strain responses or derived by discretization of the cross section into fibres, as illustrated in spread plasticity fibre models. An assumption of these models is that the strains are linearly distributed over the cross section. The fiber based models are catergorized into two types; displacement- based (stiffness-based) and forced-based (flexibility-based). Displacement- based requires a predefined displacement shape-function to interpolate the displacements along the element length with respect to the nodal displacements and force-based (flexibility-based) requires using interpolation functions to estimate

the forces along the element length with respect to the nodal forces. These will be discussed in more detail in its application in Seismostruct in chapter 6.

The distributed plasticity approach behaviour is examined by numerical integrations through the member cross sections and along the member length. Uniaxial material models are defined to capture the nonlinear hysteric axial stress –strain characteristics in the cross section. The plane sections remain plane assumption is reinforced, where uniaxial material fibers are numerically integrated over the cross section to obtain axial forces and moment stresses as well as incremental moment curvature and axial force strain relations. The cross sections are then integrated numerically at discreet sections along the member length, using displacement or force interpolation functions (Kunnath et al.1990, Spacone et al. 1996).

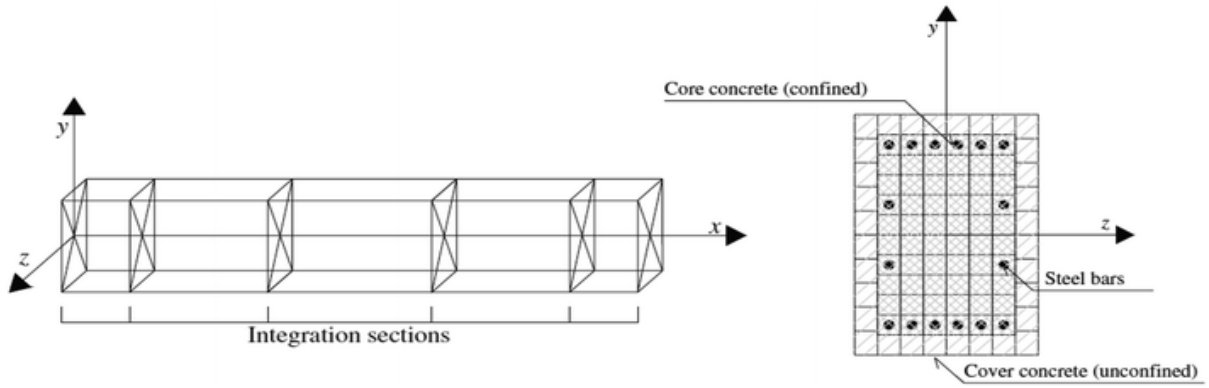



**Figure 2-3: Showing integration of sections and discretized reinforced concrete element**

Distributed fiber formulations do not generally report plastic hinge rotations, however, it provides the resultant strains in concrete cross sections. This is due to the strain demands having a highly sensitive response to moment gradient, integration method, element length and strain hardening parameters. Therefore, the strain demands and threshold damage state limits should be referenced with concentrated hinge models, which considers plastic hinge rotations (Nassirpour, 2018).

Although there has been continuous research and development to the concentrated and distributed plasticity modelling there are some considerations that need to be highlighted when conducting numerical analyses. Therefore, following section provides a summarised insight into the advantages and disadvantages of the abovementioned numerical modelling techniques.

## Advantages and Disadvatages of Lumped and Distributed Plasticity

### *Lumped Plasticity*

### Advantages

- Simplicity reduces computation effort, computational costs and storage requirements and improves the numerical stability of computations.
- Can specify complex behaviour.
- Lumped plasticity models include hysteretic rules for the hinge behaviour, which can account for many physical phenomena for example cyclic degradation in stiffness and strength, pinching under reversal.
- Applicable to various types of components such as beams, shear walls connections
- Preferred for performance based simulations
- Captures interface effects such as bar pull out and shear sliding.

### Disadvantages (Almeida, J .P. Tarquinii, D.and Beyer,K, 2014)

- They are over simplified e.g. important aspects of the cyclic behaviour of reinforced concrete members such as the post-yield response and axial-flexural interaction which can produce inaccurate results.

- The use of empirical control parameters in limits the generality as the values of these parameters are usually selected by trial and error to produce model response that fit with experimental results of a limited number of reinforced concrete components.
- Selection of parameters for representing the experimental hysteretic behaviour because a). The model parameters depend not only on the section characteristics but also, on the load and deformation history, thus limiting the generality of the approach.
- Inability to describe adequately the deformation softening behaviour of reinforced concrete members. This is observed as the reduction in lateral resistance of an axially loaded cantilever column under monotonically increasing lateral tip displacement.
- It has to be mentioned that such models usually lead to better response estimates for steel rather than for concrete structures.
- Localization occurs if a trilinear approximation of the moment –curvature relation with softening branch is defined for the plastic hinge.
- Cannot capture axial force- moment interactions.
- Model parameters are calibrated on a dataset consisting of mainly columns with flexure dominated failures model parameters are pre-defined, and therefore, it is not capable of

***Distributed Plasticity models advantages and disadvantages (Almeida, J .P, Tarquinii, D. and Beyer, K, 2014)***

**Advantages**

1. Can capture the spread of plasticity.
2. Hysteretic behaviour is implicitly defined at the uniaxial material stress-strain level.
3. Capture flexural deformation and its spread along an assumed number of integration sections along element.
4. P -delta effects: they can be accounted for in the finite element formulation.
5. Sectional response (local level) can capture axial load –moment interaction
6. Are independent of cross sections.
7. Does not require a predetermined length where the inelasticity can occur.
8. Less reliant on calibration of elements.

**Disadvantages**

- The definition of the integration scheme and number of integration sections requires expertise.
- Computational Cost: For structures composed of many elements and a large number of fibres per section, computing time can increase considerably for nonlinear dynamic time histories.
- Anchorage slip (strain penetration): requires explicit (separate) modelling, e.g. with a zero length element.
- Cannot capture complex response (softening, pinching) modes easily.(Nassipour,2018)
- Assumes a strain-hardening response.

## Software

***Opensees***

The Open System for Earthquake Engineering Simulation (Opensees) is a software framework for simulating the seismic response of structures. Opensees has been developed as the computational platform for research in performance-based earthquake engineering at the Pacific Earthquake Engineering Research Centre. (PEER) by Frank McKenna and Gregory L. Fenves. It has different material

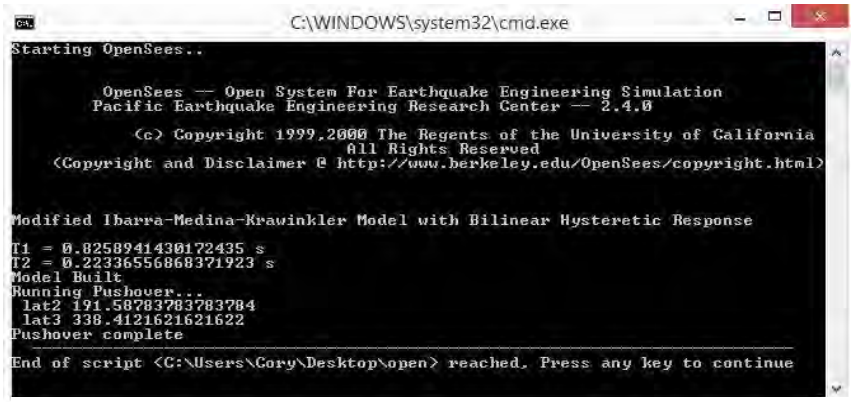



**Figure 2-4: Showing Opensees processing interface for pushover analysis**

models, elements and solution algorithms used for conducting structural and dynamic analyses. The software is based on finite element methods and interprets scripts of tool command language (Tcl). Furthermore, it is an open-source and gives access to all earthquake engineering researchers and students. The main advantage is that the user must create the model manually and define all the steps throughout the procedures. This however enable interested researchers the ability to gain an analytical skills in manual numerical modelling. It has recently been upgraded to include a graphical user interface (GUI) however this may take away from understand the functions and commands of the software. An disadvantage is that some material models may not perform as they should, i.e. confined elements. Figures 2-4 and 2-5 provides a visual of the processing interface of the software.


**Figure 2-5: An example of a tcl-script for a dynamic time-history analysis**

### *Simulation strategies for nonlinear beam-column in Opensees*

There are three different beam-column element options available in Opensees (McKenna, 2011) to simulate nonlinear material response. The first method consist into model the column using lumped plasticity in which the nonlinear behaviour is concentrated at the ends of an elastic element. The other two modelling solutions allow the simulation of nonlinear response using a distributed plasticity formulation based on finite-element methods. For the purposes of this research, only the lumped plasticity option would be discussed.

### *Lumped plasticity Element*

As discussed in section 2.2, the lumped plasticity can be introduced consists of an elastic beam-column element with two zero-length elements at both the element extremities. The zero-length elements are associated to a rotational hinge model with hysteretic rules able to capture the flexural behaviour of the elements. The behaviour of rotational hinge is associated to a uniaxial material that express the plastic hinge behaviour in terms of moment-rotation relationship, however, caution is advised in implementing the stiffness property of the element connecting the elastic beam –column element to the hinges. The moment- rotation relation can be represented as monotonic backbone curves. These curves are often calibrated to a particular monotonic response. These are bilinear, trilinear, elastic – nonlinear hardening and lastly a monotonic curve including capping or residual strength.

### Modified Ibarra-Medina-Krawinkler Deterioration Model

The Ibarra- Medina-Krawinkler model (IMK) analytical model developed by Ibarra et al (2005), is implemented in Opensees (Mckenna, 1997) and is used to represent the concentrated plasticity zero length element. The monotonic curve used to represent the response of the IMK model is the bilinear curve shown in Figure 6 below. The model specifies the demand limits of the structural member also

simulating the strength deterioration (negative slope) once the maximum moment capacity ($M_c$) is reached. If the model is asymmetrical, a similar response is seen upon but for a negative moment capacity.

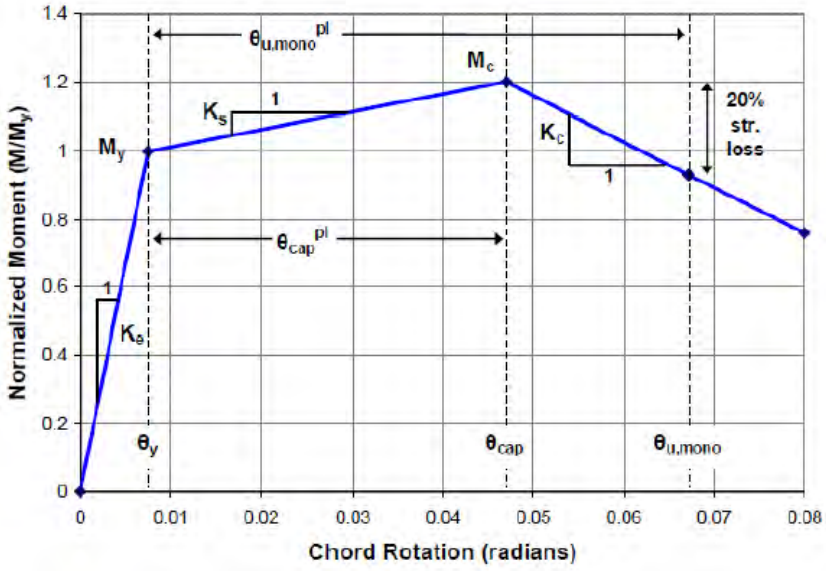



**Figure 2-6: Showing monotonic bilinear backbone curve (elastic perfectly plastic with linear hardening)**

The characteristics that defines the monotonic curve in the modified IMK model as shown in figure 6, are initial elastic stiffness $K_e$, the effective yield moment strength $M_y$, the post yield strength ratio $M_c / M_y$ or $\theta_{cap\ pl}$, and the residual moment strength $M_r = {}_kM_y$. The backbone curve can be described by three deformation parameters. These are the:

- Pre capping plastic rotation, $\theta_{p,}$ which is associated with the components behaviour prior to local instabilities (buckling of reinforcing bars). This represents the initiation of the loss of strength.
- Post capping plastic rotation $\theta_{pc}$; which is associated with component behaviour after the occurrence of local instabilities. The smaller the value, the sooner the component reaches zero bending strength capacity therefore building collapse is imminent.
- The ultimate rotation $\theta_u$, which is associated with failure modes consisting of sudden strength loss of a structural component (e.g., ductile tearing). (Ibarra, 2013).

If the hysteretic/cyclic behaviour of a structural component is asymmetric, the aforementioned parameters is also defined for positive and negative loading directions as illustrated in Figure 7.

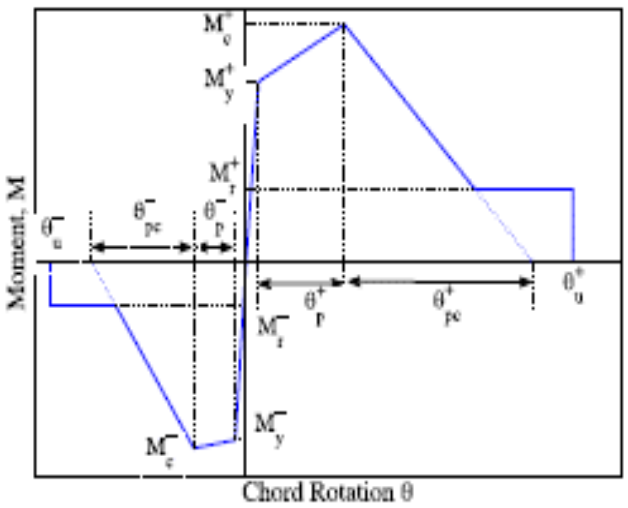



**Figure 2-7: Showing the modified (IMK) model behaviour to positive and negative loading**

**Description of hysteretic models without degradation**

The hysteretic models available to conduct nonlinear analysis are: a bilinear, peak-oriented, and pinched hysteretic response, which represents is a modification to the traditional hysteretic models needed to incorporate the deteriorating backbone curve.

***Modified Ibarra-Medina-Krawinkler (IMK) deterioration model with bilinear hysteretic response***

This numerical model is able to consider asymmetric cyclic deterioration in strength and stiffness in order to simulate the behaviour of composite steel beams. It is also able to consider the residual strength of steel components when subjected to monotonic/cyclic loading. This model is based on the standard bilinear hysteretic rules with kinematic strain hardening. These basic rules are preserved once post-capping and residual strength branches are included. However, it is necessary to consider the demand limitations as shown in Figure 8 when the backbone curve includes a section with negative gradient.

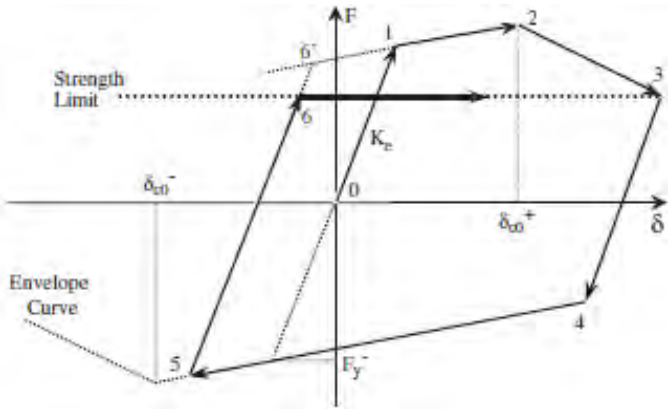



**Figure 2-8. Bilinear hysteretic response model with strength limit**

***Modified Ibarra-Medina-Krawinkler (IMK) deterioration model with peak-oriented hysteretic response***

This numerical model is able to consider asymmetric cyclic deterioration in strength and stiffness in order to simulate the behaviour of reinforced concrete beams that primarily fail in a flexural mode. This model has been calibrated with more than 200 RC beams (Lignos and Krawinkler 2012). This model keeps the basic hysteretic rules, however this curve is upgraded to incorporate strength capping and residual strength. The inclusion of a negative post capping stiffness however does not have an impact on the simple rule of the model (Lignos and Krawinkler 2012).

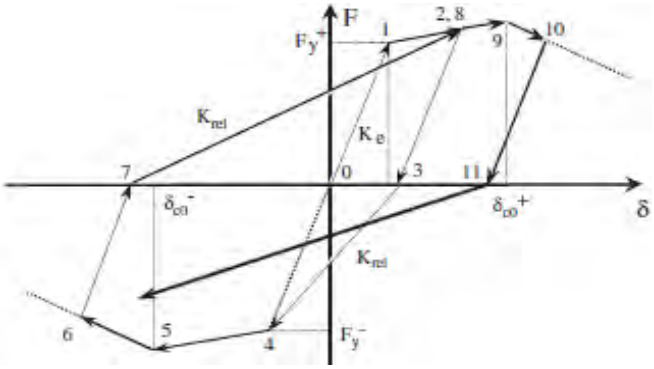



**Figure 2-9 Peak oriented hysteretic response model**

***Modified Ibarra-Medina-Krawinkler (IMK) deterioration model with* Pinching model *with hysteretic response.***

This numerical model is able to consider asymmetric cyclic deterioration in strength and stiffness in order to simulate the behaviour of reinforced concrete beams that fail primarily fail in a shear mode. This model is also able to simulate the hysteretic behaviour of shear connections, beam-to-column gusset plate connections and wooden components. The pinching model is similar to the peak-oriented model, except that reloading consists of two parts (Lignos and Krawinkler 2012).

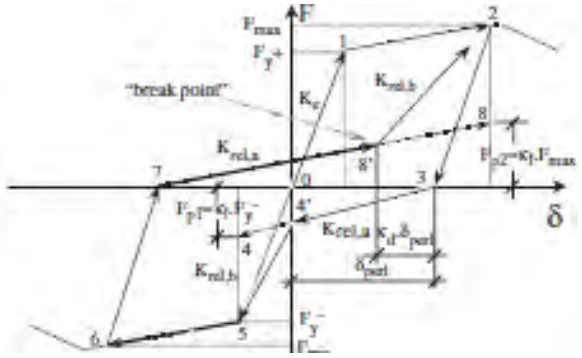



**Figure 2-10 a Pinching hysteretic model basic rules**

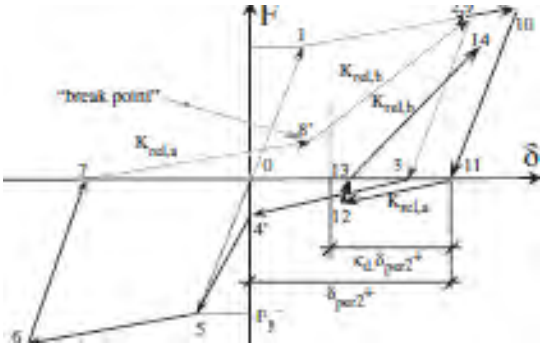



**Figure 2-10 b Modification of hysteretic model**

***Seismostruct***

This finite element program is has the ability to estimate large displacement responses of 2 and three dimensional models when conducting dynamic and static analyses. The programs also has the ability to consider for both material inelasticity and geometric nonlinearities. Seismostruct has built in database that stores structural materials models along such as steel, concrete, alloys and fiber- reinforced plastic. Additionally, it consists of three dimensional elements that utilize the material model configurations.

In order to generate a building with accuracy, Seismostruct uses offers the option if spread plasticity distributed along the members length and cross section. The loading capabilities offered in this program consists of static forces, displacements and earthquake ground motions for dynamic analysis. Furthermore, the program it allows for different types of analysis to be conducted. These are modal (eigenvalue) analysis, static analysis, static pushover analysis, static adaptive pushover analysis, incremental dynamic analysis, dynamic analysis and response spectrum analysis. (Seismosoft, 2016)

There are four nonlinear modelling strategies that can be implemented in this software, that utilize the two formulations above mentioned.

- Inelastic force-based frame element where plasticity is distributed along the entire length of the structural member inelastic.
- Inelastic force-based frame element where inelasticity is spread within a fixed length of the element. (Scott and Fenves (2006)).
- Inelastic displacement –based frame element, where the displacements and the plasticity is distributed along the length of element.
- Inelastic displacement–based frame element where the concentrated plasticity–displacement based element is within the plasticity concentrated at two element ends.

The modelling strategy applied to each column and beam was the distributed plasticity strategies. While the evaluated numerical models are based on different assumptions, input parameters for these elements are primarily physical properties such as section geometry and uniaxial behaviour of materials. The main advantages of this software is it incorporates a visual interface, which reduces the configuration time of models. Other aspects are that Seismotruct can be used directly with other programs such as excel. Finally, it has an advanced post-processing facility, including the ability to format output graphs and deformed shapes, which increases working efficiency. The main disadvantages are that the computational-times can be lengthy especially for nonlinear time history analysis also material and element configurations may not always be reliable.

## Methodology

This chapter outlines the procedure implemented in this study to investigate the response of the frames to nonlinear linear analysis in both Opensees and Seismostruct. The method is outlined schematically using a flow chart (see below).

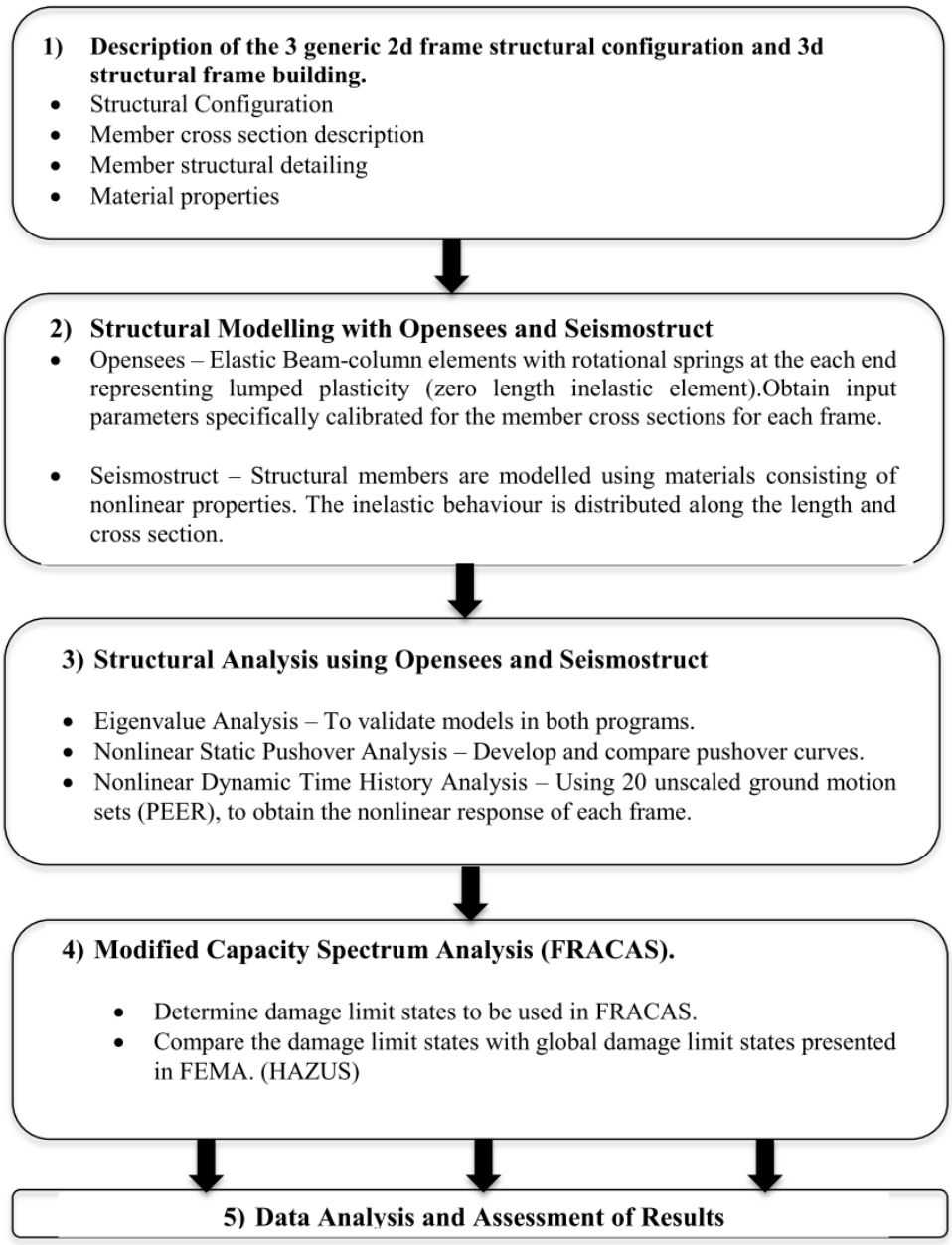



**Figure 3-1: Flow chart illustrating the analysis procedure**

## Description and Design of Reinforced Concrete Buildings

### Introduction

In this chapter, the structural characteristics and of the three low rise reinforced concrete (RC) generic frames are discussed. The three typologies used in this case study have the same height, bay width and number of bays whose lateral force resisting system consists of low code reinforced concrete moment-resisting system. However, to compare seismic responses, the members in the each frame are varied, resulting in classifying the three frames as weak, mid, strong frame.

The structural database used in this study is the Pacific Earthquake Engineering Research Centre's Structural Performance Database (PEER) (2005). This database was developed by Berry, Parrish, and Eberhard (Berry et al. 2004) at the University of Washington. It consists of cyclic and monotonic tests

results from 306 rectangular columns and 177 circular columns, where the data was transformed into equivalent cantilevers for ease of comparison (Berry et al.2004).The database provides reports on the column geometry, and reinforcement information, the failure mode, and force displacement history. (Haselton et al 2007).

This database was utilized as the parameters required for the Ibarra-Medina–Krawinkler rotational spring to be implemented in Opensees, was developed by Haselton, Liel, Lange and Deierlein (Haselton et al. 2007) using this database. The study was aimed at developing a database, to present a beam-column element models calibrated for predicting flexural response leading to global collapse of RC frame buildings. The lumped plasticity element model developed by Ibarra et al (2005) is used to model the behaviour of reinforced concrete beam column elements where the backbone curve and its respective cyclic rules provide for versatile modelling of cyclic response also capturing the negative stiffness of post peak response, enabling the modelling of the strain softening. This behaviour is critical for simulating the collapse of RC frame structures. The Ibarra element model plastic rotation capacity and cyclic deterioration parameters were calibrated to 255 reinforced concrete column test. They were able to produce predictive equations that can be used to determine a specific columns element model parameter for input into analysis. The parameters used for each structure would be presented in chapter 6.

## Building Descriptions

The three low rise RC buildings had the story heights i.e. first story having height of 15 feet and the second storey having height being 12 feet. The bay width in the x direction is 16.4 feet center to center span length (see Figure 4-1), however each lateral resisting system variation is described below.

**Frame 1** consists of beams and columns having cross sections of 7.78 inches by 7.78 inches, **Frame 2** beam and column elements with 13.77 inches by 13.77 inches and **Frame 3**, with the largest sections with 17.96 inches by 17.96 inches. These configurations are compared as they are simple representations of RC structures that can be idealised as reinforced concrete houses.

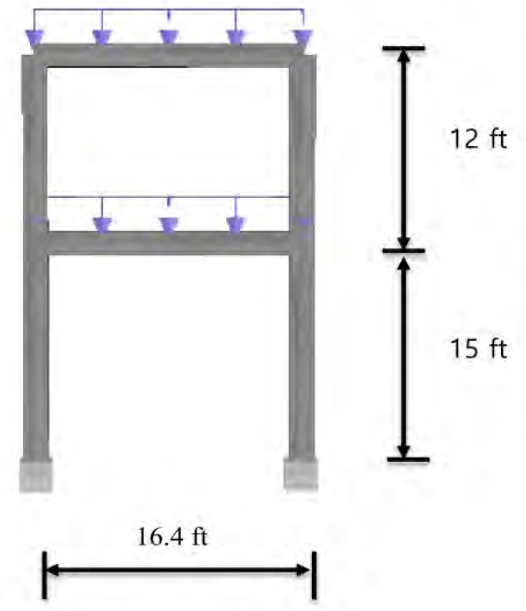
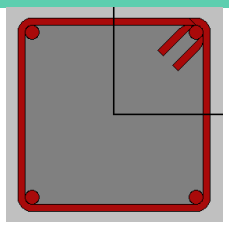



**Figure 4-1: Showing 2d frame structural dimensions**

*Table 4-1: Showing design cross sections and structural properties*

| Frame | Cross section | Reinforcement | Cross section layout |
|---|---|---|---|
| 1 | 7.78 x 7.78 in<br>Cover = 0.47 in | Longitudinal bars :<br>4 #5 bars<br>Transverse Bars : #<br>2 bars @0.5 in c/c |  |

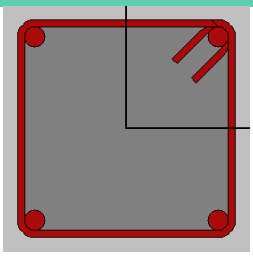
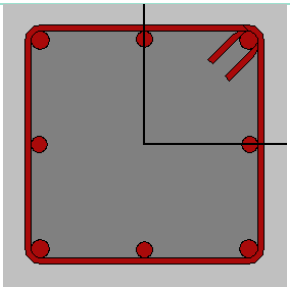
| Frame | Cross section | Reinforcement | Cross section layout |
|---|---|---|---|
| 2 | 13.77 x 13 .77 in<br>Cover = 0.88 in | Longitudinal bars :<br>4 # 9 bars<br>Transverse Bars :<br>#3 bars @ 3 in c/c |  |
| 3 | 17.96 x 17.96 in<br>Cover = 1.497 in | Longitudinal bars<br>Corner: 4 # 9<br>Interm: 2 # 8<br>Transverse bars :<br>#3 @7.9in<br>c/c |  |

*Table 4-2: Showing structural material properties*

| Frame | Characteristic Comp. Strength of Concrete, Fck (Ksi) | Modulus of Elasticity, Es,(Ksi) | Yield stress of long. Reinf. (Ksi) Fyl |
|---|---|---|---|
| 1 | 3.132 | 3190.37 | 53.808 |
| 2 | 5.047 | 4924..84 | 62.366 |
| 3 | 5.69 | 5230.79 | 63.671 |

## Masses and Loading

***Gravity loads***

The gravity loads based on the tributary areas is applied as a distributed load along the beams of the original frame members while the gravity loads from the original frame columns are applied as point loads on the nodes on the first floor and second floor leaning columns. The leaning columns were modelled only in Opensees to represent p-delta effects. The concept of the inclusion of the leaning column is to simulate P-$\Delta$ effects where the leaning column receive load from gravity loads only. It is connected to the frame using axially-rigid truss elements. The gravity loads were applied as constant time series load pattern because they always act on the frame. Any lateral resistance provided by leaning columns in ignored as its base is pinned at the base and between floors.

*Table 4-3: Showing the dead loads and point loads for each frame*

| Frames | Distributed load (kips/in) | | *Point loads (kips) (Pdelta column) | |
|---|---|---|---|---|
| | First floor beam | Second floor beam | First floor NO | Second floor |
| **1** | 0.05 | 0.04 | 6.10 | 5.15 |
| **2** | 0.08 | 0.06 | 11.93 | 8.97 |
| **3** | 0.11 | 0.08 | 17.94 | 12.90 |

### Lateral Loads

The lateral loads were calculated based on the effective weights of each floor. This weight includes the dead load from beams, columns and a 4 inch slab. The loads are then distributed in proportion to the individual floor weight and elevation. The loads are applied to nodes along the height of the frame. It is also worth mentioning that the seismic masses is applied and distributed equally as point loads at the beam –column joints of each floor. A summary of the lateral loads for the 3 frames are illustrated in the table below. A summary of the lateral loads for each frame are shown in the table above.

*Table 4-4: Showing lateral loads for each frame*

| Floor | Lateral loads (Kips) | | |
|---|---|---|---|
| | FRAME 1 | FRAME 2 | FRAME 3 |
| 2 | 5.557233034 | 8.17918895 | 10.87 |
| 1 | 3.430276924 | 5.635543456 | 7.91 |
| TOTAL | 8.99 | 13.81 | 18.79 |

## Numerical Structural Model

### Introduction

In earthquake engineering, the finite element model is usually the approach utilized for design and analysis of structures. The purpose of this approach is mainly to determine and adopt an accurate and reliable numerical structural model to perform linear and non-linear analysis. In this research, the frames are modelled using the two well-known software packages: Opensees and Seismostruct. In order to verify the accuracy of the finite element models, the natural frequencies of the numerical models are determined and compared.

### 5.2 Basic Model Description

The frame is represented as two-dimensional model. The model consists of beam –column elements, where masses from tributary as well as gravity loads are applied on beams. From the figure below, the original frame is idealised consisting of pier 1 and pier 2 .The leaning column which is modelled as pier 3 is introduced to account for P- delta effects. This is modelled only in Opensees as Seismostruct considers these effects differently. This would be discussed further in the next section. The leaning column is connected to the original frame by rigid links.

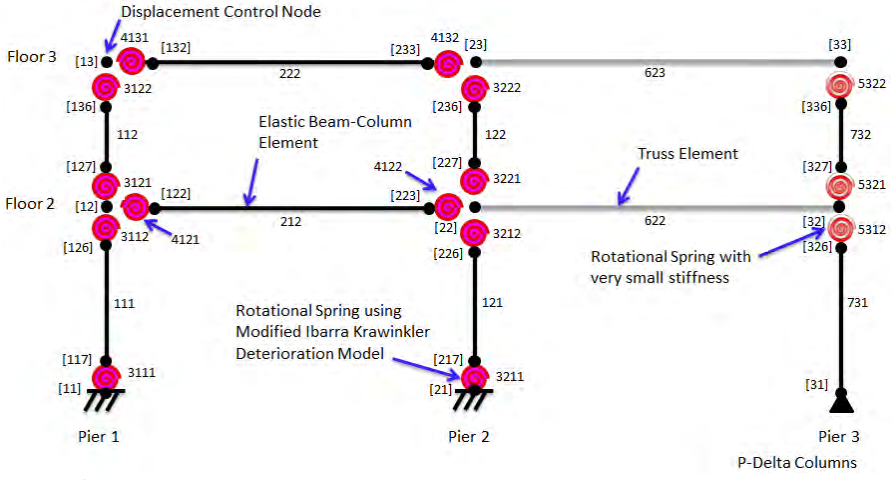



**Figure 5-1: Schematic representation of concentrated plasticity Opensees model with element number labels, node number labels and springs representing zero length elements (Opensees.berkeley.edu, 2018)**

### Material

***Defining the elastic column elements***

The materials used in both programs are defined based on the material properties from the Haselton et al. (2007) database. In Opensees, the beam- column elements are modeled as elastic elements while the nonlinear behavior is concentrated at the ends of which will be represented as zero-length rotational springs which is further discussed in the sections below. The elastic properties required for the Opensees model are the sectional area, moment of inertia and Young's modulus of elasticity. The formula used to

calculate the modulus of elasticity in Opensees; Ec = 57000 $57000\sqrt{f'c}\,psi$ (Review of Building Code Requirements for Structural Concrete (ACI 318-95) and Commentary (ACI 318R-95) by ACI Committee 318, 1996).The reinforcing steel is not modeled in these elements as the nonlinear action is represented by the rotational springs. The table below provides a summary of the Opensees input parameters.

*Table 5-1: Showing input parameters for Opensees software*

| Frame | C.S.A ($in^2$) | Moment of inertia ($in^4$) | Young's Modulus E (ksi) |
|---|---|---|---|
| 1 | 60.52 | 305 | 3190 |
| 2 | 189.61 | 2994 | 4049 |
| 3 | 322.5616 | 8667 | 4303 |

However, in Seismostruct, the material model used for concrete is the Mander et al. (1988) based on its nonlinear stress-strain relationship. See figure below. This concrete model is utilised because it considers the high strain rate with the concrete strength and stiffness increasing with loads being applied rapidly. It can also be used for various reinforcement configurations and in unconfined concrete. The confinement effects provided by the lateral transverse reinforcement are incorporated where the confining pressure is assumed throughout the entire stress strain range. The main input parameters required for this nonlinear concrete model are compressive and tensile strength, strain at peak stress. The previously introduced structural database, provides the characteristic compressive stress, $f_{ck}$, therefore, this value was converted in Seismostruct to obtain the mean compressive strength.

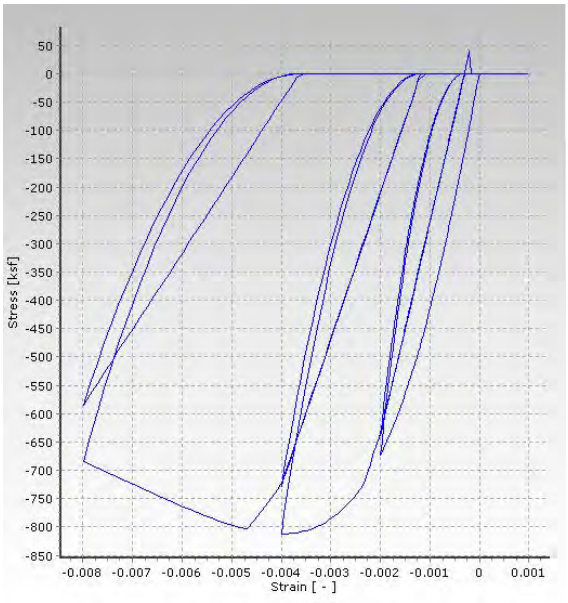



**Figure 5-1: Showing Mander (1988) Concrete material model frame 1 , (Seismostruct (2016)**

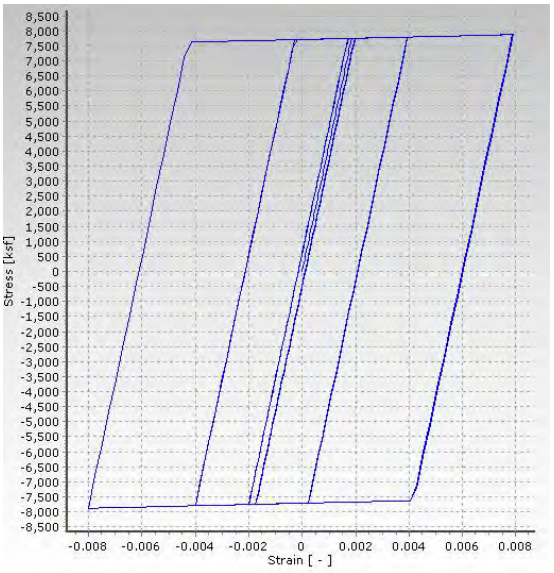



**Figure 5-2 : Showing bilinear steel model frame 1(Seismosoft (2016))**

The nonlinear model chosen in Seismostruct was the bilinear steel model. See figure below). This uniaxial bilinear stress –strain model has the capability to continue in the elastic range throughout the duration of loading. This characteristic is referred to the kinematic strain hardening. This function is assumed to have a linear response when the reinforcement is yielding.

This steel model is simple and input parameters are easily attainable. However, according to Seismostruct (2016) due to its very simple nature it is not suited for modelling reinforced concrete members subject to complex loading histories where significant load reversals might occur. This type was still selected as it represents the bilinear action represented by the bilinear rotational springs being used in Opensees. The

reinforcing steel properties for each reinforced concrete section was also provided in the database and was directly used as input in the Seismostruct.

## Elements

### *Opensees*

In Opensees, when using the lumped plasticity approach, the elements are modelled as elastic beam column elements and since it is a two dimensional frame the nodes are allowed 3 degrees of freedom considering bending and axial deformations. As previously mentioned, the cross sectional properties, reinforcement and type of element are all manually defined. The inelastic system depends on the nonlinear concept to absorb the forces acting on the structure. In order to perform the analysis the nonlinear element used is the concentrated plasticity rotational spring developed by Krawinkler (2005).This is implemented as uniaxial material known as the Modified Ibarra-Medina-Krawinkler deterioration model with bilinear hysteretic response (bilinear material).

### *Lumped Plasticity Element: Modified (IMK) Krawinkler Deterioration Model*

This element is modelled as zero-length spring elements connected at each end of the elastic elements. These elements are referred to as rotational springs which represent the structure's nonlinear behaviour. This concept is a simplification of an elements actual behaviour, however, according to Eads (2013), if implemented adequately, errors associated in the global dynamic response of the structure would not be introduced. It must be noted that the plastic hinges are only defined at the original frame column bases and not the leaning column. The parameters used for the nonlinear rotational springs are provided in Table 5-2 below, and are based on the properties provided by Hasselton et.al (2007).

*Table 5-2: Modelling parameters used for nonlinear rotational springs used in case study*

| No. | Ibarra-Medina-Krawrinkler Parameters | Frame 1 | Frame 2 | Frame 3 |
|---|---|---|---|---|
| 1 | Yield Moment ,My (kips-in) | 227 | 1695 | 3100 |
| 2 | Ratio of capping moment to yield moment Mc /My | 1.04 | 1.04 | 1.3 |
| 3 | Basic strength deterioration , Ls | 1000 | 1000 | 1000 |
| 4 | Unloading stiffness deterioration , Lk | 1000 | 1000 | 1000 |
| 5 | Accelerated reloading stiffness deterioration ,LA | 1000 | 1000 | 1000 |
| 6 | Post capping strength deterioration ,LD | 1000 | 1000 | 1000 |
| 7 | Exponent for basic strength deterioration , cS | 1 | 1 | 1 |
| 8 | Exponent for unloading stiffness deterioration cK | 1 | 1 | 1 |
| 9 | Exponent for accelerated reloading stiffness deterioration ,cA | 1 | 1 | 1 |
| 10 | Exponent for post capping strength deterioration , cD | 1 | 1 | 1 |
| 11 | Plastic rotation capacity for positive loading ,θp_P | 0.13 | 0.08 | 0.025 |
| 12 | Post capping rotation capacity for positive loading ,θ_pcP | 0.08 | 0.24 | 0.15 |
| 13 | Residual strength ratio for negative loading | 0.4 | 0.4 | 0.4 |
| 14 | Rate of cyclic deterioration for positive loading | 1 | 1 | 1 |

The Pacific Earthquake Engineering Research Center provided a summary of the various cross sections along with the model parameters. The figure below provides a visual representation of the use of the parameters on the back bone curve.

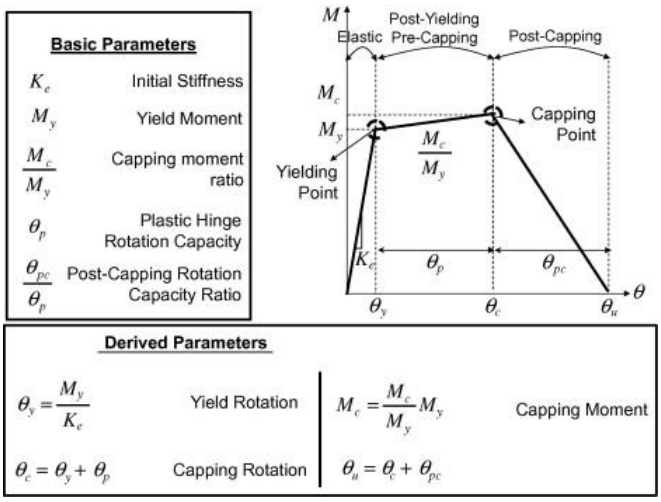



**Figure 5-3: Showing component backbone curve and its parameters (Hasselton et al. 2007)**

The PEER database, provided a summary of these parameters however they can be calculated using the equations below.

- **Equation .1** - Plastic Hinge Rotation Capacity (Haselton et al. 2007)
- $\boldsymbol{\theta\, cap\,, pl = 0.12\,(1 + 0.55 a_{sl})(0.16)^{v}(0.02 + 40\,\rho sh)^{0.43}\,(0.54)^{0.01 f'c}(0.66)^{0.1 sn}(2.27)^{10.\rho}}$

Where: $a_{sl}$ = bond slip indicator, 1 $\rho_{sh}$ = area ratio of transverse reinforcement

v = axial load ratio $s_n$ = rebar buckling coefficient

s = stirrup spacing $d_b$ = longitudinal rebar diameter

$f_y$ = yield strength of rebar c units = variable,1

- **Equation .2** - Post -Capping Rotation Capacity (Haselton et al. 2007)
- $\boldsymbol{\theta\, cap_{,pc} = (0.76)(0.031)^{v}\,(0.02 + 40\rho sh)^{1.02} \leq 0.10}$

Where: v = $P/_{Ag\ fc}$ $\rho_{sh}$ = transverse steel ratio

- **Equation 3** - Post Yielding Hardening Stiffness
- $\boldsymbol{Mc/_{My} = (1.25)\,(0.89)^{v}\,(0.91)^{0.01\ cunits\ f'c}}$

Where; v = $P/_{Ag\ fc}$ $f'_c$ = compressive strength of concrete

These experiments did not consider changes in moment capacity due to axial-moment interaction effects as the analytical software does not have this capability. From the table it is seen that all of the "L" deterioration parameter variables to 1000.0, all of the "c" exponent variables to 1.0, and both "C" rate of cyclic deterioration variables to 1.0. This is done to simplify the model and to compare with Seismostruct, also cyclic deterioration was ignored for the pushover analysis. The residual strength was not quantified in the (Haselton et al 2007) database however the value used in the table was provided from past research which uses an average residual strength used in a similar research for reinforced concrete buildings. (Zareian et al. 2012).

***Stiffness Modifications to Elastic Frame Elements and Rotational Springs***

According to (Eads ,2013), since a frame member is modeled as an elastic element connected in series with rotational springs at either end, the stiffness of these components must be modified so that the

equivalent stiffness of this assembly is equivalent to the stiffness of the actual frame member. This would prevent numerical problems and allow all damping to be assigned to the elastic element.

The same conception was done for the nonlinear portion of the assembly, where nonlinear assembly is matched to the actual frame member. This is done via modifying the strain hardening coefficient (the ratio of post-yield stiffness to elastic stiffness) of the spring, $\alpha_{spring,}$ this is shown below:

- Actual Frame member strain hardening coefficient $\alpha_{s,mem}$
- Strain hardening coefficient of the spring is denoted $\alpha_{s,spring}$

➢ **Equation 4 -**

- $\alpha_{s,spring} = \frac{\alpha_{s,mem}}{1+n(1-\alpha_{s,mem})}$

## P delta columns and rigid links

### *Leaning Columns and Frame Links*

The leaning columns are modeled as elastic beam-column elements. These columns have second moments of inertia and cross sectional areas larger than the actual frame columns representing collective effect of all gravity columns in the frame. These columns are pinned at each connection and provide no bending restraint in a frame. They don't contribute to lateral resistance, however carries gravity loads. When using leaning columns, it must be known that the p-delta effects can have large effects on post peak degradation even if they appear negligible for an elastic structure (Nassirpour, 2018).

The columns are connected in this system are connected using rotational spring elements with very small stiffness values, so that the columns do not attract significant moments. Truss elements are used to link the frame and leaning columns system, allowing the P-Delta effect to be transferred. Similar to the leaning columns, the trusses have areas larger than the frame beams, which represents the collective effect of all the gravity beams. They are however assumed to be axially rigid (Eads, 2013).

### *Hysteretic behaviour*

The hysteric model used in this study follows the rules of the bilinear hysteretic model. The backbone and its associated hysteretic rules provide for versatile modelling of cyclic behaviour. (See figure 5-4). Other hysteretic models (peak and pinch) are not considered. According to (Medina and Krawinkler, 2003, and Ibarra and Krawinkler, 2005) the sensitivity of structural response parameters (i.e. EDP and collapse capacity) to variation of hysteric models is relatively small except for pinching hysteretic model with severe stiffness degradation. Once As long as there is good detailing, pinching can be ignored, therefore in this research we only consider the bilinear hysteretic model for structural component.

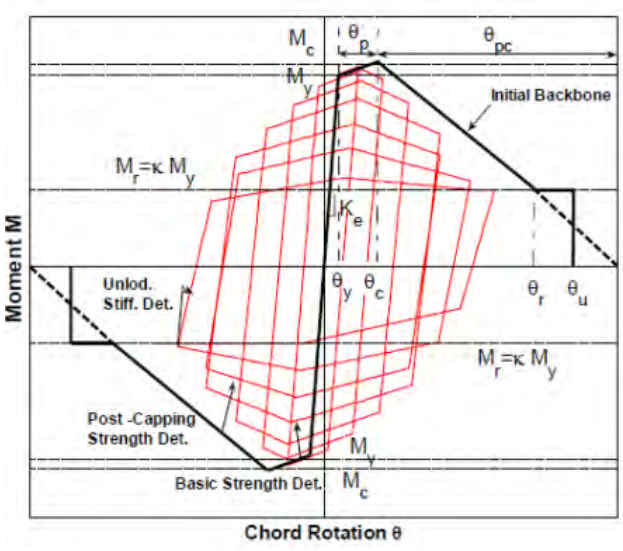



**Figure 5-4 : Showing the Modified IMK deterioration model with bilinear hysteretic response**

An important aspect of this model is the ability to represent negative stiffness branch of post-peak response, which enables modelling of strain-softening behaviour associated with physical phenomena such as concrete crushing, rebar buckling and fracture, and bond failure. The component model incorporates four cycles' deterioration modes once the yielding point is passed in cyclic loading. This element model requires the specification of seven parameters to control both the monotonic and

cyclic behaviour of the model: My, θ y, Ks, θ cap, and Kc, λ, and c.2. The connection between these model parameters and the physical behaviour of beam-column elements is explored in table below.

***Table 5-3: Description of model parameters and associated physical behaviour and properties (Haselton et.al (2007)***

| Model Parameter | Description | Physical Behaviour contributing to parameter | Physical properties /possible predictors | References |
|---|---|---|---|---|
| My | Yield moment | 1) Longitudinal rebar yielding<br>2)Concrete cracking<br>3) Concrete crushing | 1) Stress Block<br>2) Section geometry<br>3) Axial load (ratio),<br>4)Material strengths and stiffnesses | Basic beam theory Fiber moment -curvature; Fradis,2003;Panagiotakos,2001 |
| θy | Chord rotation , yield | same as above | 1) Section geometry<br>2)Level of shear cracking<br>3)Shear demand<br>4) Axial load (ratio), material<br>5) Stiffnesses/strengths | Fardis, 2003;Panagiotakos 2001;Fiber moment-curvature |
| θcap | Chord rotation ( mono) at onset of strength loss (capping) | 1) Longitudinal rebar buckling /fracture<br>2) concrete core failure<br>3) Minimal lateral confinement | 1) Confinement<br>2) Axial load (ratio)<br>3) Geometry<br>4) reinforcement ratio | Fardis, 2003;Panagiotakos 2001; Berry 2003 |
| Mc/My (or Ke) | Hardening stiffness | 1) Steel strain hardening,<br>2)Nonlinearity of concrete,<br>3)Bond-slip flexibility | 1) Steel hardening modulus<br>2) Section geometry,<br>3) Interm. long. steel | Fiber moment-curvature and plastic hinge length approach;Zarelian 2006 |
| θpc ( or Kc ) | Post capping stiffness | 1)Post rebar buckling<br>2) Behaviour after loss of core concrete confinement. | 1)Rebar slenderness between stirrups<br>2) Small stirrup spacing. | Ibarra, 2005/2003;Zareian2006 |
| λ | Normalised hysteretic energy dissipation capacity (cyclic) | 1) Concrete crushing<br>2) Stirrup fracture<br>3)Rebar buckling, longitudinal steel fracture. | Confinement, stirrup spacing ,axial load (ratio) | Ibarra, 2005/2003;Zareian2006 |
| c | Exponent Term to model rate of deterioration | same as above | same as above | Ibarra, 2005/2003 |

## Seismostruct

In Seismostruct the element type used was the inelastic forced based frame element. To conduct nonlinear analyses, the material nonlinearity can be accounted for by two methods. The lumped plastic hinge and distributed (fibre model) inelasticity elements. The lumped plasticity approach is dependent on the length of the plastic hinge and can be considered as inaccurate compared to the fibre model (Semere, 2016). Due to the influx of computational tools the distributed inelasticity elements is the approach used by many researchers. The distributed inelasticity approach has the ability to represent spread plasticity within the element cross section and along the element length.

A main benefit in using this element is that there is no length or pre calibration response parameters required,(Semere,2016).The fibres associated with the uniaxial stress strain stress strain relationship which characterises the cross sectional behaviour and sectional stress-strain state of the element is determined by the integration of each fibre. The figure below illustrates the discretization of a typical reinforced concrete cross -section.

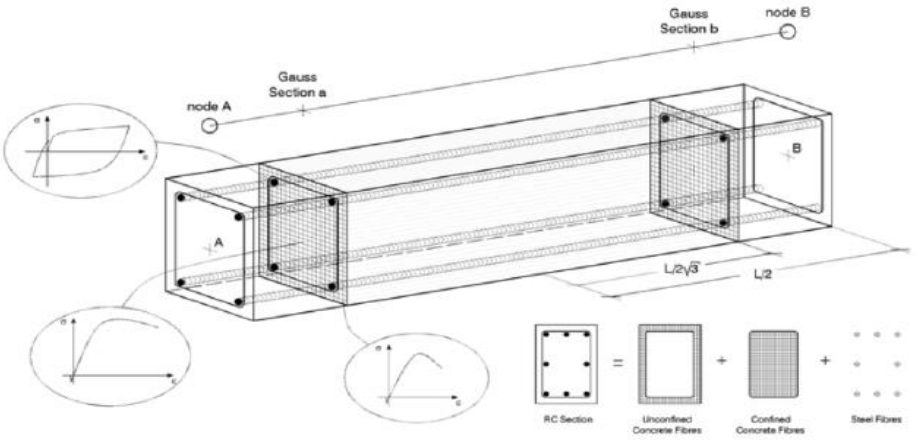



**Figure 5-5: Showing discretisation of a reinforced concrete cross section (Seismosoft, 2016)**

The fibre based elements can be modelled using two methods. The displacement –based formulation, which assigns displacement shape function to a finite element and then solving the main equations based on the stiffness of the element. This formulation is also based on a linear variation of curvature along the element. On the other hand, the forced based formulation implements a force field which is constructed on the element's flexibility. According Calabrese et al. (2010), the force based method has shown generate accurate results compared to the displacement based method. This is due to the displacement based method is unable to capture the real deformation shape in the presence of material inelasticity. In the forced based method, the solution is approximated by integration points along the element length. The number of integration points that can provide reliable results at a global level is 4. (Seismosoft 2016).In addition to the integration points, it is recommended that the Gauss-Lobatto integration scheme is utilized for force based elements. The figure below illustrates the Gauss- Lobatto integration sections.

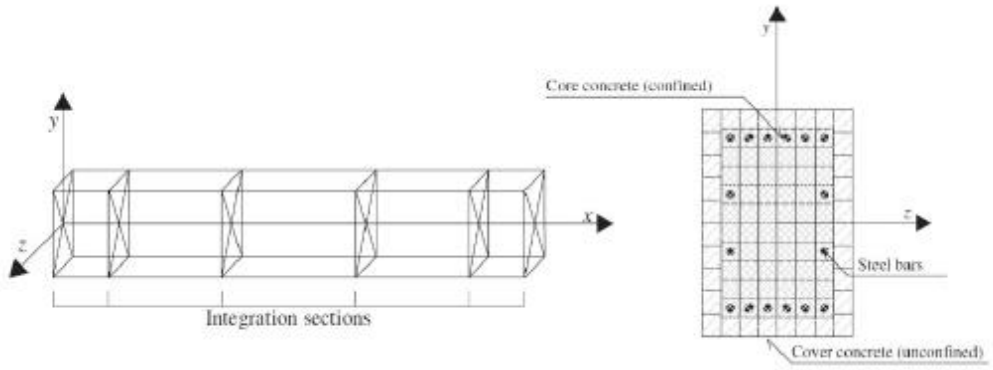



**Figure 5-6 : Showing Gauss – Lobatto integration sections.( Seismostruct 2016)**

In this research paper, the forced based beam column elements is utilized in Seismostruct model. The number of section fibres used is 100 beam column element. This is to reduce computational time. See figure 5-6 above. The number of integration points with the Gauss-Lobatto rule, used for the beam and column elements was 5 for all frames. The selection of integration point was done to reduce the issue associated with localization. This however does may not consider the convergence issues. Finally, the P- delta effects at a global level are accounted for in Seismostruct via an internal software function.

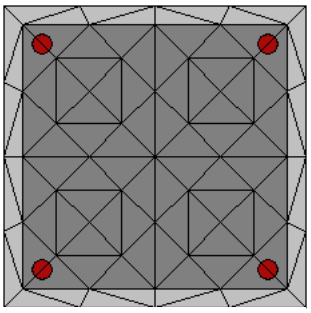


**Figure 5-7: Showing discretization pattern of the section (Seismosoft, 2016)**

***Numerical Solution Algorithms***

The iterative solution algorithm used in both programs was the Newton-Raphson method. This algorithm was used in both pushover and nonlinear time history analysis. (See script in appendix).The algorithm is implemented with prescribed displacement increments, which provide the most rapid converging process to determine the structural response.

***Damping (nonlinear analysis)***

In the non-linear time history analysis, The Rayleigh damping function is applied to represent viscous damping the frame. It expresses the damping matrix as a linear combination of the mass matrix and stiffness matrix as shown in the equation 5 below. (Chopra, 1995)

**Equation 5**

- $C = a_0\mathbf{M} + a_1\mathbf{K}$

Where: $a_0$ is the mass proportional damping coefficient

$a_1$ is the stiffness proportional damping coefficient.

M is the mass matrix

K is stiffness matrix

A damping ratio of 5% was assigned to the first and second modes of the 2 dimensional frames which is usually applied for reinforced concrete structures. In order for the model to respond properly, stiffness proportional damping is applied only to the frame elements. Damping is neither applied to the rigid truss elements linking the frame to the leaning column nor the leaning columns.

***Natural periods and Mode shapes***

Natural periods and mode shapes for all inelastic frames were generated in both programs. The gravity loads were converted into masses in order to conduct the Eigen analysis assessment. Figure 5-8 and Table

5-4 illustrate the results of the natural periods. Figure 5-9 illustrates the first four mode shapes obtained with Seismostruct, which complies with the Opensees models with minimal differences.

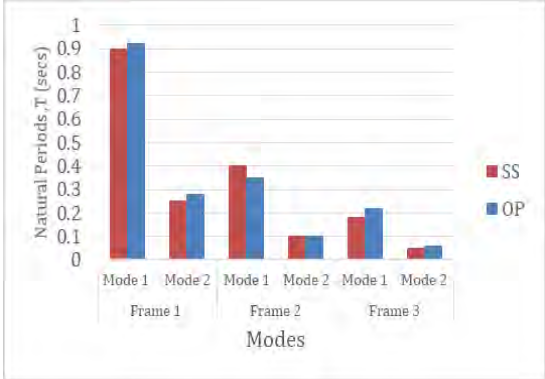



**Figure 5-8: Showing natural periods of the numerical models**

*Table 5-4 showing natural periods of the different numerical models*

| Soft-ware | Frame 1 | | Frame 2 | | Frame 3 | |
|---|---|---|---|---|---|---|
| | T1 (s) | T2 (s) | T1 (s) | T2 (s) | T1 (s) | T2 (s) |
| SS | 0.9 | 0.25 | 0.4 | 0.13 | 0.18 | 0.05 |
| OP | 0.92 | 0.28 | 0.35 | 0.1 | 0.22 | 0.06 |
| Diff-erence % | 2 | 3 | 5 | 3 | 4 | 1 |

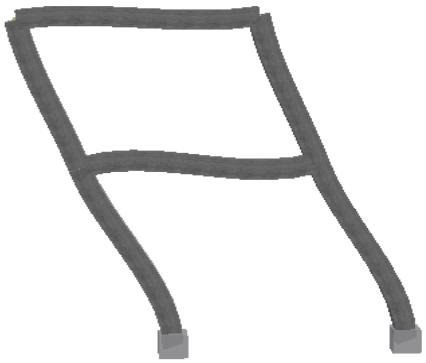


**Figure 5-9 A showing the 1st mode shape frame 3 in Seismostruct**

**Figure 5-9 B showing the 2nd mode shape frame 3 in Seismostruct**

**Figure 5-9 C showing the 3rd mode shape frame 3 in Seismostruct**

**Figure 5-9 D showing the 4th mode shape frame 3 in Seismostruct**

### Discussion

The results shows that the models generated in both programs are match with minor differences observed in models implemented in Seismostruct and Opensees with regard to the first natural period. A max of 5 % however is seen for frame 2 in the first or fundamental natural period. Furthermore, in Seismostruct, the contribution of the reinforcement to the stiffness is not included. For all frames, in both programs, there were significant discrepancies observed in the higher modes.

## Push over analysis

The Non-linear Static Analysis was executed using both Opensees and Seismostruct software packages. The performance requirements of each frame was done in comparison to Hazus MR4 technical manual, which provides the damages states in the structure. According to the Hazus data base, these includes four damage states;

- Slight Structural Damage – Flexural or shear type hair line cracks in some beams and columns near joint or within joints.
- Moderate Structural Damage- Most beams and columns exhibit hairline cracks. Ductile frames elements have reached yield capacity which is indicated by larger flexural cracks and some concrete spalling. Non ductile frames may exhibit larger shear cracks and spalling
- Extensive Structural Damage – Some of the frame element shave reached their ultimate capacity indicated in ductile frames by large flexural cracks, spalled concrete and buckled main reinforcement; no ductile frame elements may have suffered shear failures or bond failures at reinforcement splices or broken ties or buckled main reinforcement in columns which may result in partial collapse.
- Complete structural damage – Structure is collapsed or in imminent danger of collapse due to brittle failure no ductile frame elements or loss of frame stability. Approximately 13 %( low-rise), 10 %( mid-rise) or 5 %( high-rise) of the total area of C1 buildings with Complete damage is expected to be collapsed.

The inter-storey drift limits of each frame would be determined at specific stages of the pushover curve and compared to the Hazus damage states.

The pushover curves for the different frames were developed by computing the nonlinear static analyses of the numerical models. The analysis was done in one direction utilising a height –wise distribution of the lateral loads proportional to each the weight of each floor and elevation. It was conducted with constant gravity loads while simultaneously increasing the lateral loads until failure of the frames or 20 % loss of capacity is reached.

The results are presented below.

Opensees, provided shear reactions at all frame bases, however only the base shear reactions from the original frame bases were used to calculate the total base shear as the leaning column had a pinned connection.

The comparison illustrates that Frame 1 in both programs produce pushover curves that differ significantly. The maximum shear capacities from the Opensees and Seismostruct programs resulted in 5 kips and 3.82 kips respectively. It can also be seen that the

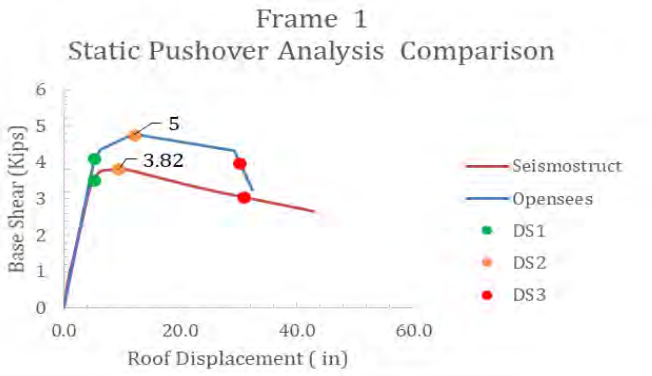



**Figure 6-1: Showing the pushover curves for frame 1**

displacements at the maximum shear capacities follow the same trend with the Seismostruct having lower displacement compared to Opensees. The curves however showed similarity in the initial elastic stiffness region. The pushover curve produced by Seismostruct, exhibited nonlinear action at an earlier stage in comparison to Opensees signifying that it has a lower yielding strength. From the plot we can say that Seismostruct produces conservative results compared to Opensees. A similar pattern was observed for frames 2 and 3.The maximum shear capacities for frame 2 resulted in 37 kips and 30.8 kips and frame 3 , 84 kips and 71 kips for Opensees and Seismostruct respectively. See figures below.

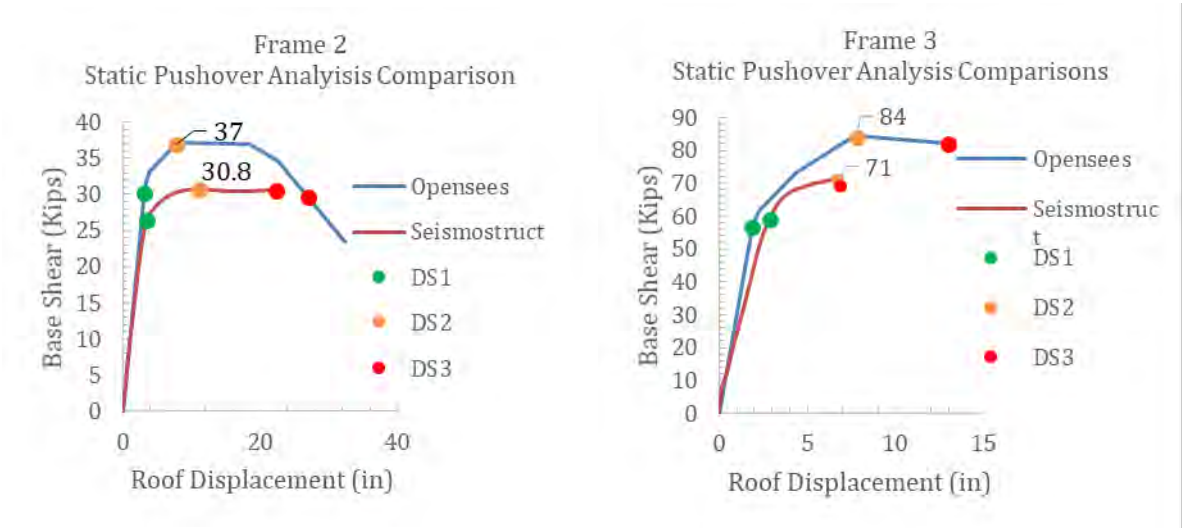
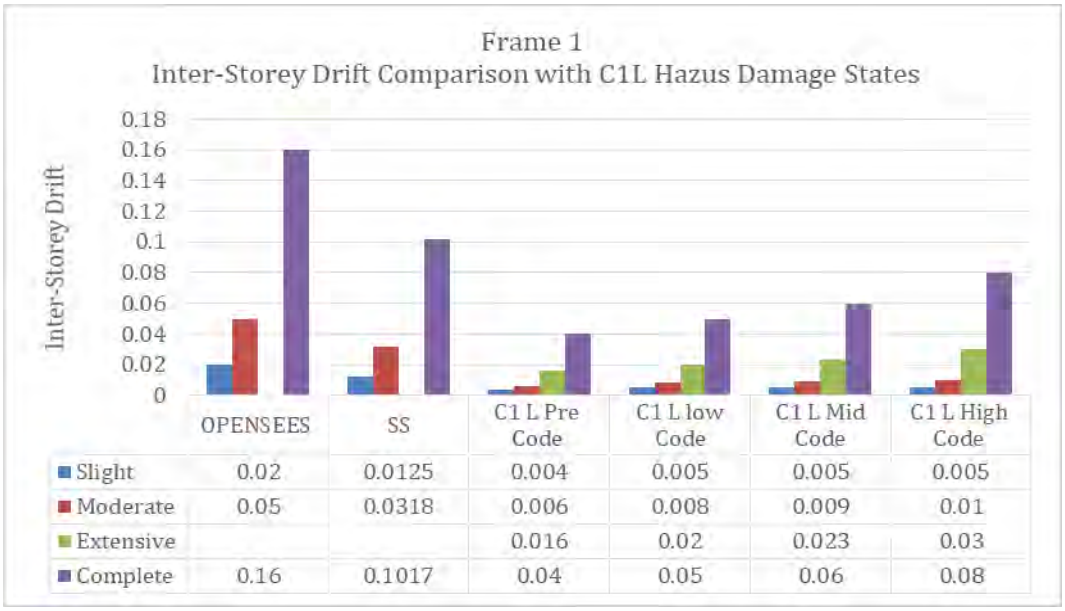



**Figure 6-2A: Showing pushover curves frame 2 6-2B: Showing pushover curves frame 3**

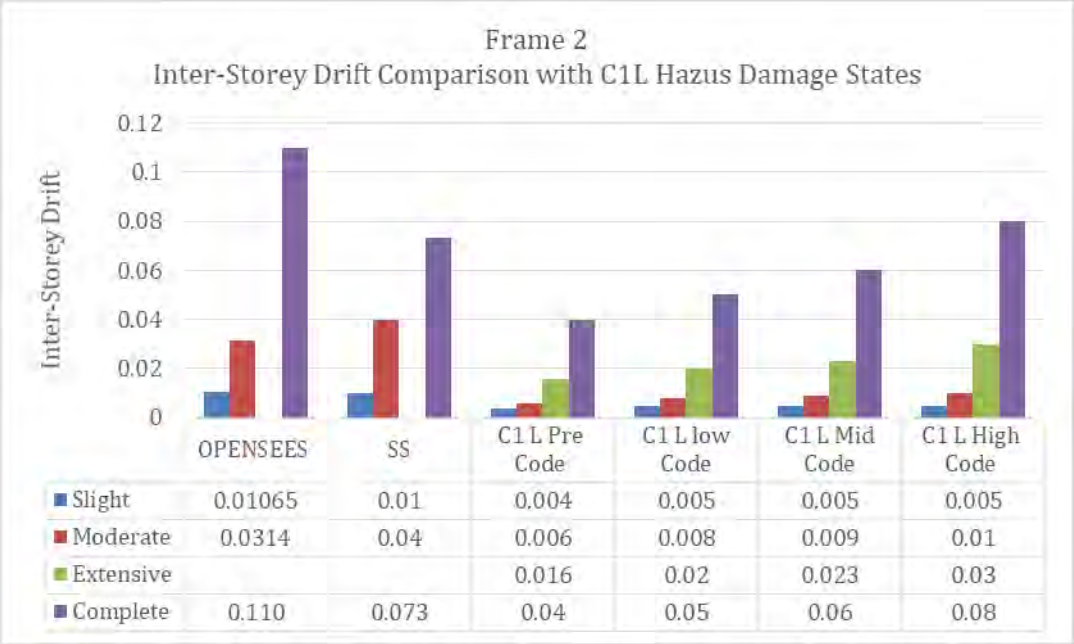
Also displayed on the push over curves are the manually selected damage states. The damage states for each of the curves were determined at critical areas of the push over curve. The yielding point, the maximum strength and the ultimate strength. The damage states were compared to the damage states provided by Hazus damage states for low rise concrete moment frames (C1 L).

These damages states were developed for many different building typologies.



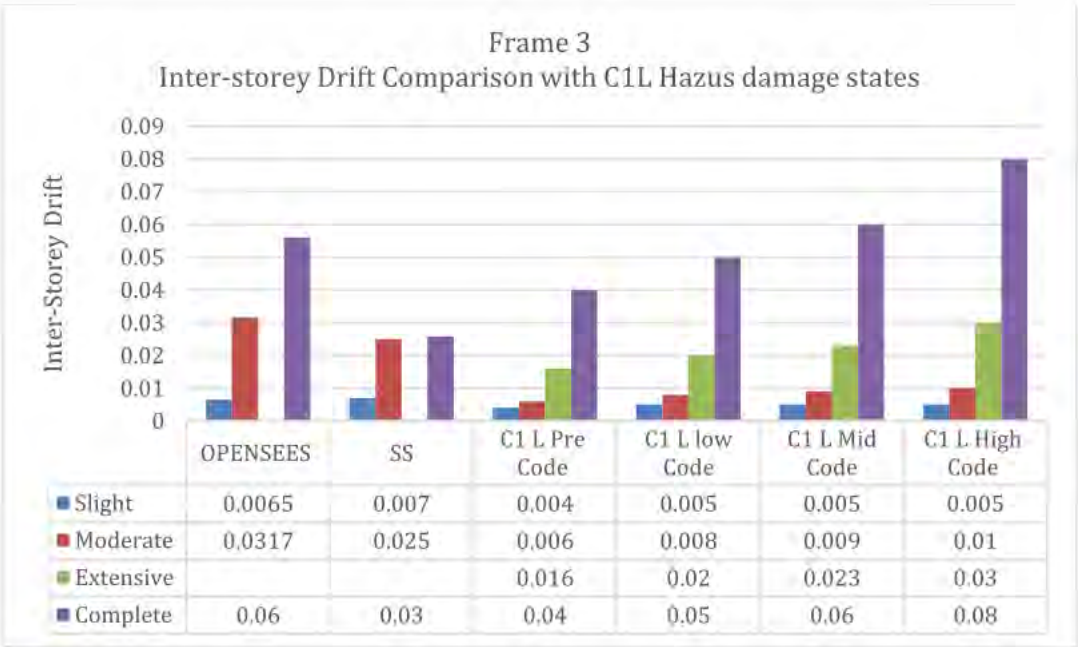

| | OPENSEES | SS | C1 L Pre Code | C1 L low Code | C1 L Mid Code | C1 L High Code |
|---|---|---|---|---|---|---|
| Slight | 0.02 | 0.0125 | 0.004 | 0.005 | 0.005 | 0.005 |
| Moderate | 0.05 | 0.0318 | 0.006 | 0.008 | 0.009 | 0.01 |
| Extensive | | | 0.016 | 0.02 | 0.023 | 0.03 |
| Complete | 0.16 | 0.1017 | 0.04 | 0.05 | 0.06 | 0.08 |

**Figure 6-3: Showing frame 1 damage state comparisons with HAZUS MR4 damage states**




| | OPENSEES | SS | C1 L Pre Code | C1 L low Code | C1 L Mid Code | C1 L High Code |
|---|---|---|---|---|---|---|
| Slight | 0.01065 | 0.01 | 0.004 | 0.005 | 0.005 | 0.005 |
| Moderate | 0.0314 | 0.04 | 0.006 | 0.008 | 0.009 | 0.01 |
| Extensive | | | 0.016 | 0.02 | 0.023 | 0.03 |
| Complete | 0.110 | 0.073 | 0.04 | 0.05 | 0.06 | 0.08 |

**Figure 6-4: Showing frame 2 damage state comparisons with HAZUS MR4 damage states**

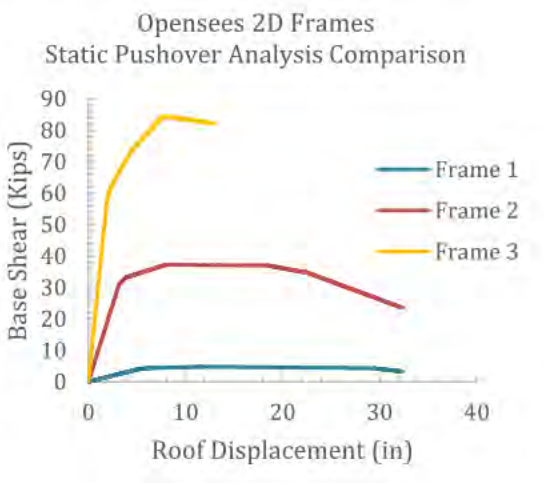



| | OPENSEES | SS | C1 L Pre Code | C1 L low Code | C1 L Mid Code | C1 L High Code |
|---|---|---|---|---|---|---|
| Slight | 0.0065 | 0.007 | 0.004 | 0.005 | 0.005 | 0.005 |
| Moderate | 0.0317 | 0.025 | 0.006 | 0.008 | 0.009 | 0.01 |
| Extensive | | | 0.016 | 0.02 | 0.023 | 0.03 |
| Complete | 0.06 | 0.03 | 0.04 | 0.05 | 0.06 | 0.08 |

**Figure 6-5: Showing frame 3 damage state comparisons with HAZUS MR4 damage states**

The figures below shows comparison of the strength of each frame, where frame 1 can be classed as weak with max displacement and least shear capacity, frame 2 medium strength and frame 3 high strength capacity and least displacement. It shows how the stiffness increases as the strengths increase as the initial elastic stiffness range gets steeper indicates as the cross sections and associated reinforcement results in an increase of the initial stiffness. This graph also shows that the stiffer the structure the less displacement it is able to undergo before failure as frame 1 has least stiffness and frame 3 most stiffness. This could be the reason why frame 2 and three failed in Seismostruct. The frames in Opensees show similar results however frame 1 and 2 was able to reach max displacements of 32.22 inches, however frame 3 did not

reach the displacement again due to the stiffness. The frame does not have enough ductility to reach a displacement shown by frame 1 and 2.



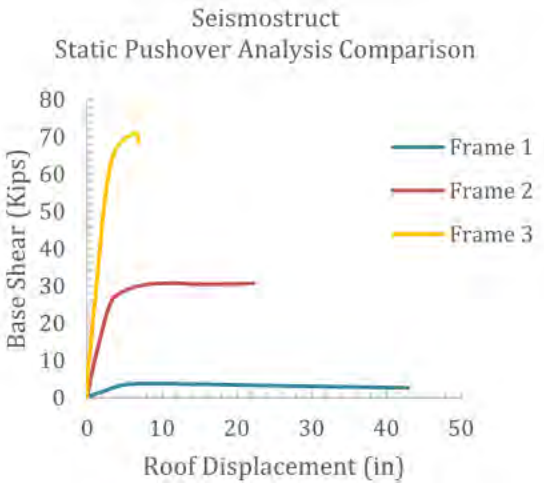
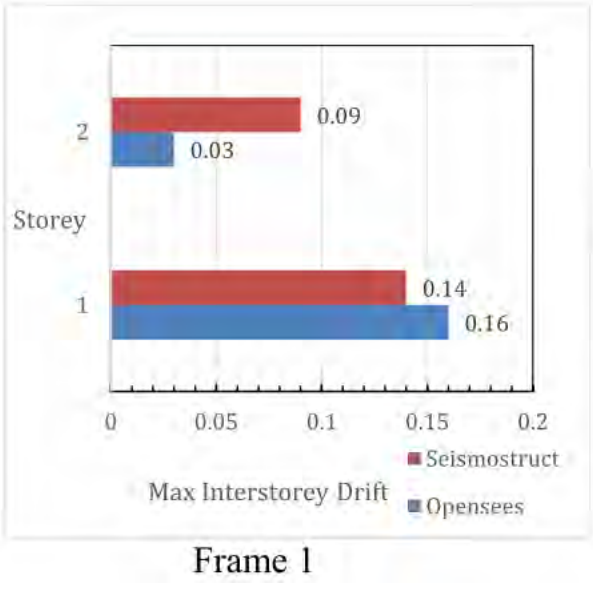




**Figure 6-6 Showing Opensees PO curves comparisons Figure 6-7 Showing SS PO curve comparisons**

## Inter-storey Drifts from Pushover Analysis

The figures below provide a description of the inter-storey drift from the pushover analysis. These curves show that Opensees produced generally larger inter-storey drifts at storey 1 with maximum values of 0.16, 0.11 and 0.06.Tho resulting in larger drift values, both software's resulted in having close results. The results for both software for the storey 2 however were less than the results observed in the first storey. This is a clear indication of soft storey action occurring during the analysis as well as P-delta effects would be the cause of failure for the structure. Storey 2 drift ratios also had close results between both software with a max variation occurring in frame 1 with a difference of 6 %.



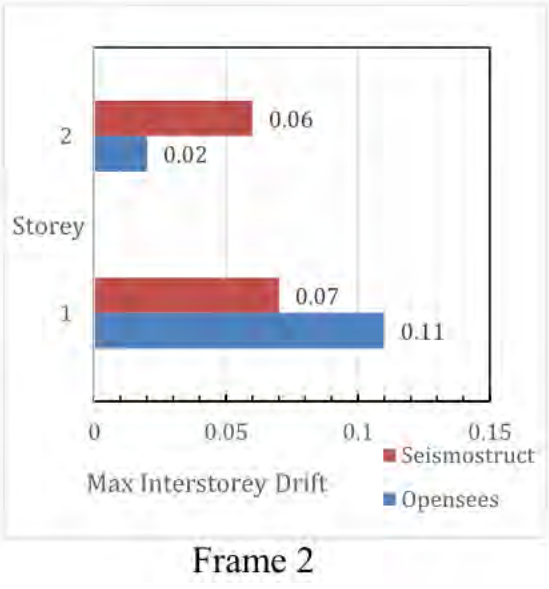




**Figure 6-8: Showing MISD comparisons FRAME 1**

**Figure 6-9: Showing MISD comparisons FRAME 2**

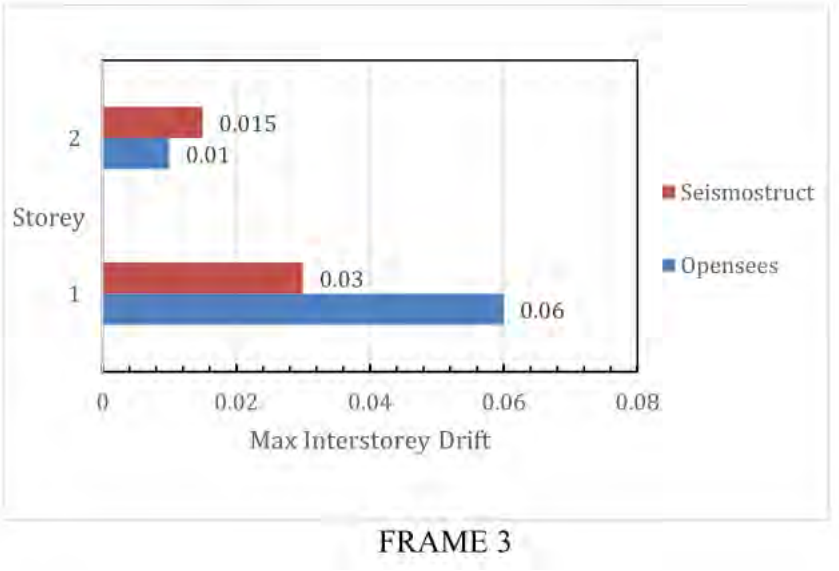



**Figure 6-9: Showing MISD comparisons for Frame 3**

## Discussion

### *Frame 1*

This result can be due to the fact that Opensees uses the Ibarra –Medina –Krawrinkler concentrated plasticity rotational spring model which captures the response of plastic hinges formed at the end of an element. This model which uses set parameters, which doesn't change during analysis. These calibrated parameters are intended to mimic the nonlinear response of a number of single beam-column element with specific structural characteristics under nonlinear forces. In reality, no one structure is the same, each consisting of various structural characteristics, resulting in their nonlinear responses being different. These responses change during the application of loading, therefore the use of concentrated springs may be not fully grasp the true response of the structure.

On the other hand, Seismostruct utilize the force based distributed plasticity along the element , with fibre section models for beams and columns with nonlinear concrete and steel material properties defined in figures above using 5 integration points. As stated previously, Seismostruct models consider the plasticity distributed along the element which check the responses of the each fibre along the length and cross sections of the elements during the analysis which change during the analysis. Therefore, Seismostruct is able to obtain the stress and strains of elements which efficiently resulted in the pushover curves resulting lower yield strength compared to Opensees.

After conducting the pushover analysis in Seismostruct, the action effects was check to determine the maximum moment experienced by the defined structural members, where the resulting moments were slightly lower than the yielding moment of the columns from the database. Another reason for this can be due to the concentrated plasticity springs were developed from only 255 reinforced concrete specimen, therefore the database may not be fully representative of the effects experienced by the elements in Opensees leaving room for errors. Whereas Seismostruct does not require calibration of empirical response parameters against the response of an actual or ideal frame element to loading, as the responses are calculated in Seismostruct.

From the plots we can see that apart from the fact that the demands for the both curves were different, Opensees pushover curve was again able to show the stages a nonlinear member experiences under loading which is known as the monotonic backbone curve. After the initial, elastic stiffness stage, based on the effective elastic stiffness, the yield strength is reached, and from that point the frame enters the nonlinear range which is known as the plastic deformation capacity section or the post yielding or pre – capping portion, reaching a maximum demand of 5 kips and displacement of 12 inches. This portion of

the curve is defined on the capping moment ratio (Mc/My), 1.04 which uses the yield moment, My and the capping moment, Mc produced at the maximum base shear. The yield moment as stated earlier was 227 kips had a base shear of 4.1 kips. The higher capping moment ratio, the steeper the slope resulting in higher capping moment. Once the capping strength was achieved it can be seen that strength deterioration has occurred indicating the beginning of the softening stage. These stages are not clearly shown in the pushover curve produced by Seismostruct which is one of the advantages of using the rotational springs. Since Seismostruct uses the force based distributed plasticity along the element, this type of formulation assumes a strain hardening response and fails to capture strain softening hence in Opensees, there are distinct points along the curve and in Seismsostruct a negative slope is seen after the maximum strength is achieved. See tables below showing the yield and maximum strengths of each pushover curve for each frame.

***Frame 2***

Similar to frame 1, the Opensees pushover curve is able to provide distinct points compared to Seismostruct for reasons previously indicated. However the Seismostruct pushover curve showed that the post yield strength was maintained until there was a iteration error causing Seismostruct to not be able to apply load, when compared to frame 1, where the strength was reduced post yield. This error may be due to the structure failing or Seismostruct may not being able to show the strain softening resulting in the pushover curve shown above. According to Seismosoft (2016), forced based frame elements require a number of iterations to be conducted to ensure equilibrium internally is reached. If equilibrium is not achieved there would result in errors. After manipulating the program properties advised by Seismostruct team, the same error was seen therefore, the structure is deemed to have failed. Opensees on the other hand, due to its mathematical nature, if the structure fails, it is able to continue the analysis until the end point specified in the script is reached. The Opensees curve also showed some similarity in reaching the max demand strength of 37 kips and maintained this in the post capping stage until strain softening is experienced at a displacement of 17 inches.

***Frame 3***

This frame did not follow the pattern as the first 2 frames regarding the initial elastic stiffness. The Seismostruct pushover curve seemed to have decreased midway of the elastic region. It simply states that there was a sharp reduction in the frames elasticity or stiffness upon loading. This may be due to the longitudinal or transverse steel reinforcement being used in the design suggest by Berry et al.(2006).To reiterate the structural design and beam –column material and sectional properties modelled in Seismostruct produced the parameters used for the concentrated rotational plasticity springs required as input for the Opensees script. Despite the discrepancies associated with initial elastic stiffness, the push over curve for Seismostruct showed early failure until iteration error was obtained. As suggested by the Seismostruct team, the software settings were changed however once the load phase steps was changed from 100 to 50 steps the pushover curve produced the figure below.

## Nonlinear Time History Analysis Results

### Introduction

Seismic analysis entails determining the response of a structure during an earthquake. The nonlinear time history analysis provides a more reliable assessment of earthquake performance compared to the nonlinear static analysis. It is mainly applied when retrofitting existing structures. This analysis is also used when higher modes and structural behaviour after the first mechanism is of interest. Additionally, it provides estimates of both the peak and residual deformations. In nonlinear time history analysis, the nonlinear properties such as material properties are incorporated in the numerical model and considered as part of the time domain analysis.

For the dynamic analysis, the damping of the frames were considered globally and locally. The critical damping was applied to the initial stiffness of the frames. As suggested in previous research, for

reinforced concrete structures, 5 percent damping ratio is applied to the first and second modal frequencies of each frame.

### Seismic Input motions

To conduct this analysis, 20 well known earthquakes which are typically used by researchers were used to determine the responses.This database was developed by the US Federal Emergency Management Agency as a selection of ground motion records used to conduct the collapse assessment of structures using nonlinear dynamic analysis methods. This database is used highly utilized in the earthquakes engineering field when conducting structural or dynamic analysis.

The database includes a ground motion recording from sites located at a distances greater than or equal to 10 km from fault rupture, (far field record set (22 NS and 22 WE individual components for 22 seismic events), and a set of ground motions recorded from sites located less than 10 km from the fault rupture, referred to as near field record set (28 NS and 28 WE individual components for 28 events).

These far field records also have magnitudes larger than 6.5 but with a maximum of 7.6.They were recorded from sites located in either soft rock or stiff soil conditions according to Eurocode 8 and generated from thrust or strike slip source zones. The strongest ground motions have PGA greater than 0.2 g and have PGV greater than 15 cm/s. (Pioldi and Rizzi, 2017)

The table below provides a summary highlighting the main properties of the set of earthquakes.

*Table 7-1: Showing main properties of the 22 far field set of P 695 earthquakes (Pioldi and Rizzi, 2017)*

| EQ ID | EARTHQUAKE | | | | | | Station Name - Owner |
|---|---|---|---|---|---|---|---|
| | M | PGA (g) | year | Name | Dur. (s) | fs (Hz) | |
| 12011 | 6.7 | 0.52 | 1994 | Northridge, USA | 29.99 | 100 | Beverly Hills, Mulhol-USC |
| 12012 | 6.7 | 0.48 | 1994 | Northridge, USA | 19.99 | 100 | Canyon Country -USC |
| 12041 | 7.1 | 0.82 | 1999 | Duzce, TURKEY | 55.9 | 100 | Bolu-ERD |
| 12052 | 7.1 | 0.34 | 1999 | Hector Mine , USA | 45.31 | 100 | Hector.SCSN |
| 12061 | 6.5 | 0.35 | 1979 | Imperial Valley, USA | 99.92 | 100 | Delta - UMAMUCSD |
| 12062 | 6.5 | 0.38 | 1979 | Imperial Valley, USA | 39.035 | 200 | El CENTRO Array #11 |
| 12071 | 6.9 | 0.51 | 1995 | Kobe , Japan | 40.96 | 100 | Nishi-Akashi - CUE |
| 12072 | 6.9 | 0.24 | 1995 | Kobe Japan | 40.96 | 100 | Shin-Osaka - CUE |
| 12081 | 7.5 | 0.36 | 1999 | Kocaeli, Turkey | 27.085 | 200 | Duzce - ERD |
| 12082 | 7.5 | 0.22 | 1999 | Kocaeli, Turkey | 30 | 200 | Arcelik - KOERI |
| 12091 | 7.3 | 0.24 | 1992 | Landers, USA | 44 | 50 | Yermo Fire Station - CDMG |
| 12092 | 7.3 | 0.42 | 1992 | Landers, USA | 27.965 | 300 | Cool water - SCE |
| 12101 | 6.9 | 0.53 | 1989 | Loma Prieta ,USA | 39.955 | 200 | Capitola - CDMG |
| 12102 | 6.9 | 0.56 | 1989 | Loma Prieta ,USA | 39.945 | 200 | Gilroy Array #3 - CDMG |
| 12111 | 7.4 | 0.51 | 1990 | Manjil, Iran | 53.52 | 50 | Abbar - BHRC |
| 12121 | 6.5 | 0.36 | 1987 | Super. Hills ,USA | 40 | 200 | El Centro Imp. Co. - CDMG |
| 12122 | 6.5 | 0.45 | 1987 | Super. Hills, USA | 22.3 | 100 | Poe Road (temp) - USGS |
| 12132 | 7 | 0.45 | 1992 | Cape Mendocino,USA | 36 | 50 | Rio Dell Overpass - CDMG |

| EQ ID | EARTHQUAKE | | | | | | Station Name - Owner |
|---|---|---|---|---|---|---|---|
| | M | PGA (g) | year | Name | Dur. (s) | fs (Hz) | |
| 12141 | 7.6 | 0.44 | 1999 | Chi Chi, Taiwan | 90 | 200 | CHY101 - CWB |
| 12142 | 7.6 | 0.51 | 1999 | Chi Chi, Taiwan | 90 | 200 | TCU045 - CWB |
| 12151 | 6.6 | 0.21 | 1971 | San Fernando, USA | 28 | 100 | LA Hollywood Stor - CDMG |
| 12171 | 6.5 | 0.35 | 1976 | Friuli ,Italy | 36.345 | 200 | Tolmezzo |

To reduce the computational effort, only the component with highest peak ground acceleration were used resulting in to 20 ground motions. Seven of these are graphical represented below. The remainder are illustrated in the appendix. These unscaled ground motions are applied at the base of the numerical models in both software's as a uniform lateral excitation pattern. A selected few are presented below.

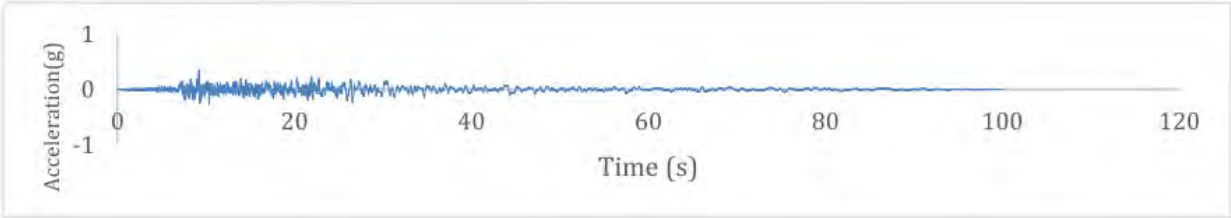



**Figure 7-1 A EQ4 Imperial Valley PGA 0.35 g**

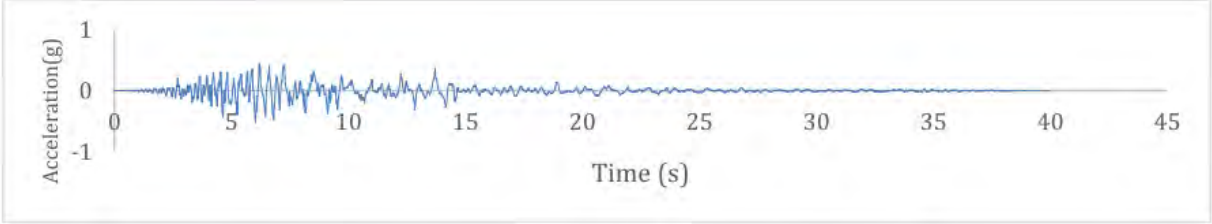



**Figure 7-1 B EQ8 Loma Prieta PGA 0.511 g**

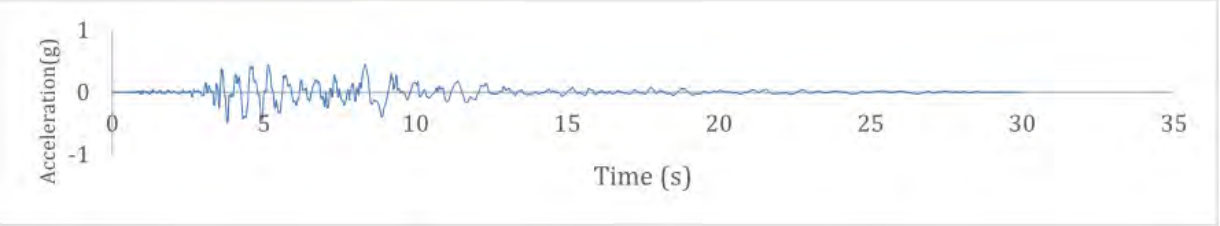



**Figure 7 -1C EQ 12 Northridge PGA 0.49 g**

## Scaling of time histories

Each record was scaled to distinct spectral acceleration (Sa) levels, ranging from 0.1g to 2.5g, in increments of 0.1g (a total of 25 analyses for each selected record). This therefore covers the entire range of structural response, from elasticity, to yielding and finally collapse. The spectral shape of mentioned ground motions was not a criterion in the selection process, as the FEMA P695 far-field ground motion set are independent of site hazard or structural type. According to (Nassirpour, D' and Ayala, 2017) these applied records are not reliant on period, any building-specific property of the structure and hazard disaggregation. The mean of the scaled accelerations is indicated by the solid black line.

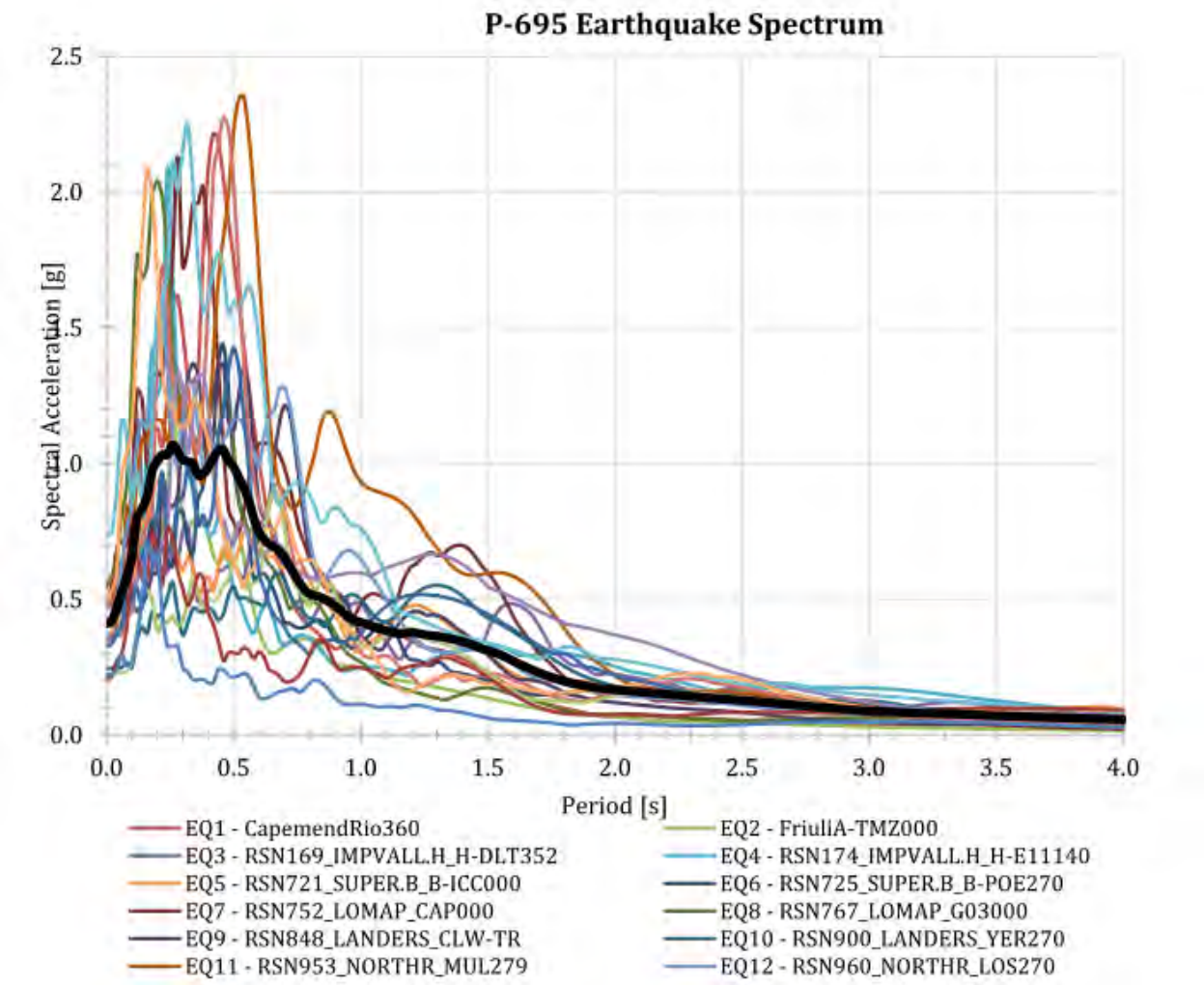



**Figure 7-2: Showing scaled earthquakes (Nassirpour, D' and Ayala, 2017)**

## Nonlinear Responses

***Frame 1***

Similar to the pushover analysis, the control node at the roof in the nonlinear analysis was used to obtain the responses for roof displacement, roof drift and max inter-storey drift. A comparison of the final roof displacements is illustrated in figure 7.3 below. From figure 7.3 we can see that Seismostruct produced larger displacement values compared to Opensees. The time history records are also shown in figures 7.4 .It also shows the comparison between both software with the intention of revealing any inconsistencies among the software. From the time figures you can see that the frequency pattern of each response for both software matched showing that the structures are relative modelled accurately. It is observed in some instances that the peak response is achieved at different times along the time history for both programs. This can be due to non-linear behaviour and contribution from higher modes. This is shown for Imperial valley had roof displacement of 6.4 in at 31 secs for Seismostruct and 5 inches at 28.12 secs for Opensees, Northridge – 12 in at 10 .6 secs and 9 inches at 8.33 secs for Seismostruct and Opensees respectively and Kobe experiencing max displacements of 4 inches however at 16.8 secs and 16 .4 secs for Seismostruct and Opensees programs respectively. On the other hand the peak responses occurred in the same time step for the remaining illustrations below.i.e Loma Prieta, SanFernando and Friuli earthquakes. The maximum roof displacements for frame 1 in Seismostruct and Opensees was observed for EQ 16, Kocaeli and

EQ12, Northridge earthquakes with a response of 12 inches and 9 inches respectively .See figure below for comparison of all max displacements.

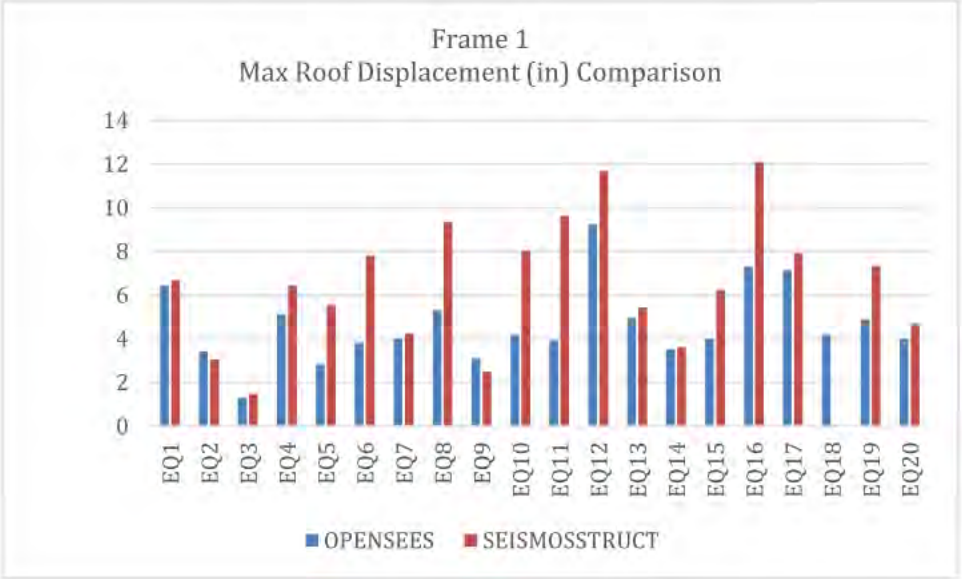



**Figure 7-3 showing Max roof displacement software comparisons.**

All maximum displacements occurred during the time ranges of high frequency for all earthquakes. At this point according to the hazus inter-storey drift ratio damage states for low-rise buildings, the building is able to achieve displacements beyond the threshold limits in hazus.

Frame 1

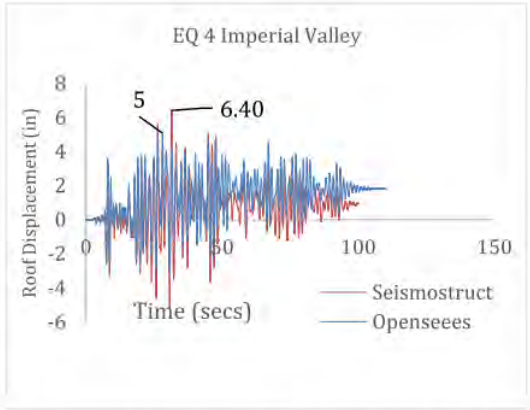



**Figure 7.4 A Peak Displ. Frame 1 NLTHA, EQ 4**

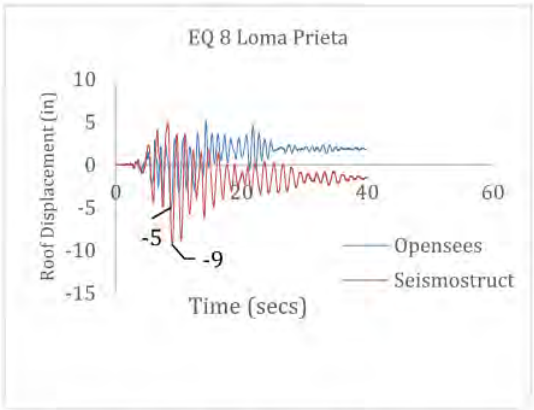



**Figure 7.4B Peak Disp. Frame 1 NLTHA, EQ 8**

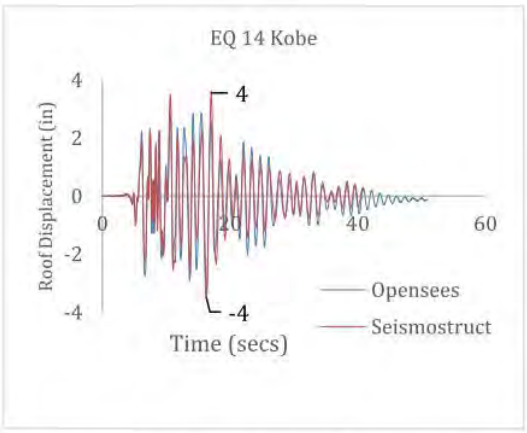



**Figure 7.4C Peak Displ. Frame 1 NLTHA, EQ 14**

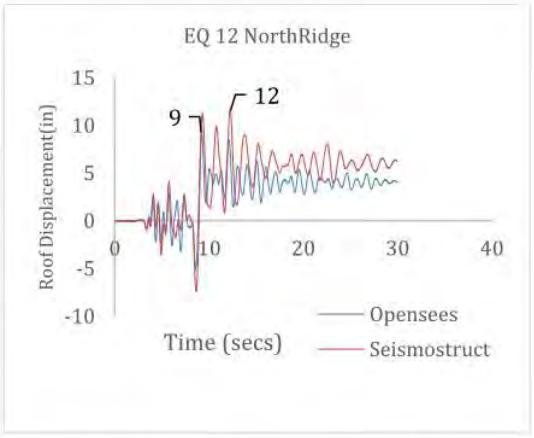



**Figure 7.4D Peak Displ. Frame 1NLTHA, EQ 12**

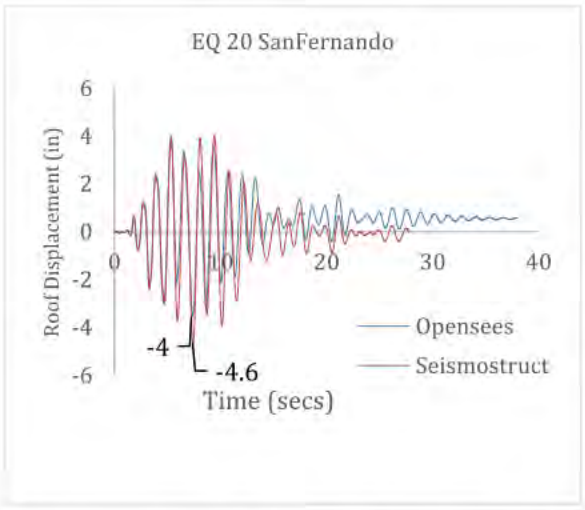



**Figure 7.4 E FRAME 1 Peak Displ. Frame 1 NLTHA, 20**

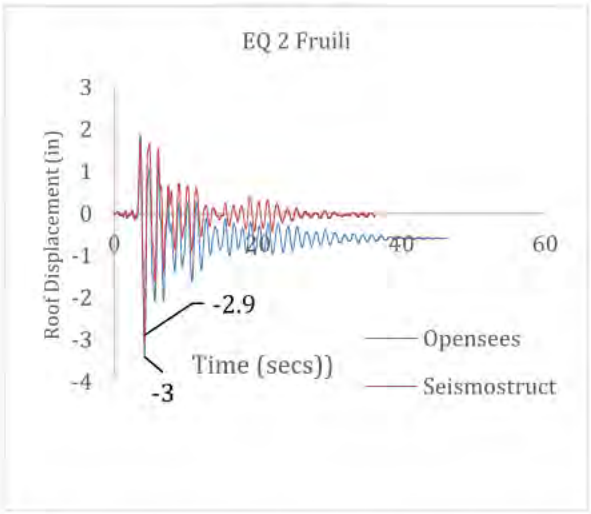



**Figure 7.4F: Peak Displ. Frame 1 NLTHA, EQ 2**

From the dynamic analysis, the maximum roof drifts and inter-storey drifts were also extracted for each earthquake for the different software's. A graphical representations comparing the responses are shown below. The maximum inter-storey drift ratios are representative of the response of the first storey for both programs. These were extrapolated because they were larger than those from the second storey and the failure of the structure would be due to soft storey action occurring.

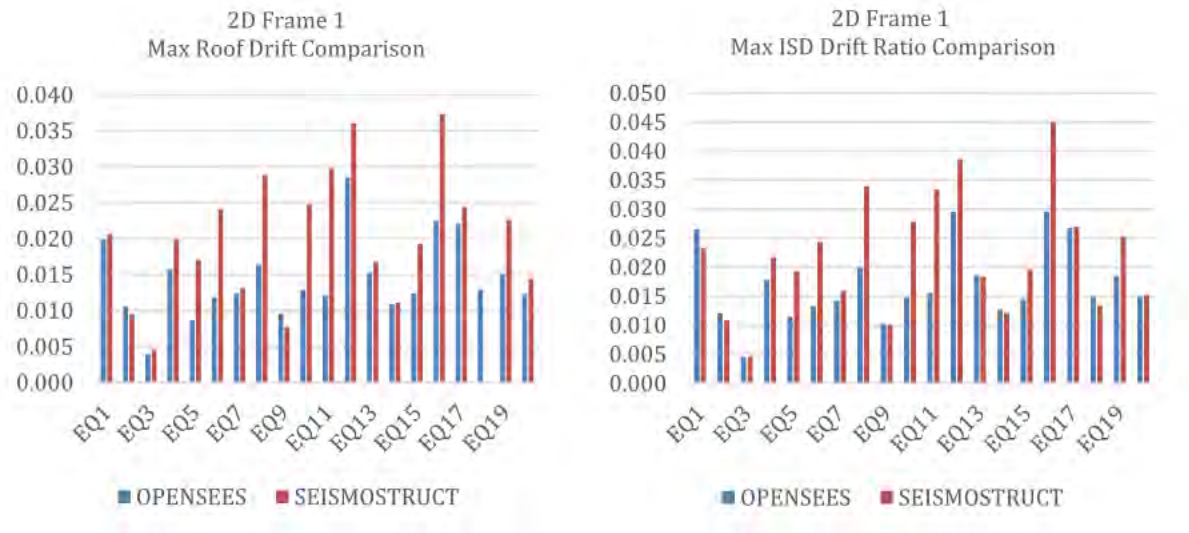



**Figure 7.5A: Showing max roof drift comparison Figure 7.5 B Showing MISDR comparison**

It can be seen that generally Seismostruct produced larger responses in both figures. Despite the Seismostruct producing larger values, the average of the differences between both programs for the maximum inter-storey drift ratio at second floor was found to be 0.005 in. However there were larger variations shown for Loma Prieta, Landers and Kocaeli. This can be due to the fact that these earthquakes have the largest peak ground acceleration values and Seismostruct interpretation of the ground motion recording caused the larger responses compared to Opensees.

***Frame 2***

The figures below show the response of frame 2 to ground motion records. Similar to Frame 1, the frequency patterns of each response match for both earthquakes, the peak responses occurred at different times during the analysis. However these differences in time step occurred for differently for the same earthquakes presented for frame1. From the earthquakes presented below, Frame 2 experienced peak responses simultaneously for Imperial Valley and Kobe earthquakes with roof displacements of 1.1 inches for Seismostruct and 2.82 inches for Opensees. The remaining earthquakes presented below resulted in peak roof displacements occurring different times during the analysis. Once completing the analysis for all 20 earthquakes, the maximum roof displacements for frame 2 in both software were observed for EQ 12, North Ridge. Seismostruct resulted in a peak response of 4.24 inches while Opensees resulted with the larger, being 4.74 inches. All maximum displacements occurred during the time ranges of high frequency for all earthquakes. Similar to frame 1 at this point according to the Hazus inter-storey drift ratio damage states for low rise buildings, the was able to go beyond the threshold limits. The figure below shows the distribution of the max displacements for all unscaled ground motion records.

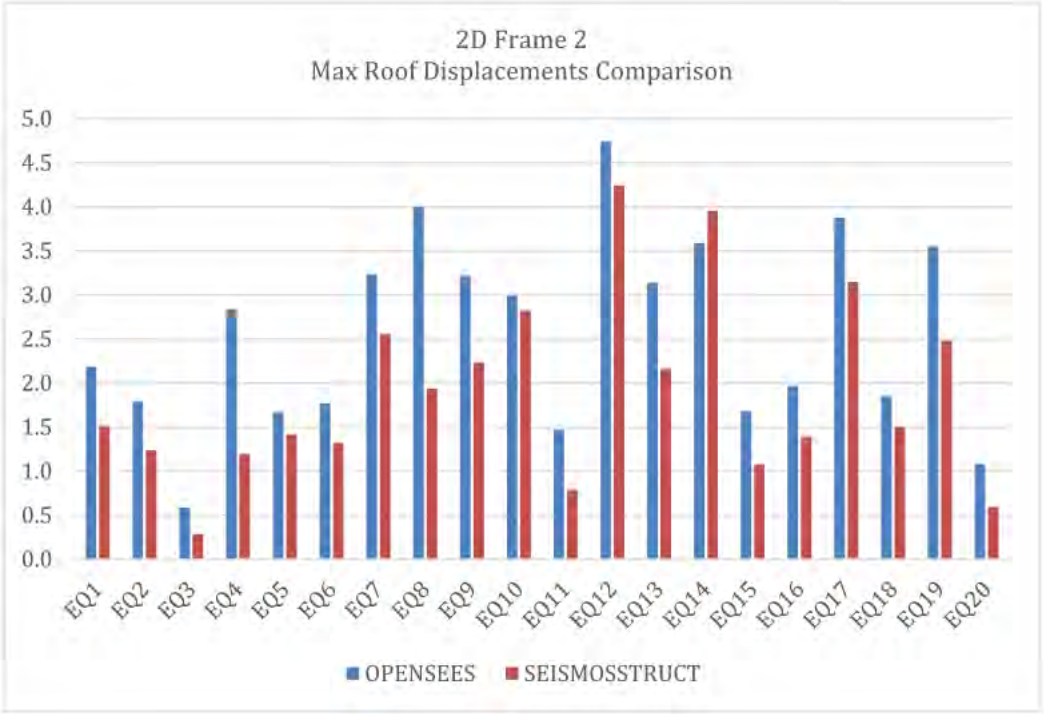
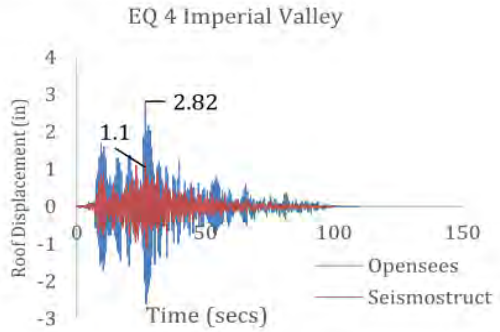



**Figure 7.6: Showing max roof displacements for all ground motion records for frame 2**

From the results, it is also observed that Opensees produced larger responses for frame 2, as opposed to the results obtained for frame 1.The reason for this will be discussed further in the discussion. The maximum roof drifts and inter-storey drift were also extracted and are displayed in figure 7.7 below, with the maximum inter-storey drift ratios are representative of the response of the first storey for both programs. It can be seen that generally Opensees produced larger responses in both figures. Despite this fact, the average of the differences between both programs for the max inter-storey drift ratio at second floor was found to be 0.002 inches. However, these values seem to show closer comparison compared to those presented in frame 1 where a few of the earthquakes generated larger responses in Seismostruct analysis.

FRAME 2 NLTHA RESULTS



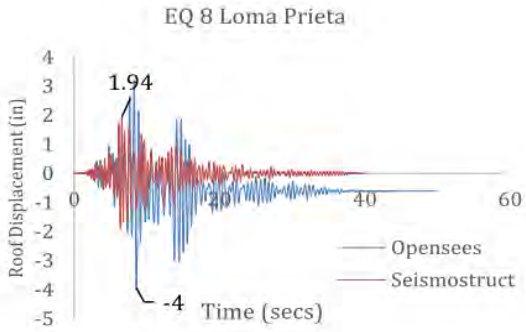




**Figure7.7A: Peak response, frame 2, EQ4**

**Figure7.7B: Peak response, frame 2, EQ8**

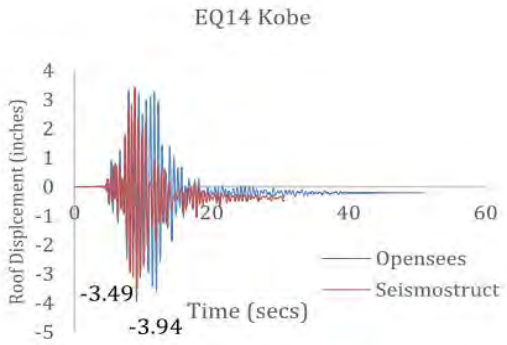



**Figure7.7C: Peak response, frame 2, EQ14**

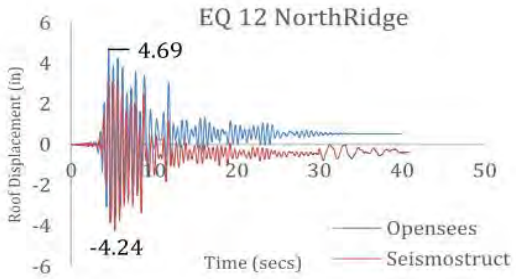



**Figure7.7D: Peak response, frame 2, EQ12**

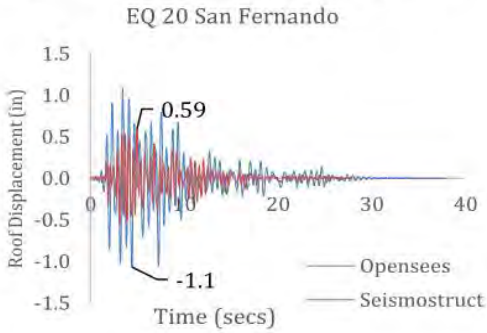



**Figure7.7E: Peak response, frame 2, EQ20**

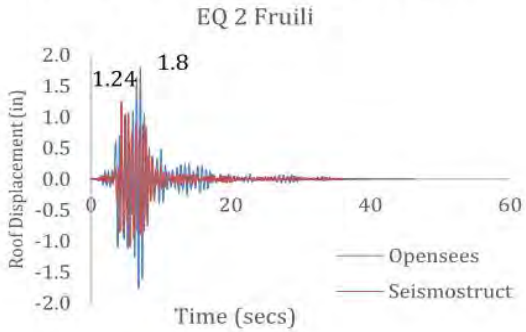
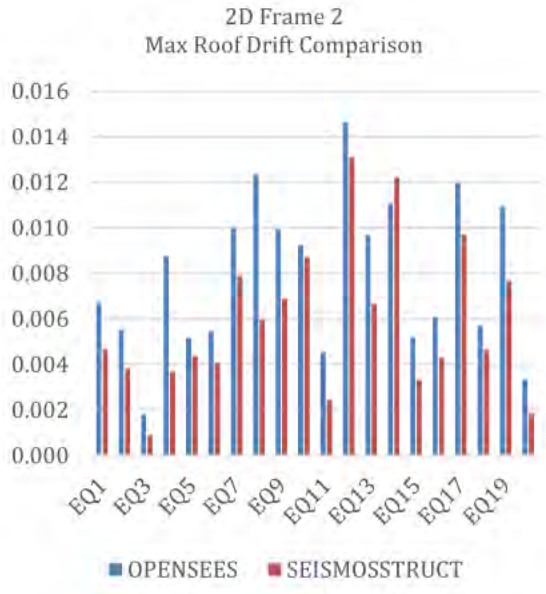
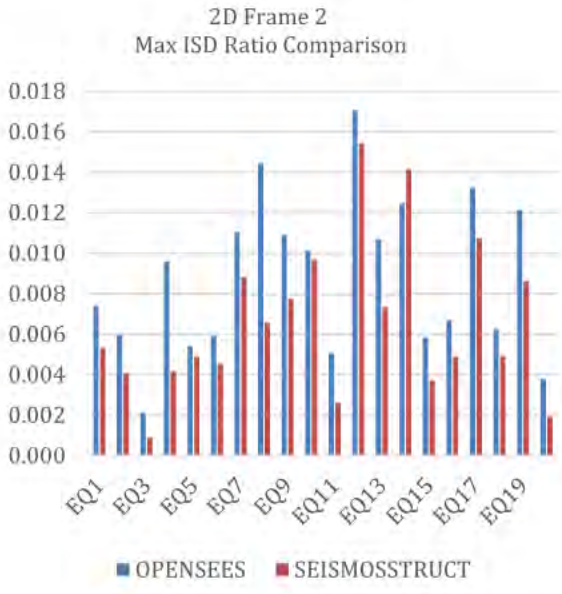



**Figure7.7F: Peak response, frame 2, EQ2**




**Figures 7.8: Showing max roof drift Frame 2 Figure 7.9: Showing max ISD ratio Frame 2**

***Frame 3***

Frame 3 demonstrated a similar response to frame 1 where Seismostruct generally generated larger roof displacements. However these displacements are numerically smaller as frame 3 relatively has the largest cross section and strongest design. The response frequency from both programs are identical which indicate the model was generated with some accuracy. The max responses, similar to the previously discussed frames, occurred during the high frequency portion of the earthquake however not always occurring at the same time for both software. From the six response time histories presented below, Earthquake 2 resulted in max responses occurring simultaneously with magnitude of 0.7 inches and 0.4 inches for Seismostruct and Opensees programs respectively. The max responses for the remaining earthquakes occurs presented below occurred at varying times for both programs. The distribution of the max responses for all 20 earthquakes for both programs are illustrated in the figure 7.9 below. The maximum response occurred for Loma Prieta in Seismostruct with a magnitude of 1.89 inches and for Opensees a max response of 1.19 inches for earthquake 9 which is the same earthquake however recorded from a different station.

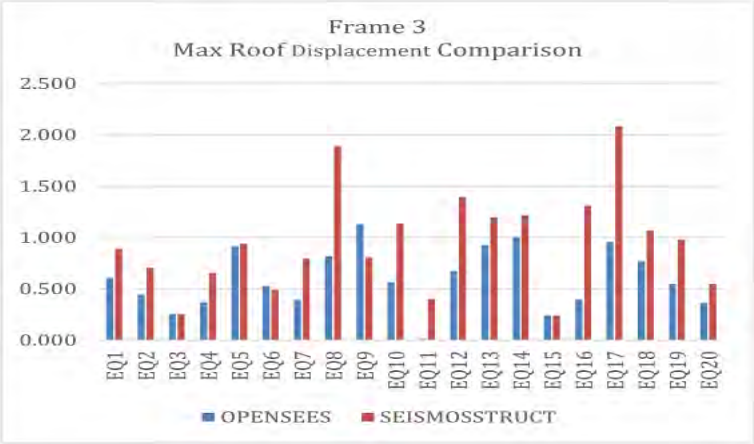



**Figure 7.9 Showing max roof displacements for all 2 ground motion records for frame 3**

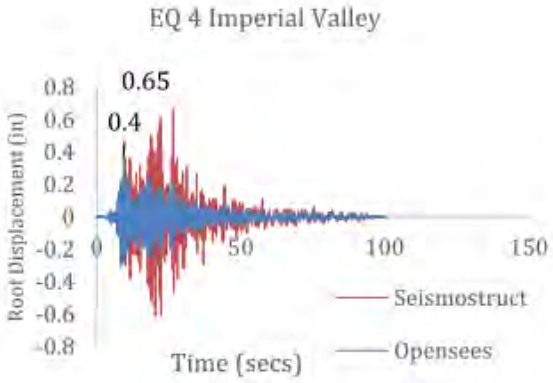



**Figure 7.10 A: Peak Displ. Frame 3, EQ4**

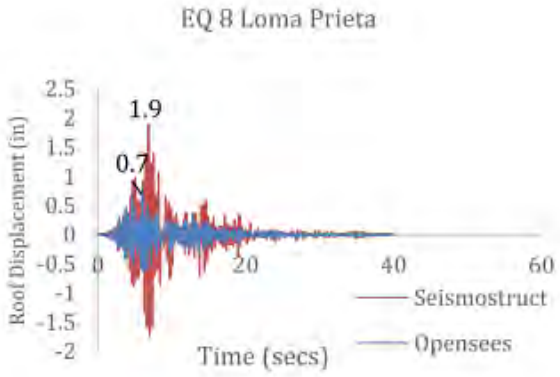



**Figure 7.10B: Peak Displ. Frame 3, EQ8**

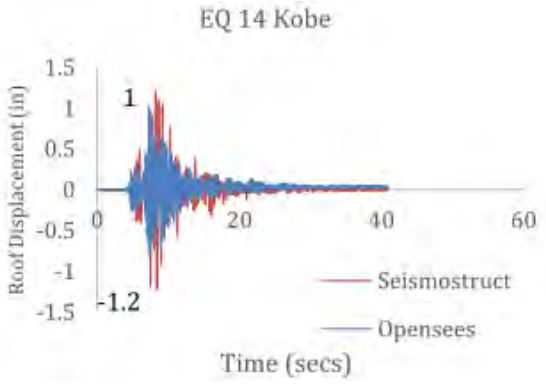



Figure 7.10 C: Peak Displ. Frame 3, EQ14

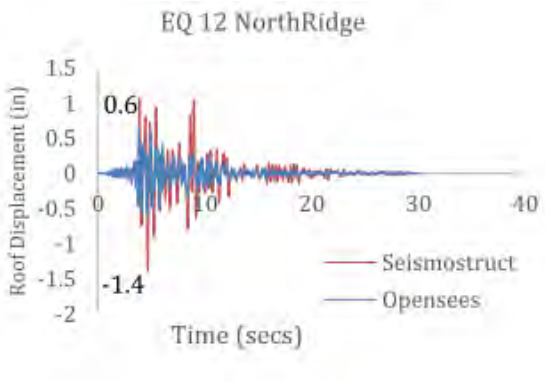



Figure 7.10 D: Peak Displ. Frame 3, EQ12

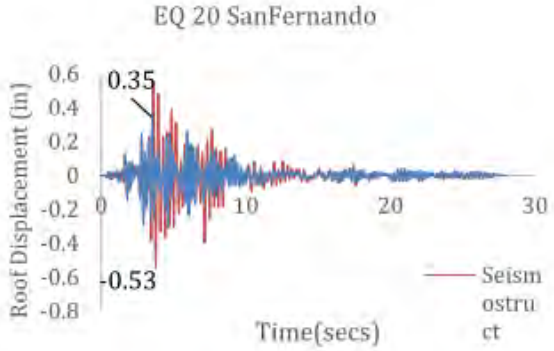



Figure 7.10 D: Peak Displ. Frame 3, EQ20

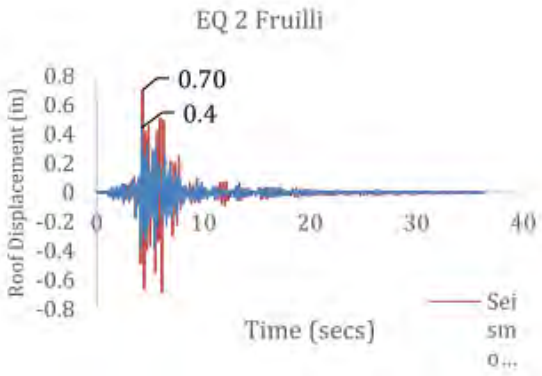



Figure 7.10 E: Peak Displ. Frame 3, EQ2

The maximum roof drifts and inter-storey drift were also extracted and are displayed in figure 7.11 below. Similar to frame 1, the response generated in Opensees for frame 3 were larger. The average differences between both programs for the max inter-storey drift ratio was found to be 0.0015 inches. When these values were compared to the hazus inter-storey drift ratio damage states for low rise buildings, it is observed that the building allow displacements pass the threshold.

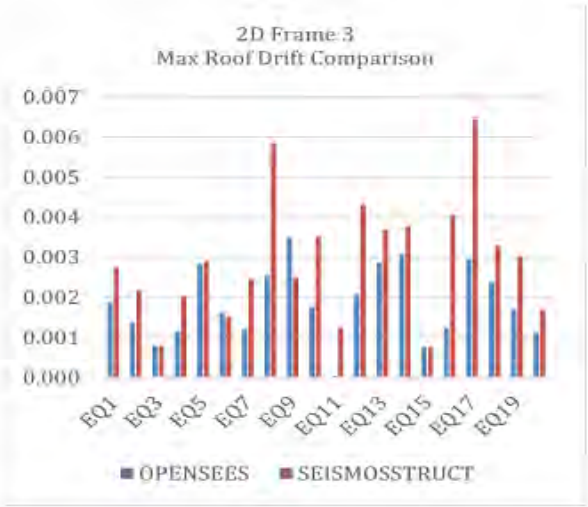



Figure 7.11: Showing max roof drift comparison

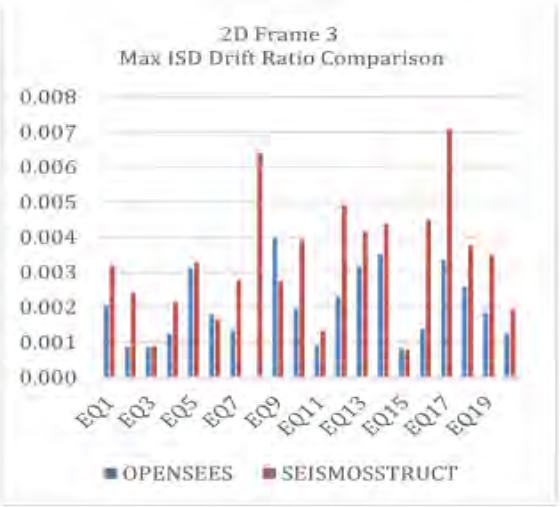



Figure 7.12 max ISD ratio comparison

The max roof inter-storey drifts were compared. From the figures above we can see the same trend where Opensees produced conservative results. As compared to Seismostruct with frame 2 showing a similar trend in results. They show a difference of average a 0.0023 inches for frame 2, 0.0014 inches for frame 3 and 0.00496 inches in frame one.

The inter-story drifts from the nonlinear time history analysis was then compared to push over analysis values at second floor for all frame .For frame 1, Opensees produced similar values in both analysis having values of 0.03 inches in push over analysis and 0.02 inches in nonlinear time history analysis with a 0.01 difference. For the same frame Siesmostruct produced drift values of 0.09 inches for the pushover analysis and 0.02 for the nonlinear time history analysis. These show a difference of 0.07 inches. In frame 2 Opensees had results 0.01 for nonlinear time history analysis and 0.02 push over analysis. While Seismostruct produced 0.06 pushover and 0.01 nonlinear time history analysis. For frame 3, 0.002 (NLTHA) and 0.01 pushover analysis, and Seismostruct 0.015 in pushover analysis and 0.003 nonlinear time history analysis.

From these results we see the Opensees showed similar values in both analysis compared to Seismostruct which relatively had greater difference in values. However in frame three Seismostruct and Opensees produced similar values. This is may be due to Seismostruct not able to produce results for cross sections frames. However Opensees was able to produce results despite the size of the cross section.

The table below provide a summary of the information presented above in a tabulated format. They also highlight the peak ground accelerations and spectral accelerations generated from the scaled earthquake based on the first period of the each frame. Further explanation of the use of these intensity measures is done below.

*Table 7-2: Showing intensity measure, max roof displacement and max roof drift Frame 1*

| Earthquake ID | PGA (g) | Sa (T1)g | SEISMOSSTRUCT | | OPENSEES | |
|---|---|---|---|---|---|---|
| | | | Max Displacement (in) | Max Roof Drift | Max Displacement (in) | Max Roof Drift |
| EQ1 | 0.54893 | 0.346 | 6.66557 | 0.0206 | 6.43227 | 0.020 |
| EQ2 | 0.35133 | 0.2564 | 3.05522 | 0.0094 | 3.42326 | 0.011 |
| EQ3 | 0.3497 | 0.1131 | 1.47661 | 0.0046 | 1.28879 | 0.004 |
| EQ4 | 0.36681 | 0.499 | 6.4434 | 0.0199 | 5.11902 | 0.016 |
| EQ5 | 0.35726 | 0.2344 | 5.5341 | 0.0171 | 2.8204 | 0.009 |
| EQ6 | 0.47498 | 0.3646 | 7.81156 | 0.0241 | 3.81898 | 0.012 |
| EQ7 | 0.51113 | 0.3373 | 4.2491 | 0.0131 | 4.01543 | 0.012 |
| EQ8 | 0.55912 | 0.4498 | 9.34313 | 0.0288 | 5.31013 | 0.016 |
| EQ9 | 0.4172 | 0.3074 | 2.50208 | 0.0077 | 3.10808 | 0.010 |
| EQ10 | 0.24452 | 0.4911 | 8.0306 | 0.0248 | 4.17684 | 0.013 |
| EQ11 | 0.48796 | 0.5059 | 9.6364 | 0.0297 | 3.92061 | 0.012 |
| EQ12 | 0.47163 | 1.0516 | 11.67356 | 0.0360 | 9.24603 | 0.029 |
| EQ13 | 0.48323 | 0.6771 | 5.44037 | 0.0168 | 4.95939 | 0.015 |
| EQ14 | 0.225 | 0.4212 | 3.60043 | 0.0111 | 3.52511 | 0.011 |
| EQ15 | 0.36418 | 0.4324 | 6.2419 | 0.0193 | 4.01732 | 0.012 |

| Earthquake ID | PGA (g) | Sa (T1)g | SEISMOSSTRUCT | | OPENSEES | |
|---|---|---|---|---|---|---|
| | | | Max Displacement (in) | Max Roof Drift | Max Displacement (in) | Max Roof Drift |
| EQ16 | 0.73925 | 0.5951 | 12.09336 | 0.0373 | 7.29806 | 0.023 |
| EQ17 | 0.51456 | 0.8028 | 7.91393 | 0.0244 | 7.13443 | 0.022 |
| EQ18 | 0.32819 | 0.3973 | 0.00542419 | 0.0000 | 4.18537 | 0.013 |
| EQ19 | 0.20988 | 0.3427 | 7.34368 | 0.0227 | 4.88623 | 0.015 |
| EQ20 | 0.21884 | 0.2438 | 4.68385 | 0.0145 | 4.00079 | 0.012 |

### Discussion

Seismostruct is able to provide the relative displacements therefore to determine the drifts at each floor or roof drift we have to divide by the height of the floor for the floor drift to by the height of the building for the roof drift. The plots above for the roof displacement show that Seismostruct generally provided larger displacements. However, Frame 2 generated results with the values from Seismostruct being conservative compared to Opensees. This result may not be fully accurate because from the push over analysis of frame 2, Siesmostruct encountered convergence problems resulting in the target displacement not being reached. As shown in the push over analysis of frame a second plot is shown attempting to rectify the issue of the first plot. This was done however when conducting the nonlinear analysis, Seismostruct encountered more errors. Therefore the choice was made to use the first pushover curve to run the dynamic analysis. We saw that the displacements reached I the push over analysis were less compared to those in Opensees and a similar trend is seen in the dynamic analysis. If Seismostruct was able to carry out the analysis to the target displacement without any errors, the nonlinear time history analysis would have resulting in Opensees providing conservative results. Also based in the results the reason why Seimostruct produced such larger responses may be due to the use of the bilinear steel element used for the analysis. Even though it models the nonlinear behaviour similar to that of the rotational spring, however according to seism soft (2016) if used in heavy seismic loading analysis the results would not be a good estimate of the occurs in real life. In this analysis the records used had complex loading histories therefore this can be the reason for the responses.

## Fragility Curves

The vulnerability of a structure exposed to seismic actions is usually expressed using vulnerability and fragility functions. These functions express the relationship between the levels of ground shaking expected at a site due to the probability damage. Fragility curves incorporate these functions which are used to describe graphically, the probability that specified structures will reach or exceed specified damage states for certain levels of intensity earthquakes. Fragility functions are usually expressed in the form:

$P\ (DS \geq ds_i\ |IM)$ for $IM_{min} \leq IM \leq IM_{max}$

Where: DS is the damage state of the building class being assessed, $ds_i$ is a predetermined damage state and IM which represents the intensity measure expressing the ground motion damage potential, with respect to the specified building.(Rossetto et al. 2016)

### Fracas methodology

The fragility curves in the research will be generated using the fragility through capacity spectrum assessment (FRACAS).This procedure builds and expands on a modified capacity spectrum method initially developed by (Rossetto and Elanashai, 2005). FRACAS applies the said methodology but

improves it, allowing for a more sophisticated capacity curve idealizations, the use of various hysteretic models for SDOF in the inelastic demand calculation, and the construction of fragility functions through numerous statistical model fitting techniques. This method is efficient allowing the fragility curves to be generated from the analysis of a specific structure subjected to a number of acceleration time histories with distinct characteristics. The variation in seismic input and structural characteristics on the damage statistics for the modelled building class are also accounted for in this method along with the uncertainty in the prediction is evaluated.

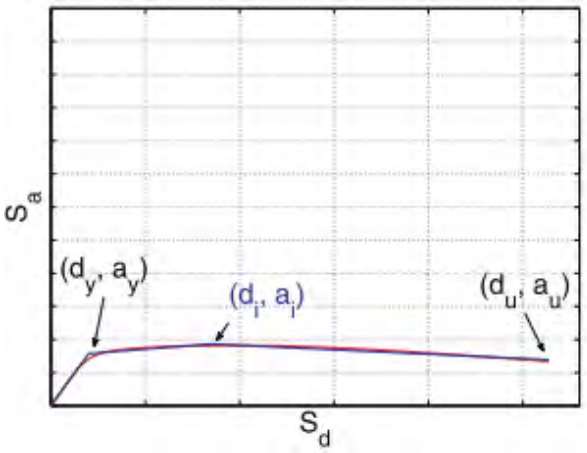



**Figure 8.1 A Capacity Curve Idealisation**

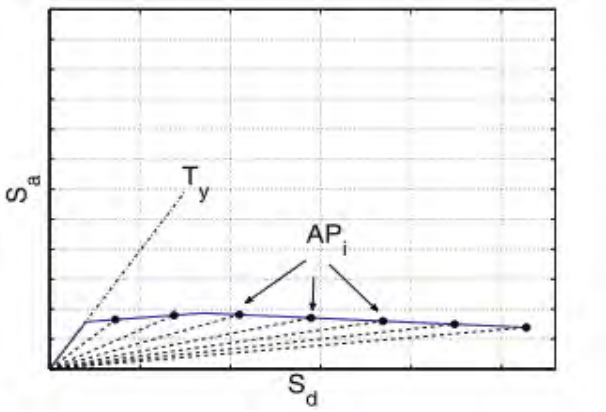



**Figure 8.1B :Discretization into post yield periods**

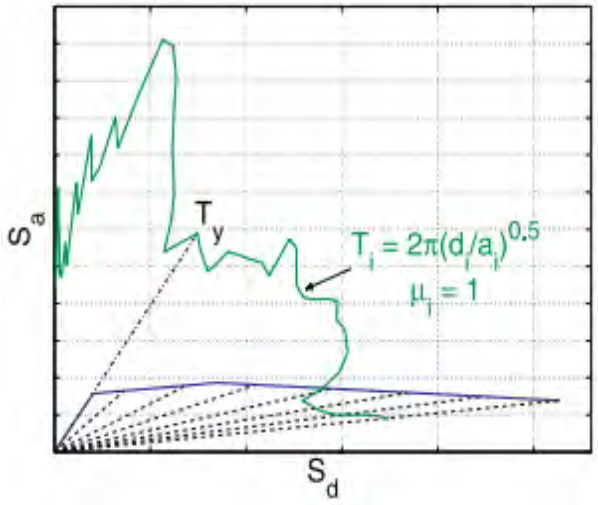



**Figure 8.1 C Elastic Response Period**

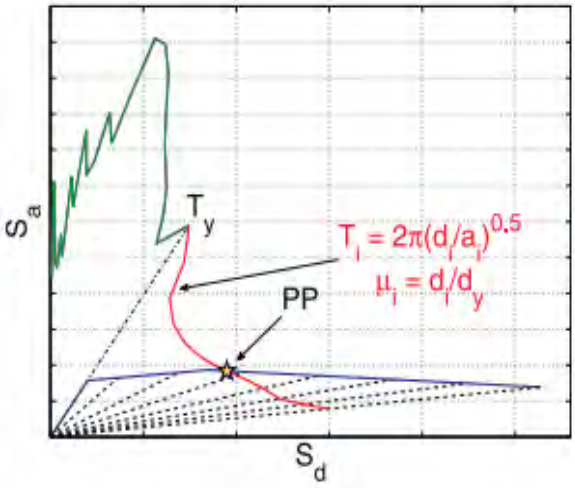



**Figure 8.1D : Inelastic Response Spectrum & PP**

The figures above illustrate the steps involved in developing the perfomance point , (Rossetto et al. 2016)

The procedure used to determine the performance point is summarised below.

1. The first step involves converting the force – displacement curve into a capacity curve relating to a single degree of freedom model. This process utilizes the floor masses and inter-storey displacements generated from the push over analysis.
2. The second step involves idealisation of the capacity curve which can be modelled using different idealisation models, yielding point, hardening and ultimate point This curve is represented using various nonlinear characteristics, point of yielding, hardening characteristics and structures capacity.
3. The third step divides the capacity curve into a number of points along with respective pre- and post-yield periods.

4. The forth step consist of utilizing the input ground motions to generate an elastic response spectrum where the demand is determined up to the yielding
5. The fifth step entails computing the inelastic demand of the equivalent single degree of freedom relating to the specified post-yield periods.
6. The final step defines the performance point. This is defined as the point where the capacity curve is intersected by the demand curve. The equivalent engineering demand parameters can be determined by back calculating the performance point to the force-displacement representation.

The fragility analysis was conducted for the frame 1 and 2 in both programs presenting the sensitivity of each model has on the risk assessment.

**Table 8-1 Showing parameters for frames OP 1**

| Damage State | Opensees Frame 1 | |
|---|---|---|
| | Median | Dispersion |
| Slight | 1.36 | 0.54 |
| Moderate | 3.25 | 0.54 |
| Complete | 21.51 | 0.70 |

**Table 8-2 Showing parameters curves for SS frames 1**

| Damage State | Seismostruct Frame 1 | |
|---|---|---|
| | Median | Dispersion |
| Slight | 2.65 | 0.61 |
| Moderate | 15.47 | 0.72 |
| Complete | 0 | -2.64E+13 |

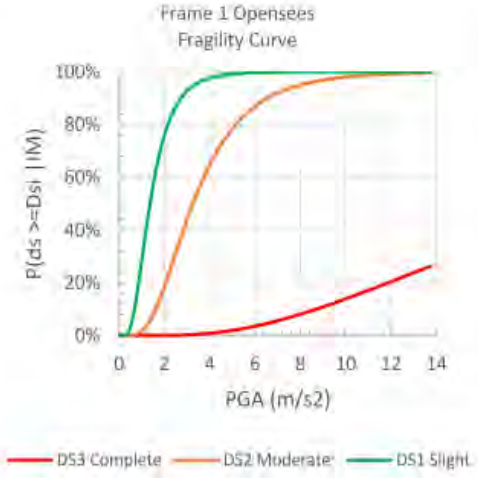



**Figure 8.2: Showing Fragility curves frame 1OP**

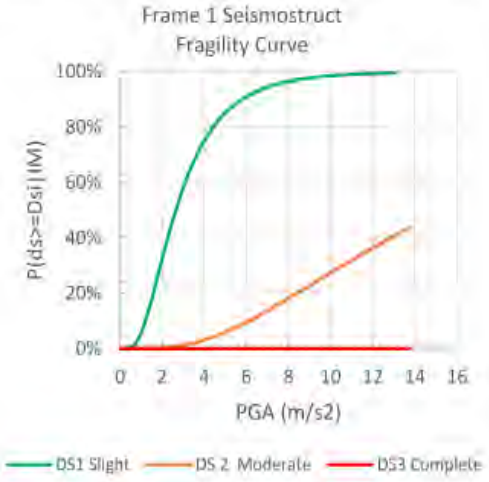



**Figure 8.3: Showing Fragility curves frame 1SS**

| Damage State | Opensees Frame 2 | |
|---|---|---|
| | Median | Dispersion |
| Slight | 3.00 | 0.37 |
| Moderate | 14.14 | 0.37 |
| Complete | 0.00 | -2.64E+13 |

| Damage State | Seismostruct Frame 2 | |
|---|---|---|
| | median | dispersion |
| Slight | 4.08 | 0.31 |
| Moderate | 0 | -2.63E+13 |
| Complete | 0 | -2.63E+13 |

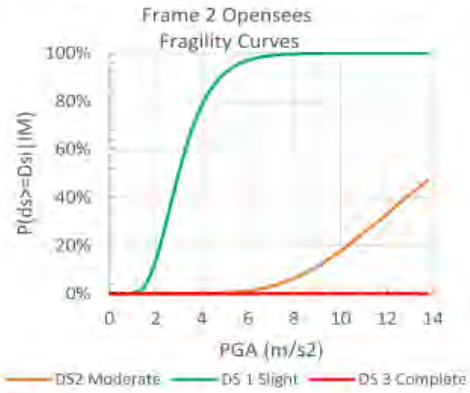



**Figure 8.4: Showing Fragility curves frame 2, OP**

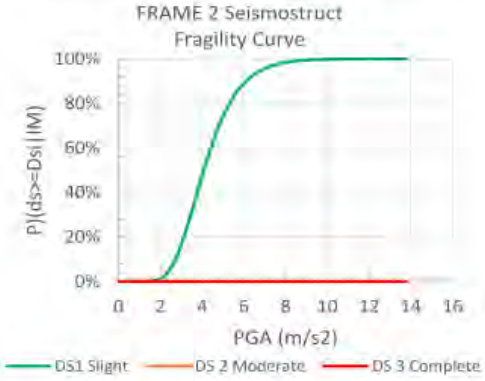



**Figure 8.5: Showing Fragility curves frame 2, SS**

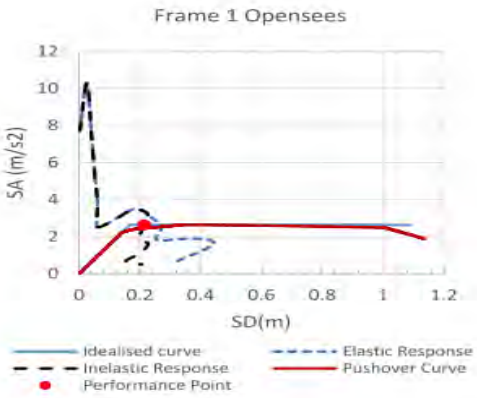



**Figure 8.6A: Showing PP for frame 1 in Opensees**

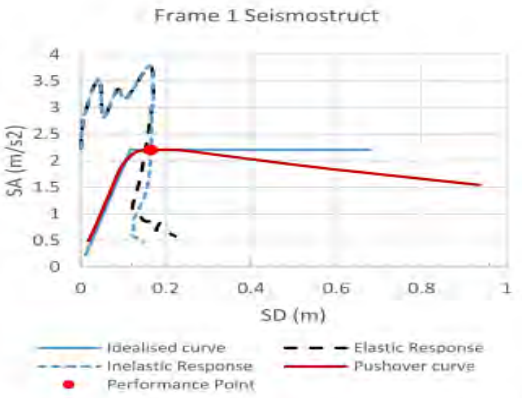



**Figure 8.6 B: Showing PP for frame 1 in Seismostruct**

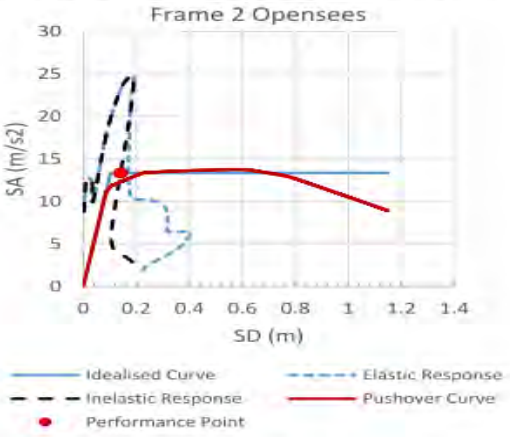



**Figure 8.6 C: Showing PP for frame 2 in Opensees**

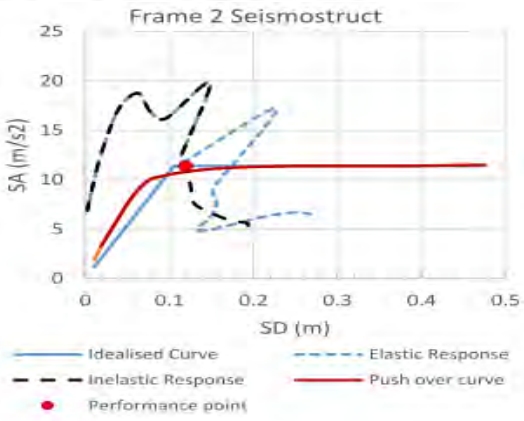



**Figure 8.6 D: Showing PP for frame 2 in Seismostruct**

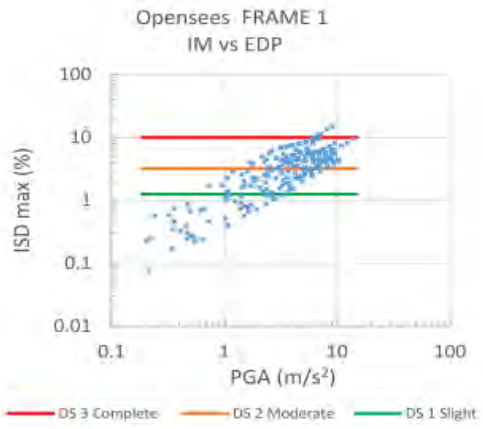



**Figure 8.7 A: Showing IM and EDP plot frame 1, O.P**

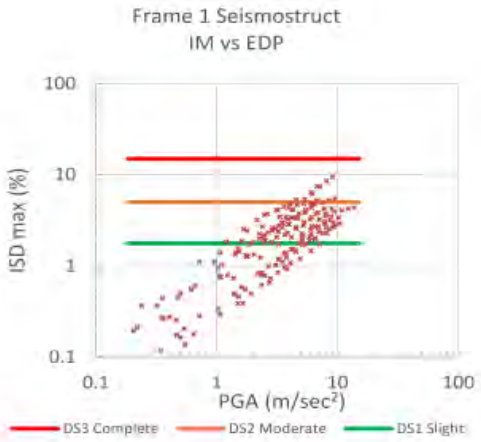



**Figure 8.7 B: Showing IM and EDP plot frame 1, S.S**

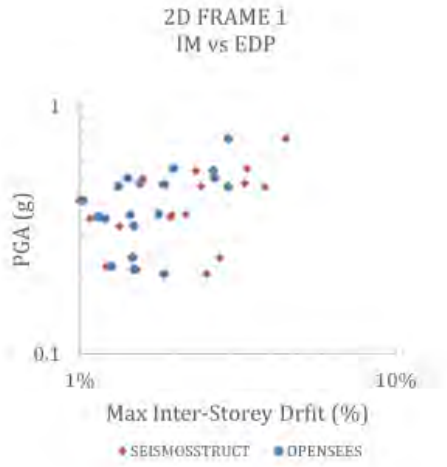



**Figure 8.8 A showing IM and EDP comparison, frame 1**

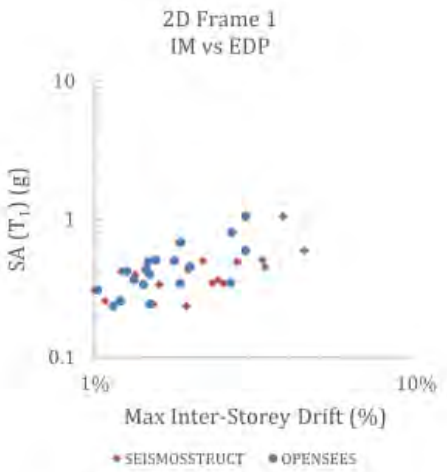



**Figure 8.8 B showing IM and EDP comparison, frame 1**

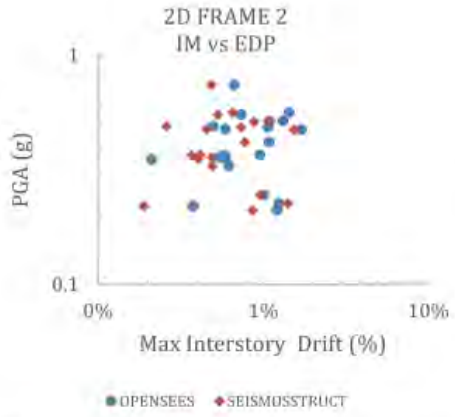



**Figure 8.8 C showing IM and EDP comparison, frame 2**

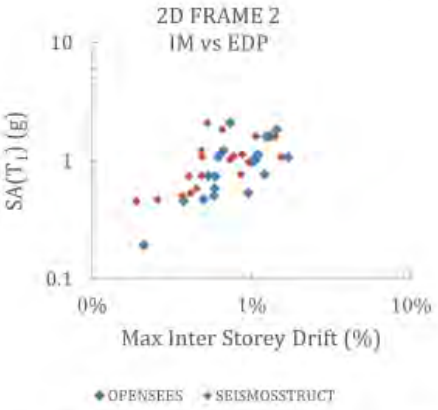



**Figure 8.8 D showing IM and EDP comparison, frame 2**

## Further Analysis

**Opensees Fibre based elements vs Seismostruct forced based concentrated plasticity and displacement based inelasticity.**

The figure below shows the pushover curves a reinforced concrete 3D building. The plot shows the comparison of pushover curves using fibre section distributed plasticity element in Opensees, force based concentrated plasticity in Seismostruct and Displacement base distributed plasticity. The results show the initial elastic stiffness is the same for all curves however the Opensees had a slight reduction. This could be due to the material characteristics in the different programs having minor differences. The distributed plasticity in Opensees tend to be a conservative and while the displacement based plasticity in Seismostruct produced high demands.

*Table 9 .1 Eigen analysis results for 3d building*

| Seismostruct | |
|---|---|
| **Mode 1 ,T1** | **Mode 2, T2** |
| 0.43 s | 0.34 s |
| **Opensees** | |
| **Mode 1, T 1** | **Mode 2, T 2** |
| 0.40 s | 0.40 s |

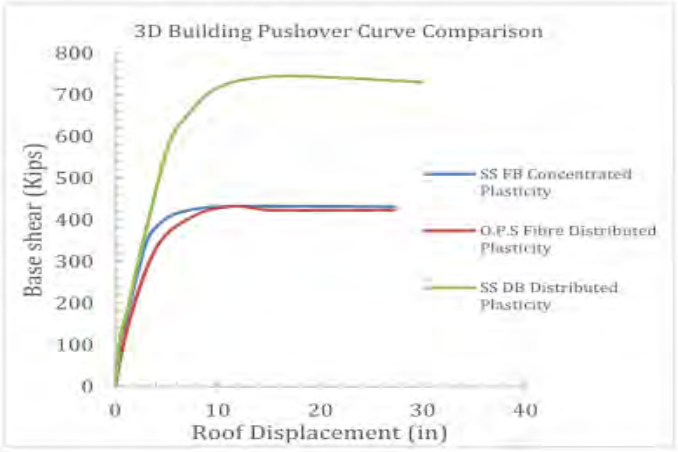



*Figure 9.1: Pushover curves for 3d building*

### Future Works

To gain further insight into understanding the inconsistencies with both modelling techniques used I would suggest the following:

1) Conduct the same analysis using the IMK springs in Opensees in a 3 dimensional real life earthquake resistant structure and model the same structure in Seismostruct and compare the response of the structure via Nonlinear Static push over analysis and Nonlinear Time history Analysis. This would further allow us to understand if the results would follow the similar pattern observed in the 2d frame above. Also, varying the heights and bays of the 2 d frames to get an understanding of how varying stiffness along the height would produce any changes in the previous results.
2) Continuing from the 3d building analysis, conduct nonlinear time history analysis using the three element types of the 3 dimensional building presented previously to determine which elements type responses match.

## Conclusion

### Nonlinear analysis

The investigation first examined the effects of modelling assumptions and two different computer programs on nonlinear response of 2 dimensional buildings. It was found that modelling assumptions significantly affected the pushover curves. From the nonlinear pushover analysis, it was found that Seismostruct reproduced conservative base shear displacement results compared to Opensees. The results from the nonlinear time history analysis showed that Seismostruct produced larger peak displacements compared to Opensees. The main reason this could have happened is due to the steel material models not being able to be used in complex loading situations.

# Barriers to Flood Mitigation among Households in St. Mary, Jamaica

*By Sean Hylton*

This paper is the report of a research project presented submitted in partial fulfilment of the requirements of the degree of Master of Science in Sustainability (Environment and Development), University of Leeds – 2014

**Abstract**

This paper explores factors that impede the implementation of flood mitigation measures by householders in two flood prone communities in St. Mary Jamaica. It reveals that floods impact households in numerous ways, and unearth strategies employed by householders to lessen the negative effects of floods. This paper reports that householders draw on various resources to facilitate their process of implementing flood mitigation measures; however, the implementation of additional resistance and resilience measures is made difficult by a combination of barriers including information and financial barriers.

## Background

Early flood risk management projects were designed and implemented by government agencies and focused on large-scale structural solutions (e.g. dams and levees) (Bubeck et al. 2012; Bichard and Kazmierczak, 2012; Laska 1986); this strategy evolved over the years to include non-structural, regulatory measures (Laska, 1986); it is important to note that these approaches to flood risk management excluded householders from the process to a great extent (Bubeck, 2012; Laska, 1986) and achieved limited success (Laska, 1986). However, it is now widely acknowledged that flood risk cannot be totally eliminated by public flood mitigation solutions (Osberghaus, 2014 ;Birkholz, 2014; Lopez-Marrero and Yarnal, 2010; Wilby and Rod Keenan, 2012; Paul and Routray, 2010; Wisner et al., 2004), hence, recent efforts in flood risk management in some countries also seek to address the role of citizens in implementing flood mitigation measures (Birkholz et al., 2014; Bubeck et al, 2012; Bubeck et al, 2012B; Bichard and Kazmierczak, 2012).

Although it is now widely acknowledged that citizens have an integral role to play in flood risk management (Osberghaus, 2012; Bubeck et al., 2012; Bichard and Kazmierczak, 2012; Harris, 2012; Lamond and Proverbs, 2009); numerous studies have indicated that residents of flood prone communities often fail to implement flood mitigation measures (e.g., Bichards and Kazmierczak; Harvatt et al. 2010;). Lamond and Proverbs (2009) conducted a literature review of empirical studies and argued that any programme aimed at encouraging home owners to implement flood protection measures must overcome barriers which may be informational, emotional and financial. Other barriers according to Lamond and Proverbs (2009) depend on local circumstances, financial and regulatory regimes.

This paper explores the local circumstances in Jamaica which impede flood mitigation among households, drawing on insights from Port Maria and Annotto Bay. More specifically, this paper focuses on the flood impacts and mitigation measures as well as factors that promote and hinder the implementation of flood mitigation measures among households. It is true that numerous studies have been conducted on flood mitigation at the household level (Few 2003), however, some researchers call for more studies on the subject to enhance understanding and aid in decision making (Bubeck et al., 2012; Few. 2003)

Port Maria and Annotto Bay are flood-prone – coastal towns, which have experienced flooding on many occasions. It has been reported that these communities are without appropriate public mitigation measures; hence, experts have recommended the implementation of same in these communities. For

example, Mandal and Maharaj (2013, p.166) points out that Port Maria "…lacks proper flood control measures" whilst recommending that "the river channel [Port Maria River/Outram river] needs to be widened by dredging and the existing drainage system of the area needs to be improved to clear clogged drains" (Mandal and Maharaj, 2013, p. 170). With regards to Flood Mitigation in Annotto Bay, the Office of Disaster Preparedness and Emergency Management – ODPEM (2013) points out that various public mitigation measures (e.g. Dikes, Detention Ponds) are recommended by the National Works Agency (NWA) for implementation in the community.

Based on the foregoing, measures implemented at the household level could be the only flood protection for some residents of Port Maria and Annotto Bay. It is therefore important to investigate the strategies employed by residents to lessen the negative effects of floods, as well as to explore the factors that influence the implementation of flood protection measures at the household level in these communities.

## Aim

This study is aimed at finding out the barriers to the implementation of flood protection measures among households in Port Maria and Annotto Bay, Jamaica. More specifically, this research focuses on the factors that make it difficult for householders to lessen the effects of floods through the implementation of resilience and resistance measures. It should be noted that resistance measures also referred to as dry proofing (Lamond and Proverb, 2009) are designed to keep water out of the property/building, and may be temporary measures (Bichard and Kazmiercak, 2012), in which case they are implement just before a flood (e.g. the implementation door barriers); or permanent measures such as raising floors and the use of waterproof doors (Bowker, 2002 cited in Bichard and Kazmiercak, 2012).

Resilience measures on the other hand are referred to as wet proofing (Lamond and Proverb, 2012) and are aimed at reducing damages to the dwelling, "including the interior and furnishing, thereby facilitating the quickest possible recovery (Pitt 2008, cited in Bichard and Kazmiercak, 2012).

It is true that the implementation of resistance and resilience measures are only two of the many ways that residents of flood prone areas to cope with floods; the various types of coping strategies will be discussed later.

## Objectives

The objectives of this study are:

- To investigate the ways in which floods affect households in Port Maria and Annotto Bay.
- To identify the strategies employed by residents of Port Maria and Annotto Bay to lessen the negative effects of flooding.
- To investigate the rationale behind the mitigation strategies employed by residents of Port Maria and Annotto Bay.
- To assess the effectiveness of flood mitigation measures employed by residents of Port Maria and Annotto Bay.
- To investigate the factors that foster the implementation of Flood Mitigation measures among households in Port Maria and Annotto Bay.
- To investigate the factors that hinder the implementation of Flood Mitigation measures among households in Port Maria and Annotto Bay.

## Structure of Thesis

The overall structure of this study takes the form of five (5) chapters, including this introductory chapter. The paper proceeds as follows: Chapter two (2) explores the literature which speaks to topics relating to the aims and objectives of this paper and provides an explanation of key words used in this study. The third chapter is concerned with the methodology used for this study and also gives an overview of the study area. Findings and analysis are presented in Chapter four. The final chapter provides a synopsis of findings and identifies areas for further research.

## Literature Review

The purpose of this chapter is to review the literature which speaks to flood impacts and mitigation strategies among households, as well as to investigate current understandings of the factors that influence householders' mitigation behaviour. It begins by exploring the general socio-economic and environmental effects of flooding.

### Flood Impacts

Floods produce both positive and negative effects (Braun and ABheuer, 2011;Few, 2003; Pelling 1999;Wisner et al., 2004); however, it can be argued that floods are renowned for their negative effects. Wisner et al (2004, p.176) point out that "although we understand all too well the damage floods do, we have not, until recently, understood very well the beneficial aspects of flooding;" moreover Wisner et al., (2004, p.176) argue that it is the collapse of confidence in public mitigation measures that fostered an increased interest in the 'living with floods' approach, which goes beyond the negative consequences of flooding to recognize the positive effects of this natural hazard. It should be noted that the positive effects of floods are varied and many, and include (but not limited to) the maintenance of diversity in flora and fauna which support livelihoods that depend on these resources (Wisner et al. 2004).

Positive effects of flood on households The work of Pelling (1999) provides examples of the positive effects of floods to individuals and institutions. Pelling (2009) noted that flooding may provide financial gains for some entities and individuals through contracts obtained to provide services aimed at lessening the effects of floods (e.g. contracts to clean drains, raise yards, etc.). Additionally, the work of authors such as Wisner et al., (2004) and Few (2003) reveals that in some regions (e.g. in Bangladesh) different terms are used to differentiate between beneficial floods and destructive floods.

### Negative effects of floods

As mentioned previously the negative effects of floods are well known, as floods often produce extensive destruction to life and property – which varies from catastrophic floods that drown people and live stock - to less severe floods which hinder access to services and business activities and which may increase health risks (Wisner et al. 2004; Few 2003). Residents of flood prone communities may have to face these situations on many occasions over long periods of time; residents may implement various strategies to lessen the negative effects of floods. Strategies which may be employed by flood-plain residents to tackle the negative effects of floods are discussed below.

### Strategies to Cope with Floods

As was mentioned in the previous chapter, property level flood protection is only one of many approaches to cope with floods (Mavhura et al., 2013; Islam et al., 2012; Paul and Routray, 2010; Wisner et al., 2004; few, 2003). Before providing greater detail regarding the features of property level flood protection, it is necessary to look at coping strategies in general. Wisner et al. (2004, p.100) defines coping as "the manner in which people act within the limits of existing resources and range of expectations to achieve various ends." It should be noted that strategies to cope with floods may be applied before, during, or after the event (Wisner et al., 2004; few, 2003) and operate at different levels from the individual level (e.g. household) and community level to institutional levels (e.g. city-wide or beyond) (Jabeen et al 2011). Coping strategies are also categorized as structural or non-structural (Mavhura et al. 2013; Islam et al., 2012; Aboagye, 2012;Paul and Routray, 2010; Few, 2003 ) as well as indigenous (traditional) or modern (Mavhura et al. 2013 Paul and Routray, 2010;).

Coping strategies are further categorized under different headings (which will be discussed later) and are explored in different schools of thought. The following section discusses the approaches to understand 'coping strategies' in the fields of disaster risk reduction and climate change adaption, two schools of thought that explore similar ideas using different terms (Jabeen et al, 2010).

Various researchers have indicated that households can reduce their vulnerability to floods through the implementation of "coping and adaptive strategies" Linnekamp et al (2011, p.448). These researchers are

often linked to the fields of disaster risk reduction and climate change adaptation. Jabeen et al. (2010) points out that there is a growing integration of these two fields, as there is greater understanding that alleviating socio-economic vulnerability to natural hazards or the impacts of climate change reflects similar schools of thought. As stated by Jabeen et al. (2010, p.416) "the two fields use subtly different language to describe similar activities;" for example 'coping capacity' (as defined in the field of disaster) and 'adaptive capacity' (as defined in the climate change field) (Jabeen et al., 2010).

Several authors also presented information regarding the types of coping strategies (e.g. Mavhura et al. 2013; Islam et al., 2012; Jabeen et al., 2011; Paul and Routray, 2010; Wisner et al. 2004; Few, 2003;) . Wisner et al. (2004) differentiated between preventative and impact minimization coping strategies (also referred to as 'mitigation') and suggested that the decision to avoid living on flood plains is a preventative coping strategy. In contrast to preventative strategies, impact minimizing strategies are aimed at reducing loss and facilitate recovery. Unlike Wisner et al. (2004) who linked the term 'preventative strategy' to decision to avoid living in flood prone areas; authors such as Islam et al. (2012) and Paul and Routray (2009) use the term 'preventative strategies' on a temporal basis - to refer to actions applied before the event, whilst using the term 'mitigative strategy' (or 'corrective strategy' (Islam et al 2012)) to refer to actions taken during and after flood events.

In general, research on coping strategies reveals that coping techniques include (but are not limited to):

1. Modification to the physical and built environment (e.g. the implementation of property level flood protection measures, which involves making changes within /outside of the house) (Jabeen et al. 2011);
2. Building up stores of food, water and saleable assets (Mavhura et al., 2013; Jabeen et al, 2011; Wisner et al. 2004). 3. Diversifying production and Income Sources (Jabeen et al, 2011; Paul and 16 Routray, 2010; Wisner et al. 2004); 4. Development of social support network (Jabeen et al, 2011; Wisner et al. 2004).

This paper is mainly concerned with coping strategies that are linked to modification of the physical and built environment at the household level and will explore both 'traditional' and 'modern' strategies that are implemented before, during and after floods, to lessen the negative effects of this natural hazard. The following section looks at property level flood protection in greater detail.

This research focuses on strategies employed by flood-plain residents to keep water out of their home and to protect the interior and furnishing of the house. These strategies are often referred to as flood proofing/property level flood protection measures and are further categorized as resilience or resistance measures (Kazmierczak and Bichard 2010), however, other terms are also used in the literature to describe these strategies. For example, terms including (but are not limited to) "mitigation measures" (e.g. Poussin et al, 2014) and "adaptive measures" (e.g. Kellens, et al. 2013) are used to refer to similar activities and are sometimes further categorized based on temporal features (based on the stages of the hazard cycle) or on the strategy being structural or non-structural.

According to Kellens, (et al. 2013, p.38) "people can adapt to floods by taking various adaptive measures, such as raising one's home above the highest flood level, by placing sand bags, or by taking out flood insurance." Associated with adaptive measures are: (1) mitigation measures which are implemented before the event (e.g raising home above expected water level), (2) Preparedness Measures which are implemented just before or during a flood (e.g. the use of sand bags and moving furniture to higher floor) and (3) Recovery Measures (e.g. Flood insurance) (Kellens et al. 2013).

It is therefore true that strategies aimed at keeping water out of homes and to protect the interior and contents of home are referred to in the literature using different terms, however, for this paper these strategies will be referred to as property level protection measures, however, other terms such as private mitigation measures/flood mitigation measures will be used to describe these activities. The following section explores these measures in more detail.

As discussed above, property level flood protection involves Flood proofing of homes and is concerned with the implementation of resistance (dry proofing) or resilience (wet proofing) measures (Lamond and Proverb, 2009). Resistance measures are designed to keep water of a property; while the resilience approach is to allow water into the dwelling whilst implementing measures to facilitate quick recovery after a flood event (Dhonau and Lamond, 2012). Most accounts suggest that flood proofing of homes can be beneficial for flood plain residents; however, these measures may be ineffective and unsuitable in some cases (Lamond and Proverb, 2009). According to Dhonau and Lamond (2012) resistance measures are suitable in flood events that involves quick run off time, with low velocity; moreover, Dhonau and Lamond (2012) point out that resistant intervention are more suitable where the depths of floods do not exceed a metre, as above the mentioned depth, there is some risk to the structural integrity of the building. Dhonau and Lamond (2012) also acknowledged difficulties in keeping water from entering the property which relates to water entering buildings in many different ways, as well as the fact that water can seep through building materials. As stated by Lamond and Proverbs (2009, p.63) "some floods will cause structural damage and sweep away the best designed homes, " however it is also true that where resistance measures are not successful, they may assist by providing householders extra time to evacuate the premises and to protect contents from flood waters (Dhanau and Lamond, 2012). Resistant and resilient buildings are also seen to produce a dual advantage of costing less on average to restore after a flood as well as taking less time to restore (Dhonau and Lamond, 2012; Lamond and Proverb, 2009), hence it is suggested that the implementation of resistance and resilience measures enables flood victims to return quickly to their homes and reduce their stress and expenses (Dhonau and Lamond, 2012; Lamond and Proverb, 2009). However, it is also acknowledged that resistant and resilient buildings are not always cost-effective solutions and that planning for evacuation to emergency shelters may be a better approach in some cases. Indeed, as stated by Lamond and Proverb, 2009 "resistant and resilient building are not a panacea for all ills." Therefore, it is of vital importance that governments and planners determine the most suitable approach to deal with flood hazards (Lamond and Proverb, 2009); however, as stated earlier, a shift can be observed in flood risk management in some countries (e.g. UK and Germany), from a state-centred-approach towards one where citizens are expected to implement property level flood protection measures (Osberguhaus; 2014; Dhonau and Lamond, 2012; Bichard and Kazmierczak; 2012; Bubeck et al., 2012; Lamond and Proverb, 2009).

This research explores householders approach to flood proofing their homes (or the lack there off) in a country where citizens [for the most part] are not being encouraged to implement flood protection measures. Using examples from communities that "…lacks proper flood control measures" (Mandal and Maharaj (2013, p.166) and where recommendations are being made for the implementation of public mitigation measures, this study also explores barriers to the implementation of flood protection measures among households. The following section explores the literature which speaks to factors that influence the implementation of flood protection measures at the household level.

### Factors that influence flood mitigation among households

A number of researchers have explored factors that may influence the implementation of flood protection measures among householders; these factors as presented in the literature are varied and many, however, information regarding same is not presented in a straightforward manner (Birkholz et al., 2014; Bubeck et al. 2012; Bichard and Kazmierczak (2012;). In reviewing factors that may influence flood mitigation behaviour, Bubeck et al. (2012 p. 1482) state that "these factors are currently not clear due to the complexity of the existing literature on this topic;" moreover, Bubeck et al. (2012) suggested that prior to their work such review was not available for flood risk in the literature, and pointed out that their work "aims to identify the most important factors, thereby reducing the existing complexity in the current literature" (Bubeck et al. 2012, p.1488). Similarly Bichard and Kazmierczak (2012, p.637) point out that the literature on the subject provide some level of understanding, however, "the information is scattered among many sources." It is important to note that factors explored by researchers include (but are not limited to), perceptions of risk, perceptions on the role of government, experience with flooding,

knowledge of flood hazard, knowledge of solutions and access to resources; these and some of the other factors that are presented in the literature are discussed below.

## Perceptions of Risk

Much of the current literature on factors that may influence private flood mitigation measures pays particular attention to perceptions of risk; this was pointed out by a number of authors (e.g. Bubeck et al. (2012); Kellens et al. 2013). For example, whilst acknowledging that there is a growing body of literature which investigates the factors that influence householders' flood mitigation behaviour, Bubeck et al. (2012, p.1482) suggests that among these factors, "flood risk perceptions have been the most dominant." Flood risk perception is regarded as a complex research field which is in its infancy stage; moreover research on the subject is based on various theories (among others - Psychometric Paradigm and Protection Motivation Theory (PTM)) and methodologies (Kellens et al. 2013). The literature also suggests that most studies on flood risk perceptions have been conducted in Europe; however, a number of studies have also been conducted in North America and Asia as well (Kellens et al., 2013).

It is important to note that information contained in review articles on the subject suggest that results are mixed, as some researchers have found a positive relationship between risk perceptions and householders' mitigation behaviour; while findings from other studies reveal the opposite. Interestingly, these reviews present different findings regarding the number of research reporting positive or negative relationships. For example the work of Bubeck et al. (2012) which reviews empirical evidence from seven countries indicate that findings from most of the reviewed studies shows no or only a weak relationship between the two variables; on the other hand, based on a review of studies that were also carried out in regions mentioned above, Osberghaus (2014, p. 4.) point out that "almost all cited sources finds a positive and significant correlation in their sample between flood risk perception and the uptake of mitigation measures".

Perceptions of risk according to Bubeck et al. (2012) are deemed to provide valuable insights for risk management as well as risk communication strategies, a notion which emanates from the expected positive relationship between individuals' flood risk perceptions and their willingness to implement mitigation measures; however, while it is true that householders' need to be aware of, and perceive, a certain risk in order to react to it, the foregoing suggest that high perceptions may not result in improved mitigation behaviour (Bubeck et al. 2012). Weak relationships between flood risk perceptions and the implementation of mitigation measures according to Bubeck et al. (2012) may be explained based on Protection Motivation Theory (PTM) as well as methodological issues associated with cross-sectional surveys.

## Experience

Perception of risk is often linked to residents' experience of floods (Kellens, 2013;Lamond and Proverb, 2009) moreover, experience with flooding is deemed to be central to the implementation of flood mitigation measures, however temporal aspect is critical to the implementation process ((Bubeck et al., 2012, Lamond and Proverb, 2009). Authors such as Kellens (2013) and Bichard and Kazmierczak (2012) point out that empirical evidence indicate that, generally, individuals who have experienced flooding perceived their risk from flood as high and are more likely to implement protection measures.

It is therefore not surprising that most studies that assess the relationship between experience with flooding and mitigation behaviour reported a positive one – a situation that is applicable to the natural hazards in general (Bubeck et al., 2012). However, recent literature suggests that central to the implementation of mitigation measures is the severity of the negative effects experienced and not the experience with flooding per se; moreover, as previously stated timing is also a fundamental factor in this regard, as the literature suggests that the influence of experience can diminish in a relatively short time after a flood event (Kellins et al. 2013; Bubeck et al, 2012, Lamond and Proverbs, 2009). According to Burn (1999 cited in Kellins et al 2013, p.43) "prior experience with flood events appear to be most useful when it is recent and relevant to the current event"

### Perception on the Role of Government

Some researchers (e.g. Bichards and Kazmierczak, 2012; Harvatt et al., 2010;) have also Investigated how perceived responsibility affects flood mitigation behaviour among householders; these studies have indicated that some householders' express the notion that the state is responsible to implement measures to protect their homes from the effects of floods (Harvatt et al., 2010), while others believe that responsibility should be shared between the government and citizens (Bichards and Kazmierczak, 2012).

For example, a study conducted in Scotland by Werritty et al. (2007, cited in Bichards and Kazmierczak, 2011, p.638) revealed that "less than a quarter of respondents accepted individual responsibility for flood protection, and attributing responsibility to local or central government was the main reason not to undertake any major measures to protect their properties." Unlike the findings in the work of Werritty et al (2007), studies conducted by Bichard and kazmierczak (2011) found that responsibility was seen as shared between government and householders.

### Other Factors

Some researchers also explore the influence of socio-economic and geographic factors (e.g. age, gender, income, land tenure, proximity of property to river, etc.) on flood mitigation (Poussin, et al. 2014; Bubeck et al., 2012;). Reviews conducted by various authors (e.g.Poussin, et al. 2014; Bubeck et al., 2012) suggest that results are mixed with regards to the influence of socio-economic and geographic factors on householders' mitigation behaviour.

### Barriers to Implementation

Lamond and Proverbs (2009) link the lack of implementation to barriers that hinder the process. Lamond and Proverbs (2009) conducted a literature review and identified stages that a flood plain resident must go through, in order to implement mitigation measures. These stages according to Lamond and Proverbs (2009, p.64) fall into the category of 'desire to act' and 'ability to act'.

Lamond and Proverbs (2009) postulate that the desire to act depends on: awareness of the flood risk, the perception that action is required based on the risk, and the resident owing the problem instead of expecting other stakeholders to address same. Once the desire to act is achieved, the flood plain resident must have the ability to act which is dependent on that person being knowledgeable about solutions to the problem, that person must also have the necessary resources to implement the required solution; moreover, the resident must believe that the solution will be beneficial (Lamond and proverbs, 2009). According to Lamond and Proverbs (2009, p.64) "Barriers that stand in the way of any of these stages can upset the process of installation of mitigation measures."

In the work of Lamond and Proverbs (2009) barriers to implementation of mitigation measures are divided into four categories, namely: financial, informational, emotional and timing constraints. This paper explores the barriers to implementation of flood mitigation measures based on local circumstances in Jamaica.

This chapter reveals that as a natural hazard, flooding is not a phenomenon of only negative consequences (Wisner, 2004; Few, 2003); in order to lessen the negative effects of floods householders may implement various strategies at each stages of the disaster management cycle; however, a combination of complex factors may influence householders' mitigation behaviour. This research seeks to provide insight into the impacts of floods as well as strategies employed at the household level in St. Mary Jamaica to lessen the negative effects of floods; moreover this research, explores the factors that influence flood mitigation behaviours among households in the mentioned locality. Features of the study sites, as well as the methodology employed in this study are discussed in the flowing section.

## Study Sites and Methodology

This study was conducted in the communities of Port Maria and Annotto Bay in St. Mary, Jamaica W.I. Both Communities are located on the northeast coast of Jamaica (see appendix – A and B) and are susceptible to various natural hazards with riverine floods being the most recurring; the communities are

also susceptible to flooding from storm surges (ODPEM, 2013; Town Planning Department, 1981). These communities are traversed by rivers - with Annotto Bay having four (4) major rivers - Annotto, Pencar, Motherford and Crooked Rivers (ODPEM, 2013); while Port Maria has two (2) major rivers - Outram River/Port Maria River and Paggee River (NWA, 2013; Town Planning Department, 1981).

### History of flooding the study areas

Floods in Port Maria and Annotto Bay are triggered by rainfall events and tropical cyclones, (ODPEM, 2013; Mandal and Maharaj, 2013). According to the Office of Disaster Preparedness and Emergency Management (2013), the community of Annotto Bay experienced 35 major riverine Floods during the period 1901 – 2009; the last major flood according to ODPEM (2013) was associated with a tropical storm in 2001.

Appendix C shows the areal extent of the 2001 flood in Annotto Bay as presented in the work of the ODPEM (2013). This flood event affected approximately 593 households located in districts including Cane Lane, Fort George Road, Dump and Cargill Lane) (ODPEM, 2013).

No historic data was found regarding the number of floods in Port Maria over the period mentioned above (1901-2009), however, Mandal and Maharaj (2013) points out that reports from local newspaper dating back to 1924 indicate that Port Maria has experienced several severe floods.

Over the past ten years, Port Maria has been impacted by two (2) major floods (NWA, 2013). The first of the two (2) floods took place in November of 2006, which was associated with a rainfall event (Mandal and Maharaj, 2013; NWA, 2013), the other major flood occurred in November of 2012; this event is deemed by many to be the worst flooding in the history of the community (NWA, 2013). It should be noted that the November 2012 flood was also triggered by a rainfall event; APPENDIX – D shows areas affected by the November 2012 flood in Port Maria. Affected areas included Paggee, [Part of] Frontier and Port Maria Proper (Based on SDC (2009) categorization of districts within Port Maria). Other districts within Port Maria that are not located in the flood plain are Cox Street, Trinity Land, Wentworth and Albion Mountain. The NWA (2013, p.2) points out that the incidence of flooding in Port Maria has increased since 2006, A situation "which catapult [Port Maria] into national attention"

### Population of Study Areas

The 2011 population census indicates that the population of Port Maria and Annotto Bay is approximately 7463 and 6017 respectively (STATIN, 2012). The number of households recorded in the 2011 census for Port Maria and Annotto Bay were 2741 and 1961 respectively (STATIN, 2012). As stated in chapter one (1), this study focuses on households in the flood-plain of both communities. The ODPEM (2013) pointed out that as it relates to exposure to the natural hazards of riverine floods, earthquakes and storm surges in Annotto Bay, the largest proportion of people (2708) are exposed to riverine flooding. No data was found regarding the number of people/households that are vulnerable to flooding in Port Maria.

### Rationale for Study Sites

Annotto Bay and Port Maria were selected for this study based on their history of flooding as well as their demographic features; however, consideration was also given to the fact that Port Maria (as the Parish Capital) and Annotto Bay (a major urban centre) are dominant administrative and service centres in St. Mary.

## Methodology

This section explains the research method employed to achieve the objectives outlined in Chapter one (1). For this study, primary and secondary data collection methods were used to collect both qualitative and quantitative data.

### Secondary data collection

The use of secondary data was integral to the completion of this research. In an effort to anchor the study in the body of external material, information was obtained from various books and journals. Information

pertinent to the study was also obtained from a number of organizations (both governmental and non-governmental); for example flood Hazard Maps were obtained from the Office of Disaster Preparedness and Emergency Management (ODPEM), Water Resources Authority (WRA) (Governmental Organizations), while community profiles was obtained from the Social Development Commission (Governmental Organization) and the Annotto Bay Community Development and Environment Benevolent Society (Non-Governmental Organization).

### Primary data collection

During the period July – August 2014, primary data were obtained through semi-structured interviews with householders; interviews were also conducted with other stakeholders (Including personnel from Community Based Organization and Agency representatives). Moreover, observation also provided valuable insight into features within the study areas.

### Semi-Structured interviews with householders

Forty (40) semi-structured interviews were conducted with householders who reside in the flood-plains of Port Maria and Annotto Bay (20 interviews in each community). Residents of the study areas were contacted at their homes where interviews were conducted with the head of the household or an adult member of the household. Interviews encompassed both open and closed ended questions; however, questions were mostly open ended. Interviews have been used in other studies which investigated householders' flood mitigation behaviour (e.g. Lopez-Marrero, 2010; Linnekamp et al., 2011)

The first part of the interview sought information on households' experience (or the lack there of) with floods and general awareness of flood hazard and mitigation activities, as well as information on effects of flooding on the household.

The second part of the interview focused on the resistance measures and resilience measures respectively and the rational for action (or inaction). This part of the interview also encompassed questions regarding the effectiveness of the strategies employed based on the judgment of the participants. Moreover, in this part of the interview, participants were also asked about the factors that help in implementing mitigation strategies. The third part of the interview focused on householders' perceptions regarding flood risk.

The fourth and final section of the interview sought information regarding householders' general life in the community; in the final section closed ended questions were employed to capture some of the household resources.

Households in the communities were identified through Flood Hazards Maps, and based on discussions with residents of the community. Households were randomly selected for participation in this study.

### Observation

Additional information on flood mitigation strategies was garnered through observation of building designs, public infrastructure and the general layout of the study sites. To acquire greater insights on phenomenon observed, the researcher engaged further with stakeholders (householders, agency representatives) which allowed for better understanding of facts and situations as they exist in the study areas.

### Data Analysis

Data obtained from interviews were examined and separated into various themes. Additionally, secondary data was used to support the main findings of this research.

### Ethical Considerations

Prior to commencing fieldwork, approval was obtained from the University of Leeds; hence due consideration was given to risk assessment. For this research informed consent and confidentiality was of vital importance; hence, all participation in this study was voluntary; participants were informed about the objectives of the study and were given the opportunity to ask the researcher questions about the study; moreover, participants were informed that they could discontinue the interview at anytime. Anonymity

was assured as the names of participants were not recorded. Fundamentally, no pressure was exerted on the participants.

### Limitations

This study could have been more effective if surveys were conducted with a greater proportion of households, as well as if more key informants (e.g. Engineers) were interviewed. Despite these limitations, this study has the capacity to produce useful information

## Findings and Analysis

This section provides empirical data to achieve the research aim and objectives; it begins by providing information on participants' experiences with floods. Discussions regarding flood impacts in the communities, mitigation strategies and their effectiveness. Factors that foster and hinder flood mitigation among householders are also discussed.

### Flood Experience

The Majority of participants (97% or 39 participants) have experienced flooding over the past 10 years (see table 1). Most participants in both communities have indicated that their household experienced flooding 2 – 4 times during the above mentioned period. Table 1 also shows that all participants in Port Maria had experienced flooding; this was not the case for Annotto Bay, as one participant (5% of participants) in that locality did not have any experience with flooding; this participant was however aware that their home was located in a flood risk area.

**Table 1 Flood experience over the past ten (10) years, in percentages (N=40)**

| Study Site | Once | 2-4 | 5 or more | No Experience | *Number of times not specified | Total |
|---|---|---|---|---|---|---|
| Port Maria | | 75 | 20 | | 5 | 100 |
| Annotto Bay | 10 | 65 | 5 | 5 | 15 | 100 |
| Total | 5 | 70 | 13 | 3 | 10 | 100 |

Interestingly, some participants expressed that they had experienced flooding "many times" over the past 10 years and were unable to specify the number of times; therefore a participant form Annotto Bay said "My household experienced flooding many time over the past 10 years…we experience flooding every time it rains… if it rains 50 times our home is flooded 50 times". A participant from Port Maria also mentioned experiencing "many floods", whilst making a distinction between "dangerous floods" and "minor floods"; as this participant puts it "My household experienced 3 dangerous floods and many minor floods… dangerous floods have greater magnitude of water". As was discussed in the literature review not all floods are deemed to be destructive floods. Perhaps some participant made reference to "major floods" in answering the question relating to the number of times they experienced flooding over the past 10 years.

Although the literature regarding the conditions necessary for the implementation of flood protection measures indicate that flood experience may or may not have an influence on mitigation measures. Based on the work of Lamond and Proverb (2009) it can be argued that one of the stages necessary for the "desire to act" is in place among all participants.

Although most participants have experienced flooding over the past ten years; as discussed in the literature review, based on many factors, floods may impact households in different ways. Findings regarding the effects of flooding as reported by participants in this study, as well as findings based on information garnered from secondary sources are discussed below.

## Flood impacts

Participants were asked about the impacts of flooding on their households. It should be noted that 8% percent (or three (3)) of the participants reported that they have not been impacted by floods over the past 10 years, a situation that will be discussed in greater detail later. It should be noted that participants in this study who have not experienced flooding or who have experienced flooding but in which case flood waters did not enter the dwelling, expressed that floods have "no effects" on their household. As a participant from Port Maria Puts It "I have experienced flooding, but it had no effect… no water came into the house". A participant from Annotto Bay with a similar experience said "the house at the front has problems with floods our part of the yard was elevated, so flood doesn't have any impact on us… We have problems with breeze [Hurricanes] not floods". A participant from Annotto Bay who had not experienced flooding said "We never experience flood so it doesn't have any effect on us."

As discussed in the Literature Review floods may produce both positive and negative effects (Few, 2003); however, it is not surprising that the majority of participants (93 %) described negative effects of flooding. Only two (2) participant (5% of participants) reported effects of floods that they deemed to be positive.

### *Negative effects*

The negative effects of floods expressed by the participants are varied and many. Table 2 shows that damage to furniture and appliances was the most reported negative effect of flooding on households in the study areas. A significant proportion of participants also reported damage to clothing as a negative effect of flooding.

**Table 2: Negative Effects of flooding on households by area in percentages (N = 40) xxx**

| Study Site | Damage to Building | Damage to Furniture and Appliances | Damage to Clothing | Damage to Books and Documents | Stress | Health Problems | Loss of Crops and Animals | Loss of Groceries |
|---|---|---|---|---|---|---|---|---|
| Port Maria | 5 | 70 | 55 | 20 | 10 | 10 | | 5 |
| Annotto Bay | 10 | 60 | 35 | 5 | | 5 | 10 | |
| Total | 8 | 65 | 45 | 13 | 5 | 8 | 5 | 3 |

In response to question regarding the negative effects of floods on the household, an interviewee from Port Maria said "floods affects me negatively, my table glass was broken during the last flood, the flood damaged my mattress, clothes and books…Only my life I do not lose as yet." In answering the question relating the effect of flood on the household, a participant from Annotto Bay said: "Washing Machine damaged; Furniture damaged; stove damaged… and no form of compensation." Although this participant expressed that no form of compensation was received for damages to furniture and

appliances, as will be discussed later, some participants indicated that their household received financial assistance from the state, however, while one participant expressed that "The only good [from floods] is that I got $3000.00 from the government…", compensation from the state was largely not reported to be an effect of flooding (whether positive or negative). It is also important to note that none of the participants expressed that their house was covered by flood insurance; hence, grants from the state might be the only financial assistance/compensation that some households would have received.

As it relates to the effects of floods on the structure of buildings, only two (2) participants indicated that floods caused damage to the structure of their house. A closer look at the data revealed that damage to the floor of the building was reported. In referring to the negative effects of flood a participant from Port Maria reported that "The flood burst the floor of my house"… In explaining how flood impacted her house negatively, a female interviewee from Annotto Bay said: "We don't have any floor from the flood during [hurricane] Sandy."

Other responses regarding the negative effects of floods on the participants' households include the following:

*"Flood destroy everything, and cause me to have high blood pressure and stress…" (Participant from Port Maria)*

*"…The dirty water gave me an infection in one of my toes and it still doesn't get better" (Participant from Port Maria)*

*"I lost all livestock… all of my fowls and goats" (Participant from Annotto Bay)*

An effect of flood that could be classified as negative which was not reported by participants in this study is "loss of school time" as the November 2012 flood caused the Port Maria Primary school to be closed for approximately two (2) months. Loss of school time is a negative effect of flooding that was reported in studies conducted elsewhere (e.g. Linnekamp et al., 2011).

***Positive Effects***

Participants were also asked about positive effect of flooding on their household. It was not surprising that the majority of participants indicated that flooding does not produce any positive effect; as one participant puts it: "There is nothing positive about floods" It is however, important to note that the only 5% percent (or 2) of the participants reported positive effects relating to obtaining work to clean business places after flood and monetary assistance from the state. Below are comments from these participants.

*"After the last flooding, I was employed by operators of supermarkets in the town to clean mud from their establishments." (Participant from Port Maria)*

*"The only good is that I got $3000.00 from the government…" (Participant from Port Maria)*

Other household indicated government funds in the sum of JA$30,000 / JA$60,000 as a source to that assist in their recovery process, however, only one participant identified grant from government as a positive effect of flooding.

The following section explores the strategies employed by households to keep water out of their home and to protect the interior of their home from flood waters.

## Resistance Measures

A minority of seven (7) participants (18%) indicated that they implemented strategies to keep water out of the dwelling/reduce the amount of water that enter the dwelling. Table 3 shows that 10% (or 4) of the participants in Annotto Bay Indicated that they dug drains to channel water to the river (Crooked River), while 8% (or 3) of the participants stated that sand bags were used in an effort to keep water from entering their houses.

Additionally, a participant from Annotto Bay indicated the elevating (dumping) the yard as a strategy used to keep water out of the home.

**Table 3: Strategies employed by participants aimed at keeping water out of the home, in percentages (n=40)**

| Study Site | Sand Bag | Dump Yard | Drain | Total |
|---|---|---|---|---|
| Port Maria | 10 | | | 100 |
| Annotto Bay | 5 | 5 | 20 | 100 |
| Total | 8 | 3 | 10 | 100 |

***Resistance Measures – Rationale for Implementation***

Two themes emerged for the rationale behind the strategies implemented to keep water from entering the home: (1) "Knowledge of Strategy" and (2) belief that the strategy will work". For example, a participant

from Port Maria said "I use sand bags because it is the only thing I know that can keep the water out". Talking about the reason for elevating the yard, a participant from Annotto Bay said "The land was swampy so we had to dump it up before we build the house, dumping up the land is the best way to ensure that the house is not flooded." In discussing the reason for the implementation of a drain a participant said"…that is the strategy I know…" Based on the work of Lamond and Proverbs (2009) these seven (7) participants (18%) would have successfully gone through the stages covered under "Desire to act" and "Ability to act" in implementing the abovementioned measures.

***Resistance Measures - Effectiveness of strategies***

Participants were asked to rate the effectiveness of these strategies, based on a scale of 1 – 5; where 5 is very effective and 1 is not effective, the participant who elevated the land [before building the house] indicated that the strategy was very effective (level of effectiveness = 5), as "flood waters never enter her house over the years." The use of drains was viewed by participants to be effective to some extent; it was revealed that participants believed that drains were effective during floods with low intensity. As these participants put it:

"I give this strategy a 3, because sometimes the drain overflows..."

"I give it a 5, because it helps to keep the water out, but, when we have constant rain, you cannot stop water, you just have to make the water come in and ensure that you protect your things"

Interestingly all participants who used sand bags as a measure to keep water out of their home expressed that this strategy was not effective (level of effectiveness =1 or 2); participants who used sand bags during flood events suggested that this measure was not effective as it did not stop water from entering the house. Below are responses regarding the effectiveness of sand-bags:

"I have to give it 2 because it cannot really stop the water from coming in….". (Participant from Annotto Bay)

"I give this strategy a 2… I don't think I am going to bother using sand bag again because it cannot keep water out of the house" (Participant from Port Maria)

***Resistance Measures: Factors that aid implementation***

Residents utilized various resources to implement the mentioned resistance measures. Natural resources, financial resources and human resources were integral in the implementation of these strategies. Participants who identified the use of strategies to keep water out of their house discussed their household's ability to implement the strategy without outside help or the ability to pay others for assistance. Below are some of the responses regarding the factors that enabled participants to implement the mentioned resistance measures:

"We have sand that was left over when we completed this house…we don't need help from others to do this"… (Participant from Port Maria)

"The beach is only a stone throw away so I collect my sand in my bag…"

"…I would pay a young man to dig the drain for us" (Participant from Annotto Bay)

***Strategies Observed***

It was observed that in general, most houses were not constructed in a manner that would keep water out of the home during a flood with a depth of more than 2 feet. In Port Maria it was observed that structures in their early stage of construction have floors that are significantly higher than other structures in the community (See Figure 1). Based on discussions with owners of these buildings, it was revealed that these structures are being built with higher floors due to recent experiences with flooding of depth up to 5 feet. One of the developments observed involved a house that will be constructed on stilts – a strategy that has been used successfully elsewhere (e.g Puerto Rico and Guyana) (Lopez-Merrero, 2010; Linnekamp, et al, 2011)

*Figure 1: Observation made on house that is being built with an elevated floor as a resistant measure*

*Figure 2: Observation made on site for proposed house to be built on stilts as a resistant measure*

***Resistance Measures - Factors that hinder implementation***

The majority of participants (83% or 33 participants) expressed that their household does not implement resilience measures in preparation for floods or during floods. The main reasons expressed by participants regarding the lack of action to implement resistance measure are: (1) they cannot do anything to keep water out of their homes or (2) they are unaware of strategies that could be used in this regard. Comments regarding the reasons for not implementing any measures to keep water out of the home or to reduce the amount of water that enter the home include:

"We can't stop it, we know that we must get our blocks quickly to hoist what we are able to hoist" Participant from Annotto Bay

"There is no way to keep water out of anyone's house, even if you build the house high water is still going to come in…not even sand bag can stop it" Participant from Port Maria

Participants were asked if they could think about ways in which their household could prevent flood waters from entering the dwelling or to reduce the amount of water that entered the dwelling. Some participants (13 participants) who had not implemented resistance measures indicated they could not identify any resistance strategy. Although it is true that resistance measures may not be appropriate or effective in all cases, it could be argued that participants' inability to identify resistance strategies could be linked to information barriers. It is also true that Information regarding flood proofing of homes is available on the website of the Office of Disaster Preparedness and Emergency Management (ODPEM); however, residents may not be aware of same. As stated in the Literature Review, having knowledge of

strategies does not automatically translate into implementation (Lamond and Proverbs, 2009), a situation that is discussed below.

Twenty (20) participants who had not implement any measures to keep water out of their home identified resistance measures such as the use of sand bags (7 participants), raising the floor of the house (6 participants), water proof door (1 participant), water proof gate (1 participant), boundary wall (2 participants), and elevated land (2 participant) as strategies that could help to keep water out of the home, however, various reasons were given for lack of implementation.

Participants who identified sand bags expressed that this strategy would be ineffective in keeping water out of the home for a combination of reasons including the design of their home which would allow water to enter through the floors. Barriers to the implementation of the other strategies include financial constraints, land ownership issues and possible negative effects of alteration on neighbouring properties.

Participants were generally prepared to protect some of their household items from flood damage; these strategies are explored in the following section.

***Resilience Measures - Lack of implementation of Strategies***

The majority of participants (93% or 37 participants) indicated that flood waters have entered their dwelling over the past ten years. As mentioned earlier, one (1) of the participants (3%) did not have any experience with floods; it is not surprising that this participant as well as two (2) other participants who had experienced flooding without water entering the home indicated that they did not implement any measures before or during floods to protect their belongings. The rational for not implementing any measures is based on the belief that flood water will not enter the home; hence there is no need to make any preparation for floods. As one participant puts it "I know that water will not come in, I am only afraid of the breeze." The lack of implementation of flood protection measures for these participants seems to be based low perceptions of risk which may be linked to their experience with floods.

Of the 37 participants (93%) who indicated that water entered their home over the past 10 years, one participants indicated that no measure was implemented to protect the interior of the home and contents; the reason for inaction was due to the participant not being at home during the two times that flood waters entered the dwelling. As this participant puts it "I was not at home during [the flood that was associated with tropical storm] Sandy and the flood after that, so I did not get the chance to do anything to protect my things" the above comment is a reflection of the types of strategies employed by participants in the study areas. As will be discussed below, protection measures implemented by participants in this study are usually implemented during or just before flood events.

***Resilience Measures – Strategies Implemented***

In order to protect items from flood waters, the majority of participants elevated valuable items from floor level by various means, however, the use of concrete blocks was the most dominant strategy mentioned by participants; 88% (or 35) of the participants employed this strategy (see table 4).

**Table 4. Strategies to protect items inside of dwelling in percentages (N=40)**

| Study Site | Elevate items using concrete blocks and/or furniture | Made furniture in preparation for future floods | Tied Items in the roof | Pack items in the ceiling | Place belongings in plastic bags | Total |
|---|---|---|---|---|---|---|
| Port Maria | 85 | 5 | 15 | 10 | 30 | 100 |
| Annotto Bay | 90 | | | | 15 | 100 |
| Total | 88 | 3 | 8 | 5 | 23 | 100 |

The use of concrete blocks to elevate furniture and appliances is usually implemented shortly before or during flood events; this is a temporary strategy for most households. Only one participant indicated the furniture remained on concrete blocks in order to lessen the hassle in the future. In general, participants mostly used a combination of elevating items using concrete blocks and placing household items on beds and dining tables. However, In addition to elevating belongings from floor level using blocks, one participant made pieces of furniture in preparation for future floods (See Figures 3 & 5). As shown in Table 4 above, other strategies employed by participants during or just before a flood include: placing belongings in plastic bags (9 participants); using ropes to tie household items (e.g. Mattress) to the roof (3 participants from Port Maria) (see figure 4); placing items in the ceiling (2 participants from Port Maria).

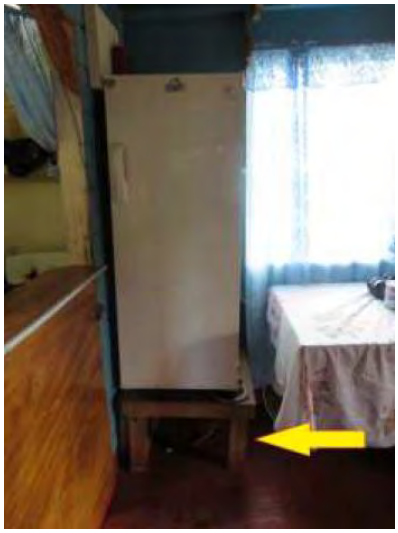
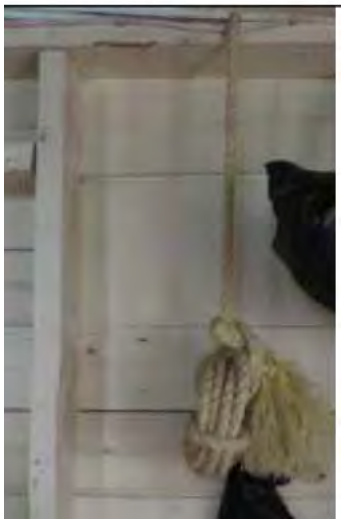


**Figure 3 Refrigerator elevated in preparation for future floods***

**Figure 3 (A) Furniture constructed in a manner that would allow the householder to elevate household items on it during floods***

**Figure 5: Furniture constructed to protect household items in future floods***

**Figure 4: Rope to be used to elevate items (e.g. mattress) during floods*.**



***Resilience Measures - Effectiveness***

In general, participants in both communities expressed that their strategies were effective; the mean value for each strategy in both community is four (4). As it relates to the participant who mentioned that items were made to reduce damage in future, it was stated that although there has been no flood since implementation of these strategy, a five (5) could be applied. This interviewee said "Things won't be damaged in another flood, unless the water covers the house… so I am going to give it a 5"

Below are some of the comments regarding the effectiveness of elevating items:

"… As long as the blocks are high I am all right" (Participant from Port Maria)

Re: Placing bed on concrete blocks "... During all of the floods I was able to sleep on my bed" (Participant from Port Maria)

"It is the blocks that caused my thing not to get wet so I have to give it five out of five. The things that got wet are those that weren't place on blocks" (Participants from Annotto Bay)

"After the rain stopped falling and the water receded, the place was full of silt, only things that were not elevated got damaged. (Participant from Annotto Bay)

***Resilience Measures – Factors that help in implementation***

21 participants explained that they received concrete blocks and/or assistance from neighbours in elevating household items. On the other hand 15 participants discussed that no outside assistance was needed to implement strategies to protect their belongings from flood waters as they always have blocks at home, and that no outside assistance was required as there were enough family members to perform the task.

***Resilience Measures - Factors hindering implementation***

Participants were asked if they could identify other strategies that could protect the interior of their home from flood waters. Only 3 participants (8%) identified other resilience measures; these participants suggested having a two storey building but suggested that they would not be able to implement same due to restrictions from building regulations and financial challenges.

***Willingness to Implement other Strategies***

There are a number of features of houses in the study areas that make them resilient to floods; these features were not necessarily implemented in preparation for floods or with the aim of reducing flood damage, but are in place based on traditional ways of building and based on the personal preference of householders. For example, most houses in the study areas have concrete floors instead of board floors; some houses also have electronic fixtures above the usual height of flood waters (see figure 6); where these features are not in place, if implemented, they could aid in reducing damage from floods. Residents were asked if they would consider implementing additional measures that could assist in reducing flood damage e.g. elevating electronic fixtures and replacing timber floors with concrete floors. Although having an elevated floor may not be effective in all floods, residents were also asked if they would consider raising the floor of their houses.

**Figure 6: electronic fixtures above the usual height of flood waters**

The minority of 35% (or 14) of the participants in this study reported that their houses have timber floors (Table 5), however, one participant indicated that the strategy to replace board floor with concrete floor would not be considered owing to the fact that the land that the household occupies is squatted.

**Table 5: Type of floor by area in percentages (n=40)**

| | Concrete | Timber | Total |
|---|---|---|---|
| Port Maria | 55 | 45 | 100 |
| Annotto Bay | 75 | 25 | 100 |
| Total | 65 | 35 | 100 |

***Raising electronic fixtures***

45 % (or 18) of households reported that electronic fixtures were already above the expected height of flood waters, however, these participants explained that this strategy was not implemented in preparation for floods, but based on their personal preference; further investigation reveals that regulations may have also played a role. The remaining 55% (or 22 participants) indicated that they would consider raising electronic fixtures.

Participants were generally willing to consider implementing the additional strategies above. However, as stated previously, the implementation of other strategies including raising the floors of houses and having a two storey building as identified by some participants may be hindered by financial barriers and legal barriers (Land ownership issues and building regulation restrictions).

## Role of Householders and Government

The majority of participants (90%) either Strongly Agree or Agree that householders have a responsibility to protect their homes from flooding (Table 6). The minority of participants (10%) who indicated that households are not responsible for protecting their home expressed that they are unable to protect their home from flooding, hence they cannot be responsible.

**Table 6 responses to question "householders have a responsibility to protect their home from flooding". This question was adapted from the work of Kazmierczak and Bichards (2010)**

| Study Area | Strongly Agree | Agree | Neither | Disagree | Strongly Disagree | Total |
|---|---|---|---|---|---|---|
| Port Maria | 55 | 35 | | 10 | | 100 |
| Annotto Bay | 5 | 85 | | 10 | | 100 |
| Total | 30 | 60 | | 10 | | 100 |

The majority of Participants (53%) either disagreed or strongly disagreed that "It is the government's responsibility to protect their home from flooding" (see table 7). A closer look at the explanations given reveal that although participants gave different responses on the role of government; they generally share similar opinions explaining that householders should protect things that are within the boundaries of their homes, while the government should deal with drainage issues.

**Table 7 – Responses to question "It is the government's responsibility to protect your home from flooding" in percentages. This question was adapted from the work of Kazmierczak and Bichards (2010)**

| Study Area | Strongly Agree | Agree | Neither | Disagree | Strongly Disagree | "It Depends" | "Not in every way" | Total |
|---|---|---|---|---|---|---|---|---|
| Port Maria | 35 | 15 | 5 | 35 | 5 | | 5 | 100 |
| Annotto Bay | 10 | 15 | 5 | 60 | 5 | 5 | | 100 |
| Total | 23 | 15 | 5 | 48 | 5 | 3 | 3 | 100 |

As it relates to the role of government in protecting homes from flooding, one participant from Port Maria did not choose from the list of options but opted to add the option "Not in every way" whilst explaining that the government's responsibility is to "clean the drains." A participant from Annotto Bay also did not choose from the options but answered by saying "it depends," this participant went on to explain that if the householder purchase a property from the government, it is the government's responsibility to implement proper drainage systems; however, the government would not have any responsibility to protect the household from flooding if they choose to live on the river bank, a situation that is a reality in some areas in Jamaica.

As it relates to the role that government should play in protecting home from flooding, only one participant did not provide an explanation that reflects that government should be responsible for dealing with drainage issues; this participant blamed the government for the effects of flooding on households and pointed out that government should not collect taxes from people in flood prone areas, but instead, should provide opportunities for people to live in areas that are not vulnerable to flooding; this participant went on to explain that grants in the sum of $30,000.00 / $60,000.00 issued after floods that are associated with hurricanes would not be necessary and could be used to assist with building homes in less vulnerable areas or to provide employment.

In general participants take responsibility for protecting their home from flooding; however that situation could change if the state proposes that additional flood protection measures be implemented by householders. Perceptions of risk regarding flooding is also relatively high among participants in this study (see table 8); as the majority of participants expressed that there is a high chance or very high chance that their homes will be flooded in the next twelve (12) months; this is also a situation that could change due to factors such as less floods over time and the implementation of both private and public flood protection measures.

**Table 8: Participants responses regarding the chances that their homes will be flooded in the next 12 months, in percentages (N=40)**

| Study Area | Very High | High | Low | Very Low | Don't Know | Total |
|---|---|---|---|---|---|---|
| Port Maria | 40 | 10 | 10 | | 40 | 100 |
| Annotto Bay | 15 | 45 | | 5 | 35 | 100 |
| Total | 28 | 28 | 5 | 3 | 38 | 40 |

This chapter has provided insights into the ways in which flooding impacts households in Port Maria and Annotto Bay; it also reveals that the implementation of mitigation measures in the mentioned localities is largely dependent on household members being at home during flood events, as most participants employ temporary strategies that are implemented during or just before floods; however, participants expressed that the strategies implemented are highly effective. Residents draw on numerous resources during the implementation process; however, a combination of factors also hinder the implementation of protection measures especially resistance measures.

## Conclusion

Flooding is relative frequent in the Port Maria and Annotto Bay, this natural hazard impacts households in numerous ways, however, it may be argued that the negative effects outweigh the positive effects. Residents of the study areas faces numerous constraints in implementing flood protection measures (particularly resistance measures), residents are mostly aware of sand-bags as a resistance measure; however, this strategy is deemed to be ineffective. The elevation of homes – another resistance measure is made difficult by financial barriers, land tenure issues and design features of some homes which restrict householders' ability to make changes to their homes to lessen the negative effects of floods.

Perhaps the implementation of resistant measures is not the best strategy for the communities as implementation of same may not be cost effective and effective in all cases. It can be argued that residents are prepared to allow water into the dwelling whilst they implement measures to protect their valuable items within the house. Resilience strategies employed by householders may be described as "traditional", yet effective in making their homes resilient to floods, however, householders must be at home during flood events for these strategies to be implemented, moreover adequate warning is integral for the successful implementation of resilience measures in the communities.

In preparing for future floods some households are implementing both resistance and resilience measures based on their experience with floods (e.g. making furniture to protect belongings and making new buildings with elevated floors). These strategies are being implemented on the householders' own initiative and perhaps, may be adopted by other householders in the future.

The relatively high frequency of floods in both communities caused householders to be fully aware of the risks that they face from floods. For the most part, householders take responsibility for protecting things within the boundaries of their home and see the government as being responsible for the implementation of measures to improve the efficacy of drainage systems in the communities to reduce flood damage to households.

Further research is needed to find out what additional measures may be appropriate for the study areas (or specific sites within the areas) based on local circumstances; as well as the willingness and ability of householders to implement additional measures. As mentioned by Lamond and Proverbs (2009) research into strategies that may be appropriate for a particular locality may be tedious, however, this could be a venture that could reduce damage from floods in these localities and may also be reproduced/modified in other communities with similar socio-economic and environmental conditions.

Further research is also needed into the strategies employed by other stakeholders including (but not limited to) business operators, institutions (e,g. schools) and farmers to lessen the negative effects of floods, as well as the factors that hinder (or may hinder) their willingness and ability to implement measure to lessen the negative effects of floods.

Residents of Port Maria and Annotto Bay face various barriers in implementing mitigation measures. Some residents are unable to make informed decisions as they are not aware of approaches and the procedure for contacting experts e.g. engineers in their implementation process. However, where knowledge is in place residents are restricted by socio-economic, housing design, legal and resource based challenges to implement mitigation measures.

Indeed, measures implemented by private households may lessen flood damage to a great extent; however, these strategies may be more effective if integrated with the traditional approaches to flood defence (construction of dams, levees, etc.); moreover, other mechanisms including evacuation and relocation may be necessary in some instances.

# Flood Risk Perception, Risk Communication and Flood Management in the Commonwealth of Dominica: A case study of Coulibistrie

*By Viola Pascal*

This paper is an extract from a dissertation submitted in partial fulfilment of the requirements of the degree of Master of Science in Risk, Crisis and Disaster Management at the University of Leicester – 2017

## Introduction

The issue of adopting protective behavior is being given much attention (Bubeck *et al.*, 2012; Kirschenbaum, 2005; Siegrist and Gutsher, 2008). A longstanding concern is the level of individual and social responsibility exhibited by the population towards warnings and mitigation measures for the hazards that they face. It is felt that disaster management, in order to be effective, requires much more than the formal institutional responsibility and must incorporate contribution of the general public and, in particular, vulnerable communities. This would require individuals and the community as a whole to take more active consideration for their personal well-being rather than depending on government to bear the financial brunt and to 'payout' after each flood event. Considerations of building practices, location of dwellings, land use practices and garbage disposal are all seen as vital in this process. Consequently, the research is anchored within the broad framework of disaster risk reduction and seeks to assess the public perception of flood risk and flood risk communication in the Commonwealth of Dominica and to determine how the information garnered can be used to inform flood management in the country.

*Picture of collapsed bridge due to Tropical Storm Erika floods at Coulibistrie*

## Background

The Commonwealth of Dominica is a small island of approximately 751 km$^2$ in the Eastern Caribbean and has a population of approximately 70,000 (Central Statistical Office, 2011). The topography of Dominica is mountainous and steep with very little gentle sloping land (Convention on Biological Diversity, 2014: 5) and is characterized by many rivers and tributaries traversing down from the elevated interior to the coast. Flash floods and riverine floods where swollen rivers overflow their banks are the main types of flooding that affect Dominica. With an average of over 2600mm (102 inches) of rainfall annually, Dominica enjoys an abundance of rainfall which makes it one of the wettest islands in the Caribbean.

Dominica is considered to be highly vulnerable to hydro-meteorological and geological hazards, a characteristic shared by many Small Island Developing States (SIDS). The impact of climate change is seen as another pertinent factor that will exacerbate the vulnerability of the country. Mimura *et al*., (2007: 691), in the Intergovernmental Panel on Climate Change (IPCC) report on the impact of Climate Change

on SIDS, indicated that "heavy rainfall events are on the increase". Recurrent flood episodes coupled with landslides are among the most frequent hazards to affect the island (Benson *et al*., 2001: 2). Such events, at times, result in loss of lives, social displacement and significantly hamper sustainable development. The research was conducted a year following the intense rainfall and subsequent flooding produced by Topical Storm Erika in August 2015 that resulted in extensive damage and loss of lives. The community of Coulibistrie, situated on the west coast in the parish of St. Joseph, was selected for this research on flood risk perception because it is one of the areas that was severely impacted by Tropical Storm Erika's flood rains.

## Objectives of the Research

In order to explore Flood Risk Perception and Communication in Dominica, the objectives of the research are to:

I. Assess the local perception of the risk of flood in Dominica with a focus on the community of Coulibistrie
II. Explore the association between risk perception, risk communication and protective behavior (safety practices or response to flood warnings)
III. Determine how the findings may help to inform flood management practices and policies

## Theoretical Framework

### Risk Perception

Risk perception explores "people's attitudes, judgements, feelings and cultural values towards hazards…specific to the field of psychology, risk perception examines the way in which individuals make sense of or learns to know the environment" (Pidgeon *et al*., 1992: 89, 98). Risk perception study is summarized by Kellens *et al.*, (2011: 1056) as "the examination of people's awareness, emotions, and behaviour with regard to hazards". Three objectives or goals of risk perception research that help to guide this work are indicated by Slovic *et al.*, (1982: 83) as: 1) to improve the methods for obtaining information about risks; 2) to provide a basis for understanding and anticipating public responses to hazards and 3) to improve the communication of risk information among lay people, technical experts and decision-makers

### Risk perception and behaviour motivation theories

The literature review uncovered several studies that have made reference to behaviour modification specifically towards adopting flood protection or mitigation practices. Kellens *et al.*, (2013) carried out a comprehensive review of 57 empirical articles that focused on risk perception and communication towards flood following a rigorous selection process. Common risk perception variables uncovered included "awareness, likelihood, impact, affect, controllability, dread, severity of consequences, perceived probability and fear" (Kellens *et al.*, 2013: 27-34). The behavioural variables prominent in the articles included "preparedness, insurance, risk behaviour, information seeking and evacuation" (Kellens *et al.*, 2013: 27-34). Several of these variables were considered applicable to this research and were utilized in constructing the questionnaire to garner data from in the research area. In his work on "operationalizing risk perception" (Shreve *et al.*, 2016) provided a review of several research and attendant theories employed in the study of risk perception more so as it relates to motivating protective behaviour. One of the main theories cited was the "Protection Motivation Theory" (PMT) put forward by Rogers (1975).

The decision by an individual to adopt protective behaviour towards natural hazards, and flood in particular, is influenced by many factors. Prominent among them is previous experience with the hazard (Burns and Slovic, 2012: 582; Terpstra *et al.*, 2009: 1143; Whitmarsh, 2008: 353). Economic status or having access to the resources to move from intent to action (Grothmann and Reusswig, 2006: 106; Nathan, 2010: 151), social status, culture, information available about the hazard, trust in the organization providing hazard information and acceptability of flood risk are also considered to have a bearing on "protection behaviour" (Brilly and Polic, 2005).

## Protection Motivation Theory

Protection Motivation Theory, as initially laid out by Rogers, looked at three components that drive fear to include "the magnitude or intensity of a hazardous event, the probability of the hazard occurring and the effectiveness of response to the hazard" (Rogers 1975: 93). The theory depends, to a considerable extent, on the modulation of fear where "a higher degree of fear is more likely to promote behaviour change than a lower degree of fear" (Rogers, 1975: 94). He further clarified that fear would in turn be influenced by the "severity of the hazard, the level of vulnerability or exposure of those likely to be affected, the value of the avoidance response and how concern one is about being affected" (Rogers 1975: 94). Fear, in the context of the theory, is defined as "a relational construct aroused to what is considered as a dangerous situation and for which protective action is taken" (Rogers, 975: 96). It therefore means that if a hazard has not been "appraised as severe, is not likely to occur and in any event nothing can be done about the hazard, then no protective motivation would be activated resulting in no change in behaviour" (Rogers, 1975: 99).

The theory was reviewed and modified by Maddux and Rogers (1983). In addition to the three components, a forth was added that of 'self-efficacy' adopted from Self-efficacy Theory by Bandura *et al.*, (1977). Self-efficacy is described as "the belief that one can execute a particular behaviour or action to achieve a desired outcome…and that the level of belief in an individual's effectiveness will determine if protective behaviour will initially be attempted" (Bandura *et al*., 1977: 126). Self-efficacy theory also made reference to the contribution of experience.

Protection Motivation Theory will therefore form the basis or framework of the analysis of whether or not individuals or groups vulnerable to flood in the community of Coulibistrie adopt protective behaviour. While conducting field work for the research, the factors of 'fear' and 'emotion' were regularly displayed in the consideration toward adopting protective behaviour from future flooding. This of course was found to be linked to experience with the hazard, in this case the recent flood damage from Tropical Storm Erika. Drawing on Rogers Protection Motivation Theory, the research uncovered where the unprecedented magnitude of the recent flood event (severe hazard ), the fact that some respondents believe that flooding can occur in the future (probability of occurrence) and there is no consensus on how effective future response is likely to be (efficacy of response), suggests that fear will remain a prominent feature to influence respondents decision to act or demand mitigation measures from political representatives. Self-efficacy was judged by the level of preparedness indicated by respondents, the purchasing of insurance and the popularity of the view that the government should cover the cost of recovery from flooding.

This initial observation lends support to the argument that experience and how easily past knowledge of floods could be readily recalled is likely to have an influence on risk perception level (Brilly and Polic, 2005; Siegrist and Gutscher, 2006: 972; Whitmarsh, 2008). It was interesting to note how respondents in the community expressed varying views on their flood experience. This in turn appears to have some effect on future flood protection behaviour or consideration particularly as it relates to evacuation. The critical factor at work appears to be the level of damage experienced. Therefore, persons who received a greater degree of loss exhibited a higher level of willingness to evacuate. On the other hand, those who received less damage have a lower inclination toward evacuation even though they remain vulnerable. This finding is supported by Visschers and Meertens (2010: 73) who indicated that "different people may have different perceptions of the same risk, which may result in different levels of concern about this risk and different responses to it".

## The concept of risk communication

The National Research Council (NRC) describes risk communication as "an interactive process of exchange of information and opinion among individuals, groups and institutions. It usually involves multiple messages about the nature of risk that express concerns, opinions, or reactions to risk messages" (NRC, 1989: 21)

The form of risk communication most commonly practiced however is the "distribution of single risk messages from the communicator to the general public". This conforming to the "deficit model of risk communication where communication is unidirectional with little if any feedback from the receiver" (Module 2, Unit 3: 3.4-3.7).

Similar to risk perception, there are several approaches to the study of risk communication, but only those considered applicable for this research are selected. Lundgren and McMakin (2009) cited by Höppner *et al.,* outlined these approaches to include: 1) The mental models approach which places emphasis on the characteristics and needs of the audience; 2) the culture and ethnicity approach where there is the need to understand the general characteristics of ethnic subcultures in affected communities; 3) crisis communication approach which is normally utilized to trigger the appropriate behavioral response in emergency situations and 4) the social amplification of risk approach which is primarily concerned with risk amplification and attenuation by varying groups particularly the media.

### Goals of risk communication

The research has particular interest in the role of risk communication to the extent that it promotes positive behavior change towards flood protection. Studies have shown that "simply providing the information is no guarantee that persons will act upon it" (Höppner *et al.*, 2010: 45; O'Neill, 2004: 6). What is sometimes lacking in the communication of flood risk, and was highlighted by respondents as an improvement to warning messages, is the provision of information on how to protect oneself from the hazard. This recommendation by survey respondents was supported by other studies where it was noted that "informing the public about flood hazards must be complemented by information about what people can do to prevent flood damages" (Siegrist and Gustcher, 2006: 978). Shreve and Fordham in their research found that:

> …many people do not have knowledge of protective measures particularly private precautionary measures…and this could have a bearing on important representations of risk for policy and decision makers for evaluating how public opinion of preparedness may or may not reduce or create additional risk (Shreve and Fordham, 2014: 38).

## Data and Methods

The survey was conducted just over a year after the flood caused by Tropical Storm Erika in 2015 which means the event could be recalled with relative ease. A literature review was conducted to examine some of the researches already carried out on flood risk perception and flood risk communication as well as theories relating to protection behaviour. Importantly, the examined researches were mainly peer reviewed articles from relevant natural or social science journals. The variables included in each section of the questionnaire were selected based on information garnered from the literature review particularly work done by Adelekan and Asiyanbi, (2016), Kellens *et al*., (2013) and Urcan, (2012).

For this research, selected risk perception and risk communication variables are outlined in the table below.

| Selected Risk Perception Variables | Risk Communication Variables |
|---|---|
| Frequency of flood hazard | Social responsibility of respondents |
| Perceived likelihood of flood future occurrence | Information seeking behaviour |
| Respondent's level of fear of impact | Awareness and understanding of warning messages |
| Cause of the hazard | Trust in warning agencies |
| Level of damage experienced | Views on improving warning messages |
| View on vulnerability of the community | Consideration of protective action towards flood |

### Sample and data collection process

The close knit community has a confined geographical spread with a population of approximately 419 persons. 51 questionnaires were administered which represented approximately 12% of the population. The survey was done over a two month period and basically took the form of non-probability convenience sampling. The researcher however purposefully chose to represent mainly persons who have experienced flooding. To satisfy this scenario, the community of Coulibistrie was used as the case study to collect primary data for the research given that it was ravaged by a recent flood event. Two methods were used. Firstly, a "face-to-face interview schedule" (May, 2011: 103; Simmons, 2008: 188-187) was initially utilized with contact being made by a community walk-through. This process provided the distinct benefit of field observation both of the physical environment of the research area as well as the respondents displayed emotions (May, 2011: 104). Thereafter, a "self-completion questionnaire method" (May, 2011: 103) was selected to reduce time limitation. Descriptive and frequency analysis show the "distribution of the variables across the sample" (Punch, 2003: 45) Correlation analyses were carried out using either the "Pearson product-moment correlation coefficient or the Spearman correlation" (Module 3, Unit 8: 8.25 – 8.27).

## Analysis and Results

### Risk Perception Variables - analyses and evaluation

Perception on the cause of flooding of the study area was explored through a multiple response question. Thirty-seven (37) participants believe that heavy or prolonged rainfall is the main cause of flooding, 32 believe it is caused by climate variability and change and 30 respondents express the belief that flooding resulted from the limited capacity of waterways to carry high a volume of water. As it relates to the current level of vulnerability of the community to floods, approximately 92% of the respondents believe that the community is vulnerable with 39% choosing very vulnerable and 41% extremely vulnerable. Approximately 94% of the respondents are of the view that Coulibistrie has become even more vulnerable since the impact of Tropical Storm Erika and is said to be mainly due to the elevated river bed and lack of flood water barriers. Most of the respondents believe that their community could be flooded in the future with 45% believing this is likely and 41% extremely likely.

Given that the community is considered to be more vulnerable post Tropical Storm Erika, a correlation test was done to explore possible association between perception of future flooding of Coulibistrie and the perceived increased level of vulnerability outlined by the respondents. The Pearson correlation showed a moderate but negative correlation ($r = -0.401$) which was considered significant at 0.01 significance level between perceived increased vulnerability of the study area and perception of future flooding.

Of the total number of respondents (51), 38 believe that they will be affected by future floods, 9 are uncertain while 3 respondents believe that they will not be affected. Extensive damage was experienced by 47% of the respondents while moderate and completely damaged were respectively reported by 9 respondents each.

Due to the high number of respondents who believe they are likely to be affected by future floods, the next logical step in line with the objectives of the research was to assess how concerned respondents were about being directly affected by a future flood event. As previously stated, the level of concern is one of the variables utilized to explore the degree of fear expressed by survey participants. Based on the Pearson correlation results, there is a positive and strong correlation between likelihood of future flooding of Coulibistrie and degree of concern (fear) of future personal impact where $r = 0.548$. Similarly, the correlation between level of damage (degree of experience) and degree of concern is positive and strong where $r = 0.498$. Both correlations are considered very significant at the 0.01 significance level. Research has shown that the degree of experience with a hazard plays a significant role in how individuals perceive the hazard (Siegrist and Gutscher, 2008: 772). Some respondents in the survey showed indication of being affected by their flood experience particularly in having a high level of concern about future impact.

Several respondents stated that, having experienced a recent catastrophic flood event, their feeling of dread and emotional or mental strain with regards to floods have increased significantly. According to research carried out by Grothmann and Reusswig (2006: 107-108), recent experience may force individuals to have a high risk perception. This research was conducted one year after the impact of Tropical Storm Erika. Therefore, the flood was still very vivid in the minds of persons who were in the community during the event. Some thought must be given to the level of objectivity that respondents are able to apply to flood "threat appraisal" (Grothmann and Reusswig, 2006: 108) because of the very recent impact.

### Risk Communication Variables - analyses and evaluation

In any disaster risk reduction effort, including flood management, "early warning is seen as a critical component" (Fowler, 2015a). Similarly, risk communication is integral to the effectiveness of early warning system. Hainsworth (2015), cited by Fowler (2015a), noted that "having the best warning system in the world without the message getting through to the person on the ground is of no use". The research attempts to investigate the extent to which respondents consider accessing or seeking out warning information, a socially responsible behaviour that is beneficial to both the individual and the wider society. This question is in line with the view of how much an individual considers their personal protection against a hazard as their responsibility (Kellens *et al.*, 2013:43). Of the respondents, 76% are in agreement of which 14 % strongly agree that it is considered being socially responsible to seek out warning information.

Following the high agreement on the need to obtain flood warning information, the results on the frequency of listening to the weather report was almost equally distributed. Weather reports were rarely to occasionally accessed by 49% of the respondents and a similar 49% listened quite often to always. Radio and television broadcast are the most frequent options used to obtain flood warning messages with 74% and 69% of the cases, respectively. Other options such as email, calling in directly to the local meteorological office and social media are utilized to a much lesser extent (Appendix D: Table 22). Respondent's view on the most effective way to receive messages did not see much change on the current methods being used. Radio and television were again selected as the best methods equally selected in 71% of the cases. However, other options were seen as quite beneficial with social media selected in 47% of the cases and interestingly the use of indigenous methods was selected in 17% of the cases.

Nearly half the respondents (22) exhibited a low level of awareness regarding warning messages while 28 respondents vary from being very aware to extremely aware of issued warning messages. The extent to which respondents understand warning messages is also quite important. This in part helps to determine the effectiveness of risk communication and possible prompting protective behaviour. At a Sendai Framework meeting, Sy (2015), cited by Fowler (2015b), stated that "there is a need to take the scientific information to communities in a way that is comprehensible". The frequency distribution of how well respondents understand flood warning messages indicted that approximately 10% had a limited understanding of the message, 20% indicated fair, approximately 56% indicated good to very good and 14% said they have an excellent understanding of the message.

Although most of the respondents indicated that they have a good understanding of the message, it is important to know how the message can be improved to increase effectiveness especially towards taking protective action. Unfortunately, this question had a high no response rate. However, for the 12 who answered, two improvements were emphasized. The first given by 5 of the respondents is that the message should contain more specific impact based information and what measures to take in order to protect themselves. This recommendation corroborates the findings of the TACTIC research carried out by Shreve and Fordham (2014). The authors also found that there is a need to provide the public with information on specific measures to secure personal protection.

The second improvement stated by 7 respondents is to simplify the language used in the messages. Though the responses are limited, they are in line with one of the main impediment to effective risk

communication. This issue of language specification was also highlighted in the literature review by Faulkner and Ball (2007: 75) where there is a debate on 'top-down' approach to informing the public of hazards. The language or technical terms used in the message given to the public was also discussed at the Sendai Framework meeting where Jarraud (2015) cited by Fowler (2015b) is of the view that "meteorological services should move away from mechanistic warnings riddled with technical terms and place greater focus on intelligible impact based warnings". It is felt that messages will be more readily received if they are "tailored to reflect people's learning style, cultural identity and certain demographic characteristics" (Burns and Slovic, 2012: 582). The responses also bring into focus one of the shortcomings of the "deficit model of risk communication where risk assessments and arguments are presented in technical terms and language that are unfamiliar to the average citizen" (Module 2, Unit 3: 3.4 – 3.5).

The level of seriousness, the second fear assessment factor, given to warning messages or how receptive respondents are to the information provided was also explored. It is believed that if the message is given due diligence then some form of protective action will be taken or at least considered. Approximately 60% of respondents take warning messages very serious and 20% extremely serious. The decision to place importance on flood warning message is considered to be a useful step in the process towards "private flood mitigation behaviour" (Kellens *et al.*, 2013: 42-43). Trust in warning authority or agency providing flood warning messages has a role to play in risk communication and how receptive the public is to the message. The issue of trust is even more critical due to the plethora of sources from which information can be obtained (Renn, 2009: 87). This, Jarraud (2015) cited by Fowler (2015b), summed up as "having multiple sources of warning are a source of confusion not a source of warning". The survey data indicates that approximately 29% of the respondents have a high level of trust in the warning authority, 28% very high and 10% completely trust the authority and the message provided. On the other hand, 2% of the respondents did not trust at all, 4% very low trust and 23% have a low trust.

Association between risk perception, risk communication and protective behaviour is the central theme of the research. Therefore, it is necessary to ascertain how many respondents consider taking any form of protective action upon receiving flood warning information. Of the 51 respondents, 49 consider taking some form of protection from flooding when the warning message is received. Respondents were given the option to select multiple protection measures normally practiced or considered. A high information seeking and sharing behaviour was indicated where 38 survey participants selected staying abreast of warning information and 32 indicated that they share information with others. Cancelling outdoor activities and travel plans also had a high selection rate of 37 and 28, respectively. Measures that appear to require more resources to execute had a lower selection rate where 19 respondents indicate that they clear drains around home and only 4 would try to know where the assigned shelter is located.

Obeying evacuation orders and the purchase of flood insurance, which are also considered as protection behaviour, were analysed separately. Approximately 91% indicated that they would be willing to evacuate, but with varying degrees and 8% indicated that they were not willing to leave their homes. Based on field observation and expressed views by respondents, the decision not to leave home was based on the level of impact experienced during Tropical Storm Erika. Some respondents believe that if they did not evacuate during that major flood event, it is not necessary to do so in the future. Only 12% had flood insurance not withstanding that most respondents believe that the community is even more vulnerable to flooding.

Correlation tests were done to determine association between several risk communication variables. The results showed a weak but positive correlation between sense of personal responsibility to access warning message and frequency of access where $r = 0.189$. However, awareness of warning messages has a positive and strong correlation with frequency of access where $r = 0.512$. There is also a positive and moderate correlation between awareness and level of understanding of the message where $r = 0.435$. Both values are significant at the 0.01 level of significance. Understanding of warning messages showed a weak but positive correlation with frequency of accessing weather information ($r = 0.0175$).

Consideration of protection action against flood impact showed a positive but weak correlation (r = 0.083) with how much respondents understand the message.

### Risk perception, risk communication and protective behaviour

An attempt was made to determine the association between selected risk perception and risk communication variables as well as any variable deemed to promote protection against flood hazard. The risk perception variable of likelihood of future flooding of the community showed positive but weak correlation with the risk communication variable of level of seriousness toward warning message (r = 0.270). Level of concern (fear) of being personally affected by future flooding has a weak but positive correlation with frequency of accessing weather information (r = 0.020), as well as with the extent to which respondents consider protection against floods (r = 0.152). Concern of personal impact did however show a moderate and positive correlation with the level of seriousness applied to flood warning messages where r = 0.449. This correlation is significant at the 0.01 level of significance. The level of attention or seriousness placed on the message as previously stated serve a dual role. On one hand, the degree of importance given to the message indicates some amount of fear of future impact. On the other hand, the act or process of giving serious thought to the message could be viewed as a first step in deciding the course of protective action, if any, that should be taken. The research is, however, cognizant of the fact that the correlation between the level of seriousness placed on the message and consideration to take protective action has a weak and negative correlation (r = -0.150). This, however, points to the possible need for other necessary conditions to be in place or a case of "non-protection response" (Grothmann and Reusswig, 2006: 106) likely associated with other social and or economic factors.

The literature review highlighted the point that receiving or being made aware of a warning message does not guarantee that the public will act on the information for varying reasons (Höppner *et al*., 2010: 45). The research also corroborates with this finding. Pearson correlation test between respondent's awareness of the warning message and whether they consider protection showed a weak and negative correlation where r = -0.079. Recalling that experience has an influence on protective behaviour, correlation was done between damage experienced from Tropical Storm Erica and how serious the respondents view the warning messages as well as if protection is considered when the message is received. The result showed that level of damage experienced had a weak but positive association with the level of importance placed on the message (r=0.264). Damage experienced also had weak and positive association with whether respondents consider protection from flooding where r = 0.176. Another perception variable, level of vulnerability of Coulibistrie to flooding, showed a weak and positive association with frequency of accessing weather information (r = 0.105). Vulnerability also showed a weak but positive association with considering flood protection (r = 0.125). However, correlation between level of vulnerability and how serious warning messages are viewed showed a moderate and positive association where r = 0.377 which is significant at 0.01 level of significance.

Given that the theoretical framework of the research is linked to the Protection Motivation theory (Rogers, 1975), it is prudent to draw reference to key findings that either support or detract from some assumptions of the theory. Utilizing the flood event precipitated by Tropical Storm Erika, all but one respondent have experience of a severe event that they can relate to. An overwhelming 86% of the respondents perceive that the community could be flooded in the future and since Coulibistrie is now considered to be even more vulnerable, with little being done for flood protection, the research bears some similarity to the central tenets of the theory. An elevated level of fear which is deemed necessary to drive protection motivation should therefore be evidenced. However, the results showed that the 'fear' factor of concern of future flood impact had a weak association with the decision to take protective action. It would seem to suggest that even though fear is present, the degree to which it is modulated is insufficient to generate a greater push or override other limiting factors in order to give more consideration to flood protection. It does however provide the opportunity to look at the effects of other variables that could present a limitation on adopting protective action. The theory postulated that no protective action or no change in behaviour would take place if the "hazard is not viewed as severe, is not

likely to occur and nothing can be done about the hazard" (Rogers, 1975: 99). Since this is not the scenario observed in the research, the issue of self-efficacy (Maddux and Rogers, 1983: 476) could be explored to determine the extent to which it may have an influence on considering flood protection.

### Flood Management: the public's perspective

The views of respondents were solicited on the possibility of the study area enjoying "zero risk" (Motoyoshi, 2006: 125-127) from flooding. Of the respondents, 25% believe that flood risk can be completely removed while 71% are of the view that flood will always pose a risk to Coulibistrie. The research explored possible flood management measures for Coulibistrie by providing five options to select multiple responses. The most frequent option was to build flood barriers which was selected by 44 respondents. This was followed closely by river training and dredging selected by 21 persons. Most of the respondents are in favour of 'hard' flood management measures rather than 'soft' measures such as increasing flood awareness which was selected by 11 participants. Answers to the open ended question on why the community is more vulnerable post Tropical Storm Erika saw most persons mentioning elevated river bed and the absence of flood barriers. This means that the options provided for flood management in the survey instrument are indeed applicable and relevant to the local situation and in part addresses validity of the research. A willingness to help authorities to manage flooding of the community was expressed by 94% of respondents, 26% were very willing, 20% extremely willing to assist and 41%, the majority, were simply willing to help in implementing flood protection.

Proactive behaviour towards flood preparation was partially assessed by the number of respondents who took part in any form of community disaster training. Of the 51 respondents, only 22% have had some form of exposure to disaster training while 78% had no training. The reasons behind the lack of participation in disaster training exercises ranged from 6% of the participants were not interested in training, 14% were physically unable to take part in training and the majority, 49%, declared that they were not aware of when any form of disaster preparedness training was conducted. Assessing the level of preparedness against future flood is pertinent given the high number of respondents who believe the risk will always exist and that they are very likely to suffer personal impact. Distribution of the responses showed that approximately 27% of the respondents believe that they are unprepared to deal with anther flood event, 16% somewhat prepared, 33% say they are prepared and 22% are well prepared.

In an age where risk transfer is an important component of disaster risk reduction and in some situations the only preparedness mechanism, the research seeks to assess the number of respondents who have flood insurance. One of the initial reasons for interest in the research was to look at the social responsibility of the public in taking ownership of their personal protection from flood. The purchase of flood insurance was considered to be one of the most feasible options in this regard. Additionally, the reason for those who did not purchase flood insurance was ascertained. Only 12% of the respondents had flood insurance and an overwhelming 86% did not have insurance, 20% of the respondents believe the flood insurance is too costly and 29% believe that the options offered by insurance companies are limited. The research found that 28% of the respondents are of the view that the government should stand the cost of their recovery from flood events.

## Discussion of Findings

### Risk Perception results

The variables used to guide the research are similar to those used in previous flood perception research. During the analysis process, it was prudent to bear in mind previous findings to ascertain similarities or new developments in this research.

The frequency distribution showed that most of the respondents (92%) believe that the community of Coulibistrie is vulnerable. A higher amount (94%) believes that the level of vulnerability has increased since the impact of the storm. It is therefore a reasonable expectation that perception of the likelihood of flooding in the future would be high as indicated by approximately 76% of the respondents in favour of occurrence. Additionally, 75% of the respondents believe that they are likely to be affected and an

overwhelming majority of 96% expressed concern or fear of being affected by future flood events. Pearson correlation test indicated a moderate and positive association where both the possibility of the hazard occurring and concern of impact or fear increases. The correlation test for degree of damage which is used as the modulation of experience returned a significant and strong association where level of concern or fear increase as damage experienced increases. Similarly, the association was strong and significant between perception of likelihood of flood occurrence and level of damage and both are positive. What these results indicate is that there is a high level of risk perception among respondents. Importantly, this heightened level of risk perception is associated with the level of damage or degree of experience with flood hazard. These findings returned similar results to the conclusion drawn by previous researchers whose work was reviewed by Kellens *et al.*, (2013: 34) and Shreve and Fordham (2014).

One association test was found particularly interesting. The correlation test between increased vulnerability specifically from Tropical Storm Erika and respondent's perception of likelihood of future flooding returned a moderate and negative association which is significant at the 0.01 significance level. What this may seem to suggest is a strong presence of "avoidance behaviour, wishful thinking or threat denial" (Grothmann and Patt, 2005: 203) in that such a catastrophic event occurred very recently therefore it is not likely in the near future.

Given that the correlations indicate a high level of risk perception, the research also explored the association between concern (fear) of impact and if respondents actually consider to take protective action when flood warnings are issued. The correlation test indicated a weak but positive correlation that is not considered statistically significant. Similarly, experience with flood or level of damage showed a weak but positive correlation with consideration of flood protection. Even though the results showed some correlation between fear and protection behaviour, the association is weak. This as previously stated means other factors could be having greater influence on decision to protect against flood.

### Risk communication results

Influencing behaviour change towards adopting protection from impending hazards is one of the key goals of risk communication. Recalling that the type of flood risk communication now utilized is of the deficit model, this research provides the opportunity to gain feedback from a segment of the population. How serious the respondents view the warning message showed a moderate but significant and also positive association with the perception of how vulnerable the community is to flooding and also with how frequent respondents access weather information. This finding is similar to the aspect of the Protection Motivation Theory where vulnerability and fear should motivate protective behaviour in this case placing importance on flood warning messages.

Exploring if the increase in accessing information was translated to protection intention or action yielded a weak but negative association. A weak and negative correlation also exists between frequency of access and level of seriousness given to warning messages. How much the respondents understand warnings indicated a marginal but positive correlation with how much consideration is given to protection. However, understanding of warning messages indicated a statistically significant and positive association with frequency of accessing weather information. These correlation results appear to corroborate the view that receiving and even understanding the message will not automatically translate to protective action (O'Neill, 2004: 6). The finding also point to the need to assess other variables that could push protection motivation such as "coping appraisal" as suggested by (Bubeck *et al.*, 2012: 1492).

## Conclusion and Recommendations

The analysis of the variables produced mixed results in terms of the strength and direction of some correlations. The overall view is that respondents indicate a high risk perception but as found in previous studies, it does not automatically prompt respondents to display protective behaviour. This conclusion is drawn due to the high number of respondents who selected responses that supports being vulnerable, the possibility that flood can occur, a high possibility of personal impact and a high level of concern about being affected.

## Enhancing flood risk communication

The risk communication and flood management responses have provided very useful and practical thoughts and recommendations that can be used to inform flood management and policies. In the area of risk communication, the recommendations on how to improve warning messages should be given due diligence. There is no guarantee that making the changes recommended, such as simplifying the language used in flood warning messages and providing the public with specific protection measures, will solve all the issues pertaining to social responsibility towards personal protection from floods. There are underlying socio-cultural factors that must be realigned to appreciate the significance and potential benefits of taking greater responsibility for personal protection from flood hazard. Additionally, to implement the recommended change further research will be necessary preferably using a focus group setting to garner more information on the type of language the public will be more comfortable with. Similarly, utilizing such a forum will also provide better insight on practical protection measures as seen through the eyes of the utility group. This process therefore calls for the establishment of an interactive process of information exchange and clearly a shift away from the "deficit model of risk communication" (Module 2, Unit 3: 3.4). In this setting, both risk managers and persons who are likely to be affected will receive the opportunity to be informed from the 'expert' and 'non-expert' perspective.

Nearly half of the participants did not have any exposure to community disaster training because they were not aware of when the training is conducted. Public education and awareness therefore remain a key component in disaster risk communication and management.

## A case for risk transfer

28% of the respondents who did not purchase flood insurance are of the view that the cost of their personal recovery from flooding should be the government's responsibility. This choice by respondents to rely on the government was also found in empirical reviews by Kellens *et al.*, (2013: 33). The finding has several implications including the need for public education on the benefits of the natural hazard insurance product and also insurance companies need to provide greater product diversity. This scenario strengthens the role being played by companies that currently provide specially tailored insurance products to aid quick recovery from natural hazards such as the Caribbean Catastrophe Risk Insurance Facility (CCRIF) SPC. The platform operated by CCRIF that provide some products that catered particularly to lower income groups could be further extended or replicated. Given that the government is expected to bear the cost, this cost sharing could come in the form of tax incentive for persons who act proactively and obtain some form of natural hazard insurance.

## Key recommendations coming out from this research

1. Warning messages should contain more specific impact based information and what protective measures vulnerable people should take
2. Simplify the language used in warning messages which will be aided by considering the type of audience and culture of recipients
3. Public education activities on natural hazards should include a psychological component that encourages a transformation of the socio-cultural mindset of the people to being more receptive and proactive to warning messages
4. Risk transfer is critical in disaster recovery and building back better and should be given more emphasis among disaster risk reduction measures.
5. Building flood barriers along the river banks and dredging of the river to remove excess silt and debris are considered critical flood management activities for the community

# Discussion: For reasons of taste and decency and to speed investigation, disaster scenes should be "off-limits" to victims' relatives

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This paper was written as part of the assessment process for a module – Models of Risk, Crisis and Disaster Management – in the MSc. programme in Risk, Crisis and Disaster Management at the University of Leicester – 2018

## Introduction

Disasters often strike without warning and leave a trail of destruction in their wake (Stein, 2011). Few persons in this lifetime may never experience the overwhelming effects of a disaster but sadly, the unfortunate will look up to the authorities and experts to return their lives to normalcy. The essay topic states, "For reasons of taste and decency and to speed investigation, disaster scenes should be "off-limits" to victims' relatives. Discuss."

The essay will discuss disaster scenes in the context of disaster response and recovery planning to address the needs of the diseased, associated relatives and by extension the community. It will be argued that disaster scenes should not be off limits to victims' relatives. The first section will focus on the definition of theories and key terms like, risk management, disaster management, victims and victims' relatives. The second section will provide a brief discussion of a case study while the third section will seek to link the case study with the theories and the essay question. The essay will then conclude with a summary of the discussion presented in relation to the question.

## Conceptual framework

Disasters are amendable to different constructions and these constructions may be incommensurate and cannot be measured by the same standards particularly for the various players, the pathologist, law enforcement and the victims' relative who have different constructions of the event (Institute of Lifelong Learning (2006) Module 5, Unit 1: 1-8). Each individual with varied interest in the disaster; thus feel that they have certain rights to the disaster. It is their disaster as they are one way or another directly or indirectly affected by the situation.

The World Health Organisation (WHO, 2002) asserts that a disaster occurs when the hazard encounters the vulnerability. The hazard is therefore the catalyst that ignites the disaster. In very simple terms, Hood and Jones (1996: 11) observe from the anticipationist point of view, that in hindsight, disasters are events waiting to happen. Hood and Jones' statement suggest that the hazard is a component of risk and no activity is risk free. Dembrowsky (1995) on the other hand states that a disaster has ephemeral significance; it is a trigger, a flag, which stimulates a specific reaction. According to Dembrowsky's (1995:242) analysis, "disasters are not the cause of the effects, but rather, the effects of the situation is called the disaster". Drawing from Dembrowsky's definition, the consequences or effect of the situation for the victim's relative is chaos and social breakdown among others.

Theoretically, however, disasters are not ubiquitous and are not measurable by the same standards; therefore, response is not a, "one size fits all" situation. In any case, the effects of the event is inherently unpredictable and may require a response from local to national or even international level. Additionally, the disaster may result from natural disasters, technological disasters, terrorist attacks, pandemics and other hazards. Considering the limited word count in this essay, it is not feasible to have a detailed discussion regarding the various types of disaster and levels of response. For this reason, a disaster scene

requiring intervention at national and international levels with multiple deaths and numerous victims' relatives is the scenarios considered. Additionally in this scenario, the term victims are the ones directly affected (injured, missing and diseased) by the disaster while victims' relatives are the ones indirectly affected.

For any nation, disaster prediction, mitigation and response mechanisms will reflect, in some degree, current cultural expectations and circumstances (Institute of Lifelong Learning (2006) Module 5, Unit 6: 6-3). When a disaster occurs variable amounts and types of losses are experienced; it leaves in its wake total chaos and disruption in the social balance of a community or nation. Albeit the numerous challenges in dealing with the victims and their relatives further compounds the response and recovery. The perception of risk, which is essential in decision-making, varies for each stakeholder regarding the scene.

According to Toft and Reynolds (1997) no specific accident occurs twice, notwithstanding accidents do appear to have similar features at some levels of analysis. Morgan et al. (2006) also notes that management of the dead is one of the most difficult aspects of disaster response regardless of the numerous disaster management manuals and plans, which have been prepared over the years. Oftentimes irrational fear among response personnel, policy makers, and the general public, that corpses are widespread transmitters of infectious diseases guide some of the critical decisions (Morgan et al. 2006). Historical evidence and scientific analysis, however, have repeatedly shown that this is not the case, particularly if the mortality resulted from the onset of a natural disaster (Kalis, 2005). Kalis (2005), also states that there is no evidence that, following a natural disaster, dead bodies pose a risk of epidemics.

Terms like, risk, risk perception and risk management are often defined in in disaster management literature. Risk management means different things to different people, for the politician it means financial provision, while for the politician it is dealing with issues that may threaten the government (Hood and Jones 1996: 6). For public policy, risk management refers to an analytical technique for quantifying the estimated risks of a course of action and evaluating those risks against likely benefits Hood and Jones (1996:6). In disaster management, it includes regulatory measures, public policies and social interventions to eliminate or mitigate the risks (Hood and Jones, 1996).

There is usually an overlap in disaster management and risk management where informed decisions are required. For many authors risk management refers to the identification, assessment and control of potential threats Hood and Jones (1996). The assessment of risk usually looks at the scientific aspects of things where as the management deals with the policies, politics and decision. One ought not to make decisions based on a prescriptive plan or traumatic stress, notwithstanding learning from hindsight allowing for judgement calls. Supposedly, where urgent, critical decision must be made, the acceptable risks ae considered.

In relation to disaster response, Module 5, Unit 7 comments that the response should not only accommodate the needs of the victims and the victims' relatives. Addressing issues associated with mass fatalities is an extremely important and integral part of emergency preparedness, response, and recovery (Kalis, 2005). Toft and Reynolds (1997), further argues that the isomorphic features of an accident is the reason for the creation of identical disaster situations. Thus, allowing disaster managers to obtain important observations, lessons, and best practices from case studies. Essentially, lessons learned may lead to more effective and efficient preparedness, response, and recovery planning in the proper management of disasters. Toft and Renolds (1997), further suggest that incorporating preventative and/or mitigative measures is active learning.

Bonner (2010: 255) shared a similar view that despite apparent dissimilarities, disasters have enough in common to provide great learning opportunities. Likewise Morgan et al. (2006) affirmed that disaster management is a very practical affair and lessons learned from the past, can present strategies and plans in the form of handbooks and detailed procedures to manage the survivors and the dead. PAHO as well as the Cabinet Office Civil Contingencies Secretariat have developed manuals and documents, which serve as planning and guidance tools. Some of these manuals serve national, regional, state, and local

authorities and professionals from public institutions that have roles and responsibilities in mass fatality planning, response, and recovery (Kalis, 2005).

## Case Study

Lockerbie Disaster: Experience of a victim's family

*'On 21 December 1988, the crash of the Pan-Am jumbo jet 747 was the hazard that affected the vulnerable Scottish town of Lockerbie. Two hundred and seventy (270) people died. The Police immediately assumed overall control of the investigation and set up an incident control room. The need to preserve all evidence was emphasized, particularly with respect to the bodies and debris from the aircraft, which was not to be disturbed until recorded by the official accident investigation team.*

*The decision was taken that there would be no visible identification; relatives were not allowed to see the bodies irrespective of their condition. The body of the victim's relative was identified eleven (11) days after the disaster by means of fingerprint. Despite the fact that the deceased was intact and recognisable, the relatives were denied viewing privileges. After months of requests, relatives were allowed to view photographs of the diseased. Above all, relatives should be allowed to feel that they are part of what is going on.*'

(Dix, 1998:1061-1062)

## Analysis

The Lockerbie disaster is an excellent example of the management of a disaster scene and the inconsiderate treatment of the victims' relatives. Like Pamela Dix, other relatives have expressed their experience of dissatisfaction in writing. Regardless of who tells the story, a parent, a sibling or significant other, they all had the same things in common, a hunger for information and a desire to view the body of their loved one. As stated in the conceptual framework information is a very sensitive issue and for the bereaved, honest, accurate and timely information is required. Alongside physical comfort and safety, an urgent and significant need for the relatives of the victims is information (Eyre and Dix, 2014). Those providing information should ensure that it is forthcoming and legible (Eyre, 2002).

Albeit, there should be restricted control to a disaster scene, which is the responsibility of the authority. Notwithstanding, there must be a friends and relatives' reception centre staffed by the police, local authority and suitably trained voluntary organisations. If viewing is arranged at the temporary mortuary, suitable support from trained personnel should be available before, during and after; for this reason the authorities should also consult and involve representatives of faith organisations when appropriate (Cabinet Office, 2003).

After a traumatic experience, it is common for affected persons to lose their sense of purpose or self-worth and taking away their right of informed choices compounds their ability to cope with their loss. Even those who had strong family and religious support were diagnosed with Post Traumatic Stress Disorder stated a victim's father who also had this to say;

*"…the Procurator, the Pathologist the police – decided that none of the relative would be allowed to view the bodies…it was in the interest of the families not to view the mutilated corpses…anyone with the slightest knowledge of coping with grief will know…this is absolutely contrary to best practices in grief counselling. For many, the lack of contact…remained a source of anguish through the years"*

(Institute of Lifelong Learning (2006) Module 5, Unit 7: 7-12)

It is extremely important to differentiate viewing a body for identification from viewing a body for grieving purposes (Cabinet Office, 2003). Eyre and Dix (2014) also reiterated, in the aftermath of the Lockerbie disaster, the coroner made the decision that irrespective of the condition of the bodies viewing was not permitted by the families. His intensions may have been good at the time; nonetheless, the decision to view the body should be that of the family, not the police or any other individual/agency. At

Lockerbie, the victims' relatives felt that it was their right or duty to see the diseased as part of the grieving process.

In hindsight learning, the Cabinet Office, 2003 stated that information should enable relatives to make informed choices, and responding professionals should not make decisions on their behalf. Moreover, the main reasons why victims' relatives wish to visit the scene is for information and closure. It is essential that the handling of issues surrounding fatalities is both efficient and sensitive. Dealing with fatalities during disaster, one must recognise the conflict between trying to satisfy: the emotional and information needs of the bereaved relatives or friends of the deceased (Cabinet Office, 2003).

Taste and decency for the relatives refers to sensitivity and respect from those who are in charge, notwithstanding the experts in the Lockerbie disaster were merely concerned with the investigation. The relatives were not concerned with how the bodies looked or that they were contaminating evidence. The diseased were treated as evidence in an investigation and not as someone's' loved one. The coroner's office should give consideration to privacy for the relatives and protection from media and public access suitable information on the processes involved so that relatives know what to expect (Cabinet Office, 2003).

The psychosocial needs of individuals affected by a disaster must be a prioritized activity by all responding organisations. Additionally, there should be integration of agencies while conducting interviews, or investigations. Cooke et al. (1992) likewise, that accident and emergency departments need to integrate their services with the community when dealing with the bereaved. This will limit the number of times the victims' relatives have to answer the same question regarding the diseased. For reasons of taste and decency, again arrangement should be made to ensure that the body is presented in a manner which takes account of the wishes of the relatives with regard to the preservation of dignity for the deceased (Cabinet Office, 2003 39). Anyone involved in responding to the needs of bereaved relatives should have an awareness of cultural, faith or religious sensitivities (Cabinet Office, 2003). Moreover, an appointed family liaison focal point should give support to relatives during this difficult time. There should be a sympathetic and caring approach to the families throughout the process and mistaken identification should be avoided (Morgan et al. 2006).

Cohen (1987), following the Armero, Colombia, earthquake in 1985, observed that bereavement is delayed by lack of formal confirmation of the deaths hence causing many victims' relatives to remain in a state of "expressed tension," hence, they are unable to dispel the belief that the missing person could be found. For reasons of taste and decency, relatives can view photographs of the diseased if it is too difficult to view the body. However, this should be their decision to make (Cabinet Office, 2003).

Deaths from disasters results in sudden and untimely losses, hence, according to Woods (2014) an important duty for any society is to manage the deaths of its members efficiently. Identification of victims should take priority since knowing the fate of their loved ones is of high priority for the affected families (Morgan et al. 2006). Additionally, Morgan et al. (2006) noted that the victims' families should be among the first to receive information about findings and the identification of their loved ones before anyone else. Additionally, Walter (2012) recognized that in most cases there are highly evolved social and cultural traditions, as well as civic procedures, which informs the management routine. The loss of a loved one through disaster is one of the most traumatic events a person can experience and can often lead to negative long-term effects on mental health (Norris et al, 2002). Cohen (1987), following the Armero disaster in 1985 where a volcanic eruption buried 22,000 residents, observed that the initiation of bereavement was delayed by lack of information and formal confirmation of the deaths.

The absence of specialist advice or mass fatality planning, often result in the mismanagement of human remains (Morgan et al. 2006). It is the duty of the affected state to assume the leading role in the management of dead bodies (Kalis, 2005). Many different people or groups are involved in body recovery. Communication and coordination with them is often difficult (Morgan et al. 2006).

Albeit, the responsibility to manage the dead lies within the jurisdiction of the impacted society, some of the victims may not be members of that society, for instance victims of a plane crash. There may also be religious and cultural rites that would require the relatives to gain access to the disaster scenes and the body of the bereaved. In such situations, it is common to make decisions based on assumed risks. Grieving and traditional individual burial are important factors for the personal and communal recovery or healing process therefore, allowing relatives to view the bodies of their loved ones should be respected (Morgan et al. 2006). The aim of those caring for relatives should be to provide support through the early stages of bereavement and build a foundation for recovery (Cooke et al. 1992). The welfare and support for those dealing with or affected by events, including the relatives and friends of those killed, injured or traumatised (Cabinet Office, 2003:21) is equally important.

Cohen (1987), report indicated that persons who were centrally involved in a disaster-displayed ambivalence about learning the details of the even. Cooke et al. (1992) indicated that not knowing the fate of their loved one has caused many victims' relatives to remain in a state of "expressed tension," and an inability to abandon the belief that the missing person could be found. Lacey (1972) cited in Kohn and Levav (1990:62) and Raphael (1979) cited in Kohn and Levav (1990:62) made similar observations of the need to confirm death by viewing the body of the deceased. Information must be accurate, clear, timely and current to reduce unease and the spreading of rumours by the affected communities (Morgan et al. 2006). Drawing from these authors observations it is important that all relatives should have confirmation of the death. Ideally, verbal and written information to relatives should be part of the routine process (Cooke et al. 1992). Additionally, they suggested that information should be available in locally relevant languages.

Unlike in most forms of sudden death, however, those bereaved by a disaster often have to cope with multiple deaths and material losses (Kohn and Levav, 1990). Bereavement is one of the most painful experiences of life (Shear, Monk, Houck, et al, 2007, cited in Bergh Johannesson, 2010, p.16). Deaths occurring in the accident and emergency department are mostly unexpected and often cause prolonged grief and psychological morbidity (Cooke et al. 1992). The psychological and social impacts on those affected by major emergencies are many and varied (Eyre, 2006). All accident and emergency staff should have regular training in bereavement care. Grief after the death of someone close is a natural reaction, although its expression is highly variable. The privacy of victims and relatives bust be respected as compassionate care of bereaved people is of great importance (Morgan et al. 2006).

An efficient response plan should discuss the potential victims, the extent of care post disaster appropriate internal and external resources to deal with relatives and the bereaved. The care of those involved in a major emergency and the way they are treated lie at the heart of the response (Coyle et al., 2007).

No single organisational arrangement will be appropriate to deal with every type of major emergency; nor will a single organisational planning blueprint meet every need (Cabinet Office, 2003). There is need for an integrated plan for the effective and efficient management of disaster scenes.

"*…an effective disaster response will accommodate not only the needs of those directly affected (victims) but also the needs of those indirectly affected (victims' relatives, friends acquaintances and careers)…it is no longer acceptable that the effectiveness of a disaster response is judged only on… how quickly 'normal service" is restored. A comprehensive and holistic assessment requires that a disaster response also be judged on whether those indirectly affected are treated humanely, sensitively and with equanimity*"
Scarman Centre for the Study of Public Order cited in (Bonner, 2010: 213)

It is also clear that restricting access aims to allow rescue services to carry out their work unhindered and to preserve evidence during investigations (Cabinet Office, 2003). Notwithstanding the circumstances, preventing the relatives to visit the scene or to view the body may not only be unlawful but may seriously affect the grieving process (Cabinet Office, 2003 39).

Visual identification is not a scientific approach and mistakes have been made in the past. Therefore, the decision by the authorities to identify the bereaved by other methods like fingerprints and DNA profiles is respectable. It is best, therefore, to ensure accurate identification prior to releasing body. Families should never be allowed to view numerous bodies in the hope that they will make an identification. Releasing the wrong body can lead to increased trauma for the families involved, legal difficulties and embarrassment for professional individuals and/or agencies (Cabinet Office, 2003).

## Conclusion

Good emergency plans now include arrangement for outreach programmes and support for those affected by disaster (Eyre and Dix, 2014). Disaster response ought to assess the needs of all persons affected by the situation, reduce suffering, and by extension limit the consequences of the disaster. Dix (1998) in her personal experience after her brother's sudden death indicated that catastrophic death or injury destroys the lives of the victims' family to the point where they feel that they are no longer in control of their affairs. In the Lockerbie disaster, family members had no access to the scene in order to prevent contamination of evidence.

To manage a disaster scene, one must first understand the disaster situation, know the consequence of the impact and affected persons (directly and indirectly). The location of the disaster and the nationality, culture and social wellbeing of persons involved is also very important. Addressing issues associated with mass fatalities are extremely important and ought to be an integral part of emergency preparedness, response, and recovery (Morgan, 2005). All identified dead bodies should be released to relatives or their communities for disposal according to local custom and practice (Morgan et al. 2006). After a disaster, the collection of dead bodies is not an urgent task for the response team; the priority is to care for survivors (Morgan et al. 2006).

Today there is a paradigm shift in the having no access to disaster scenes to the victims' relatives being told, "We think it's good for you to visit". Most of this change, owed to disaster action Committees. Individual like Anne Eyre, Pam Dix and other relatives of disaster victims who come together to seek information, humanitarian rights and to just be with others who understand the trauma because they too have suffered loss. The Disaster Action Committees continue to raise awareness in terms of the needs of the victims' relatives.

The effect of dealing with a disaster is profound and again in hindsight advice from others is invaluable. At the disaster site the victims who have been affected indirectly could come together and support each other, there is always strength in numbers.

Families of the dead and missing must be given realistic expectations of the process, including the methods used and timeframes for recovery and identification of remains (Morgan et al. 2006). The dead and the bereaved should be respected at all times.

Verbal and physical contact in whatever way should be encouraged; persons grieve differently and may consider it appropriate (Cooke et al. 1992). The bereaved treats the body as a loved one rather than an inanimate object, as sometimes occurs with adults, and a photograph is taken as a final lasting memory (Cooke et al. 1992). A strong recommendation for persons managing disaster scenes is to improve planning to incorporate all types of risks in the process (psychosocial, financial, political, etc.). This is everyone's disaster and the scene should not be off limits to those affected, the victims' relatives need closure to move to carry on.

# A Flood Vulnerability Assessment for the Downtown Port of Spain Area, Trinidad, W.I.

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## Literature Review

### Vulnerability in Disaster Risk Management

The process of using administrative directives, organisations and operational skills and capacities to implement strategies, policies and improved coping capacities in order to lessen the adverse impacts of hazards and the possibilities of disasters is defined as disaster risk management (UNISDR 2009). As such, disaster risk management plays an integral part in the management of a country's resources and population, safe guarding it against the possible impacts of potentially damaging hazards. Hurricanes, earthquakes, landslides, volcanic eruptions and floods account for some of the most destructive and disastrous events to have impacted the Caribbean, resulting in loss of life and property. A category five hurricane such as Ivan in 2004 was responsible for $3 billion in losses in the Caribbean and over 92 deaths in total (National Hurricane Centre 2005). The earthquakes in Haiti and Japan which occurred in 2010 and 2011 respectively resulted in millions of dollars in losses as demonstrated in Japan and almost 250,000 lives in Haiti. In 2011 alone, the United States of America recorded approximately eleven major natural disaster occurrences ranging from tornadoes, to drought to hurricanes (Huffington Post 2011). In Trinidad and Tobago the impact of flooding is a perennial issue which results in millions of dollars in lost revenue. Therefore, it is apparent that now more than ever strategies must be put applied to reduce the impact of such hazards. These strategies must seek to reduce the occurrence of the hazards, as well as reduce the vulnerability of populations so as to increase their capacity to withstand the impact of disastrous events.

Vulnerability is one of the central tenets of disaster management. Understanding vulnerability, its root causes, its effect on populations and how it can be reduced can assist in building resilient communities which are better able to cope with the onslaught of a natural disaster. Vulnerability is defined as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard (UNISDR 2009). Therefore an area may be defined as being vulnerable based on its features such as socio-economic and physical characteristics. The age structure of the population, the economic status of the country and the lack of or presence of well-defined social structures and networks can determine the level of vulnerability which a country or community is exposed to. According to Wisner et al. p. 52 (2004) "The most important root causes that give rise to vulnerability (and which reproduce vulnerability over time) are economic, demographic and political processes. They affect the allocation and distribution of resources, among different groups of people". Therefore, all these factors should be considered as far as possible when assessing vulnerability.

In recent times there has been growing appreciation for the value of sound disaster management strategies which seek to minimize the effects of the natural disasters. The World Conference for Disaster Reduction (WCDR) held in Hyogo, Japan in 2005 illustrated this. At this Conference representatives from over 148 countries agreed to integrate disaster management into their development programmes following guidelines outlined in the Hyogo Framework for Action (HFA). Within the HFA, Five Priorities for Action were developed as guiding pillars for the global advancement of disaster risk reduction. Amongst these, priority two aptly describes the importance of the vulnerability assessment process. Priority two

seeks to address the need for identifying, assessing and monitoring hazard risk and enhancing early warning (UNISDR 2005). Activities necessary to achieve this priority include hazard and vulnerability assessments, early warning enhancement and capacity building. According to priority two, "The promotion and reduction of disaster risk starts with the knowledge of hazards, the physical, social, economic and environmental vulnerabilities to disasters" (UNISDR 2005). The extent of hazards can only be assessed through proper data collection and analysis of the hazard and its effects on society. This priority therefore illustrates the necessity and enormous value of the vulnerability assessment in disaster management.

At the regional level, the relevance of the vulnerability assessment is also illustrated. The Caribbean Disaster and Emergency Management Agency (CDEMA) has developed guidelines for disaster risk reduction which regional disaster management organisations follow called the Comprehensive Disaster Management (CDM) strategy. The CDM provides direction for the national disaster management organisations of the region to encourage and guide disaster risk reduction in the Caribbean. In the 2001 CDM Framework (UNDP 2011), five results or outcomes were highlighted as desirable. Result five highlights the importance of the vulnerability assessment in disaster management. Result five states "Hazard information is incorporated into development planning and decision-making" (UNDP 2011). In order for hazard information to be incorporated into development strategies, good data collection must first be employed. This may be achieved by carrying out a hazard vulnerability assessment. Thus one may say that the hazard vulnerability assessment provides the basis for the best decisions to mitigate and reduce the effects of hazards.

## Assessing Vulnerability

Assessing vulnerability is an essential tool necessary for designing comprehensive disaster risk management strategies. Recognizing the vulnerabilities within an area, assessing them and developing a plan to reduce these same vulnerabilities is key to achieving the overall aims and objectives of disaster risk reduction. As such, the first step to planning disaster risk management strategies should include a vulnerability assessment.

Vulnerability by itself does not result in disastrous impacts from natural hazards. It forms part of an equation which seeks to demonstrate those push and pull factors which result in a disaster. A disaster event consists of two elements working with or against each other to produce a catastrophic event. The equation is given as

**Disaster/ Risk = Hazard x Vulnerability**

Here the hazard refers to the natural events that may affect different places singly or in combination (coastlines, hillsides, earthquake faults, savannahs etc.) at different times (season of the year, time of day, over return periods of varying duration) (Wisner et al. p. 49 2004). The risk or disaster is understood as a compound function of the natural hazard and the number of people, characterized by their varying degrees of vulnerability to that specific hazard within a given time and exposed space.

In this scenario, the disaster or risk is exacerbated by a combination of an increase in the hazard along with an increase in vulnerability. Therefore, when a significantly vulnerable population experiences a hazard and suffers damage and/or disruption in livelihoods in such a way that recovery is unlikely without external help; this is defined as a disaster. A reduction in both or either will result in a reduced risk and therefore a lower chance of a disaster occurrence. In Wisner et al. (2004), this equation forms the basis for assessing the resulting impact of both factors interacting with each other.

Similarly, various models utilize this basic principle formula to explain how disasters occur due to the interaction between vulnerability and the hazard. For example, the Pressure and Release (PAR) model illustrates that interaction between hazards and the vulnerability with the intersection of the two creating a disaster. This model seeks to demonstrate that vulnerability does not just occur in isolation but results from a series of root causes which create pressure and dynamic changes on the population and environment. This leads to the creation of conditions which increase vulnerability in various sectors as

previously mentioned, such as the economy and the physical environment. With the onslaught of a hazard, the high level of vulnerability is unable to withstand the hazard due to a lack of coping mechanisms and thus a disaster is produced. In other models such as the Access model, it is the lack of access to resources which leads to the increased vulnerability. This model differs from the PAR model in that it tries to understand the various complex social and environmental events which may be associated with a disaster event. Unlike the PAR model, the Access model seeks to address the roles and the responses of the various actors involved as the disaster situation unfolds. Both models seek to analyse in detail how vulnerability when combined by some triggering event such as a hazard result in disaster.

### Vulnerability Assessments in the Caribbean

In the Caribbean region, disaster management has become an important focal point for development. The Caribbean faces a multitude of threats owing to natural and anthropogenic causes such as hurricanes, earthquakes, floods, chemical spills and the like. Additionally, the effects of climate change have increased the number of threats as well as exacerbate existing ones. Thus there is an urgent need for disaster management in the region.

As mentioned, the hazard vulnerability assessment is essential in deciding on the best plan to reduce the effects of hazards. An intimate understanding of the hazards which affect an area is therefore imperative. Ahmad (2007) in his report on the implementation of disaster risk management strategies in the Caribbean highlights that often the lack of proper understanding of the hazard leads to improper mitigation strategies. For example, he pointed out that the floods in 2004 and 2005 in Trinidad and other Caribbean countries were treated as common water floods in spite of the hazard exhibiting characteristics of debris floods. This information is useful in determining the most effective mitigation strategies such as in the construction of storm drains for the removal of flood water and debris.

However, in the Caribbean region hazard vulnerability assessments are few due to the lack of trained personnel as well as funding to execute thorough assessments. In some instances where assessments have been undertaken, the results of the assessments are not considered in the development of mitigation strategies to alleviate the effects of the hazards. This is similar in Trinidad and Tobago. In a CDEMA country report completed in 2003 it was found that hazard vulnerability assessments were lacking in Trinidad and Tobago. Findings showed that only one hazard mapping project was done i.e. a seismic hazard mapping exercise conducted by the Seismic Research Centre. In the case of hazard vulnerability assessments none had been recently completed. Two initiatives were expected to come on stream; a flood assessment initiative for specific flood basins and landslide assessment. These assessments have been completed for the most part. However, due to funding and lack of technical expertise the results of these projects have not been beneficial in alleviating the threat of hazards. Thus, there have been few effective mitigation strategies to reduce hazard risk.

One may therefore surmise that the vulnerability assessment is crucial to developing strategies to alleviate the effects of hazards. The execution of these assessments can provide an in-depth analysis of the hazard and its effects on the natural and built. In turn, the results of the assessment aid in shaping the most effective strategies for disaster risk reduction that are most suited to the existing environment allowing society to cope and avoid such disasters. This study is therefore most relevant at this time as Port of Spain continues to be repeatedly affected by flooding with little success in the strategies employed to reduce the effects of flooding thus far.

## Introduction

### Aim of Study

The Caribbean may be described as a multi-hazardous environment affected by a wide range of both natural and anthropogenic hazards. This is mainly due to geophysical and climatic conditions of the Caribbean. Among the various hazards, flooding is the most common and repeatedly affects the small island developing states (SIDS) of the Caribbean resulting in millions of dollars in property and human losses. The actions of physical development and environmental degradation as well as the effects of

climate change continue to exacerbate the effects of flooding. It is therefore imperative that the effects of flooding be analysed with a view to propose sustainable and practical interventions to reduce the vulnerability of populations.

In Trinidad flooding is a perennial hazard. Flooding occurs widespread throughout the island with a greater number of flood events occurring in urban areas with increasing intensity in some instances. The Port of Spain area is one such area which continues to be flooded on an annual basis. As the capital, Port of Spain serves not only as the Central Business District (CBD), the hub for most ministries and multi-national corporations and transportation but also the seat of governance. Port of Spain is therefore the main location of many of the nation's assets. A nation's physical assets serve as the foundation for effective governance, economic vitality, and a resilient civil society. These critical facilities must therefore be protected against the effects of all hazards including flooding as they can potentially cripple the development strategies of a nation. Ensuring the resilience of such critical infrastructure is therefore imperative.

This study will seek to address specific questions as they relate to flooding in the downtown Port of Spain area. It is expected that this study will provide the relevant answers to these questions and therefore suggest recommendations to alleviate the problem of flooding in the study area. The main research questions to be answered include:

1. Flooding in Port of Spain
    a. What is the nature of the flood events?
    b. What are the main causes and contributing factors to flooding?
    c. What have been the effects of flooding?
2. Vulnerability of the Commercial Sector/ Physically Challenged
    a. What services are provided by these elements?
    b. What is the level/ extent of vulnerability of the commercial sector and the Princess Elizabeth Centre to flooding?
3. Perception of Flood Vulnerability
    a. To what extent are these sectors aware of the cause and effects of the hazard?
    b. How do the sectors explain or perceive flooding in their area?
4. What are the possible solutions to flooding?

This study will examine the vulnerability of populations within Port of Spain, Trinidad to flood hazards. It will seek to examine the level, type and the root causes as far as possible, of the vulnerabilities experienced within the commercial sector as well as the issue of vulnerability of special populations i.e. the physically challenged. This will be done using various techniques such as questionnaires and interviews with the relevant target groups.

The commercial sector was chosen as Port of Spain is the commercial and financial 'mecca' of the country. Port of Spain serves as the centre for various types of economic activity; small and large scale retail and wholesale sales, banking and finance, transportation, service industries at varying scales, insurance and the headquarters for many multinational corporations. Additionally, persons of various nationalities converge on Port of Spain to conduct business or have established local businesses in the city. Therefore the importance and value of the economic transactions, assets and capital is high and as such building resilience is important. In order to achieve this, the existing vulnerabilities must be examined so that progress can be made in developing resolutions.

It should be re-iterated that certain characteristics of a population may increase its vulnerability. Within this study, the vulnerability of one of the many populations found within Port of Spain will be examined i.e. the physically challenged. The Princess Elizabeth Centre is located within the city of Port of Spain and is home to many young persons who suffer from orthopaedic disabilities including scoliosis of the spine; it also serves as a centre for orthopaedic surgeries. It is the only facility of its kind in Trinidad and

Tobago as well as the Eastern Caribbean, making it one high in demand and of great importance. Since 2003, the Centre has experienced flooding of varying degrees which has often severely affected its physical structure as well as its community. Therefore the Princess Elizabeth Centre may be considered to represent a very vulnerable unit of the population in Port of Spain.

It is hoped that by observing as well interrogating the operations of these two sectors of the population a conclusion indicating Port of Spain's vulnerability will be derived. This will provide the basis for recommendations on the possible methods that can be utilised to mitigate the effects of flooding in the study area.

## Description of the Study Area - Port of Spain

### *Physical Description*

Port of Spain is the capital city of Trinidad. It is located to the north west of the island and like other Caribbean capital cities, is a coastal port. It was chosen as the capital mainly due to the flat coastal land and its sheltered harbour away from the North East Trade winds (See Fig 2.1).


**Figure 2.1** Map of Trinidad and Tobago showing location of Port of Spain. (Source:http://www.ezilon.com/maps/north-america/trinidad-and-tobago-physical-maps.html)

The city consists of flat land at the coastline which was formed by alluvium deposits and covers an area of approximately 13km$^2$. The land gently rises approximately between 5ft to 15ft above sea level. This area was once protected by mangrove but has been cleared over a 40 year period to almost nothing. Now tall high rise buildings can be found on the near shore regions. Surrounding the flat land the topography changes and steeply rises into the Northern Range. Here, the land reaches heights greater than 1000ft above sea level. The Northern Range is characterised by steep slopes with tropical vegetation and endemic species of fauna and flora of great importance. In recent times, urban encroachment along the slopes of the Northern Range has reduced the vegetation cover significantly. These actions have resulted in landslides and contributed to flooding.

Port of Spain is drained by two main rivers which originate in the Northern Range and flow in a southerly direction through the city. The St. Ann's River becomes the East Dry River when it enters Port of Spain at the eastern boundary where it drains into the Gulf of Paria. The Maraval River is found to the western boundary of the city and empties into the Gulf of Paria as well, near Woodbrook (See Figure 2.2). These two rivers topple their banks quite often resulting in flooding especially in the near shore areas of the city.

### *Human and Social Description*

The city of Port of Spain is home to approximately 49,031 persons (CSO 2002). Given that the city consists of an area of 13km$^2$ one can envision the high population density. Therefore it may be suggested that the dwelling population within the city faces greater vulnerability due to its high concentration of persons within the given area coupled with its being juxtaposition between two rivers as well as the Northern Range.

As the capital, Port of Spain may be described as the business and financial hub of the country. It serves as the headquarters of many multinational corporations especially oil and gas companies such as British Petroleum and British Gas companies. Other international agencies also have situated their headquarters here such as the United Nations Economic Commission for Latin America and the Caribbean (UNECLAC), the Association for Caribbean States (ACS) as well as the Caribbean Court of Justice. Additionally, Port of Spain houses the local judicial headquarters and seat of government for the country; both the Trinidad and Tobago High Court and the parliamentary buildings are housed here as well as various ministries. Thus, Port of Spain plays an important role as a prime location for well- established institutions.

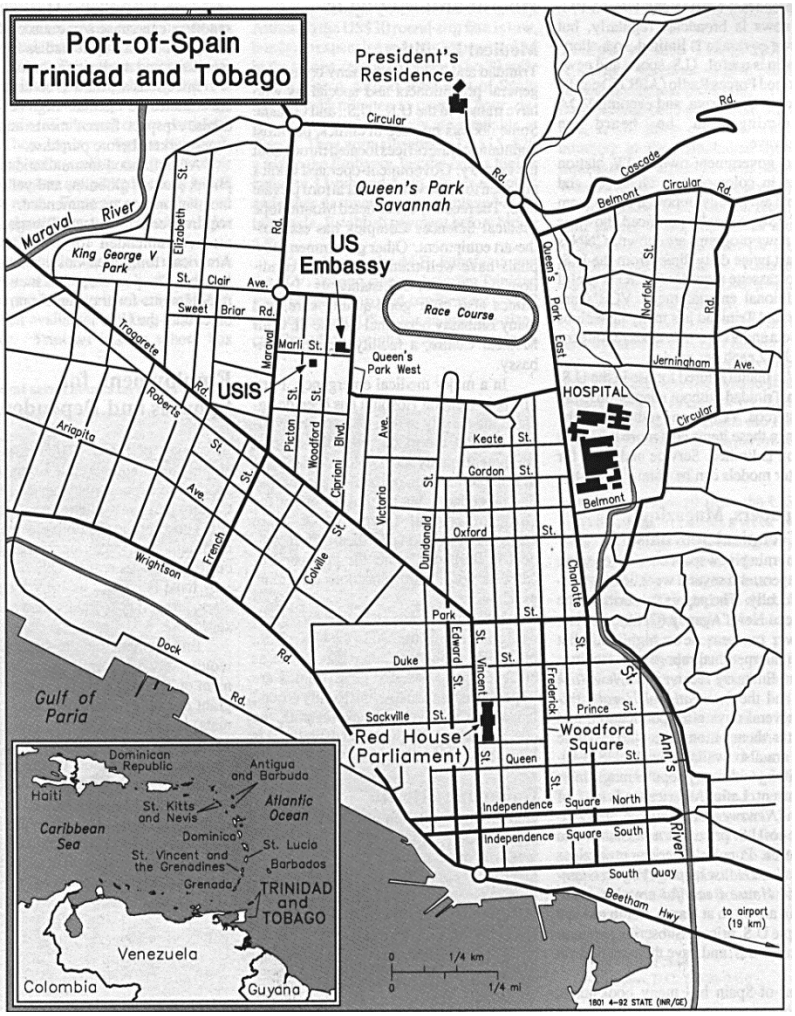



**Figure 2.2** Map of Port of Spain Showing major landmarks and features.
Source:http://images.nationmaster.com/images/motw/world_cities/Port of Spain.jpg)

Although Port of Spain holds no large industries, financial transactions are always occurring. The Central Bank of Trinidad and Tobago as well as the Trinidad and Tobago Stock Exchange can be found in the city centre. Port of Spain also serves as a vibrant commercial centre as it has many wholesale and retail outlets. According to the Central Statistical Office (CSO) Port of Spain had approximately 5,111 established business in 2009 (see Table 2.1). From Table 2.1 it is observed that of all the municipal corporations, Port of Spain has the greatest number of established businesses. This therefore suggests that Port of Spain is the most favourable area to establish and conduct commercial activity. It also suggests that Port of Spain dominates the rest of the country in terms of commercial activity. Thus, prevention and mitigation of the impact of hazards such as flooding is essential if the city is to maintain its economic dominance. It also implies that a flood event of sizeable nature can cause devastating damage to the various commercial establishment found within the city.

**Table 2.1** Number of Business Establishments by Municipal Corporation 2007-2009

| Corporations | 2007 | 2008 | 2009 |
|---|---|---|---|
| **City Corporations** | | | |
| **Port of Spain** | 5,284 | 5,312 | 5,111 |
| **San Fernando** | 2,025 | 2,132 | 2,028 |
| **Borough Corporations** | | | |
| **Arima** | 984 | 1,038 | 1,003 |

| Corporations | 2007 | 2008 | 2009 |
|---|---|---|---|
| **Chaguanas** | 1,563 | 1,660 | 1,571 |
| **Point Fortin** | 436 | 447 | 437 |
| | | | |
| **Municipal Corporations** | | | |
| **Diego Martin** | 2,210 | 2,269 | 2,175 |
| **San Juan/Laventille** | 2,906 | 2,992 | 2,948 |
| **Tunapuna/Piarco** | 3,178 | 3,262 | 3,164 |
| **Couva/ Tabaquite/ Talparo** | 3,063 | 3,186 | 3,158 |
| **Mayaro/ Rio Claro** | 650 | 670 | 653 |
| **Sangre Grande** | 907 | 940 | 922 |
| **Princes Town** | 1,169 | 1,210 | 1,201 |
| **Penal/Debe** | 1,528 | 1,602 | 1,561 |
| **Siparia** | 1,143 | 1,165 | 1,154 |
| **Total Trinidad** | 27,046 | 27,881 | 27,096 |
| **Tobago** | 2,451 | 2,476 | 2,397 |
| **Total Trinidad and Tobago** | **29,497** | **30,357** | **29,483** |

*Source: Central Statistical Office - Business Surveys Establishments Register*

This demonstrates the extent to which Port of Spain exerts urban primacy. In fact according to Udika (2010) Port of Spain has never relinquished its urban primacy mainly due to affordable lands located along the main roads leading to the city as well as the growth in automobile ownership. In 1997, 24 per cent of the total number of jobs was located in Port of Spain, while 79 per cent of persons working in the city resided outside of Port of Spain (Halcrow Group in Udika 2010). According to the report completed by the Halcrow Group Ltd (2000) approximately 20,000 person trips were made into Port of Spain via the eastern transport route (Churchill Roosevelt Highway) during the peak early morning period, translating to approximately 90,000 persons entering the city on a daily basis. In contrast a significant number approximately 12,000 persons leave the city on a daily basis as well. Thus, the city also functions as a transportation hub.

From Port of Spain, a range of transportation services can be accessed going in every direction of the island. The City Gate transportation hub managed by the Public Transportation Service Corporation is located on South Quay within the study area. City Gate is well located with the main access routes from across the island converging near to the transportation hub (Audrey Jeffers Highway in the west, Churchill Roosevelt Highway and the Priority Bus Route to the east and the Solomon Hochoy Highway to the south). Additionally, the South Quay area located near the port is the hub for sea transport. The Port of Port of Spain is located nearby and is the point of entry for cargo and passenger ships including the service to the sister isle of Tobago. Nearby, is located the ferry service which transports commuters from San Fernando the nation's second city in the south to Port of Spain each day. Therefore, the impact of a flood hazard can overwhelm the demand for these services as persons try to make their way in and out of the city. City Gate may therefore be viewed as a potentially vulnerable element to flooding based on its location at South Quay.

There are many groups or sectors of the population which may be identified within Port of Spain. These include migrants, the economically disabled and the physically challenged. Many persons have been encouraged to utilize Port of Spain as their main port of entry because of its many favourable pull factors. Port of Spain is often the first point of entry for many migrants, especially those coming from the smaller islands in the Eastern Caribbean and Guyana. For example, many persons from St. Vincent and Grenada have settled within the city usually in suburban dwelling units close to sources of labour within the city.

Port of Spain therefore presents a series of intricately connected services which when affected by a hazard such as a flood can negatively impact its activities such as business, transport, provision of services etc.

## Nature of the Hazard

Flooding hazards continue to be one of the most common and disastrous hazards in the world. They are caused by the inundation of areas by water which previously were without. Flood events may be considered to be one of the most frequently occurring natural hazards in the Caribbean (Udika 2010). In the region, flooding exerts a substantial and consistent influence on the societies of Caribbean SIDS and can create disastrous situations (Ahmad 2007). In Trinidad, flooding over the past 20 years has caused damages to over 1,000 homes and businesses (Ramlal 2008). Within Port of Spain the situation is no different.

There are many types and causes of flooding. The main types of flooding include-

1. Riverine flooding. This is caused by rivers toppling their river banks. It is usually accompanied by heavy and intense rainfall occurring in the river catchment.
2. Flash flooding. This type of flooding is characterised by sudden increases in water levels with often equally quick run off periods. It is its suddenness which makes it hazardous and destructive.
3. Coastal flooding. Flooding occurs here as a result of powerful storm surges pushing water inward onto the coastal areas. It is often associated with hurricanes and tsunamis.
4. Urban flooding. The paving and concreting of surfaces retards interception and percolation of water into the ground allowing for pooling and eventual flooding in urbanised area.

The flooding experienced in Port of Spain for the most part may be described as flash flooding where the water often rises very quickly and dissipates within a matter of minutes. However, it is still disruptive to conducting business in the capital as almost all streets become conduits for this water. In some cases, the rainfall occurs over the Northern Range in the catchment areas and the rivers become swollen and both the Maraval and St. Ann's Rivers topple their banks as they enter the city, leading to flooding of the riverine type. Flooding has also occurred as a result of the passage of tropical waves and other weather phenomena across the island.

### *Weather Phenomenon*

Much of the rainfall which occurs in the study area is as a result of convectional rainfall production. This occurs whereby heating of the ground causes warm air to rise and upon reaching the atmosphere leads to cloud formation; once dew point is reached rainfall occurs. However, a phenomenon called the westerly convergence has been identified by the Trinidad and Tobago Meteorological Service as being the main cause for rainfall in Port of Spain.

The westerly convergence phenomenon is attributed to the readily available heat sources located on the west coast. These heat sources are ideal for rainfall development due to the presence of high acreage of impermeable surfaces (asphalt and concrete) which have smaller specific heat capacities and as a result heat to greater levels than dry earth or grass covered earth. This concentrated heating is facilitated by the breakdown of the easterly trade winds which usually occurs during the wet season months from August to November (wind speeds less than 7.6km/hr.). The presence of densely urbanised and paved surfaces found on the west coast of the country such as in Port of Spain, Point Lisas and San Fernando therefore are highly favourable for the development of the west coast convergence rainfall.

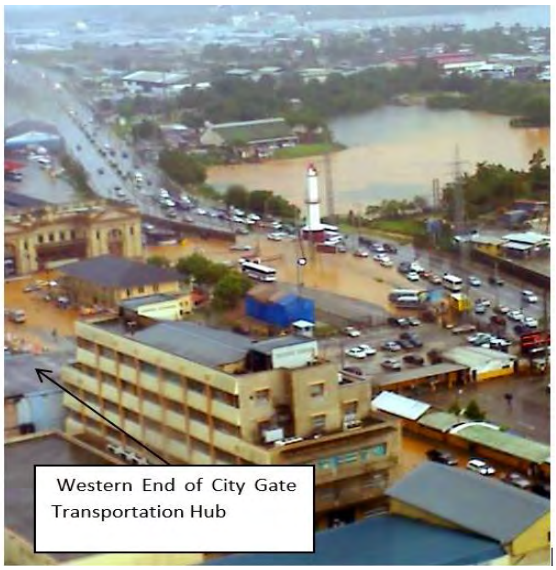
With the concentrated heating, the air close to the surface heats up and this rises, cools and condenses. Moist maritime air from the nearby Gulf of Paria then rushes in to take the place of the air which rose. This in turn heats up and rise, cools and condenses. This cycle continues allowing for large cloud development (cumulonimbus clouds or thunder clouds) over the city. The cycle also develops a reverse or westerly wind or wind coming from the Gulf of Paria. Sometimes this wind becomes strong and finds it way inland to significant distances. It may even move the thundercloud activity from its place of

occurrence to locations further inland. This leads to intense yet limited rainfall events which dump large amounts of rainfall, resulting in flooding (*pers. comm.*)

***Historical Flooding***

Historically, Port of Spain has been affected by flooding over a long period of time. Although historical records have been discontinuous, the available records show that flooding has affected Port of Spain from as far back as in the 1960s. According to the hazard database of the Office of Disaster Preparedness and Management (ODPM), flood events of varying degree have affected the capital city for more than 40 years.

In 1963, intense rainfall led to flooding in the capital city with approximately 11 persons including 7 children losing their homes after flood waters swept away their houses. Another example of the catastrophic effects of flooding is given by the case where in 1993 flooding in the city resulted in the deaths of five persons, eight homeless and approximately US$70,000 in damages (ODPM Database 2011). In 2008, Port of Spain experienced some of the worst flooding it had seen in a long time with flood events occurring in September, November and December of that year. The lower portion of the city in the South Quay region was completely flooded after abnormally intense rainfall which occurred over a three day period culminating with flooding on November 18th 2008. One fatality was recorded and thousands of dollars in damages was recorded as well as traffic congestion and transportation issues (See Photographs 2.1, 2.2 & 2.3).




**Photograph 2.1** Aerial view of South Quay, Port of Spain during Floods of November 2008.


**Photograph 2.2** Debris and Flood water near the City Gate Transportation Hub at South Quay Port of Spain (November 2008)


**Photograph 2.3** View of raging flood waters moving down the East Dry River/ St. Ann's River towards South Quay, Port of Spain (November 2008)


**Photographs 2.4 and 2.5** Showing Flooding on November 19th 2011 at Princess Elizabeth Centre

In 2010, similar events occurred as well with persons being trapped in buildings. Most recently, in June and November 2011 (See Photographs 2.4 and 2.5) flooding occurred due to the tributaries of the Maraval River spilling onto the streets and homes of persons in Woodbrook. One such affected was the Princess Elizabeth Centre. Ten children and caretakers had to be rescued and relocated from the Centre after flood waters surrounded the home suddenly (Dowlat 2011). The flood also caused millions of dollars in damages as the operating theatre was also flooded and equipment was lost. Most recently, flooding has occurred in Port of Spain in October after more than three days of heavy rainfall over the island.

Given this information, it is apparent that the Port of Spain area is vulnerable to flooding. The ODPM through its Mitigation, Planning and Research Unit has compiled these events to develop a Flood Susceptibility Map for Trinidad inclusive of Port of Spain (See Figure 2.3). Figure 2.3 highlights the high susceptibility of the Port of Spain area and illustrates the high possibility of flood occurrence throughout the city.

***Causes of Flooding in Port of Spain***

There are many contributing factors to flooding in Port of Spain. These factors have worked together to produce some spectacular flood events with debilitating impacts which have resulted in millions of dollars in losses and even deaths. The main factors which have contributed to flooding may be categorised into physical and human induced factors. These include

1. Physical
    a. Topography
    b. Intense rainfall and weather phenomena
    c. Tidal influences
2. Human Causes
    a. Poor Land Use Practices- these include subsistence farming, quarrying, private and public housing and squatter settlements especially in unsuitable lands. Recent land use trends have been dominated by an increase in inadequately managed urban

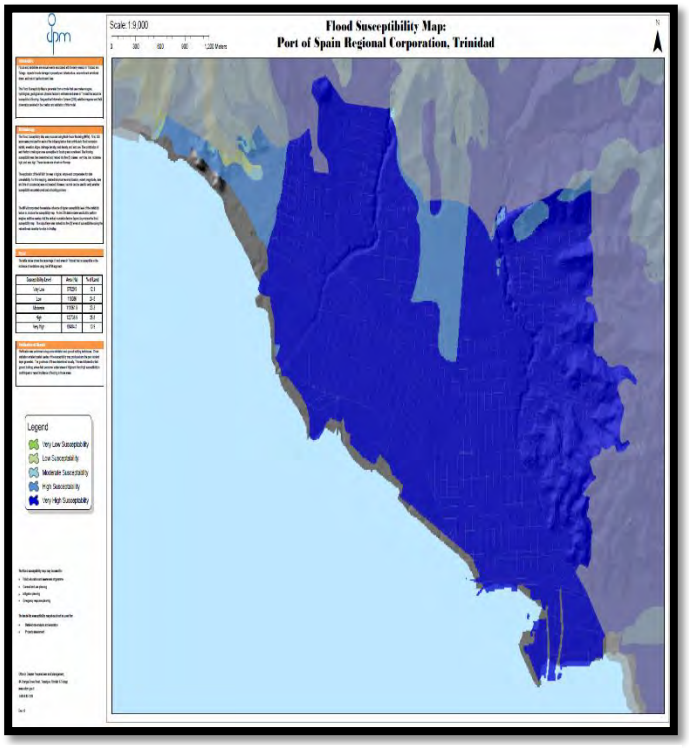



**Figure 2.3** Flood Susceptibility Map for Port of Spain

growth patterns. It has been ascertained that the conversion of natural areas for residential purposes has been linked to an annual population growth rate of approximately 1.1%. This has resulted in urban development sprawled along the east west corridor and up the hill slopes of the Northern Range (EMA 2004)

b. Poor Sanitation. Inadequate garbage collection within the city as well as antiquated drainage systems encourage flooding.
c. Excessive Surface Runoff. This occurs as a result of clearing of the vegetation cover on the hillsides outside the city area. With denuded slopes, there are greater quantities and rates of flow of surface runoff allowing for flooding to take place owing to insufficient water capture (overland flow is greater than infiltration and inadequate river systems). Rapid urbanization within the city is the root cause of this. There has been an increase in the number of paved surfaces in recent times both on the coast as well as within the city. This has created a unique situation whereby the increased paved areas in the city have contributed to increased surface runoff which naturally tends to flow towards the sea. However, building on the coastline has raised the coastline retarding the rate of run off into the sea, leading to ponding and flooding within certain areas such as Woodbrook.
d. River Morphology. The river morphologies of both the St. Ann's River and the Maraval River have been altered naturally and through human intervention over the years. In order to accommodate land use developments and to alleviate some of the flooding issues, the river courses have been concreted and straightened to increase run off rates. Additionally, as with all rivers the morphologies have naturally changed within the flood plain. However, the presence of land developments on the flood plain has resulted in flooding and costly hazard impacts.

The natural factors which cause flooding are difficult to mitigate against. However the human induced causes of flooding can be reduced through both structural and non-structural mitigation measures. Port of Spain faces an all too familiar situation where it must seek that balance between competing land use developments and maintaining the physical environment so that it can adequately perform its functions with respect to runoff and drainage. The increase in these human activities at alarming rates has resulted in the increased flood potential of the city of Port of Spain.

### Conclusion

This chapter has set the scene for a better understanding as to the characteristics of the study area. Many of the vulnerable elements have been identified, highlighting the effects of flooding on them. The physical characteristics of the city's location and topography have influenced the growth of the city. The location has also allowed for the growth of the area as a commercial centre with paved areas and tall buildings where various types of commercial activity are carried out. This dense urbanisation has also influenced the type of weather phenomenon which affects Port of Spain resulting in heavy torrential downpours. Both physical and anthropogenic features work together to cause flooding to occur affecting the city's population. One may therefore suggest that there is a deeply intertwined connection amongst all the characters involved to produce an area that is vulnerable to flooding. Therefore it is worthwhile to understand those areas which are highly vulnerable to the impact of flooding in order to recommend possible measures which may reduce this vulnerability.

## Methodology: Conducting the Vulnerability Assessment

### Popular Methodologies for Conducting a Vulnerability Assessment

Vulnerability assessments play a critical element in disaster risk management. As mentioned in the previous chapter, identifying those vulnerable elements within a community or population can assist in the formulation of proper disaster risk reduction strategies to reduce these vulnerabilities or provide coping mechanisms for at risk populations. According to Winrock International India (2011) the primary objective of undertaking a vulnerability assessment is to anticipate the problems and possible solutions to

save lives, protect assets, reduce impact and facilitate speedy recovery. Conducting a vulnerability assessment can achieve this in that it allows decision makers, governments and communities to make risk based choices to reduce vulnerability through mitigation against hazards and prepare effective response and recovery measures. Thus vulnerability assessments are essential in disaster risk reduction.

There are many types of vulnerability assessments and methodologies currently being employed. A wide range of organisations involved in security and environmental services have developed different assessment methodologies. Some assessments include matrices; some are dependent on spatial data while others use simpler tools. Overall, the main goal is to thoroughly understand the level of exposure, impact, the nature of the hazard event and sensitivity of the community to the hazard impact.

It has been found that understanding vulnerability cannot be done from a distance or based purely on statistical data and historical information; one must engage the populations or communities which are perceived to be at risk or vulnerable. In the 1990s when mainstream disaster risk reduction took off, many institutions became involved in conducting vulnerability assessments (HFA 2007). At first, before accepted methodologies evolved, information for the vulnerability assessments were based mainly on existing information such as statistics and historical information on hazard impacts etc. However, it was found that in many instances once gathered and analysed, the results did not prove fruitful and the ensuing mitigation strategies and coping mechanisms did not fit with the needs of the community and as such there was limited or no support for the projects. As a result, the projects failed or were abandoned. In order to bridge that gap and make the resilience building initiatives more relevant vulnerability assessments which worked with the communities were developed.

Two of the most popular types of vulnerability assessment tools are those utilized by the International Federation of Red Cross and Red Crescent Societies (IFRC) and the National Oceanic and Atmospheric Association (NOAA). The IFRC has developed a tool called the Vulnerability and Capacity Assessment (VCA) while NOAA has developed and utilizes the Community Vulnerability Assessment Tool (CVAT). These two are often combined or used solely by agencies and viewed as being successful in truly understanding and therefore assessing vulnerability at the community level.

According to the IFRC (2007), VCA is defined as a method used to investigate the risks that people face in their locality, their vulnerability to those risks and their capacity to cope with and recover from disasters. This tool is targeted for use by the National Societies to assist communities in building resilience against disasters. The general methodology involves a twelve step process from planning to completion (IFRC 2007). The actual VCA is carried out in Phase Two; it follows the planning and training phase and precedes Phase Three, the action phase. It must be remembered that the outcome of such an exercise is to make recommendations aimed towards building capacity within the affected community. The main components of the Assessment phase include

1. Acquiring an understanding of the community/ study area. This supports the choice of community to carry out a VCA. Having an understanding of the community determines the priority level for the completion of the VCA as well as identifies the tools to be used.
2. Identification of the Assessment Tools. This includes identifying those processes which will yield best results based on the environment or community which the team will be going into. Some of the tools proposed include, secondary sources, questionnaires, direct observation, spatial maps, interviews, focus groups, historical timelines, transect walks and problem trees. The VCA handbook suggests utilizing a combination of these tools or all of them as possible in order to be very thorough in one's assessment.
3. Choosing the most appropriate tool. The choice of tools will be based on what is most appropriate to obtain the most relevant information from the community. This is often based on the characteristics of the community.
4. Field work. Once the tools have been chosen and preparation work has been completed the actual field work takes place to gather data.

5. Data analysis. This involves putting the data in the most relevant manner to be understood. It is considered the process whereby the data speaks to the individual. This allows for the VCA team to formulate accurate conclusions and reflect what is occurring in the community. For example, prior knowledge shows that persons continue to build near a cliff prone to landslides. The perception may be that these people are ignorant of their vulnerability and the threats which they face. The data gathered and through its analysis may reveal that the people are aware of their situation but choose to stay there due to other factors such as lack of land tenure. Therefore the analysis of the data will provide answers to some of the behaviour of the community.
6. Presentation of results to the community. This involves providing the findings of the vulnerability assessment to the community for their approval and support. This allows for any wrong perceptions to be corrected.
7. Recommendations and Strategies. This phase allows for the building of resilience and the developing of coping mechanisms for the community's vulnerable elements.

It must be noted that, in many instances the recommendations have very little to do with disaster preparedness strategies. In many cases, those factors which promote or cause the vulnerability are outside the realm of disaster management and therefore the strategies which must be implemented require assistance from outside the National Society.

Similarly, the Community Vulnerability Assessment Tool (CVAT) seeks to address the vulnerability of communities, but does so based on assessments of various sectors within the community. This assessment is different in its methodology. The following describes the methodology for conducting the CVAT.

1. Hazard identification and prioritization
2. Hazard analysis
3. Critical facilities analysis
4. Social Analysis
5. Economic Analysis
6. Environmental Analysis
7. Mitigation and Opportunities Analysis

According to NOAA, this assessment owes its merits to the fact that it seeks to link the social, economic and environmental aspects or sectors of the community. The key to the success of this method is the adequate collection of data from each of the sectors. The analysis depends on data such as inventories of critical facilities, economic assets and environmental units. Included also, is the spatial extent of these elements such as the extent and location of the hazards, location of banks, commercial centres etc. The data to be collected requires great detail. The main outputs of the CVAT are a series of maps which are derived using Geographic Information Systems (GIS) software. These maps show the spatial interconnection between the various analyses. For example, it shows the relationship between the flood hazard and the economic sector. The intersection between the economic elements such as the location of the Central Bank and the location of the flood highlight the possibility of this and other buildings being affected by flooding. The attribute data will corroborate this analysis as buildings constructed according to strict codes or which conduct no business on their ground floors may not necessarily be affected by the hazard.

In comparing the CVAT and VCA methods it must be noted that both aim to assess vulnerability at the community levels. However, the approaches differ. The VCA methodology seeks to include the community by engaging them in discussion about their vulnerability. In contrast, the CVAT method is based on more data gathering especially where the data has some spatial aspect to it. The CVAT's tools are more sophisticated in the use of GIS mapping to highlight and illustrate vulnerabilities based on location and the attribute data related to that location i.e. it is data dependent. In developing countries that data is often inaccessible. An additional merit is that the spatial output provides users and decision makers with a visual from which the data can be manipulated to create scenarios and thus derive various

outcomes and conclusions. This method is therefore advantageous in its ability to adapt to changes in the community.

The VCA method is truly community based and must have the support of the community. It allows the VCA team to get involved with the community and understand issues which may not have been identified in the CVAT method such as relational and social issues amongst the various groups. Behavioural attitudes towards disaster risk management are easily highlighted within the VCA method. The CVAT method because of its reliance on the use of GIS systems has not been able to integrate behavioural as well as other social observations into its analysis. Another advantage of the VCA methodology is the many tools available to conduct the analysis. However, within this there is the disadvantage of not choosing the appropriate tools to meet the specific needs of the study area. Overall, the CVAT method is ideal for a larger community and where data is readily available whereas the VCA works well in a smaller spatial area and provides a more intimate analysis.

### Methodology used to collect data within the Study Area

In this study, aspects from both methodologies were drawn upon to conduct the assessment. The vulnerability assessment for the study area is based on prior knowledge of the hazard impact of flooding on the Port of Spain area. From the CVAT methodology, the aspect of a sectorial analysis was chosen. Given the vast and varying activities and functions of the city of Port of Spain as well as the limited time frame in which to complete the study, certain sectors were selected to be assessed. In order to choose the highest priority sectors historical data was collected and a time line of flood occurrences and impacts was sourced from various newspaper archives as well as the ODPM which has a database of flood events and some of the impacts. The sectors were chosen based on the priority which they play in the city's functioning, the impact of flooding based on location as well as income generation. Thus, the economic sector was chosen as an indicator of flood vulnerability. The category of special populations for the purpose of this study is defined as those persons who are physically challenged in that they are affected by orthopaedic or spinal injuries and attend the Princess Elizabeth Centre. This group was chosen because of the repeated effects of flooding which it has experienced. The CVAT method was therefore used in identifying the most relevant aspects of the community to be assessed based on priority.

One major limitation of this study was the time frame which was available for field work. The shortened period did not allow for a more thorough investigation of the factors affecting the vulnerability of the sectors. As a result a smaller subset of the entire downtown Port of Spain area was chosen. This area is perceived as the area which is perennially impacted by flooding. The area extends in an easterly direction towards the East Dry River and westerly towards the Maraval River. It is bound by Independence Square to the North and South Quay in the south (See Figures 3.1 & 3.2).

In order to acquire the necessary data for the vulnerability assessment a series of tools similar to those highlighted in the VCA methodology were utilised. Initially a transect walk was taken through the study area. This assisted in identifying the type of commercial activity that was taking place within the study area, the spatial layout and significant features of the area which might affect their vulnerability.

The transect walk also assisted in providing a background into the type of existing physical structures and infrastructure as well as some insight into the best approaches for data gathering. Along the transect walk, photographs of the study area were taken. Once the transect walk was completed, a questionnaire was developed to be administered to the businesses within the study area. The aim of this questionnaire (Appendix I) was to acquire information about the following:-

1. The nature of the businesses in the study area.
2. The impact of flooding on their business
3. The type and monetary value of losses due to flooding
4. The level of preparedness of the businesses
5. The perception of the businesses with respect to flooding and flood mitigation.


**Figure 3.1** Satellite Imagery showing the section of Downtown Port of Spain where data was collected and transect walk done (highlighted in red)

The questionnaire consisted of twenty-two open and close ended questions. In order to achieve the best possible response, businesses which were located in the flood impact zone were administered the questionnaire. Not all businesses were sampled; the ones chosen were located along the main thoroughfare i.e. South Quay from St. Vincent Street to Duncan Street, as well as those which had permanent structures to carry out business. This resulted in twelve businesses of varying type of commercial activity; firm size and ownership being questioned. Therefore a wide range of answers were generated in response to flood vulnerability. To support the questionnaire an interview with the President of the Downtown Owners and Merchants Association (DOMA) was conducted. This interview was done to obtain an overall view point of the business community on flooding and its impact on business within the Port of Spain area. The results of the questionnaire were interrogated using the SPSS software.

For the assessment on the vulnerability of the services provided to the physically challenged community, an interview and site visit was made to the Princess Elizabeth Centre. The impact which the Centre faces has been most costly in terms of the value of property damage as well as the delay in its ability to perform its functions. The interview was conducted with the Manager of the Centre, 'the Matron' as she is called. The aim of the interview was to gain a first-hand knowledge of how the Centre has been affected by flooding, the impact of the flood and the resulting losses. The interview also intended to identify the local coping mechanisms for assisting the Centre in its flood preparedness planning. The site visit yielded evidence of the impact of the last flood event which took place in June 2011.

The data collected from the interviews were analysed using qualitative methods. Qualitative methodologies aim to analyse various behavioural issues. It analyses the level of knowledge people have and how this knowledge affects their actions. It also looks at people's behaviour given various situations or circumstances as well as the effect of culture on the behavioural patterns. The method of content analysis was used whereby transcripts of the interviews were analysed for key phrases which pointed or

suggested their levels of vulnerability. Content analysis is a research tool used to determine the presence of certain words and phrases within text. The researcher looks for relationships and trends within the text amongst the chosen categories of words. This allows for inferences to be made about the messages found within the texts. It allows for relationships between cause and effect to be identified, for example.


**Figure 3.2** Satellite Imagery showing Princess Elizabeth Centre (green star) in relation to the Maraval River (blue arrow). The red line denotes the transect walk.

For this analysis the use of the Nvivo software was utilised. The software is a qualitative data management tool which allows the user to manage a wide range of data sources such as audio, literary and photography. The data is analysed through the use of nodes or themes related to the data under scrutiny. In this case the two aforementioned interviews were interrogated using this software. The transcript (See Appendix II) of each interview was dissected under specific themes or nodes. This allowed for simple analyses of correlation between the themes as well as categorising of the interviewees responses under these themes. The main themes which were used to assess flood vulnerability were:

a. Perception- this included flood perception and causes of flooding
b. Flood Awareness- this identified how aware the interviewees were aware of flooding as it related to their situation.
c. Flood Preparedness- this looked at the actions or lack thereof taken to reduce flooding.
d. Extent of Flooding- this identified the effects of flooding, both physical and monetary as far as possible.
e. Flood Vulnerability – this looked at those issues which led to greater exposure to flooding. It included sub- nodes of Environmental Degradation, Infrastructure and Planning.
f. Solutions to Flooding- this theme identified those recommendation or strategies which were interviewees were currently employing or have considered.

Therefore through a combination of mixed methodologies inclusive of quantitative and qualitative data conclusions about the vulnerability of the targeted sectors were derived. Appropriate recommendations could now be suggested based on the responses to the research questions.

## Presentation of Data and Analysis

### Introduction

The data once collected was analysed using various techniques. These included the use of the Statistical Package for Social Sciences (SPSS) as well as Nvivo software. SPSS is a software package which assists in providing simple analyses of statistical data such as correlation, average as well as standard deviation of the data. Quantitative data yields information which points towards trends or indicators such as the number of businesses affected, the type of effects and the losses incurred. These can be used to infer the extent of vulnerability.

Qualitative data sets on the other hand do not lend themselves easily to statistical representation and must be analysed in a different manner. Therefore the other data sets such as the interviews and photographs were analysed using the Nvivo software and through a photographic analysis respectively. These tools allowed for the data to be processed into a format which could provide indicators or suggest answers to the main research questions regarding the vulnerability of the highlighted sectors in Port of Spain.

### Quantitative Data Presentation – Results of the Questionnaire

As previously mentioned, the vulnerability of the commercial sector was assessed using a questionnaire directed at businesses located in frequently flooded areas. Twelve businesses were administered the questionnaire. The responses to each of the questions were put into a table where they were prepared for coding within the SPSS software as well as Microsoft Excel spread sheets. The results of the questions were then depicted as graphs for analysis as well as provide visual answers to the questions asked. The following graphs illustrate the answers to the various questions posed to the business owners.

Figure 4.1 shows the gender of the participants of the questionnaire. Of the twelve participants the majority were male totalling 8 persons while the remaining were female. Figure 4.2 illustrates the longstanding involvement of the business owners in their various activities. Approximately 8 persons were involved in their respective businesses for more than 10 years. This demonstrates their commitment to the business activity in which they are involved. The twelve businesses that were questioned had been at their current location for varying periods of time. The majority of businesses were located within the study area for more than ten years. In Figure 4.3, the pie chart shows that three quarters of the businesses had been at their present location for more than 10 years[1]. This suggests a certain level of satisfaction with these present locations.

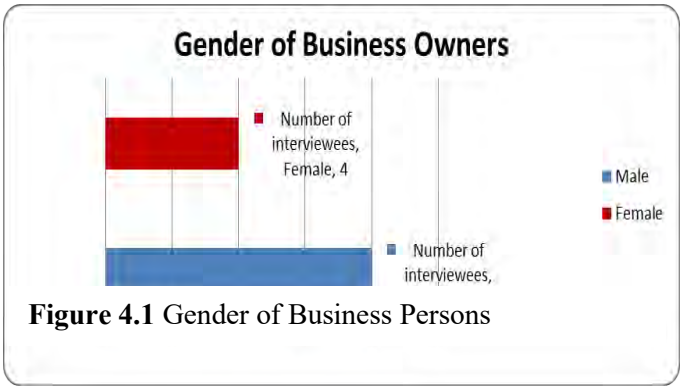



**Figure 4.1** Gender of Business Persons

[1] One business identified that they had been at that location conducting business in shipping since the early 1800s.

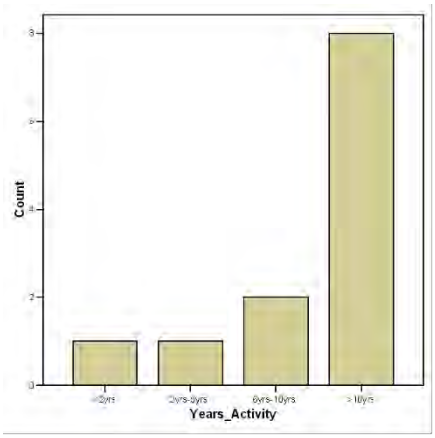



**Figure 4.2** Number of years involved in business activity

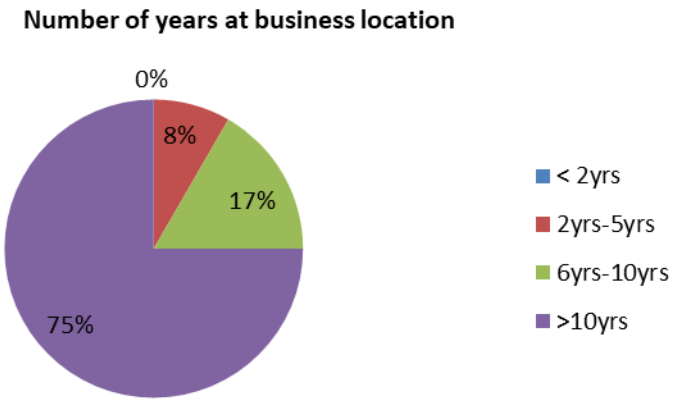



**Figure 4.3** Number of years at current business location

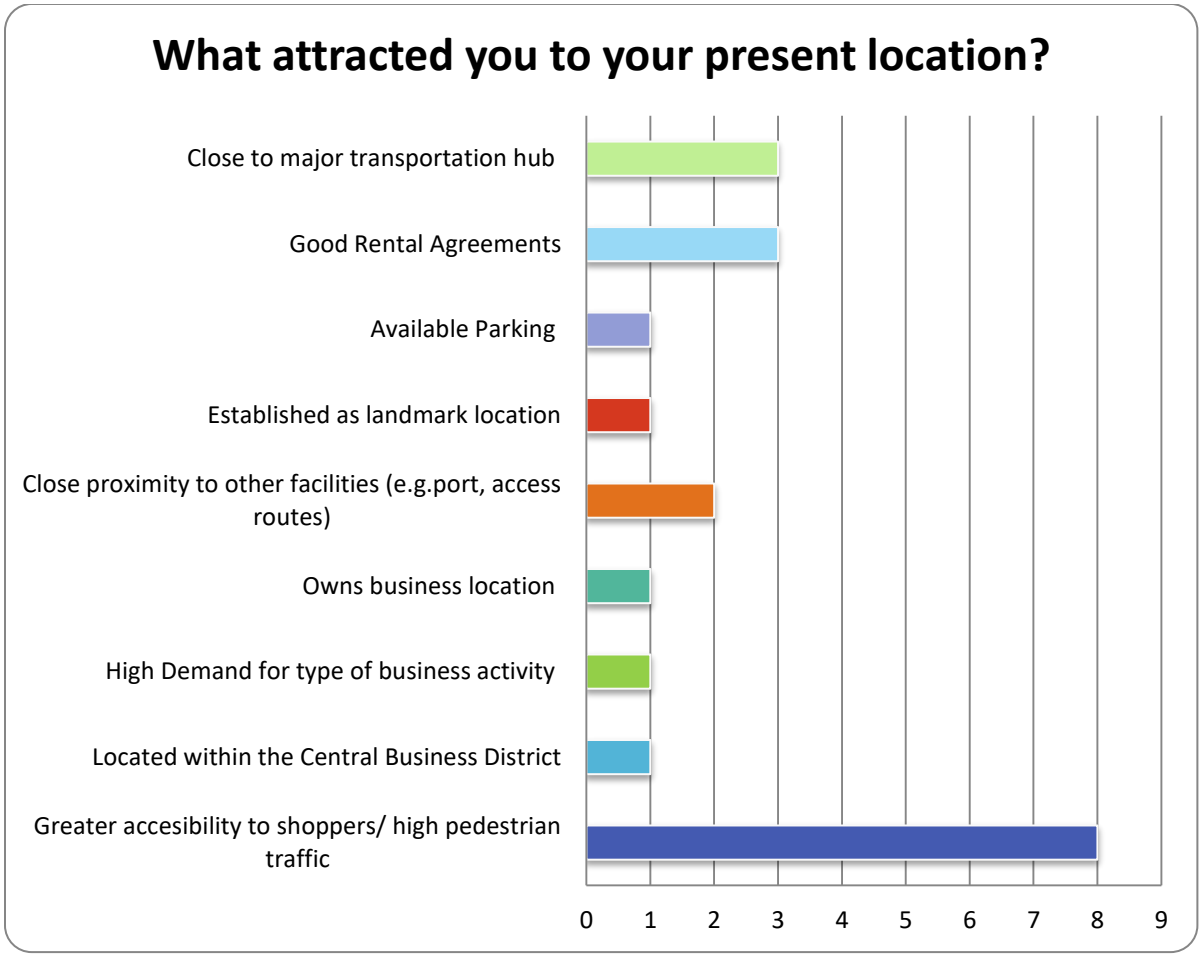



**Figure 4.4** Bar Graph showing reason for choosing business location

Many of the businesses cited a wide range of reasons for their present location as demonstrated in Figure 4.4. Amongst the most popular reasons was the greater accessibility to shoppers/ high pedestrian traffic by shoppers. Secondly business owners identified the close proximity to the main transportation hub at City Gate being one of the main reasons for them choosing this location. The availability of good rental agreements was also a favourable reason for the business owners' choice of location. Two businesses cited the close proximity to other facilities such as the port and major roads as a major deciding factor in choosing that location. Thus one may surmise that Port of Spain role as a major commercial centre holds true based on the responses of the participants.

From the pie chart in Figure 4.5, it was noted that almost all the respondents were aware of the flooding issues which existed within the area. One suggestion is that the location is highly favourable in spite of the possibility of flooding. Alternatively, businesses choice to locate in the flood prone areas is an indication of the shortage of commercial space for small and medium sized firms.

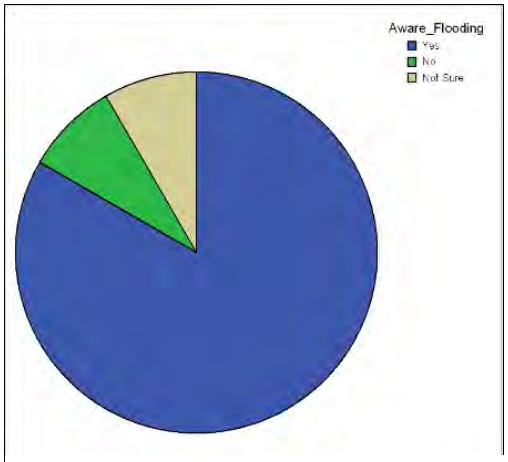



**Figure 4.5** Awareness of Flooding within the study area

The bar graph in Figure 4.6 highlights business owners' reaction to weather reports. Of the twelve businesses interviewed, the majority of them were not consistent in listening to the weather report in order to have early warning to prepare for possible flooding in the city. This therefore presents a situation whereby the business owners are more vulnerable to possible flooding due to a lack of awareness.

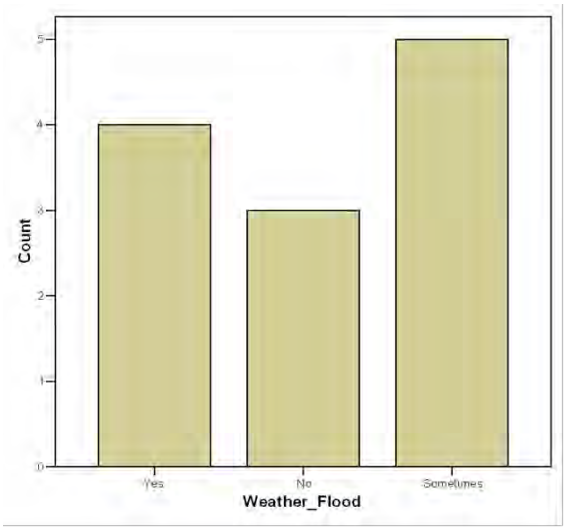



**Figure 4.6** Persons who listen to weather report

All the businesses interviewed have been affected by flooding in some manner as illustrated in Figure 4.7. This supports the view that flooding is a major problem within Port of Spain. When asked how they were affected, the businesses owners presented various combinations of effects. The pie chart in Figure 4.8 shows the various effects of flooding on commercial activity within the study area. Businesses cited the loss in sales as the most frequent effect of flooding. This was followed by loss of stock. Of the possible responses that could be given, a significant number of businesses cited all of the above as a response (all possible effects). In a few cases, business owners identified their building being affected as one of the effects of flooding.

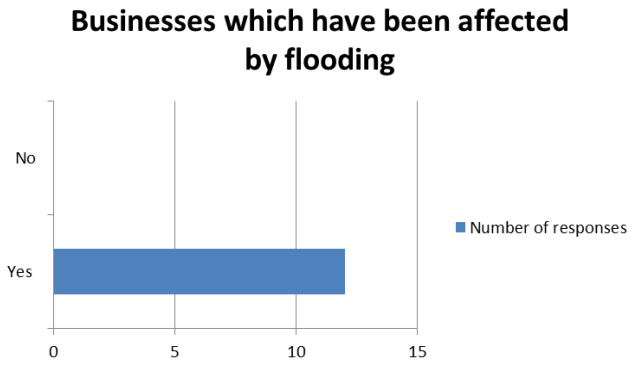



**Figure 4.7** Businesses that have been affected by flooding

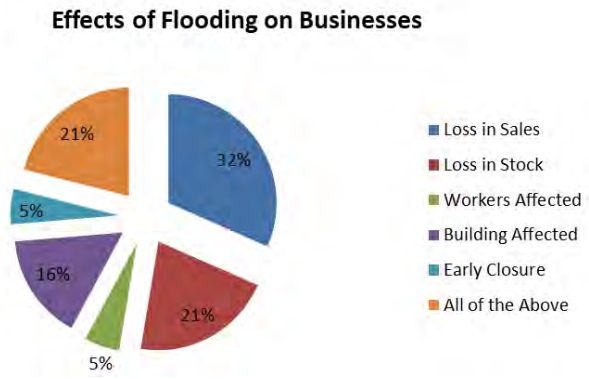



**Figure 4.8** Effects of Flooding on businesses

These results demonstrate that flooding has impacted commercial activity to a significant degree in Port of Spain. This indicates that the businesses are highly susceptible to the effects of flooding.

Another indicator of the impact of flooding on the commercial sectors is the record of the actual losses which businesses incurred. The ability to quantify the losses sustained supports the view that flooding events adversely affect the business community. It also supports the importance of having effective flood mitigation measures in place. The extent of losses reflects the level vulnerability of the businesses and is directly related to recovery time. From Figure 4.9 it is noted that two thirds of the businesses actually recorded the losses which they incurred during various flood events. Many of the business owners identified their accounting sections and insurance as the bodies who recorded their losses.

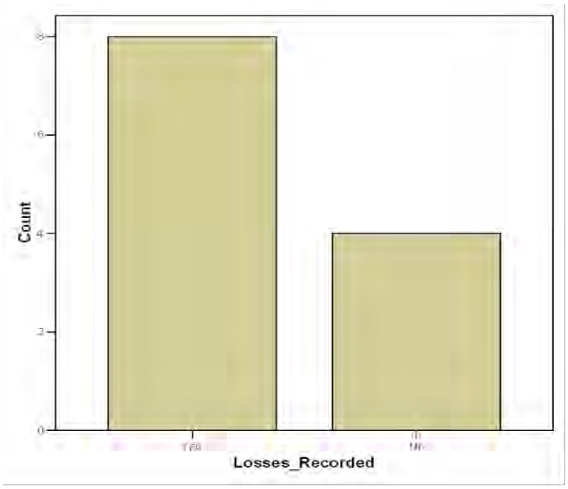



**Figure 4.9** Number or Businesses who had their losses recorded

Figure 4.10 illustrates the monetary value of damages incurred by the businesses interviewed. Business owners were asked to approximate the value of losses based on the last major flood event which affected their business. One quarter of the businesses was unable to provide a monetary value of what they had lost due to flooding. The largest group of business owners estimated damages approximating between TT$10,000 –TT$14,999. Two businesses recorded losses between TT$20,000 TT$24,999 during a single flood event. Given the evidence provided by the pie chart it can be deduced that businesses in Port of Spain incur significant damages during flooding. This suggests that the businesses are very vulnerable to flooding hazards.

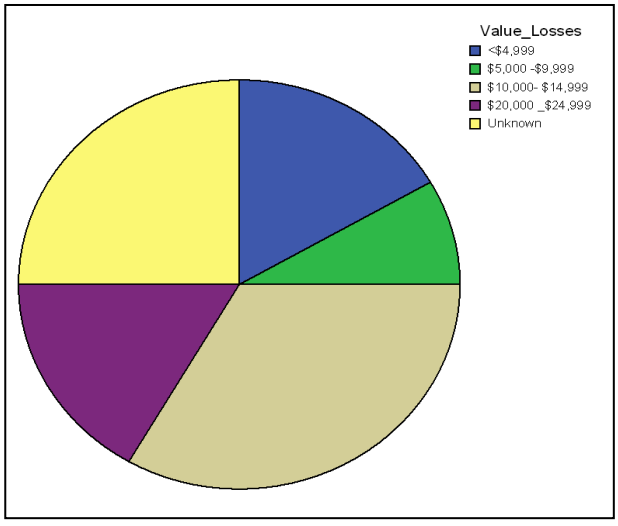



**Figure 4.10** Approximate losses in monetary terms of the last flood event which affected the business

Given the effects of flooding on businesses within the study area and the losses incurred, a preparedness plan or some action to prevent these recurring issues is important. Figure 4.11 shows the responses of the business owners when asked if there was a preparedness plan for flooding. Ten of the respondents identified that they had some plan in place or actions which they carried out when faced with flooding. One business said they had no plan and another was not sure if the business had a plan.

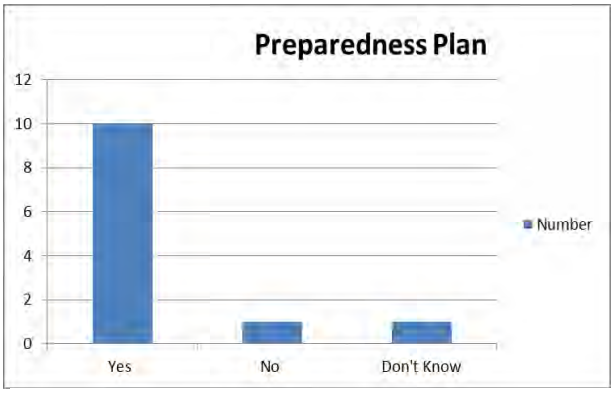



**Figure 4.11** Business Owners who have Preparedness Actions

According to the businesses surveyed, the most favoured action was to move goods found on lower shelves to higher ground or spaces above flood waters (See Figure 4.12). Five businesses cited sandbags as their means of preparation against flooding. Some of the larger businesses had established structural measures within their buildings. Structural measures included altering of building construction such as raising floors, steps, rectifying drainage etc. Two businesses stated that they closed the doors of the business in order to block flood waters from entering. The remaining businesses had pumps to get water out in case of the business becoming flooded as well as did routine building maintenance such as roof repairs etc. Figure 4.12 indicates that many of the businesses were prepared in some manner. The measures taken demonstrate that it is imperative that preparedness measures are taken in order to safe guard against the impact of flooding on the businesses.

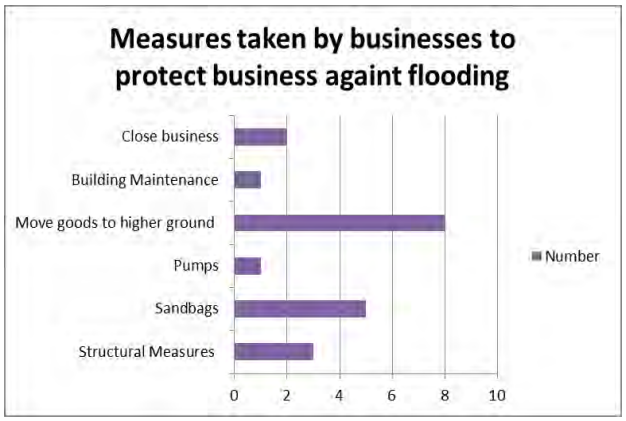



**Figure 4.12** Measures taken by Business Owners during flooding

When asked how flooding could be reduced in Port of Spain, businesses gave a wide variety of answers with improved drainage being the most popular method to reduce flooding. Better infrastructure management, improved garbage disposal as well as law enforcement were seen as equally good means of reducing the issues of flooding in the city. One person each highlighted the need for a flood plan and improved engineering works as possible solutions to reduce the problem of flooding. These answers suggest that the business owners, view flooding as a serious issue affecting Port of Spain. It also shows that there is the view that improvements can be made to reduce the vulnerability to flooding and therefore build capacity.

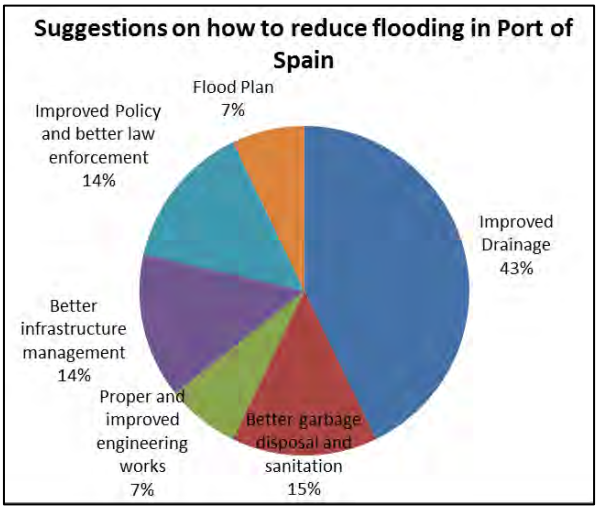



**Figure 4.13** Pie Chart showing business owners' suggestions to reduce flooding in Port of Spain

## Photograph Analysis

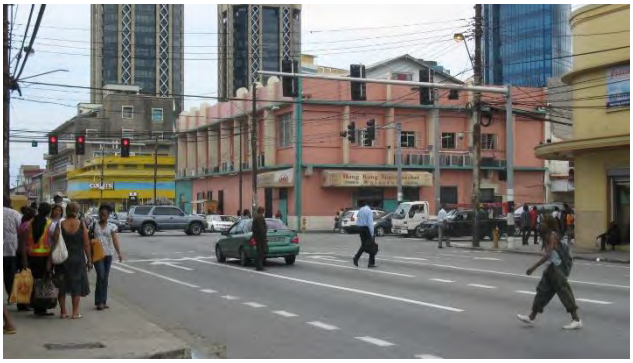
***Photographic Analysis of the Commercial Activity***

Photographs were taken throughout the study area to illustrate the importance and wide variety of commercial activity in the city as well as illustrate the vulnerabilities of the city to flooding which affect the commercial sector. Photos, 4.1, 4.2, 4.3 and 4.4 show some of the businesses located along South Quay. From the photos it can be seen that there is a mixture of business located in the South Quay area. There are small businesses owned by immigrants selling mainly clothing and haberdashery goods. They are located opposite the main transportation hub - City Gate. As one walks westwards the businesses change with many well-known and well established businesses such as chain furniture and jewellery stores (See Photo 4.4). Pedestrian traffic is also high as persons move from City Gate to the Central Business District of the city.

**Photograph 4.1** Businesses along South Quay (North) Port of Spain


**Photograph 4.2** City Gate- Main Transportation Hub, South Quay (South) Port of Spain

**Photograph 4.3** View of Henry Street and small businesses near South Quay



**Photograph 4.4** Pedestrian traffic along South Quay

Photograph 4.5 illustrates the inadequate or antiquated drainage which exists within the city. The picture represents what happens after a short period of rainfall i.e. ponding of water on roadways etc. as mentioned previously, some of the main issues causing flooding in the city of Port of Spain include inadequate drainage as well as poor sanitation. Photographs 4.6, 4.7 and 4.8 illustrate this.

**Photograph 4.5** Ponding of water along road way after short rainfall

**Photograph 4.6** Storm drain filled with garbage

**Photograph 4.7** Overgrown storm drain grate

**Photograph 4.8** Storm drain filled with grabage

The photos show garbage clogged drains as well as overgrown storm grates which should allow water to pass from the roadway and pavements and into underground drains. These pictures support the views expressed by the businesses in Figure 4.12 in which business owners made suggestions as to how flooding can be reduced. The problem of poor drainage was highlighted as being one of main components which needs improvement. One may suggest that this problems stems from a lack of law enforcement for littering as well as poor sanitation collection and disposal of garbage in Port of Spain. These factors serve to increase the potential for flooding in the city.

Another issue which has increased vulnerability is the close proximity of businesses to the banks of the rivers. In Photographs 4.9 and 4.10 it can seen that certain buildings are located along the banks of the East Dry River. Additionally, roadways and bridges which form the main arterial roads of the city traverse the river. Thus when the river is in spate and topples its banks as it has been known to do, business places are flooded and transportation becomes difficult as the roadways become new waterways.

**Photograph 4.9** Northwards View of the East Dry River. Note the presence of buildng on the river banks as well as low bridges across the river.

**Photograph 4.10** Seaward view of East Dry River. Note the presence of buildings on either side of the river channel as well as low bridges across the waterways.

These photographs highlight the issue of unregulated planning within the city. Buildngs are located adjacent to the East Dry River within the flood plain of the river. This location allows for the businesses as well as other activities to be more vulnerable due to their location. The low hanging bridges compromise use of the bridge when the river floods. This supports the views expressed by the business owners that better planning and management is necessary to reduce the problem of flooding in Port of Spain.

Photographs 4.11 and 4.13 illustrate the measures which have been undertaken by business owners to protect their businesses from flooding. In Photograph 4.11, these buildings are located on lower St. Vincent Street. This business has permanently placed sandbags at the one of its entrances in preparation for possible flooding. In Photograph 4.13, this business has taken structural measures by raising its showroom approximately 3 feet above the road level so as to prevent flood waters from entering the

showroom and causing damage to its stock of lighting fixtures etc. These photographs clearly suggest that flooding is a definite issue in Port of Spain. It also highlights the level vulnerability of the businesses which are unable to mitigate against the impact of flooding in the city.

**Photograph 4.11** Sandbags positioned at doorway at business on St. Vincent Street, Port of Spain


**Photograph 4.13.** Business raised floors to prevent water from entering

### *4.2.2 Photographic Analysis of Princess Elizabeth Centre, Woodbrook*

The Princess Elizabeth Centre (PEC) is a Centre for physical challenged persons. It was founded in 1953 and is the only one of its kind in the Eastern Caribbean. The Centre provides physiotherapy and conducts surgery for persons with orthopaedic related issues. The Centre has been affected by flooding perennially since 2003. The PEC is ideally located on flat land in what was previously a residential area called Woodbrook just outside downtown Port of Spain. The PEC caters to approximately one hundred and twenty children with accommodation for sixty persons. Therefore, the services which they provide are very necessary and in demand.


Location provides flat land and wide expanse ideal for accommodating patients.

**Photograph 4.14** Compound of Princess Elizabeth Centre

The Princess Elizabeth Centre has been affected by flooding almost on an annual basis causing significant destruction to the Centre. Photographs 4.15 and 4.16 show the still evident flood water mark from the major flood in 2003. This flood was unexpected and caused damage to the operating theatre and offices of the PEC.

**Photograph 4.15** Flood water mark of flood event in 2003

**Photograph 4.16** Illustrates the height of the flood in relation to the surroundings, showing the flood to be approximately two feet in some places.

Figure 4.17 illustrates the extent and strength of the flood. The flood in June 2011 was so powerful it was capable of toppling an empty water tank which was on the compound. These pictures demonstrate the effects of flooding on this special population which resides in the capital city. In the aftermath of the flood, the operating theatre was devastated with the entire area having to be specially sanitized and equipment worth thousands of dollars replaced. As a result the Centre has been unable to carry out surgery. Additionally, the lack of proper drainage exacerbates the issue of flooding resulting in catastrophic flood events like that of June 2011 as seen in Figure 4.18.

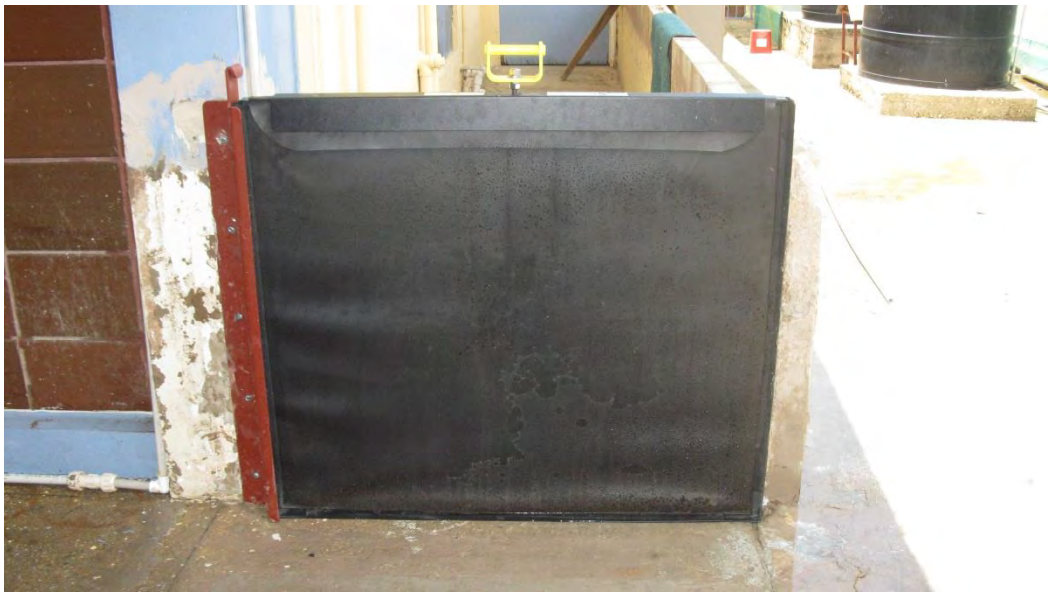
**Photograph 4.17** Empty water tank which was toppled by the force of flood waters in June 2011 flood


**Photograph 4.18** Inadequate drainage to remove flood waters

The Centre has developed its own coping mechanisms to deal with the flooding which affects them. One such measure has been the raising of equipment such as washing machines and dryers in the laundry (See Photograph 4.19). The Centre's accommodation of persons with physical disabilities makes it difficult to raise floors and install steps as these hamper patients in wheelchairs etc. from moving around the facility.

**Photograph 4.19** Measures taken to reduce the impact of flood events

In photograph 4.20, the Centre has invested in a flood dam to prevent water from entering the operating theatre where millions of dollars in equipment are stored and used in orthopaedic surgeries. This dam will prevent flood water from getting into the operating theatre in the future.



**Photograph 4.20** Flood barrier placed at entrance to Orthopaedic surgery theatre to prevent flood waters from entering

Based on the data presented and the analysis one can surmise that Port of Spain is very much at risk from flood hazards. This is due to a high level of vulnerability as exhibited by the commercial sector as well as special populations such as the Princess Elizabeth Centre. The graphs illustrate some of the views presented by the commercial sector and are supported by many of the photographs presented.

## 4.3 Analysis of Interviews

As part of the methodology, two interviews were conducted in order to obtain some more information about flood vulnerability in Port of Spain as it directly relates to the target groups chosen for analysis. As

mentioned these interviews were analysed using Nvivo software package. The following is an analysis of the interviews under specific themes.

1. Perception. This theme was used to categorise how the interviewees perceived flooding and the causes of flooding in general. The general perception of flooding was fairly accurate by both interviewees. The DOMA president was able to describe in detail the causes of flooding in the city as well as the type of flooding which affected the city i.e. flash flooding. He was very knowledgeable about these details (See Appendix II). However, the perception that flooding was not a significant issue in Port of Spain stood out. The DOMA President is quoted as saying "We are more interested in earthquakes. A major earthquake during working hours can really affect the city". "In this city centre we have not had the losses that the newspapers have reported".

   At the PEC, the matron was also able to identify and describe clearly the way in which flooding occurred, describing the extent of flooding, the history of flooding in the area and the extent of damage by floods.

2. Flood Awareness. This theme categorised those parts of the interview which illustrated the interviewees' knowledge of flooding. Both interviewees had a good awareness of flooding. For example, the DOMA president was able to identify those streets which frequently flood – "More than half an hour of rainfall results in about 10 inches of water on the main streets; Frederick, Charlotte, and Henry". The Matron was able to illustrate similar awareness in her comment "Normally we expect floods in July and August". "We've had flooding here which was not heavy, just ponding on the grass. But the worst to hit us was in 2003".
3. Flood Preparedness. This theme reviewed the ways in which the interviewees and their members prepared for flood events. The DOMA president highlighted that businesses undertook precautions such as elevated entrances and sandbagging as the primary methods of flood preparation. However flood preparedness plans for the business sector were absent. At the PEC, there were a myriad of flood preparations. Electronic equipment such as the dryer was placed on higher ground; a flood barrier was installed to protect the operating theatre; drainage was altered to direct water into existing drains and away from buildings. The PEC also had a simple plan to evacuate residents to the school building when heavy flooding occurred. This demonstrates a higher level of preparedness as well as their ability to implement simple coping mechanisms for flooding.
4. Extent of Flooding. This theme illustrates how flooding affected the two sectors. In the case of the commercial sector, the DOMA president mentioned water collecting on the main streets in the Central Business District; shoppers being stranded on streets; losses in work hours but an overall low monetary loss with few claims made by businesses. The PEC was better able to give more details about the extent of flooding over the years. For example, in 2003 they had to replace the x-ray machine which cost approximately $500,000 after that flood event. The Matron highlighted damage to kitchen equipment, loss of children's books, shoes and clothing, operating theatre equipment as well as the closure of the facility for lengthy periods as the main damages which they sustained.
5. Causes of Vulnerability. Three main issues were apparent from the interviews; infrastructure, planning and environmental degradation. The most popular contributors to increased vulnerability were issues concerning infrastructure and environmental degradation. Both interviewees pointed out the state of drainage and the lack of changes to this, as being responsible for the flooding in Port of Spain. For example, the Matron at the PEC illustrated that when storm drains were constructed, the Centre they did not experience any flooding for a couple of years. She also pointed out that the drainage within the compound was now not adequate to hold the surface runoff received. The DOMA president highlighted that the drainage system inherited by the British some 40 years ago had not been added to while city had grown both in population and physical development, thus increasing vulnerability to flooding.

6. Solutions to Flooding. Both interviewees made some suggestions to alleviate flooding in Port of Spain. The president of DOMA in his interview suggested the ramping of bridges as the low hanging bridges prevented material from being removed from the river and led to flooding. The PEC made suggestions to their situation which included the ramping of entrances to reduce flooding of the lower buildings.

The analysis of the interviews yielded results which supported much of what was said in the questionnaires as well as the photographs i.e. the commercial and special population sector is very much vulnerable to flooding. Similar issues of vulnerability were illustrated such as drainage, physical planning and environmental degradation; with each sector developing or utilising the most available coping mechanisms at hand to reduce their vulnerability.

## Conclusion

### Introduction

The data presentation and findings suggest a wide range of conclusions which answer the various research questions. The data presented demonstrated beyond a doubt that Port of Spain has been affected by flooding for a long period of time. Taking into consideration the equation which highlighted risk as being a function of the interaction between vulnerability and the hazard, it may be suggested that Port of Spain faces a high risk of flooding. Firstly, the hazard i.e. flooding is a frequent almost perennial occurrence, characterised by flash flooding as well as larger riverine floods. The most common type of flooding is flash flooding which happens very quickly as highlighted in the interviews and dissipates quickly as well.

The vulnerability of the various sectors has been highlighted in the data presentation. The data analysis shows that both the commercial sector and the physically challenged face varying levels of vulnerability to flooding. For example, it may be deduced that the Princess Elizabeth Centre faces a high level of vulnerability based on the evidence which shows that they have been repeatedly affected by floods, the high value of property losses and the often forced closure of the Centre. This therefore reduces its ability to carry out its main functions. In the case of the commercial sector, the value of property loss and losses in stock and sales indicates the level of vulnerability of this sector.

This leads one to ask the question of what are those factors which influence or make these two sectors sustain such losses and therefore more vulnerable than other sectors or persons within Port of Spain. The following are the factors which make the commercial sector and physically challenged more vulnerable to flooding:-

1. Structural Vulnerability
    a. Issues with the existing drainage system
    b. Engineering works and maintenance
    c. Lack of proper garbage collection and disposal

2. Non Structural Vulnerability
    a. Poor or Ineffective Physical Development Plans
    b. Poor implementation of land use policy and legislation
    c. Lack of public awareness and education about disaster preparedness

### Structural Vulnerability

The data analysis showed some recurring themes found across all the data sets. One of the most frequent recurring causes of flooding was issues with the drainage in the area. Within the questionnaires, the photos and the interviews, persons identified issues with drainage as the most significant problem facing persons in the city and which favoured flooding. Vulnerable elements of a structural nature were identified. These elements consist of certain physical factors that can be fixed through actions such as engineering and construction. The main issue identified was an old or antiquated drainage structure which

has not grown at the same pace as development within the city. The drainage infrastructure was constructed in the early 1940s and since then very little has been done especially with respect to the underground drainage that exists. Above ground, new buildings have been constructed and now more than ever the extent of paved areas has increased. As such, surface runoff has increased to the point where the present drainage system cannot adequately remove the water fast enough to prevent flooding from occurring. This has therefore increased the vulnerability of the city especially those in the commercial sector to flooding.

Another issue which was highlighted was the lack of effective engineering works and maintenance. For example, within the interview with the DOMA president, he highlighted how ineffective the existing infrastructure itself was encouraging flooding to occur. One such engineering issue was the low, flat bridges which crossed the East Dry River as well as the Maraval River. This type of bridge caused two problems allowing for increased vulnerability of the city. Firstly the low flat bridges made it easier for water to flow onto and over the bridge during heavy rainfall and flooding. Thus, cars were unable to use the bridge adequately during times of heavy flooding. Secondly, the low bridges helped trap material flowing within the river. Trees, bamboo and other large material became trapped when it reached the bridges and formed dams blocking the flow of water within the river from emptying into the sea. Another example was the observation of overgrown drains. These drains are therefore unable to hold the influx of surface runoff experienced when there is rainfall. Therefore improved engineering works and maintenance are needed in order to reduce flood vulnerability.

Throughout the city centre, many garbage bins could be seen. Some were overflowing, while others had been overturned by nearby homeless persons. Results of the questionnaires showed that business owners believed that a proper garbage disposal regime was necessary. The interviews also revealed the view that the city was inundated by garbage. Photographs showed storm drains filled with plastic bottles and other garbage. Garbage which collects in the drainage system reduces the amount of water which can be removed from the city and thus contributes to flooding. Vulnerability is therefore increased due to an inadequate and compromised drainage system.

### Non Structural Vulnerability

Non-structural vulnerability is attributed to those factors which cannot be remedied through physical changes but are more than often as a result of absent or poor policy and legislation as well as behavioural choices.

The flooding which occurs in Port of Spain is not only as a result of factors found within the city but outside as well. The city is flanked by the Northern Range as previously mentioned. In recent years there has been advancement up the steep slopes for the construction of houses, quarrying and agriculture. These activities have stripped the slopes of almost all the vegetation cover. Therefore when rain falls, the top soil is easily removed making its way into the rivers and drains reducing the capacity of the drains, resulting in overland flow onto streets. This view is supported by what was said in the interviews. Both interviewees identified or mentioned the destruction of the hillsides affecting the type of floods which occurred in Port of Spain. This was supported in their discussion about cleaning up silt and mud deposited by the flood waters. Therefore, the issue here is one of a lack of policies which seeks to regulate and protect the Northern Range from destruction as well as control and regulate development on the hillside. This is supported by the Environmental Management Authority's State of the Environment Report (2004) on the Northern Range. This report suggests that a new strategy and updated policy is necessary to address the rampant and unregulated hillside development which is occurring. There is a need for adjustments to the policies that exist which change the way in which they are executed so as to improve monitoring and implement regulations.

Garbage disposal is not just an issue of collection and removal to landfills etc. but it also includes appealing to persons to change behavioural attitudes towards the way they dispose of their garbage. Garbage disposal begins with citizens conscientiously making the effort to properly dispose of their refuse

in the right manner. The photos and questionnaire results illustrate the issue of the city of Port of Spain being inundated with more garbage than it can get rid of especially plastic bottles. This lack of willingness to dispose of garbage appropriately may be due to the improper enforcement of the relevant legislation such as the anti-dumping and littering laws. This indirectly adds to the level of vulnerability of the city to flooding.

Disaster preparedness through proper public awareness can assist in reducing the vulnerability of a society. A society which is prepared is less likely to be affected by that hazard. This is due to a better understanding of the hazard and the existing vulnerabilities which must be reduced where possible. From the results of the data, the information which is most apparent is the lack of preparedness by some persons. For example, very few persons listened to the weather report as a source of information to prepare for possible flooding in the city. There is also an apparent apathy towards flooding in the city. This is illustrated by the interesting fact that many of businesses have remained at their location for ten years or more in spite of enduring many flood events and the ensuing effects of these events. It suggests that flooding is not taken into consideration when choosing a location or that in spite of the knowledge of possible flooding, businesses are willing to take that risk rather than locate somewhere outside the flood zone. Therefore a better understanding of disaster preparedness measures can help reduce the vulnerability of the sectors at risk.

Overall it can be surmised that flooding is a real and apparent threat to the various sectors in the Port of Spain area. Within recent times it has caused great damage for some sectors especially the commercial sector as well as special service centres such as the Princess Elizabeth Centre. These two sectors are at greater risk because of various factors such as their location as well as the nature of their operations. As such there is a great need for the relevant mitigation strategies both in the short and long term. These strategies can address the causes of flooding and thereby reduce the effects of flooding on both sectors. This in turn can result in a reduction of their vulnerability and by extension the city of Port of Spain.

## Recommendations to Reduce the Vulnerability to Flooding

### Introduction

Over the last few years Port of Spain has endured repeated flood events. These events have become increasingly disastrous causing more damage with each successive event. These memorable events have been interspersed between frequent flash flood events. Flooding is therefore a hazard of potentially great magnitude and frequency in the city. Additionally, there are many factors which have increased the vulnerability of the city's citizens exposing them to the effects of flooding. The data presentation and findings pointed towards specific factors which heightened the vulnerability of the commercial sector as well as special populations. The alleviation of these conditions through the appropriate mitigation measures may allow for a reduction in vulnerability and as a result the risk of flooding which Port of Spain faces.

The literature has shown that many mitigation strategies exist which can alleviate flooding. These measures must be carefully considered and examined to ensure that the most appropriate measures are chosen to reduce the risk of flooding. The measures which are chosen should consist of not only physical measures but also include non-structural mitigation measures such as policy and legislation. The measures which can assist in reducing flood vulnerability cannot all be accomplished immediately and should be done in well planned out phases. Some measures are better accomplished in the short term while others in the long term. Given the discussion in the previous chapter the following are some of the mitigation measures deemed to be most appropriate for the reduction

### Recommendations for Structural Measures

Short term recommendations usually consist of structural measures which can be easily executed once budgetary allocations and the technical and engineering knowledge are available (See Figure 6.1)

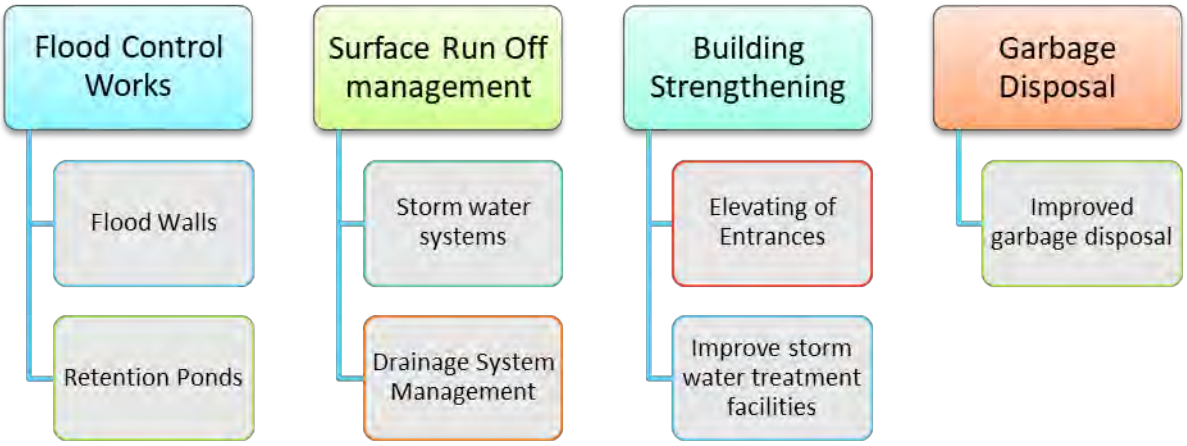



**Figure 6.1** Structural Measures to Alleviate Flooding in Port of Spain

1. Flood Control Works. Flooding is unavoidable in Port of Spain due to its location and topography. As such, it is imperative that solutions which can control flooding to avoid the productive sectors such as the commercial sector are important.
    a. Flood Walls are simple inexpensive structures that consist of reinforced concrete that act as barriers against flood waters. These are built parallel to the river channel. This measure may be effective as there is not much available land along the floodplain of both the Maraval and St. Ann's Rivers. This is due to extensive land development near the flood plain.
    b. Retention Ponds. These structures may be beneficial to alleviating flooding through the controlling of the amount of surface runoff which makes its way to the river channels. By doing this, water is released in such a way to prevent the overflowing of rivers and storm drains. These basins hold or retain water which provide a host of options for use, such as for irrigation and watering of lawns. This can be useful in Port of Spain as not only does it reduce flooding but the water can be used by farmers located outside the city or by homes in Woodbrook for lawns etc.
2. Surface Runoff Management has been highlighted as one to best perceived solutions to the flooding problem by almost all the respondents from both sectors.
    a. Storm water management consists of maintenance of urban storm systems as well as land based treatments. These land based treatments include maintenance and cultivating of shrubbery, grasses and trees as well as slope stabilization techniques. These measures will be especially helpful in the Northern Range where slopes are being denuded and large amounts of silt find their way into river courses contributing significantly to flooding. Therefore a programme which seeks to protect the vegetation of the Northern Range is important. This may involve the defining of buffers consisting of major tracts of forest cover along the river banks within the Northern Range. For example, a buffer zone of 1km on either side of the St. Ann's river may be maintained with no development being allowed to take place. This can assist in reducing the rate and the quantity of inflow into the river system.
    b. Drainage system management. This includes the maintenance and improvement of drainage infrastructure. Channels for the removal of water should be cleaned of over growth and garbage on a regular basis; aging drainage should be rebuilt to meet new carrying capacities of surface runoff and all peripherals such as culverts, storm grates, sewer pipes and back up valves should be maintained and

checked on a regular basis to reduce flooding. This measure is imperative to reducing the effects of flooding especially near the Princess Elizabeth Centre where storm drains seem to have worked in previous years until recently.

3. Building Strengthening techniques provide structural measures aimed at strengthening or flood proofing of structures so as to avoid the effects of floods.
    a. Elevation of entrances. In Port of Spain many of the commercial buildings and even the Princess Elizabeth Centre have been built on or very near the flood plain of the St. Ann's and Maraval Rivers. As such the elevation of these existing buildings provides a simple solution which is more cost effective than relocation and is easily accomplished as it does not disrupt neighbours. It is achieved by physically building up of the lowest floors of the buildings above the average or high flood level mark. By doing this, businesses can still maintain their floor space but protect their property. This may be ideal for those commercial businesses which have low entrances such as Courts Ltd and have much to lose during flood events. However, due to the target audience of the Princess Elizabeth Centre the entrances will have to be raised via ramps which would allow for wheelchair access.
    b. Improving storm water treatment facilities can assist in reducing flooding in the city. This measure consists of the maintenance of existing facilities such as pump houses and storm water treatment facilities. In the case of Port of Spain, there is one pumping station which is used to remove water from the city during flooding. However, this water is removed into the East Dry River. This in itself poses a problem. It is believed that consideration of including the use of a second pump as well as the removal of the water in holding basins such as retention ponds be done. This will increase efficiency in flood water removal as well as provide alternatives for the use of this water.
4. Garbage Disposal. This was another significant issue highlighted by the respondents of the questionnaire as well as interviewees.
    a. A regular and well maintained garbage disposal system is necessary in the city. Bins should be visible on every street as well as skips be used for the removal of large amounts of garbage from businesses rather than placing them on the pavements or along drains. The removal of plastic bottles is a major problem and a long term solution to this may include development of a plastic bottle recycling programme which can also act as a means of livelihood for the less skilled in the city.

### Non-Structural Measures to Alleviate Flooding in Port of Spain

Policy, information dissemination, training and awareness campaigns are examples of non-structural measures that can be utilised to alleviate the effects of flooding. These strategies seek to address the behaviours and attitudes of the citizens and as such may be considered long term measures. In many instances they are on-going and go beyond the extent of a government's term in office. Therefore budgetary allocations must be made to cover the extent of such measures. In Udika (2010) the Water Resources Agency (WRA) states that in order to alleviate flooding substantial capital investments which may not be available in the short term is necessary. Hamza and Zetter (1998) indicated that with the changing role of cities (such as Port of Spain which aims to change its economic status as being the financial 'mecca' for the Caribbean) they will have to facilitate access to capital as well as new technologies in order to carry on their expanding roles. This role includes disaster risk reduction through sustainable environmental management. Such roles can only be executed through the appropriate policy implementation. The following illustrate some of the non-structural measures to reduce flood vulnerability (See Figure 6.2)

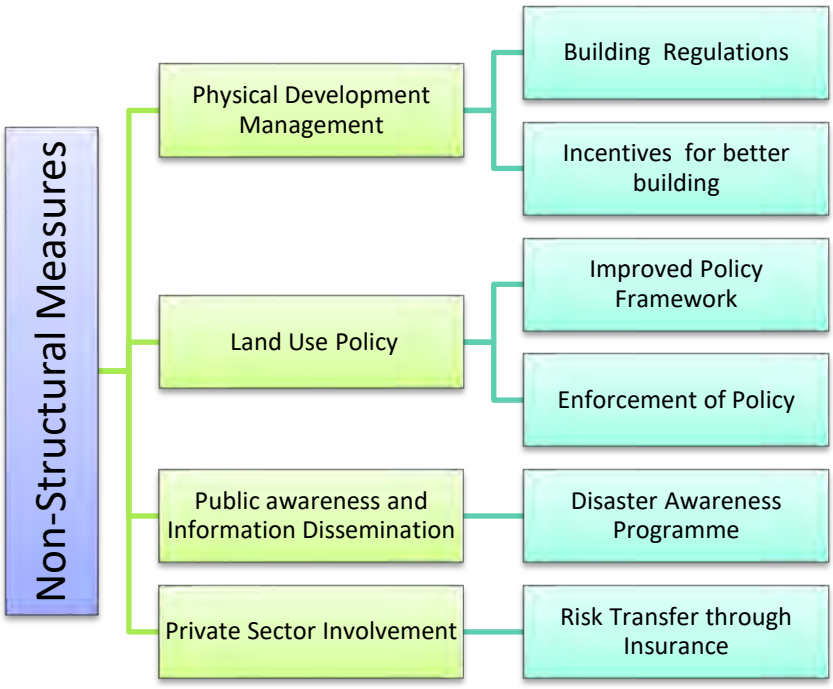



**Figure 6.2** Non Structural Measures to Alleviate Flooding Vulnerability in Port of Spain

1. Physical Development Management involves the use of various strategies to manage and control physical development within a spatial area. In Port of Spain, this is sorely lacking. This is due to the inadequate and lack of enforcement of existing legislation. As a result, development has occurred unregulated to a point where relocation is almost impossible.
    a. Building Regulations. In Port of Spain proper land use zonation which identifies areas which are best suited for specific types of land use can assist in reducing the vulnerability of flooding. This includes identifying the various hazard risk zones so that potential land owners and builders can be aware of the proper building stipulations which must be adhered to. For example, businesses such as those interviewed that are located near the East Dry River/ South Quay must be constructed so that their ground floors are raised above the mean flood water mark so as to minimise property loss during floods. Additionally, the requirement of drainage in and around buildings which can adequately accommodate the surface runoff produced by that building's footprint should be compulsory and validated by the authorities such as the Town and Country Planning Division. Therefore criteria for building for different land use types within the city must be determined and made mandatory.
    b. Building Incentives. A variety of incentives to encourage better building practices especially by the commercial sector can help to reduce the vulnerability of this sector to flooding. One such incentive may be through special building tax concessions relevant to the cost of undertaking mitigative work to reduce flooding of their property for business and/or building owners. This would be effective for the larger businesses. For small businesses such as the ones on South Quay who may not have the collateral to make building renovations, small or micro- financed loans through credit unions at lower interest rates may be a viable option.

2. Effective land use policy is the basis for proper planning. The legislation of Trinidad and Tobago provides the instruments via which proper and guided land use development is allowed to occur. Legislation such as the Town and Country Planning Act (1969), the State Lands Act (1980), the

Forestry Act (1980) and the Draft National Hillside Policy of 1976 all provide for the regulation and control of land use development especially on the Northern Range. However, as demonstrated by the existing land use and incidents of flooding these policies have been ineffective in carrying out their mandates. Therefore measures are necessary to improve these laws.

a. An improved policy framework is imperative in order for the effective working of the existing laws. At present there are many laws but the instruments are vested in various government ministries. Additionally, many of the laws do not reflect the reality with respect to land use in the country. Cropper (2008) recommends public policy that reflects understanding of sources of exposure and vulnerability which addresses the causal factors and the consequences of these actions and how they can be minimized. Therefore an improved policy framework which accurately reflects and addresses the existing land use issues is necessary.

   Another issue facing the land use policy framework is the segmented way in which the law is being addressed. Many of the instruments of the existing legislation lie within the ambit of many ministries and as a result there is an overlap in the execution of the law as well as confusion in the roles and functions of government agencies. Udika (2010) describes it best in that this translates into a widely segmented approach to planning which is bounded in the various sectors i.e. each sector is trying to accomplish certain aspects of the law various. Therefore the legislation must be clear and succinct in its aims. This may be best accomplished by one overarching physical development policy with the instruments existing within one single ministry.

b. Policy enforcement is sorely lacking in Trinidad and Tobago and by extension the capital city. Currently, there are limited resources to adequately ensure that land use development follows existing legislation. There are complaints of bureaucratic 'red tape' which slows down the process of development approval and as such developers and land owners continue to build with limited or no approval. Therefore more dedicated resources to efficiently review development and ensure the adherence to regulations can reduce flood vulnerability related to environmental degradation.

3. Public awareness is important in order to achieve a reduction in vulnerability. Citizens should be educated about those issues which increase their vulnerability to hazards as well as their role in reducing such. Within the assessment it was found that persons' awareness was limited. For example, many persons did not understand the value of the weather forecast as a means of early warning to safe guard their property. Currently, the Office of Disaster Preparedness and Management (ODPM), is engaged in various public awareness campaigns which target specific communities but not specific sectors such as the business community nor does the DOMA have any specific flood preparedness plans for its members. A public awareness programme which works with the commercial sector within Port of Spain is necessary. This programme should include educating the business community of their flood vulnerability, methods for reducing this vulnerability through various initiatives as aforementioned as well as a flood preparedness plan inclusive of business continuity planning.

   In the instance of the physically challenged special population, it is imperative that this sector be included in public awareness programmes. From the analysis, the Princess Elizabeth Centre is quite aware of its vulnerabilities and has developed its own coping mechanisms to safe guard against property and loss of life with some success. Their experiences can be shared with other similar organisations in order to encourage a better understanding of how to reduce their vulnerability. Therefore the PEC should be included in disaster management programmes and activities such as a flood preparedness plan for Port of Spain.

4. Private sector involvement is essential especially when talking about the commercial sector. The analysis shows that many businesses of varying type and firm size are affected by flooding and incur much monetary losses due to flooding in Port of Spain. One way of alleviating the vulnerability is to pass on the cost of the flooding or the risk associated with flooding to external parties through insurance. The transfer of risk is currently being encouraged for both small and large firms whereby firms are insuring their assets against the risk of hazards such as flooding based on yearly premiums. The interview with DOMA president and the results of the questionnaires showed that many of the businesses were insured but were unaware of their coverage. The PEC had limited coverage for some of the equipment owned but the coverage was insufficient to meet the costs of their losses. It is therefore recommended that stronger links be made within the private sector to play its role in educating as well as developing policies to meet the needs of the commercial and special populations sector. The Association of Trinidad and Tobago Insurance Companies (ATTIC) should work closely with DOMA to ensure that members are adequately educated on the various policies available to them and ensure that the coverage which they have is relevant to their asset holdings.

   In the case of small sized firms, who may be unable to access insurance for various reasons, the strategy of risk pools may be considered. Risk pooling is a means of transferring risk whereby the involved parties contribute to a central pooling system and those affected receive a disbursement related to the contributions made. These initiatives can only be successful where there is a closer relationship amongst agencies within the private sector working together to manage flood risk.

## Summary

The vulnerability assessment provides an alternative view of the problem in a manner which allows for the interrogation of the various issues contributing to the vulnerability of the spatial area and the population that lives there. This study has highlighted some of the issues associated with the location of the commercial sector and the PEC such as their location on the flood plain of the two main rivers surrounding them. It also highlighted some of the inadequacies of the existing infrastructure such as the drainage system. The underpinning issues of land use policy and enforcement have also been illustrated throughout the study.

These issues come together to create an environment which has exposed Port of Spain and its citizens to flooding and its ensuing effects. Therefore in order to reduce this exposure and thereby reduce vulnerability these issues must be addressed through well-defined and relevant disaster mitigation strategies. These strategies must be formed in a holistic manner working synergistically; addressing the physical and anthropogenic causes of flooding and involving all relevant sectors of the population which depend on the services and functions provided by the city of Port of Spain. This is the best means by which vulnerability can be reduced.

As part of its economic development strategy, the government of Trinidad and Tobago envisions Port of Spain as the future financial ‘mecca’ of the Caribbean, making it the premier place to conduct business. If this is to become a reality, the vulnerability to flooding and by extension other physical and anthropogenic hazards must be reduced. This will ensure that Port of Spain is a more resilient city which is prepared for any eventuality and has the propensity to withstand future flood events. If the appropriate recommendations are not employed, annual flood events can derail the development goals of the government. Thus not only will there be hesitation to conduct business and use the services found within in Port of Spain but the image of the city will be negatively affected.

# Analysis of the Financial Services Sector Responses to Climate Change Risks in Antigua

*By Delamine Andrew*

This paper was prepared as part of the Dissertation Module to the University of Exeter towards the degree of Master of Science by advanced study in Sustainable Development: Climate Change and Risk Management -- 2015

## Introduction

The IPCC (2014) states that climate change will result in an increase in frequency and intensity of extreme weather events. Small Island developing states (SIDS) in the Caribbean are amongst the most vulnerable to the impacts of climate change (Lal et al., 2002; Taylor et al., 2012) but most specifically extreme weather events. Caribbean SIDS are exposed annually to climate hazards such as hurricanes, tropical storms, droughts, flooding, and landslides amongst others (CDERA, 2000; Ferdinand et al., 2012; Chmutina, K and Bosher, 2014). The increase in frequency and intensity of such weather events will in turn have negative impacts and disrupt economic processes and development in countries as well as organization, including the financial services sector. Globally, the financial services sector has seen rising additional costs as a result of extreme climate events. Unfortunately, there exists a dearth of research on the impacts of climate change on financial institutions outside the realms of insurance and as a result, the response measures undertaken and implications thereof by this sector remains unknown.

The financial services sector plays a critical role in financing and investing developments (Lutzkendorf et al., 2011) that affect long-term economic growth (DFID, 2004). It therefore has a significant role in how society responds to climate change because the physical impacts thereof will affect assets and investments (Sullivan, 2014).

While the physical effects of climate change are being felt across a variety of industries (Hoffmann et al., 2009; Winn et al, 2011), the financial services industry has seen rising additional costs brought on by extreme climate events (Cogan, 2005; UNEP FI 2006; Barthel and Neumayer, 2011). Globally, weather related losses, from reinsurance giants such as Munich, from 1980 – 2008, increased by an average of US$1.4 billion per year (Barthel and Neumayer, 2011) *see figure 1*.

The IPCC (2014) notes, with the exception of the insurance sector, there is limited research on the impacts of climate change on other financial institutions and organizations. From an organizational viewpoint, the financial data of reinsurance companies provides an overview of climate impacts through "damages from property losses and business interruption due to natural disasters" (Winn et al., 2011). This data, however, gives little indication of the response measures being undertaken to

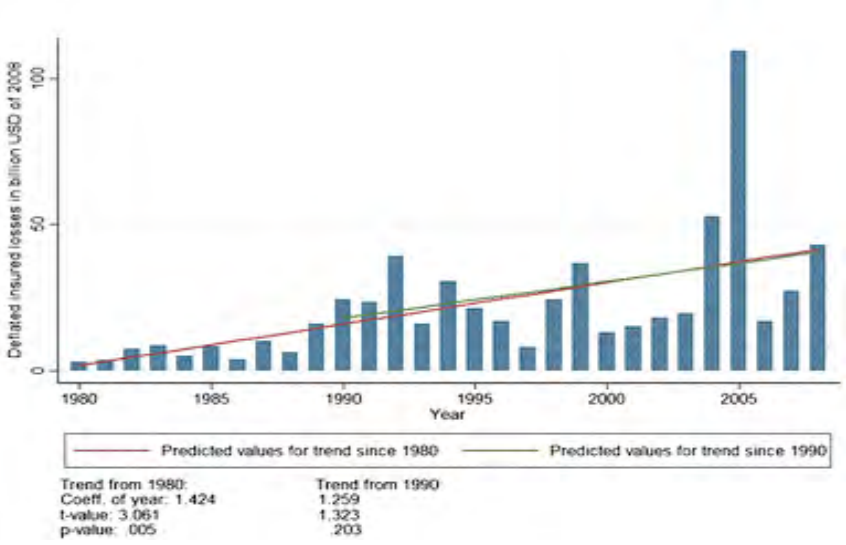



*Figure 1: Trends in weather related losses from 1980 to 2008*
Figure sourced from Barthel and Neumayer, 2011.

adapt to climate change risks within the financial services industry.

The Caribbean is experiencing more intense extreme weather events, such as droughts, floods, and hurricanes (IPCC 2007, Leslie, 2008; Farrell et al., 2010). Moreover, the Eastern Caribbean, as a group of SIDS, has been ranked among the top ten disaster prone countries in the world (IMF, 2014) and are extremely vulnerable to climate change impacts and associated sea level rise (Joyette, 2014). This vulnerability is increased by the fact that the main settlements and economic infrastructure are most often concentrated in low-lying coastal areas (USCEC, 2006; Goldenberg, 2007; IPCC, 2007), and by the region's inability to fully absorb the financial impacts of disasters (Joyette, 2014). Iyahen (2010) notes that natural disasters have equated to an average of two percent of the region's annual GDP since 1970. The cumulative economic loss incurred by SIDS in the Caribbean as a result of storms during 1979 -2005 are estimated at US$613 million annually (Ghesquiere et al., 2007; Mitchell, 2007).

Extreme weather events increases economic losses and despite the uncertainties regarding the impacts of climate change and its influence ratio on past and occurring events, the region's exposure to natural hazards and climate change impacts could "undermine the economic, environmental and social resilience" of the islands (Joyette, 2014). Adapting to the impacts of climate change is now critical given the growing number of regional projects and initiatives currently undertaken (CYEN, 2011). However, corporate action in response to the physical impacts of climate change in developing countries, especially SIDS, is limited (Pulver and Benney, 2013).

Antigua and Barbuda, a small twin island state, recently participated in one such regional initiative and will now become the focus of this research. The Mainstreaming Adaptation to Climate Change Project (MACC), ran from 2004 -2008 with the aim of building the capacity of SIDs to develop adaptation strategies and measures to respond to climate change impacts (CARICOM, n.d.). Although the project enlisted participation across all sectors, little is known on the national financial sector responses to climate change.

Given the lack of data on the responses of the financial services sector to climate change risks in the Caribbean, this research examined the responses of the financial services sector to climate change risks using a case study of Antigua and Barbuda. The research first explores existing theories that may influence the response measures of the financial services sector through a literature review. Due to the dearth of information on the topic of response measures and to a further extent, the Antigua's financial service sector responses to climate change, the research took an exploratory approach through qualitative data collection and analysis. Non-probability sampling was employed to ascertain cultural data pertaining to climate change risks perceptions and awareness of climate change impacts from expert informants. The concluding analysis of this research is provided with recommendations for private sector engagement and partnership as well as areas for further research.

### Aim & Objectives

- To analyze the responses of the financial services sector to climate change risks

## Research Objectives

- To identify the perception and awareness of climate change risks
- To determine the responses of the Antiguan financial services sector to climate change risks
- To identify the factors that encourage or hinder responses to climate change risks

## Methodology

### Literature Review

A review of existing literature was conducted to first define responses to climate change risks and examine the major theories on institutional perceptions and responses to climate change risks within organizations and to a further extent the financial services sector.

Responding to climate change risks incorporates adaptation and it presents a significant challenge to decision making (Tompkins and Adger, 2005). Adaptive responses refer to the actions undertaken to address the consequences of climate change, both before and after the impacts are felt (Tompkins and Adger, 2005). The adaptive capacity would now refer to the ability or potential of an organization to adapt to change and requires various resources including finance, information, skills, and technology, amongst other things (UNEP FI, 2006). Given the long time frames, slow onset and scientific uncertainty about climate change impacts on all facets of society, adaptation to climate change impacts surpasses present capabilities of decision makers. Policy responses therefore depend on individual attitudes towards risks (Schneider, 2002).

Perceptions of climate change risk vary globally and individually (Tompkins and Adger, 2005; Van Der Linden 2014). It is viewed more seriously in developing countries. Various studies highlight a multitude of factors ranging from, political ideology, world view, culture, and experience, amongst others (Lewis, 2001; Van Der Linden, 2014).

Weinhoffer and Busch (2013) note that the "extent to which companies actually start managing climate risks depend on management's risk beliefs and interpretations." This implies that understanding management's recognition of climate change risks is important in assessing their response measures to such risks. Winn et al. (2012) highlight that there is much research on climate change mitigation and "carbon management regimes for businesses" and organizations but there is sparse research on the impacts of climate change on businesses and organizations. The authors attribute this lack of research to the many uncertainties in the understanding of climate impacts that may affect response measures. These uncertainties relate to the type, severity, predictability, immediacy, and the location of anticipated impacts. Therefore, there is a need for a "better understanding of climate related organizational impacts and for firm capability to prevent, respond or adapt" to climate change impacts (Heal and Kristrom, 2002).

Despite the dearth of research on the impacts of climate change on institutions, various declarations and strategies have been developed in an attempt to respond to global climate change. Twenty financial institutions within the Climate Group, a non-profit international organization, collaborated to launch "The Climate Principles" in 2008 as a framework for the financial sector (Climate Group, 2008). The Climate Principles highlight the "stewardship role" of the financial sector in assisting clients' response to the risks, opportunities, and adaptation needs relating to climate change (Climate Group, 2008). Although the principles highlighted the need for further research to understand climate change risks to the financial sector, little was done in the 2011 progress review (Climate Group, 2011). Moreover, Furrer et al. (2012) draw attention to the inconsistencies between the Climate Principles and the financial sector, as only five of the twenty financial institutions publicly endorsed these principles and publicly disclosed commitments to action. However, little action has been taken since. Furthermore, research on the social and environmental disclosures of firms in the Caribbean has highlighted consistently low levels of responses to address environmental and social challenges (Bowrin, 2013). This demonstrates unresponsiveness to climate change and its related risks.

Climate change poses many risks to the financial sector, particularly insurance and banking. An analysis of the North American financial sector, EcoSecurities (2006) highlights that climate change poses many risks to bank loan portfolios. These risks were categorized into policy related risks, input and output pricing risks, and physical risks (EcoSecurities, 2006). Input and output pricing are of sole relevance to climate change mitigation via greenhouse gas emissions reduction by the institutions' operations and investments. Policy related risks incorporate both climate change mitigation and adaptation based on domestic and international regulations. Physical risks relate to the direct impact of extreme weather events associated with climate change. Moreover, UNEP FI (2006) draws attention to other physical risks via client behaviour, such as default on mortgage payments due to personal damages from extreme weather events. Physical risks of climate change may be further categorized according to the "classical

six-point risk analysis" that banks use to determine the credit worthiness for investment proposals (UNEP FI, 2006). Table 1 provides a brief overview of these categories.

Table 1: Areas of risks to the financial services sector

| **Risk Form** | |
|---|---|
| Market | If the price or cost of the basic material is volatile, that constitutes a market risk. The obvious concern here is that climate-related catastrophes will happen more frequently and cost more than anticipated, which would make all types of financial services connected with property riskier. |
| Operational | Extreme events will make operations (and productivity) more difficult for all businesses. |
| Reputational | A report by The Carbon Trust concluded that the banking sector was highly exposed to reputational risk on climate change, because of its size and the intangible product offering. During disasters, insurers and banks may ease their usual terms of business, which helps clients and improves their own image. |
| Counterparty | In banking, this might be client default during a drought. In insurance it could be moral hazard (inattention to risk), anti-selection (selective purchasing by high-risk clientele), or failure of a reinsurer. |
| Political/ Legal | The regulatory framework can increase costs for financial companies, or undermine markets. Lax control of development or construction results in a stock of property that is more vulnerable to damage. Conversely, regulations that promote hazard management will reduce risk and promote growth. Soft government loans after a disaster can reduce client defaults, but also make clients disinclined to buy insurance. |
| Business | Companies that ignore advances in knowledge underperform. Insurance underwriters have to use geographical information systems (GIS) for natural hazards. In investment, adding socially responsible factors, including climate change, into stock assessment and portfolio management gives a more reliable performance. |

(Source: UNEP FI, 2006, climate change risks to the financial sector)

The major impact of climate change risk to the insurance sector is the increase in insured property losses from extreme weather events, which may affect their financial viability, longterm investment and property management (Linnenluecke and Griffiths, 2015). Response to climate change by the insurance sector ranges from disbelief, disinterest, acknowledgement to active action (Dlugolecki, 2000).

## The Framework for Assessment

Furrer et al (2012) in assessing the effectiveness of climate strategies utilized a framework with three distinct levels, namely, operations, business, and governance.

| **Assessment Levels** | **Definition** |
|---|---|
| Operations | This relates to the physical undertakings in response to climate change, which often focuses on GHG emissions. |
| Business | This relates to the organization's offering of specialized climate investment products and services and by financing organizations that mitigate or adapt to climate change |
| Governance | Relates to the organization's integrated structures and policy |

| Assessment Levels | Definition |
|---|---|
| | procedures to implement change at the business and operations level (Weaver *et al*., quoted in Furrer *et al.,* 2012). |

Although this framework places emphasis on climate change mitigation, it also presents a foundation to assess responses to climate change risks in the case study of Antigua and Barbuda. For the purposes of this research, an analysis of the operations level focuses on the risk assessment strategies used in financing or insuring properties on the island. It also includes adaptive strategies undertaken to mitigate against perceived climate change related risks.

***Surveys & Interviews***

A preliminary survey was first developed and distributed electronically via survey monkey, and via post to management executives of all financial institutions on the island. The survey had two objectives: first to maximize interviews by obtaining information relating to the size of the institution, knowledge, and perceptions of climate change risks and institutional role in addressing perceived risks prior to the interview. The second objective was to sensitize and guide discussions with interviewees. Close-ended questions were used in addition to Likehart scales to determine the extent of knowledge, attitude and practices within the sector. Telephone follow-ups were conducted to schedule interviews based on the willingness of management to participate further.

***Limitations of the Research***

- The time frame given to complete the research was limited to three months during the summer. This impacted the timeline for all activities including following up with institutions for a more holistic view of responses across the sector.
- Data collection was influenced by the allotted time made available to conduct this research and based on the time constraints and research focus, interviews could not be held with contracted engineers to review sample reports submitted to banks and insurers.
- Interviews with some institutions were significantly brief given the level of interest and perspective that the research was irrelevant to their institution as well as time available by respondents.
- The research was undertaken during industrial action regarding changes to the banking system by the ECCB, and the public lawsuit of one major insurer.
- Responses from credit unions were limited given the structure, in which three only had two clerical staff personnel with decisions being addressed through an annual general meeting (AGM).
- The use of surveymonkey as online resource was noted as offensive by two respondents, which may have accounted for the low responses online.
- Interview questions were sometimes too heavily worded.
- In adequate knowledge of the intricate operations of the financial services to adequately identify areas for in-depth discussions.

## Survey Findings: Awareness, Knowledge

A total of 18 institutions participated in this research. Participating institutions included seven banks (a representative sample of 88 percent of banks on the island); eight insurance firms (representing 62 percent of insurers on the island); and two credit unions (only 33 percent represented). The characteristics of respondents have been captured below in *Table 4*:

*Table 2: Characteristics of sampled financial institutions*

| | |
|---|---|
| Gender | 12 males<br>5 Females |
| Status of Institutions | 4 International<br>4 Regional<br>10 Domestic |
| Number of Employees | 13 (1- 50)<br>3 (51-100)<br>2 (100 and over) |

Overall, the majority of respondents felt they had an average knowledge of climate change issues namely, climate change mitigation, adaptation, and risks to Antigua and Barbuda. However, knowledge specific to climate change adaptation varied between a little and average, see *figures 3 -5*.

A look at knowledge based on institution type shows that a majority of banks (57%) rated themselves as having average knowledge across all three climate change related terms. However, average knowledge on climate change risks and impacts to Antigua and Barbuda was highest amongst insurance firms including the regulatory authority with a majority of 67 percent of respondents.

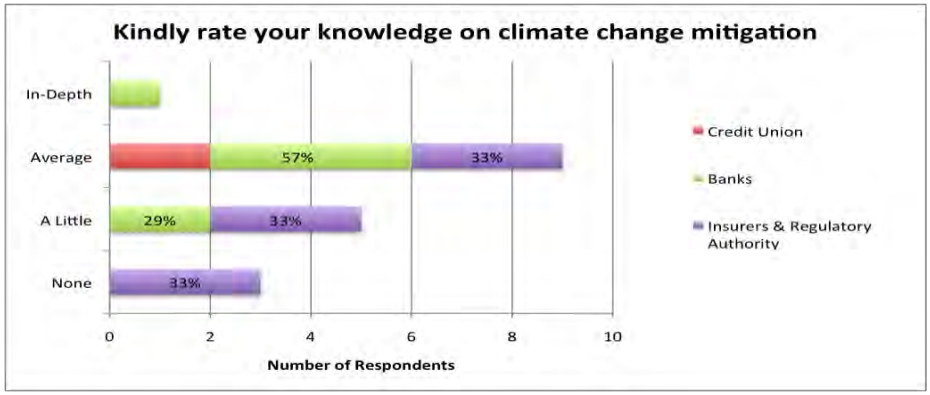



*Figure 2: Respondents' self-rated knowledge of climate change mitigation*

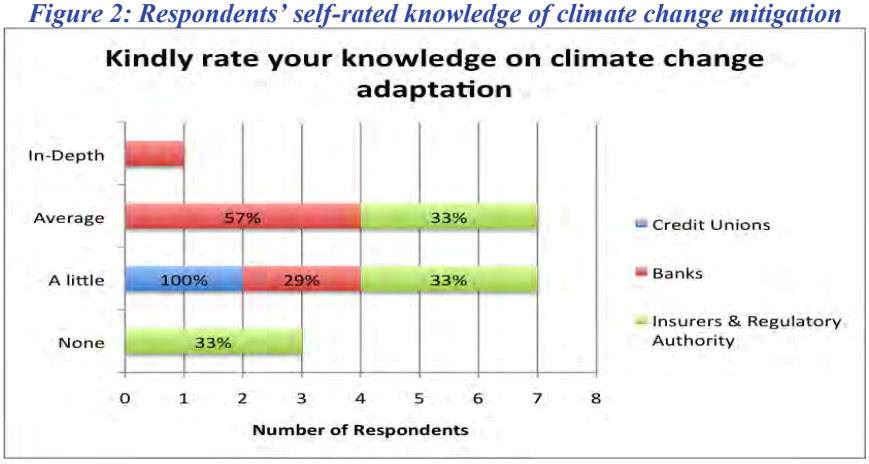



*Figure 3: Respondents' self rated knowledge of climate change mitigation*

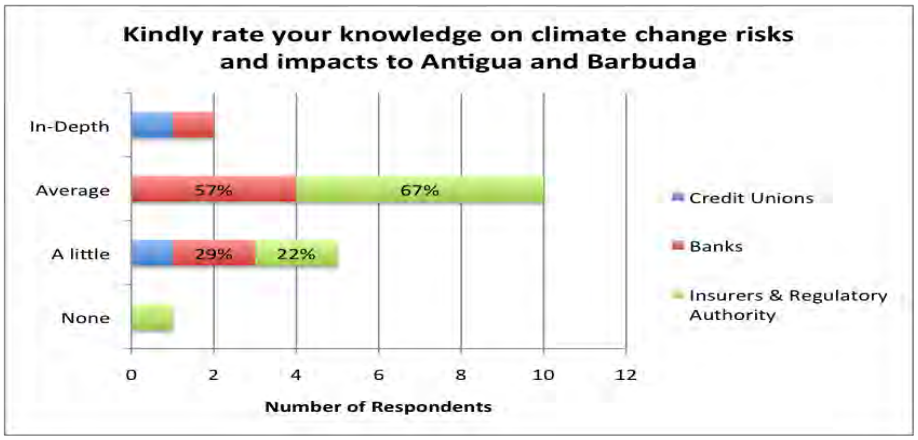
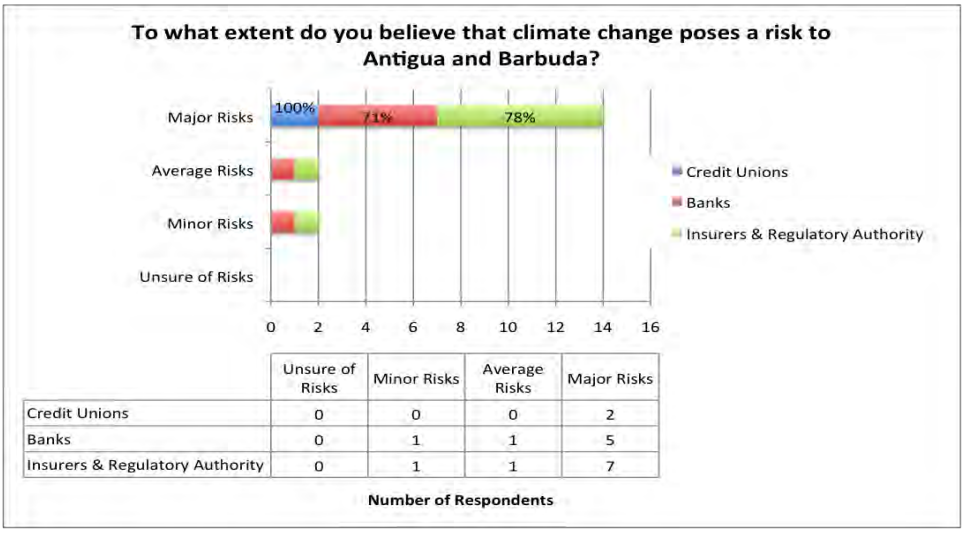


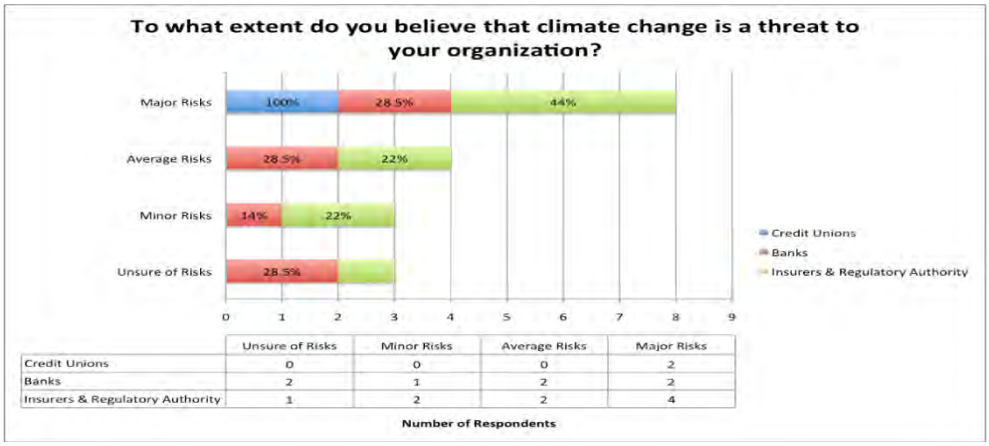

*Figure 4: Respondents' self-rated knowledge of climate change risks and impacts to Antigua and Barbuda*

The majority of respondents (78%) felt that climate change was a major risk to Antigua and Barbuda while only a majority of 44% felt that climate change was also a major risk to their organization. This perception was highest amongst insurance firms; *see figures 6 and 7*.




| | Unsure of Risks | Minor Risks | Average Risks | Major Risks |
|---|---|---|---|---|
| Credit Unions | 0 | 0 | 0 | 2 |
| Banks | 0 | 1 | 1 | 5 |
| Insurers & Regulatory Authority | 0 | 1 | 1 | 7 |

*Figure 5: Perception of climate change risks to Antigua and Barbuda*




| | Unsure of Risks | Minor Risks | Average Risks | Major Risks |
|---|---|---|---|---|
| Credit Unions | 0 | 0 | 0 | 2 |
| Banks | 2 | 1 | 2 | 2 |
| Insurers & Regulatory Authority | 1 | 2 | 2 | 4 |

*Figure 6: Perception of climate change risk to organization*

The majority of respondents (44%) agreed that climate change had become a priority concern for their organization. This view was most common among insurers; see figure 8.

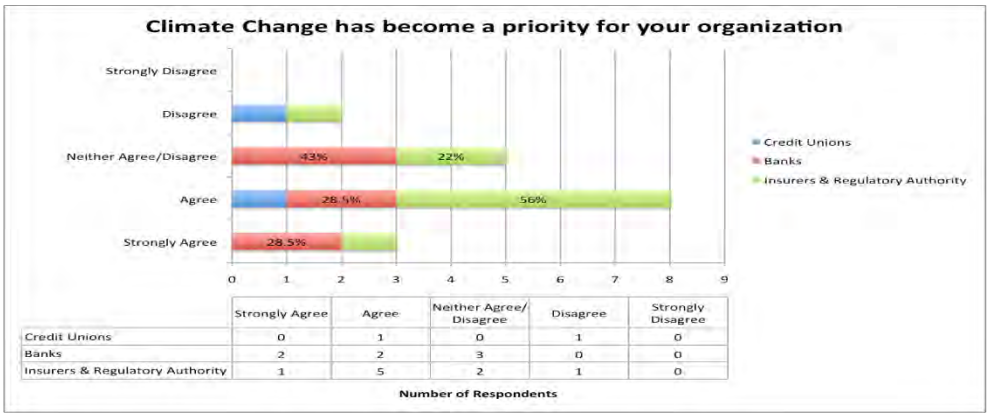



*Figure 7: Extent of organization's concern for climate change*

## Risk Assessment Consideration

While the majority of respondents (50%) agreed that environmental hazards and climate risks were strongly considered by their institutions, this view was highest among insurers (67%); *see figure 9*

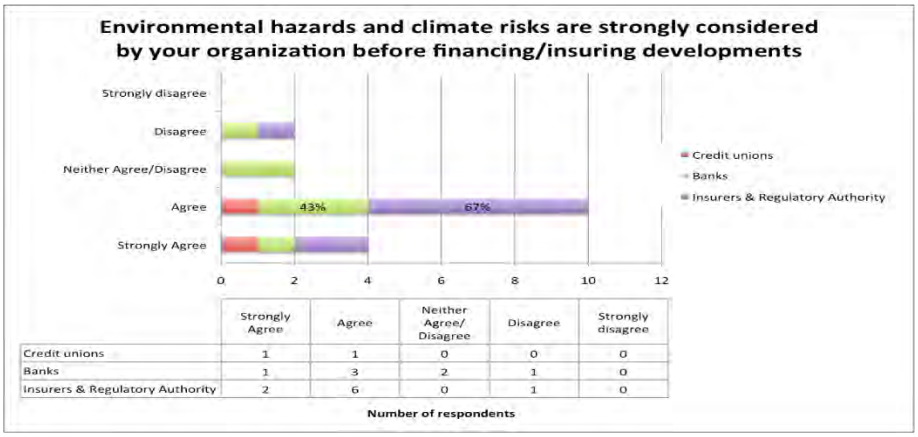



*Figure 8: Extent of environmental/climate hazard considerations in operations*

39 percent of respondents felt they had a major role to play in addressing climate change risks. This was also the same percent of respondents (39%) who felt they had a minor role to play in addressing climate change risks. On one hand, most insurers (44%) felt they had a major role to play. On the other hand, the majority of banks felt they had a minor role to play in addressing climate change risks.

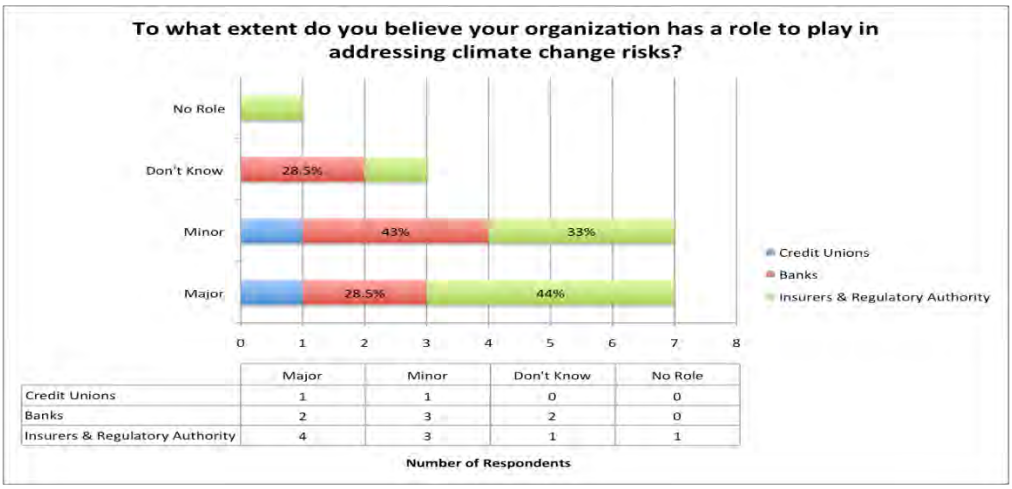



*Figure 9: Perception of role in addressing climate change risks*

Here concludes the major findings of the surveys:

- Knowledge of climate change mitigation, adaptation and risks to Antigua and Barbuda was considered average by the majority of respondents.
- Majority of respondents agreed that climate change has become a priority concern
- Environmental hazards and climate risks are strongly considered by the majority of financial institutions
- Respondents felt they had both a major and minor role to play in addressing climate change risks.

***Interview Findings: Content Analysis***

During the interviews when asked as to what were the major impacts of climate change to Antigua and Barbuda, all respondents highlighted hurricanes, both frequency and intensity, to climate change, *see figure 11.*

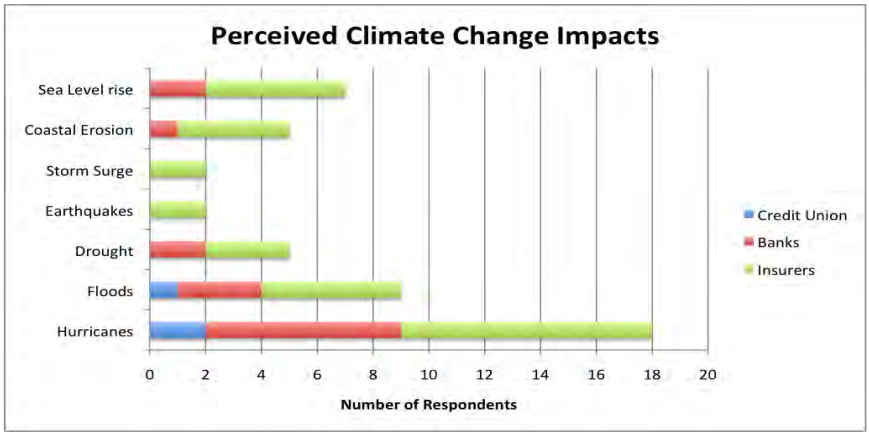



*Figure 10: Perceived impacts of climate change*

Respondents were also asked to comment on their opinion of climate change risks that could have an effect on their institutions. Interestingly, mainly insurance firms saw climate change as affecting their operations and financial solvency, *see figure 12.*

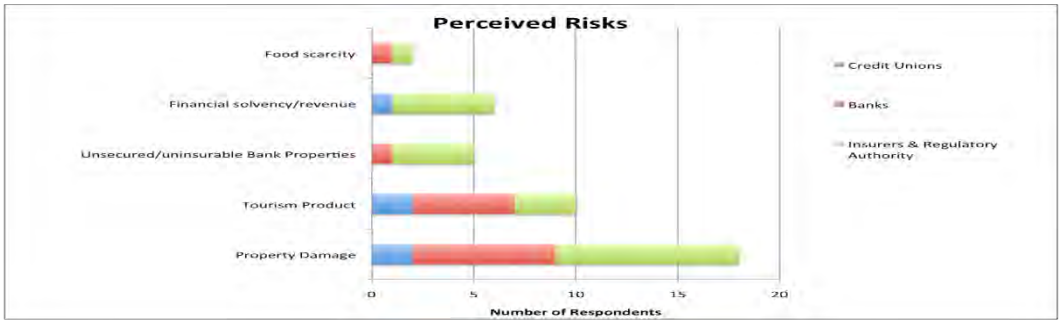



*Figure 11: Perceived risks to organizations*

Moreover, there were contradictions in the perceived risks to bank properties and their insurability. As a means of risk mitigation and security, banks require all financed properties to be insured but were unaware of insurers' ability to retract coverage as well as non-issuance of coverage. Here are a few comments relating to this coming from the interviews:

***a.*** *"Well an insurance would not retract a policy because claims are exceeded because that's why you have insurance. They would retract if you fail to pay your premium. I think there is a 3month grace period and if you fail to make the necessary arrangement with the insurance company then they are in their right to cancel their policy. But I've never heard of an insurance company canceling because of too many claims. There are systems in place that protects them for that, for example you have reinsurance, and the deductible." B3*

***b.*** *"I don't think we've had that issue here, the issue you mentioned is in developed countries. There's been no issue in terms of the relationship with insurance companies." B2*

***c.*** *"The financial sector puts things in place to mitigate against those risks, things like insurance. So therefore, the financial institutions and their clients won't bear that kind of costs anyway. And those loans that go delinquent maybe just a 5 or 10 percent of their portfolio while 90 is making you money." C2*

Further, when asked as to the sources of their information on climate change, respondents all cited non-governmental affiliations, including the media and personal internet searches, and reinsurance newsletter publications and professional subscriptions.

In establishing the role of financial institutions to address climate change risks, although the survey highlighted that the majority of respondents had a major role , many respondents were unaware as to how they could play such a role. Many respondents (11 respondents) felt they required more localized information on climate change risks. Additionally, the survey highlighted that majority of banks felt they had a minor role but during the interview majority of bank respondents (4 respondents) felt that it was outside of their financial mandate or scope of works. Comments on this topic included:

i. *"We believe that it is minor risks, primarily because of the business that we do."* B4
ii. *"well it's not a huge relevance to the financial services sector, I would say, mainly in terms of what we do."* B2
iii. *"Well I don't think we would mind having more information, cause relating climate change specifically to Antigua and Barbuda would be more relevant and I believe the technicians in the Environment (Department) would probably know more about what specific risks we face with respect to climate change effects in Antigua and Barbuda. So highlighting those more to the financial services sector institutions would be useful."* C1
iv. *"For the sector, I think education is one of the things we need to push. We need to know the triggers, we need to have an idea as to what the effects climate change has on not only the island because we're such a small country but there is a domino effect, if one industry is affected it trickles down to affect us all. Education is a key factor in helping us."* I4

***Operations: Risk Assessment Strategies***

Although many respondents agreed that environmental hazards and climate risks were strongly considered prior to financing or insuring developments, risk assessment strategies were very limited as majority of institutions (93%) employed visual assessments through a site visit and an engineers' structural report of the proposed development solely. There was only one institution that collected geographical positioning (GPS) data of properties prior to insurance for risk modeling by their reinsurer. Moreover, risk assessment strategies for retail and housing developments were very minimal from the perspectives of banks as they relied solely on a client obtaining planning approval via the Development Control Authority (DCA). See below for the respondents' comments:

*"No, it's a visual assessment. We get an engineer's report which usually doesn't tell you about environmental factors so we do a visual site visit... he will look at the house or property and see it standing by itself and say any winds blow this house will be damaged. He doesn't go deep enough to say that with the changes in the climate we are likely to have more intense hurricanes. Our risk managers don't do that…" I4*

*"Well there are no assessments except that if we're going to finance a mortgage, a home, then the requirement is that the developer or homeowner must acquire the relevant approval from town and country planning, DCA. We would expect that as part of the town and country planning, that the environmental impact would have been considered. So once they get that approval from the town and country planning then we move forward. So we don't do any due diligence as far as homes are concerned." B3*

*"A lot of our personal retail loans, and mortgages, etc. we wouldn't typically assess from an environmental standpoint. Now if there is a project which has an environmental consideration aspect we would assess it from not necessarily the specific risk but just to ensure that the borrowers or the principals have considered what impact it would have on the environment and potential lawsuits from a banking stand point. That is really the extent of it. It's just an internal assessment not even visual, just an internal assessment of the project. " B6*

## Business Products

Although strongly associated to hurricanes, all insurers provided a rating factor to clients. Properties deemed most exposed to climate risks are given higher premium rates and higher deductibles than those less exposed; (7 respondents – 100% of insurance firms sampled). Exposure relates to the property's locale in anecdotal or traditional knowledge of flood prone areas or in areas exposed to high winds. However, all banks and credit unions (8 respondents) offered hurricane or hurricane recovery loans in which the conditions for approval was relaxed. These institutions were also focused on exploring the development of green energy financing initiatives, which addresses climate change mitigation.

## Adaptive Strategies

Adaptive strategies within the sector fell within three categories: business operations, structural, and societal adaptation. Insurance firms mainly undertook strategies relating to business operations, while the other institutions focused on securing their physical premises against extreme weather events as well as societal adaptation. Only three banks highlighted their development phases of a business continuity plan to maintain service to customers during and post extreme climatic events. Their business continuity plans incorporated all disasters, including fire, and earthquake.

Adaptive strategies within insurance firms were as follows:

- No sale of insurance during the advent of a storm or extreme weather event
- Education of clients on ways to mitigate risk exposure- if recommendations for mitigation of climate risks are undertaken, clients are given reduced premium rates

- Improved data collection through GPS mapping of properties (1 respondent); and the use of photographs and a thumb tacked paper map to highlight parishes with vulnerable insured properties (2 respondents).
- Establishment of an internal catastrophe fund in the event of reinsurers inability to cover all claims (1 respondent)
- Discriminate policies – e.g no insurance coverage offered to beach front properties and, or flood prone areas (3 respondents)
- Retracting coverage/Non renewal of coverage: in the event of excessive claims related to climate hazards, (2 respondents)
- Random site inspections of properties prior to policy renewal (3 respondents)
- Consultation with reinsurers prior to offering insurance coverage (4 respondents).

Sample responses:

b. *"Over the years we have seen the encroachment of the sea on a number of properties that we insure and as a result of this; I know of one particular property we actually came off risk because of the fact that the sea has come so far into that property...we've made that decision with respect to properties in Barbuda because it's just too close to the ocean. "* I1

c. *"One of the strategies that we have here, is that over the years we stay away from beach front properties. Because coming out of Hurricane Luis in 1995, a lot of the insured properties we had were washed away and we are aware that those are aspects that climate change can affect our businesses,..."* I4

Banks, and credit unions, through their corporate social responsibility activities as well as structural adaptation, engaged in societal adaptation activities but were unaware of the linkages to climate change:

1. *"Last year, we installed water tanks to eight different schools in Antigua, focus was mainly on the primary schools, cause we recognize many of them didn't have adequate water and we wanted to ensure that this was captured. So those are some of the initiatives we undertake as part of our CSR…climate change affects the whole island is something that should be addressed by the government."* B1

2. *"Now the storms are coming more frequent and more violent so therefore we have to put more things in place to protect the building, so for example, shutters and so on."* C2

3. *"Actually, this institution has had instances with flooding in the past. And when it used to seriously rain, our neighbours yard would flood and the water would backup and flood the whole parking lot. So all the cars would get flooded and so on. And it's flash too, it's not like 4,5, 6 hours. It would happen in an hour so we would have to be running outside to move our cars. It was really pretty bad. We had to spend upwards of about $250,000 to build a box drain at the back, which alleviated flooding for all the residents living upwards…If climate change was a priority concern we would have a policy and we don't."* C1

### Governance

No institutions within the sector had a climate strategy or policy. Moreover, many institutions, particularly banks, felt that a government mandate was needed to initiate an effective response to climate change risks and adaptation:

a. *"I think a direction needs to come from a central authority, a bankers association, etc. In reality, there is no force pushing us in that direction, we do it as a good corporate citizen. But if as a country there is a policy that comes down then that further pushes the process together to get to the levels of addressing it, and that's what you want."* B2

b. *"There is no mandate from government requiring us to do that. I think if we channeled our efforts into that (adaptation) then it would make a big impact in addressing adaptation and climate change risks."* B4

c. *"I don't think there is any coordinated approach. I think to a larger extent it is left to individual entities to carve their own niche and find their own road within the grand scheme of things. What would help is to have a coordinated approach led by a Government agency to take charge and set the policy framework so that others can follow. This will avoid the sort of haphazard approach with various organizations doing one thing and another doing some other thing; it's disorganized."* B7

### Emerging risks

The interviews further highlighted two key emerging risks which primarily related to the role of the government, and the role of reinsurance. A major concern among insurers is the role of reinsurance not only within the island but throughout the Caribbean Region. As climate change impacts are realized in frequency and intensity, the performance and rates of reinsurance fluctuates resulting in a transference of increased costs to customers as well as limiting the affordability of insurance. Respondents' comments:

*"Let me tell you what happened during that 10 year period we had those hurricanes as an insurer. The reinsurance costs went through the roof and as a result of that we had to increase our rates… and that is passed on to the consumer. There is a serious risk to Antigua, as well as the Caribbean Region. At one point, Antigua was known as Hurricane Alley because of the frequency of storms coming this way. And at one point reinsurers were threatening to not cover Antigua cause you have to consider that premiums and revenue generated here are small when compared to the high risk coverage due to the region's frequent disasters."* I1

*"I recalled us going through that. Not only did they threaten to withdraw but some of the reinsurers folded or collapsed because they couldn't manage the claims. I mean we were being hit almost twice every year and then they couldn't afford to pay us."* I7

In addition to requiring government guidance to climate change risks, activities of government agencies were often seen as increasing the vulnerability of the sector to climate change risks through poor development planning approvals, as well as through public works and maintenance of infrastructure such as drains and waterways. Responses:

*" I believe that watercourses should be cleared from time to time but again, you see them (Government) clearing water courses where you see them clearing all the vegetation so its now just earth waiting to be washed away. What I think needs to happen, is to clean the watercourses not just 10ft wide then if you get heavy rains then it overflows into property areas around. Maybe it needs to go to 20ft wide. Do it one time, don't just go there every year doing the same 10ft wide and when it rains. Do a proper assessment, maybe it needs to be 20ft wide and let the grass grow back so when we do get the heavy rains it will contain water in that area ."* I1

*"…we had an incident in Barbuda where we were getting the business and we hadn't gone to look at it but we got the engineers report and sent it to the reinsurers. When they saw the location of the property, they said the property was built incorrectly and the DCA shouldn't have approved it because it was built too close to the coastline. This presents a challenge cause in the case of Barbuda, it was a hotel, and they couldn't get insurance here so they had to get it from someone over seas. Had it been a private home where all local insurers refused to insure that property can you imagine the repercussions? One, the bank would not be pleased because the bank can't get security for their properties, and two, the home owner would be left at the mercy of the environment….So DCA needs to pay more attention. I was wondering where was DCA, did they not see that it was too close to the water line; was there no site visit before approving…this exposes everybody. If insurance firms are silly enough to cover it then they have that exposure, and the bank already loaned money to build it and they would have loaned the money because*

*of DCA's people and approval. So they are trusting the government to know what they are doing and in that case they let us down, and I am very sure that they have let us down quite a few other times."* I7

## Summary of Research Findings

Antigua and Barbuda's financial services sector is aware of the physical risks of climate change but limited in their perceptions of risks to the island as well as to their organization and also their role in addressing climate change risks. In terms of the sector's operations, risk assessment strategies are minimal and consist mainly of visual assessments and an engineer's structural report. Insurers mainly undertook operational adaptive strategies while other financial institutions undertook structural as well as societal adaptation activities through their CSR policies. Some banks are in the final stages of finalizing their business continuity plans to maintain their operations in the event of a catastrophe, which is inclusive of extreme weather events as well as other hazards including earthquakes and fire. At the governance level, there is no formal climate policy or infrastructure to address climate change risks. The sector requires a national mandate from a government or central authority before any formal response to climate change could be undertaken.

## Implications of the Research Findings

### Awareness and Perception

While the financial services sector is marginally aware of the physical risks of climate change, the perceptions of risks to the island and to the various financial institutions are limited, given the small majority in responses. Weather losses experienced are predominantly by hurricanes (Dlugolecki, 2000), which may be a contributing factor in the strong association to climate change despite the science. This association may also hide the increasing trends and risk perceptions of other ongoing extreme events such as flooding, and droughts. The limited perception of risks may primarily stem from their sources information. Respondents often cited their own investigations and personal readings through various media as major sources of information. The implication of this is that the information may not be localized and, or contextual. While the media has considerable influence in framing opinions and perceptions of climate change (Cavahlo, 2010; Lyytimaki, 2011; Dolsak and Houston, 2013) it lacks content on adaptation activities, and it primarily frames adaption as just a needed response to climate change risks (Ford and King, 2015). Moreover, scientists who wish to lobby certain interests, including climate skeptics, can also use the media and mitigate the perceptions of risks. As a means of validating and ensuring consistency in the information provided to the financial sector, the government through its various agencies must therefore play a lead role (Stern, 2009).

### Private Sector Engagement

The research indicates low levels of private sector engagement not only in development planning but also in addressing climate change risks. Biangini and Miller (2013) argue that private sector engagement in developing countries are low despite the vast opportunities available. Engaging the private sector, such as financial institutions, enables the mobilization of resources, technical capacity, advances government efforts and also engages other members of society (Biangini and Miller, 2013). In the case of Antigua and Barbuda's financial services sector, through CSRs of financial institutions, adaptation efforts were undertaken but not linked to climate change efforts on the island. This highlights awareness as a barrier to climate change response by the financial services sector.

The research concurs with previous international studies that highlight the awareness of risks, risk assessment methodologies, and the lack of government and political engagement and leadership hinders the progress on adaptive responses to climate change (IPCC, 2014; Linnenluecke and Griffiths, 2015). As highlighted in the research, risk assessment strategies were minimal within the financial services sector, despite the availability of GIS data through government agents.

## Financial vulnerability

As a developing SID, the physical risks of climate change can significantly threaten the financial viability of the financial services sector. The projected increases in frequency and intensity of extreme weather events will inevitably negatively affect insurers as well as banks, and individuals. Hawker (2007) notes that changes in climatic events will possibly reduce the ability and capacity of insurers to price and cover weather related risks owing to increases in claims for damaged properties. Following the occurrence of Hurricane Andrew in 1992 in south-eastern Florida, nine insurers became insolvent owing to unforeseen losses (Herweijer et al., 2009). Such firms did not anticipate the intensity of the hurricane and how it would affect their business as it occurred during an inactive season based on historical records. This implies that use of historical records and trends can no longer be used as a basis for risk pricing. Given climate variability, the response of some insurers to increased weather impacts in the United States was to drastically reduce the number of homeowner policies or complete pull-out from regional markets. Consequently, approximately 3 million U.S. households remained without private insurance coverage as well as being exposed to risks between 2003 and 2007 (Stenek et al., 2010). The interviews highlighted that such occurrences have occurred within Antigua

*"We have historic information on companies who have underestimated their need for catastrophe reinsurance coverage, have failed and are now no more. Antigua has such experiences with companies going under as a result, going back to 1989 with Hurricane Hugo and 1995 with Hurricane Luis."* I7

The frequency of extreme weather events potentially increases the maximum risk of losses (Herweijer *et al.,* 2009) and as such increase in insurance premium levels is a usual response (Linnenluecke and Griffiths, 2015). This in turn adversely affects insurance affordability and availability, which is already materializing in the case of Antigua and Barbuda given the previously mentioned adaptive strategies undertaken by insurers within the island. Additionally, the availability and rate fluctuations of reinsurers presents a major challenge not only to the sector but also to individuals as this cost is passed on to individuals through higher premiums and deductibles. This presents a challenge for persons living in vulnerable areas. As an island surrounded by the sea the majority of the country's population resides in coastal communities, and the economy is highly dependent on tourism. With insurers opting to either increase premiums, retract coverage, or non-issue of coverage, specifically in the case of coastal properties, increases the vulnerability of the island both socially and economically. Vulnerable coastal communities will be left to carry the risks of extreme weather events. Further, with banks in Antigua and Barbuda being unaware of such strategies, their asset based loan portfolios and the real estate market may increase with uninsurable properties and irrecoverable debts (Linnenluecke and Griffiths, 2015):

*"There was a period of time where we had a lot of boats and fishermen claiming on insurance and that involved one particular insurance company pulling out of the market and that happened all of a sudden. So that could be something like what you're referring to about retracting coverage. Yes they did give us notice alternative insurance and go through the whole process of getting the boats valued and so on, which is an expense to them. That actually impacted one of our customers quite significantly because after that, he couldn't get insurance and we were left with the debt."* B6

This has further implications for an already weak bank system in the Eastern Caribbean Currency Union (ECCU), which is made up the smaller islands, like Antigua and Barbuda. IMF (2013) notes that poor risk management strategies, and inadequate regulatory supervision, particularly within domestic banks, have led to capital shortfalls increasing the vulnerability of the financial sector. It is also noted that there have been an increase in non-performing loans or irrecoverable debt. While this may not be explicitly linked to impacts of climate change, without proper diligence, the banking sector may become plagued with uninsurable properties (Linnenluecke and Griffiths), which could further add to the value of non-performing loans. Additionally, Strobl (2012) highlights that on average, the effects of natural disasters, specifically hurricanes, reduce the financial output by one percent within the region as well as increases the debt to GDP ratio by five percent following storms. Given the slow onset of climate change impacts,

the cumulative risks of extreme weather events in addition to a weak system, the vulnerability of the sector is increased as well as the island's pursuit of sustainable development.

Moreover, Herweijer *et al*. (2009) adds that discriminate polices may increase the proportion of un insurable properties as well as threaten the financial viability of private insurers through a reduced number of policies sold. It is therefore imperative that both insurers and banks specifically address climate change risks through improved risk assessment methodologies, and anticipate how their respective asset and risk based properties can adapt to the increasing frequency and intensity of extreme weather events.

The findings of this research are indicative of both areas of further research, and strategic areas of improvements, namely, awareness, risk assessment strategies and capacity, and governance.

## Further Research

1. Climate change awareness and perceptions of property development stakeholders to include engineers, contractors and developers.
2. Government and private sector engagement in climate change issues within the Caribbean
3. The role and performance of reinsurers within the OECS
4. The value of Non-performing loans attributed to the un-insurability of assets
5. The value of financial impacts of extreme weather events on residential and commercial property developments

## Recommendations

1. Increase private sector engagement with Government national authorities through formal information exchange and through the development of a sustainable development public private partnership initiative. Through the CSR policies of the financial services sector, advancements in climate change adaptation and mitigation can be attained.
2. Financial institutions should develop and foster national sustainable development goals within publicly disclosed formal policies on corporate social responsibilities (CSR). These policies should address climate change and the institutions actions to address national policies.
3. Development of a national climate change strategy that includes a strategic framework for engaging the private sector.
4. The financial services sector should lobby the government on the risks of developments in hazardous areas and the enforcement of stricter laws and regulations (Clemo, 2008). Both banks and insurers have a role to play in the quality of developments.
5. Improve risk assessment strategies within the sector through the increased use of GPS mapping and by establishing a shared Geo-database with a central hub, either through a government agency or private association. As part of a public private partnership, the Government could facilitate basic GPS and GIS training within the sector. Financial institutions can pay for an annual service that enables them to access the existing Geo-database and facilitate GIS simulated queries.
6. All financial institutions should complete and utilize business continuity plans.
7. All insurers should establish internal catastrophe funds to alleviate the reliance on reinsurer payouts.
8. Development of public relief insurance scheme to assist individuals living in vulnerable areas who are also unable to secure property insurance
9. Mobilize regional action to improve the responses of the financial services sector to climate change via CARICOM, CCRIF, CDB, and the ECCB.

## Conclusion

While the financial services sector is seeing rising additional costs from the occurrences of extreme weather events associated to climate change, little is known about the responses of the sector to the physical risks of climate change. This is particularly true in the case of the Caribbean, which is one of the most vulnerable regions to climate change impacts.

This research took an exploratory approach to analyze the responses of the financial services sector to the physical risks of climate change, using a case study of Antigua and Barbuda. The sector was analyzed across four main areas, namely, awareness and perception; operations to include risk assessment strategies and adaptive strategies; business products; and governance in terms of policy. The research methods involved a preliminary survey to ascertain the awareness and perceptions of risks, followed by interviews. A total of 18 institutions participated in this research

The major findings of the research were that although the sector was marginally aware of climate change risks, the perception risks were limited. This may be attributed to the communication of climate change risks, minimal risk assessment methodologies, and low levels of private sector engagement by the government. The research concludes that there is no formal response to climate change risks within the financial services sector of Antigua and Barbuda and that adaptive strategies are uncoordinated.

It is important to note that the findings of this research are not to be generalized but are rather indications of the factors that encourage and hinder responses to climate change within the OECS.

# Effective Communication for Climate Information Services: *A Jamaican Case Study Assessment Using Perspectives from Multi-End-User Stakeholder Feedback*

***By Sarah Buckland***

This paper is an adapted excerpt of Sarah Buckland's undergraduate thesis as part of the BSc Geography Programme,
submitted to The University of the West Indies, Mona Campus - 2015

**ABSTRACT**

Tailored Climate Information Services (CIS) have become critical components of disaster risk reduction planning globally. The efficiency and effectiveness of these services, in both production and end-user uptake aspects, are particularly crucial for resource-rationed Small Island Developing States (SIDS), which stand to experience heightened exposure to the effects of increased climate variability. Effective communication strategies are fundamental to bridge the gap between CIS producers and end-users, however, there is still a dearth in understanding the dynamics of end-user uptake, particularly in the Caribbean context. This paper forms part of a wider evaluative study aiming to develop a single integrated tool compatible with existing global frameworks for assessing National Meteorological and Hydrological Services (NMHS) in their charge to develop and disseminate tailored CIS, incorporating aspects of internal operations, information delivery and end-user uptake. The presentation below however concentrates on the end-user perspectives of CIS delivery using the Jamaican context as a case study. The study employs a concurrent triangulation mixed model design consisting of site visits and consultations, garnering perspectives from key informant end-users within the agricultural sector, with emphases on farm-level feedback (N=76). The end-user assessment is framed using a 5-dimensional criteria matrix consistent with the Global Framework of Climate Services (GFCS): The case of Jeffrey Town, St. Mary highlights that there is alignment between the relevance of climate information provided with what agricultural end-users deem most important. Limited CIS awareness and accessibility to media of transmission, limited trust in formal climate information and understandability constraints due to low formal education levels were found to be the main barriers in the CIS communication process. The results from this case provide critical farm-level guidance for CIS producers for future community-level engagement approaches.

## Introduction

### Background and Context of Research Problem

Jamaica as a Small Island Developing State (SIDS) is faced with a plethora of physical and socio-economic vulnerabilities owing to its geographic characteristics and historical and contemporary processes. Of the vulnerabilities faced, the threat of weather and climate hazards is one to which Jamaica is most frequently and increasingly susceptible, owing to its location within the Atlantic hurricane belt. Effective communication of relevant climate information is critical for risk reduction.

During the past few decades, Jamaica has been affected by increasingly extreme climate events, causing severe socio-economic setbacks. According to Richards (2008), between 2002-2007 hurricane and flood climatic disasters in Jamaica amounted to J$73.19 billion. Jamaica's agricultural system has experienced heightened exposure-sensitivity with increasing external pressure from the effects of the double exposure to increased climate variability and economic globalization, the former which often limits produce quantity and quality and the latter, which demands consistently competitively priced yet high quality produce. Over the past few years, the Meteorological Service of Jamaica (MSJ) has partnered with various local and international organizations to offer more specialized climate services, embarking on

initiatives such as the Caribbean Agro-Meteorological Initiative (CAMI, 2009), and the Jamaica Rural Economy and Ecosystems Adapting to Climate Change (JaREEACH, 2012). As it is unclear as to the extent of the effectiveness of climate services in Jamaica since these initiatives have been undertaken, on-going evaluation of the effectiveness of these projects is critical to ensure quality and relevant services to each stakeholder involved as needs continue to change. In light of this gap, this paper seeks to present in-depth case study feedback on the effectiveness of the CIS communication for agriculture from the perspectives of key end users and linked organizations to Jamaica's agriculture sector. The aspects of 'effective' CIS communication as presented in this paper (figure 1) include a subsect of indicators used in a wider study by this researcher, consistent with the Global Framework on Climate Services (GFCS, 2011). The additional frameworks integrated in the development of each indicator will be elaborated on in the methodology.

The results from this research aim to provide useful practical and theoretical insights on the progress and barriers which may affect effective communication for climate adaptation, particularly in agriculture, specifically applicable for the region. It is hoped that this research will provide useful feedback for refining current and future approaches to climate service communication and lay the foundation for further research to foster improvement of this critical sector of society.

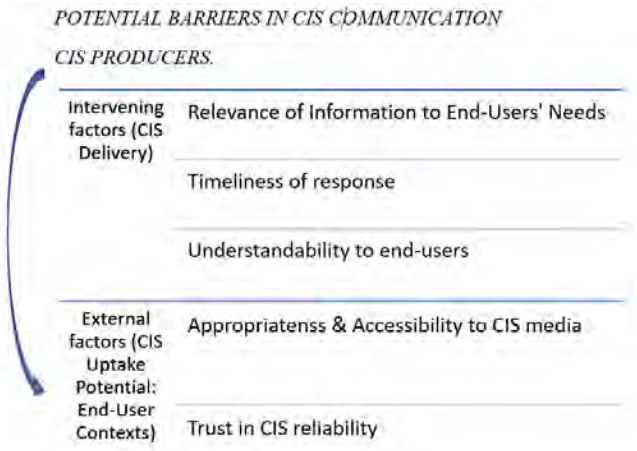



***Figure 1.1: Variables examined in Effective Climate Information Communication Framework Used in this Study***

## Literature Review

### Overview

Recently much emphasis has been placed on ensuring sustainable development and food security in the face of projections of increased climate variability, which has already been detected in various sectors, including tourism and agriculture (Simpson, *et al*, 2012). The MSJ's roles have simultaneously broadened over the years from providing more generalized to more specialized weather and climate services to stakeholders deemed most vulnerable. This literature review aims to gain an overall understanding of the reason for this shift to more targeted services, as well as the gaps and changing needs of weather and climate services. This will be followed by an analysis of case studies of past climate service evaluation methodologies to examine various possible approaches and appropriate indicators as used in other studies to evaluate '*effectiveness*' of CIS communication.

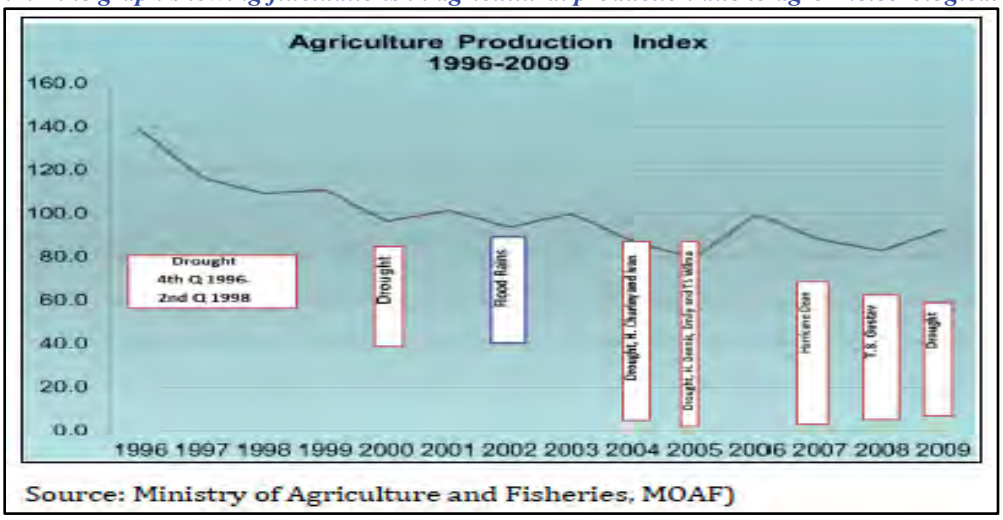
### Contemporary Context: Changing Roles, Developments and Challenges

From the latter part of the 20th Century to the present, increased research globally projecting greater climate variability, extremities and climate change according to Global and Regional Climate Models (GCMs & RCMs), have resulted in a more concerted effort in local and international policy-making to mitigate climatic hazards. Specifically for the Caribbean, projections for both high and low emission scenarios by international and regional scientists mostly agree indicating a general warming and drying trend (of up to 5ºC), concentrated in North-Western Caribbean (including Jamaica), particularly during summer months by the 2080's, with increased severity of climatic hazards and disasters (IPCC, 2007, 2013; Taylor *et al*, 2013).

Caribbean agriculture has been noted to be particularly vulnerable to the stresses of environmental change due to our small landmass and limited adaptive capacity, which limit competitiveness in the face of economic globalization, posing challenges to Caribbean food security (Barker, 2012; Taylor *et al*, 2012). Several studies investigating conditions and perceptions at the farm-level across Jamaica, including

Southern St. Elizabeth, and Northern Clarendon have also revealed that climate change effects are not only limited to theoretical projections, but have been felt at the farm-level through lower crop quality and yields, increased pests and diseases and threatened livestock health (Campbell, Barker & McGregor, 2010; Gamble, *et* al, 2012; Campbell *et al*, 2011; Simpson *et al*, 2012; Albrecht & Tomlinson, 2014;),. General production losses have also been tangibly observed during extreme climatic events such as the El Niño Southern Oscillation (ENSO) drought of 1998 (figure 2.1).

***Figure 2.1: Line graph showing fluctuations in agricultural production due to agro-meteorological hazards***




*Adapted from Jamaica Strategic Programme for Climate Resilience (hereafter Jamaica SPCR), 2011*

In an attempt to address these hazards, various coping strategies have been employed ranging from generally indigenous techniques at the local farm-level, to the implementation of various general and targeted hazard and disaster mitigation plans, policies and projects at the community and national level over the years incorporating various stakeholders. MSJ's role in disaster risk management primarily encompasses preparedness and mitigation (table 2.1).

***Table 2.1: Timeline of key general and targeted hazard/disaster mitigation plans, policies and projects in Jamaica directly or indirectly related to ADRM (Up to 2015)***

| Year | Plan/Policy/Project | MSJ role (direct or implied) |
|---|---|---|
| **1997** | National Disaster Action Plan | Member of National Disaster Committee (NDC) and National Disaster Executive (NDE). |
| **2005** | Jamaica National Hazard Mitigation Policy | General hazard mitigation (McAlla, 2012). |
| **2009** | Agriculture Disaster Risk Management Plan (ADRMP) | Primarily responsible for hydro-meteorological hazard analysis, including flash weather hazards and long-term climate pattern analysis, and to develop specialized tools, climate service products and Early Warning Systems (EWS) for agro-meteorological hazard mitigation in collaboration with various stakeholders through the applied meteorology section (Spence, 2010). Linked with National and Parish Agriculture Disaster Risk Management (NADRM and PADRM) committees at the community and national level to promote sustainable agricultural practices (pilot done in 5 communities) (Rhiney, 2012; ADRMP, 2012; Mclean, *personal communication*, 2014). |
| | Caribbean Agro- | In keeping with the ADRMP, this was the first major project |

| Year | Plan/Policy/Project | MSJ role (direct or implied) |
|---|---|---|
| | Meteorological Initiative (CAMI) [2009-2012] | aimed at providing direct climate products services for agriculture (Francis-Rhiney, 2013). The Caribbean Agro-meteorological Initiative (CAMI) The project came out of initial consultations in St. John's, Antigua with Regional Meteorologists from the Caribbean and representatives of the WMO/FAO (Rankine, *personal communication*, 2014). The project was implemented in 10 CARICOM countries under the direction of the Caribbean Institute of Meteorology and Hydrology (CIMH) and each National Meteorology and Hydrology Service (NMHS), funded by the European Union and the African, Caribbean and Pacific (EU/ACP) Science and Technology programme. |
| **2011** | Jamaica Strategic Programme for Climate Resilience (Jamaica SPCR) | Provided with support for improved weather-monitoring and forecasting equipment under investment project I: *Improving Climate Data and Information Management.* |
| **2012** | Jamaica Rural Economy and Ecosystems Adapting to Climate Change (JaREEACH) project | This project has a similar mandate as CAMI and aims to address the needs from the outcomes of the CAMI project. It was implemented by the MSJ, funded by ACDI/VOCA. |
| **2013** | Building Disaster Resilient Rural Communities (BDRC) and Livelihood Project | Indirect link with the MSJ. Pioneered by ODPEM, the project focuses on building resilience of vulnerable farming and fishing communities to disasters across the island. |
| | Green paper of Jamaica National Climate Change Policy Framework and Action Plan for sectoral-specific climate change strategies | Primary source of climate data specific for Jamaica. |
| | Formation of a Climate Service Working Group | This group was formed around the time of the Third International Conference on Climate Services (ICCS3) held in Montego Bay, Jamaica, 2013. It is co-chaired by MSJ and RADA, and also consists of the Caribbean Agriculture Research Development Institute (CARDI), ACDI/VOCA and the Ministry of Agriculture. |
| **2014** | Disaster Risk Management Act (Revised) | Member of National Disaster Risk Management Committee. |
| **Currently under revision** | National Land and Agricultural policies to include climate change factors | Primary climate data source for Jamaica. |

*Compiled from National Disaster Action Plan (1997),pp. 42-44, McAlla (2012),pp.52,67, ADRMP (2012), Rhiney (2012), Disaster Risk Management Act (2014), Spence (2010), Jamaica SPCR (2011),pp.85-85, Simpson et al, (2012), p.111, Climate Change Policy Framework and Action Plan (2013); Spence (2013); Francis-Rhiney (2013); Linton (2014)*

## Measuring 'effective' Communication of Climate Information: Comparative methodological approaches

Various strides have been made in formulating basic guidelines for evaluating climate services, most notably the Global Framework for Climate Services (GFCS) by the WMO (Global Framework for Climate Services [GFCS], 2011) and the development of a methodological framework by Tall & Njinga

(2013) to evaluate climate services for farmers in Africa and Asia. Box 2.2 summarizes the main principles of each.

***Box 2.2: Comparison of the principles of GFCS and Tall & Njinga, (2013)***

**GFCS (2011):** Some of the main principles and components of the GFCS implementation are:

- Climate service user interface platform to facilitate feedback to ensure relevance of services
- Adequate climate service information systems and infrastructure for monitoring and observation of climate variables at agreed standards
- Climate services enhanced through strong partnerships, with governments playing a central role (including through research, prediction and modelling, to support capacity development for the resources needed for effective climate services)
    - Better accessibility and use of climate information by users
- Continuously updated and operational climate services
- Free and open exchange of climate data
- Needs vary at different spatial scales

**Tall & Njinga (2013): Similarly, among the baseline monitoring and evaluation guidelines for climate services mentioned include:**

- Tracking *'information flow'*, i.e. data/information transmission
- '*Institutional assessment*', i.e. co-operation among institutions involved in climate services
- Feedback from end-users: to find out how the end-user uses the information and the impact

The resultant framework utilized in this paper will focus on the delivery (intermediary) and uptake-potential (decoder) aspects of the CIS communication processes. This integrated framework aims to uncover the strengths and weaknesses within the communication processes of the present Jamaican CIS context, from multiple end-user perspectives at these stages of the communication process.

## Methodology

### Overview

To effectively achieve the paper's objectives, a concurrent triangulation mixed-method approach was used. Primary data collection spanned from July 2014 to February 2015 and was done extensively through consultations with 76 key informants using both qualitative and quantitative research methods. Figure 3.1 shows the primary data collection sites visited and methods used. This paper will specifically focus on the feedback obtained through the telephone consultations mainly from participants in Southern parishes who were participants in past Farmer Forum training sessions, and field studies with farmer end-users in the case study community of Jeffrey Town, St. Mary.

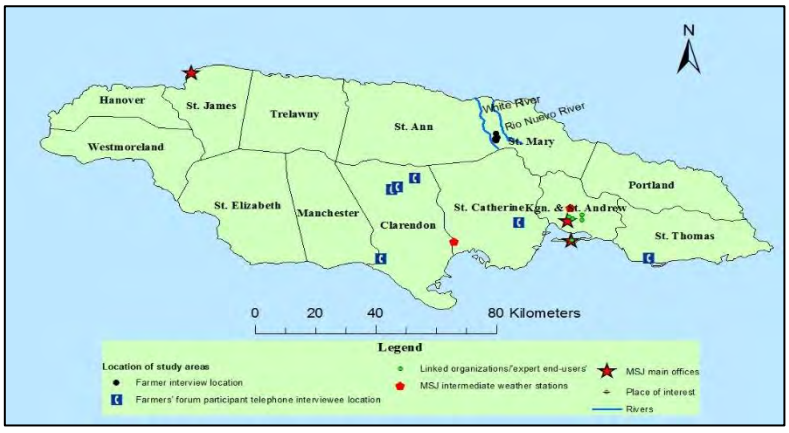



*Figure 3.1: Location of Study Areas*

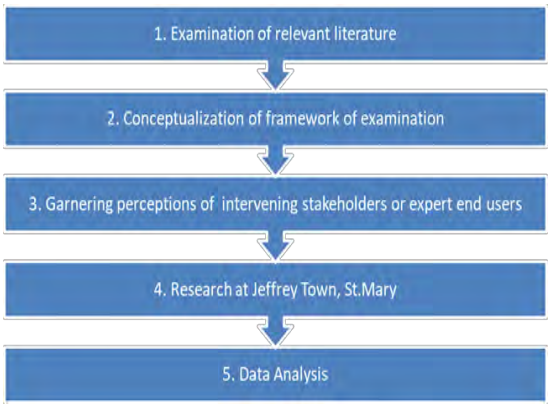
## The Research Process

The research process could be divided into 5 main phases as shown in figure 3.2. The following subsections detail each aspect of the research process.

### *Examination of literature and conceptualization of framework of examination*

Prior to conducting the field studies, several pieces of literature were examined to ascertain which indicators would be appropriate in conceptualizing the '*effective communication*' of CIS, some of which were mentioned in the literature review, among which included the requirements for traditional and applied meteorological services, and past case study climate service evaluation methodologies e.g. Tall & Njinga (2013), and Vogel *et, al,* (2014). The resulting framework of factors, as expounded in Chapter 1 (figure 1.1), assimilated CIS delivery and external factors that were perceived upon examination of the literature to be central to the balance between the requirements for weather/climate service providers and the needs of the end-users in the agricultural system. This framework is used to examine 'effective CIS communication', emphasizing the importance of the micro-scale, assessing end-user needs with site visits to a farming community to which the climate services had been introduced. The data collection instrument questionnaires and interview schedule were formulated based upon this framework.

*Figure 3.2: Main stages of research process*




### *Selection of key informants & Garnering the Perspectives of Intervening Stakeholders.*

A purposive methodology was taken in the selection of interviewees for the evaluative process, using the maximum variation principle to include the perspectives of key stakeholders with different roles within the agriculture sector. These included linked organizations and individuals in the ADRM framework (ACDI/VOCA, RADA extension officers, researchers) who provided feedback from a policy point of view. Receipt of direct grass-roots' end-user feedback was also a critical component of the evaluative process.

In examining the CIS communication process and its implications, it was deemed to be useful to examine various stakeholders who fall into the intermediate category playing a dual role, being 'primary' end users of MSJ data (i.e. directly receiving data from the MSJ prior to data processing and secondary transmission), as well as those whose operation potentially or directly affects the effectiveness of the mitigation of agro-meteorological hazards. As such, qualitative semi-structured surveys and a mixture of face-to-face and electronic consultations were done with 20 stakeholders from 6 institutions directly or indirectly acquainted with MSJ operations and data, whether through research and policy-making (Climate Studies Group, UWI Mona; select lecturers, Dept. of Physics and Geography and Geology, Caribsave), logistical connections (JCAA; WRA), or financing, implementation and execution of agro-meteorological projects (RADA; ACDI/VOCA) in order to gain feedback and recommendations concerning both the perspectives on climate information delivery and other aspects of MSJ operations pertinent to CIS. Purposive sampling methods were combined with snowballing in the selection of stakeholders who were known to have experience with MSJ data and/or agriculture.

### *Research at Jeffrey Town, St. Mary*

Subsequent to gathering perceptions of intervening stakeholders, efforts were made to garner the perceptions of the main end-users of agriculture climate services: farmers, on a local-scale. In keeping with the research aims, the community chosen would have to be involved in at least one climate service project supported by the MSJ for the effectiveness of the services to be evaluated. The community of Jeffrey Town, St. Mary was chosen as a possible model community case study upon secondary research which revealed that the community had participated in at least two climate service projects (CAMI and

JaREEACH) in addition to having an active Farmers' Association with its own community radio station which has been the recipient of various international awards for climate resilience efforts. Internal estimates from the Jeffrey Town Farmers' Association (JTFA) state that the community has a population of around 150 farmers, including unregistered farmers.

Field work in the area began with a field reconnaissance on November 8, 2014, which included tours of sections of the community, chaperoned by a senior member of the JTFA, Mr. Lincoln Small, vice-president for agriculture. Preliminary data collection was started during this time, and completed between December 29-30, 2014. A total of 37 Jeffrey Town residents (36 sample farmers, 1 administrator of the local community station, JET FM) were surveyed, using a mixed-method approach, using cluster and judgemental sampling where farmers from each of the 9 districts in Jeffrey Town were surveyed through the administration of orally administered questionnaires, with unstructured in-depth interviews being conducted with 3 key personnel in the community. The combination of sampling at the judgement of the chaperone (geared mainly towards farmers as opposed to other groups within the community) with cluster sampling, compensated for personal lack of acquaintance with the community, while allowing for a more representative sample, including both participant and non-participant farmers in climate services. Quantitative analysis of questionnaire responses would provide a general idea of perspectives and needs of this sub-group of end-users, which could be a useful guide for future climate services. The use of a GPS device and digital camera were employed to assist in providing a spatial and visual context for interview sites.

To complement the feedback from the case study community, additional in-depth qualitative interviews were conducted using a systematic random sampling method (N=6) selecting from participants of 4 different CAMI and JaREEACH farmers' forums, spanning the parishes of Clarendon, St. Catherine, Kingston and St. Andrew and St. Thomas, using the initiatives' lists of participants as the sampling frame. Feedback from these participants and references to other similar studies will compensate to provide a wider picture where response trends may provide a useful comparative context for analysis.

## Data Analysis

Qualitative and quantitative survey (interview and questionnaire) responses from the aforementioned stakeholders were synthesized, analyzed and compared alongside observation findings and relevant secondary sources in order to attain a comprehensive understanding of the data in relation to research aims. Data presentation and analysis was completed using various tools including the Statistical Package for the Social Sciences (SPSS), Microsoft Office and Geographic Information Systems (GIS) in the form of maps, diagrams, boxes, plates and graphs. Consistent with the case study approach, stakeholder feedback was primarily analyzed using descriptive statistics, rather than inferential. Manual thematic content analysis of stakeholder responses was also done.

## Challenges, limitations and extensions of study

Several challenges were faced during research which led to a reduction of the research scope due to time and resource constraints. As the initial topic aimed to examine implications of MSJ efficiency on disaster management in Jamaica, efforts were made to obtain feedback from a wide cross-section of end-users island-wide. However, delayed and non-responses were experienced from various organizations, particularly for database requests of climate service forum participants, leading to the examination of a local-scale case study community, which limits the generalization of results.

Although the sample size selected within the farming community was deemed sufficient to garner the trend of end-users' needs as a starting point of analysis of the effectiveness of Jamaica's weather and climate services, use of a larger sample size and scope of end-users would decrease the margin of error and allow for a greater representativeness for end users.

## Results & Discussion of Key Findings

Knowledge and appreciation of the socio-demographic contexts of the end-users in any prospective site for climate adaptation intervention initiatives are critical for facilitating appropriate rapport and adjusting communication strategies to the context. Comparing the perspectives and preferences of various sub-populations of end-users also provides a useful basis for determining 'good practices' for CIS communication in future interventions. The following sub-section provides an overview of the socio-demographic characteristics of the primary end-user farmer population interviewed in this study.

### Case Study Farming Community Context

Jeffrey Town is a small, active farming community located in St. Mary between the White and Rio Nuevo Rivers (see figure 3.1, chapter 3), consisting of predominantly small-scale subsistence male crop farmers over 60 years old, around 97% of whom have been farming for over 10 years and nearly 43% of whom have participated in some climate training (see figures 4.1A-D).

*Figure 4.1 A: Pie chart showing proportion of types of farming done by respondents in Jeffrey Town, St. Mary*

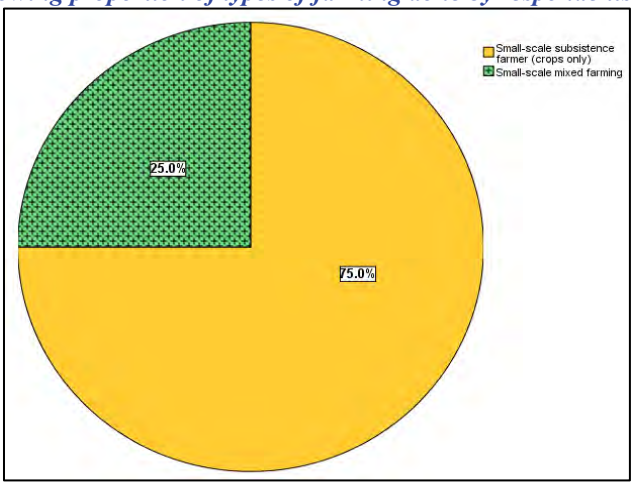



*Figure 4.1 B: Population pyramid of Jeffrey Town sample farmers*

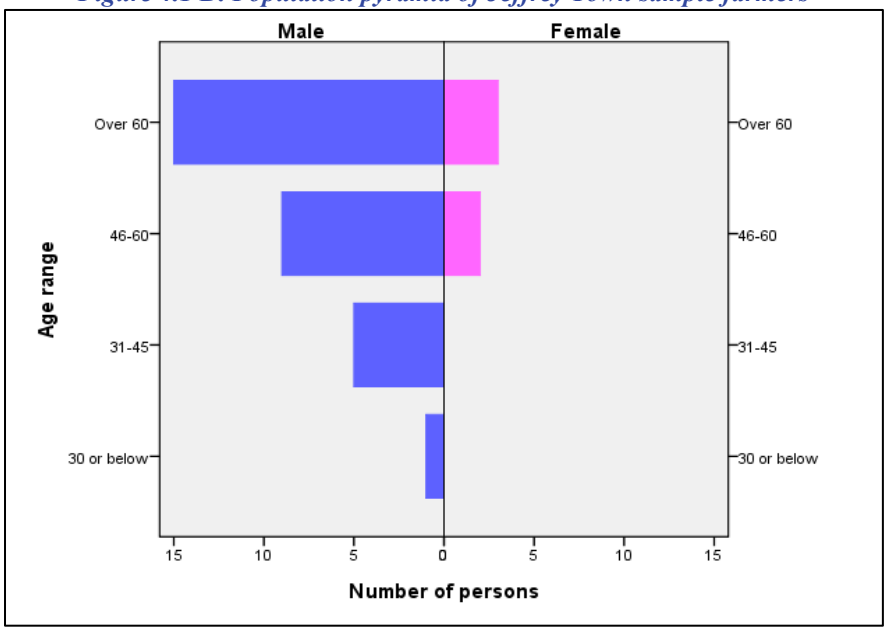


*Figure 4.1 C: Pie chart showing the number of years Jeffrey Town respondents have been farming*

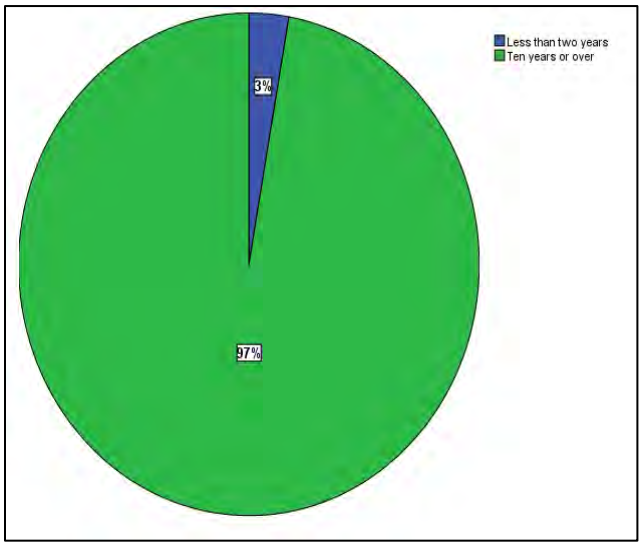
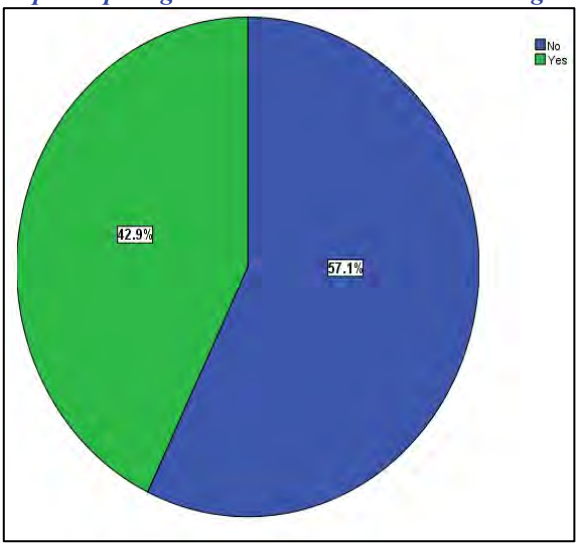



*Figure 4.1D: Pie chart showing the percentage of Jeffrey Town respondents who admitted to participating in climate risk reduction training*




Bearing in mind these socio-demographic tendencies, the following sections systematically detail the feedback obtained on the seven indicators of 'effective CIS communication' used in this study.

## Progress & Constraints in CIS Communication: End user feedback

***Relevance of data to end-users' needs***

For climate services to be effective, the information supplied by climate service providers must directly address farm-level vulnerabilities, taking into account farmers' decision-making processes on varying temporal and spatial scales and specific agro-meteorological hazards faced (Tall & Njinga, 2013).

Farmer respondents were asked to rank information related to farming decision-making in their perceived order of importance (with a rank of '1' having the highest perceived importance). Tables 4.1A and B compare the present CIS available from the MSJ, with farm-level feedback. As indicated, it was found that the parameters of focus by the MSJ basically coincide with the main factors farmers in Jeffrey Town deem important when making farming decisions, namely rainfall and pest information. This feedback generally coincides with the most urgent needs expressed from farmers in other areas locally (Albrecht & Tomlinson, 2014). It must however be noted the high priority farmers place on non-climatic factors such as indigenous knowledge, including astronomical data and market data, which are yet to be fully incorporated into local climate services.

*Table 4.1A: Main climate products and services for agriculture currently provided by the MSJ*

| Main agro-meteorological element targeted | Climate product/service offered |
|---|---|
| **Rainfall** | • 3-month Seasonal Precipitation Index (SPI) outlooks<br>• Drought monitoring & forecasts |
| **Pests and/or diseases** | • Pest forecasting |
| **Temperature** | • Seasonal Temperature Outlooks |

*Table 4.1B: Frequency table showing the most important factors taken into consideration by Jeffrey Town respondent farmers when making farming decisions.*

| Parameter | Rank | Frequency | Percentage of sample that mentioned the parameter as being important when making farming decisions |
|---|---|---|---|
| **Rainfall** | 1 | 33 | 92% |
| **Non-climatic parameters (including lunar cycles ('McDonald' almanac) and the market** | 2 | 9 | 25% |
| **Pest information** | 3 | 6 | 17% |
| **Wind direction** | 4 | 4 | 11% |
| **Wind speed** | 4 | 4 | 11% |
| **Humidity** | 5 | 3 | 8% |
| **Temperature** | 6 | 2 | 6% |
| **Soil moisture** | 6 | 2 | 6% |

***Specific vulnerabilities and the role of indigenous local mitigation strategies***

As seen in figure 4.2, the most frequently cited agro-meteorological hazard affecting Jeffrey Town farmers was drought, followed by pests and floods. Despite expressing vulnerabilities, farmers cited numerous examples of local mitigation efforts employed as shown in plate 4.1 and figure 4.3. Interestingly, the use of scientific forecasts was not greatly evident among respondents, possible reasons for which will be subsequently discussed.

*Figure 4.2: Bar graph showing the hazards cited as affecting the Jeffrey Town residents most often*

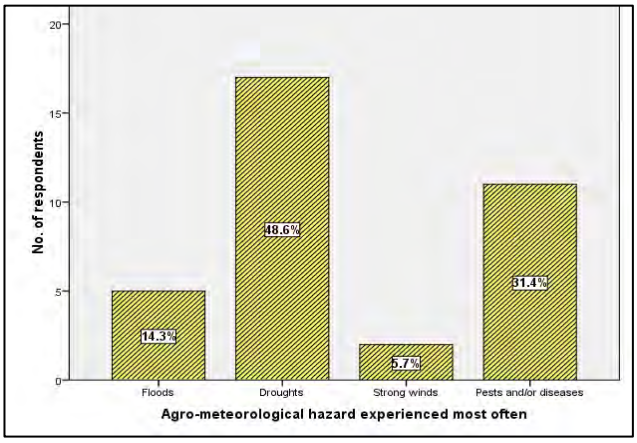
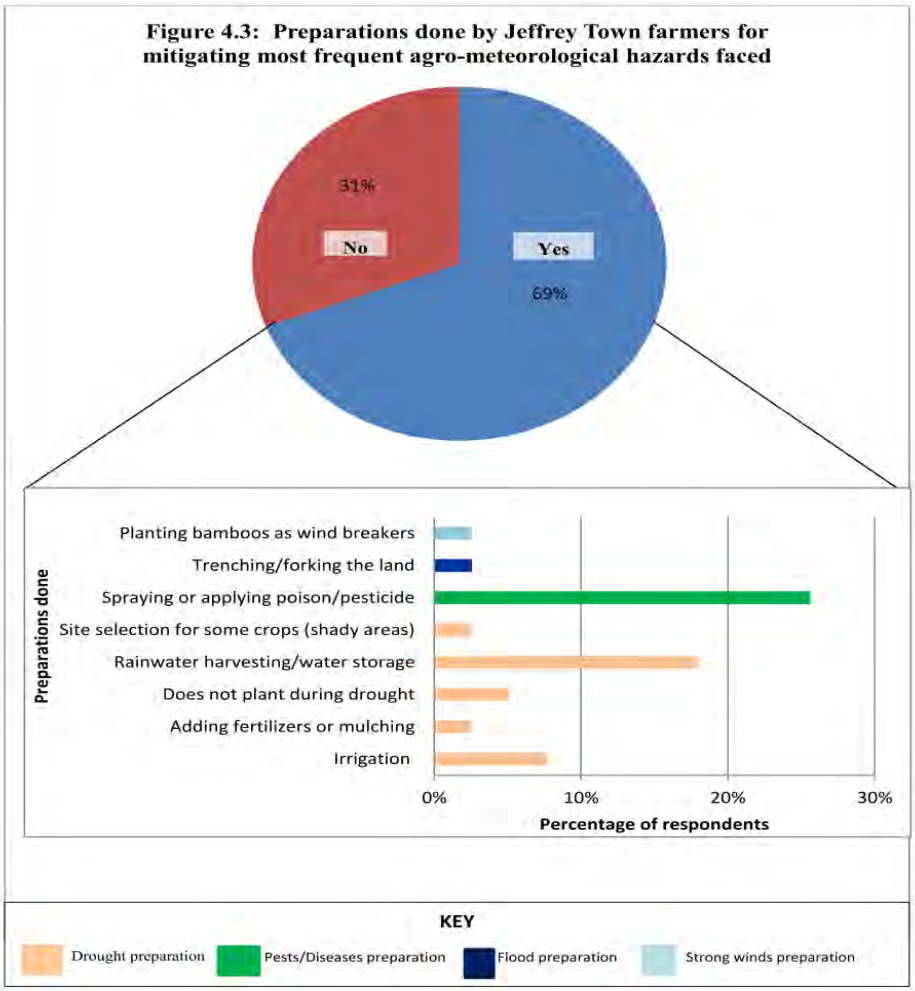



***Plate 4.1: Rain water harvesting and 'bottle-drip' irrigation: Main local mitigation/adaptation strategies observed in Jeffrey Town***


Figure A: Water harvesting tank implemented by the Jeffrey Town Farmers' Association; Figure B: Rainwater harvesting on a farm for livestock. Despite having these mitigation strategies in place, large losses were reported due to the 2014 drought, averaging around J$119,200 per farmer according to responses.


'Bottle-drip' irrigation allows for alleviating drought conditions through water application, water conservation (as water slowly seeps into soil) as well as recycling waste plastic bottles.




***Appropriateness and accessibility of communication media***

Even with relevant information being conveyed by climate service providers, if the end-users are unable to access the information, climate services will not be effective. As shown in box 4.1, the main medium currently used by MSJ for agriculture-specific climate information is the internet. A text message system is also in place. The resolution of climate information presented through radio and television media channels is coarse, consisting of primarily generalized reports and forecasts. There is currently limited use of radio/television media for agriculture-specific climate information.

***Box 4.1: Main media currently used by the MSJ to convey climate service information for agriculture***

The MSJ currently produces:

- Farmers' outlook bulletins (Generally available on the RADA website)
- Community-specific 5-day forecasts for agriculture communities (agrilinksja.com)
- Additional agricultural climate information on jamaicaclimate.net
- Email database from farmers' fora
- Text message system (particularly used during extreme events)
- Face-to-face contact with agriculture extension officers

As is shown in figure 4.4A, the main media that Jeffrey Town respondents stated they were aware of for weather forecasts was radio/television, with less than 40% of respondents being aware of internet forecasts. Despite internet access being available at the JTFA community centre, figure 4.4B highlights another barrier to internet access: nearly 70% of respondents stated that they were unable to use the internet. It is also seen that awareness of these bulletins did not necessarily translate into use, as only 11% admitted to using outlook bulletins compared with the nearly 40% who admitted awareness. Therefore, as figure 4.4C highlights, the vast majority of Jeffrey Town respondents deem the use of radio/television to be the most convenient media for agriculture climate bulletins.

***Figure 4.4A: Comparison of levels of awareness of weather updates for various communication media among Jeffrey Town respondents***

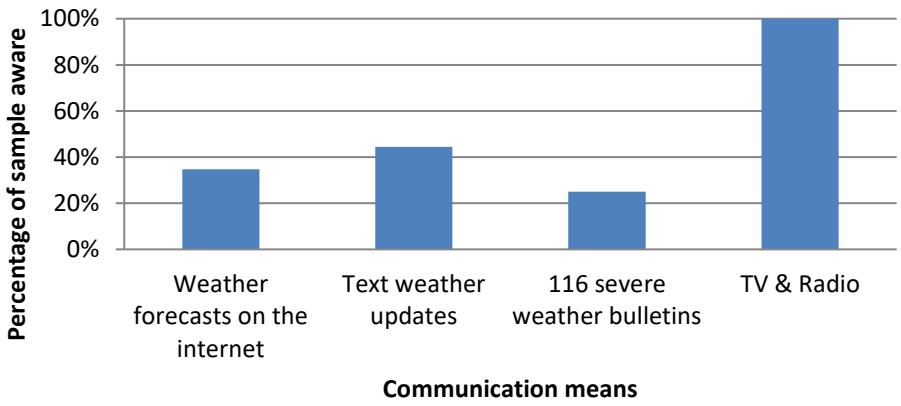
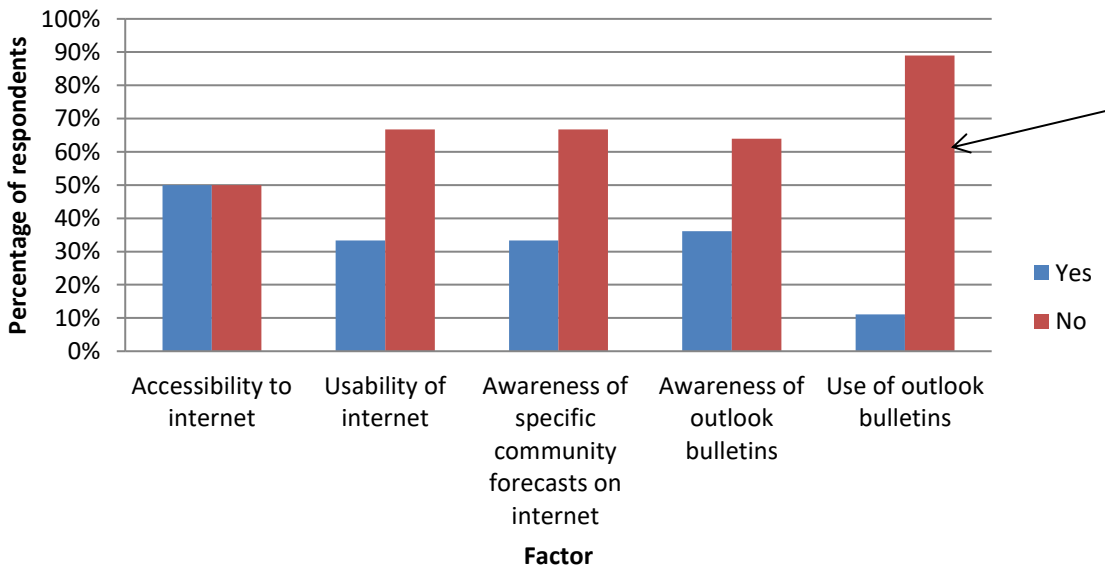


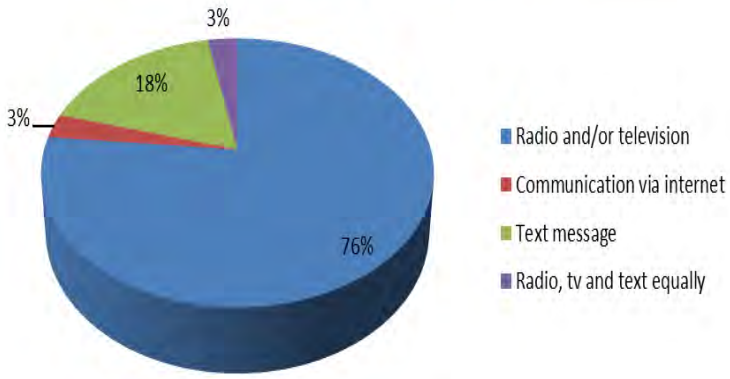

***Figure 4.4B: Comparative bar graphs showing various aspects of the reach of weather bulletins via internet among Jeffrey Town Farmers***




It can be seen that the reach of Farmers' Outlook Bulletins is currently very limited in Jeffrey Town (only 11%) [compare box 2.3]

It must be noted that in addition to general inaccessibility and unawareness of climate services by internet, several Jeffrey Town farmers expressed never having seen the agriculture extension officers, further limiting their access to climate information.

*Figure 4.4C: Pie chart showing most convenient means of communication for Jeffrey Town farmer respondents*




***Understandability of CIS to end-users***

Effective communication of climate services not only relies on the accessibility of communication media, but also that end-users understand exactly what is being conveyed and how they should respond. As figure 4.5A highlights, the jargon used in local climate service media tends to be technical, presenting a communication barrier to the average farmer, who has a low educational attainment (figure 4.5B).

**Summary and Expected Agricultural Impacts**

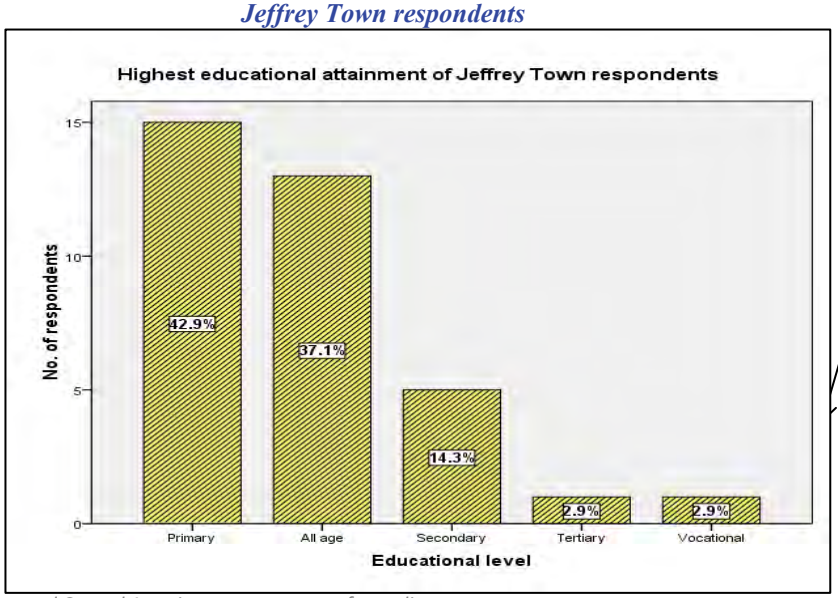
There is medium to high confidence in the CPT precipitation outlook for August through October for below normal rainfall to continue for most stations. The greatest concern exists now for stations that are already significantly affected by drought and expecting below normal rainfall through to September. Farmers and other interests should therefore maintain alternative measures and plan for conditions to continue until the end of September before any significant change is expected. The temperature outlook forecast of above normal temperatures combined with already parched conditions in some parishes will only exacerbate evapotranspiration rate which will b a key issue for the farming sector. Increased temperatures could also see the introduction of pests in the fields and therefore preventative measures should also be considered.

**Excerpt adapte from: National Agromet Bulletin, July 2014**

*Figure 4.5A: Observed communication barriers in local climate services*

The incorporation of various technical terms as shown (highlights added) decreases the ability of farmers to act on the information to reduce their vulnerability given their generally low educational attainment. Without simplification, there is undue dependence on agriculture extension officers (which are severely short-staffed), to convey the messages.

*Figure 4.5B: Bar graph showing highest educational attainment of Jeffrey Town respondents*

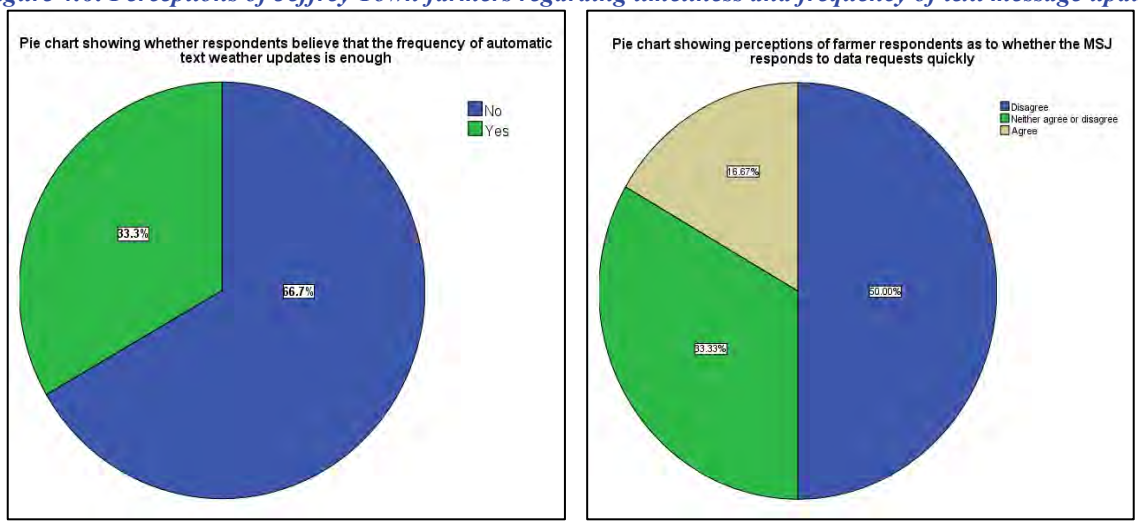


***Local climate services feedback mechanisms: Timeliness of response***

According to the Global Framework on Climate Services (2011), platforms to facilitate feedback and interaction between climate service providers and end-users are vital for effectiveness. This is particularly crucial in cases of emergency.

As shown in figure 4.6, from the relatively small percentage of respondents who actually see MSJ feedback via text messages, there is general dissatisfaction of the timeliness of response and frequency of automatic updates of the text message bulletins. Delays in feedback may limit the capacity of farmers to effectively prepare for possible hazards, thus perpetuating vulnerability.

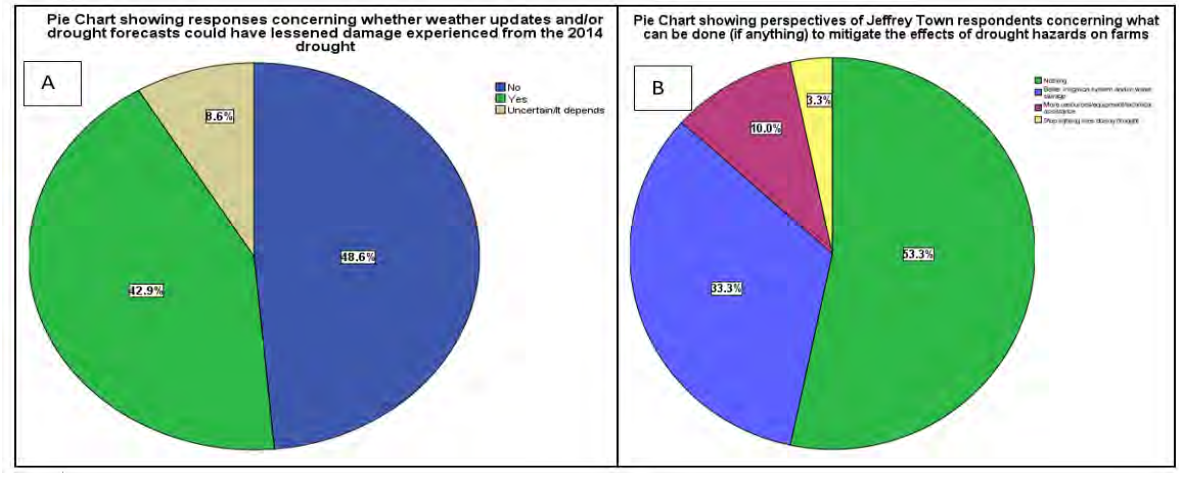
***Figure 4.6: Perceptions of Jeffrey Town farmers regarding timeliness and frequency of text message updates***




***Farmer Trust in Reliability of Weather Forecasts and CIS***

A major potential barrier to effective climate services is a lack of trust in the reliability of weather forecasts. Results from farmer perspectives gauged is presented in figure 4.7A). In addition to a general sentiment of distrust or uncertainty on the reliability of forecasts, respondents displayed an outlook of 'hopelessness', as over 50% believe there is little to nothing that can be done by anyone to minimize agro-meteorological hazard risk (figure 4.7B) This would limit the willingness of farmers to take warnings seriously and thus reduce the effectiveness of mitigating agro-meteorological hazards.

***Figure 4.7: Perceptions of Jeffrey Town residents concerning the reliability of weather forecasts and their sbility to mitigate on-farm hazards***



Reasons given for the belief that weather forecasts could not lessen damage include:

- Inaccuracy of the forecasts
- Local uncontrollable factors, including the vulnerability of the outdoor farm
- Lack of available water (including in river) to be able to prepare
- High dependency on farming for livelihoods, so many will risk loss even when warned.

## Summary and Conclusions: Climate service delivery components

Being steeped in tradition, various studies globally have found that farmer adaptive action and uptake-potential of new information is heavily based on their experiential perception of its utility for benefits on the short-term problems that are high priority based on their own observation (Maddison 2007, Banerjee 2015). Given these tendencies, the onus is on CIS providers to make use of success stories of new CIS applications and use immediate connectors to farmers' immediate environment for a potentially greater appreciation at the local level. Once this increased trust is achieved at the local level, particularly among community leaders, it may have a ripple effect across other farmer sub-populations.

### *Role of agriculture support groups in climate service participation*

Social capital, such as membership in agriculture support groups has been noted to possibly reduce vulnerability (Cannon, Twigg & Rowell, (2002). From interview findings, it was found that nearly 75% of Jeffrey Town respondents were members of one or more agriculture support groups. To ascertain whether membership of these groups contributed to greater likelihood of climate training participation, a cross-tabulation was done (table 4.2), which showed that no significant relationship exists in Jeffrey Town between one's agriculture-group membership and participation in climate services (Approx. sig =0.212). Despite this, given the high membership in these groups, the use of these associations would be helpful in disseminating climate information among farmers.

*Table 4.2: Cross-tabulation of involvement in agriculture support group and participation in climate risk reduction training*

A

| Count | | Have you ever participated in any climate risk reduction training in agriculture? | |
|---|---|---|---|
| | | No | Yes |
| Are you a part of any agriculture support group? | No | 6 | 3 |
| | Yes | 14 | 12 |
| Total | | 20 | 15 |

B

**Symmetric Measures**

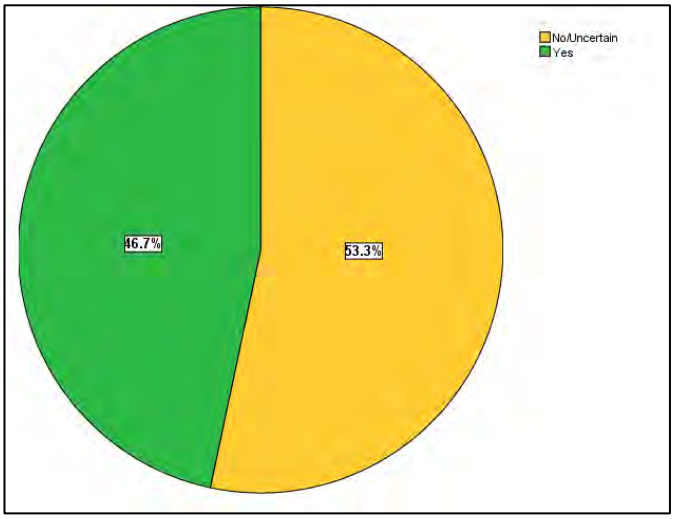
| | Value | Approx. Sig. |
|---|---|---|
| Nominal by Nominal Cramer's V | .294 | .212 |

### Assessing the Progress of CIS: Farmers' Perceptions of Effectiveness of Climate Services in Improving Production

Direct feedback was obtained from participant farmers in climate services to ascertain the extent to which climate training was perceived to have assisted in improvements in farm production. As shown in figure 4.8 the effectiveness of climate training in reducing hazard risk and increasing production is still inconclusive, as responses are split almost evenly.

These results corroborate with the conclusion of Vogel et al, (2014), which indicates that the duration of local climate service implementation is too short to adequately assess its effectiveness in increasing agricultural productivity.

*Figure 4.8: Perceptions of Jeffrey Town respondents who participated in climate training regarding whether farming production improved due to training*




## CONCLUSIONS & RECOMMENDATIONS

The results presented indicate that from multi-stakeholder feedback, end-users perceive some benefits in CIS, particularly in the areas of relevance of information to their needs. Opportunities for improvement have been expressed relating to limited accessibility to CIS, especially in the context of rural farmer end-users, as the case study of Jeffrey Town, St. Mary highlights. As was mentioned, over three-quarters of the respondents (76%) specified television and/or radio as their preferred means of obtaining climate information. It is therefore recommended that these accessible media be utilized to achieve greater effectiveness in farmer engagement with CIS, including for those who have low literacy levels, who would already have heightened levels of vulnerability. The case of Jeffrey Town also highlighted the barrier that limited formal education levels of many rural farmers may face, to understand the climate information produced in farmer bulletins. It has also been expressed that opportunities for improvement also exist for on-demand support by Climate Service Providers in terms of timeliness of response in text message CIS. Farmer trust of formal climate information also has room for improvement, and appears to compete with indigenous information sources, such as farmer almanacs, upon which many farmers rely. Further research into an integrated, participatory approach to CIS communication, including an assessment of existing indigenous techniques, may aid to bridge this gap. In order to address these issues, a multi-dimensional approach has to be taken. Figure 4.9a highlights recommendations compiled from consultations from both intermediate end-users and farmer end-users in an effort to continually enhance climate service delivery.

*Figure 4.9a: Key Recommendations from Intermediate End-Users in Study*

| | |
|---|---|
| Financing | Mainstreaming climate services in policy/legislation, incorporating each ministry and local parish councils. |

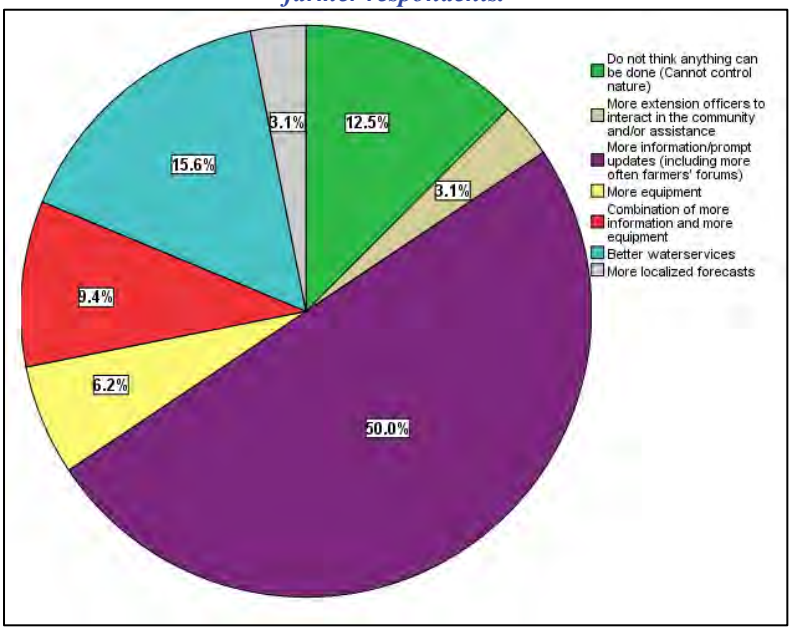
- Greater need of understanding the value of the MSJ and other CIS providers.
- Forge more local and regional partnerships.

| | |
|---|---|
| Increased awareness among populace | More farmer interaction on a local level, e.g. more frequent farmer fora, with climate adaptation strategies and to increase awareness of climate products. |

- Increased consultation with the masses while developing climate products.
- Using more widely accessible mass media (radio/television) and text message systems.

| | |
|---|---|
| Improvements in execution of CIS | Using a context-specific approach: Moving from research to implementation and focus on internal factors that contribute to vulnerability |

*Figure 4.9b: Farm-level recommendations for improvement for climate services according to Jeffrey Town farmer respondents.*



# Temperature Susceptibility of Asphalt Binders for Climate Change

*By Kellesia Tricia Williams*

This research paper was submitted as the requirement of the course Special Investigative Project for the degree of Bachelor of Science in Civil with Environmental Engineering at the University of the West Indies, St. Augustine – 2016

## Introduction

Paved roads will need to increase by 25 million road lane-kilometres by 2050, under the Energy Technology Perspectives 2012 (Dulac 2013). This has led to an increased demand in stability and durability of binder products. Flexible pavement has been incorporated into the transportation system of Trinidad and Tobago. This type of pavement structure is most common because of how fast local commuters can access the roadways.

The duty of asphalt binder is to bind the fine and coarse aggregates of the surface layer. Asphalt is defined as a dark brown to black cementitious material in which the predominating constituents are bitumen which occur in nature or are obtained in petroleum processing (ASTM 2016). TLA is a naturally occurring asphalt deposit found in the Pitch Lake of south-west Trinidad. Its consistency is attributed to its constant soluble bitumen content when refined. Individual components of TLA work in combination to produce improved stability and durability of pavements (Widyatmoko et al. 2005). In 1870, Trinidad Lake Asphalt (TLA) recorded its first use as an asphalt binder. Despite the benefits offered by TLA, the demand for paved roads exceeded the supply of lake asphalts in the late 1800s (Horan 2003). This shortfall led to the use of petroleum asphalts as the substitute for TLA in the pavement wearing course in the early 1900s.

Petroleum asphalts are commonly regarded as a waste product from the refinery process of crude oil. The properties of refined bitumen are dependent on the refinery operations and the composition of the crude oil at the source. Refined bitumen is characterised by its visco-elastic behaviour which dominates many facets of road performance. The rheological behaviour of refined bitumen is predominantly influenced by temperature and applied loads, which is evidenced between two extremes: purely viscous and purely elastic (Horan 2003). An asphalt binder should be elastic for dissipation of energy at low temperatures without fatigue cracking and viscous at high temperatures to prevent rutting. At ambient temperatures, bitumen is a stable semi-solid. However, exponential increase in traffic and significant variations in daily and seasonal temperatures have shown some limitations in asphalt binder performance (Pareek et al. 2012).

The Trinidad and Tobago Meteorological Office has recorded significant increases in the mean annual temperature, with an increase around 0.6 °C since 1960; an average of 0.13 °C per decade (Mc Sweeney et al. 2010). Climate change causes deterioration of the hydrological cycle, economy and of pavement structures (Viola and Celauro 2015). Within this study, under the broad topic of climate change, its temperature impact is the main focus. NCHRP Report 750 (Meyer et al. 2014) draws upon several climate models and future emissions scenarios and identifies that as average temperatures increase, an increase in the frequency and duration of extreme temperatures is also projected.

Accurate prediction of the temperature profile in pavements greatly aids pavement engineers in the design process (Yavuzturk et al. 2005). Thermal environmental conditions, to which pavements are exposed, significantly impact pavement stability and long-term performance. Cracking, rutting, and potholes are common distresses associated with flexible pavements. In general, climate change will not introduce new consequences for the pavement, but increases the likelihood and scale of deterioration of catastrophic

failure (Willway 2008). The vulnerability of a pavement to temperature impacts of climate change is determined by pavement materials and pavement design. Susceptibility of binders to high temperatures are seen in hot months (summer) where air temperatures exceed 30 °C. The surface temperature of asphalt pavements may increase by 50 °C or more, which may reach or exceed the softening point of asphalt (Shen 1999).

The purpose of this study is to analyse and compare TLA modified bitumen and RLP modified bitumen blends to determine their temperature susceptibility to regional high temperature increases. This investigation was carried out on TLA 60-70 penetration bitumen and polymer modified bitumen. This study is limited to short term ageing which is representative of production, transport and compaction of the bituminous pavement layer. Short-term ageing is identified by high temperatures which indicate high oxidation rates (Hofko et al. 2017). The Thin Film Oven Test (TFOT) simulates short term ageing for the intent of this report. Short term ageing of bitumen significantly affects the durability of asphalt mixtures. The objectives of this research paper are to examine and analyse traditional and fundamental properties of TLA modified bitumen and polymer modified bitumen blends. Long term ageing is not investigated by this paper.

## Test Program

**Materials and preparation.** The base asphalt binder; refinery bitumen of 60-70 penetration grade was obtained from Trinidad Lake Asphalt by the evaporation of lighter hydrocarbons. The base asphalt was mixed with varying percentages of modifiers to evaluate the traditional and fundamental properties. The ratio of raw TLA and Rubber Latex Polymer to the based 60-70 asphalt is shown in Table 1. The percentages represent the TLA or polymer by weight of bitumen. All blends were prepared at a temperature of 150 °C. It was ensured that all modifiers were thoroughly mixed with the 60-70 bitumen to achieve homogenous blends.

**Table 1. Blending of TLA and Rubber Latex Polymer to 60/70 bitumen.**

| **% TLA Blending** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Sample ID** | TLA20 | TLA25 | TLA30 | TLA35 | TLA40 | | | |
| **Blend %** | 20% | 25% | 30% | 35% | 40% | | | |
| **% Rubber Latex Polymer Blending** | | | | | | | | |
| **Sample ID** | RLP2 | RLP2.5 | RLP3 | RLP4 | RLP5 | RLP6 | RLP7 | RLP10 |
| **Blend %** | 2% | 2.5% | 3% | 4% | 5% | 6% | 7% | 10% |

**Traditional Testing.** Penetration and Specific Gravity tests were performed to investigate the experimental properties of the blends. The penetration test was performed in accordance with ASTM D5-06: Penetration of Bituminous Materials. The Specific Gravity of each asphalt binder sample was performed according to ASTM D 70-03: Specific Gravity of Semi-Solid Bituminous Materials. Linear regression analysis was performed to measure the strength between the dependent variable Y (Specific Gravity) and the independent variable X (percent Modifier). The test for significance of regression is done to determine whether a trend is present between the dependent variable and a subset of independent variables. The test significance was $P \leq 0.05$.

**Short-term Ageing.** Short term ageing was done on 50% of the asphalt binder samples. It was aged in compliance to ASTM D1754 – 09: Standard Test Method for Effects of Heat and Air on Asphaltic

Materials using Thin Film Oven Test (TFOT). Binder samples were placed in the oven at $163^0$C for five hours to simulate short term ageing of asphalt pavements during production and compaction.

**Dynamic Shear Rheometer (DSR) Frequency Testing.** The determination of the Complex Modulus (G*), the phase angle, torque and applied frequency was acquired by implementation of ASTM D7175 – 15: Standard Test Method for determining the rheological properties of Asphalt Binder Using a Dynamic Shear Rheometer. Dynamic oscillatory testing was strain-controlled with a gap of 1.00mm. The test temperatures of each sample were 40 °C, 45 °C and 50 °C which are representative of peak pavement temperature for temperature increase in Trinidad; where rutting is predominant. This temperature range was adopted from the Long-Term Pavement Performance (LTPP) Model (Sun 2016) which were defined as follows:

$T_{d(min)} = -1.56 + 0.72T_{a(min)} - 0.0041Lat + 6.26 \log (d+25)$

$T_{d(max)} = 54.32 + 0.78T_{a(max)} - 0.0025Lat + 15.14 \log (d+25)$

The total depth of the asphalt surface layer was assumed to be 40mm (4.0cm) with the highest pavement temperature at the centre of the layer (20mm). It is at this location where the pavement temperature was computed for a worst-case scenario of an increase of 10 °C due to increases in atmospheric temperature.

## Results and Discussion

**Traditional properties.** Penetration Testing was conducted on all asphalt binder blends to investigate the response of the base asphalt to varying percentages of modifier content. As shown in Figure 1, the measured penetration value decreased with an increase in modifier content resulting in logarithmic decay. The based bitumen modified with maximum 40% raw TLA, experienced a 56% decrease in penetration. While bitumen modified with 10% polymer (the maximum percentage studied) experienced a 27% decrease in penetration. There is a greater increase in stiffness of the base asphalt with the addition of TLA. Adequately, stiff binders allow for minimal deformation under applied loads whereas excessively stiff binders experience cracking. The determination of the modifier content which produces the required stiffness is critical to the durability and adapted pavement management system.

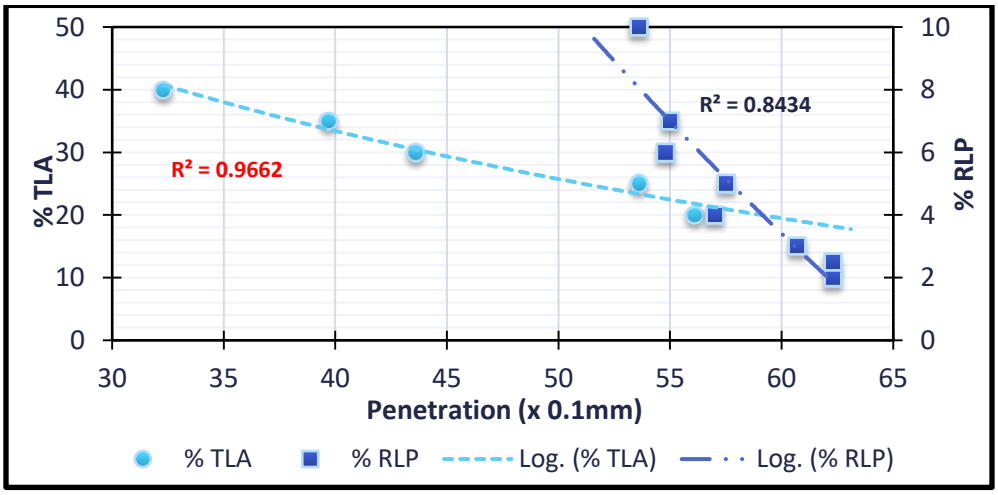



*Figure 12. Penetration of unaged TLA and RLP.*

Figure 2 shows the specific gravity of the unaged TLA and RLP blends. Although, the reported best fit line shows a linear relationship for both sets of modified samples, the general trend of the data points was noted. TLA modified blends showed an increase in Specific Gravity with increasing percentages of TLA, showing an increase in the density of the modified samples with increasing modifier content. Data points

were evenly and closely distributed around the regression. This distribution suggests a homogenous and general compatibility mixing between the 60-70 bitumen and TLA.

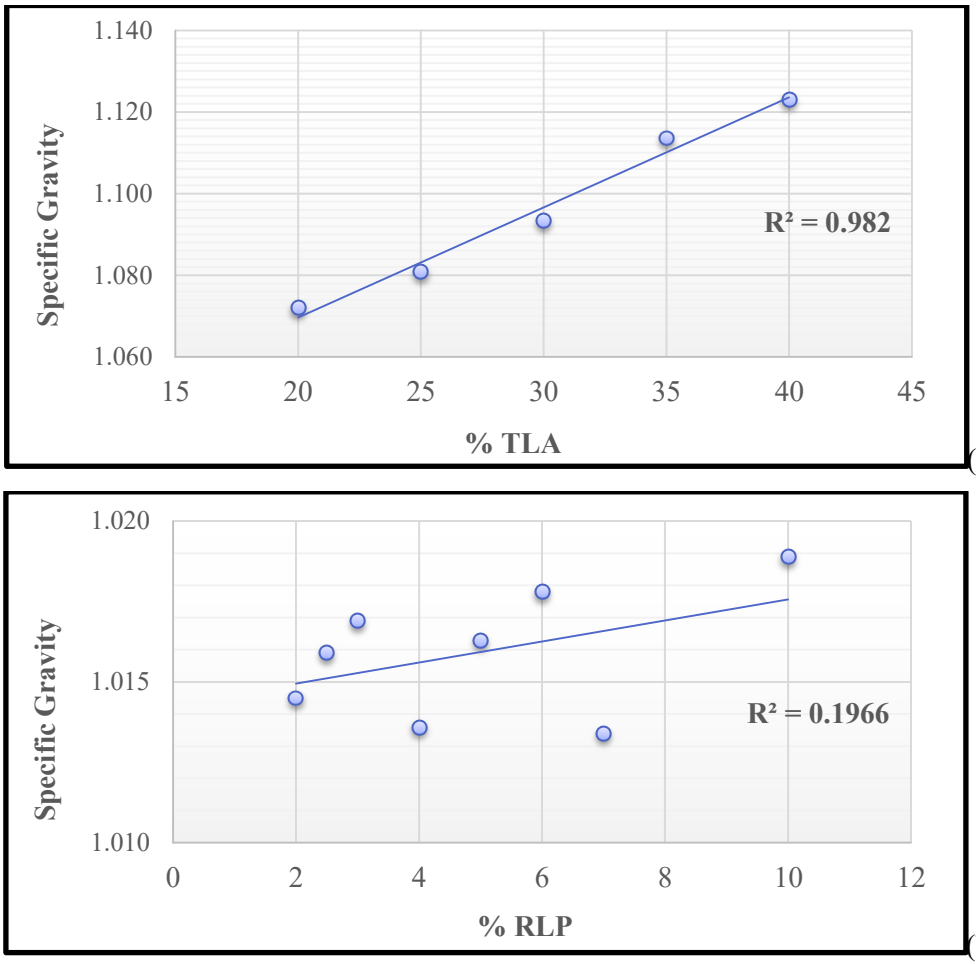



*Figure 13. Average specific gravity of (a) unaged TLA and (b) RLP blends.*

Alternatively, polymer modified blends generated a regression line with a gentler slope when compared to TLA modified blends. This shows that the increase in density of the polymer blends occurred at a slower rate than TLA blends. However, data points were unevenly distributed about the regression line, with a noticed decrease in density with an increase in polymer percentage for some samples (e.g. 4% and 6% blends). This may be attributed to some extent of incompatibility between 60-70 bitumen and polymer. Air bubbles within the mix and an incomplete burning of the rubber fines could have influenced the sporadic distribution of data points and noticed decrease in density with increase in polymer. If the density of a pavement is too low, air voids are interconnected and premature distresses may occur (Blankesnship 2009). Implementing required compaction during mixing and pavement construction inhibits the likelihood of reduced density.

As shown in Table 2, TLA modified blends p-value was recorded as 0.00001. It can be suggested that the increase in TLA significantly changes the specific gravity properties of the blend. For polymer modified blends, the p-value was recorded as 0.88554. Unlike TLA blending, RLP did not significantly change the specific gravity properties of the blend when the percentages were increased.

**Table *2.* Specific Gravity Model Summary.**

| Model | R | $R^2$ | Adjusted $R^2$ | Std. Error of the Estimate | P-value |
|---|---|---|---|---|---|
| Percentage of TLA added | 0.99740 | 0.99481 | 0.99351 | 0.00299 | 0.00001 |
| Percentage of polymer added | 0.05633 | 0.00317 | -0.13923 | 0.00226 | 0.88554 |

**Complex Modulus ($G^*$) and Phase angle (δ).**

Essential properties of the base asphalt, specifically the complex modulus (G*) and the phase angle (δ) were determined by rheological tests with frequency sweeps over a range of frequencies between 0.1 to 15.91 Hz. Plots of G* and δ versus frequency at $50^0$C for the base asphalt at blends of 40% TLA and 10% RLP are shown in Figures 3 and 4.

TLA shows a noticeable increase in the stiffness (G*) and a decrease in viscoelastic response (δ) of the 60/70 pen bitumen for both TFOT aged and unaged blends. Figure 3 shows that G* increases with increasing frequency while Figure 4 shows that δ values decrease with increasing frequency for increasing concentration of TLA. This implies that stiffness is increased but the response becomes more elastic (δ values tends to $0^0$) as the frequency increases. In addition, RLP shows relative increase in both G* and viscoelastic response, δ for both TFOT aged and unaged blends. This result demonstrates an increase in stiffness and viscosity with increasing frequency and concentration of RLP.

It must be noted that the viscoelastic response values decrease from 60/70 pen bitumen to TLA blends to RLP blends; an indication of increased elasticity. Additionally, TLA blends had the highest G* values followed by an arrangement of 60/70 pen bitumen and RLP blends. As expected, TLA increases the stiffness of the base asphalt.

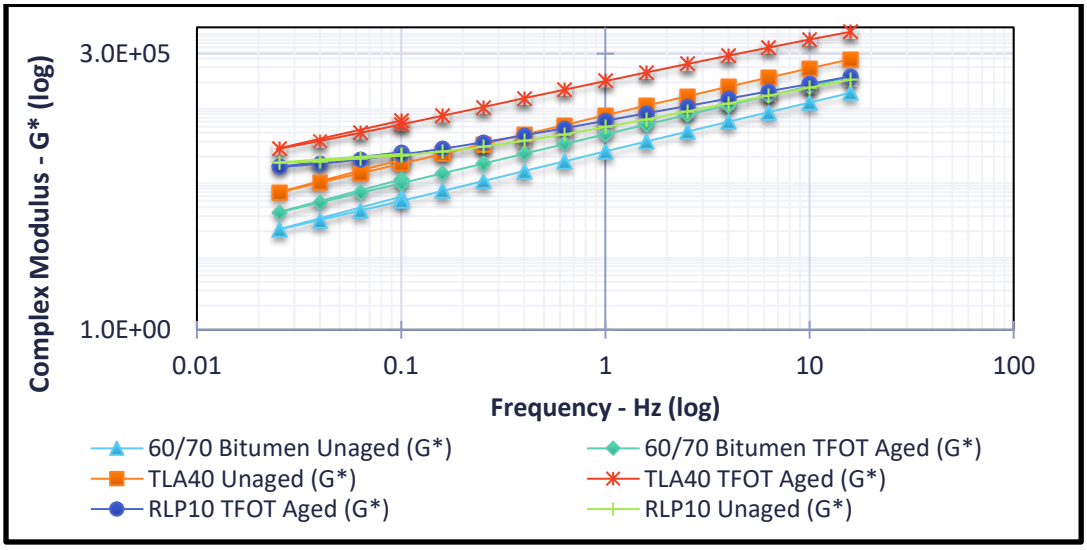



*Figure 14. Complex modulus (G*) at 50 $^0$C.*

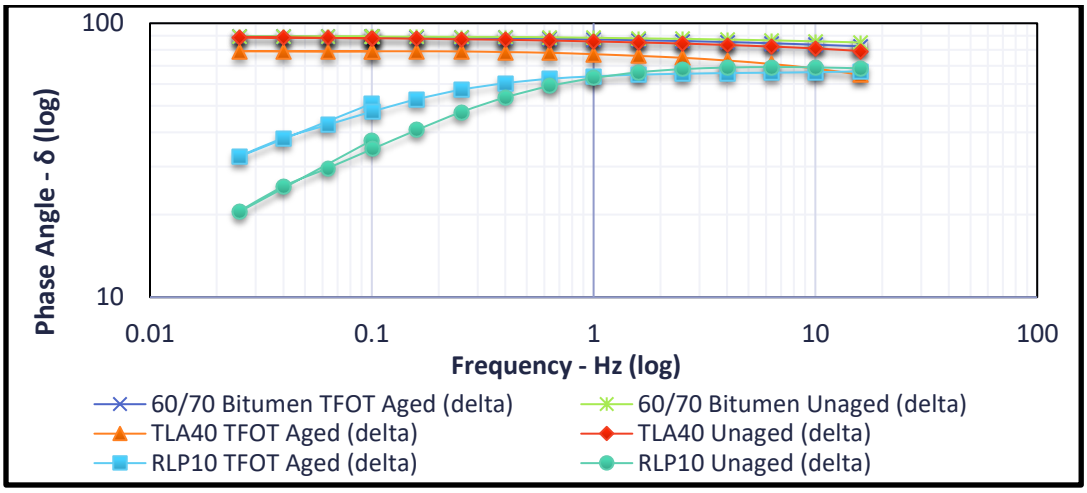



*Figure 15. Phase angle (δ) at 50 $^0$C.*

**Viscosity vs Elasticity.** With the purpose of evaluating the effect of TLA and RLP on viscosity and elasticity, a plot of the fatigue cracking parameter (G*sinδ) against the rutting parameter (G*/sinδ) for 40% TLA and 10% RLP at test temperatures and frequencies is shown in Figure 5. Unaged blends for TLA binders demonstrated more linearity when compared to TFOT aged TLA binders. The curvature of the aged blends at higher values of G* is indicative of a loss in stability of both viscous and elastic components as G* increases. This implies that the probability of rutting and cracking increases as the asphalt becomes stiffer with reduced ability to rebound after load deformation. Additionally, unaged polymer blends demonstrated similar linearity when compared to TFOT aged polymer blends. This implies that viscosity and elasticity of polymer blends are independent of age.

It is noteworthy to mention, that RLP stabilised the 60/70 pen bitumen when compared to the response of TLA modified binders. Evidence of this is the reduction in curvature from TLA to RLP blends. An increase in the stability of the base asphalt represents increased stability of the asphalt surface layer for intended traffic loads and temperature variation.

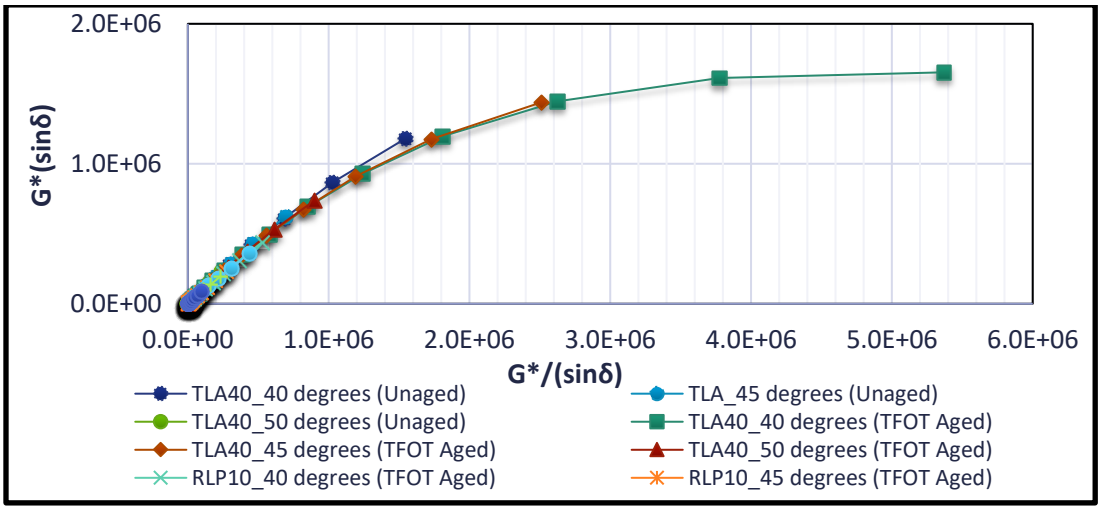



*Figure 16. G*(sin δ) and G*(sin δ) at test temperatures and frequencies.*

**Elasticity vs Temperature.** Figure 6 shows the rutting parameter, G*/sinδ for 40% TLA and 10% RLP at the test temperature range. G*/sinδ represents the elasticity response of the asphalts. An increase in temperature for both TFOT aged and unaged samples, reported a decrease in the elasticity. This implies

that the base asphalt and all blends become less viscous and less elastic with an increase in temperature, regardless of age. TLA blends exhibited more elasticity than RLP blends and the base asphalt over the temperature range. In addition, the recorded decrease in elasticity for increasing temperature was greatest for TFOT aged TLA. This implies that rutting would be most significant in TLA modified asphalt, with increasing temperature.

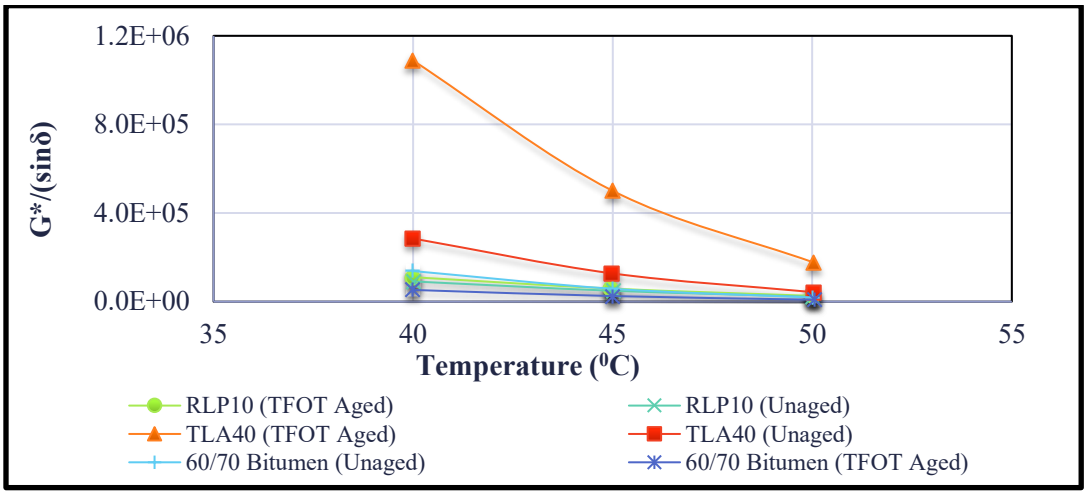



*Figure 17: Elasticity of binder and blends.*

## Conclusions

This study was conducted to evaluate temperature susceptibility of asphalt binders. The findings presented and analysed suggest that polymer modified blends may be the better suited for present and potential pavement temperatures in Trinidad and Tobago. Although, TLA is readily available in Trinidad, it's implementation as a binder modifier for tropical climates may decrease the performance of the pavement after short-term ageing since stiffness (G*) increases with increasing load frequency and elasticity is significantly reduced for increasing temperatures. Additionally, RLP stabilised the 60/70 pen bitumen when compared to the response of TLA modified binders for the analysis of the fatigue cracking parameter (G*sinδ) against the rutting parameter (G*/sinδ).

It is recommended that the study be extended to include the determination of the yield energy for the base asphalts and corresponding blends. Yield energy quantifies the energy needed to cause permanent deformation of the asphalt pavement surface.

SECTION 3

# EXPERT NOTES

# FOR LIST OF **EXPERT NOTES**

- *CCRIF SPC – Perspectives and Experiences for InsuResilience Global Partnership Forum Fishbowl Dialogue*
  By Isaac Anthony, Chief Executive Officer, CCRIF SPC
  Shared at: ***UNFCCC COP 25 Chile/Madrid***
  December 2019 in Madrid, Spain

- *Perspectives on Developing a Blue Economy for a Resilient Future*
  By Gillian Golah, Chief Operations Officer, CCRIF SPC
  *Shared at:* ***Development Bank of Latin America (CAF) Seminar, Envisioning Long-Term Sustainability in Trinidad and Tobago: Productivity, Innovation and Resilience***
  *November 2019 in Port of Spain, Trinidad*

- *The Importance of Disaster Risk Financing in Advancing Economic Growth, Innovation and Development in Small Island Developing States – The Case of CCRIF SPC*
  By Elizabeth Emanuel, Head, Technical Assistance Manager and Corporate Communications Manager, CCRIF SPC
  *Presented at:* ***51st Annual Monetary Studies Conference of the Eastern Caribbean Central Bank in conjunction with the Caribbean Economic Research Team***
  *November 2019 in Basseterre, St. Kitts*

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These speeches and notes are available on the CCRIF website at www.ccrif.org.

# CCRIF SPC – Perspectives and Experiences

*Isaac Anthony, Chief Executive Officer, CCRIF SPC*

This expert note is based on the experience and perspectives of CCRIF CEO, Mr. Isaac Anthony and is adapted from the InsuResilience Global Partnership Forum Fishbowl Dialogue that included stakeholders from the African Risk Capacity, World Food Program and Pacific Catastrophe Risk Assessment and Financing Initiative
COP 25 Chile/Madrid
December 2019
Held in Madrid, Spain

**On the possibility that insurance may lose its prominence as a tool of disaster risk financing in the near future and the future of sovereign risk pools**

The importance of catastrophe risk insurance in the face of a changing climate cannot be overstated and is supported by the UNFCCC, G7 leaders and the Paris Agreement all of which have established insurance as an acceptable climate adaptative instrument. Insurance therefore must be an essential component within governments' fiscal policy frameworks and an important tool of changing climate adaptation as we strive to advance the sustainability agenda.

CCRIF SPC was the first multi-country risk pool in the world and was the first insurance instrument to successfully develop parametric policies backed by both traditional and capital markets. CCRIF is a regional catastrophe fund for Caribbean and Central American governments to limit the financial impact of devastating hurricanes, earthquakes and excess rainfall events by quickly providing quick financial liquidity when a policy is triggered. We currently offer four parametric insurance products – for tropical cyclones (based on wind and storm surge), earthquakes, excess rainfall (based on rainfall), and fisheries.[1]

Today, CCRIF has 22 members – 6 more than the original 16 governments that joined in 2017 – 3 from Central America and 19 from the Caribbean.[2] CCRIF has demonstrated that catastrophe risk insurance can effectively provide a level of financial protection for countries vulnerable to natural disasters. In fact, since 2007, CCRIF has made 41 payouts totalling US$152 million to 13 member governments.[3]

Within the context of the range of DRF instruments, CCRIF and its parametric insurance products really is about:

- providing quick liquidity when a policy is triggered
- allowing governments to quickly support the most vulnerable in their population immediately after a disaster – for food, shelter, medication, etc.
- reducing budget volatility
- not increasing the existing debt stock of countries – as insurance is not a form of disaster relief as are credit facilities
- offering diverse products for both a range of perils and economic sectors and industries
- offering products and services not readily available in traditional insurance markets

[1] As of October 2020, CCRIF offers a fifth product – for electric utilities

[2] As of October 2020, CCRIF has 19 Caribbean member governments, 3 Central American governments and 1 electric utility member

[3] Between 2007 and October 2020, CCRIF made 45 payouts totaling US$163 million to 14 member governments.

CCRIF and the parametric insurance products it provides must not be seen in isolation from other disaster risk financing tools. Countries in the region need to take a more holistic approach to disaster risk financing and build a financial protection strategy that combines a number of risk financing instruments that address different layers or types of risk – incorporating instruments that support low and high probabilistic events as well as those that address both low or high severity events – such as disaster reserve funds, contingent credit facilities, risk insurance, CAT bonds etc. All of these instruments have unique and distinct characteristics and are necessary to finance early response, recovery, and reconstruction needs while protecting a country's fiscal balance and preventing further disruptions caused by reallocations from other priorities (such as primary health care, education, national security among others).

Today in the Caribbean, a few countries such as Jamaica and Saint Lucia are putting in place disaster risk financing policies as a means of improving the understanding of the fiscal risks of natural disasters and recommending various risk financing tools and strategies, to support meeting their targets for fiscal and debt sustainability and contributing to their development agenda. Others such as The Bahamas, which may not be as advanced in developing a DRF policy, are employing multiple risk financing instruments such as risk insurance, contingent credit facilities etc.

CCRIF was never designed to be a complete and comprehensive disaster response strategy for its members or to cover all losses on the ground. Following a natural disaster, the provision of immediate access to liquidity provided by the facility post disaster allows governments to reduce their budget volatility and to provide some amount of capital for emergency relief such as providing assistance to the affected population and restoring critical infrastructure and homes, thereby reducing post-disaster resource deficits. Providing quick liquidity to affected countries post disaster was the main rationale for the establishment of CCRIF in 2007.

**On assisting governments to address perils such as slow onset events such as droughts, rapid onset events such as tropical cyclones and floods and even outbreaks and epidemics**

When it was launched in 2007, CCRIF started with two products – for tropical cyclones and earthquakes – and in 2013 we added a product for excess rainfall. Each year our member governments purchase insurance for those perils to which they are exposed. Many purchase all three products, whilst some countries that do not have earthquake risks for example would not purchase those. Some countries purchase more cover for one peril over the other given the analysis of their exposure and vulnerability to that peril. A good example is Trinidad which is highly vulnerable to earthquakes and less vulnerable to tropical cyclones but also highly vulnerable to excess rainfall events – that country therefore purchases higher cover for earthquake as opposed to tropical cyclones and they also purchase cover for excess rainfall.

We are currently scaling up – that is we are adding new products to the risk pool based on the explicit demands of our member governments. In July, we launched a new product for the fisheries sector – COAST – or the Caribbean Ocean and Aquaculture Sustainability Facility – in two of our member countries. While this is a sovereign product purchased by governments, it incorporates a social protection component in that is designed specifically to protect the livelihoods of those persons working the fisheries sector - fisherfolk, boat captains and crew, fish vendors and also seeks to ensure that women, many of whom manage the fish markets are also able to benefit from COAST. The policy is structured to include a mechanism to transfer funds from a payout received by the Government from CCRIF to pre-identified beneficiaries in the fisheries sector. We believe that this model can be transformational in supporting the most vulnerable in our communities. This is the first time globally such as product has been made available.

We also are developing products for drought agriculture, flooding (run-off) and public utilities and we are starting with energy sector; and public utilities. Today, insurance within the context of

disaster risk financing is both relevant and necessary given the realities we are now faced with, with respect to climate

Recently governments in the region have been asking us to investigate the possibilities of providing parametric cover for other assets such as housing and other infrastructure such as schools and hospitals which are also impacted by events and in many cases not insured or the payout from indemnity insurance is not immediate.

**On CCRIF members benefitting from premium support**

Most countries in CCRIF do not benefit directly from premium support and each year countries pay their premiums for the policies they purchase – and this has really been from inception in 2007.

At its inception, CCRIF was capitalized through contributions to a Multi-Donor Trust Fund (MDTF) by the Government of Canada, the European Union, the World Bank, the governments of the UK and France, the Caribbean Development Bank and the governments of Ireland and Bermuda, as well as through membership fees paid by participating governments.

In 2014, a new MDTF was established by the World Bank to support the development of CCRIF SPC's new products for current and potential members, and facilitate the entry for Central American countries and additional Caribbean countries. The MDTF currently channels funds from various donors, including: Canada, through Global Affairs Canada; the United States, through the Department of the Treasury; the European Union, through the European Commission, and Germany, through the Federal Ministry for Economic Cooperation and Development and KfW. In 2017, the Caribbean Development Bank, with resources provided by Mexico, approved a grant to CCRIF SPC to provide enhanced insurance coverage to the Bank's Borrowing Member Countries and in 2018, the Government of Ireland provided support to CCRIF to support the development of new products and the increase in coverage levels and broader utilization of CCRIF's products by its members.

CCRIF SPC operates as a not-for-profit organization and seeks to minimize the premium costs for its members. Each year, the Facility has provided premium discounts – even following 2017 when CCRIF paid out US$62 million to 10 member governments. In addition to premium discounts, CCRIF provides other cost-saving options, such as offering special pricing for bundling different policies, allowing changes in policy elements (e.g. reduction in minimum attachment point - or deductible); and allowing member governments to use a portion of their participation fee toward premium, among others.

Notwithstanding these efforts to make the premiums affordable, there are instances where donors have provided direct premium support to member governments. For example[4]:

- Haiti has received premium support since CCRIF's inception. In CCRIF's first years, the Government of Canada and the Caribbean Development Bank paid the premiums for the Government of Haiti. From 2013 to 2018, the Bank paid 100 per cent of Haiti's premiums and for the 2019/20 policy year, the Bank paid 50 per cent of the premium with the Government providing the remainder.
- Other CCRIF members have obtained low-interest loans from CDB to pay all or part of their premiums.
- Assistance was provided to Nicaragua, the first Central American country to become a member of CCRIF. The World Bank, through the International Development Association, provided a loan to finance the country's participation fee and first few years of insurance premiums.
- Following the devastation of Hurricane Maria to Dominica's economy in 2017, the Government of Canada paid that country's CCRIF premiums for two years.

[4] In 2020, as part of the response to COVID-19, the European Union, through its Regional Resilience Building Facility managed by the Global Facility for Disaster Reduction and Recovery (GFDRR) and The World Bank, provided premium support for Caribbean members and CCRIF, through the MDTF, provided premium support for Central American members.

Despite these instances, CCRIF member countries continue to renew their policies from year to year, increasing coverage levels and selecting new policies which are offered. All this in recognition that CCRIF catastrophe insurance is an indispensable part of their national disaster risk financing framework**.**

**On working with government clients and the private sector to better assist in the expansion of insurance use to manage disaster risk and especially to reach scale in bottom-up disaster risk insurance approaches such as micro-insurance schemes**

In the Caribbean, it is estimated that indemnity insurance used to hedge the immediate impacts/direct losses from natural disasters is only about 3 to 5 per cent, compared to developed countries, which is more than 40 per cent. CCRIF is playing a role in closing this gap as it makes available products to support natural disasters at the sovereign level

But we also recognize that we need to adopt bottom-up approaches whereby access to climate risk insurance is extended directly to the most vulnerable

And we are working in this area on 4 main fronts:

1. By being a key partner with the MCII CRAIC (Climate Risk Adaptation and Insurance in the Caribbean Project), which developed a microinsurance product called the Livelihood Protection Policy (LPP)
2. Introducing products such as the new COAST product for the fisheries sector which has direct benefits to fisherfolk and those working in the fisheries sector including women; the COAST parametric insurance product provides cover for losses attributed to the fisheries sector due to unusually bad weather conditions, and/or high wind and storm surge caused by tropical cyclones throughout the policy year.
3. Engaging governments to support microinsurance schemes such as CRAIC by:
    - infusing microinsurance in social protection strategies thereby allowing ministries of social protection to purchase these microinsurance policies as part of their investment in social protection and providing payouts when policies trigger to the most vulnerable affected individuals or communities – similar to how cash transfers operate but using insurance as the mechanism for the cash transfer
    - providing subsidies for policy premiums or waive the premium taxes or GCT/VAT
    - incorporating microinsurance into existing government rebates and subsidies for the fisheries or agriculture sector
    - requiring purchase of the LPP as part of the registration process for farmers, MSMEs etc.
    - including insurance requirements in policies for fisheries, agriculture or MSMEs
    - sensitizing vulnerable persons/low-income persons to the importance of insurance and these new microinsurance products and the linkages with financial inclusion

We will work with the private sector to enhance insurance literacy related to climate risk insurance and engage them as key partners for the marketing and distribution of microinsurance products such as the LPP. Thus, one potential opportunity would be for private sector entities to play an active role in distribution – particularly insurance companies, credit unions and cooperative banks.

CRAIC aims at protecting the livelihood of low-income people against extreme weather events (specifically, excess rainfall and high winds), which are expected to be exacerbated by climate change. The Livelihood Protection Policy is targeted at individuals such as farmers, fishers, season tourism workers etc. This project is being implemented in five Caribbean countries. We have recognized that the scale that we envisaged is not being realized – that is the amount of persons that we would want to access this insurance is not being realized and we are looking at new and innovative approaches in distribution.

**On the use of payouts and lessons learned**

Whilst CCRIF does not require justification up front how payouts are spent, CCRIF does request reports from governments on the use of payouts

which countries are required to provide in a requested format. Reports are required from countries within six months of receipt of payouts.

The construct behind CCRIF is to provide immediate liquidity once a policy is triggered to assist with immediate needs after a disaster – recognizing the needs may differ per country based on vulnerably and also based on the extent of damage. We know that our member governments employ a range of governance principles in the management of their economies and the facility firmly believes that the governments – and as autonomous sovereign nations – are best able to assess their priorities at this time and as such determine how resources from a payout are to be utilized.

In September 2018, this reporting requirement was formalized when countries' Participation Agreements (similar to contracts with CCRIF) were amended to include requirements to submit a report using a specified format within six months of the payout.

As such, governments are requested to provide information on:

- How the funds were used
- When the funds were used
- The decision making process used to determine the use of funds
- The number of persons who benefitted
- The benefit of receiving the funds within 14 days

Governments have used payouts for a variety of purposes, including immediate recovery and repair activities; humanitarian aid for affected persons; stabilizing facilities such as water treatment plants; improving critical infrastructure such as roads, drains and bridges; mitigation activities to increase resilience against natural hazards and climate change; and to "keep the wheels of government turning", for example by paying salaries of critical government personnel.

Our assessments have revealed that CCRIF payouts have benefitted over 2.5 million persons (with about 1.5 million of those persons having benefitted following Hurricane Matthew which affected Haiti in 2016 – those persons were provided with water, food, shelter and medication) in the Caribbean and Central America.

These reports are made public through a publication available on our website titled "Use of CCRIF Payouts". We find that publicizing the information not only allows countries to get a sense of how payouts are used but it also provides some level of accountability and transparency to the general population of countries in terms of how payouts received have been used. Our donors are also pleased with this type of information that they are able to receive.

# Envisioning Long-Term Sustainability in Trinidad and Tobago: Productivity, Innovation and Resilience

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## 1. How can waterfront cities and towns optimize the opportunities offered by the blue economy?

In many small island developing states and certainly in most of our Caribbean economies, as much as 90 per cent of these countries' GDP is generated along the coast, and an estimated 60 to 80 per cent of their populations live within 3 to 5 km of the coast. It is therefore critical for governments to fully recognize the strategic importance of preserving the health and vitality of coastal and marine resources… as a means of increasing our economic growth prospects and well as advancing sustainable prosperity for all.

The marine space offers great potential beyond traditional industries such as tourism, shipping and fisheries. It is well known that the small island states of this region possess exclusive economic zones far greater than their country's land space, making business prospects in areas such as blue energy, shipping logistics, green shipping, nutraceuticals and other bio-based industries new areas that we need to explore as we pursue growth, investment and development that "leaves no one behind" (SDGs).

Today, one of the most significant opportunities in regard to the marine environment is the emergent concept of the blue economy, which encompasses the sustainable management and use of the resources found in the marine environment whilst simultaneously optimizing economic and social benefits now and in the future.

A 2017 World Bank study indicated that the blue economy is growing much faster than the traditional economy, being set to double by 2030. Unfortunately, island economies account for a small percentage of that growth.

The potential of the blue economy remains largely untapped in this region, due to low levels of awareness, inadequate technology, policy, investment. Whilst elements of a blue economy exist in many of our islands, many of these countries have not promulgated coherent policy frameworks or investment plan to advance this blue agenda to allow both the private sector and governments to recognize and exploit the value of our oceanic capital… and to ensure that the blue economy is fully characterized and integrated into long-term development planning processes.

Some critical areas of investment for our islands in the region in advancing the blue economy are provided below:

- Development of modern national spatial plans that emphasize the importance of the blue economy and exploiting the EEZ in a sustainable way.
- Development of climate-smart fisheries management plans, which would focus on increasing awareness of the fisheries community to better and more sustainable fishing practices as well as to introduce sustainable fishing practices in the sector
- Having in place modern fisheries legislation to address the sustainable development of the

fisheries sector and to focus on food security and enhancing the sustainable livelihoods of those working in that industry as well as to develop fish sanctuaries

- Implementation of plans and projects across the region for coral reef restoration, recognizing the importance of our coral reef systems not just to tourism but to shoreline protection (against storm surge especially in light of a changing climate), beach stability and also to support the livelihoods of many fishers
- Putting in place sustainable tourism plans
- Implementation of sustainable land and marine use management initiatives – from ridge to reef – to restore ecosystems and advance the notion of ecosystem-based approaches to environmental management
- Focus on South-South cooperation
- Determination of the economic value of marine and coastal ecosystems and assessment of the costs associated with losing these ecosystems; this must be a priority going forward as it would allow us to make much better economic and social decisions as well as investment decisions related to our development pathway whilst at the same time protecting our natural resources. It is oftentimes particularly easy to determine the direct use values of coral reefs such as the value of fish stocks – but indirect use values such as the value of genetic resources or the physical protection that reefs provide to the shoreline are much harder to value – but are so important - In other words, can the genetic resources on our reefs be the answer to, or cure for breast cancer or prostate cancer
- Waste management as we must begin to not only reduce but as far as possible eliminate land-based sources of pollution from all sectors – moving towards zero waste, closed loop manufacturing, use of cleaner technologies among others – this is especially critical for Trinidad and Tobago which has a relatively large manufacturing sector compared to other Caribbean nations.
- Increasing awareness among the general public to the importance of the marine environment and the interconnectedness of the blue and green and circular economies including engagement in partnerships at all levels with local, regional and international collaborators, to facilitate knowledge and technology transfer, research and much needed investments.

Some countries in the region such as Jamaica with an Exclusive Economic Zone (EEZ) more than 20 times greater than the size of its land mass, has in the last few years, put in place an entire organization structure called the Special Economic Zone Authority to foster economic growth prospects within the marine space by exploring the benefits of the blue economy and providing stewardship over their marine resources ensuring that they are used and managed sustainably. In Saint Lucia, there is currently the development of Castries Vision 2030 in which that Government is looking towards advancing the sustainable development of its capital city, ensuring among other areas that new growth areas such as the blue economy are fully considered in development planning.

## 2. How does the governance of coastal regions and ecosystems respond to the challenges of communities depending on the blue economy?

CCRIF (formerly the Caribbean Catastrophe Risk Insurance Facility), recently made available a product called COAST to two countries in the region – Saint Lucia and Grenada. CCRIF is the world's first multi-country risk pool and was the first insurance instrument to successfully develop parametric policies backed by both traditional and capital markets. CCRIF is a regional catastrophe fund for Caribbean and Central American governments to limit the financial impact of devastating hurricanes, earthquakes and excess rainfall events by quickly providing quick financial liquidity when a policy is triggered. We currently offer 4 parametric insurance products – for tropical cyclones (based on wind and storm surge), earthquakes, excess rainfall (based on rainfall) and for fisheries[5]. CCRIF currently has 22 member governments – 19 in the Caribbean and 3

[5] In September 2020, CCRIF launched a 5th product – for electric utilities.

in Central America. Since our inception we have made 41 payouts totalling 152 million to 13 of our member governments (including 3 payouts to the Government of Trinidad and Tobago) all within 14 days of the event.[6]

The Caribbean Oceans and Aquaculture SusTainability Facility or COAST was launched against the backdrop that the fisheries sector is a major source of livelihoods and contributes significantly to food security. In the Caribbean, this sector employs over 300,000 persons, both directly and indirectly. It is a sector that is highly vulnerable to climate hazards such as storms and hurricanes as well as bad weather events. COAST was designed to address both the vulnerability and livelihood issues that impact the sector and advance the blue economy.

What is COAST?

- COAST is the first ever climate risk parametric insurance developed for the fisheries sector allowing fishing communities to have access to insurance that has been developed specifically for their needs
- COAST is a catalyst for promoting resilience in the fisheries sector, through the development and implementation of strategies to reduce the risk that climate change poses to the fisheries sector and to incentivize policy reforms for the uptake of climate smart fisheries practices as well as coastal resilience.
- COAST covers tropical cyclones and also is the first insurance cover to provide for "bad weather" –covering losses attributed to the fisherfolk due to "bad weather" events, defined in the COAST model as high waves and occurrence of heavy rainfall throughout the policy year.
- COAST is unique in terms of its payouts – as payouts will be channeled through the Ministry of Finance within 14 days of the covered event as is customary for all of CCRIF's payouts, followed by a rapid transfer to the fisherfolk – in other words, fisherfolk are the direct beneficiaries of COAST.
- COAST encourages inclusiveness and participation of women and will provide payouts to the many women who contribute to the fishing industry as managers of and vendors in fish markets etc.

  COAST is highly innovative. On one hand, it links sovereign level risk insurance with social protection strategies and will directly contribute to supporting fisherfolk and others working in the fisheries sector (boat boys, market vendors etc.), who are highly vulnerable to the impacts of natural disasters. On the other hand, COAST is designed to support the development of strategies to ensure that marine resources are managed and used in ways that are sustainable – that is, coral reefs, sea grass beds, fisheries etc. COAST acknowledges that we must pay close attention to the goods and services provided by the marine environment – goods such as fish and shellfish to genetic resources; biodiversity and ecosystem services such as shoreline protection and employment among others.

COAST will directly contribute to achieving many of the sustainable development goals (SDGs) especially SDG 1 – ending all forms of poverty everywhere; SDG 5 – gender equality; SDG 10 – reduced inequalities; SDG 14 – life under water; and of course, SDG 13 – climate action. The plan is to roll out COAST not only to additional Caribbean members but also to CCRIF members in Central America.

### 3. How should coastal cities restructure their public expenditures and investments to fully harness the potential of the blue economy?

In a recently published document from the CDB on financing the blue economy provides valuable information for government and business leaders as countries pursue this innovative pathway to growth which recognizes the importance of the blue economy and finds ways of linking the blue and green economies with the circular economy and moving away from the red economy. To finance the blue economy the region needs to focus on innovative financing options that are

[6] Between 2007 and October 2020, CCRIF made 45 payouts totaling US$163 million to 14 member governments.

becoming more and more available. These are some examples:

1. Green Bonds - The green bond market has seen explosive growth in the past decade, presenting an unrivalled opportunity in climate finance. Annual issuance has now risen from zero to more than US$155 billion globally, with more growth ahead. Green bonds generate financing for projects in renewable energy (blue energy - offshore wind energy and ocean renewable energy) for example
2. Impact Investments – This is intended to finance projects, organizations and social enterprises to intentionally create a measurable social or environmental impact alongside financial returns. One innovative instrument is the social impact bond (SIB) –through which private investors pre-finance the intervention, and governments or donors provide funding solely when the intended outcome goes beyond what would have occurred otherwise. Some applications of SIB include Youth Employment Programmes, Homelessness and the Blue Economy.
3. Debt for Nature Swaps - This instrument can mobilize resources for protecting nature while reducing the debt burden of developing countries. In exchange for debt forgiveness, the debtor-government commits to invest the accrued savings in conservation and/or climate-related expenditures – investments in fish sanctuaries
4. Crowd Funding – This is a collective effort of individuals who pool their resources to support initiatives promoted by other people or organizations. Using social networks and the viral nature of online communication, individuals and companies have raised billions of dollars in debt, equity, and donations. – we can focus here on the role of cooperatives in establishing fish sanctuaries
5. Blended Financing – This is targeted use of concessional funding on high impact projects where actual or perceived risks are considered as too high for commercial finance. The benefits of this approach are that it increases capital leverage; enhances impact and delivers risk-adjusted returns. It is mostly used to fund major projects such as infrastructure and in the construct of the blue economy would apply to offshore wind energy and ocean renewable energy.

# The Importance of Disaster Risk Financing in Advancing Economic Growth, Innovation and Development in Small Island Developing States – The Case of CCRIF SPC

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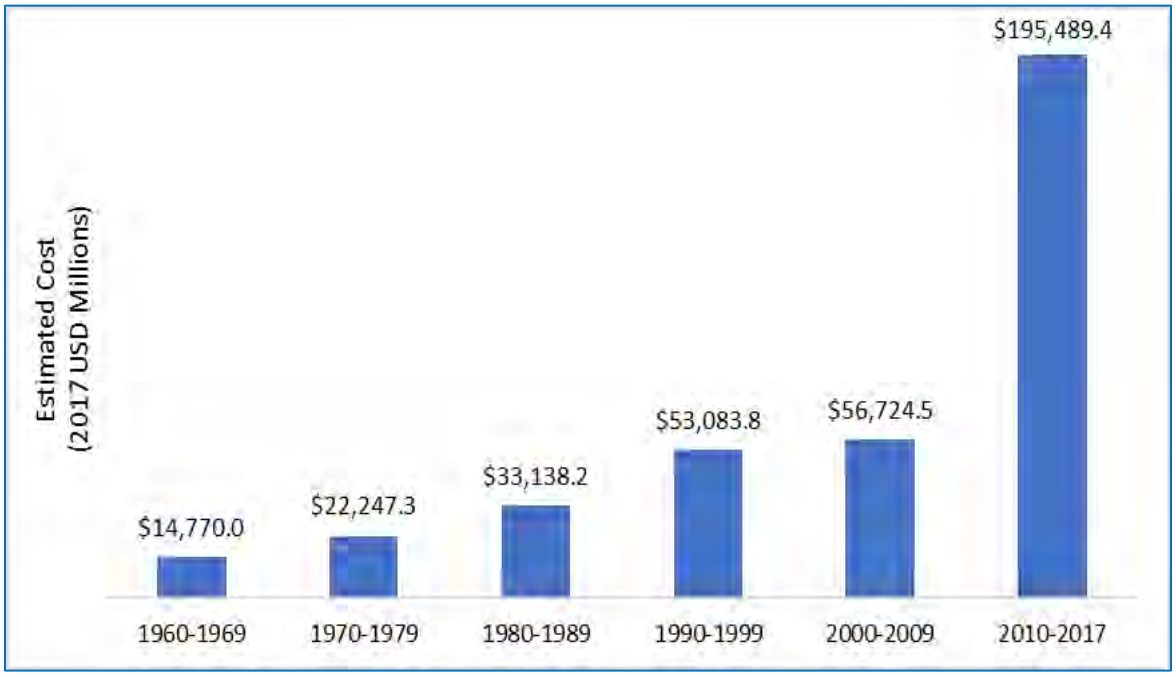
The Caribbean region comprises a large number of small states with developing economies prone to the two main global catastrophe hazards, earthquakes and tropical cyclones (known in the wider Atlantic Basin as hurricanes). In these small states, single catastrophes can have a disproportionate effect on both the national and regional economies. Development is largely concentrated in coastal areas which are generally flat and which in some islands are the location of more than 70 per cent of economic infrastructure; these areas have relatively high exposure to hydro-meteorological hazards (particularly flooding) and to earthquake shaking (due to the nature of the soil/rock in these areas). This fact, and the increasing impact of global climate change on the frequency, intensity and potential impact of hydro-meteorological hazards, make the adequate consideration of catastrophe hazards an important priority for governments in their pursuit of sustainable development.

The most significant natural hazard risk in the Caribbean is hurricane risk, particularly because of the possibly large span of territories that can be impacted by any single event. Hurricanes have had an inordinate impact on the economies of Caribbean countries, many of which depend on tourism and agriculture as their main economic drivers. In the Caribbean and Central America the frequency of hazards and disasters is increasing, and although mortality resulting from disasters seems to be decreasing, economic costs are rising precipitously. In fact the Caribbean region is one of the most disaster-prone regions in the world. For example, between 1980 and 2015, Caribbean countries suffered from 390 (documented) natural disasters, most of them tropical cyclones and floods. Similarly, another 366 natural disasters occurred in the Central American region. Also, the International Monetary Fund (IMF) has stressed that natural disasters, which can have a large negative impact on government finances and economic growth in affected countries, are the second-leading cause – after banking crises – of materialization of contingent liabilities for emerging market sovereigns and are sometimes the direct cause of sovereign default.




**Worldwide Natural Disasters**

*Adapted from Ram, Justin 2015. Caribbean Development Bank. Presentation to Donor Meeting in Support of CCRIF, March 2015*

According to Moody's, the average annual damage from natural disasters over 1980-2015 was 1.5 per cent of GDP in emerging markets vs. 0.3 per cent of GDP in developed economies. The average share of affected population over the same period was 3.0 per cent in emerging markets vs. 0.4 per cent in developed economies. In fact, among the 20 most vulnerable countries globally, more than half represent small island states across the Caribbean and Pacific regions. These 20 countries bear average losses between 20.1 per cent and 2.1 per cent of their respective GDP every year. The countries in the Caribbean that are referenced here include Belize, Jamaica, The Bahamas, and St. Vincent and the Grenadines.

This paper will focus on identifying the various disaster risk financing strategies that are necessary for countries to use and the key requirements for the development of a disaster risk financing framework, highlighting the importance of these frameworks in advancing sustainable prosperity and development that "leaves no one behind". The paper also will explore the "CCRIF Story" and the important role that risk transfer is playing in advancing sustainable prosperity in the Caribbean and Central America. A focus also will be placed on the impacts of natural hazards on national development and will illustrate through empirical evidence and examples that reducing vulnerability can be achieved by linking disaster risk financing instruments with fiscal policy frameworks within the context of national sustainable development planning.

**Climate Change**

Climate change is increasing both the frequency and intensity of natural hazard events. Take the example of Hurricane Irma in 2017: The Economist articulated that damage in the Caribbean from Irma was US$13 billion. In Dominica, Hurricane Maria resulted in total damages of US$931 million and losses to the economy of US$382 million, which amounted to 226 per cent of 2016 GDP. The IMF noted that Dominica would face a protracted recovery with GDP projected to decline by 16 per cent in 2018, before rebounding in 2019 as reconstruction gathers pace. The storms also affected the agriculture sector in Dominica, Antigua and Barbuda, and St. Kitts and Nevis – severely damaging farm housing, irrigation infrastructure, feeder roads, crop and livestock production, forest reserves and coastal fisheries.

Natural disasters therefore have severe macroeconomic effects including directly impacting a country's economic and government fiscal strength and increasing external vulnerability, expressed through increasing debt-to-GDP levels and worsening external balances, as well as increasing poverty levels which tend to have a disproportionate impact on the poorer, more vulnerable segments of populations as well as on older persons.

Left unchecked, the economic impact of natural disasters can generate large losses that disrupt long-run economic growth trajectories and by extension countries' pathway to a sustainable future. To some extent, one can compare natural disasters to financial crises – both are typically exogenous events that represent covariate shocks across a country and households. Economic damages from natural hazards can jeopardize the health of national economies at a level comparable to or greater than that of financial crises. Natural disasters also destroy human and physical capital stocks of countries – something that financial crises do not. For example, persons left in the wake of these natural disaster events have lost homes, loved ones and sometimes an entire way of life. Disasters impact the health, psychology and well-being of populations and it is oftentimes difficult to quantify the psychological impact of a disaster. Disasters have impacts on the mental health of populations – effects that are deeper than property damage or physical injuries.

**Role of Disaster Risk Financing vs Disaster Risk Management in National Development**

Historically, and up to the last 10-12 years, when one focussed on, or thought of disaster preparedness, the notion of disaster mitigation often came to mind – building sea walls, improving building codes etc. The question is – "Is mitigation enough?" The short answer is NO. While disaster mitigation is critical to this disaster preparedness equation, countries must consider disaster risk financing as part of their development strategies.

Today in the face of a changing climate, countries ought to consider the following disaster preparedness equation:

**Disaster Preparedness = Disaster risk mitigation + Ecosystem management + Disaster risk financing + Social protection strategies that reduce current and future vulnerability + Strategies that address psychological impact of future disasters on populations**

Countries can better prepare for natural disasters by incorporating both risk mitigation and risk financing strategies in their national development strategies. Whilst countries often view "preparing" as an expensive proposition, with subventions to the environment and disaster risk management sectors oftentimes being below optimal, countries need to be mindful that being inadequately prepared is far more costly when faced with a disaster. In other words – fail to prepare, be prepared to fail!

Ecosystems management also is critical to the disaster preparedness equation as risk mitigation must take due consideration of the sustainable management and use of environmental and natural resources and carefully focus on the roles that healthy ecosystems – such as coral reefs, forests, wetlands and watersheds – can play in reducing the impacts of natural disasters. Healthy and vibrant coral reefs for example, are able to protect coastlines from storm damage, erosion and flooding by reducing wave action approaching a coastline.

There are many disaster risk mitigation strategies that countries in the region are developing and implementing such as:

- Mainstreaming climate change issues into sectoral policies (e.g., tourism and agriculture) at the national level and other decision-making processes
- Adopting best practices for climate change adaptation
- Creating and strengthening national platforms for hazard risk reduction
- Modernizing legal frameworks to address hazard risk reduction and vulnerability
- Establishing measures to incorporate hazard risk reduction in land use practices and the development of human settlements
- Implementing modern building codes

- Putting in place the necessary infrastructure such as sea walls to protect coastlines
- Conducting vulnerability impact assessments of communities and determining best practices and actions to reduce future vulnerability

**But the question is - Is risk mitigation enough?**
In the face of a changing climate the answer is no. Risk mitigation is not enough to protect our small island developing states form the impacts of natural hazards in the face of a changing climate. So whilst is it essential for countries to develop and implement strategies to better protect their populations, economic assets, economic growth prospects, they must also have in place financial protection strategies to enable them to better respond financially to natural disasters – resources for immediately after a disaster for emergency response and to fill the liquidity gap and resources for the long run to support reconstruction and rehabilitation – towards reducing the volatility of their country's national budgets.

**Disaster Risk Financing**
When developing countries face natural disasters such as hurricanes, earthquakes, excess rainfall, floods and fires, the cost of rebuilding becomes even more of an issue as these countries are already heavily burdened with debt. Often, when these natural disasters occur, foreign aid is received. However, these countries still have to continue to pay existing debt payments as well as make arrangements to service the new debt accrued from the natural disasters. This results in even less money available for expenditures on critical areas such as health, education and national security among others.

For Central American and Caribbean countries, the peculiarities associated with the impacts of natural hazards are particularly pronounced given their small physical and economic size. It becomes clear that beyond the immediate and tragic loss of life, catastrophe events can also unleash a set of circumstances which can hinder a government's ability to effectively finance its immediate recovery and longer-term redevelopment processes. This impact has a further reverberating effect on the wider economy of the country, meeting a range of fiscal targets whilst also exacerbating poverty levels.

Considering disaster risk in fiscal policy provides an efficient means for countries to financially protect themselves against events that cannot be prevented. Integrated disaster risk financing strategies allow countries to increase their financial response capacity in the aftermath of disasters and reduce their economic and fiscal burden. Governments are encouraged to develop, make provision for, or participate in integrated disaster risk financing strategies as part of their overall risk management strategy. Such strategies allow governments to reduce their budget volatility through a combination of self-retention (such as dedicated reserve funds and contingent credit facilities) and risk transfer instruments (such as parametric insurance and catastrophe bonds).

Governments are often challenged with the significant task of financing recovery efforts after a disaster. Whilst dealing with the fiscal demands to undertake relief operations such as ensuring the availability of emergency assistance and sourcing funding for shelter, food and medical attention for displaced persons, governments also have to contend with the simultaneous challenges of mobilizing enough resources to undertake the medium- to long-term recovery and reconstruction process. This can include tasks that range from the clearance of debris to the restoration of critical services such as access to water and electricity to the reconstruction and rehabilitation of key public infrastructure. These expectations are themselves precariously balanced with the need for governments to subsidize the reconstruction of private assets such as homes for low-income families who would have been displaced as a result of a given catastrophe and all of which must be accomplished within a scenario of a dramatic decline in revenue.

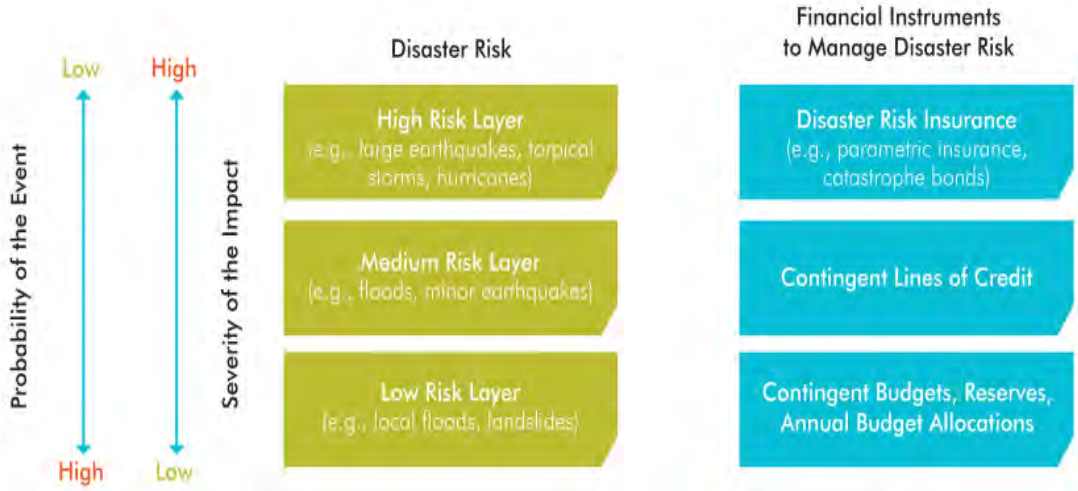
These situations have resulted in governments recognizing the need to employ a variety of ex-ante and ex-post risk financing instruments to address these financial exposures. These strategies can include a range of mechanisms from the consistent accumulation of financial reserves to the utilization of contingent debt agreements to insurance and alternative risk transfer solutions.

There are two main types of disaster risk financing strategies – ex-post and ex-ante. Ex-post financing instruments are sources that are implemented without advance planning. These instruments include budget reallocation, domestic credit, external credit, tax increases, and donor assistance. Ex-ante risk financing instruments such as catastrophe insurance requires proactive advance planning and involves investing in disaster risk financing prior to a natural disaster occurring. Ex-ante strategies allow governments to reduce their budget volatility through a combination of self-retention (such as dedicated reserve funds) and risk transfer instruments (such as insurance that CCRIF provides). CCRIF is an example of an ex-ante risk financing instrument.

A country's financial resilience to natural disasters is therefore dependent on its ability to manage internal and external resources to finance post-disaster needs. Both sets of mechanisms are necessary to finance response, recovery, and reconstruction needs while protecting the country's fiscal balance and preventing further disruptions caused by reallocations from other priorities (such as primary health care, education, energy security etc.).

In the case of ex-ante financing instruments, the main advantage is that they are secured before a disaster and thus allow for quick disbursement post disaster. On the contrary, ex-post instruments can take some time to mobilize. Ex-ante financing instruments have many benefits. Beyond repairing public infrastructure damages, ex-ante risk financing instruments can provide capital for emergency relief and assistance to affected households, businesses and communities. If governments lack the necessary infusion of post-disaster capital or liquidity to rebuild critical infrastructure, restore homes and provide humanitarian assistance, indirect costs can greatly surpass the direct losses of a disaster. Additionally, developing countries have a higher propensity for post-disaster resource deficits. Governments of developing countries typically must divert from their budgets or from already disbursed development loans to finance post-disaster expenses, also relying on new loans and donations from the international community. Historically, these sources of post-disaster finance too frequently prove inadequate to fund a timely humanitarian response.

Managing disaster risk therefore requires a multi-faceted approach that requires governments to build a financial protection strategy that combines a number of instruments that address different layers or types of risk and incorporating a range of instruments such as budget allocations and reserves, contingent credit, and risk transfer instruments.




**The different risk layers and corresponding disaster risk management instruments**

*Source: World Bank, 2014. Caribbean and Central American Partnership for Catastrophe Risk Insurance*

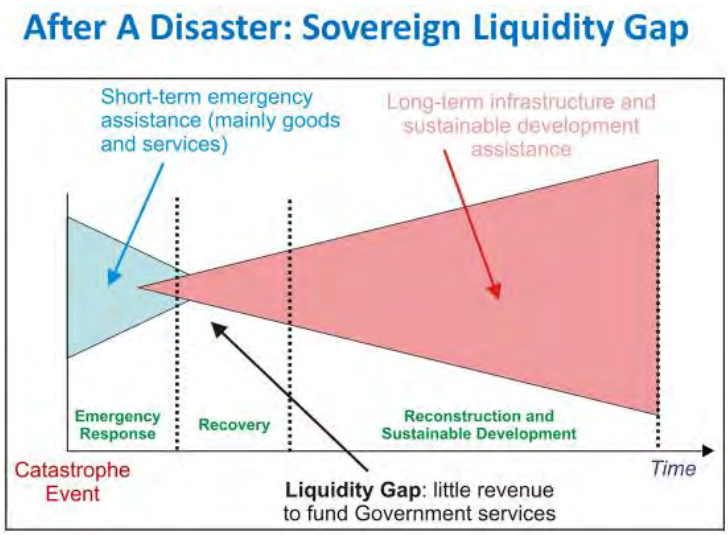
Both Saint Lucia and Jamaica are in the process of promulgating comprehensive disaster risk financing strategies that include a mix of instruments suitable to assist with different frequencies of disasters and varying levels of impact.

**CCRIF SPC – An Example of an Ex-Ante Disaster Risk Financing Instrument Available in the Caribbean and Central America**

In developed countries, insurance and capital markets are widely used to hedge the immediate adverse impacts of natural disasters. According to Munich Re, more than 40 per cent of the direct losses from natural disasters are insured in developed countries. At the same time, Munich Re estimates that less than 10 per cent of losses are covered by insurance in middle-income countries and less than 5 per cent are covered in low-income countries. The CCRIF Story is one that showcases access to insurance to hedge against the adverse impacts of natural disasters in the small island and coastal states of the Caribbean and Central America.

CCRIF was created as an immediate response to Hurricane Ivan in 2004, which caused billions of dollars of losses across the Caribbean; in both Grenada and the Cayman Islands, losses were close to 200 per cent of the national annual GDP. Following the passage of Ivan, the Caribbean Community (CARICOM) Heads of Government approached the World Bank for assistance to design and implement a risk financing mechanism to support member governments and provide quick liquidity in the aftermath of disasters. This marked the beginning of what would become the Caribbean Catastrophe Risk Insurance Facility, which was established in 2007 as the first multi-country risk pool in the world to successfully develop parametric policies backed by both traditional and capital markets – with 16 Caribbean governments as members. It was designed as a regional catastrophe fund for Caribbean governments to limit the financial impact of devastating hurricanes and earthquakes by quickly providing financial liquidity when a policy is triggered. In the years since, CCRIF – now known as CCRIF SPC – has expanded its membership to include Central America and other Caribbean countries and its current membership is 19 Caribbean governments and 3 Central American governments.

CCRIF insurance products are parametric. Parametric insurance products are insurance contracts that make payments based on the intensity of an event (for example, hurricane wind speed, earthquake intensity, volume of rainfall) and the amount of loss calculated in a pre-agreed model caused by these events. Therefore, payouts can be made very quickly after a hazard event. This is different from traditional insurance settlements that require an on-the-ground assessment of individual losses after an event before a payment can be made. CCRIF therefore has been designed to provide quick liquidity once a country's parametric insurance policy is triggered. The Facility is not designed to cover all losses on the ground but to ensure that governments have resources available to meet their most pressing needs after a natural disaster.



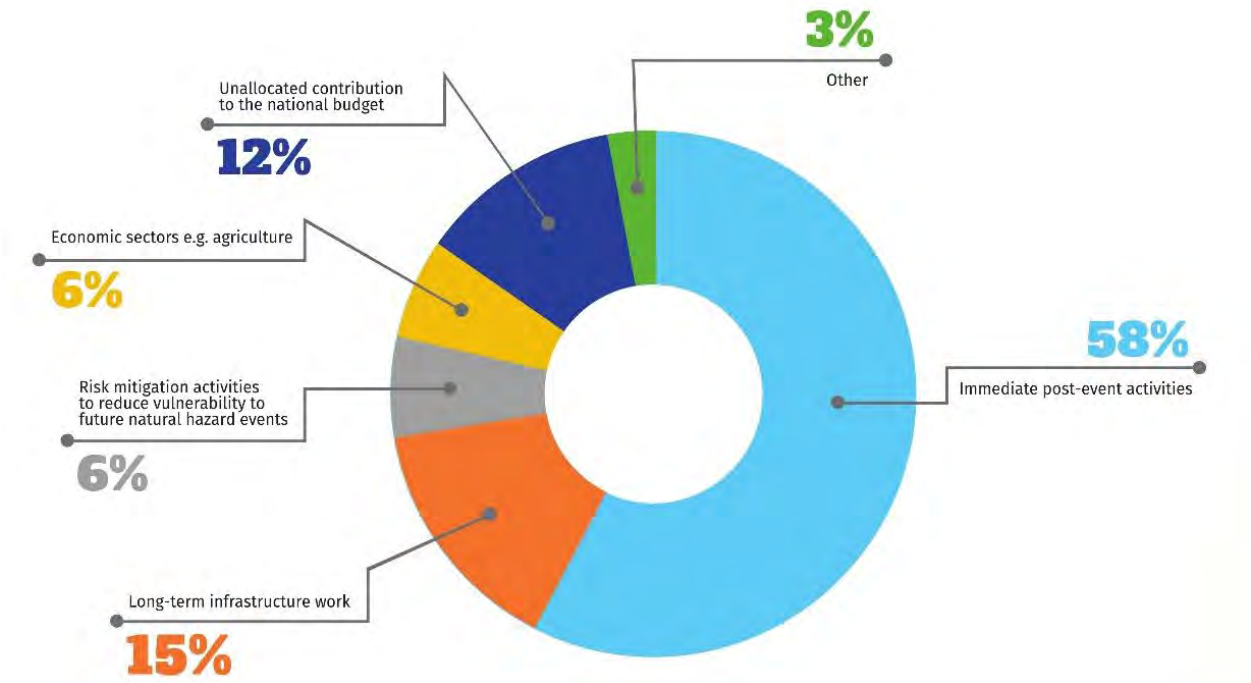

*Source: "World Bank Group. 2014. Financial Protection Against Natural Disasters: An Operational Framework for Disaster Risk Financing and Insurance."*

CCRIF offers Earthquake (EQ), Tropical Cyclone (TC) and Excess Rainfall (XSR) policies to Caribbean and Central American governments and since July 2019, a product for the fisheries sector called COAST (Caribbean Oceans and Aquaculture Sustainability Facility) which is currently available in Saint Lucia and Grenada. The Tropical Cyclone product (which has been available since CCRIF's inception in 2007) is linked to wind and storm surge damage in a defined tropical cyclone. Rainfall is not covered by TC policies. The Excess Rainfall product (first offered in 2013) is linked to damage from rainfall and an XSR policy can be triggered if rainfall thresholds are met due to a tropical cyclone or to non-cyclonic systems such as trough systems. The TC and XSR products operate independently since the perils they are covering are different. A given tropical cyclone may trigger just one policy or both; if both policies are triggered by a given tropical cyclone then payouts on both policies would be due. The COAST parametric insurance product provides coverage for losses caused by adverse weather on fisherfolk and other persons in the fisheries sector and for direct damages caused by tropical cyclones (wind and storm surge) to fishing vessels, fishing equipment and fishing infrastructure. CCRIF is currently developing products for drought, agriculture and public utilities.

During CCRIF's 12 years in existence, the Facility has demonstrated that disaster risk insurance can effectively provide a level of financial protection for countries vulnerable to tropical cyclones, earthquakes and excess rainfall.

Since its inception in 2007, CCRIF has made 41 payouts totally US$152.3 million to 13 of its 22 member governments all within 14 days of an event. Immediate access to liquidity is critical for governments post disaster. The international community provides ex-post relief, but such funds are slow to mobilize (often taking 4-12 months) and are not always efficiently used. Government borrowings and budget reallocations take time. Smaller countries such as those in the Caribbean and most SIDS with high debt burdens can no longer afford to self-finance disaster risk or rely solely on ex-post financing strategies such as debt relief which are invariably loans, or using their own limited budgets through budget reallocations or taking resources away from funded projects and programmes to support recovery and reconstruction.

Essentially, what CCRIF does is to fill that liquidity gap post disaster and it supports its member governments to help their populations after a disaster – communities, businesses and key sectors such as education, agriculture etc. A rough assessment of the beneficiaries of CCRIF payouts show that over 2.5 million persons in the Caribbean and Central America have benefitted directly or indirectly from these payouts after a hazard event. Use of payouts over the years has included providing food, shelter and medicine for affected persons; stabilizing drinking water plants; providing building materials for persons to repair their homes; repairing critical infrastructure such as roads and bridges as a means of enabling movement and access in and out of communities; payment of government salaries for critical first responders to facilitate the injured being cared for; and support for the agriculture sector, among other uses.




**Uses of payouts by CCRIF member countries**
*Source: CCRIF SPC, 2019. Use of CCRIF Payouts 2007-2018*

So, while these payouts are relatively small compared to the overwhelming cost of rebuilding, all recipient governments have expressed appreciation for the rapid infusion of liquidity, which they are able to use to address immediate priorities and to support the vulnerable. CCRIF members consistently indicate that these rapid payouts are an invaluable benefit of membership. Almost immediately after an event, CCRIF is able to inform countries if their policies were triggered and if so, the approximate payout amount. These infusions of cash within two weeks after an event are critical for immediate repair and recovery activities. This is a clear illustration that the parametric models work and are fit for purpose. As a former Minister of Finance in Haiti said in 2016 following Hurricane Matthew, "whilst it may appear that the payout of US$23.4 million from CCRIF is small, it is very significant and so far has been able to provide much needed support to at least 1.4 million persons who were adversely affected and displaced by Mathew by providing them with food and shelter and the purchase of medication especially for children". CCRIF's payouts were used in Haiti after Matthew for immediate recovery and repair activities, stabilizing facilities such as water treatment plants, improving critical infrastructure, mitigation activities to increase climate resilience, and to "keep the wheels of government turning". This year (2019) CCRIF made a payout of US$12.8 million to The Bahamas following Hurricane Dorian.

CCRIF was not designed to cover all the losses on the ground – but rather to allow governments to reduce their budget volatility and to guarantee sufficient capital for emergency relief. CCRIF therefore acts as a vast security blanket for its members which are vulnerable to the increasing severity and frequency of climate and weather-related perils.

Furthermore, CCRIF has been able to provide this coverage at the lowest possible price, recognizing that it is important to provide insurance that is affordable. By pooling countries' risks into discrete diversified portfolios, CCRIF is able to provide insurance at the minimum price possible as pooling makes the overall risk more stable and therefore more attractive to the reinsurance market, thereby reducing the cost of reinsurance. Empirical evidence based on studies undertaken by the World Bank illustrates that insurance

obtained through CCRIF could be as low as half the cost of coverage a member country could obtain on its own. Importantly, whilst CCRIF makes payouts directly to governments, there are linkages between payouts and social protection, where payouts have been allocated to the most vulnerable, thereby also playing a key role in achieving poverty reduction outcomes.

The CCRIF Story is a powerful way to demonstrate the linkages between country disaster risk management strategies and disaster risk financing strategies and the linkages among risk transfer, poverty reduction and economic growth. CCRIF effectively supports the goals of promoting sustainable economic growth, ensuring environmental, social and fiscal sustainability and reducing poverty – as evidenced by its mission statement: "A resilient Caribbean region and beyond with optimized disaster risk management and climate change adaptation practices supporting long-term sustainable development".

Today, CCRIF represents a truly innovative risk pooling scheme that represents a paradigm shift in the way governments manage risk. However, to advance sustainable prosperity, organizations that focus on financing and economic planning must effectively engage with the disaster management community, the organizations that deal with social protection and community development and the NGO community as we all seek to ensure that our development planning frameworks are proactive and inclusive and that our people continue to be at the centre of our development pathway as we strive to create a world where we "leave no one behind".

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